International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R M.2221
(10/2011)

Feasibility of MSS operations in certain frequency bands

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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REPORT ITU-R M.2221

Feasibility of MSS operations in certain frequency bands

(2011)

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1 Introduction

Under WRC-12 Agenda item 1.25 and Resolution **231 (WRC-07)** studies are required to determine the feasibility of additional allocations to the mobile-satellite service (MSS) with particular focus on the bands between 4 GHz and 16 GHz.

During the consideration of WRC-12 Agenda item 1.25 in ITU-R, all bands in the range 4-16 GHz were assessed. A number of frequency bands were not considered appropriate for MSS allocations for obvious non-compatibility with incumbent services.

In addition, in the following frequency bands, detailed technical studies and information on the deployment of existing and planned services was presented within ITU-R which led to the conclusion that sharing is not feasible between the MSS and existing services. Consequently these bands are no longer under consideration for new MSS allocations.

Frequency band	MSS direction	Existing services
4 400-4 500 MHz	DL or UL	FS and MS
4 800-4 990 MHz	UL	FS, MS and radio astronomy
7 750-7 900 MHz[1]	UL	FS and METSAT
14.8-15.35 GHz	DL or UL	FS, MS and space research

DL: downlink.

UL: uplink.

This Report provides sharing studies in certain frequency bands: 5 150-5 250 MHz, 7 055-7 250 MHz, 8 400-8 500 MHz, 10.5-10.6 GHz, 13.25-13.4 GHz and 15.43-15.63 GHz.

The sharing studies in this Report relate to GSO MSS systems. Sharing with non-GSO MSS systems has not been studied.

Throughout this Report, references to the Radio Regulations reflect the situation as per the 2008 Edition of the Radio Regulations.

2 MSS satellite system characteristics

The MSS satellite system considered in this report is based on a constellation of geostationary satellites and the use of multiple spot beams to provide near-global coverage.

Four types of terminals are foreseen with diameters and maximum data rates as shown below.

Terminal	Diameter (m)	Maximum data rate (kbit/s)
Pocket-size	0.2	256
Notebook-size	0.3	512
Briefcase-size	0.4	1 024
Suitcase-size	0.5	2 048

[1] Studies for the band 7 850-7 900 MHz also considered the use of this band for MetSat, as is considered under WRC-12 Agenda item 1.24.

These characteristics are based on land mobile satellite applications. However, it may be assumed that similar characteristics would apply to maritime and aeronautical applications. Services are expected to be primarily data services (e.g. Internet connectivity).

The satellite is a geostationary, with a multi-spot beam payload. The coverage area of the satellite is divided into about 200 spot beams generated on demand.

The modulation is assumed to be M-PSK, with channel bandwidth of 1 MHz. Multiple access technique is assumed to be TDMA/FDMA.

Annex 1 contains example link budgets and gives more detail of the technical characteristics. These characteristics have been used in the analyses below. For the analysis of interference from other systems into the MSS system, the interference criterion used is that traditionally used as a coordination trigger, i.e. 6% of the noise ($I/N = -12.2$ dB). Depending on the circumstances, interference above this level may be acceptable. Some studies were also based on short-term criteria and it may be necessary to consider short-term criteria for proposed new MSS systems.

Many of the interference cases assessed in this Report involve interference from one ground based station to another (e.g. from an MES to a fixed radio-relay station). In such situations, a terrain data base has been used for example locations. The propagation model in Recommendation ITU-R P.452-13 is used together with a terrain data base. The terrain data used is the Shuttle Radar Topography Mission (SRTM) data which has a resolution of approximately 90 m and is freely available[2].

In the case of MSS downlink bands, where interference may be caused to an MES receiver from a terrestrial source (which could be an earth station or a terrestrial station), an MES may be able to operate successfully by selecting a channel which does not overlap with the interfering signal. For example by scanning all potential channels before establishing a call, one or more interference free channels may be identified. The MES could signal the available channels to the MSS channel assignment system during call establishment, and an interference free downlink channel could be assigned to the MES. This technique is already in use in some terrestrial mobile systems. At least one existing GSO MSS system has the capability of selective channel operation, also known as frequency-hopping. Naturally, it is desirable for MSS systems to operate in an environment with as little interference as possible, but the possibility of interference should not be seen as ruling out potential MSS operations.

