International Telecommunication Union

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Radiocommunication Sector of ITU

Recommendation ITU-R M.1747

(03/2006)

Protection of the Earth exploration-satellite service (passive) in the band 1 400-1 427 MHz from unwanted emissions of mobile satellite service feeder links that may operate in the bands 1 390-1 392 MHz (Earth-to-space) and 1 430-1 432 MHz (space-to-Earth)

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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SM	Spectrum management
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***Note**: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R M.1747[*]

Protection of the Earth exploration-satellite service (passive) in the band 1 400-1 427 MHz from unwanted emissions of mobile satellite service feeder links that may operate in the bands 1 390-1 392 MHz (Earth-to-space) and 1 430-1 432 MHz (space-to-Earth)

(2006)

Scope

This Recommendation provides unwanted emission power levels for the protection of the Earth exploration-satellite service (EESS) (passive) satellites operating in the band 1 400-1 427 MHz from MSS feeder links (space-to-Earth) that may operate in the band 1 430-1 432 MHz and mobile-satellite service (MSS) feeder links (Earth-to-space) that may operate in the band 1 390-1 392 MHz.

The ITU Radiocommunication Assembly,

considering

a) that WRC-03 made a provisional allocation on a secondary basis to the fixed-satellite service (FSS) for mobile-satellite service (MSS) feeder links through No. 5.339A of the Radio Regulation (RR) in the bands 1 390-1 392 (Earth-to-space) and 1 430-1 432 MHz (space-to-Earth);

b) that these allocations are limited to use by feeder links for non-geostationary-satellite networks in the mobile-satellite service with service links below 1 GHz, and Resolution 745 (WRC-03) applies;

c) that the band 1 400-1 427 MHz is allocated to the Earth exploration-satellite service (EESS) (passive), radio astronomy and space research (passive) services on a primary basis in all Regions and that RR No. 5.340 also applies to the band 1 400-1 427 MHz;

d) that Resolution 745 (WRC-03) calls for compatibility studies, including the measurement of emissions from equipment that would be employed in operational systems, to validate that the MSS systems using this band meet all requirements for the protection of passive services in the band 1 400-1 427 MHz;

e) that the band 1 400-1 427 MHz is most suitable for EESS (passive) for the measurement of soil moisture, sea surface salinity and vegetation biomass;

f) that Recommendation ITU-R RS.1029 contains the protection criteria for the EESS (passive);

g) that Recommendation ITU-R M.1184 provides technical characteristics of mobile-satellite systems in frequency bands below 3 GHz for use in developing criteria for sharing between the MSS and other services;

h) that studies for MSS feeder links (Earth-to-space) as contained in Annexes 1 and 2 concluded that the most suitable criterion to protect EESS (passive) would be an unwanted power spectral-density specification applicable to MSS feeder-link stations in the band 1 400-1 427 MHz;

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[*] This Recommendation was jointly prepared by Radiocommunication Study Groups 7 and 8 and any future revision will also be undertaken jointly.

j) that a margin of around 2 dB is advisable on top of the results obtained for an interference probability of 0.05% to account for the fact that only a limited number of feeder-link and passive sensor combinations could be studied and that actual MSS characteristics may deviate slightly from the ones assumed in the studies,

noting

a) that the reduction of unwanted emissions to levels required for adequate protection of passive services in the band 1 400-1 427 MHz is feasible with baseband processing techniques for typical combinations of data rates and modulation techniques without a specific post amplifier filter;

b) that an additional post amplifier filter can be used in cases where the baseband processing referred to under *noting* a) is not sufficient to meet the required unwanted emission levels;

c) that the unwanted emission level at the input to the MSS feeder-link satellite antenna required to protect the RAS is below the level given in *recommends* 1 (see Recommendation ITU-R M.1748,

recommends

1 that, in order to protect the EESS (passive) in the band 1 400-1 427 MHz, unwanted emissions of MSS feeder links should not exceed the following power levels in the band 1 400-1 427 MHz:

– −63 dBW at the input to the earth station antenna for MSS feeder links (Earth-to-space) operating in the band 1 390-1 392 MHz;

– −46 dBW at the input to the satellite antenna for MSS feeder links (space-to-Earth) operating in the band 1 430-1 432 MHz.

Annex 1

Protection of the EESS (passive) sensors in the band 1 400-1 427 MHz from MSS feeder links that may operate in the FSS around 1 400 MHz

1 Technical characteristics of the EESS passive sensor satellite

Frequencies near 1 400 MHz are most suitable for measuring soil moisture, sea surface salinity and vegetation biomass. NASA is currently developing an instrument for measuring sea surface salinity (the Aquarius mission) which will collect measurements in the entire passive microwave band under consideration (1 400 to 1 427 MHz). NASA is also developing an instrument for measuring soil moisture (the HYDROS mission) in the 1 400 to 1 427 MHz band. The technical characteristics of the Aquarius and HYDROS passive sensing satellites are presented in Table 1.

The Aquarius science goals are to observe and model the processes that relate salinity variations to climatic changes in the global cycling of water, and to understand how these variations influence the general ocean circulation. The HYDROS science goal is to measure soil moisture which is a key variable in the hydrologic cycle with significant influence on evaporation, infiltration and runoff.

TABLE 1

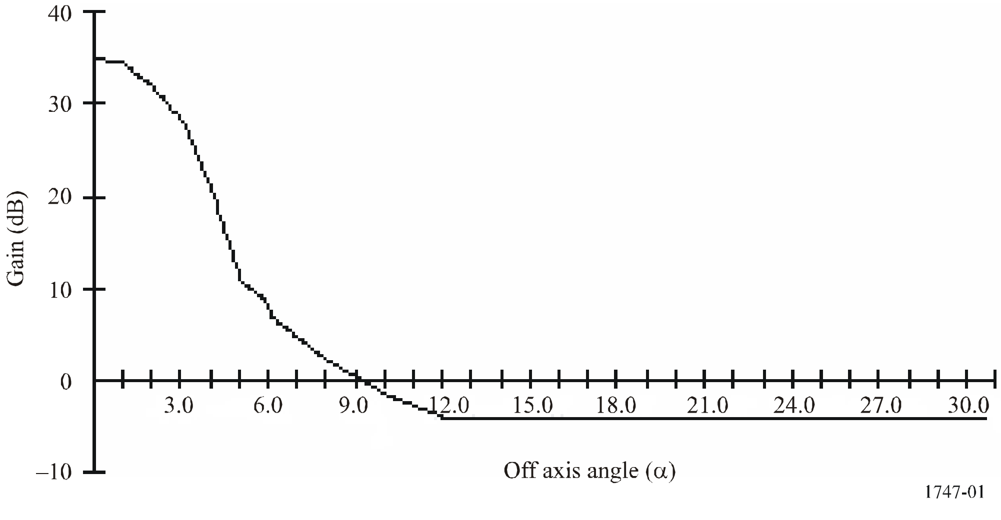
Aquarius and HYDROS passive sensor parameters

Parameter	Aquarius	HYDROS
Peak antenna gain (for each beam) (dBi)	31.1	35
3 dB beamwidth (for each beam) (degrees)	5.5	2.6
Antenna polarization	Horizontal and vertical	Horizontal and vertical
Antenna pointing (degrees from nadir)	*Beam 1* Cross track: 37.2 Along track: 4.8	40 off-nadir Antenna scans about nadir at 6 rpm with a sampling time of 72 ms/cell
	Beam 2 Cross track: 28.9 Along track: −9.5	
	Beam 3 Cross track: 20.7 Along track: 4.8	
Orbit	600 km altitude 98° inclination	670 km altitude 98° inclination
Receiver bandwidth (3 dB) (MHz)	25	27
Permissible interference level (dB(W/27 MHz))	−174	−174
Percentage of time interference may be exceeded (%)	0.1	0.1

HYDROS uses a scanning antenna at a 40° offset from nadir. The gain pattern for the HYDROS antenna is illustrated in Fig. 1. Aquarius uses a three-beam push-broom radiometer configuration with each sensor beam having a gain pattern similar to HYDROS. Each beam represents a single pixel with an average integration time of 10 s.

