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(09/2014)

Sharing analyses of wideband Earth exploration-satellite service synthetic aperture radar transmissions with stations in the fixed, mobile, amateur, and amateur-satellite services operating in the frequency bands 8 700-9 300 MHz and 9 900-10 500 MHz

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Remote sensing systems

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

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REPORT ITU-R RS.2314-0

Sharing analyses of wideband Earth exploration-satellite service syntetic aperture radar transmissions with stations in the fixed, mobile, amateur, and amateur-satellite services operating in the frequency bands 8 700-9 300 MHz and 9 900-10 500 MHz[1]

(2014)

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[1] The Administration of the Islamic Republic of Iran in considering this Report expressed its serious concerns regarding the scope and objectives of SAR systems which assumes the bandwidth larger than 600 MHz due to the fact that it may contradict the purpose and objectives of Resolution 174 (Guadalajara 2010) “Risk of illicit use of information and communication technology”.

1 Introduction

This Report comprises results from sharing studies between Earth exploration-satellite service (EESS) (active) and incumbent services FS, MS, ATS, and AS allocated in the frequency ranges 8 700-9 300 MHz and 10.0-10.5 GHz.

– Section 2 provides the assumed characteristics of wideband EESS SAR-4 systems operating at center frequencies around 9 600 MHz with a maximum chirp bandwidth of 1 200 MHz as described in detail in Recommendation ITU-R RS.2043.

Sharing studies are provided in

– Section 3 regarding the sharing between the EESS (active) and the FS in the frequency bands 8 700-8 750 MHz and 10-10.5 GHz.

– Section 4 regarding the sharing between the EESS (active) and the MS in the frequency band 10-10.5 GHz.

– Section 5 regarding the sharing between EESS (active) and the amateur and amateur-satellite radio services.

– Section 6 provides the list of supporting documents. This list also includes Report ITU-R RS.2274 which provides information on the use of wideband EESS SAR-4 and the analysis of spectrum demand for additional 600 MHz.

It should be noted that this extended bandwidth is still under consideration. Consequently all assumption on the use of 600 MHz additional bandwidth is purely provisional until WRC-15 decides on the matter.

Acronyms and abbreviations used in this Report are listed in the Annex.

2 Characteristics of typical Earth exploration-satellite service synthetic aperture radar used in the studies

Figure 1 below provides definitions and terminologies of a SAR-4 type instrument operating in the wideband spotlight mode.

Recommendation ITU-R RS.2043 provides the characteristics of synthetic aperture radars (SAR) operating in the EESS (active) around 9 600 MHz. Table 1 provides the characteristics of SAR-1, SAR-2, SAR-3 and SAR-4 systems which were also taken into account in the studies of Report ITU-R RS.2094. SAR-4 represents a new generation of SAR systems intending to provide high resolution performance using a chirp bandwidth of 1 200 MHz. Tables 2 to 6 are taken from Recommendation ITU-R RS.2043. The detailed timing definitions for the brief periods of potential exposures are taken as given by the Recommendation.

FIGURE 1

EESS SAR imaging geometry for high resolution spotlight mode (wideband with 1 200 MHz chirp bandwidth)

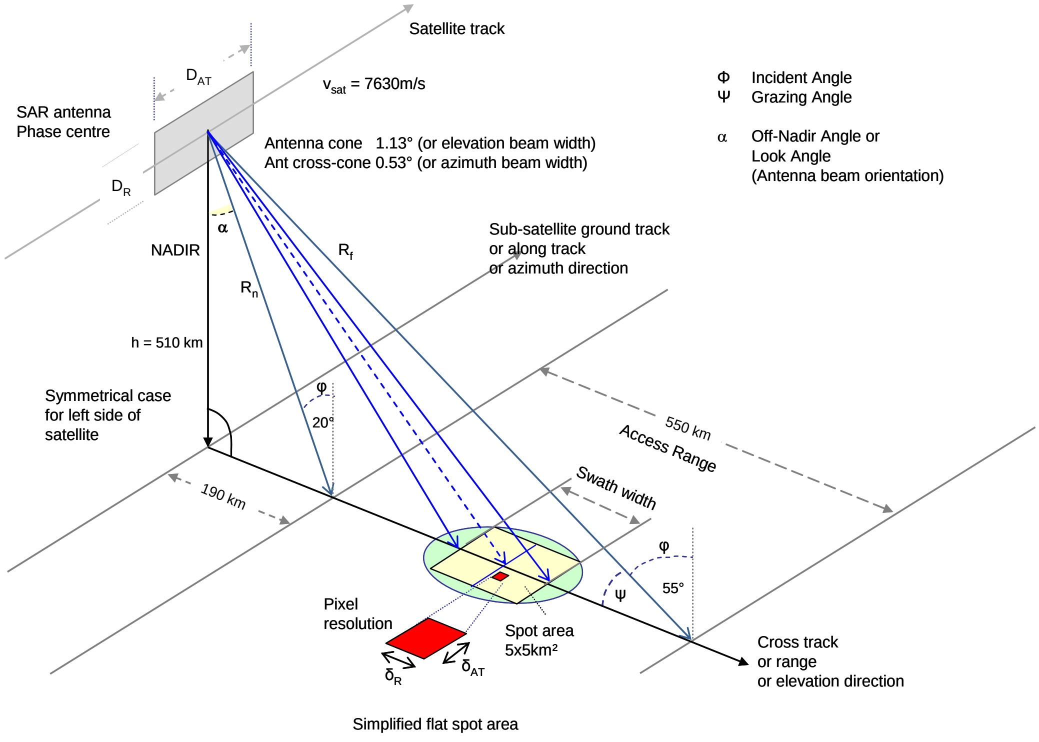


TABLE 1

Technical characteristics of EESS SAR systems

Parameter	SAR-1	SAR-2	SAR-3	SAR-4
Orbital altitude (km)	400	619	506	510
Orbital inclination (degrees)	57	98	98	98
RF centre frequency (GHz)	9.6	9.6	9.6	9.3-9.9*
Peak radiated power (W)	1 500	5 000	25 000	7 000
Pulse modulation	Linear FM chirp	Linear FM chirp	Linear FM chirp	Linear FM chirp
Chirp bandwidth (MHz)	10	400	450	1 200
Pulse duration (μs)	33.8	10-80	1-10	50
Pulse repetition frequency (pps)	1 736	2 000-4 500	410-515	6 000
Duty cycle (%)	5.9	2.0-28.0	0.04-0.5	30
Range compression ratio	338	< 12 000	450-4 500	60 000
Antenna type	Slotted waveguide	Planar array	Planar phased array	Planar array
Antenna peak gain (dBi)	44.0	44.0-46.0	39.5-42.5	47.0
e.i.r.p. (dBW)	75.8	83.0	83.5-88.5	85.5
Antenna orientation from Nadir	20° to 55°	34°	20° to 44°	18.5° to 49.3°
Antenna beamwidth	5.5° (El) 0.14° (Az)	1.6-2.3° (El) 0.3° (Az)	1.1-2.3° (El) 1.15° (Az)	1.13° (El) 0.53° (Az)
Antenna polarization	Linear vertical	Linear HH or VV	Linear horizontal/ vertical	Linear horizontal/ vertical
System noise temperature (K)	551	500	600	500

* Final value depends on the decision eventually taken under WRC-15 agenda item 1.12.

It should be noted that only the technical characteristics of an EESS SAR-4 with a chirp transmission bandwidth of 1 200 MHz is taken into account in the following studies.

It should be also noted that the technical characteristics of SAR-4 in Table 1 can be the baseline for the technical restrictions of SAR in the frequency band under consideration, since only SAR-4 characteristics is used in the studies.

Table 2 gives the antenna pattern of SAR-4. The antenna patterns of SAR-1 to SAR-3 systems are provided in Recommendation ITU-R RS.1166 and further analysed in Report ITU-R RS.2094.

TABLE 2

SAR-4 average antenna gain pattern near 9.6 GHz

Pattern	Gain $G(\theta)$ (dBi) as function of off-axis angle θ (degrees)	Angular range (degrees)
Vertical (elevation)	$G_v(\theta_v) = 47.0 - 9.91\,(\theta_v)^2$ $G_v(\theta_v) = 35.189 - 1.944\theta_v$ $G_v(\theta_v) = 21.043 - 0.468\theta_v$ $G_v(\theta_v) = 12.562 - 0.185\theta_v$ $G_v(\theta_v) = 3.291$	$\theta_v < 1.149$ $1.149 \leq \theta_v \leq 9.587$ $9.587 \leq \theta_v \leq 29.976$ $29.976 \leq \theta_v \leq 50$ $50.0 \leq \theta_v$
Horizontal (azimuth)	$G_h(\theta_h) = 0 - 45.53(\theta_h)^2$ $G_h(\theta_h) = -11.210 - 4.022\theta_h$ $G_h(\theta_h) = -26.720 - 0.953\theta_h$ $G_h(\theta_h) = -35.031 - 0.388\theta_h$ $G_h(\theta_h) = -41.936 - 0.158\theta_h$ $G_h(\theta_h) = -51.387$	$\theta_h \leq 0.542$ $0.542 < \theta_h \leq 5.053$ $5.053 < \theta_h \leq 14.708$ $14.708 < \theta_h \leq 30.00$ $30.00 < \theta_h \leq 59.915$ $59.915 < \theta_h$
Beam pattern	$G(\theta) = G_v(\theta_v) + G_h(\theta_h)$	

FIGURE 2

Modes of operations for SAR system in the 9 GHz EESS allocation

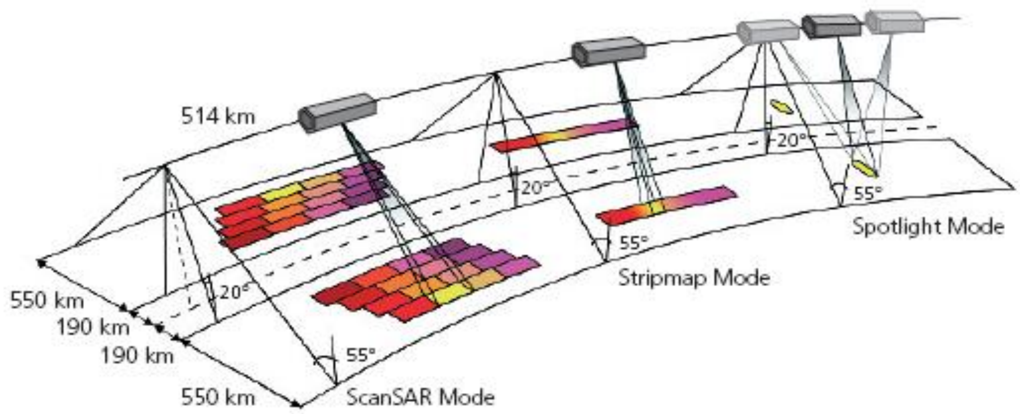


Figure 2 above illustrates the different operating modes that can be provided by typical SAR systems.

The maximum bandwidth of up to 1 200 MHz is assumed as only used by the spotlight mode of the SAR-4 system, when highest radar picture resolution is required. This mode is estimated to occur for less than 30% of all images taken by the radar. For the other SAR modes, the bandwidth will be either 600 MHz or less, thus fully complying with the existing allocation.

As shown in Fig. 2, in spotlight mode, the spot area is tracked with incident angles of between 20° and 55° selectable on either of both sides of the satellite. During picture taking the azimuth angle (cross track) is within 90° ± 2.5°, thus reducing the effective exposure time of a spot to 5 seconds.

3 Sharing between the EESS (active) and the fixed service in the frequency bands 8 700-8 750 MHz and 10.0-10.5 GHz

3.1 Introduction

Under WRC-15 agenda item 1.12 an extension of the EESS (active) allocation in the frequency band 9 300-9 900 MHz by up to 600 MHz is sought in the frequency range 8.7 to 10.5 GHz.

Within this frequency range, the FS is allocated in the frequency bands:

– 8 500-8 750 MHz on a primary basis in countries of RR No. **5.468**;

– 9 800-10 000 MHz on a secondary basis in all ITU Regions, and on a primary basis in countries listed in RR No. **5.477**;

– 10.0-10.45 GHz on a primary basis in Regions 1 and 3, as well as Region 2 countries of RR No. **5.480**;

– 10.45-10.5 GHz on a primary basis in countries of RR No. **5.481**.

Sharing studies with the EESS (active) are therefore required in those frequency bands with regard to the FS.

Prior to WRC-07, sharing studies were performed between EESS (active) and point-to-point FS in the band 9 800-10 000 MHz under WRC-07 agenda item 1.3 and Resolution **747 (WRC-03)**. Resolution **747** (**WRC-03**) was suppressed at WRC-07. The results are contained in Report ITU-R RS.2094. They show that the worst case *I/N* levels at point-to-point (P-P) FS receivers from a spaceborne SAR is –53.0 dB which is 43 dB below the long-term protection criterion for FS links. Similar results are expected for proposed space borne SARs in the bands 8 700-8 750 MHz and 10.0-10.5 GHz if technical/operational characteristics and deployment practices of both space borne SAR in the EESS (active) and FS systems are similar to the assumptions taken in Report ITU-R RS.2094.

Service characteristics and studies on sharing of EESS (active) with the FS in the frequency bands 8 500-8 750 MHz and 9 900-10 500 MHz are given in:

– Section 3.2 providing the characteristics of FS systems used in the studies.

– Section 3.3 providing a comparison of the characteristics of the new SAR system with the SARs considered in Report ITU-R RS.2094.

– Section 3.4 providing a study of the impact of EESS (active) into FS using the fractional degradation of performance (FDP) protection criterion.

– Section 3.5 providing two independent studies 1 and 2 of EESS (active) into FS using the *I/N* protection criteria.

– Section 3.6 providing studies of the impact of FS on SAR-4.

– Section 3.7 summarizing the results of the studies.

It is worth mentioning that the analyses carried out in this Report are based on available information on terrestrial services (FS) contained in Recommendations ITU-R F.758-5 and F.1777 as referred to in the studies submitted to ITU-R. There may be other FS systems for which information was not available due to certain circumstances and conditions. Therefore, the results obtained may in certain cases not reflect the actual use of the band in question for terrestrial services.

Moreover, Resolution **651 (WRC-12)** leaves the category of a potential allocation (primary or secondary) and the amount of bandwidth (up to 600 MHz) open.

Consequently, consideration of 600 MHz bandwidth on primary status as extension to the existing allocation for EESS is purely on provisional basis until WRC-15 decides on the matter.

3.2 Characteristics of fixed service

Point-to-multipoint (P-MP) FS characteristics are available in Recommendation ITU-R F.758-5 for the frequency range 10.0-10.5 GHz, but no P-P FS characteristics are available for the frequency bands 8 700-8 750 MHz and 10.0-10.5 GHz in this Recommendation.

The characteristics for FS stations operating in the band 7 725-8 500 MHz were used for studies involving P-P FS in the band 8 700-8 750 MHz, and the characteristics of FS stations in the bands 10.5-10.68 and 10.7-11.7 GHz were used for studies involving P-P FS in the band 10.0-10.5 GHz. Also, P-MP FS stations were considered for the 10.0-10.5 GHz band. In addition, FS systems for broadcast auxiliary services (BAS) are also used in the band 10.25-10.5 GHz and their characteristics are provided in Recommendation ITU-R F.1777.

With regard to the impact of FS into EESS (active), no information is currently available in ITU-R on the deployment characteristics of FS stations (such as number and density) in any of the bands listed above.

Table 3 shows the generic characteristics as given in Recommendation ITU-R F.758-5 for FS on frequencies between 7 725-11 700 MHz, and Recommendation ITU-R F.1777 for FS especially for the BAS application on frequencies between 10.25-10.5 GHz. Additional characteristics for particular FS systems, operating in the band 10.5-10.68 GHz, are given in Table 4.

TABLE 3

FS P-P generic characteristics

Frequency range (GHz)	**7.725-8.500**		**10.25-10.5**			**10.5-10.68**		**10.7-11.7**	
Reference ITU-R Recommendation	F.386		F.1777			F.747		F.387	
Modulation	16-QAM	128-QAM	QPSK-OFDM 16-QAM-OFDM 32-QAM-OFDM 64-QAM-OFDM		QPSK 16-QAM 32-QAM 64-QAM	…….	…….	16-QAM	64-QAM
Channel spacing and receiver noise bandwidth (MHz)	1.25, 2.5, 5, 7, **10**, 11.662, 14, **20**, **28**, 29.65, **30**, **40**, **60** [3], **80**[3]	1.25, 2.5, 5, 7, **10**, 11.662, 14, **20**, **28**, 29.65, **30**, **40**, **60** [3], **80**[3]	9	18	18	1.25, 2.5, 3.5, 7	1.25, 2.5, 3.5, 7	5, 10, 20, 40, **60**, 67, 80	5, 10, 20, **40**, 60, 67, 80
Tx output power range (dBW)	−6.5…20.0	−6.5…20.0	4	7	1.76	NOTE	NOTE	3…5.0	0.0
Tx output power density range (dBW/MHz) [1]	−25.5…10.0	−25.5…10.0	−5.5	−5.5	−10.8			−14.8... −12.8	−16.0
Feeder/multiplexer loss range (dB)	0…3.0	0…3.0	Tx1 Rx1	Tx1 Rx1	Tx1 Rx1			0…9.5	0…7.6
Antenna gain range (dBi)	12…48.6	12…48.6	35	35	35			44…51	36…48.0
e.i.r.p. range (dBW)	5.5…65.5	5.5…65.5	38	41	36			33.1...51.2	13.3…43.0
e.i.r.p. density range (dBW/MHz) [1]	−13.5…55.5	−13.5…55.5	28.5	28.4	28.4			15.3...33.4 (Mode 28.5)	−2.7…27.0 (Mode 15.9...)
Receiver noise figure typical (dB)	2.5…6	2.5…8	4	4	4			5	5

TABLE 3 (*end*)

Frequency range (GHz)	**7.725-8.500**		**10.25-10.5**			**10.5-10.68**		**10.7-11.7**	
Reference ITU-R Recommendation	F.386		F.1777			F.747		F.387	
Receiver noise power density typical (= N_{RX}) (dBW/MHz)	−141.5…−138.0	−141.5…−136	−140	−140	−140			−139	−139
Normalized Rx input level for 1 × 10^{-6} BER (dBW/MHz)	−121.0…−117.5	−111.3…−106.5	N/A	N/A	N/A			−118.5	−112.5
Nominal long-term interference power density (dBW/MHz) (2)	−141.5…−138.0 + *I/N*	−141.5…−136 + *I/N*	−140.0 + *I/N*	−140.0 + *I/N*	−140.0 + *I/N*	N_{RX} + *I/N*	N_{RX} + *I/N*	−139 + *I/N*	−139 + *I/N*

(1) To calculate the values for the Tx/ e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

(2) Nominal long-term interference power density is defined by "Receiver noise power density + (required *I/N*)" as described in § 4.13 in Annex 2 of Recommendation ITU-R F.758 (see also § 4.1 in Annex 1 of Recommendation ITU-R F.758).

NOTE – The intended set of parameters for two reference systems for sharing/coexistence studies are presently not or only partially available; administrations are invited to contribute. On a provisional basis, the parameters reported in Annex 3 of Recommendation ITU-R F.758-5 for the same bands may be used.

Annex 3 of Recommendation ITU-R F.758-5 provides parameters for P-P FS systems in the range 10.5-10.68 GHz. It should be noted that the first system was taken into account in the studies performed in Report ITU-R RS.2094.

TABLE 4

FS P-P characteristics

Frequency range (GHz)	10.5-10.68	
Reference ITU-R Recommendation	F.747	
Modulation	QPSK (3)	128-TCM
Channel spacing and receiver noise bandwidth (MHz)	1.25, 2.5, 3.5, 7	1.25, 2.5, 3.5, 7
Maximum Tx output power range (dBW)	−2	−3
Maximum Tx output power density range (dBW/MHz) (1)	−10	−7.0
Minimum feeder/multiplexer loss range (dB)	0	0
Maximum antenna gain range (dBi)	49	51
Maximum e.i.r.p. range (dBW)	47	48
Maximum e.i.r.p. density range (dBW/MHz) (1)	39	44
Receiver noise figure (dB)	3	4
Receiver noise power density typical (= N_{RX}) (dBW/MHz)	−141	−140
Normalized Rx input level for 1 × 10^{-6} BER (dBW/MHz)	−127.5	−116.4
Nominal long-term interference power density (dBW/MHz) (2)	−141 + *I/N*	−140 + *I/N*

Notes to Table 4:

NOTE 1 – To calculate the values for the Tx e.i.r.p. densities, channel spacing/bandwidth need to be identified. In these tables, the channel spacing indicated in bold letter is used.

NOTE 2 – Nominal long-term interference power density is defined by “Receiver noise power density +(required *I/N*)” as described in § 4.13 in Annex 2 of Recommendation ITU-R F.758 (see also § 4.1 in Annex 1 of Recommendation ITU-R F. F.758).

NOTE 3 – There are two modulations (QPSK and 4FSK) described and QPSK is selected.

Statistics for some FS deployments have been provided to ITU-R for the elevation pointing angles used at 8 GHz and 10/11 GHz.

These statistics show that, amongst an important number of FS deployed in those frequency bands, the elevation angle used in these deployments are below 24°. However for completeness, analyses took into account elevation angles up to 35°.

Table 5 provides the parameters of P-MP FS systems operating in the band 10.15-10.68 GHz.

TABLE 5

FS P-MP generic characteristics

Frequency range (GHz)	**10.15-10.3 / 10.5-10.65 / 10.0-10.68**	
Reference ITU-R Recommendation	F.1568, F.747	
Modulation format	Central station 64-QAM	Terminal station 64-QAM
Channel spacing and receiver noise bandwidth (MHz)	**1.75** (3), 2.5, 5, 28(5), 30(5)	**1.75** (3), 2.5, 5, 28(5), 30(5)
Tx output power range (dBW)	−3	−12
Tx output power density range (dBW/MHz)(1)	−5.43	−14.4
Feeder/multiplexer loss range (dB)	0.5	0
Antenna type and gain range (dBi)	15 (90º microstrip sectoral)	18 (panel)
e.i.r.p. range (dBW)	11.5	6
e.i.r.p. density range (dBW/MHz)(1)	9.07	3.57
Receiver noise figure typical (dB)	5	5
Receiver noise power density typical (=N_{RX}) (dBW/MHz)	−139	−139
Normalized Rx input level for 1×10^{-6} BER (dBW/MHz)	−112.5	−112.5
Nominal long-term interference power density (dBW/MHz) (2)	−139 + *I/N*	−139 + *I/N*

Notes to Table 5:

NOTE 1 – To calculate the values for the Tx / e.i.r.p. densities, channel spacing/bandwidth needs to be identified. In these tables, the channel spacing indicated in the **bold letter** is used. Where a modal value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified.

NOTE 2 – Nominal long-term interference power density is defined by "Receiver noise power density + (required *I/N*)" as described in § 4.13 in Annex 2 of Recommendation ITU-R F.758 (see also § 4.1 in Annex 1 of Recommendation ITU-R F.758-5).