In the case of MSS uplink bands, where an MES could cause interference to terrestrial stations or earth stations, the MES would have to comply with exclusion areas. The feasibility of MSS operation therefore depends on the necessary size, locations and number of the exclusion areas. Exclusion areas can be put into effect by using the geo-location facility which already exists in most MESs. This might consist of, for example, a GPS receiver in the MES so that its location can be determined and signalled to the MSS control facility. If the MES is located in an exclusion area, it could be prohibited from transmitting on the necessary frequencies. Alternatively, the exclusion could be applied to any MES within a particular satellite beam which overlaps with the excluded area. The latter approach may be simpler to implement but could lead to unnecessarily large exclusion areas. The former approach implies the establishment of a database to contain the exclusion area characteristics and definition. If the number of stations to be protected is very large and they are deployed in high densities, the exclusion area may have to be defined for a geographic area containing numerous stations (potentially the whole territory of a country). If the number of stations to be protected is relatively small, an exclusion area can be defined for each station individually. Hence the number of stations to be protected from MES emission is an important consideration of the feasibility of MSS operations.

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2 http://en.wikipedia.org/wiki/Shuttle_Radar_Topography_Mission.

Any necessary exclusion areas would be established between the MSS operator (and/or their administration) with the potentially effected administration. This would typically be done as part of the authorization process for operation of MESs.

In many cases, regulatory provisions for cross-border coordination would be required.

3 Analysis of certain frequency bands

The following bands are assessed in detail below:

- 5 150-5 250 MHz: Potential MSS downlink operations
- 7 055-7 250 MHz: Potential MSS downlink operations
- 8 400-8 500 MHz: Potential MSS uplink operations
- 10.5-10.6 GHz: Potential MSS downlink operations
- 13.25-13.4 GHz: Potential MSS downlink operations
- 15.43-15.63 GHz: Potential MSS uplink operations.

3.1 Frequency band 5 150-5 250 MHz

The allocation of this band in RR Article **5** is indicated below.

5 150-5 250	AERONAUTICAL RADIONAVIGATION FIXED-SATELLITE (Earth-to-space) 5.447A MOBILE except aeronautical mobile 5.446A 5.446B 5.446 5.446C 5.447 5.447B 5.447C

The band 5 150-5 250 MHz is considered as a potential MSS downlink band.

3.1.1 Sharing with the aeronautical radionavigation service

No characteristics of aeronautical radionavigation systems currently in operation have been identified. Aeronautical radionavigation service (ARNS) systems for use on unmanned aircraft systems have been proposed, but no sharing studies have been conducted.

3.1.2 Sharing with the FSS

3.1.2.1 Interference from MSS downlinks to FSS satellites

The band 5 091-5 250 MHz is allocated to the FSS (Earth-to-space), limited to feeder links of non-geostationary satellite systems in the MSS (see RR No. 5.444A and No. 5.457A). Interference may be caused to non-GSO FSS satellite receivers from MSS downlinks. To assess the interference potential, the parameters shown in Table 3.1-1 have been used for the feeder links of the non-GSO MSS system, based on the low Earth orbit (LEO) D system characteristics in Recommendation ITU-R S.1328. There are also characteristics in Report ITU-R M.2118.

For the FSS satellite antenna the pattern shown in Fig. 3.1-1 is used, which is taken from the ITU filing for the HIBLEO-4FL coordination request. Note that the peak antenna gain assumed is 7 dBi, which is higher than the 2 dBi indicated for LEO D in Recommendation ITU-R S.1328.