FIGURE 1

HYDROS antenna pattern



2 Technical characteristics of the MSS system

The 1 390-1 392 MHz and 1 430-1 432 MHz bands are under consideration for feeder links between non-geostationary mobile-service satellites and fixed earth stations located worldwide. These feeder links would transmit data to and receive data from a constellation of MSS satellites. In addition, telemetry, tracking and command functions would be carried out via these links.

Four MSS constellations comprising 128 satellites were considered in this study as shown in Table 2. The parameters for constellations “L”, “M”, “Q”, and “S” were obtained from Annex 2 of Recommendation ITU-R M.1184. A slight modification was made to the number and inclination of the satellites in the “Q” constellation in order to make this constellation consistent with actual planned systems. The number of satellites composing the “Q” constellation was reduced from 32 to 26 for this study and the inclination for 24 of the 26 satellites was increased from 51° to 66°.

TABLE 2

MSS constellation characteristics

	Recommendation ITU-R M.1184						
	Constellation L	**Constellation M**			**Constellation S**	**Constellation Q**	
Number of satellites	48	48			6	26	
Altitude (km)	950	825		775	692	1 000	
Inclination (degrees)	50	45	0	70, 108	98	66	83
Orbit planes	8	3	1	2	2	6	2
Satellites per plane	6	8			3	4	1

The MSS Earth-to-space and space-to-Earth feeder-link characteristics used for this study are described in Tables 3 and 4, respectively. Feeder-link characteristics were assumed to be identical for the four MSS constellations, and were obtained from previous ITU-R sharing studies.

The pattern on the left in Fig. 2 illustrates the gain pattern of the non-GSO MSS satellite circularly polarized feeder-link antenna used in this analysis for both transmit and receive. The pattern on the right in Fig. 2 illustrates the gain pattern of the MSS earth station antenna. This pattern is taken from Appendix 8, Annex III of the RR. Each MSS constellation is supported by 15 earth stations distributed throughout the world in representative locations, resulting in a total of 60 earth stations.

TABLE 3

Earth-to-space feeder-link characteristics

Parameter	Value
Number of earth stations	15 per MSS constellation, 60 total
Earth station locations	Distributed throughout the world for each constellation
Transmit antenna peak gain	30 dBi
3 dB beamwidth	5°
Gain floor	−1.5 dBi
Antenna pattern	RR Appendix 8, Annex III
Antenna polarization	Right hand circular (RHPC)
Antenna pointing	Tracks nearest satellite at elevations between 5° and 90°
Transmit power	10 W per 100 kHz
Line loss	1 dB
Modulation	GMSK(1), OQPSK(2), 8-PSK(2), 16-QAM(2)
Channel bandwidth	100, 300 and 855 kHz

(1) Gaussian baseband filtered with $BT_b = 0.5$.

(2) Square root raised cosine baseband filtered with $BT_s = 1.0$.

GMSK: Gaussian filtered minimum shift keying

OQPSK: Offset quadraphase shift keying

8-PSK: Octogonal phase shift keying

TABLE 4

Space-to-Earth feeder-link characteristics

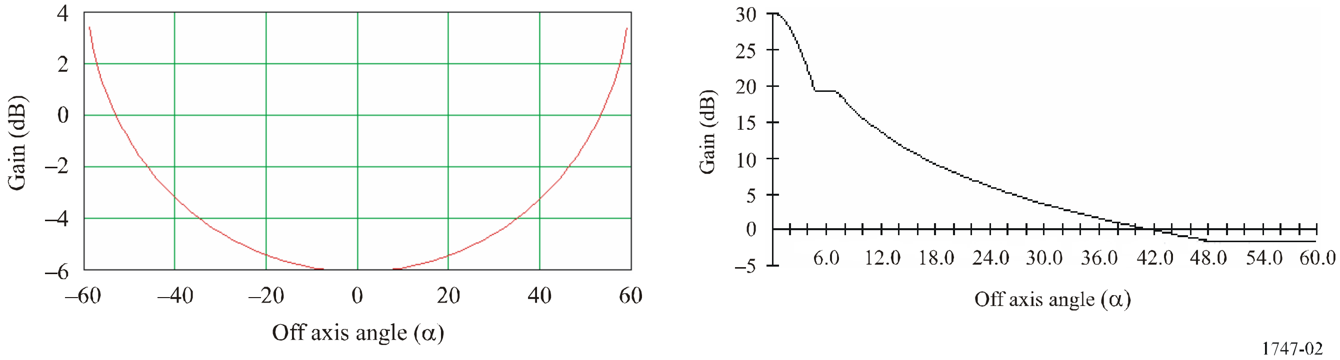
Parameter	Value
Transmit antenna peak gain	See Fig. 2
Gain floor	−6 dB
Antenna polarization	RMPC
Antenna pointing	Fixed, approx. 4 000 km diameter coverage area
Transmit power	1 W per 100 kHz
Line loss	1 dB
Modulation	GMSK(1), OQPSK(2), 8-PSK(2), 16-QAM(2)
Channel bandwidth	100, 300, 855 kHz

(1) Gaussian baseband filtered with $BT_b = 0.5$.

(2) Square root raised cosine baseband filtered with $BT_s = 1.0$.

FIGURE 2

Non-GSO MSS satellite receive and transmit antenna pattern (left) and Earth station receive and transmit antenna pattern (right)



3 Interference analysis

3.1 Overview

The dynamic interference model includes four MSS systems comprising 128 spacecraft and 60 earth stations. The simulation model calculated the cumulative distribution functions (CDFs) of co-channel interference power produced by an aggregate of an individual MSS system's uplinks and downlinks, and an aggregate of all MSS systems' uplinks and downlinks at the passive sensor receiver input.

At each step of the simulation, the model calculated the aggregate power at the output of a single sensor antenna beam produced by all visible and active MSS uplinks and downlinks, and these results were sorted into bins of 1.0 dB resolution for use in plotting the CDF. The simulations used one second time-steps for Aquarius and 50 ms time-steps for HYDROS to ensure adequate overlap with the sampling time per cell of the sensor beams. The simulations were run corresponding to a period of 14 days in real time.

The interference power level I (dBW) at the output of the passive sensor antenna was calculated using the following equation:

$$I = 10 \log P_t - L_l + G_t - \left(32.44 + 20 \log(f \cdot R)\right) + G_r - L_p - L_{atm} \qquad (1)$$

where:

P_t : interferer transmitter power (W)

L_l: transmitter line loss

G_t : interferer antenna gain in direction of victim station (dBi)

f : victim station receive frequency (MHz)

R : slant range between interferer and victim station (km)

G_r : victim station antenna gain in direction of interferer (dBi)

L_p : polarization discrimination loss

L_{atm} : atmospheric absorption loss (dB).

A value of 0 dB was used for attenuation due to atmospheric absorption (dry air and water vapour). A value of 1.4 dB was used for the polarization discrimination loss resulting from a linearly polarized passive sensor antenna and a circularly polarized MSS antenna. These calculations assumed that all of the MSS links operate on the same frequency and are within the passive sensor bandwidth. All simulations were performed at a frequency of 1 400 MHz and used transmit power levels associated with a 100 kHz channel bandwidth. It should be noted that CDF plots for 300 kHz and 855 kHz channel bandwidths would indicate higher interference levels due to scaling of the Earth-to-space and space-to-Earth link transmit power levels as a function of channel bandwidth.

In order to determine the out-of-band power from MSS feeder links in the 1 400-1 427 MHz band, modelling and simulation techniques were employed for various modulation schemes and channel bandwidths. The simulation model was first validated against the GMSK hardware measurement data, and then power spectral-density (PSD) data was generated via simulation for other modulation techniques and channel bandwidths. Using the PSD data, total integrated power relative to 1 W in the 1 400-1 427 MHz band was determined from an MSS uplink and downlink transmitter. These results are provided in Table 5. The centre frequencies for the simulated uplink and downlink signals were chosen so that the first null of the modulated signal occurred at the MSS feeder-link band edge closest to the EESS (passive) band.