NOTE 3 – This channel spacing value is not specified in the reference Recommendations (ITU-R F.1568 and ITU-R F.747).

NOTE 4 – N/A.

NOTE 5 – Frequency block bandwidth.

3.3 Comparing EESS SAR-4 characteristics with others SAR in Report ITU-R RS.2094

The orbital characteristics of all SAR systems are quite similar, as well as the antenna orientation on board the satellite.

Table 6 provides a comparison of the pfd radiated on the ground by those SAR systems.

TABLE 6

Comparison of the pfd spectral density with other SAR systems

	SAR-1	**SAR-2**	**SAR-3**	**SAR-4**
e.i.r.p. (dBW)	76	83	86	85.5
Bandwidth (MHz)	10	400	450	1 200
Pulse length (μs)	34	80	10	50
PRF (pps)	1 736	4 500	515	6 000
Mean e.i.r.p. spectral density (dBW/MHz)	54	53	37	50
Minimum slant range (km)	424	654	536	540
Mean pfd spectral density (dBW/m²/MHz)	–70	–75	–89	–75

It can be seen that SAR-4 will radiate a mean pfd spectral density 14 dB higher than SAR-3, which was considered in the sharing studies with FS in Report ITU-R RS.2094. The studies in Report ITU-R RS.2094 indicate that FS stations would be protected from harmful interference with a margin of about 43 dB. An increase of 14 dB will therefore reduce this margin to 29 dB, still a good margin to protect FS. It is important to note that the assumptions for SAR systems taken in Report ITU-R RS.2094 were based on 100% continuous transmissions while, in reality, a SAR system transmits only for up to five seconds per picture taken. During one orbit, a maximum of up to 40 pictures can be taken due to technical constraints such as heat dissipation, memory size, data downlink capacities of EESS SAR satellites, and others. Further analyses have been performed for SAR-4 using a bandwidth of 1 200 MHz with current results as provided in section 5.

With regard to potential interference caused by FS systems into EESS SAR sensors, the emission power of FS systems as given in Recommendation ITU-R F.758-5 may be up to 7 dB higher than the emission power of –2 dBW considered in Report ITU-R RS.2094 for the 10 GHz band. However, the studies in this report concluded that the SAR system would be protected from harmful interference by a significant margin of more than 20 dB.

When considering further deployments of similar FS systems, it can be expected that SAR systems would still be protected from harmful interference by a margin of more than 13 dB.

The situation might be different in the frequency range 8 700-8 750 MHz where less tangible information is available. A maximum transmission power of 20 dBW, as indicated in Recommendation ITU-R F.758-5 for the frequency range 7 725-8 500 MHz, together with further FS deployments, similar as assumed in Report ITU-R RS.2094, could mean that the actual margin might come close to 0 dB. However, it is expected that the SAR system still would be sufficiently protected, in particular due to the additional SAR processing gain.

3.4 Studies of the impact of SAR-4 on fixed service in terms of fractional degradation of performance

3.4.1 Scenario

The previous studies on spectrum sharing conditions among SAR systems operating in the EESS (active) and system operating in the FS considered the SAR systems in stripmap mode and permanently operating with an antenna pointing with a fixed offset angle of 34° from Nadir.

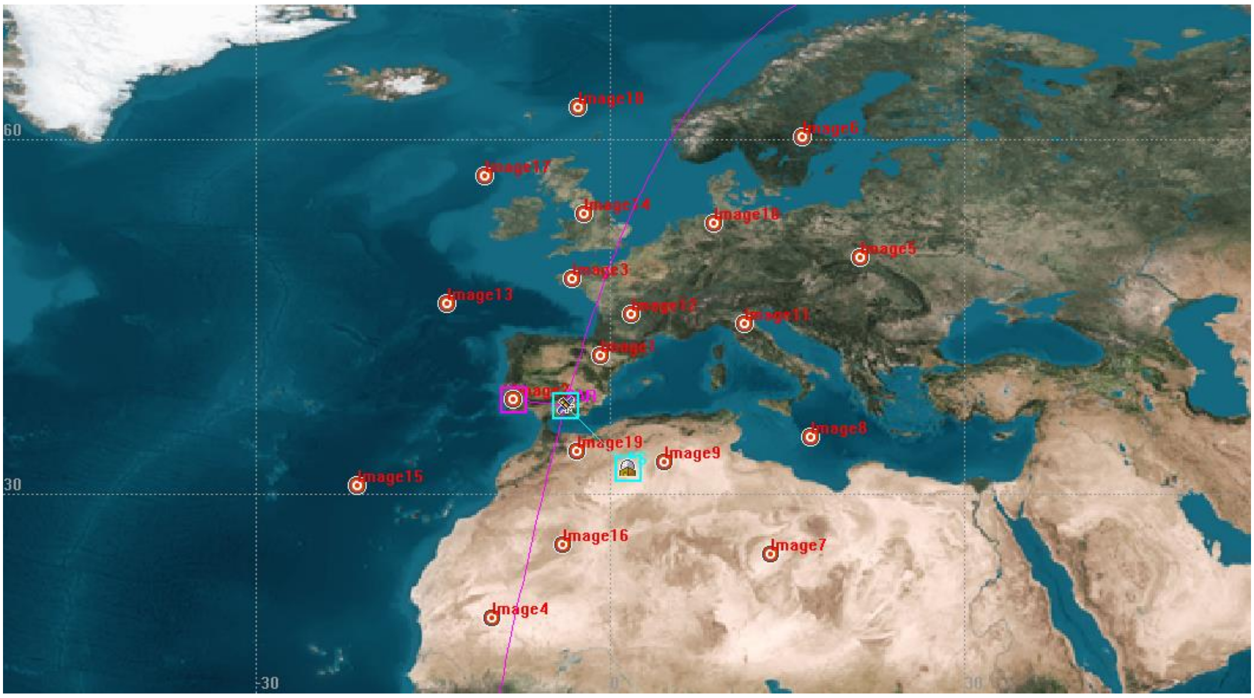
In spotlight mode, the spot area is tracked between 20° and 55° incidence angles on each side of the satellite. During the short period of time when taking a picture the azimuth angle (cross track) is within 90° ± 2.5°, thus reducing the effective exposure time of a spot to 5 seconds.

In order to assess the potential interference conditions produced by a SAR-4 system in spotlight mode, a simulation model was developed.

The victim FS station in the sharing scenario is located in the center of the spot area. The full satellite orbit is calculated for one month at time intervals of one second. The satellite illuminates the spot area around the FS station when the angular constraints are met as shown in Fig. 3. The entire illumination period of the station occurs during 5 seconds under varying incident angles.

FIGURE 3

Applied simulation scenario modelling the spotlight mode



As a first step, the assumed victim FS station was deployed in an area located around a mid-range latitude of 30°, which is representative for many countries operating FS under conditions given by country footnotes in the bands 8 700-8 750 MHz and 10-10.5 GHz . The azimuth pointing angle of the FS station is assumed to vary from 0° to 360°.

Its elevation angle is taken as +5° for P-P stations and P-MP terminals, and 0° for P-MP central stations. The key FS characteristics considered in the analysis are summarized in Table 7.

All studies considered information FS systems provided in Table 7 extracted from Tables 3 to 6. The elevation angle are not representative of actual FS deployments, additional studies have therefore been carried out with elevation angles up to 35 degrees.

TABLE 7

Key FS characteristics used in the analysis

	FS1	**FS2**	**FS3**	**FS4**	**FS5**
Type of FS station	P-P 8.7 GHz	P-P 10 GHz	P-MP central station 10 GHz	P-MP terminal 10 GHz	BAS 10 GHz
Antenna gain (dBi)	48.6	49	15	18	35
Antenna type	Parabolic	Parabolic	Sectoral 90°	Panel	Parabolic
Antenna pattern ITU-R Recommendation	F.1245-2	F.1245-2	F.1336	F.1245-2	F.1245-2
Elevation angle (degrees)	5	5	0	5	5
Feeder loss (dB)	0	0	0.5	0	1
Receiver noise (dBW/MHz)	–141.5	–141	–139	–139	–140

3.4.2 Results for a FS station considering the fractional degradation of performance criterion at mid-latitudes

The results are expressed in terms of FDP, which is described in Recommendation ITU-R F.1108. The FDP criterion has been assumed to be 10%.

FIGURE 4

Fractional degradation of performance (FDP) for FS1

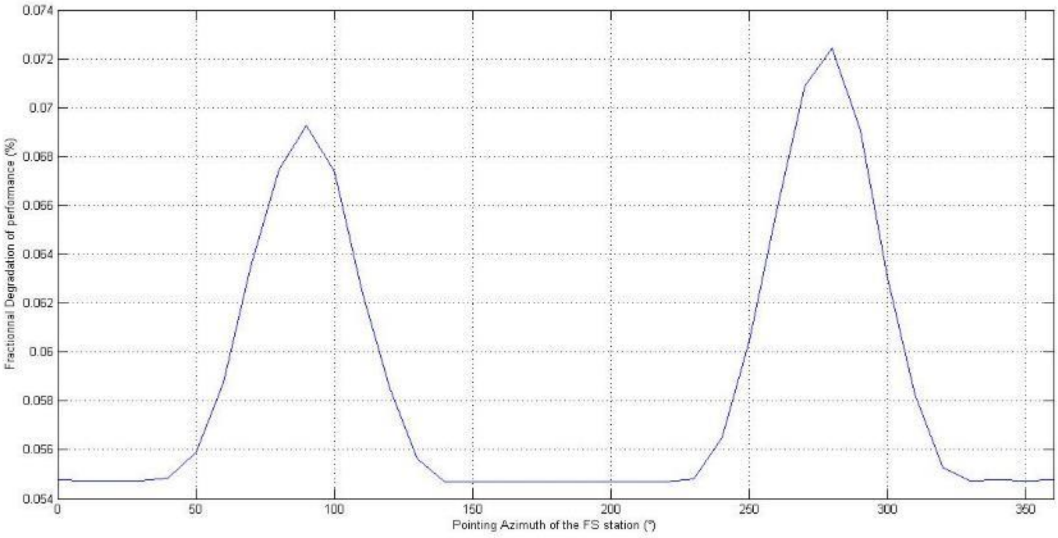


FIGURE 5

Fractional degradation of performance (FDP) for FS2

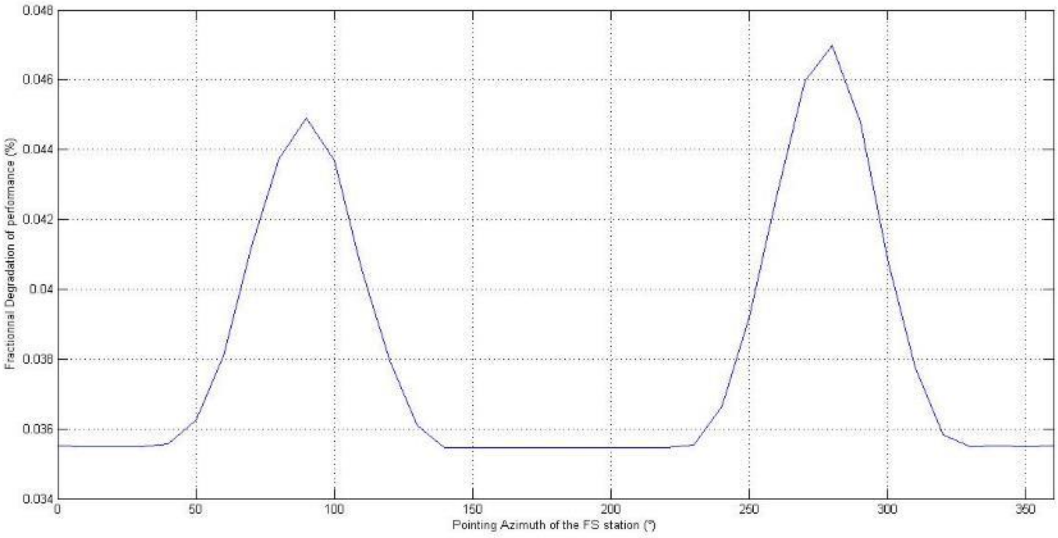


FIGURE 6

Fractional degradation of performance (FDP) for FS3

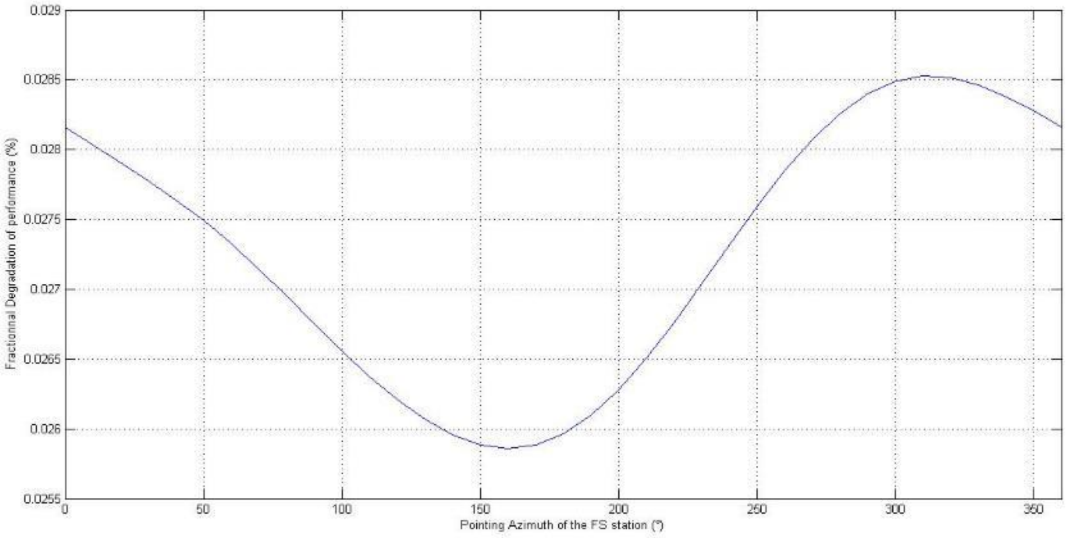


FIGURE 7

Fractional degradation of performance (FDP) for FS4

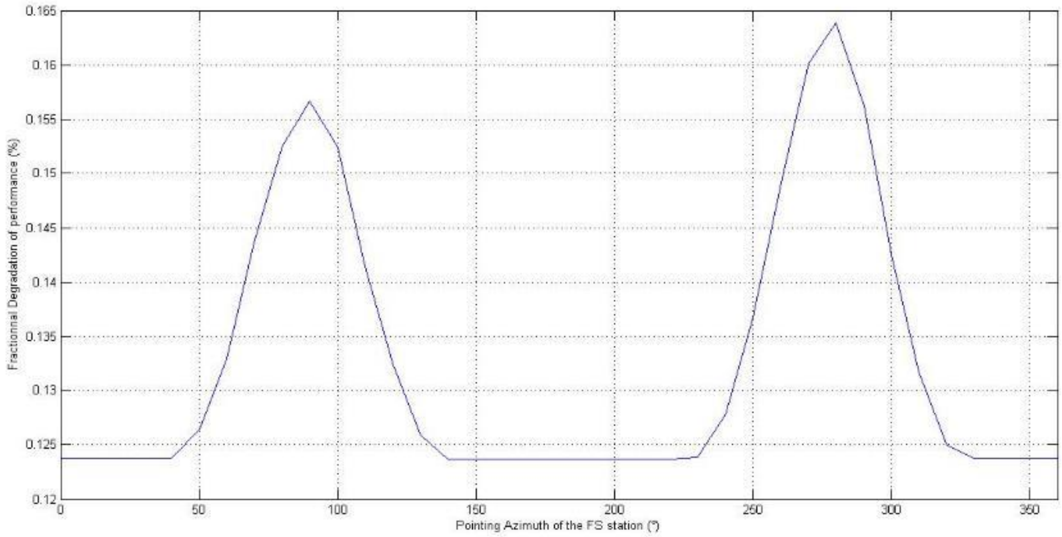
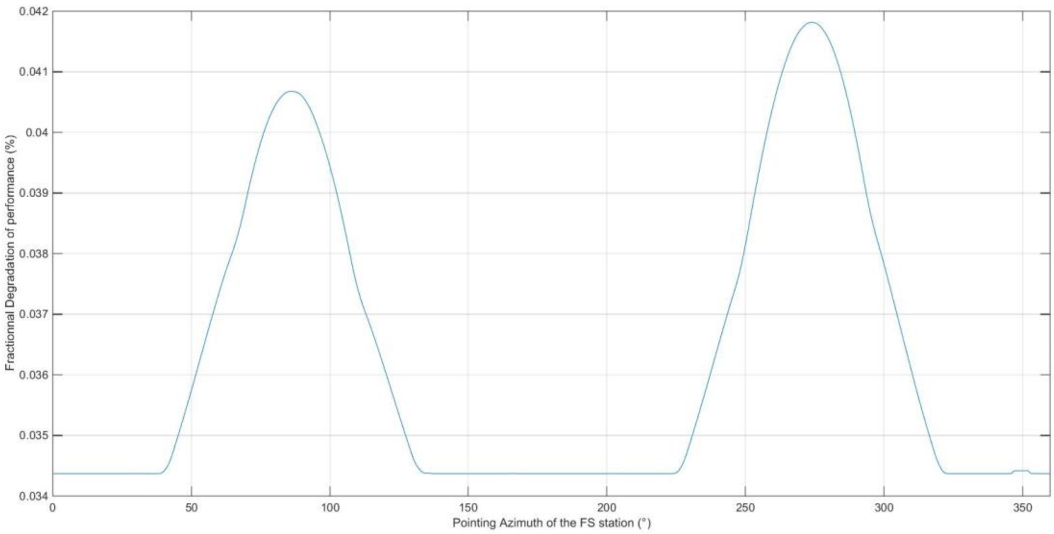


FIGURE 8

Fractional degradation of performance (FDP) for FS5



Figures 4 to 8 show that the FDP criterion always stays below 0.17%.

The worst case is obtained for a P-MP terminal station which has a rather low gain of 18 dBi. In this case the secondary lobes and sidelobes have a higher gain, the beam is wider, and there are more risks of intercepting the main beam or first sidelobes of the FS station.

The worst case interference levels for P-P stations or P-PM terminals are obtained for azimuth pointing angles around 90° and 270°. This is due to the fact, that the SAR system takes a picture only when the spot area is at an angle of about 90°, i.e. below (Nadir) the orbiting spacecraft traveling on a polar orbit (98°).

At that period, the SAR main beam will point towards an azimuth of around +90° or +270°. If the FS station points in either of those directions, the risk of main beam to main beam coupling increases.

For a high-gain P-P or a BAS station at 10 GHz, the FDP maximum value is 0.047%, which is (10/0.047=) 212 times, or 23 dB lower than the 10% criterion. This constitutes the margin with which the FS station is protected. This result has to be compared to the margin of 30 dB which was expected in section 3 from previous studies. The difference of 7 dB may be explained by the fact that in spotlight mode, the SAR antenna is tracking the target area during 5 seconds, whereas in the previously studied stripmap mode the time over a target area is in the order of 1 second.

For P-MP terminals or P-P low gain FS stations, the margin decreases to 18 dB.

3.4.3 Results for a FS station considering the fractional degradation of perfomance criterion at high latitude

Further, in comparison to the findings of Report ITU-R RS.2094, the same analysis is performed for an FS station located at high latitudes, above 60°.