TABLE 3.1-1

LEO D/HIBLEO 4 satellite characteristics

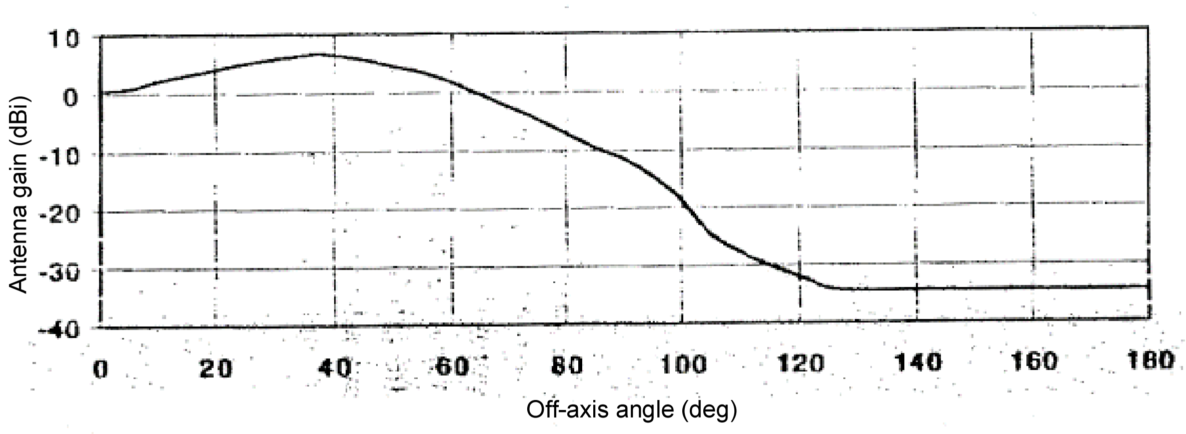
Shape of orbit	Circular
Height (km)	1 414
Inclination angle (degrees)	52
Number of satellites per plane	6
Number of orbital planes	8
Satellite separation (degrees) within plane	60
Satellite phasing between planes (degrees)	7.5
Uplink frequency (GHz)	5.091-5.250
Uplink polarization	LHCP/RHCP
Downlink frequency (GHz)	6.875-7.055
Downlink polarization	LHCP/RHCP
Receiver noise temperature (K) (from ITU coordination request)	1 100

LHCP: left-hand circular polarization.

RHCP: right-hand circular polarization.

FIGURE 3.1-1

Satellite antenna pattern for HIBLEO-4



Interference may be caused from GSO MSS downlinks to non-GSO FSS receivers. It is necessary to determine a representative MSS system configuration and this is shown in Fig. 3.1-3. The scenario is based on three geostationary MSS satellites providing near-global coverage.

Each satellite is capable of producing approximately 200 spot beams and it is assumed that a four-colour reuse scheme is used. Each beam has an e.i.r.p. of 46 dBW/MHz and a peak antenna gain of 44 dBi. The satellite antenna gain pattern is described in Annex 1. Figure 3.1-2 shows the active beams, consisting of one in four of the beams required for full coverage. Note that each of the active beams is assumed to operate 100% time and maximum power. This is very conservative for the following reasons:

– in reality it is likely that downlink power control would be used;

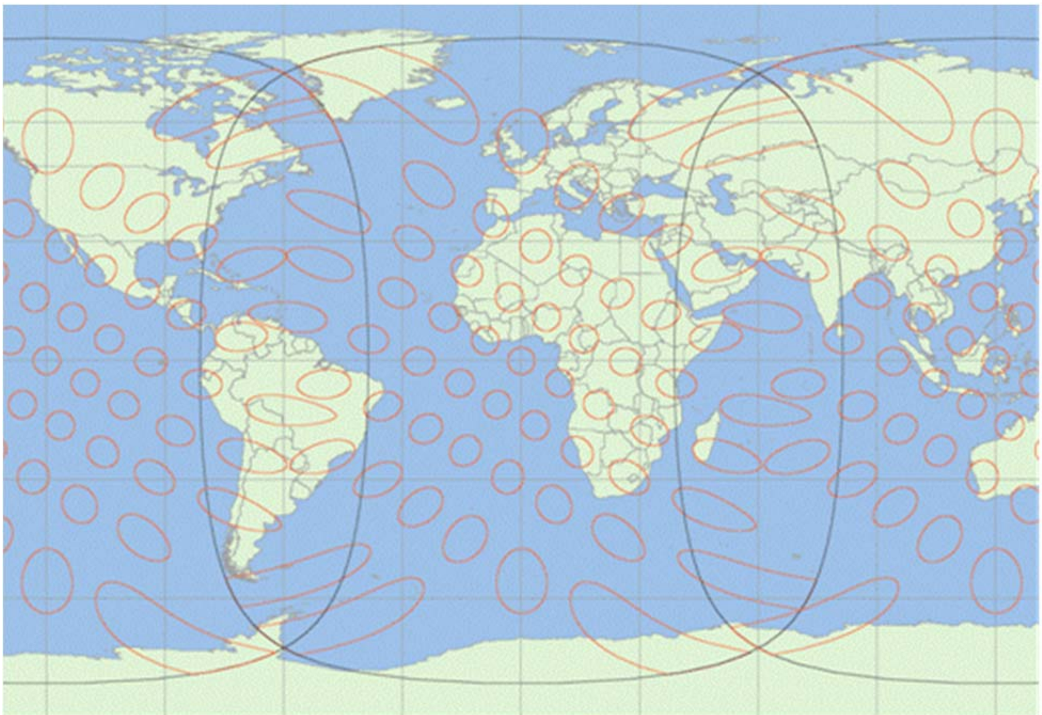
– since traffic exists in hotspots and the hotspots vary with the local time of day, it is not realistic to expect that all spot beams will be used simultaneously, especially for long periods of time;