TABLE 5

Total power in 1 400-1 427 MHz band from a possible worst case MSS feeder-link transmitter assuming 1 W transmit power (dBW)

Feeder-link channel bandwidth	**Feeder-link modulation**							
	Uplink (1 390-1 392 MHz)				Downlink (1 430-1 432 MHz)			
	GMSK	OQPSK	8-PSK	16-QAM	GMSK	QPSK	8-PSK	16-QAM
100 kHz	−75.0	−74.3	−74.4	−74.4	−71.5	−71.8	−71.8	−71.9
300 kHz	−74.1	−73.5	−73.6	−73.6	−72.2	−71.0	−71.2	−71.6
855 kHz	−75.0	−75.1	−73.1	−73.5	−71.3	−70.8	−59.1	−64.2

3.2 Analysis results – operational mode

CDF plots for Aquarius are shown in Figs. 3 through 5. Similar CDF plots were obtained for HYDROS, and therefore are not shown. The CDF for the Earth-to-space link co-channel interference power level at Aquarius is plotted in Fig. 3 for each MSS system. Figure 4 shows the Aquarius co-channel CDF plot for each MSS system space-to-Earth link. Figure 5 shows the aggregate co-channel CDF plot for all MSS Earth-to-space links, the aggregate co-channel CDF plot for all MSS space-to-Earth links, and the total aggregate co-channel CDF plot for all MSS links and systems that may interfere with Aquarius.

It is the view of both WP 8D and WP 7C that the MSS feeder links should not contribute more than 5% to 10% to the total permissible interference, taking into account that several services contribute to the total permissible interference specified in Recommendation ITU-R RS.1029, and the potential allocation status of the MSS feeder links.

FIGURE 3

Aquarius CDFs for co-channel interference into passive sensors from MSS Earth-to-space links (100 kHz channel bandwidth)

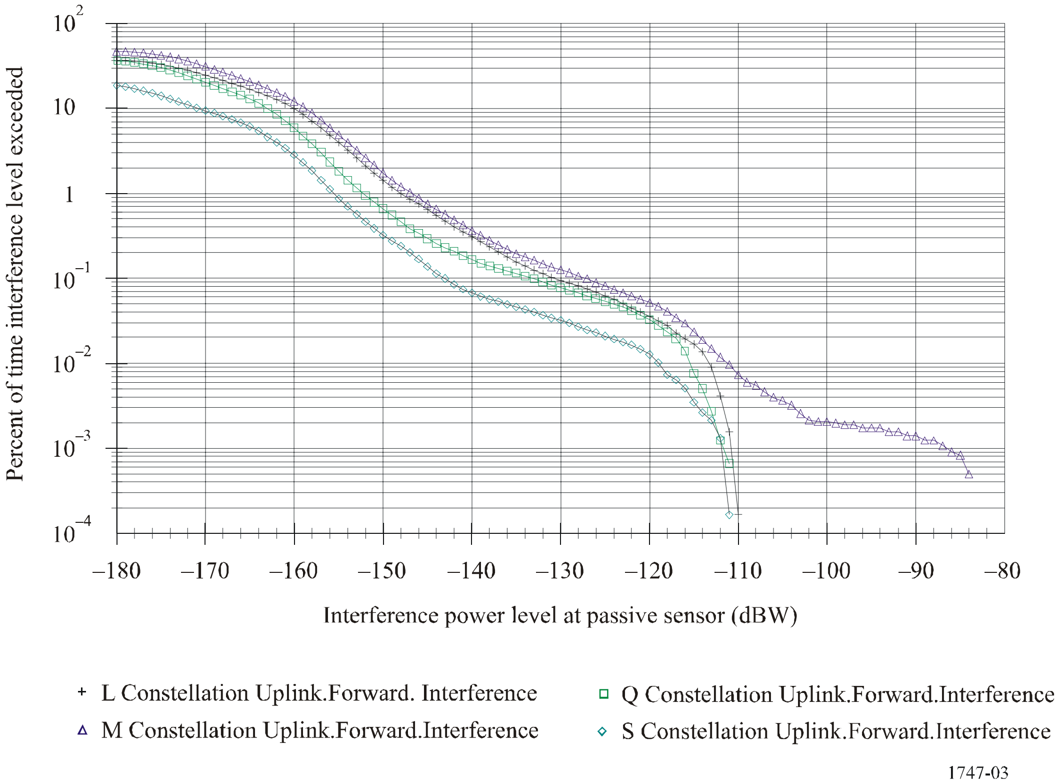


FIGURE 4

Aquarius CDFs for co-channel interference into passive sensors from MSS space-to-Earth links (100 kHz channel bandwidth)

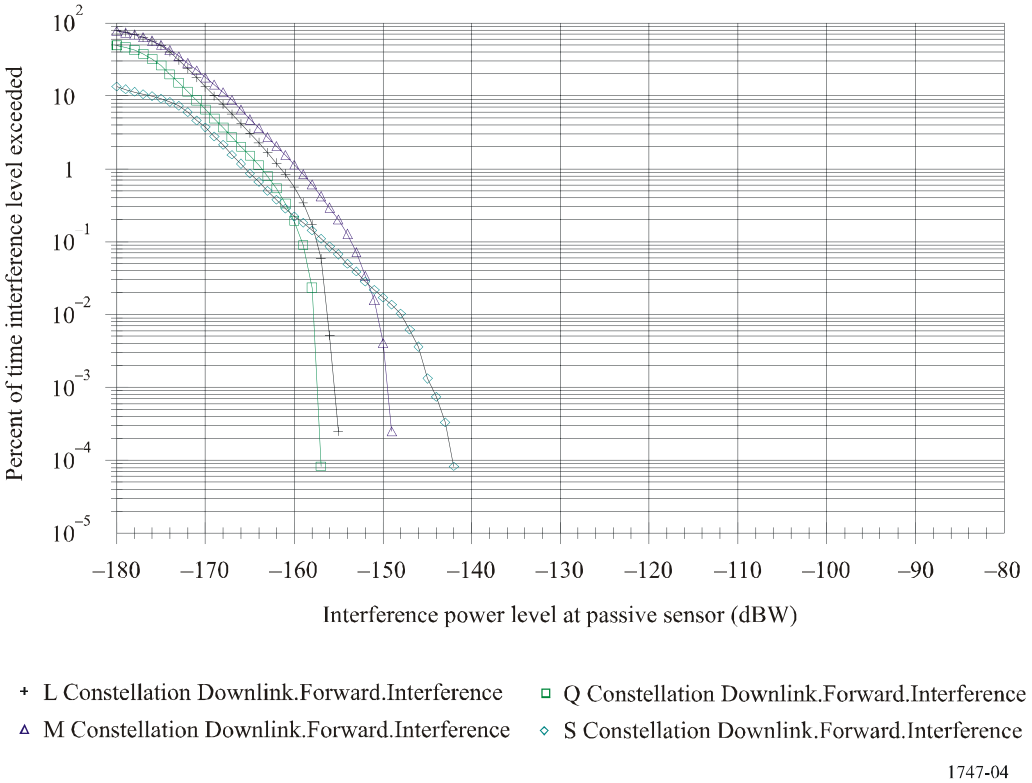


FIGURE 5

Aquarius aggregate CDFs for co-channel interference into passive sensors (100 kHz channel bandwidth)