FIGURE 9

Fractional degradation of performance (FDP) for FS1

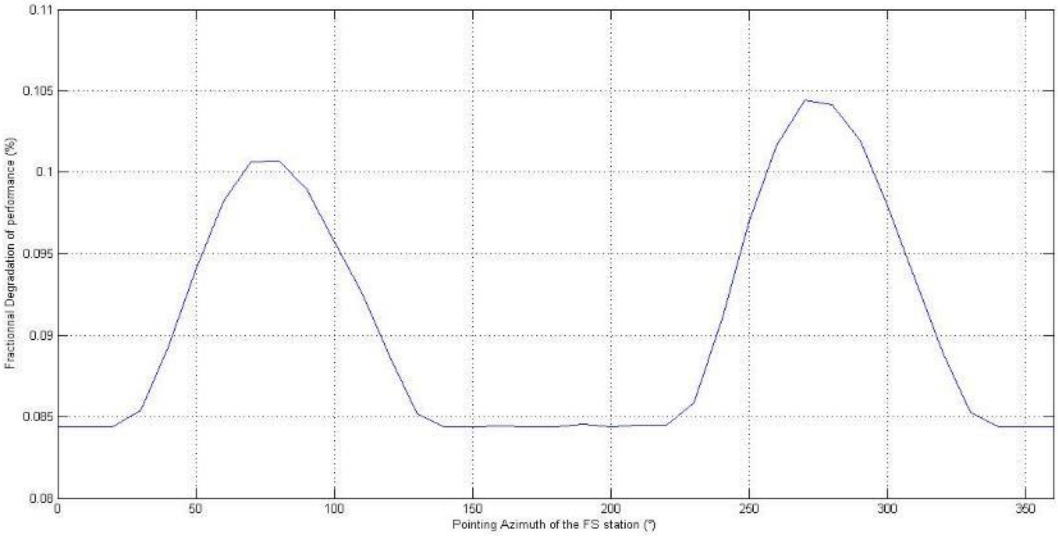


FIGURE 10

Fractional degradation of performance (FDP) for FS2

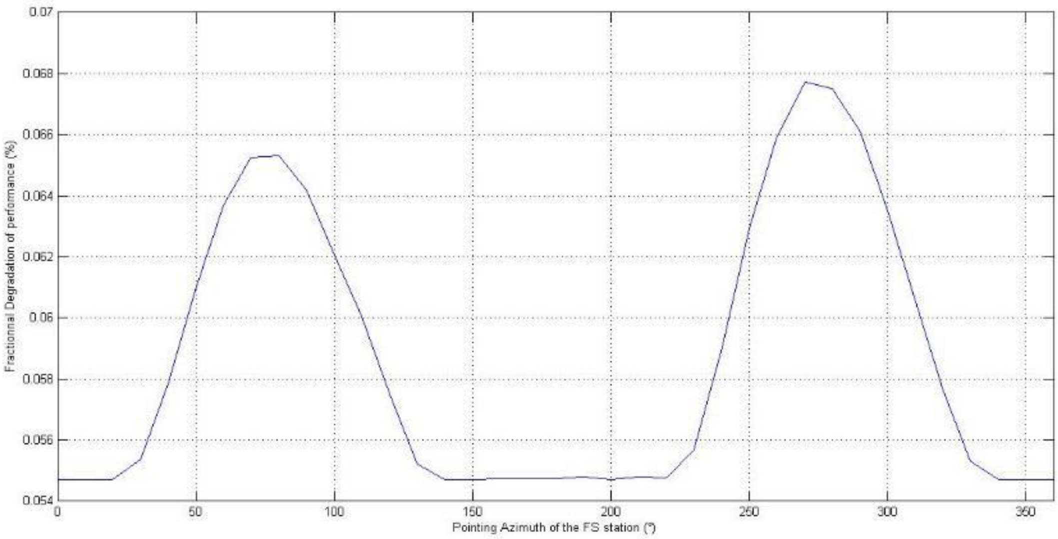


FIGURE 11

Fractional degradation of performance (FDP) for FS3

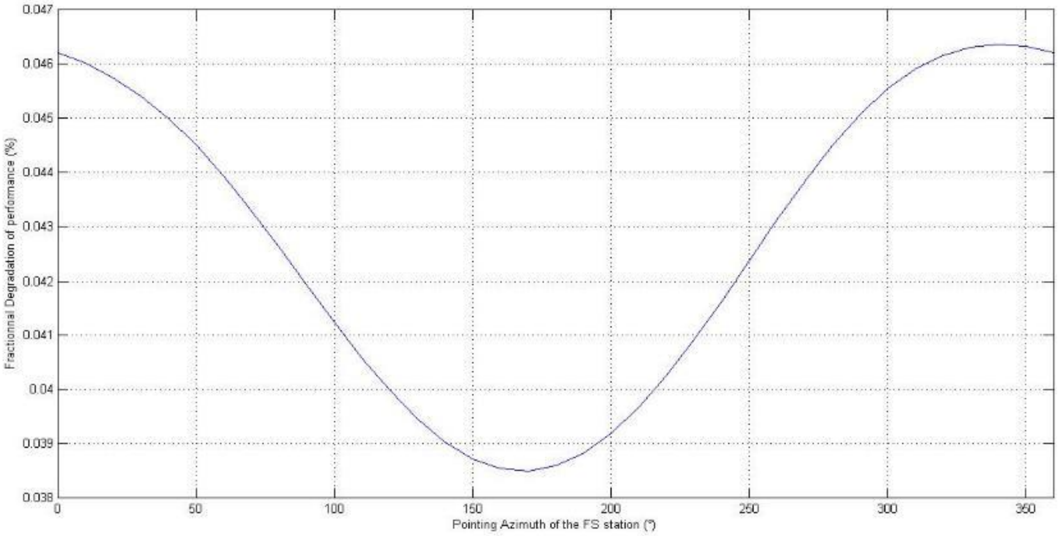


FIGURE 12

Fractional degradation of performance (FDP) for FS4

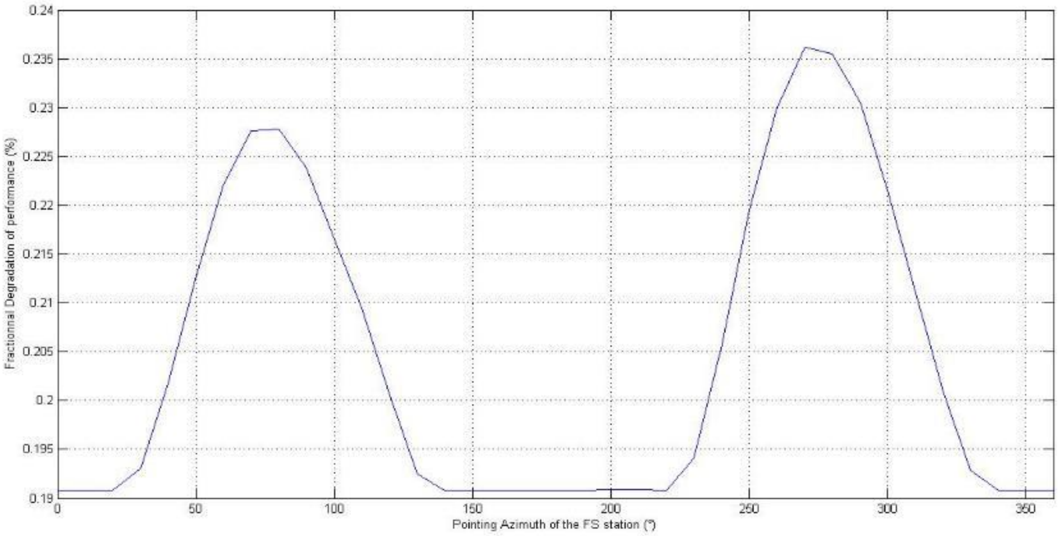
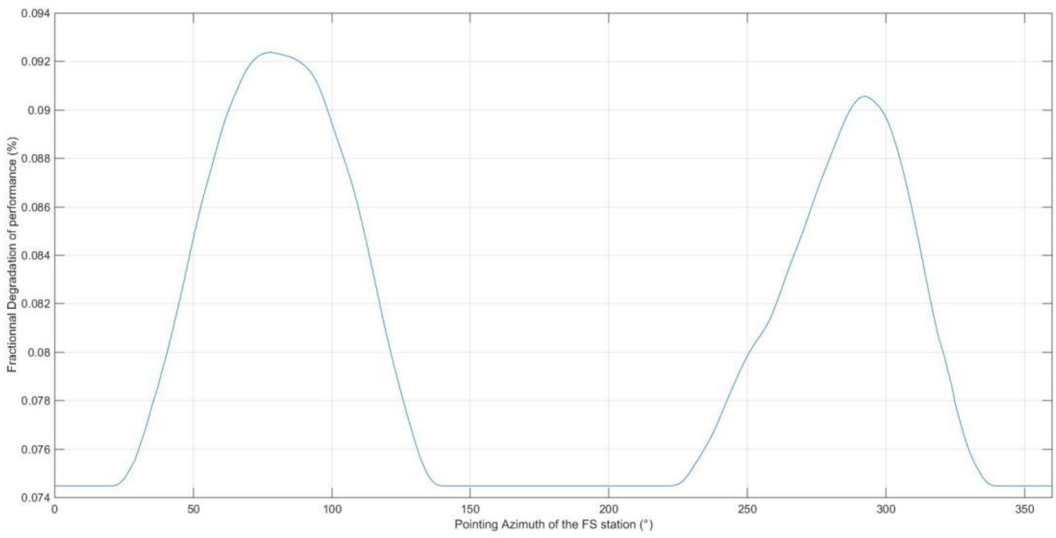


FIGURE 13

Fractional degradation of performance (FDP) for FS5



Figures 9 to 13 show similar results with an increase of 30% in the obtained FDP values, which still is well below the 10% criterion.

3.4.4 Impact of the elevation angle for point-to-point FS systems considering the FDP criterion

This section is limited to P-P systems FS1 and FS2, for which elevation angles of up to 20 degrees and even 35 degrees might be used.

Figures 14 and 15 give the results for respectively an elevation angle of 20 degrees and 35 degrees for FS1, FS2, and FS5.

FIGURE 14

Fractional degradation of performance (FDP) for FS1, FS2, and FS5 with elevation angle of 20 degrees

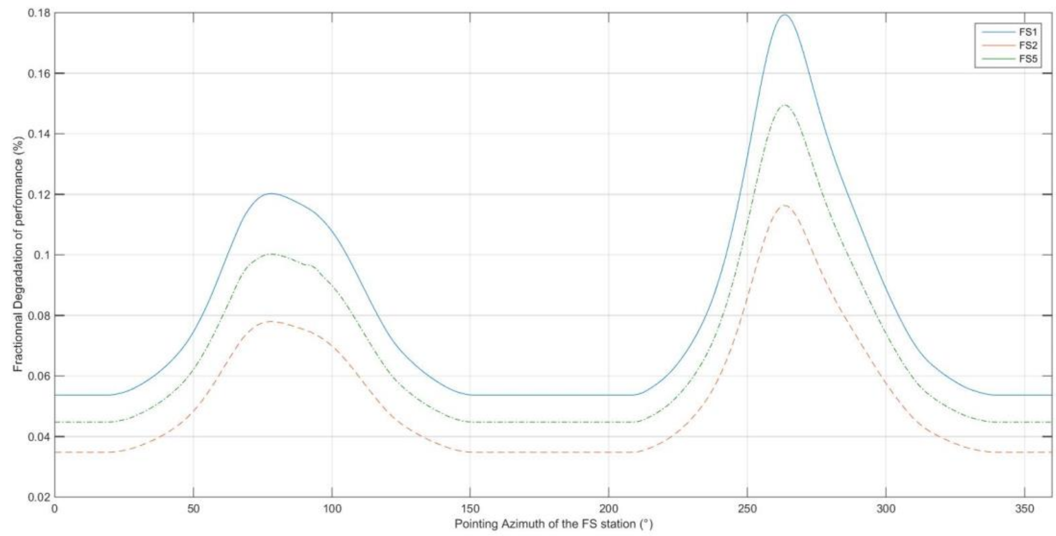
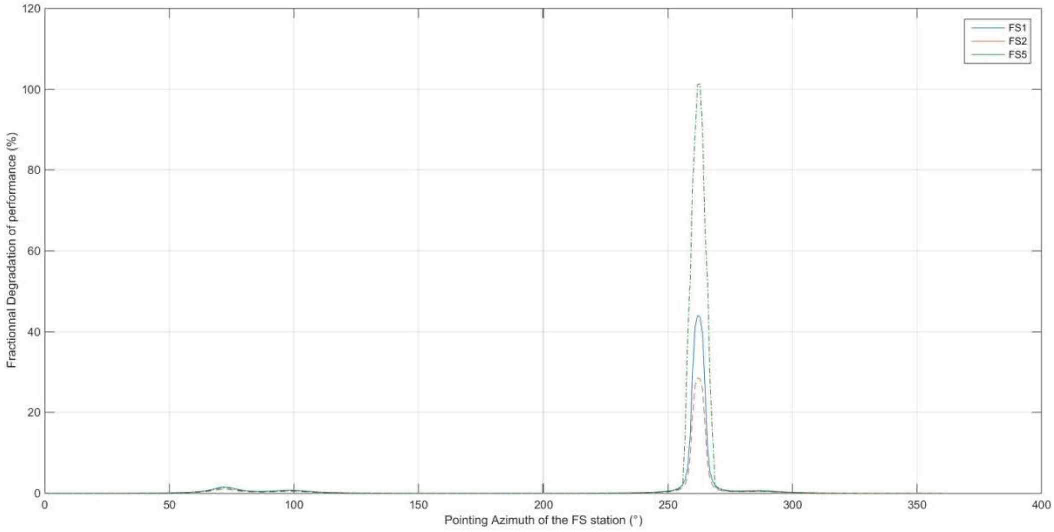


FIGURE 15

Fractional degradation of performance (FDP) for FS1, FS2, and FS5 with elevation angle of 35 degrees



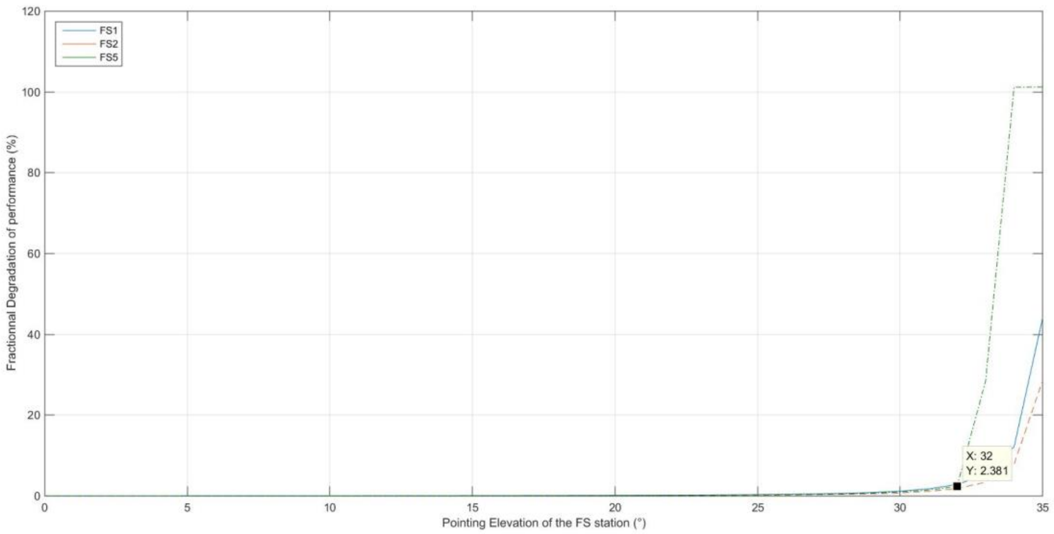
When considering an elevation angle of 20° the FDP stays below 0.18% which is comparable to levels obtained with lower elevation angles. When considering an elevation angle of 35°, the FDP can increase up to 100%, if the FS station is pointing in the direction of the transmitting SAR due to main beam to main beam coupling.

This would only occur for FS stations receiving under an azimuth of 262° for the longitude and latitude considered, with elevation angles higher than 35°.

Figure 16 shows the evolution of the FDP over elevation angle for the worst case azimuth angle 262°.

FIGURE 16

Fractional degradation of performance (FDP) for FS1, FS2, and FS5 with azimuth angle of 262 degrees



It starts to rise significantly after 30°, when the satellite has more risks to be in the FS first sidelobes or main beam. The 10% criterion would be exceeded for an elevation angle greater than 34°for FS1 and FS2, and 32° for FS5 (broadcast auxiliary services (BAS)). This is due to the larger beam of the latter. For a more practical maximum elevation angle of 20°, the FDP stays below 0.18%.

3.5 Studies of the impact of SAR-4 on fixed service in the frequency band 10.0-10.5 GHz in terms of long-term and short-term *I/N*

3.5.1 Study 1 (short-term *I/N* criterion)

3.5.1.1 Introduction

The short-term protection criterion depends on the characteristics of each FS system, including the fade margin, the use of automatic transmitter power control (ATPC), and the error performance objective (EPO). The *I/N* value and associated percentage of time may be calculated using the methodologies described in several F, SF or SM series recommendations listed in Recommendation ITU-R F.758-5. Analysis of Recommendation ITU-R F.758-5 refers to Recommendations ITU-R F.1494, ITU-R F.1495, ITU-R F.1606, ITU-R F.1669 in relation to technical characteristics and protection criteria for FS systems.

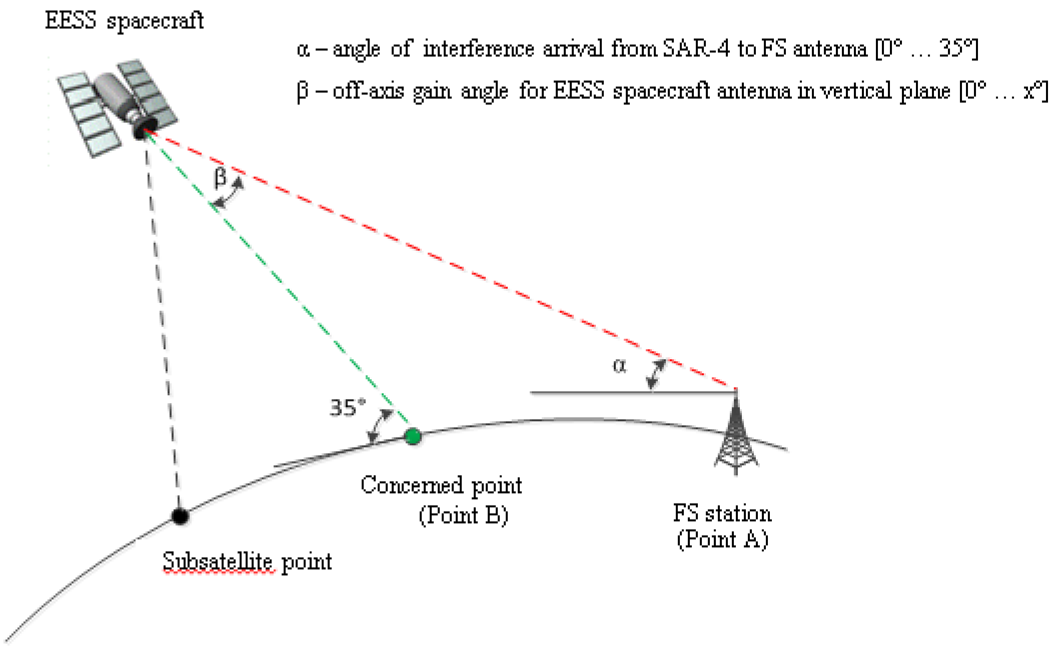
Analysis of the above listed ITU-R Recommendations showed that neither of them referred to the frequency band 9 900-10 500 MHz. However, Recommendation ITU-R F.1494 describes a short-term protection criterion for FS receivers operating in the frequency band 10.7-12.75 GHz. This study assumes that characteristics of FS systems operating in the frequency band 10.0-10.5 GHz and those operating in the frequency band 10.7-12.75 GHz are similar, it is proposed that an $I/N = +20$ dB for 1×10^{-4} % of the time in any month should be used as a short-term protection criterion in the frequency band 10.0-10.5 GHz.

3.5.1.2 Scenario of interference effects

The scenario of potential interference effect produced by SAR-4 emissions is shown in Fig. 17. It shows how SAR-4 emissions can cause interference to operation of an FS receiver deployed in Point A.

FIGURE 17

Scenario of interference from an EESS SAR-4 system into an FS receiver



In this scenario, EESS SAR-4 is taking an image of Point B, where the elevation angle of EESS SAR-4 as seen from Point B is 35°. In this case, the distance between Point B (image area) and the sub-satellite point is at maximum. The FS antenna main lobe points directly towards the main lobe of the EESS SAR-4 satellite antenna, i.e. the FS station antenna elevation angle is equal to the interference arrival angle of the EESS SAR-4 (angle alpha in Fig. 17) as seen from the FS receiver. Such a case may occur when a FS station is deployed in a mountainous rugged terrain.

3.5.1.3 Results of Study 1

The conducted studies analysed a case where the FS antenna elevation (angle of interference arrival at the FS receiver antenna) would vary from 0° to 35°. The interference simulation used a free space propagation model from Recommendation ITU-R P.525-2 and the FS system technical characteristics from Recommendation ITU-R F.758-5. The receiving antenna gain is assumed as 18 dBi and the thermal noise power spectral density is assumed to be –139 dBW/MHz. Table 8 reflects the results of the *I/N* ratio as a function of the SAR-4 elevation angle varying from 0° to 35°.

TABLE 8

***I/N* ratio at the FS receiver input (front end) vs. interference angle of arrival**

Interference angle of arrival α (degrees)	0	5	10	20	25	30	35
Angle of SAR-4 off-axis emission in FS receiver direction (degrees)	18.5	18	16.5	11.2	7.7	4	0
SAR-4 antenna gain in FS receiver direction (dBi)	12.4	12.6	13.3	15.8	20.2	27.4	47
SAR-4 off-axis e.i.r.p. in FS receiver direction (dBW)	20.1	20.3	21	23.5	27.9	35.1	54.7
Propagation loss (dB)	180.7	178.9	177.2	174.1	172.9	171.8	170.8
FS receiver antenna gain (dBi)	18						
FS receiver noise power spectral density (dBW/MHz)	–139						
I/N (dB)	–3.6	–1.6	0.8	6.4	12	20.3	40.9

Analysis of the results obtained shows that the short-term protection criteria value would be exceeded in the scenario concerned for the FS antenna elevation angles above 30°. The time when the protection criterion is exceeded would be equal to the measurement period (5 seconds) and is 1.87×10^{-4}% of the time for a 31-day month or 2.07×10^{-4}% of the time for a 28 day month. Thus, the FS receiver short-term protection criterion in the case considered would not be met even for a single measurement in Point B.

However, according to Recommendation ITU-R RS.2043, the above situation would be repeated every 11 days in case of multiple image taking of Point B or in its close vicinity which would result in exceeding the protection criterion for 5.61×10^{-4}% of the time in a 31-day month or 6.21×10^{-4}% of the time in a 28-day month. It obviously exceeds the duration of 0.0001% of the time for any month as specified in Recommendation ITU-R F.1494.

Therefore, in order to meet the short-term protection criterion for FS receivers would require imposing limitations on the spectral pfd emitted by EESS SAR-4 systems on the Earth's surface with a value providing for acceptable interference level at the front ends of FS system receivers. The value provided for meeting the criterion of *I/N* = +20 dB is proposed to be taken as a limit for the pfd.

The pfd at the antenna front end is given by:

$$pfd = I_{acc} - G_{FS} - 10\lg\left(\lambda^2 / 4\pi\right)$$

where:

- pfd : power flux spectral density (dBW/m²/MHz)
- I_{ACC} : acceptable level of interference spectral density (dBW/MHz)
- G_{FS} : FS station antenna gain (dBi)
- λ : wave length of emission (m).

Table 9 below describes FS receiver parameters used for estimating the maximum acceptable pfd level.

TABLE 9

Typical technical characteristics of FS systems

Typical receiver noise power density (=N_{RX}) (dBW/MHz)	–139
I/N ratio for FS systems (dB)	–10
Nominal power density for short-term interference (dBW/MHz)	–119
Typical FS system antenna gain (dBi)	18

Assuming the above technical characteristics for FS systems the SAR-4 spectral pfd would be –96 dBW/m^2/MHz.

3.5.2 Study 2 (short-term and long-term *I/N* criteria)

3.5.2.1 FS protection criteria

The protection criteria for FS in Recommendation ITU-R F.758-5 comprise a long-term and short-term *I/N* criterion associated to a relevant percentage of time.

The long-term protection criterion consists of an *I/N* of –10 dB not to be exceeded for more than 20% of the time. This criterion is always met when taking the short EESS SAR-4 visibility for an FS station and the very low EESS SAR activity factor in the order of seconds into account.

The short-term protection criterion depends on the characteristics of each FS system, including fade margin, the use of ATPC, and the EPO. The *I/N* value and associated percentage of time may be calculated using the methodologies described in several F, SF or SM series ITU-R Recommendations which are referred and listed in Recommendation ITU-R F.758-5.

The methodology in Recommendation ITU-R F.1494, covering FS systems operating in the frequency band 10.7-11.7 GHz, was taken as a basis for the derivation of this criterion. It has, however, to be noted that the FS applications in the band 10-10.65 GHz may differ from those in the frequency band 10.7-11.7 GHz. The frequency band 10 – 10.65 GHz is, according to the PDN Report ITU-R F.2323-0, already used for ENG applications and it is therefore not expected that FS links in this frequency band will be part of international or long-haul national transport networks, in clear contrary to the band 10.7-11.7 GHz. However, some Administrations may decide to use this band for different applications. Thus, for the sake of completeness, such applications were also considered in the study.

P-P FS links can be part of international and national long-haul networks, or part of national short-haul or access networks. P-MP FS links are mainly used to provide access from a customer terminal to a central station, but may also be used in short haul national networks.

In line with Recommendation ITU-R F.1494, the short-term *I/N* protection criterion of +20 dB is taken which should not be exceeded for more than p% of time. The methodology in Recommendation ITU-R F.1494 allows calculating the relevant percentage of time p. In absence of other information, a total fade margin of 37 dB was assumed, given for a bit error ratio (BER) of 10^{-3} as well as for a 13 dB ATPC range of the FS station, in compliance with Recommendation ITU-R F.1494.

The degradation of performance is linked to the percentage of time p by:

$$DP(\%) = \frac{DstEPO(\%).EPO(\%)}{100} = \frac{p(\%).A(\%)}{100}$$

Therefore

$$p(\%) = \frac{DP(\%)}{\mathrm{A}(\%)} 100$$

where:

DstEPO: allowed degradation of the EPO (10%)

EPO: error performance objective (%)

p: percentage of time where the short-term *I/N* may be exceeded (%)

A: percentage of time a given fade margin may be exceeded (%), (see Recommendation ITU-R P.530).

Recommendation ITU-R F.1565 provides the values of degradation of performance allowed due to interference for international, national long-haul, short-haul, and access connections, respectively. The degradation values are given for the errored second (ES) and severely errored second (SES) objectives.

The fade margin for SES is 1 dB below the fade margin for a 10^{-3} BER. The fade margin for ES is 5 dB below the fade margin for a 10^{-3} BER.

3.5.2.1.1 FS part of an international or a long haul national network

Such applications would include transport on international or national long haul network, with longer hops between the stations and, therefore, lower elevation angles.

TABLE 10

Percentage of time based on the SES for a FS part of an international network

Parameter	Value	Source
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for SES (dB)	36	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for SES (dB)	3	
Allowed degradation of performance SESR (%)	0.005	Rec. ITU-R F.1565 Table 1a – 500 km
Probability that the fade margin is exceeded (%)	3.3	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	1.52E-01	

TABLE 11

Percentage of time based on the ES for a FS part of an international network

Parameter	Value	Origin
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for ES (dB)	32	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for ES (dB)	0	
Allowed degradation of performance ESR (%)	0.001	Rec. ITU-R F.1565 Table 1a – 500 km
Probability that the fade margin is exceeded (%)	63	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	1.59E-03	

TABLE 12

Percentage of time based on the SES for a FS part of a long haul national network

Parameter	Value	Origin
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for SES (dB)	36	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for SES (dB)	3	
Allowed degradation of performance SESR (%)	0.00012	Rec. ITU-R F.1565 Table 3a – 50 km
Probability that the fade margin is exceeded (%)	3.3	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	3.64E-03	

TABLE 13

Percentage of time based on the ES for a FS part of a long haul national network

Parameter	Value	Origin
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for ES (dB)	32	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for ES (dB)	0	
Allowed degradation of performance ESR (%)	0.0006	Rec. ITU-R F.1565 Table 3a – 50 km
Probability that the fade margin is exceeded (%)	63	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	9.52E-04	

The worst case value is given for the ES and the long haul national portion as 0.00095%.

3.5.2.1.2 FS part of a national short haul or access network

Such applications would include backhauling to mobile networks or ENG which are foreseen in this frequency band. Shorter hops would lead to the possibility of higher elevation angles in mountainous areas.

TABLE 14

Percentage of time based on the SES for a FS part of a national short haul or access network

Parameter	Value	Origin
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for SES (dB)	36	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for SES (dB)	3	
Allowed degradation of performance SESR (%)	0.0015	Rec. ITU-R F.1565 Table 5a
Probability that the fade margin is exceeded (%)	3.3	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	4.55E-02	

TABLE 15

Percentage of time based on the ES for a FS part of a national short haul or access network

Parameter	Value	Origin
Fade margin for BER 10^{-3} (dB)	37	Rec. ITU-R F.1494
Fade margin for ES (dB)	32	Rec. ITU-R F.1494
ATPC (dB)	13	Assumed
I/N short-term (dB)	20	Chosen
Net fade margin for ES (dB)	0	
Allowed degradation of performance ESR (%)	0.0075	Rec. ITU-R F.1565 Tables 4a and 5a
Probability that the fade margin is exceeded (%)	63	Rec. ITU-R P.530
Probability associated with the short-term criterion (%)	1.19E-02	

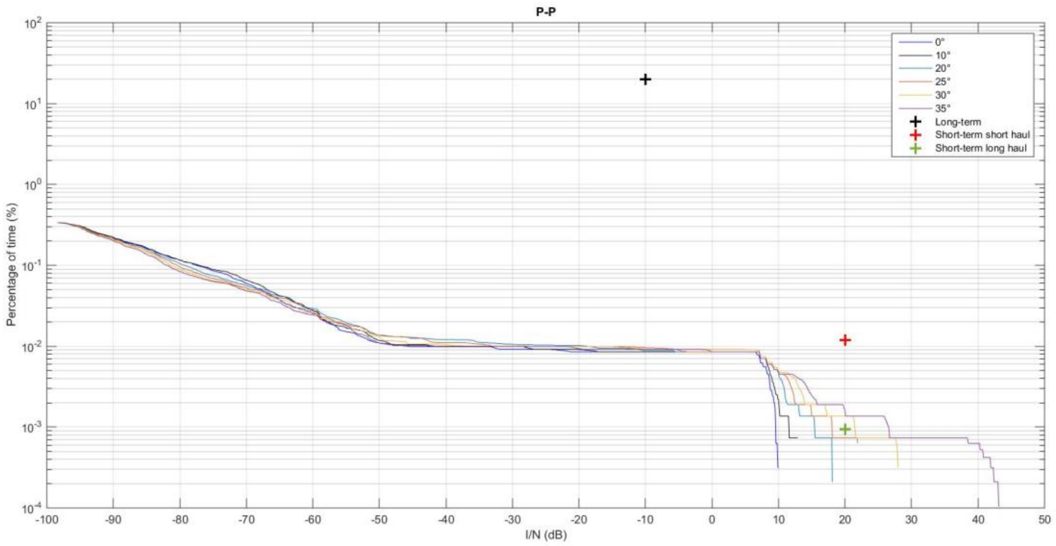
The worst case is given for the ES as 0.012%.

3.5.2.2 Simulation results using an *I/N* criterion

Figure 18 provides the cumulative distribution function of the mean *I/N* obtained from the simulation tool, for a P-P FS station at high latitude, with a maximum antenna gain of 49 dBi pointing at 0, 10, 20, 25, 30, and 35° elevation and at the worst case azimuth of 97° (determined through the FDP calculation, perpendicular to one satellite path).

FIGURE 18

Cumulative distribution function of mean *I/N* in a P-P FS station at high latitude



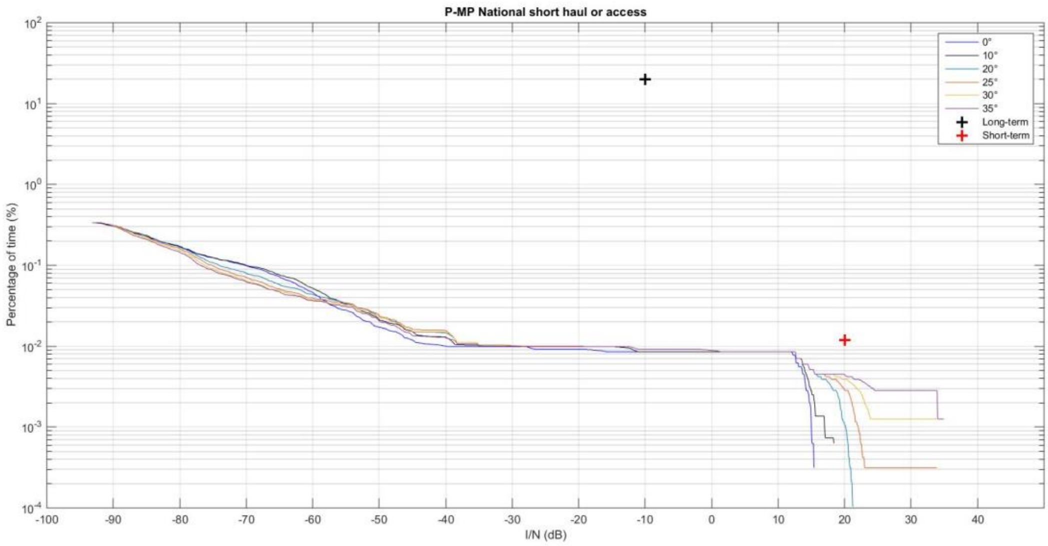
The results in Fig. 18 indicate, that the long-term criterion of I/N = –10 dB is only exceeded for 0.009% of time for one EESS SAR-4 satellite. The margin with the 20% of the time criterion is therefore fully sufficient to enable multiple EESS SAR-4 systems.

Similarly, the short-term criterion derived for FS being part of a national short-haul or access network would not be exceeded, at still very large margins. The short-term criterion derived for FS stations being part of an international or a national long haul network would only be exceeded when the elevation angle exceeds 30°, albeit this only for a few particular azimuth pointing angles. This is in line with the FDP calculation results reported in § 3.4. As mentioned above, such high elevation angles are not expected for such applications, due to larger hop distances. As an example, a 20 km hop distance from sea level to a 4 000 m high mountain level would result in a 11° elevation angle.

Figure 19 provides the cumulative distribution function (CDF) of the mean I/N obtained from the simulation tool, for a P-MP FS station at high latitude, with a maximum antenna gain of 18 dBi pointing at 0, 10, 20, 25, 30, and 35° elevation and at the worst case azimuth of 82° (determined through the FDP calculation, perpendicular to one satellite path).

FIGURE 19

Cumulative distribution function of mean *I/N* in a P-MP FS station at high latitude



The results shown in Fig. 19 also indicate, that the long-term criterion of *I/N* = –10 dB is only exceeded for 0.009% of time for one EESS SAR satellite. The margin with the 20% of the time criterion is fully sufficient to encompass multiple spaceborne SAR systems.

Similarly, the short-term criterion derived for FS being part of a national short-haul or access network would not be exceeded, and the margin is still very large. The short-term criterion derived for FS being part of an international or a national long haul network does not apply to P-MP systems, as such systems are not used for such applications.

3.5.2.3 Derivation of a pfd limit

The EESS SAR-4 satellite generates a maximum mean pfd given by the following equation:

$$pfd = e.i.r.p. - 10\log(4\pi d^2)$$

In which, EIRP is the mean EIRP per MHz given by

$$pfd = Pe_{peak} + 10\log(DC) + Ge_{max} - 10\log(4\pi d^2) - 10 * \log(B)$$

with DC as the duty cycle and B as the SAR-4 chirp bandwidth. Therefore, the maximum mean pfd radiated by the SAR-4 satellite is –76.2 dBW/m²/MHz.

It can be seen that any level increase up to 60 dB in the maximum pfd radiated by EESS SAR-4 would still meet the short-term protection criterion for national short-haul or access FS systems. However, such an increase of radiation power by a factor of one million, besides leading to saturation and probably destruction of the RF frontend of the FS receiver, would of course also lead to an unfeasible SAR system due to an unrealistic satellite primary power demand.

On the contrary, the protection of FS links being part of an international or a national long haul network requires that the *I/N* of +20 dB can only be exceeded for very short periods of time and the margin available with regard to this short term criterion is much more limited (between 2 dB for an elevation angle of 25° and 10 dB for an elevation angle of 0°). This may require the definition of a pfd limit not to be exceeded by EESS SAR-4 emissions. The value of this pfd limit would of course depend on the maximum elevation angle assumed for such links.

The pfd limits in RR Article **21** applied to non-GSO FSS for the protection of FS in the frequency band 10.7-11.7 GHz have been derived from Recommendation ITU-R SF.1482. It should be noted that in this Recommendation, the elevation angle used for the derivation of the pfd limits is not the worst case, but a 0.0° to 0.2° value, corresponding to the majority of links implemented. Other values would have severely constrained the sharing conditions with the FSS, de-facto preventing it from operation in the band. The same stands for Recommendation ITU-R SF.1483 and the 17 GHz band.

A value of 10° for the maximum elevation angle appears to be a reasonable compromise, although still an unlikely worst case for FS links being part of an international or long haul network. The maximum *I/N* value for this elevation angle is +13 dB, and the margin with regard to the +20 dB *I/N* short-term criterion is in this case 7 dB. Since the pfd radiated by the EESS SAR-4 is –76 dBW/m²/MHz, the maximum tolerable mean pfd value would therefore be –69 dBW/m²/MHz.

3.6 Studies of the impact of fixed service on SAR-4

3.6.1 Scenario

The previous studies on impact of a deployment of FS stations on SAR receivers considered the SAR systems operating in stripmap mode and permanently pointing with an antenna with a fixed offset angle of 34 degrees from Nadir. Moreover, the only SAR system considered in the studies was SAR-3. The studies are reproduced using new FS parameters and the characteristics of a SAR-4 using the spotlight mode described in Fig. 1.

The key FS characteristics considered in the analysis are summarized in Table 16.

TABLE 16

Key FS characteristics used in the analysis

	FS1	**FS2**	**FS3**	**FS4**
Type of FS station	P-P 8.7 GHz	P-P 10 GHz	P-MP central station 10 GHz	P-MP terminal 10 GHz
Antenna gain (dBi)	12…48.6	49…51	15	18
Antenna type	Parabolic	Parabolic	Sectoral 90°	Panel
Antenna pattern ITU-R Recommendation	F.1245-2	F.1245-2	F.1336	F.1245-2
Elevation angle (°)	Up to 30	Up to 30	0	Up to 5
Feeder loss (dB)	0	0	0.5	0
Output power spectral density (dBW/MHz)	–25.5…10.0	–10…–7	–5.4	–14.4

Three different scenarios are studied:

– An extension of the frequency bandwidth by 600 MHz completely below the existing EESS (active) allocation (lower case).

– An extension of the frequency bandwidth by 600 MHz completely above the existing EESS (active) allocation (higher case).

– An extension of the frequency bandwidth by 600 MHz symmetrically allocated around the existing EESS (active) allocation (symmetric case).

The scenarios are shown in Table 17.

TABLE 17

Scenarios to be studied

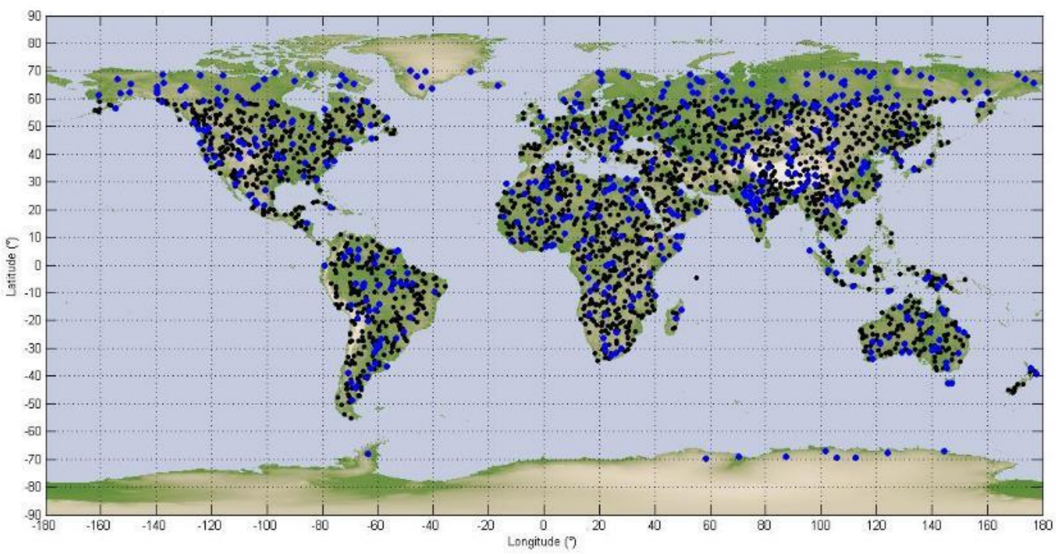
	SAR lower frequency (MHz)	**FS lower frequency** (MHz)	**FS higher frequency** (MHz)	**SAR higher frequency** (MHz)	**Location**
Lower case	8 700	8 700	8 750	9 900	Large number of African, Arabic and Asian countries
Higher case	9 300	10 000	10 500	10 500	Regions 1 and 3 + South America
Middle case	9 000	10 000	10 200	10 200	Regions 1 and 3 + South America

The analysis is made using a 1 MHz reference bandwidth. With this assumption, the higher and middle case scenarios are similar.

In Fig. 20, the black dots represent the location of 2 000 P-P FS stations transmitting in one single 1 MHz bandwidth in the band 10-10.5 GHz. The blue dots represent the area where an image in high resolution mode may be taken by the SAR system. It has been assumed that the 500 image areas were randomly positioned and not necessarily co located with the FS stations.

FIGURE 20

Deployment of FS stations and image areas



The simulation is run for 11 days with a time step of 1 second. Each time the satellite is within visibility of one area of interest (blue dot) within the relevant azimuth and incidence angles, this area is illuminated, for a duration which varies between 3 and 5 seconds. The SAR receiver will also be activated only during this portion of time. It is assumed that the rest of the time it is inactive. The aggregate interference from all FS stations in visibility during the acquisition is calculated and converted in *I/N*.

The SAR protection criterion is an *I/N* of –6 dB, not to be exceeded for more than 1% of the time for systematic interference, which is the case here. It is understood here that the reference time for this 1% allowance is the time when the SAR system is in operation (3% of the total time). When compared to the total simulation duration, the effective percentage of time of interference allowance should be in fact 1% times 3% which is 0.03% of the time. The noise level is also calculated in a reference bandwidth of 1 MHz.

3.6.2 Results for the band 8 700-8 750 MHz

There is no information on the frequency channel arrangement for this frequency band. Assuming a 14 MHz channel width, and a total of 1 000 links per channel would lead to a global number of 3 000 links deployed in all countries where FS is allocated in this frequency band, which is twice the number of links considered in Report ITU-R RS.2094. One thousand links transmitting in the same frequency channel have been spread over an area which includes nearly all countries where FS is allocated in this frequency band, as shown in Fig. 21.

FIGURE 21

Deployment of FS stations at 8700 MHz

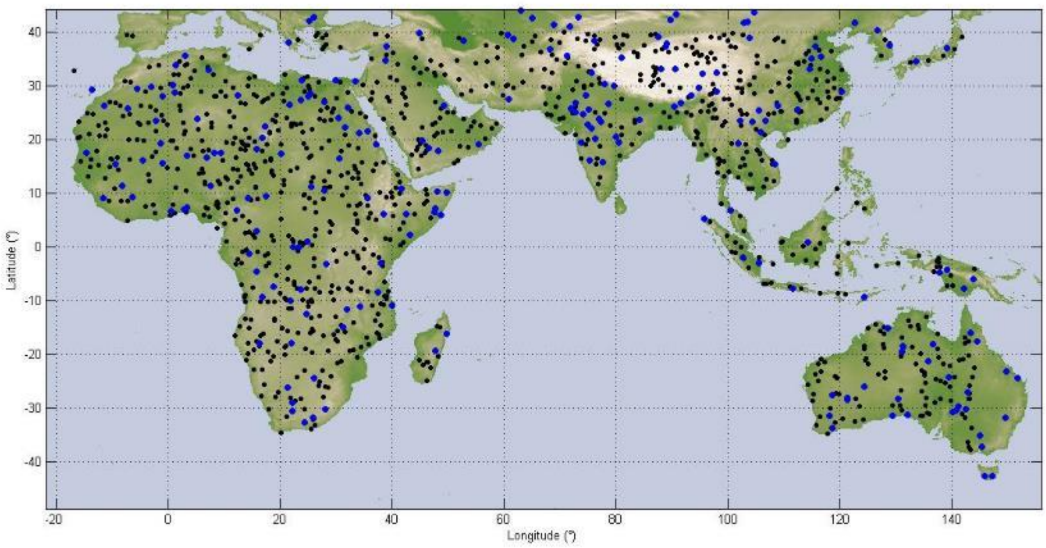
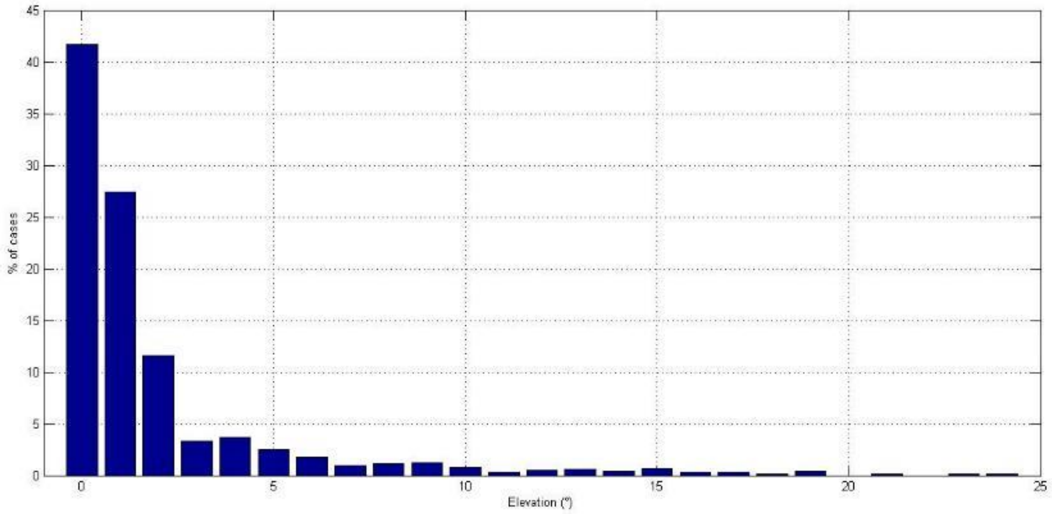


Figure 22 gives the distribution of elevation angle of FS stations. It is similar to the distribution provided to the ITU-R by one administration which territory comprises numerous mountainous areas. The maximum elevation angle is around 25°.

FIGURE 22

Distribution of elevation angles



Similarly, Figs 23 and 24 provide the distribution of output power spectral density (PSD) and maximum antenna gain used for FS stations, respectively. Both follow a Gaussian law.