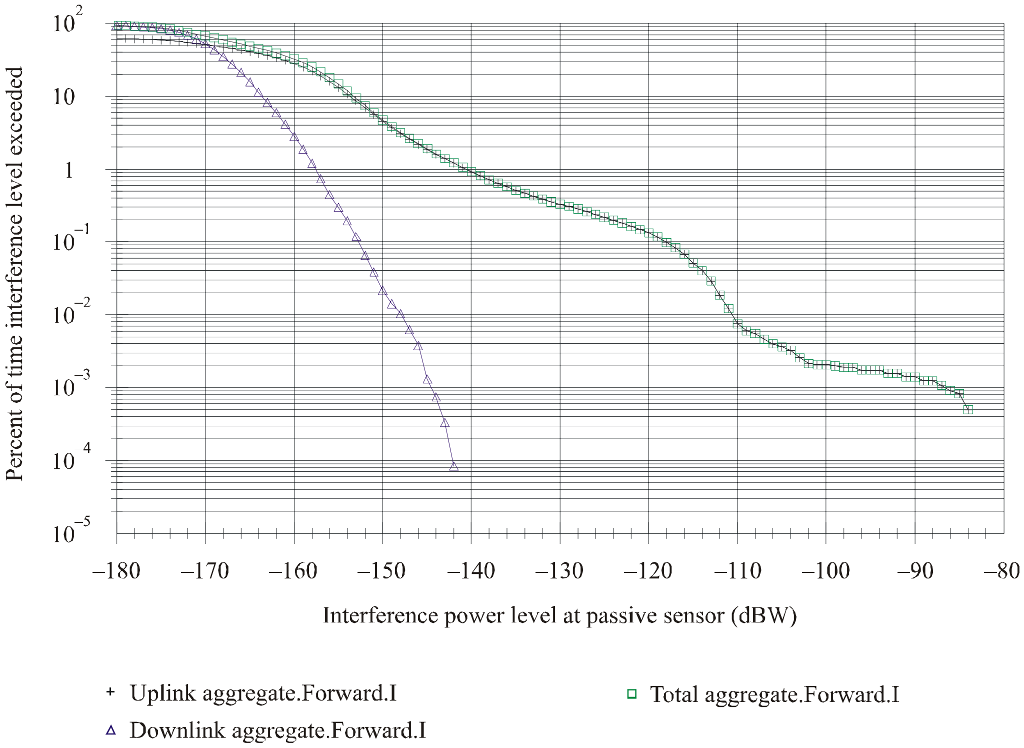


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Table 6 illustrates an example calculation of interference margin for Aquarius and MSS Earth-to-space feeder links operating in a 100 kHz bandwidth with GMSK modulation for values of 0.005% and 0.01% of time that the permissible interference level can be exceeded. A summary of Aquarius and HYDROS aggregate interference margins for all feeder-link modulations and channel bandwidths is provided in Table 7. A negative value in the interference margin row of the tables indicates the need for additional MSS feeder-link out-of-band filtering, or an improved transmitter design from what was assumed for this study.

TABLE 6

Aquarius/MSS Earth-to-space feeder-link interference for GMSK modulation, 100 kHz BW

		Constellation				**Aggregate uplink**
		L	**M**	**S**	**Q**	
MSS co-channel power (dBW)	5% time allocation	−112.0	−107.5	−116.0	−114.0	−107.5
	10% time allocation	−113.0	−111.0	−119.0	−115.5	−111.0
MSS feeder-link power in EESS band relative to 1 W (dB)		–75.0	–75.0	–75.0	–75.0	–75.0
MSS feeder-link power in EESS band (dBW)	5% time allocation	−187.0	−182.5	−191.0	−189.0	−182.5
	10% time allocation	−188.0	−186.0	−194.0	−190.5	−186.0
Permissible interference level (dBW)		–174.0	–174.0	–174.0	–174.0	–174.0
Interference margin (dB)	5% time allocation	13.0	8.5	17.0	15.0	8.5
	10% time allocation	14.0	12.0	20.0	16.5	12.0

TABLE 7

Summary of MSS feeder-link interference margins

Modulation	**Channel bandwidth (kHz)**	**Interference allocation**	**Total aggregate interference margin (dB)**	
			Aquarius	**HYDROS**
GMSK	100	5% allocation	8.5	8.0
		10% allocation	12.0	9.0
	300	5% allocation	2.8	2.3
		10% allocation	6.3	3.3
	855	5% allocation	−0.8	−1.3
		10% allocation	2.7	−0.3
OQPSK	100	5% allocation	7.8	7.3
		10% allocation	11.3	8.3
	300	5% allocation	2.2	1.7
		10% allocation	5.7	2.7
	855	5% allocation	−0.7	−1.2
		10% allocation	2.8	−0.2
8-PSK	100	5% allocation	7.9	7.4
		10% allocation	11.4	8.4
	300	5% allocation	2.3	1.8
		10% allocation	5.8	2.8
	855	5% allocation	−2.7	−3.2
		10% allocation	0.8	−2.2
16-QAM	100	5% allocation	7.9	7.4
		10% allocation	11.4	8.4
	300	5% allocation	2.3	1.8
		10% allocation	5.8	2.8
	855	5% allocation	−2.3	−2.8
		10% allocation	1.2	−1.8

3.3 Analysis results – calibration mode

Single orbit simulations were performed for the Aquarius spacecraft to determine interference levels during instrument calibration. During calibration, the Aquarius spacecraft will point its antenna into space during a portion of a single orbit by holding the spacecraft inertially fixed. Eight single orbit simulations were performed, each using different simulation parameters to vary the location of where the calibration is performed. The results, summarized in Table 8, represent the worst-case aggregate interference level from all MSS feeder links in view of the Aquarius antenna beam during a single calibration orbit. This interference level is approximately 7 dB less than the aggregate interference level obtained during simulations of normal Aquarius operations over a 14-day period.

TABLE 8

Summary of interference levels during sensor calibration for offset QPSK modulation and 300 kHz MSS feeder-link bandwidth

		Aquarius	**HYDROS**
Calibration technique		Point antenna towards space during portion of one orbit by holding spacecraft inertially fixed	Tilt antenna towards space for one entire orbit
Maximum interference power in EESS (passive) band (dBW)		−189.9	−176.9
Interference power in EESS (passive) band for 0.1% criteria (dBW)		−193.7	−189.2
Allowable interference power (dBW)	5% allocation	−187	−187
	10% allocation	−184	−184
Interference margin (dB)	5% allocation	6.7	2.2
	10% allocation	9.7	5.2

Simulations were also performed to determine interference levels at the HYDROS spacecraft during calibration of its passive sensor. The current baseline calibration scheme for the HYDROS spacecraft is to observe the Amazon rainforest and open ocean every three days, in addition to viewing space by tilting the spacecraft for one orbit every two to four months. Three single orbit simulations were performed (each using a different longitude of ascending node) to determine the interference level from the MSS feeder links while the HYDROS antenna is pointed into space for calibration. Table 8 summarizes the simulation results for the worst-case interference during space calibration. Interference levels for calibration when pointing towards the Earth are assumed to be the same or less than those presented in § 3.2 of this Recommendation.

Annex 2

Interference analysis between the EESS (passive) in the band 1 400-1 427 MHz and MSS feeder links in nearby bands

1 Introduction

This Annex has been composed of three study contributions submitted to ITU-R on compatibility between EESS (passive) operating sensors in the band 1 400-1 427 MHz and MSS feeder links in nearby bands. Many assumptions were identical to the ones used in Annex 1 and have therefore not been repeated. MSS system assumptions are identical. The main difference is based on alternative sensor applications which are described below.

2 Passive sensor characteristics and protection criteria

Soil moisture and ocean salinity (SMOS) can be measured by passive sensors operating in the frequency band 1 400-1 427 MHz. Soil moisture is a key variable in the hydrologic cycle with significant influence on evaporation, infiltration and runoff. Sea surface salinity has an influence on deep thermohaline circulation and the meridional heat transport. Variations in salinity influence the near surface dynamics of tropical oceans. Frequencies around 1 400 MHz are very suitable to measure soil moisture and sea surface salinity.

SMOS is also the name of a low Earth-orbiting satellite with a planned orbital altitude of around 760 km. Inclination is preferably 98.4° with the time of the ascending node around 0600 h. Details are given in Table 9. SMOS is based on an innovative concept, as it images at each integration time a large scene (typically 1 000 × 1 000 km) with various incidence angles at ground level (ranging from 0° to 55°). Hence, any point of the surface is measured at various view angles which is used to decouple soil and vegetation contributions. SMOS uses interferometric techniques in order to improve spatial resolution. It will use a fixed array of small antennas instead of large scanning antennas.