FIGURE 23

Distribution of output power spectral density

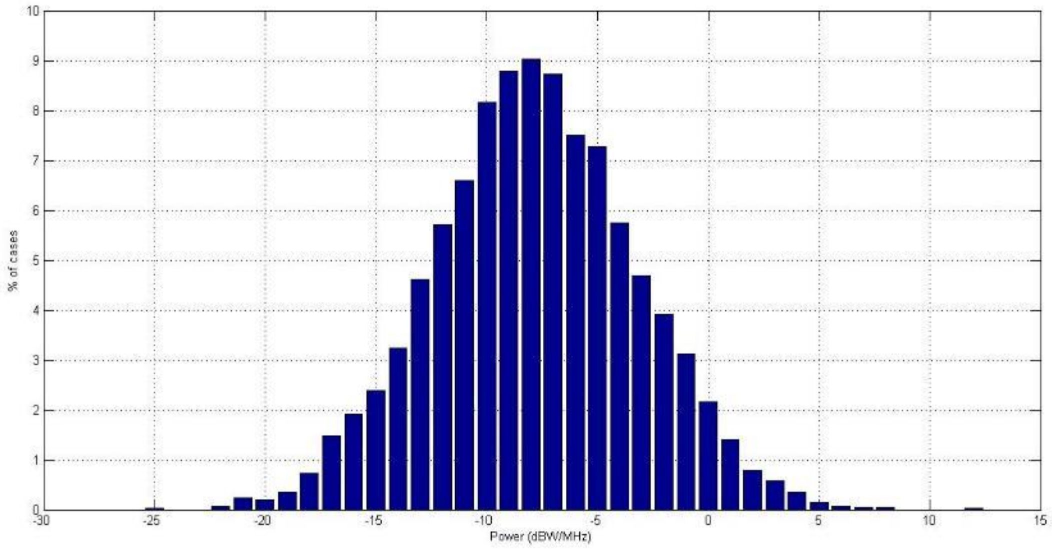
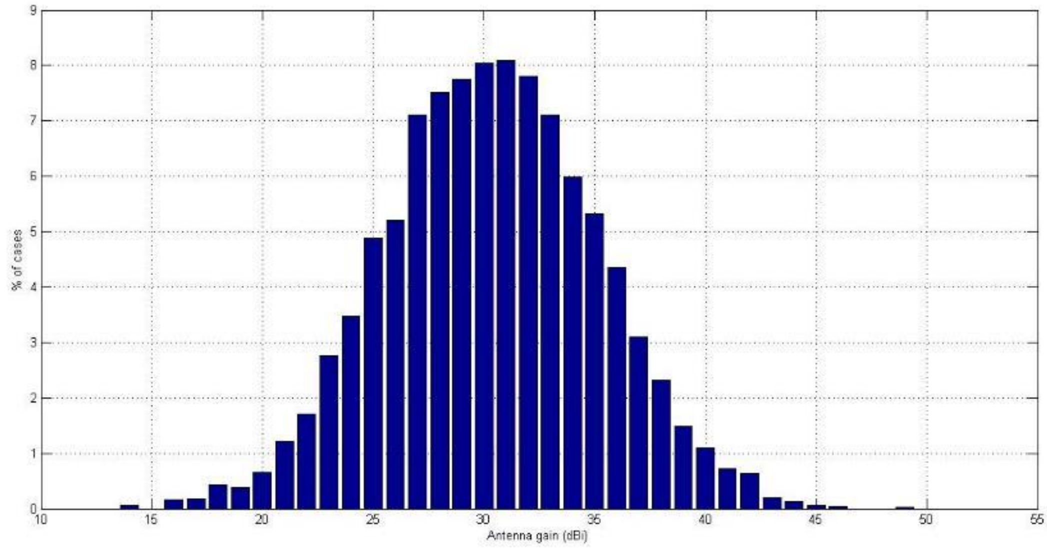


FIGURE 24

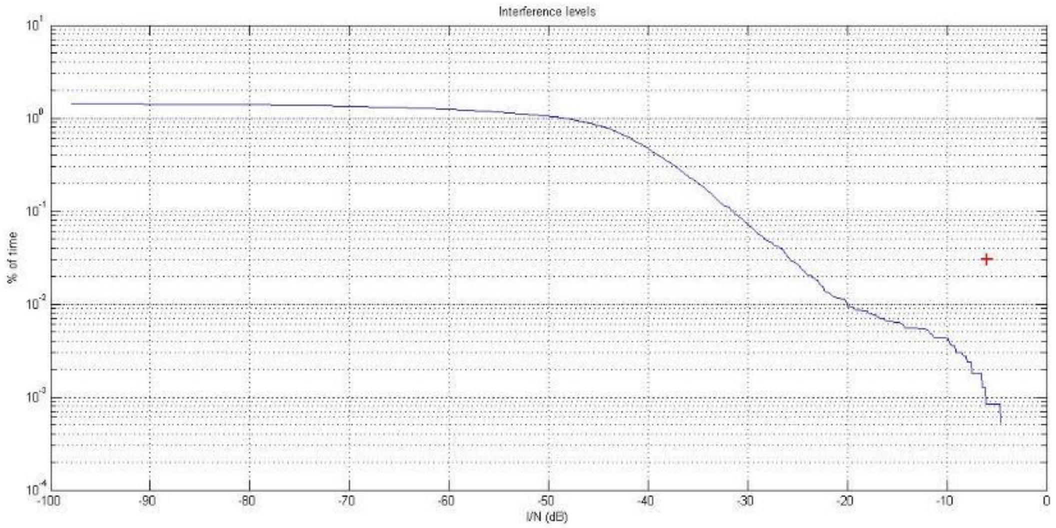
Distribution of FS maximum antenna gains



The results obtained are given in terms of CDF of the *I/N* in Fig. 25.

FIGURE 25

***I/N* CDF for 1 000 P-P FS stations in 1 MHz in the band 8 700-8 750 MHz**



The maximum *I/N* is –4.6 dB and is obtained for 0.0005% of the time. The *I/N* obtained for 1% of the time is –27 dB, which is 21 dB below the protection criterion.

3.6.3 Results for the band 10-10.5 GHz

For a question of simplification of the simulation, the FS stations have been spread worldwide, which includes North America where the band is not allocated to FS.

Recommendation ITU-R F.747 gives the frequency channel arrangements in the band 10.15-10.3 GHz paired with the band 10.5-10.65 GHz. The channel width is 3.5, 7, 14 or 28 MHz, leading to between 5 and 42 frequency channel.

A number of 2 000 FS links per channel is assumed, leading to between 10 000 and 84 000 FS links spread worldwide in the whole band 10.15-10.3 GHz, and even more in the whole frequency band 10-10.5 GHz. The deployment is provided in Fig. 17.

The distribution of elevation angles is similar as the previous case. Figures 26 and 27 give respectively the distribution of output PSD and maximum antenna gain used for FS stations.

FIGURE 26

Distribution of output power spectral density

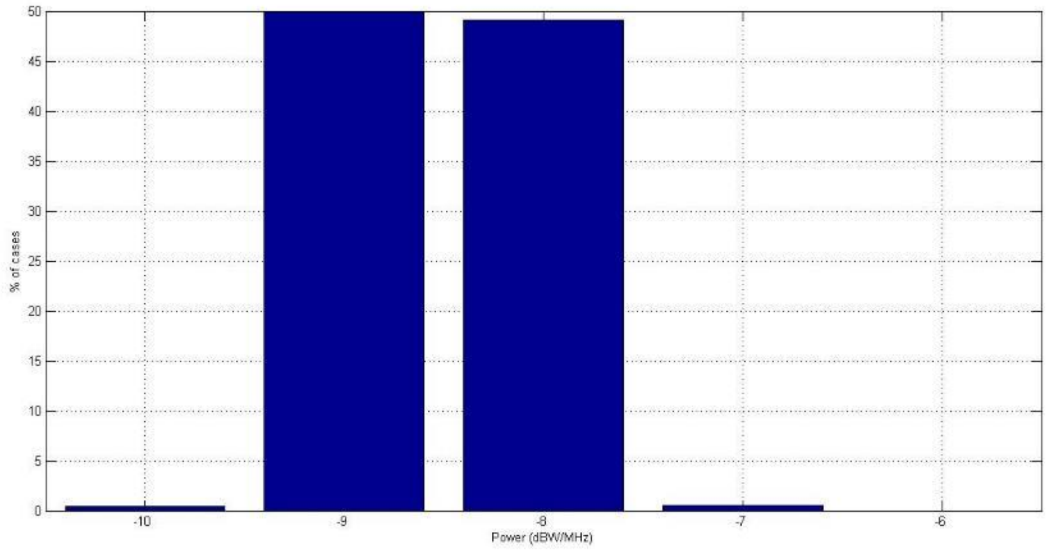
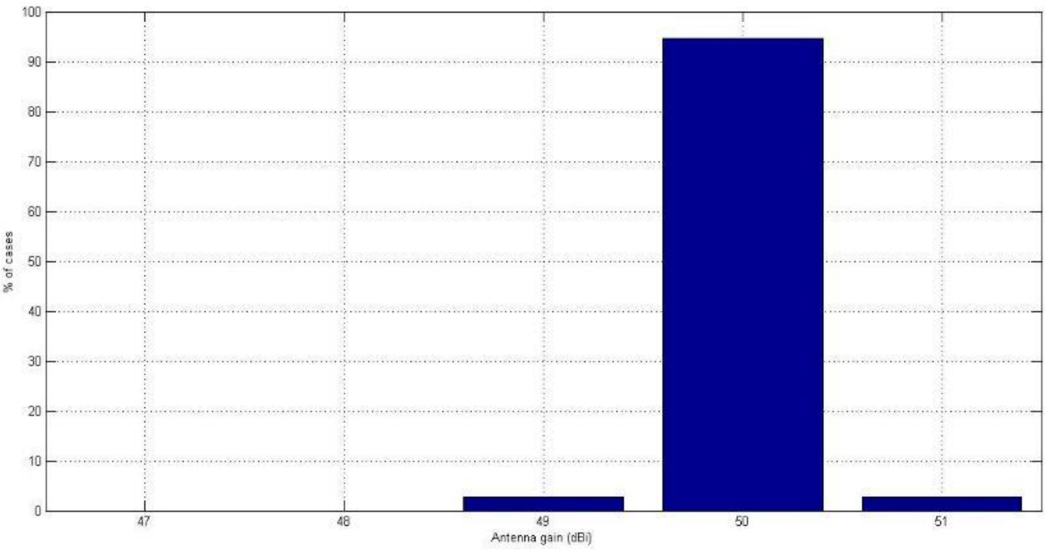


FIGURE 27

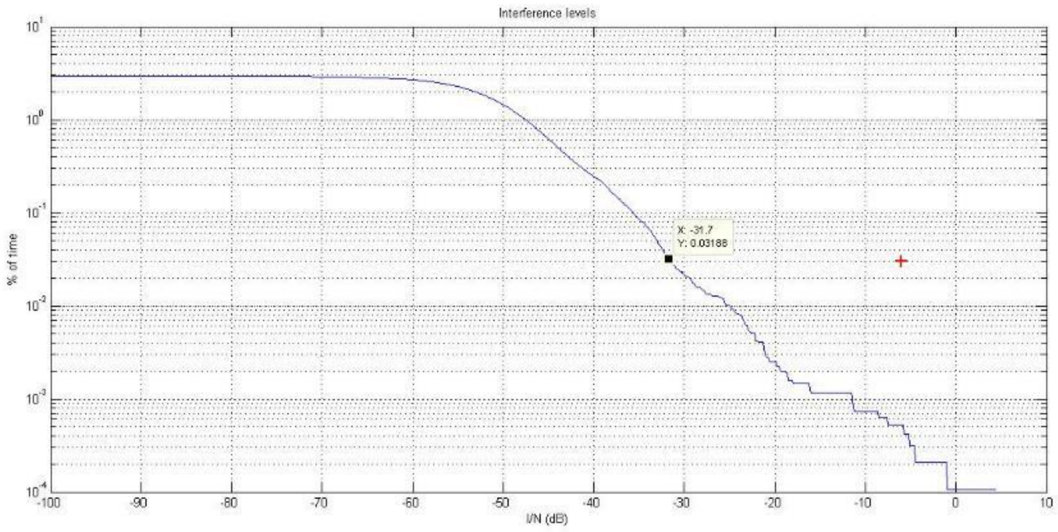
Distribution of FS maximum antenna gains



The results obtained for the P-P systems are given in terms of CDF of the *I/N* in Fig. 28.

FIGURE 28

***I/N* CDF for 2 000 P-P FS stations in 1 MHz in the band 10-10.5 GHz**



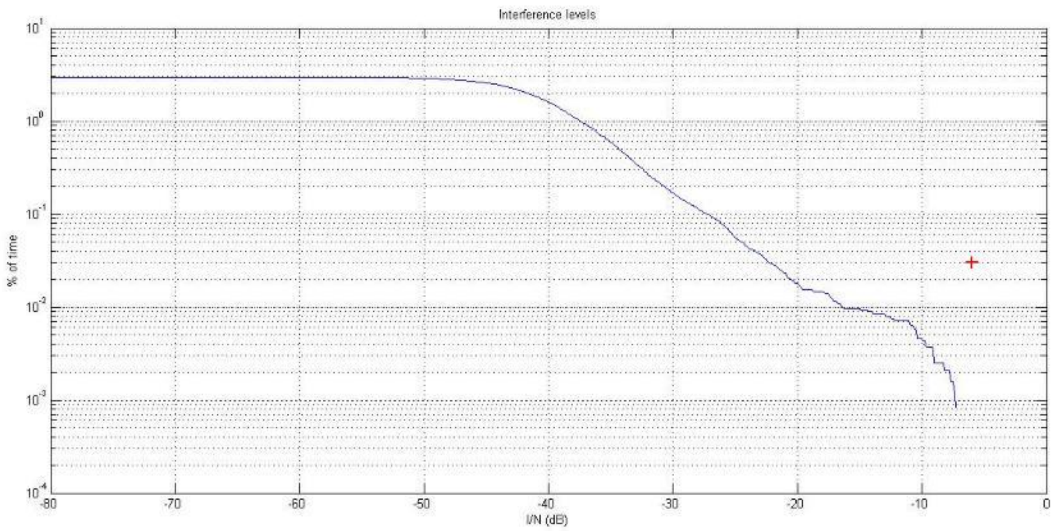
The maximum *I/N* is 3.6 dB and is obtained for 0.0001% of the time. The *I/N* obtained for 1% of the time when a EESS SAR-4 is active, or 0.03% of the total time, is –32 dB, 26 dB below the protection criterion.

Similar results would be obtained for P-MP terminals (FS4), which antenna apertures are wider, but the antenna gain is lower, as well as the PSD, and the maximum elevation angle.

For completeness, Fig. 29 shows the impact of a deployment of 1 000 central stations (FS3).

FIGURE 29

***I/N* CDF for 1 000 P-MP FS central stations in 1 MHz in the band 10-10.5 GHz**



The maximum *I/N* obtained is –7.3 dB, obtained for 0.0008% of the time, and the *I/N* obtained for 1% of the time when the EESS sensor is active, or 0.03% of the total time, is –23 dB, 17 dB below the protection criterion.

3.7 Summary

This Report provides results of sharing studies between EESS (active) and the FS allocated in the frequency bands 8 700-8 750 MHz and 10.0-10.5 GHz and compares results with conclusions on sharing conditions in Report ITU-R RS.2094. The characteristics of FS used in the sharing studies were taken from Recommendations ITU-R F.758-5 and F.1777 and are given in Tables 3 to 6.

3.7.1 Studies on the impact of EESS (active) into FS using the FDP criterion

The FDP analysis confirms and complements the results of studies performed in Report ITU-R RS.2094 which formed the basis for the extension of the 9 GHz EESS allocation decided at WRC-07. This Report takes into account the characteristics of new EESS SAR-4 systems, with a wideband spot light mode as described in Recommendation ITU-R RS.2043, for the sharing analysis instead of the stripmap mode which was previously considered.

It is shown that the resulting FDP due to the EESS SAR-4 systems emissions are well below the FS protection criteria including a comfortable margin in the order of 20 dB for P-P FS systems when considering elevation pointing angles below 30° and 16 dB for P-MP systems using the characteristics of FS deployment as referred to in § 3.2 above.

The FDP protection criterion may be exceeded in case of main beam to main beam coupling, which may only occur for FS P-P station elevation angle above 32° and azimuth pointing angle of around 90° or 270° at the same time. The studies have addressed elevation angles up to 35°.

3.7.2 Studies on the impact of EESS (active) into FS using the short-term and long-term *I/N* criteria

Based on the FS characteristics in § 3.2, studies using a long-term *I/N* criterion of –10 dB for 20% of time indicate that this criterion is met.

Based on the FS characteristics in § 3.2, studies using a short-term *I/N* criterion of +20 dB indicate that for elevation angles below 30 degrees (interference arrival angle at the FS station), there would be no impact from EESS SAR-4 emissions assuming the characteristics for EESS SAR-4 as provided by Recommendation ITU-R RS.2043. Similarly to the FDP analyses, they also indicate that for FS elevation angles above 30°, the short-term *I/N* protection criteria could be exceeded.

The pfd level corresponding to the short-term protection criterion depends on the elevation angle and varies from –96 dBW/m²/MHz for 35° up to –69 dBW/m²/MHz for 10° elevation angles.

3.7.3 Studies of the impact of FS into EESS (active)

The margins obtained, when assessing the FS interference level into an EESS SAR-4 receiver, are in the order of 20 dB for FS P-P systems. The margins obtained in cases of emissions from P-MP central stations into EESS SAR-4 receiver are also comfortable, around 17 dB. Therefore, EESS SAR-4 will be protected from FS under all circumstances and conditions.

4 Sharing between EESS (active) and the mobile service in the frequency band 10.0-10.5 GHz

4.1 Introduction

Under WRC-15 agenda item 1.12 an extension of the EESS (active) allocation in the frequency band 9 300-9 900 MHz by up to 600 MHz is sought in the frequency range 8.7 to 10.5 GHz.

Within this frequency range, the mobile service (MS) is allocated in the frequency bands:

– 8 500-8 750 MHz on a primary basis in countries of RR Nos. **5.468** and **5.469**;

– 10.0-10.45 GHz on a primary basis in Regions 1 and 3 and countries of RR No. **5.480**;

– 10.45-10.5 GHz on a primary basis in countries of RR No. **5.481**.

Sharing studies with the EESS (active) are provided in those frequency bands with regard to the mobile service.

4.2 Characteristics of mobile service

There are no MS characteristics for sharing analyses available for the frequency band 8 700-8 750 MHz.

With regard to the band 10.0-10.5 GHz, the information for electronic news gathering/outside broadcast (ENG/OB) systems was taken from Recommendation ITU-R M.1824 relating to characteristics of these systems in the band 10.25-10.45 GHz. Those systems are used for temporary P-P video links, portable video links and wireless cameras.

No information on the deployment of MS other than ENG/OB systems in the frequency band 10.25-10.45 GHz was reported to ITU-R. Therefore, studies only cover the sharing of EESS SAR-4 with ENG/OB in both directions.

Three different scenarios are investigated in this study:

– an extension of the frequency bandwidth by 600 MHz completely below the existing EESS (active) allocation (lower case);

– an extension of the frequency bandwidth by 600 MHz completely above the existing EESS (active) allocation (higher case);

– an extension of the frequency bandwidth by 600 MHz symmetrically allocated around the existing EESS (active) allocation (symmetric case).

The scenarios are shown in Table 18.

TABLE 18

Scenarios to be studied

	SAR lower frequency	MS lower frequency	MS higher frequency	SAR higher frequency	Location
Lower case (MHz)	8 700	**8 700**	**8 750**	9 900	No parameters identified
Higher case (MHz)	9 300	**10 000**	**10 500**	10 500	Regions 1 and 3 + South America
Symmetric case (MHz)	9 000	**10 000**	**10 200**	10 200	No parameters identified

It can be seen that there are MS characteristics available only for the assumption of an EESS (active) allocation extension in the upper frequencies. The characteristics are summarized in Table 19.

TABLE 19

Parameters of BAS video link systems operated in the mobile service

Frequency allocation	10.25-10.45 GHz (R1, R3, No. 5.480)		Note
Antenna type and gain	Parabolic (22-35 dBi) Helix (10-13 dBi)		H, V or circular polarization
	Horn (5-20 dBi)		Circular polarization
	Horn (15-20 dBi) Non-directional (2 dBi)		H and V polarization
Modulation	QPSK-OFDM 16-QAM-OFDM 32-QAM-OFDM 64-QAM-OFDM		16-QAM-OFDM is normally adopted
	FM		
Feeder/multiplexer loss (typical) (dB)	1		For both transmitter and receiver
Maximum antenna input power (dBW)	4	7	
e.i.r.p. (maximum) (dBW)	38	41	
Receiver IF bandwidth (MHz)	9	18	
Receiver noise figure (dB)	4		
Receiver thermal noise (dBW)	–130.5	–127.4	
Normal Rx input level (dBW)	–88	–85	
Rx input level for 1×10^{-3} BER (dBW)	–120 –113 –110.7 –108.2	–116.9 –109.9 –107.6 –105.1	QPSK-OFDM 16-QAM-OFDM 32-QAM-OFDM 64-QAM-OFDM
Rx input level for CNR = 27 (dB)	N/A	–100.4	For FM system
Nominal long term interference (dBW)	–140.5	–137.4	
Spectral density (dB(W/MHz))	–150.0	–150.0	

Since the mobile ENG/OB systems may be used for communications with a helicopter, such as in Fig. 30, it is necessary to also consider the possibility of high elevation angles. It is considered however that in this case the antenna gain would be limited to low gain antennas, i.e. ranging from 2 to 20 dBi.

FIGURE 30

Example of operation for transmitting live video to the collecting stations via vehicles

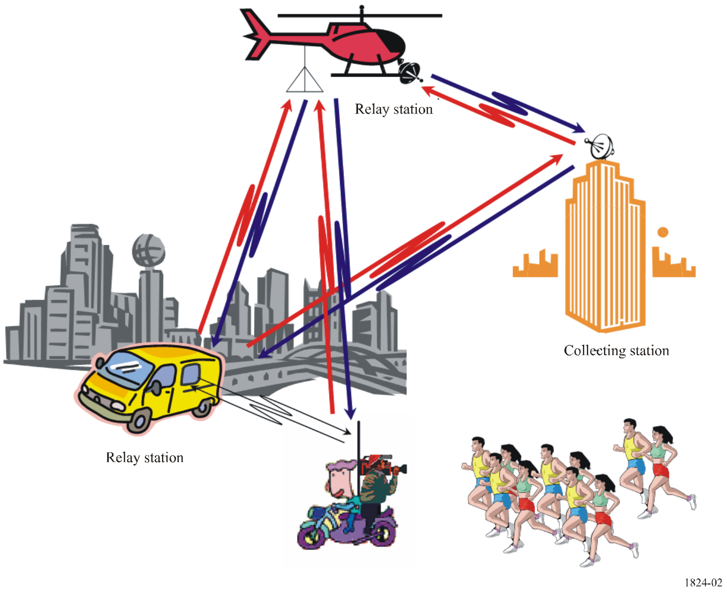


Table 11 provides the long-term criterion, which is based on an *I/N* of –10 dB. As for FS, it is assumed to be met more than 80% of the time, or not to be exceeded less than 20% of the time. The information on short-term criteria is missing. We assume that the fade/rain margin is the difference between the normal Rx input level and the Rx level for 10^{-3} BER, which is 25 dB for a 16-QAM OFDM modulation, not to be exceeded more than 0.01% of the time, which is 4 seconds per day.

4.3 Studies of the impact of EESS SAR-4 on mobile service

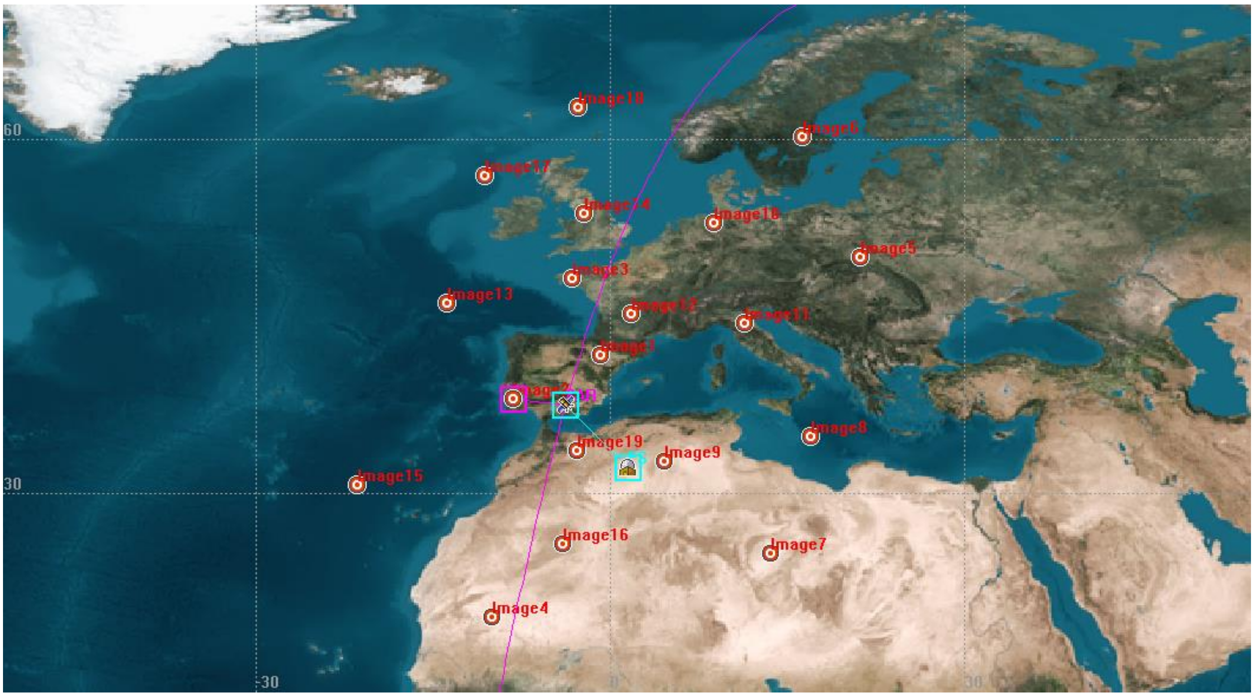
4.3.1 Scenario

In order to assess the potential interference conditions produced by a SAR-4 system in spotlight mode, a simulation model was developed.

The victim MS station in the sharing scenario is located in the center of the spot area. The full satellite orbit is calculated for one month at time intervals of one second. The satellite illuminates the spot area around the MS station when the angular constraints are met as shown in Fig. 31. The entire illumination period of the station occurs during 5 seconds under varying incident angles.

FIGURE 31

Applied simulation scenario modelling the spotlight mode



As a first step, the assumed victim MS station was deployed in an area located around a mid-range latitude of 40°, which is representative for many countries operating ENG/OB in this frequency band. The azimuth pointing angle of the FS station is assumed to vary from 0° to 360°. Its elevation angle is taken from 0° to 45°.

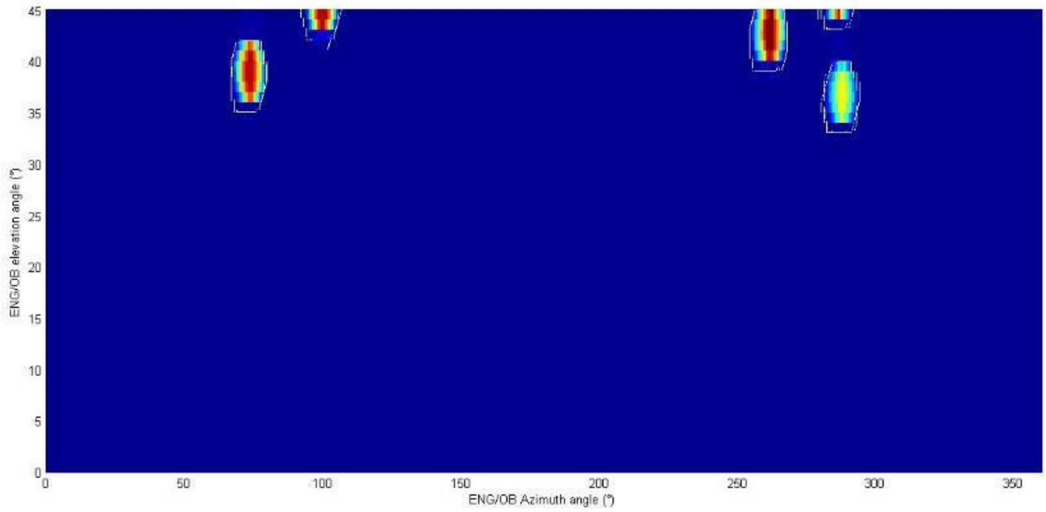
4.3.2 Determination of the worst case

The worst case to be studied will correspond to a main beam to main beam coupling situation. Since the SAR is only able to make an acquisition for incidence angles between 20° (corresponding to 80° elevation angle) and 55° (corresponding to 35° elevation angle), this means that no main beam to main beam coupling situation will occur below 35° elevation for the ENG/OB system.

In addition to that, the SAR will make an acquisition when the target area is nearly perpendicular to the orbit of the satellite, on each side (±2.5°). There are therefore 4 possible azimuths only that would be impacted. This is illustrated in Fig. 32, which gives the result of fractional degradation of performance for a 35 dBi antenna ENG/OB pointing between 0° and 45° in elevation and between 0° and 360° in azimuth.

FIGURE 32

Determination of the worst case situation



The worst case domain for this ENG/OB location is limited to the azimuths 73, 100, 263, 287 and elevation angles greater than 35°.

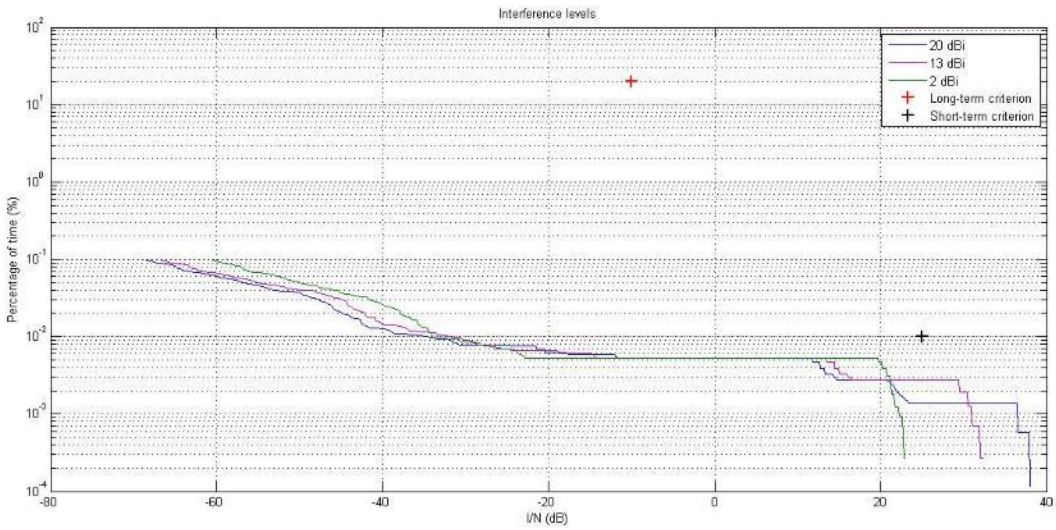
4.3.3 Results

The worst case domain corresponds to high elevation angles, which are limited to communications between the ground and a helicopter. In this case, as mentioned in § 2, it is assumed that only low antenna gains, between 2 and 20 dBi are used.

Figure 33 shows the results in terms of *I/N* for the azimuth angle 73° and the elevation angle of 40° for the ENG/OB, with different antenna gains.

FIGURE 33

Results for the worst case



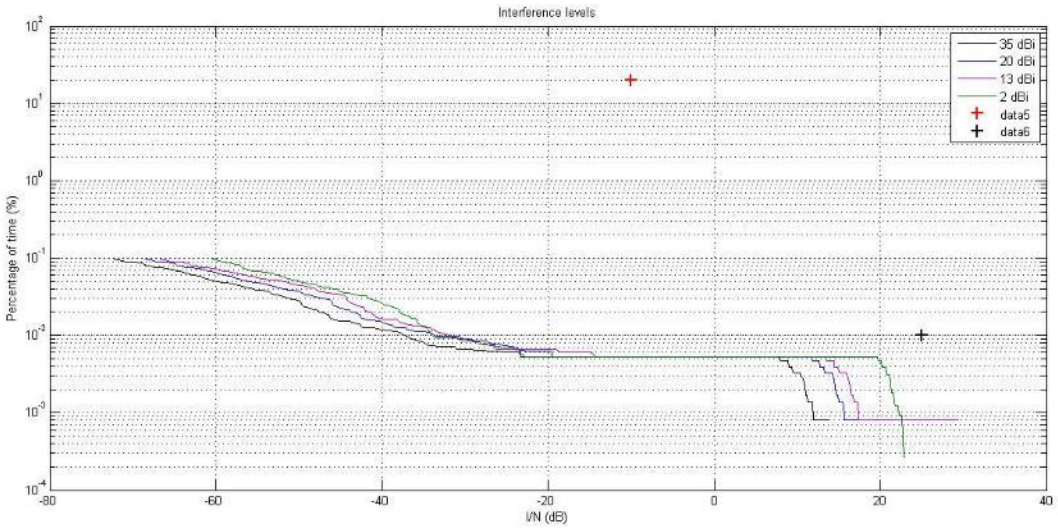
It can be seen that both the short-term and long-term protection criteria are met. There is a 22 dB margin with regard to the short-term criterion, which is the critical one. There may be cases of *I/N* higher than 25 dB, but that would be limited to percentages of time lower than 0.003%, or 2.6 seconds per day.

It should be noted that the simulation assumes that each time the spot area where the ENG/OB is located is in visibility of the SAR system, an acquisition in high resolution will be done, which would not be the case in reality. In addition, this worst case result is limited to 4 pointing azimuths for the ENG/OB system, and elevation angles greater than 35°.

Figure 34 gives the results for a more typical case, where the ENG/OB azimuth pointing angle differs from the worst case values determined in § 5.2, and/or the elevation angle is lower than 35°. The elevation is taken as 10° and the high gain antenna case is added.

FIGURE 34

Results for typical cases



Here also, both criteria are met. There is still a 21 dB margin with regard to the short-term criterion. *I/N* values higher than 25 dB are encountered less than 0.0008% of the time, or 0.7 seconds per day, and limited to the high antenna gain system.

4.4 Impact of the mobile service on the EESS (active)

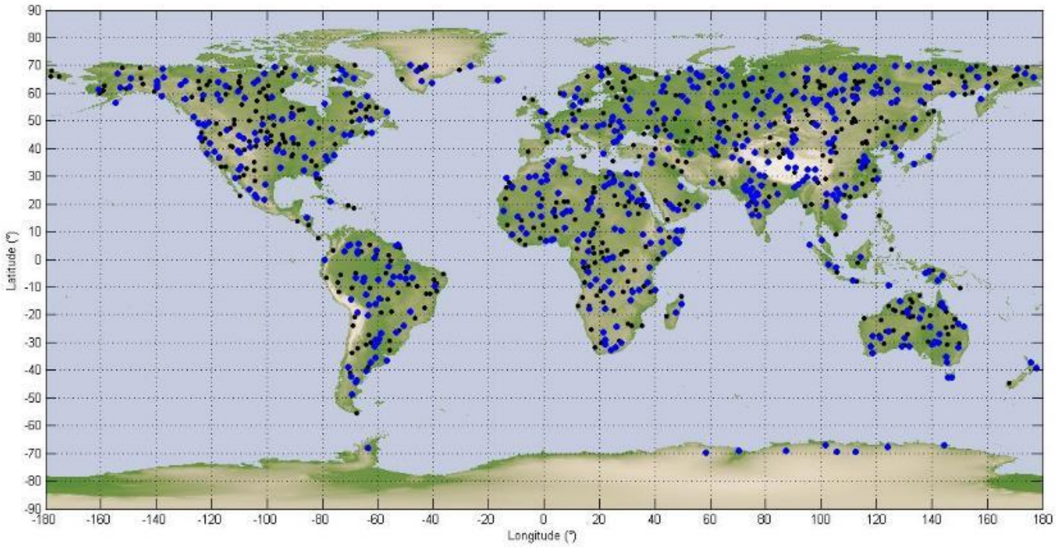
4.4.1 Scenario

In Fig. 35, the black dots represent the location of 500 ENG/OB stations transmitting in the band 10.25-10.45 GHz. The blue dots represent the area where an image in high resolution mode may be taken by the SAR system. It has been assumed that 500 image areas were randomly positioned and not necessarily co-located with the ENG/OB stations.

For a question of simplification of the simulation, the MS stations have been spread worldwide, which includes North America where the band is not allocated to MS.

FIGURE 35

Deployment of MS stations and image areas



The simulation is run for 11 days with a time step of one second. Each time the satellite is within visibility of one area of interest (blue dot) within the relevant azimuth and incidence angles, this area is illuminated, for a duration which varies between 3 and 5 seconds. The SAR receiver will also be activated only during this portion of time. It is assumed that the rest of the time it is inactive. The aggregate interference from all MS stations in visibility during the acquisition is calculated and converted in *I/N*.

The SAR protection criterion is an *I/N* of –6 dB, not to be exceeded more than 5% of the time for random or non-systematic interference, which is the case here, since the interferers are mobile by nature. It is understood here that the reference time for this 5% allowance is the time when the SAR system is in operation (3% of the total time). When compared to the total simulation duration, the effective percentage of time of interference allowance should be in fact 5% times 3% which is 0.15% of the time. The noise level is calculated within the 200 MHz used by ENG/OB.

4.4.2 Results

The results obtained for a deployment of 500 ENG/OB systems with antenna gains ranging from 13 to 20 dB, as well as a deployment of 500 ENG/OB with an antenna gain of 2 dBi, are given in terms of CDF of the *I/N* in Fig. 37. The maximum elevation angle considered is 45°, with Gaussian distribution as shown in Fig. 36. The output power has been taken as 7 dBW.

FIGURE 36

Distribution of ENG/OB elevation angles considered in the study

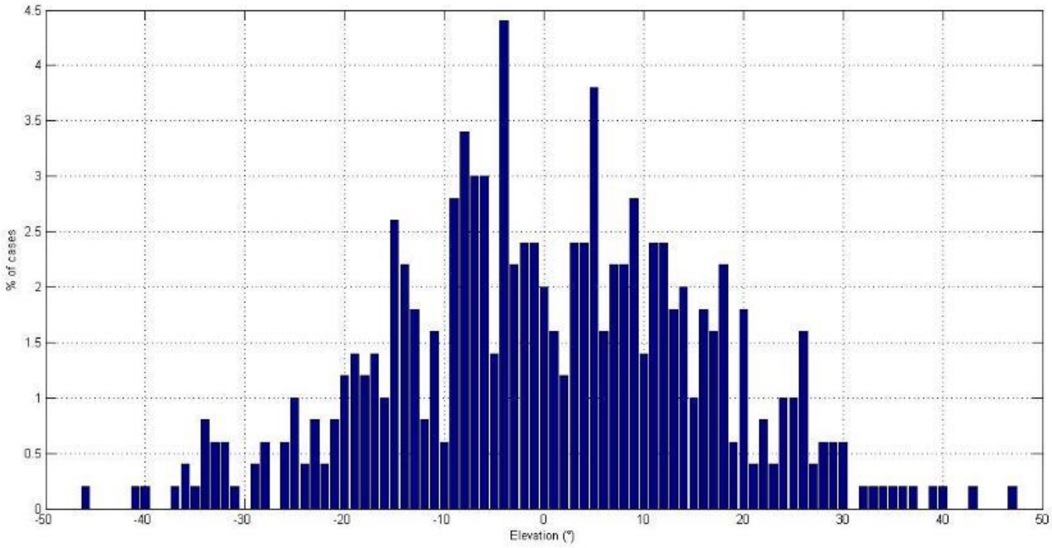
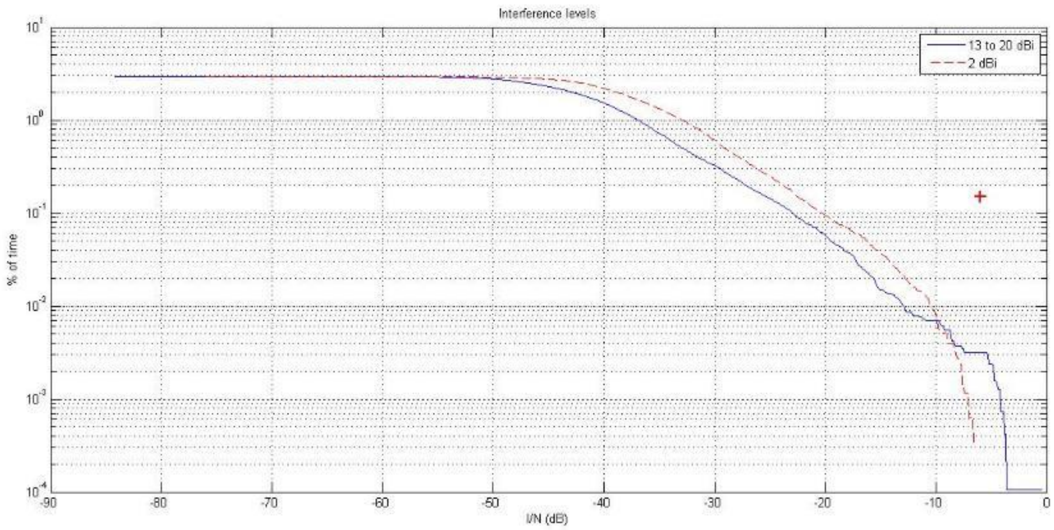


FIGURE 37

***I/N* cumulative distribution function (CDF) for 500 ENG/OB stations in the band 10.25-10.45 GHz**



The maximum *I/N* is +4.3 dB and is obtained for 0.0008% of the total time. The *I/N* obtained for 5% of the time when the EESS sensor is active, or 0.15% of the total time, is –22 dB for 500 ENG/OB with an antenna gain of 2 dBi, 16 dB below the protection criterion.

It should be noted that in reality the output power may vary from one system to the other, in particular if power control is used. Therefore, not all devices would transmit at the maximum output power all the time. Taking this into account would reduce the amount of interference by a large amount. Further information would be required in order to refine the studies. This calculation does not account for any SAR processing gain.

4.5 Summary

This Report provides results of sharing studies between EESS (active) and the MS allocated in some frequency bands around 9-10 GHz. Characteristics have been identified for ENG/OB systems in the band 10.25-10.45 GHz only, but the results are valid for the whole range 10-10.5 GHz.

The resulting RF compatibilities between EESS SAR-4 and ENG/OB are well below the MS protection criteria with a comfortable margin in the order of 21 dB in the case of low gain ENG/OB antenna.

The aggregate interference levels into the SAR receiver from ENG/OB stations depends on the antenna gain of the ENG/OB considered, but are below the protection criterion with a 16 dB margin, even when considering that all devices transmit at their maximum output power.

The sharing studies between EESS SAR-4 and the ENG/OB show that sharing is feasible in the band 10.25-10.45 GHz. No information on other MS deployment/characteristics was available to ITU-R.

Therefore, no studies were carried out in this regard in the frequency bands 8 700-8 750 MHz and 10.0-10.5 GHz.

5 Sharing between EESS (active) and the amateur and amateur-satellite radio services

5.1 Introduction

Under WRC-15 agenda item 1.12 an extension of the EESS (active) allocation in the frequency band 9 300-9 900 MHz up to 600 MHz is sought in the frequency range 8.7 to 10.5 GHz.

Within this frequency range, the amateur service is allocated on a secondary basis in the band 10.0-10.5 GHz, and the amateur-satellite service on a secondary basis in the frequency band 10.45-10.5 GHz.

Sharing studies with the EESS (active) are provided in both frequency bands.

5.2 Characteristics of the amateur and amateur-satellite services

Table 20 provides the characteristics of amateur systems used in the band 10-10.5 GHz as given by Recommendation ITU-R M.1732.

TABLE 20

Characteristics of amateur systems

Parameter	Value			
Mode of operation	Continuous wave (CW) Morse 10-50 Bd	Single side-band (SSB) voice	FM voice	Digital voice and multimedia
Frequency band (MHz)	10 000-10 500			
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	2K70J3E	11K0F3E 16K0F3E 20K0F3E	2K70G1D 6K00F7D 16K0D1D 150KF1W 10M5F7W
Transmitter power (dBW)	3-13	3-31.7		3
Transmitter line loss (dB)	0-10			1-6
Transmitting antenna gain (dBi)	10-42	0-42		36
Typical e.i.r.p. (dBW)	23-45	1-45		38
Antenna polarization	Horizontal, vertical			
Receiver IF bandwidth (kHz)	0.4	2.7	9, 15	2.7, 6, 16, 130, 10 500
Receiver noise figure (dB)	1-7			2

Tables 21 and 22 provide the characteristics of the amateur-satellite systems in the Earth-to-space and space-to-Earth directions, respectively, as given by Recommendation ITU-R M.1732. No particular information was provided regarding orbits of amateur radio satellites.

TABLE 21

Characteristics of amateur-satellite systems in the Earth-to-space direction

Mode of operation	**CW Morse, 10-50 Bd**	**SSB voice, digital voice, FM voice, data**
Frequency band (MHz)	10 450-10 500	
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	2K70J3E 16K0F3E 44K2F1D 88K3F1D
Transmitter power (dBW)	0-13	
Feeder loss (dB)	0.2-3	
Transmitting antenna gain (dBi)	–2 to 31	
Typical e.i.r.p. (dBW)	10-42	
Antenna polarization	Horizontal, vertical, RHCP, LHCP Horizontal, vertical, RHCP, LHCP	
Receiver IF bandwidth (kHz)	0.4	2. 7, 16, 50, 100
Receiver noise figure (dB)	1-7	

TABLE 22

Characteristics of amateur-satellite systems in the space-to-Earth direction

Mode of operation	**CW Morse, 10-50 Bd**	**SSB voice, digital voice, FM voice, data**
Frequency band (MHz)	10 450-10 500	10 450-10 500
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	2K70J3E 16K0F3E 44K2F1D 88K3F1D
Transmitter power (dBW)	10	0-10
Feeder loss (dB)	0.2-1	
Transmitting antenna gain (dBi)	0-6	
Typical e.i.r.p. (dBW)	9-15	
Antenna polarization	Horizontal, vertical, RHCP, LHCP Horizontal, vertical, RHCP, LHCP	
Receiver IF bandwidth (kHz)	0.4	2.7, 16, 50, 100
Receiver noise figure (dB)	1-7	

5.3 Impact of EESS (active) into the amateur service

5.3.1 Scenario

In order to assess the potential interference conditions produced by a SAR-4 system in spotlight mode, a simulation model was developed.