TABLE 9

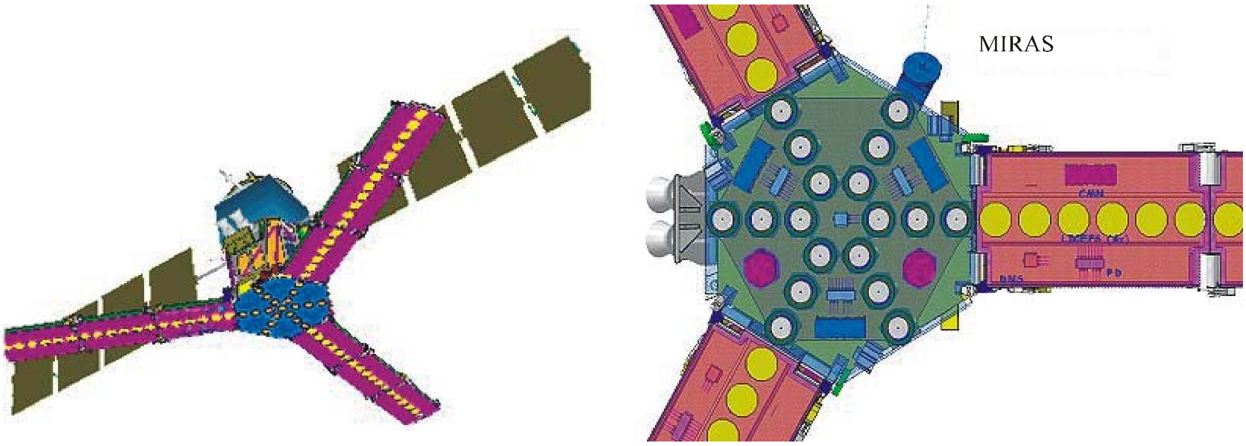
SMOS general characteristics

Instrument	Microwave Imaging Radiometer using Aperture Synthesis – MIRAS
Instrument concept	Passive microwave 2-D interferometer
Frequency	1 400-1 427 MHz
Bandwidth	27 MHz
Polarization	H & V (polarimetric mode optional)
Spatial resolution	50 km (35 km at centre FOV)
Tilt angle	32°
Angular resolution	0°-55°
Temporal resolution	Three days revisit

The actual sensor on SMOS is referred to as MIRAS (Microwave Imaging Radiometer using Aperture Synthesis). It is a dual-polarized 2-D interferometer. The design of the instrument uses three coplanar arms consisting of an elementary antenna regularly spaced (0.875 lambda, maximum redundancy) in a Y-shaped configuration (see Fig. 6). In this concept, an interferometric Fourier synthesis is applied to derive images from the correlations between each pair of antenna elements (small independent receivers) operating in the microwave region. The 2-D SMOS interferometer permits the brightness temperature to be measured simultaneously at different incidences and at two polarizations. Moreover, the instrument records an entire scene instantaneously. As the satellite moves, a given point within the 2-D field of view is observed from different angles. A series of independent measurements is obtained permitting the derivation of surface parameters with improved accuracy. The brightness temperature field of such a design is reconstructed with a resolution corresponding to the spacing between the outmost receivers.

FIGURE 6

SMOS antenna configuration



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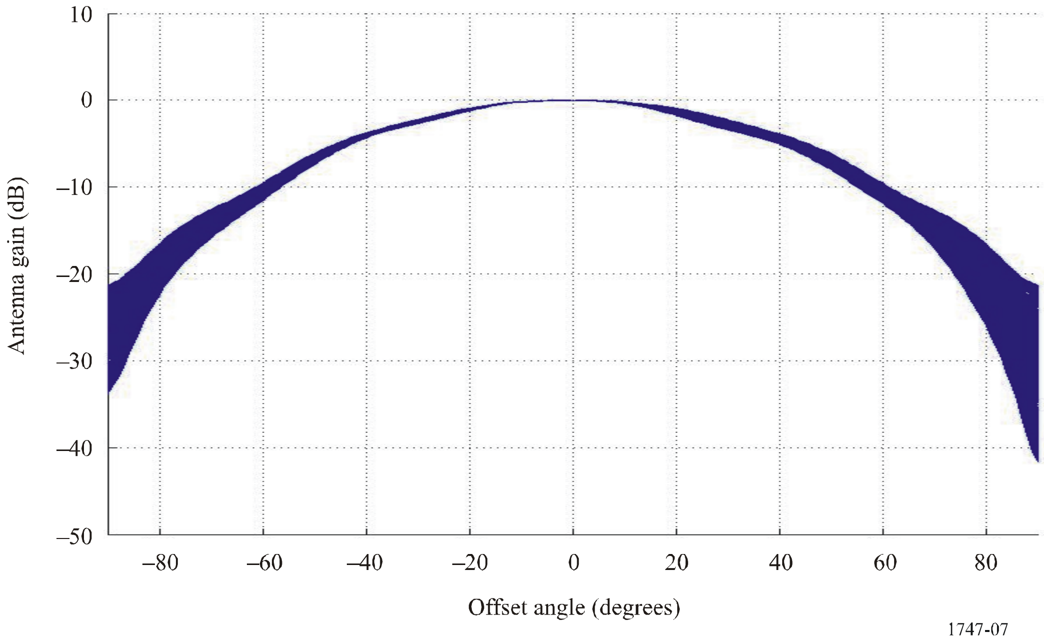
Each antenna/receiver unit is based on a patch antenna without dielectric substrate with about 70º half-power beamwidth, directivity of about 8 dB and provides both H and V polarizations with excellent cross-polarization characteristics (co-polarization/cross-polarization ratio > 25 dB). The antenna pattern for one antenna element is given in Fig. 7.

FIGURE 7

SMOS elementary antenna pattern



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A single receiver chain per antenna element is available, so each unit can operate on either H or V polarization upon command from a control unit. In each receiver the antenna signal is filtered to the selected bandwidth, amplified and finally sampled and converted to a 1 bit digital signal.

The MIRAS output data stream, combining both I and Q components and at a rate of about 130 Mbit/s, is transmitted to the correlator unit by means of an optical fibre link. Each element also receives (via a second optical fibre link) a centrally-generated reference clock signal in order to perform the frequency down-conversion and the sampling with phase coherence among all elements. An oversampling by a factor of about 2 with respect to the Nyquist criterion is achieved in each receiver, which improves the radiometric sensitivity. In the correlator unit, after conversion from optical to electrical signals, a massive bank of 1 bit/2-level correlators implemented in dedicated integrated circuits performs the cross-correlations between all signals. Horizontal and vertical polarization images are interlaced and the cross-correlation for each polarization is performed over a 0.3 s period. Up to five images are then averaged, so that two images (one per polarization) are available every three seconds.

The gain for a single element of this antenna can be expressed as:

$$G = 9 - 0.0027\,\theta^2 \qquad \text{for } |\theta| < 120° \qquad (2)$$

$$G = -30 \qquad \text{for } |\theta| > 120°$$

where θ is the offset angle from boresight (degrees).

In compliance with Recommendation ITU-R RS.1029, the acceptable interference power is −174 dBW in the reference bandwidth of 27 MHz. This level may be exceeded for 0.1% of time based on all interference sources contributing to the total interference in this band. It has been agreed by Radiocommunication Working Parties 7C and 8D to allow 5 to 10% of the total interference contribution by the MSS.

In view of the difficulty to predict all potential future sensor configurations, several antenna gains were considered as current and future sensors can have a wide range of practical antenna implementations. Based on knowledge about other sensor systems it appears that a range between 27 dBi and 40 dBi can be considered representative. The equivalent gain contours for such antennas are derived from Recommendation ITU-R S.672 but take into account that, based on experience, the antenna gain floor of 0 dBi usually overestimates the received interference. A further roll-off below 0 dBi is therefore assumed resulting in slightly lower interference results compared to strict application of Recommendation ITU-R S.672 with the gain floor.

3 Mobile satellite system characteristics

The same MSS system characteristics as in Annex 1 have been used. They are, in general, based on Recommendation ITU-R M.1184. An overview is provided in Table 10.

TABLE 10

Parameters of several non-GSO MSS networks

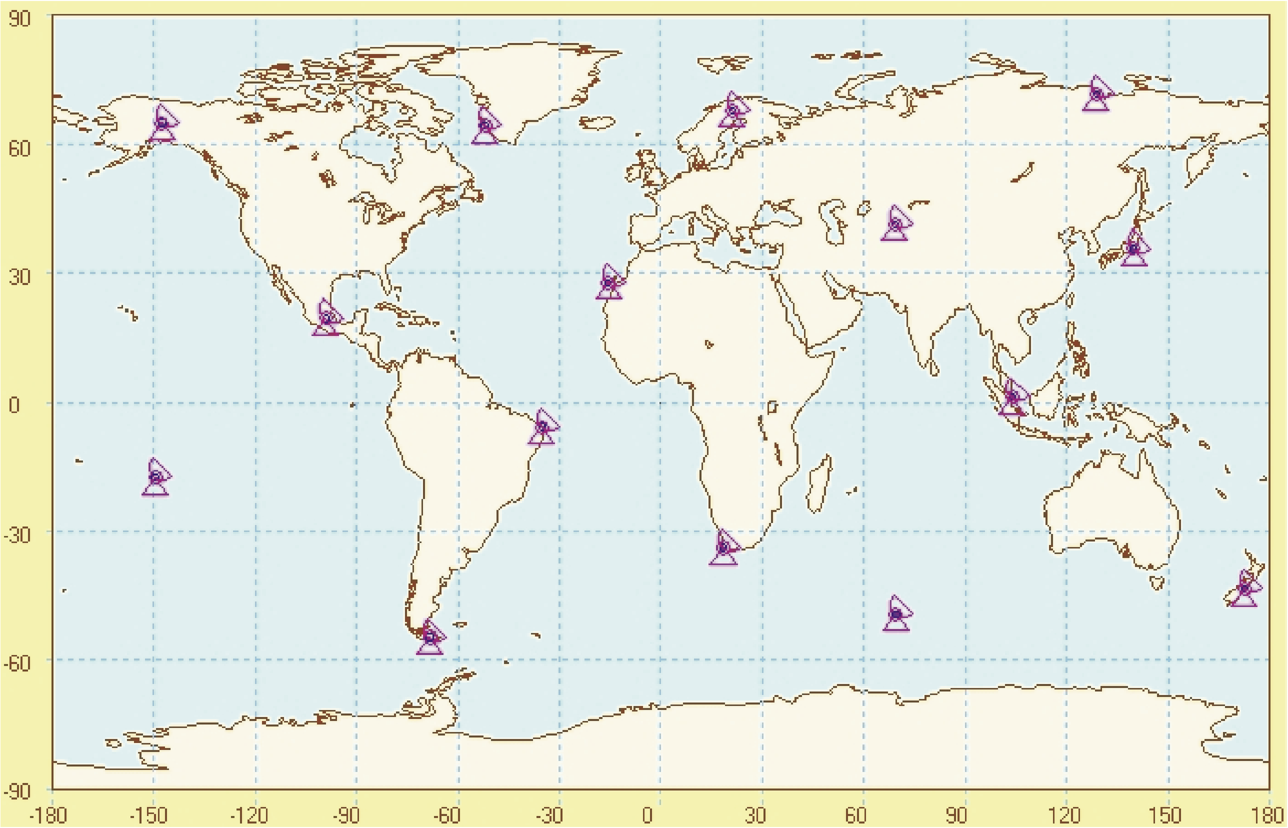
System	L	M			P	Q		S
Number of satellites	48	48			6	26 (32)		6
Altitude (km)	950	825		775	893	1 000		692, 667
Inclination (degrees)	50	45	0	70, 108	99	66 (51)	83	98.04
Orbit planes	8	3	1	2	2	6	2	2
Satellite/plane	6	8			3	4 (5)	1	3
Right ascension of ascending node (degrees)	0, 45, 90, 135, 180, 225, 270, 315	0, 120, 240	0	0, 180	9.8	0, 60, 120, 180, 240, 300	0, 90	143.5, 53.5
Channel bandwidth (kHz)	15	5			855	25		150
Polarization (Tx wave)	Linear				LHCP	Linear		RHCP

LHCP: Left hand circular polarization

Around 15 locations per MSS system have been assumed for the earth stations. The locations have been selected in a way to maximize on the one hand side coverage time but, on the other hand, also take into account limitations with respect to actually available land mass, including suitable islands. The selected locations are shown in Fig. 8.

FIGURE 8

Earth station locations for MSS systems



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4 Interference analysis

4.1 Earth-to-space links

The calculation of interference levels has been conducted in the same way as in Annex 1.

Figure 9 shows the combined interference density levels on Earth-to-space links for the four MSS systems Q, L, M and S considered in this assessment. For an acceptable interference probability of 0.005% to 0.01%, the received hypothetical in-band interference density is −103 dBW for 0.005% and −105 dBW for 0.01%. The interference excess for the hypothetical in-band signal relative to the required −174 dB(W/MHz) is therefore between 71 dB and 69 dB, respectively. Taking into account the power level of 10 W at the input to the MSS earth station, this corresponds to a maximum unwanted emission level of −59 dBW for 0.01% of time or −61 dBW for 0.005% of time in the entire 27 MHz band. The actual required attenuation for a 100 kHz signal would then be 93 dB for 0.01%, based on 69 dB to meet the criterion in the entire 27 MHz passive band plus an additional 24.3 dB for the scaling to 100 kHz signal bandwidth.

FIGURE 9

Cumulative interference density levels for four MSS systems with Earth-to-space links