The victim amateur radio station considered in the sharing scenario is located in the centre of the spot area. The full satellite orbit is calculated for one month at time intervals of one second. The satellite illuminates the spot area around the MS station when the angular constraints are met as shown in Fig. 38. The entire illumination period of the station occurs during 5 seconds under varying incident angles.

FIGURE 38

Applied simulation scenario modelling the spotlight mode

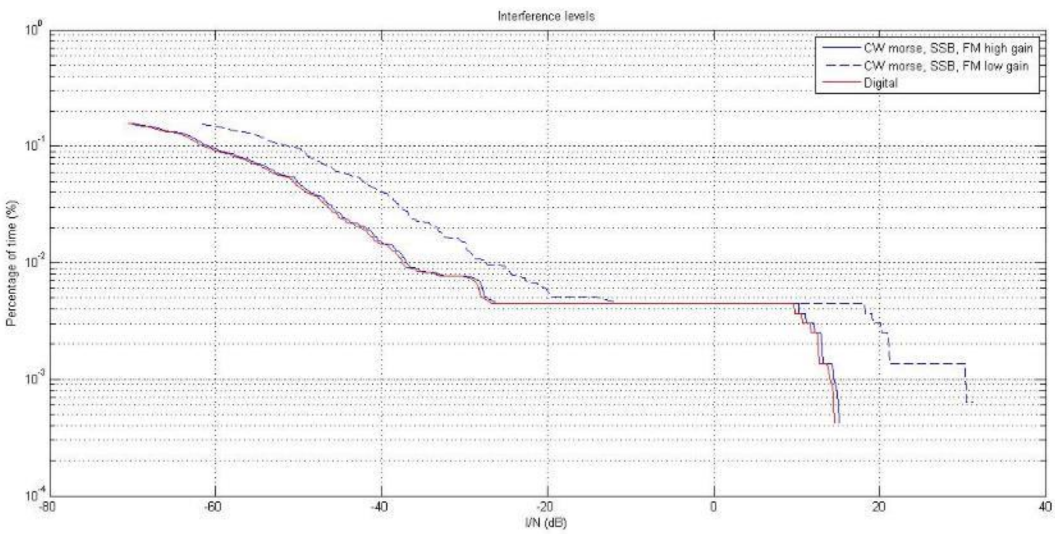
As a first step, the assumed victim amateur station was deployed in an area located around a mid-range latitude of 30°.

5.3.2 Results

Figure 39 provides the CDF of the interference produced at the amateur service receiver for the systems provided in Table 20. When considering high gain antennas, an azimuth angle of 80° and an elevation of 10° have been assumed. When considering low gain antennas, the antenna is assumed to be omnidirectional and the pointing angles have therefore no meaning. As a worst case, the amateur station is considered with the lowest possible feeder loss and the lowest noise figure.

FIGURE 39

***I/N* cumulative distribution function (CDF) of interference into the amateur radio receivers**



Although no protection criterion was specified, an *I/N* value of either –10 or –6 dB would not be exceeded more than 0.004% of the time, which is 38 seconds over the orbital period of the SAR satellite, 11 days.

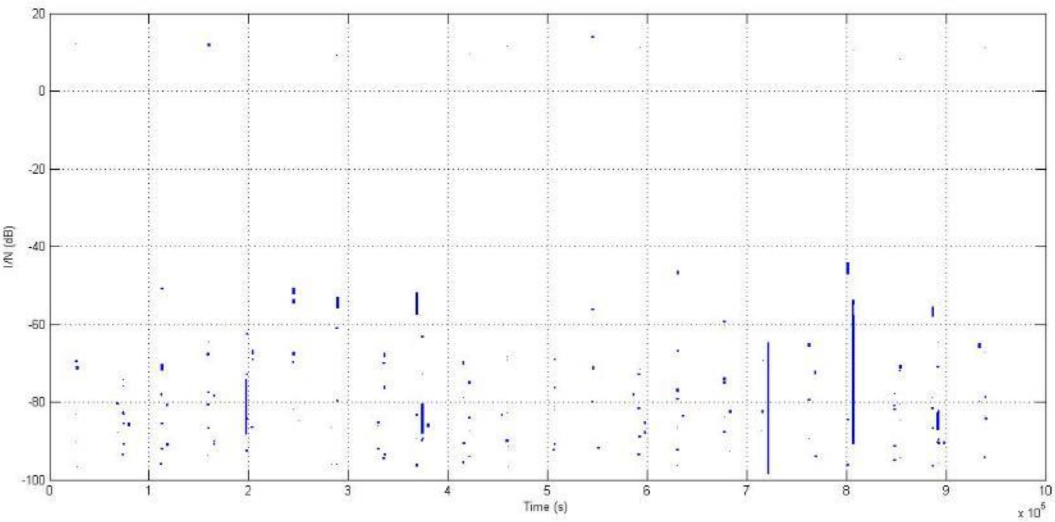
In the simulation above, an acquisition is systematically done as soon as the amateur station is under the specific angular conditions specified in Fig. 2, which happens 10 times over the 11 days for the latitude considered. The 38 seconds should therefore not be understood as a continuous duration of interference, but as 10 periods of interference of about 4 seconds, each occurring less than once per day, as shown in Fig. 40.

Indeed, when the SAR operates in spotlight mode, which is the mode where the high resolution and hence the large bandwidth is used, the spot area is tracked between 20° and 55° incidence angles on each side of the satellite. During picture taking the azimuth angle (cross track) is within 90° ± 2.5°, thus reducing the effective exposure time of a spot to 5 seconds.

In addition, under normal operation conditions, such a large number of pictures of one single area (10 per 11 days) is usually not required by SAR customers. Thus, the total interference duration would be lower than 38 seconds. Assuming one picture acquisition per area and per month in high resolution mode would lead to an overall interference duration of 4 to 5 continuous seconds over an entire month.

FIGURE 40

***I/N* into one amateur radio receiver vs. time**



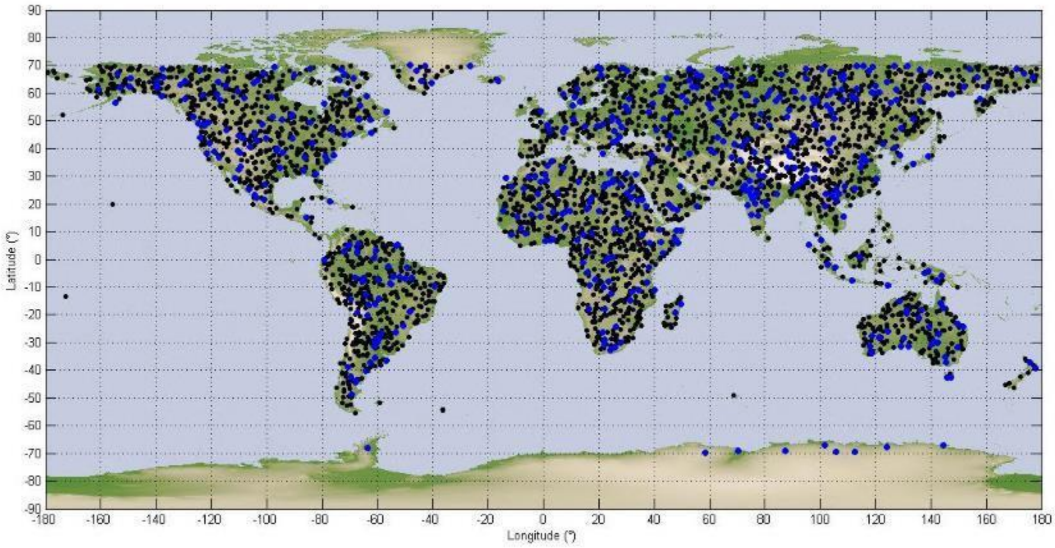
5.4 Impact of the amateur service into the EESS (active)

5.4.1 Scenario

In Fig. 41, the black dots represent 3 000 locations of amateur radio stations transmitting in the frequency band 10.0-10.5 GHz. The blue dots represent the area where an image in high resolution mode may be taken by the SAR system. It has been assumed that 500 image areas were randomly positioned and not necessarily co-located with the amateur stations.

FIGURE 41

Deployment of amateur stations and image areas



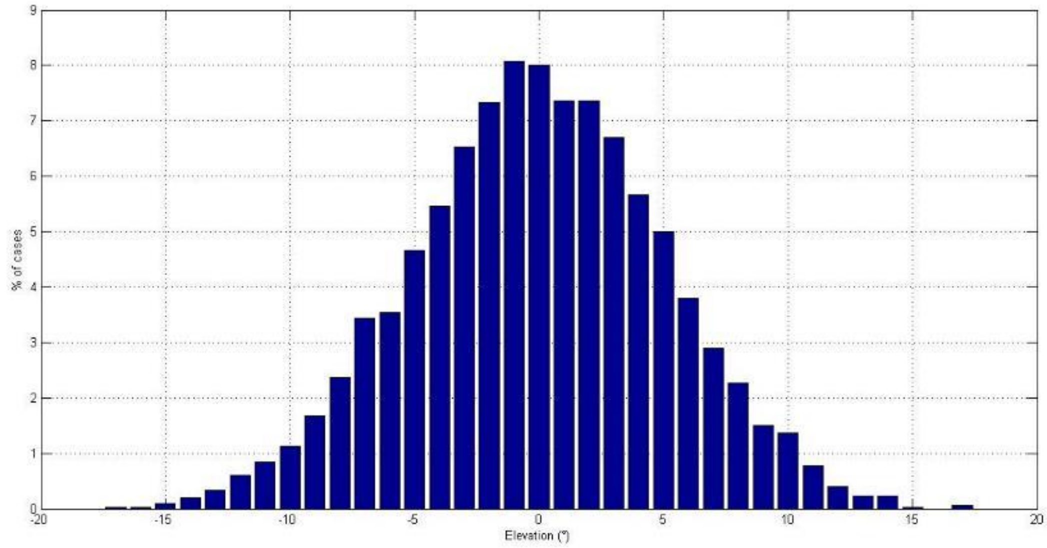
The simulation is performed for an 11 days period with time steps of 1 second. Each time the satellite is within visibility of one area of interest (blue dot), i.e. within the relevant azimuth and incidence angles, this area is illuminated, for a duration which can vary between 3 and 5 seconds. The SAR receiver will only be active for this time period. It is assumed that for the rest of the time the receiver is off. The aggregate interference from all amateur radio stations in visibility during the acquisition is calculated and converted in *I/N*.

The SAR protection criterion is an *I/N* of –6 dB, not to be exceeded for more than 5% of the time for random or non-systematic interference, which would be the case if all transmitters are not transmitting for 100% of the time. It is further understood that the reference time for this 5% allowance is the time period when the SAR system is in operation (3% of the total time). When compared to the total duration of the simulation, the effective percentage of time of interference allowance should be in fact 5% times 3% which is 0.15% of the time. The noise level is calculated within the 500 MHz used by amateur radio.

Figure 42 gives the distribution of elevation angle at the location of amateur radio stations.

FIGURE 42

Distribution of elevation angles



Similarly, Figs 43 and 44 give respectively the distribution of output power spectral density and maximum antenna gain used for amateur radio stations. The distribution follows a Gaussian type distribution.

FIGURE 43

Distribution of output power

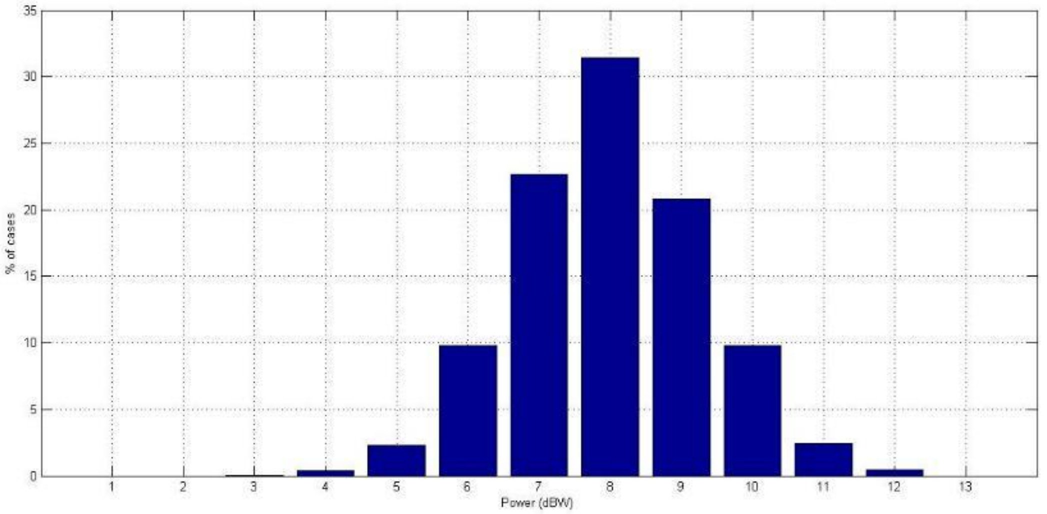
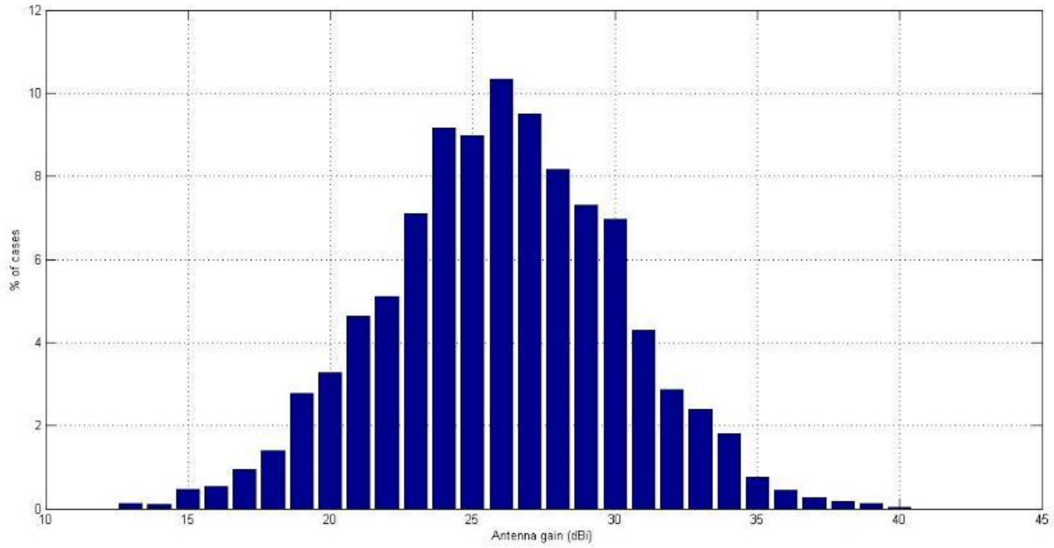


FIGURE 44

Distribution of maximum antenna gains

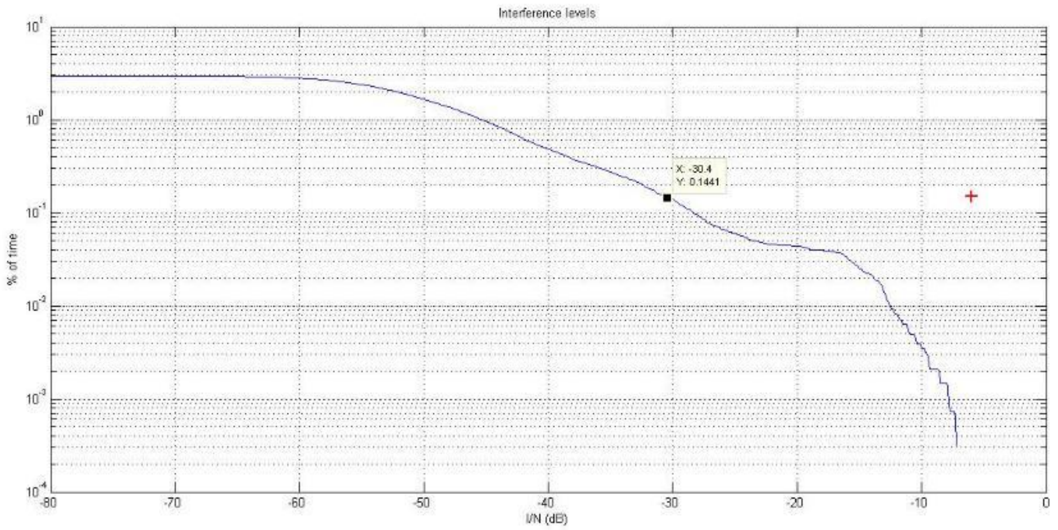


5.4.2 Results

The results obtained for a deployment of 3 000 amateur systems with antenna gains ranging from 13 to 40 dBi, and transmission power ranging from 3 to 12 dBW, and an antenna pointing elevation angle ranging from –17 to +17° are given in terms of cumulative distribution function of the *I/N* in Fig. 45.

FIGURE 45

***I/N* cumulative distribution function (CDF) for 3 000 amateur transmitters in the band 10.0-10.5 GHz**



The maximum *I/N* is 0 dB and is obtained for 0.001% of the total time. An *I/N* of –30 dB is obtained for 5% of the time when the EESS SAR-4 is active, or 0.15% of the total time. This is 24 dB below the protection criterion, which allows for far more amateur stations to operate without any constraint on either service.

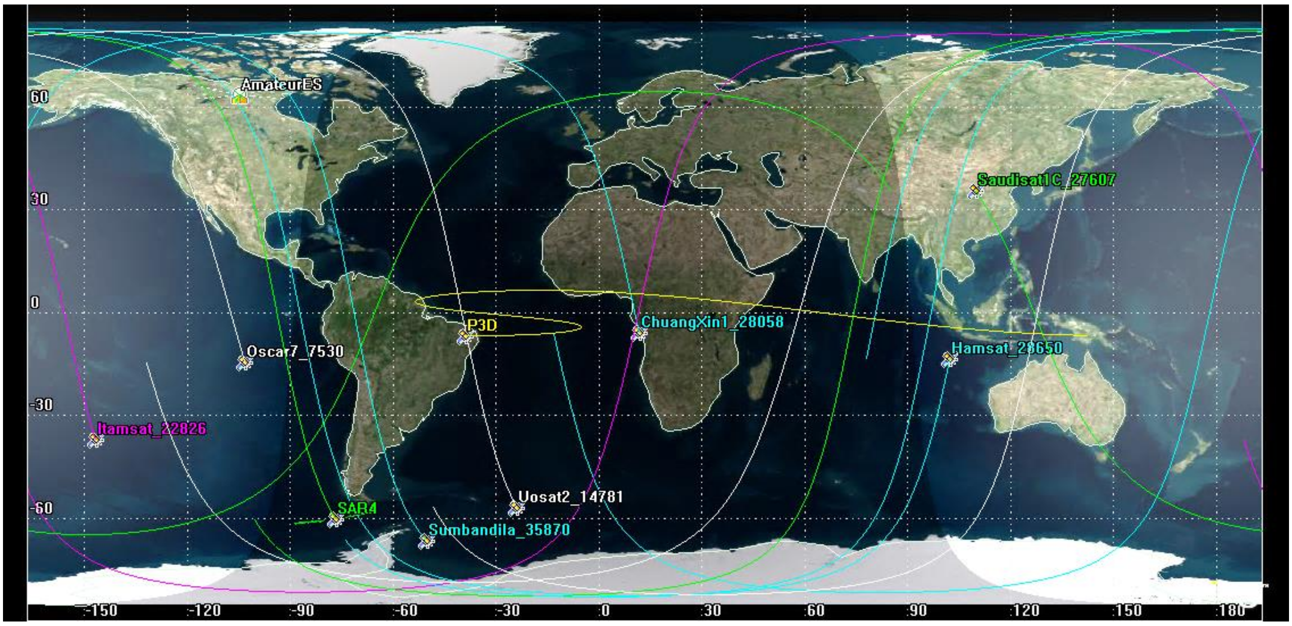
5.5 Impact of EESS (active) into the amateur-satellite service earth station

5.5.1 Scenario

An amateur satellite earth station is deployed at high latitude (63°). A number of possible amateur satellite orbits, representative of typical amateur satellites operating in several frequency bands allocated to the amateur-satellite service were considered, at different altitudes and orbital parameters, as shown in Fig. 46. Those satellites are in contact with amateur earth station as soon as they are in visibility at elevation angles of above 5°.

FIGURE 46

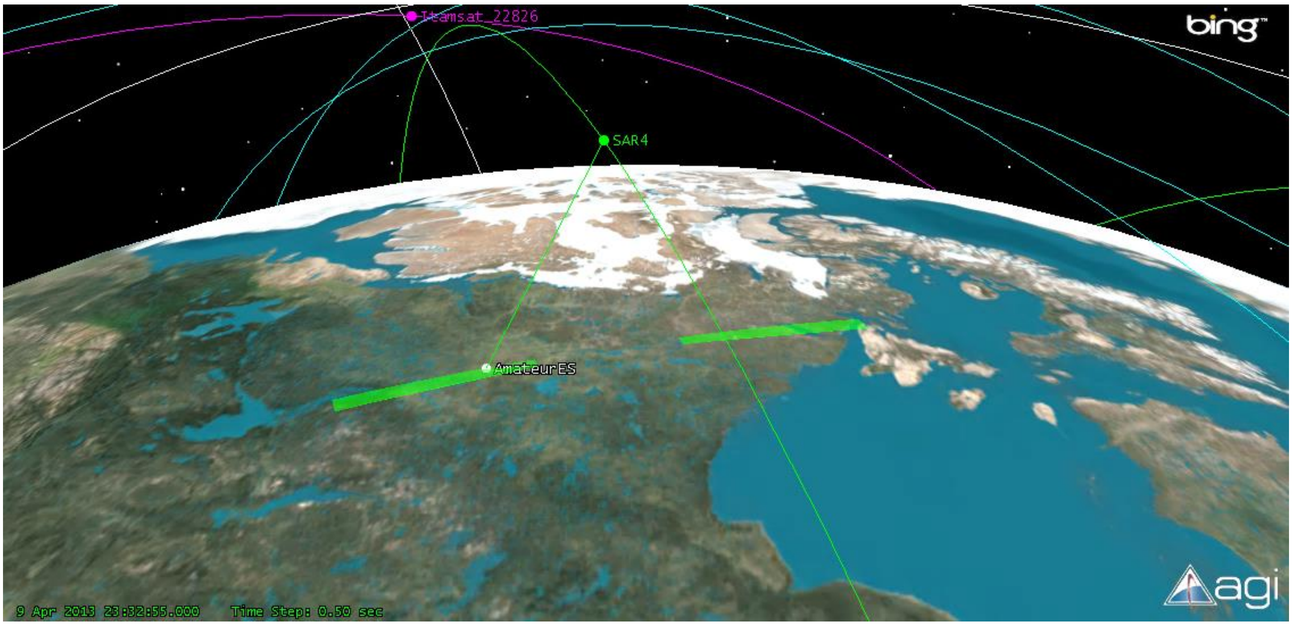
Typical amateur satellite orbits



The EESS SAR-4 satellite will take an image of the area where the amateur radio earth station is located as soon as minimum elevation conditions are given as shown in Fig. 47. This corresponds to incidence angles between 20° and 55° on each side of the satellite and azimuth angle (cross track) within 90° ± 2.5°), thus reducing the effective exposure time of a spot to about 5 seconds as shown in Fig. 47.