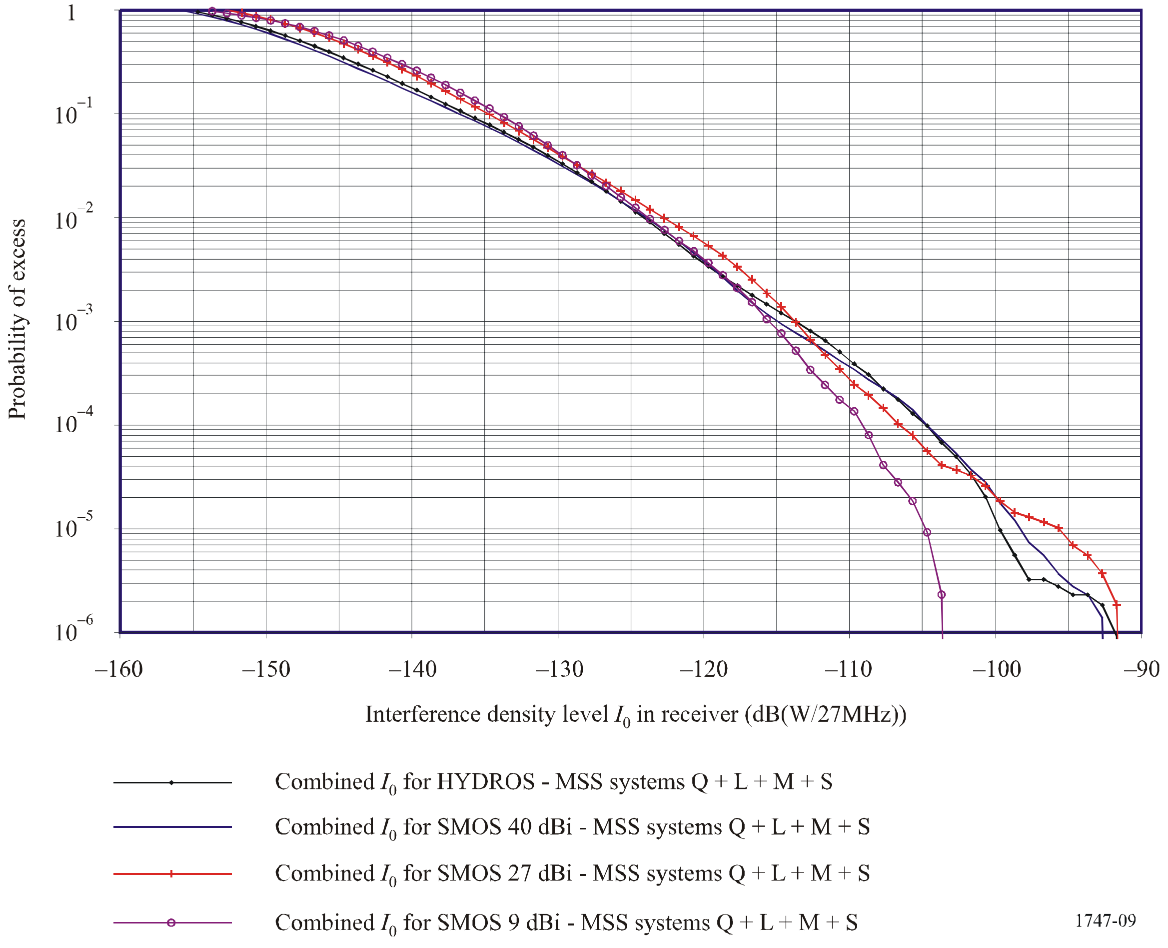


Figure 10 shows the combined interference density levels on space-to-Earth links for the four MSS systems considered in this assessment. There is relatively little dependency on the gain of the sensor down to probabilities around 10^{-4}, but rather on the orbit height difference between sensor and MSS satellites. It is obvious that the orbital height is a critical element for the downlink. Most of the interference will be caused when the satellites are rather close to each other. A minimum orbital separation may be required. In order to meet the protection requirement of −174 dB(W/MHz), the unwanted emission power level has to be less than −44 dBW to −41 dBW for 0.005% and 0.01% of time, respectively.

FIGURE 10

Cumulative interference density levels for four MSS systems with space-to-Earth links

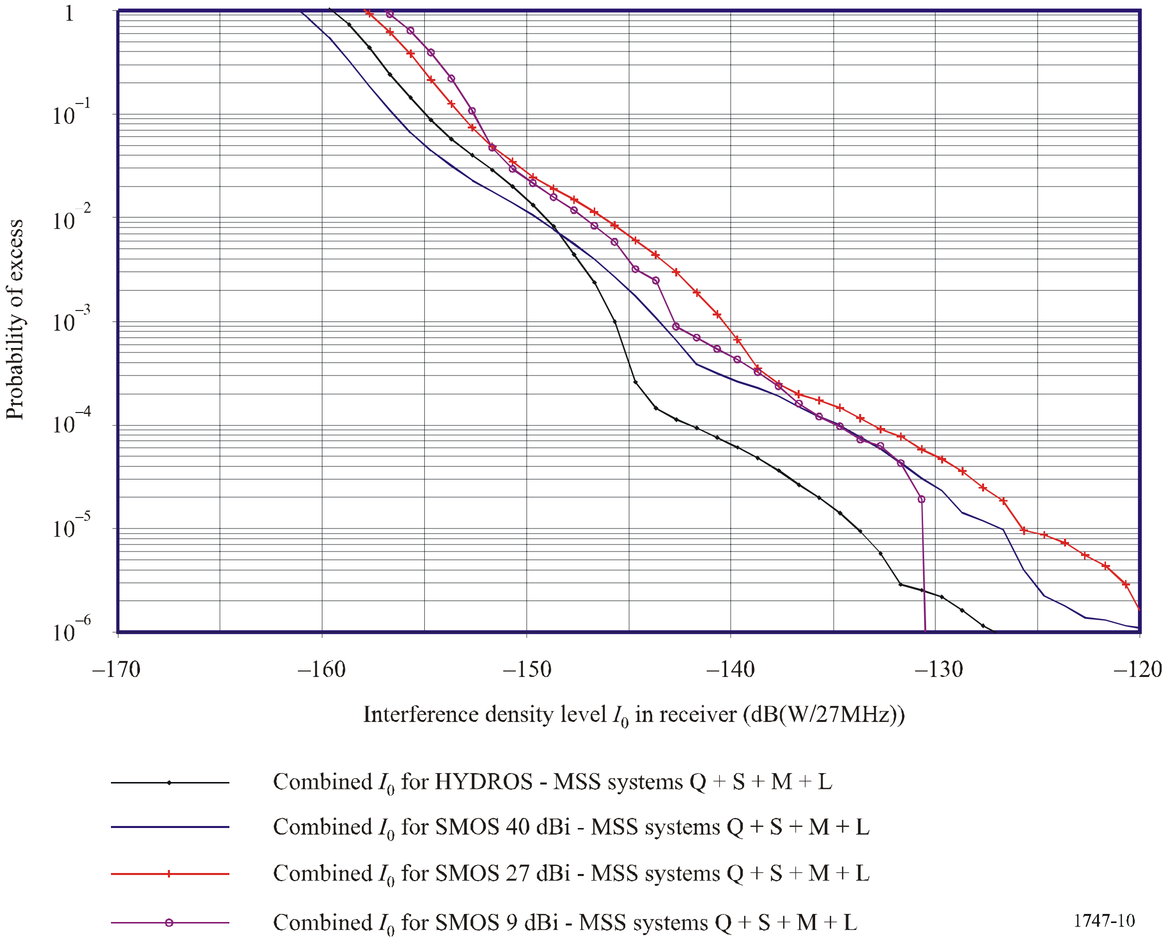
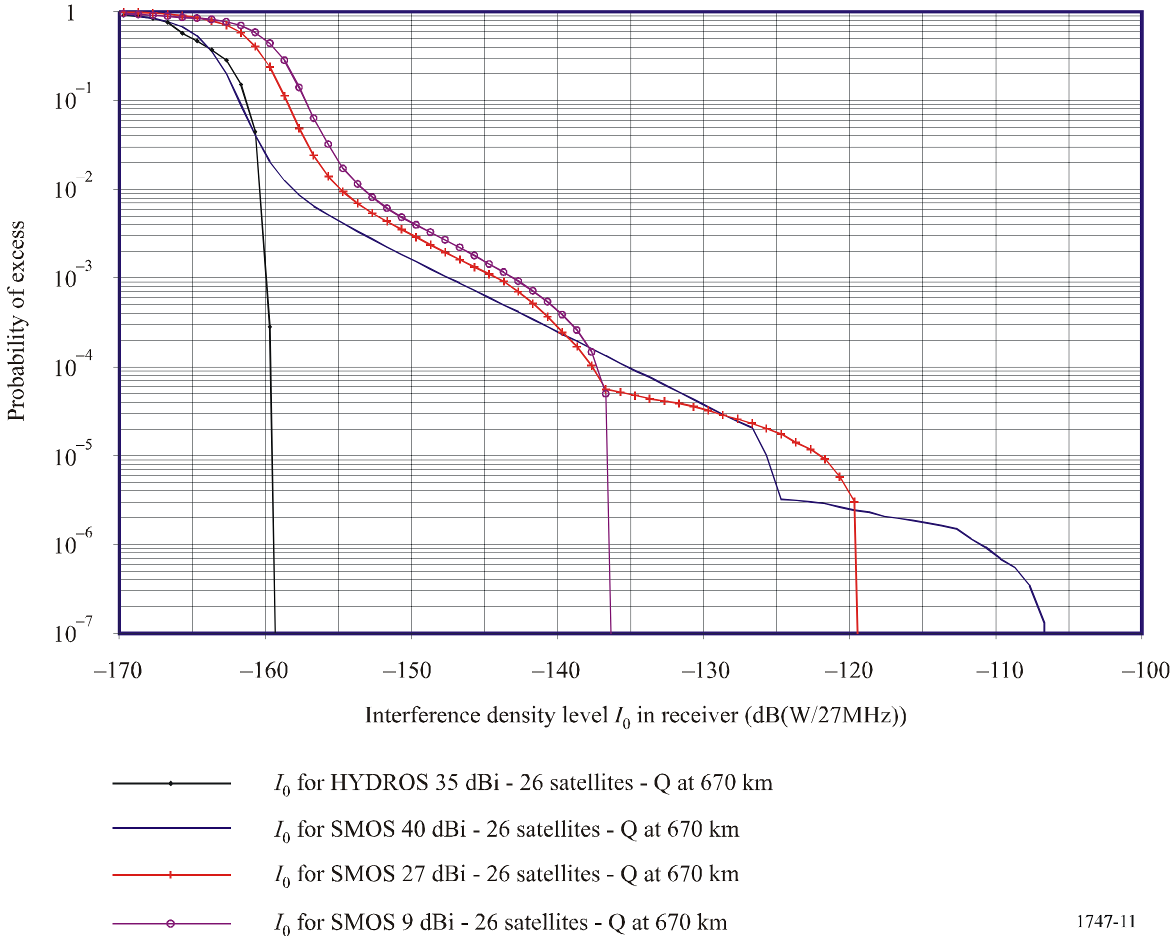