FIGURE 47

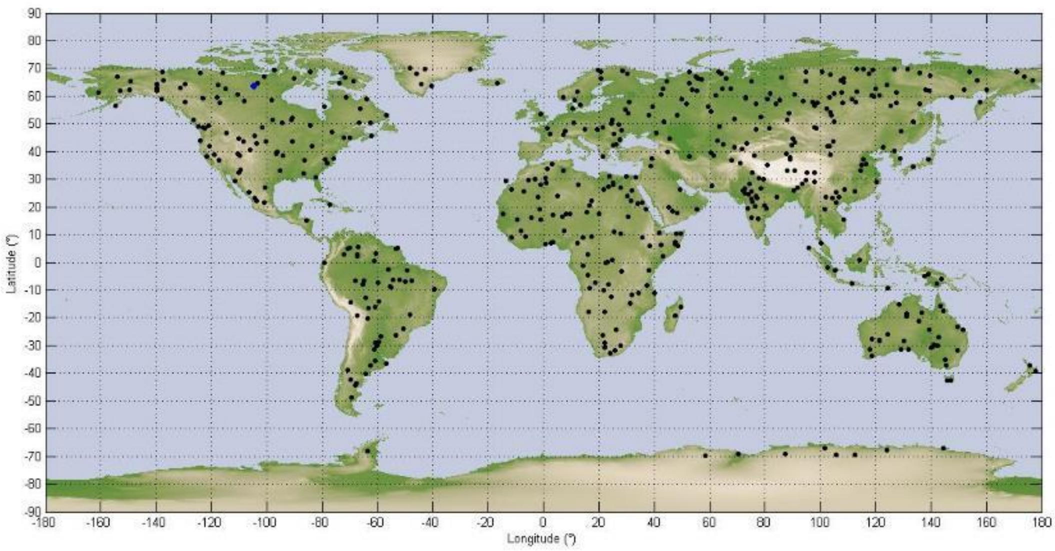
SAR-4 acquisition of the area where the earth station is deployed



In addition, 499 other target locations for EESS SAR-4 acquisitions are assumed as shown in Fig. 48, to simulate an overall percentage of activity of 3% which is typical for the spotlight mode of EESS SAR-4.

FIGURE 48

Image areas deployment



Acquisition of these targets is done under the same conditions as depicted above. The amateur-satellite earth station may only be interfered if the following conditions are given:

– The SAR system is active (i.e. making an acquisition over one target area).

– The SAR system is in visibility of the amateur earth station.

– The earth station is in visibility of the amateur-satellite of interest.

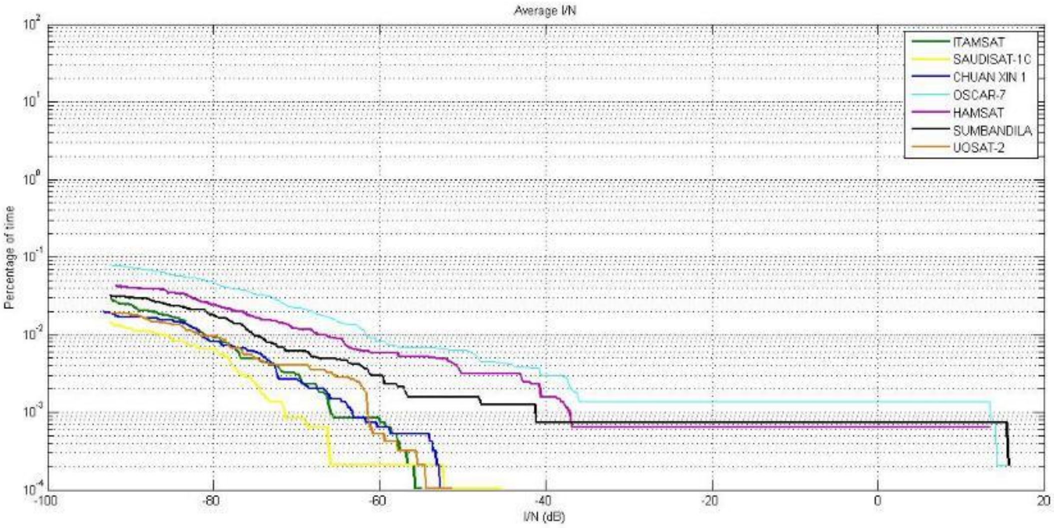
The interference level at the earth station level is then computed.

5.5.2 Results

Figure 49 gives the cumulative distribution function obtained for different amateur satellites.

FIGURE 49

***I/N* cumulative distribution function (CDF) of interference into the amateur-satellite earth station**



Although no protection criterion was specified, an *I/N* value of either –10 or –6 dB would not be exceeded more than 0.0015% of the time, which is 13 seconds over the orbital period of the SAR satellite, 11 days. The worst case is obtained for amateur satellites which orbit RAAN is close to the EESS SAR-4 orbit RAAN.

In the simulation above, an acquisition is systematically done as soon as the amateur radio station is under the specific angular conditions specified in Fig. 45, which may occur 10 times over a period of 11 days for the latitude considered, and the amateur satellite is in visibility of the earth station. The 13 seconds should therefore not be understood as a continuous interference, but as an aggregate of two periods of interference of about 6 seconds each and separated by about 5 to 6 days.

In addition, under normal operation conditions, such a number of pictures of one single area (10 per 11 days) is usually not required by SAR customers. Thus, the total duration of interference would even be lower than 13 seconds.

5.6 Impact of EESS (active) into the amateur-satellite service satellite receiver

5.6.1 Scenario

A number of possible amateur satellite orbits, representative of currently active satellites operating in UHF and VHF bands were considered, at different altitudes and orbital parameters, as shown in Fig. 46. Their receiver is supposed to be active to receive 100% of the time.

The EESS SAR satellite SAR-4 will make an image acquisition of the 500 target areas where as soon as they are seen under the angular conditions depicted in Fig. 2 (incidence angle between 20° and 55° on each side of the satellite and azimuth angle (cross track) within 90° ± 2.5°), thus reducing the effective exposure time of a spot to about 5 seconds for each target area.

The amateur-satellite may therefore get interference when the following conditions are met:

– The SAR system is active (i.e. making an acquisition over one target area).

– The amateur-satellite is in visibility of the SAR satellite.

The interference level at the amateur-satellite level is then computed.

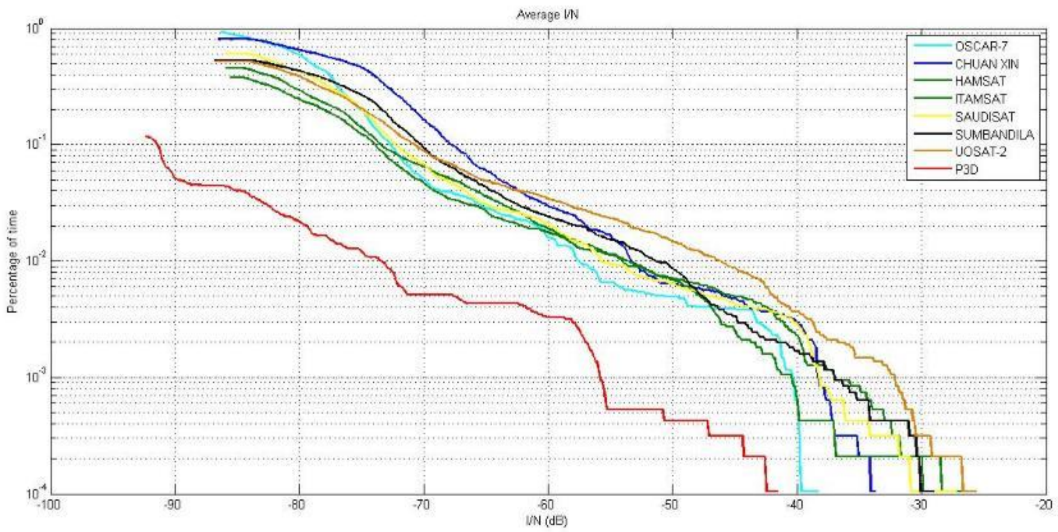
For simplification, the amateur-satellite antenna gain is assumed constant at 6 dBi.

5.6.2 Results

Figure 50 provides the CDF obtained for different amateur satellites.

FIGURE 50

***I/N* cumulative distribution function (CDF) of interference into the amateur satellites**



Although no protection criterion was specified, an *I/N* value of either –10 or –6 dB would never be exceeded.

5.7 Impact of the amateur-satellite service earth stations into the EESS (active)

5.7.1 Scenario

In this case, 500 amateur radio earth stations are assumed as deployed randomly worldwide on land masses. 500 target areas where the EESS SAR-4 will operate in spotlight mode are also randomly deployed. The 500 amateur earth stations are assumed to track one single satellite at one moment in time. Their emission power and maximum antenna gain is distributed as shown in Figs 51 and 52.

FIGURE 51

Distribution of output power

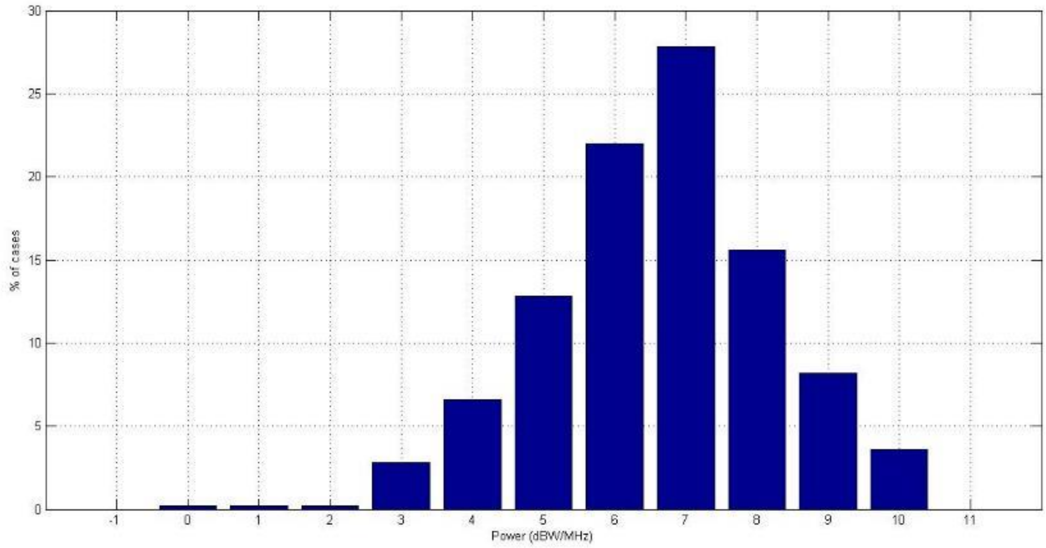
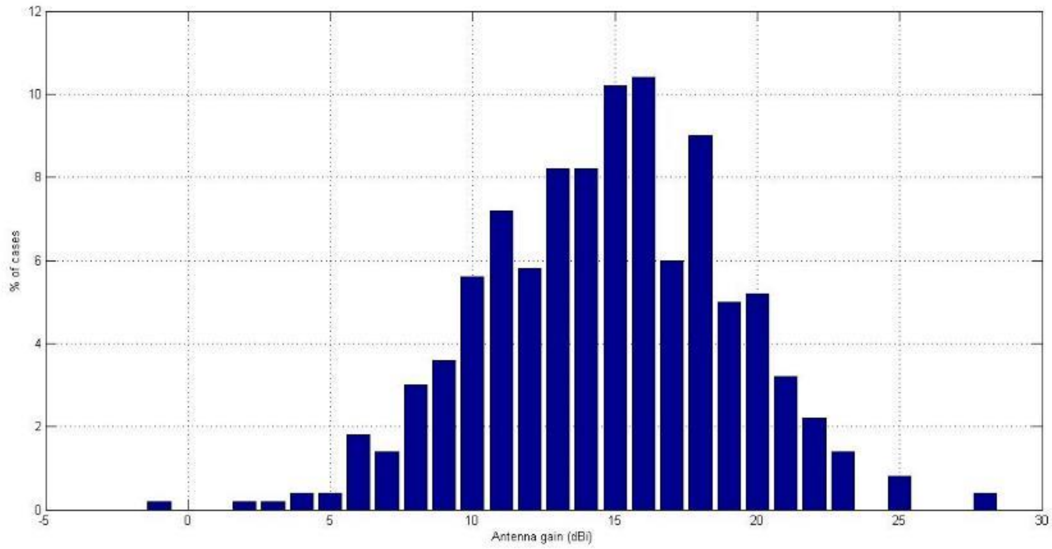


FIGURE 52

Distribution of maximum antenna gain



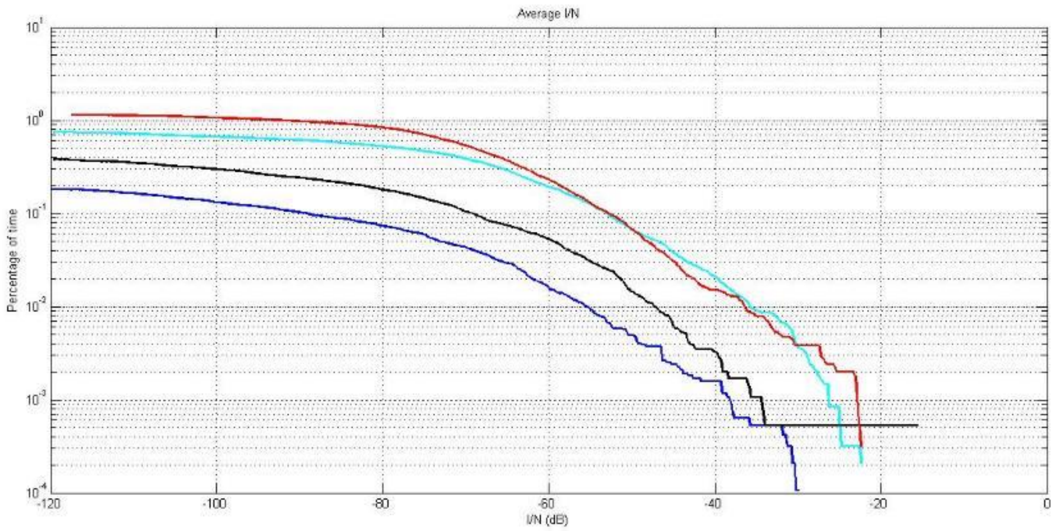
The aggregate interference level into the EESS SAR-4 receiver is then computed and compared to the noise level.

5.7.2 Results

The *I/N* CDF is shown in Fig. 53.

FIGURE 53

***I/N* cumulative distribution function (CDF) of interference from amateur-satellite earth stations into SAR-4**



An *I/N* of maximum –43 dB is obtained for 1% of the time when the EESS SAR-4 sensor is active, which is 0.03% of the total time of simulation assuming a 3% activity factor. This is 37 dB below the SAR protection criterion of –6 dB.

5.8 Impact of the amateur satellites into the EESS (active)

5.8.1 Scenario

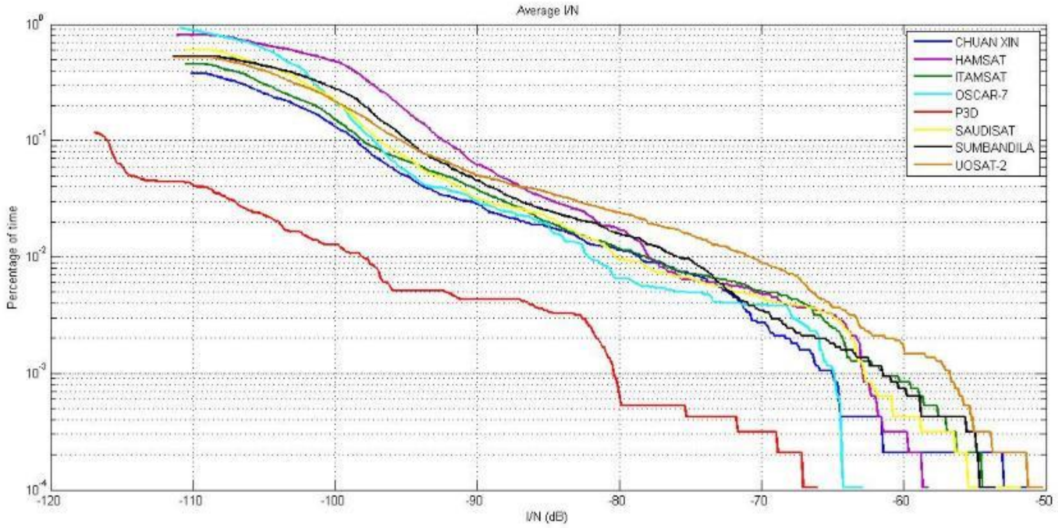
The scenario is similar to the one depicted in § 5.1, except that in this case the interference is caused by the amateur-satellite into an EESS SAR receiver.

5.8.2 Results

Figure 54 gives the CDF obtained for different amateur radio satellites.

FIGURE 54

***I/N* cumulative distribution function (CDF) of interference into the amateur satellites**



The simulation results show that the protection criterion of the SAR system, which is an *I/N* of –6 dB, will be met with a large margin.

5.9 Summary

This section provides results of sharing studies between EESS (active) and the amateur service allocated on a secondary basis in the band 10-10.5 GHz and the amateur-satellite service allocated in the band 10.45-10.5 GHz.

With regard to the amateur service, the study of impact of the EESS (active) sensor into the amateur station receivers indicates that the interference may exceed an *I/N* of –6 or –10 dB, but for a very limited period of time in the order of 10 times four seconds over 11 days, which in total represents 0.004% of the time. The study of potential interference of amateur radio transmissions into a SAR receiver shows a margin of 24 dB.

With regard to the amateur-satellite service, the study of the impact of the EESS (active) sensor into the amateur-satellite receiving earth station indicates that the interference may exceed an *I/N* of –6 or –10 dB, but for a very short period of time occurring during 0.0015% of the total simulation time over 11 days, i.e. two periods of about six seconds every five to six days. The studies of the impact of the EESS (active) sensor into the amateur satellite, as well as of the amateur satellite or the amateur earth stations into the SAR receiver indicate very large margins.

6 Supporting documents

ITU-R Recommendations

ITU-R Recommendations are cited with their current state of validity unless mentioned otherwise.

ITU-R F.386 Radio-frequency channel arrangements for fixed wireless systems operating in the 8 GHz (7 725 to 8 500 MHz) band

ITU-R F.387	Radio-frequency channel arrangements for fixed wireless systems operating in the 10.7-11.7 GHz band
ITU-R F.747	Radio-frequency channel arrangements for fixed wireless system operating in the 10.0-10.68 GHz band
ITU-R F.758	System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference
ITU-R F.1108	Determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands
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
ITU-R F.1336	Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz
ITU-R F.1494	Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 10.7-12.75 GHz band on a co-primary basis
ITU-R F.1495	Interference criteria to protect the fixed service from time varying aggregate interference from other radiocommunication services sharing the 17.7-19.3 GHz band on a co-primary basis
ITU-R F.1565	Performance degradation due to interference from other services sharing the same frequency bands on a co-primary basis with real digital fixed wireless systems used in the international and national portions of a 27 500 km hypothetical reference path at or above the primary rate
ITU-R F.1568	Radio-frequency block arrangements for fixed wireless access systems in the range 10.15-10.3/10.5-10.65 GHz
ITU-R F.1606	Interference criteria to protect fixed wireless systems from time varying aggregate interference produced by non-geostationary satellites operating in other services sharing the 37-40 GHz and 40.5-42.5 GHz bands on a co-primary basis
ITU-R F.1669	Interference criteria of fixed wireless systems operating in the 37-40 GHz and 40.5-42.5 GHz bands with respect to satellites in the geostationary orbit
ITU-R F.1777	System characteristics of television outside broadcast, electronic news gathering and electronic field production in the fixed service for use in sharing studies.
ITU-R M.1041	Future amateur radio systems
ITU-R M.1044	Frequency sharing criteria in the amateur and amateur-satellite services.
ITU-R M.1732	Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies
ITU-R M.1824	System characteristics of television outside broadcast, electronic news gathering and electronic field production in the mobile service for use in sharing studies
ITU-R RS.1166	Performance and interference criteria for active spaceborne sensors

ITU-R RS.2043 Characteristics of synthetic aperture radars operating in the Earth exploration-satellite service (active) around 9 600 MHz

ITU-R SF.1482 Maximum allowable values of power flux-density (pfd) produced at the Earth's surface by non-GSO satellites in the fixed-satellite service (FSS) operating in the 10.7-12.75 GHz band

ITU-R SF.1483 Maximum allowable values of power flux-density (pfd) produced at the Earth's surface by non-GSO satellites in the fixed-satellite service (FSS) operating in the 17.7-19.3 GHz band

ITU-R P.525-2 Calculation of free-space attenuation (This version of the Recommendation is incorporated by reference in the Radio Regulations)

ITU-R P.530 Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

ITU-R RS.2043 Characteristics of synthetic aperture radars operating in the Earth exploration-satellite service (active) around 9 600 MHz

ITU-R Reports

ITU-R Reports are cited with their current state of validity unless mentioned otherwise.

ITU-R BT.2069 Tuning ranges and operational characteristics of terrestrial electronic news gathering (ENG), television outside broadcast (TVOB) and electronic field production (EFP) systems

ITU-R F.2108 Fixed service system parameters for different frequency band

ITU-R RS.2094 Studies related to the compatibility between Earth exploration-satellite service (active) and the radiodetermination service in the 9 300-9 500 MHz and 9 800-10 000 MHz bands and between Earth exploration satellite service (active) and the fixed service in the 9 800-10 000 MHz band

ITU-R RS.2274 Spectrum requirements for spaceborne synthetic aperture radar applications planned in an extended allocation to the Earth exploration-satellite service around 9 600 MHz

Annex

List of abbreviations and glossary

ATPC	Automatic transmission power control
BAS	Broadcast auxiliary services
BER	Bit error ratio
CDF	Cumulative distribution function
CW	Continuous wave
ENG/OB	Electronic news gathering/outside broadcast
EESS	Earth exploration satellite service
EPO	Error performance objective
FDP	Fractional degradation of performance
FM	Frequency modulation
LHCP	Left-handed circular polarization
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
P-P	Point-to-point
P-MP	Point-to-multi point
PRF	Pulse repetition frequency
PSD	Power spectral density
RAAN	Right ascension of the ascending node
RF	Linear frequency modulation
RHCP	Right-handed circular polarization
SAR	Synthetic aperture radar
SES	Severely errored second
SSB	Single side band
TCM	Trellis coded modulation