Figure 11 shows the interference density as a function of MSS satellite orbit height different from those provided by Recommendation ITU-R M.1184. There are no restrictions on orbital heights in the Radio Regulations and it was therefore considered appropriate to also investigate situations where orbital heights of passive sensors and MSS satellites are nearly identical. Figure 11 shows, in particular, that interference levels are significantly increased when orbital heights are very close.

FIGURE 11

Interference density levels for MSS systems close to SMOS sensors



One study contribution showed that MSS earth station antenna characteristics can have a significant impact on the cumulative interference levels. Figure 12 shows results for earth stations with antenna gains of 15, 20 and 30 dBi, respectively. It can be seen that in the probability regions between 0.01% and 0.005%, lower gain antennas result in higher interference levels because of the poorer control of side-lobe levels.

This same study also concluded that an out-of-band e.i.r.p. limit would not be adequate for the protection of the EESS, as it varies a lot and would be more constraining for lower antenna gains. It would, in fact, be better to define an unwanted emission power limit which varies less with the antenna gain. Table 11 is an extract from this study.

FIGURE 12

Power received in the HYDROS sensor for diverse MSS ES antenna gains

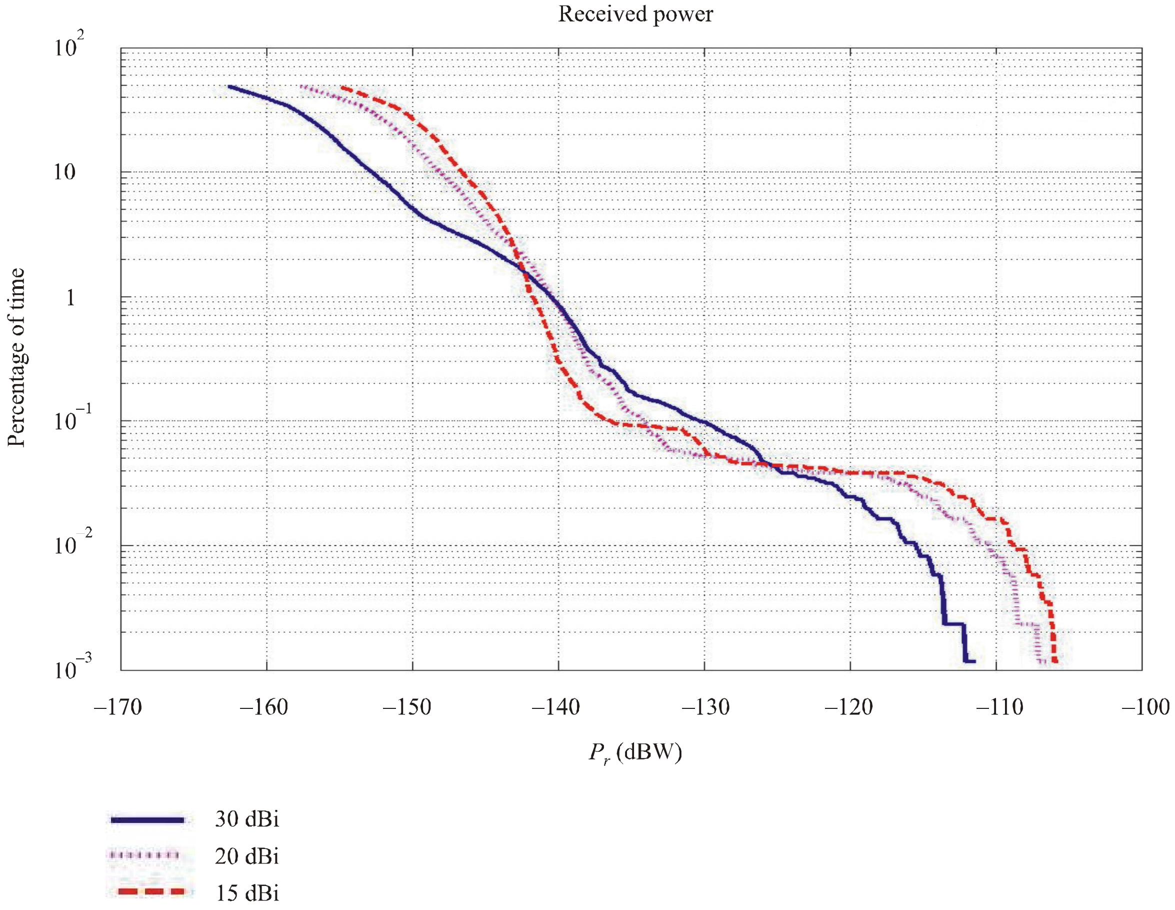


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TABLE 11

Required emission power and e.i.r.p. per MSS earth station

Parameter	15 dBi antenna	20 dBi antenna	30 dBi antenna
Received power in the passive band for 0.01% of the time (dBW) and an emission power of 10 dBW	−109	−111	−115
Margin with regard to the protection criterion −174 dBW in 27 MHz (dB)	−65	−63	−59
Required power limit in the passive band to respect the protection criterion (dBW)	−55	−53	−49
Corresponding e.i.r.p. (dBW including feeder losses)	−41	−34	−20

5 Summary

On the MSS uplinks, a restriction of out-of-band power fed into the MSS earth station antenna of −59 dBW will be required in the band 1 420-1 427 MHz in order to meet the 0.01% criterion and −61 dBW to meet the 0.005% criterion.

The actual required uplink attenuation for a 100 kHz signal is 93 dB for 0.01% and 95 dB for 0.005%. Such a high unwanted emission attenuation level is technically feasible if modulation techniques with appropriate pulse shaping and tight hardware performance specifications are used in conjunction with a post amplifier filter.

On the MSS downlinks, the unwanted emission power level at the output of the satellite antenna has to be less than −41 dBW in order to meet the 0.01% criterion and −44 dBW to meet the 0.005% criterion.

The actual required downlink attenuation for a 100 kHz signal is 65 dB for 0.01% and 68 dB for 0.005%.

The cumulative interference on the downlink depends strongly on the difference in orbit heights between the MSS satellites and the sensors. Some restrictions on orbital heights may be necessary.

On both up- and downlinks, most of the interference is received via antenna side-lobe coupling and the results are rather insensitive to sensors having different antenna gains.

Unwanted emission specifications should be based on power density levels into the antennas rather than e.i.r.p. density levels.

The interference scenarios possibly encountered in practice are many times higher than the few cases considered in all studies conducted. In order to cover cases with system assumptions different from the ones considered in this study, such as smaller MSS antennas, multiple channels per earth station, more than four MSS systems, etc., a margin of at least 2 dB should be included on top of the levels obtained for the 0.005%. Therefore, −63 dB(W/27 MHz) on the uplink and −46 dB(W/27 MHz) on the downlink are considered suitable values for defining unwanted emission limits for MSS feeder links.