– traffic is typically quite bursty, rather than constant as is effectively assumed.

These mitigating factors have not been taken into account in the study.

FIGURE 3.1-2

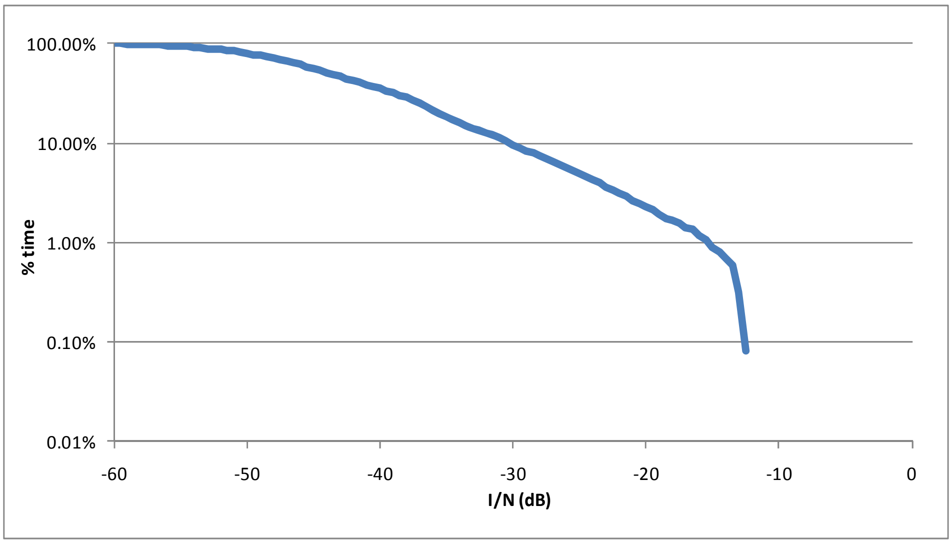
GSO MSS active downlink beams



A simulation was performed using the characteristics in Table 3.1-1 for the non-GSO FSS system. The aggregate interference from each of the MSS spot beams to a single non GSO FSS satellite is determined. The results are shown in Fig. 3.1-3.

FIGURE 3.1-3

Cdf of *I*/*N* for interference to a non-GSO FSS satellite receiver



The mean interference *I*/*N* value is −44 dB and the peak value is −12.5 dB, which may be considered acceptable.

3.1.2.2 Interference from non-GSO FSS feeder link earth stations to MESs

The band 5 150-5 250 MHz is allocated to the FSS for the feeder links (Earth-to-space) of non-GSO MSS systems. MESs operated in the vicinity of non-GSO FSS earth stations may receive interference and this interference issue is considered here.

The "pocket" MES characteristics (which is the worst case of the example MES types in this scenario) are considered with the characteristics in Table 3.1-2.

TABLE 3.1-2

Receiving MES characteristics for the band 5 150-5 250 MHz

MES antenna gain (dBi)	22.2
MES antenna pattern	Rec. ITU-R F.699
Antenna elevation angle (degrees)	25
Antenna azimuth angle (degrees)	180
Antenna height a.g.l. (m)	1
MES noise temperature (K)	400
Interference criterion (I/N) (dB)	*−12.2*

The MES elevation angle of 25° is a value that might be considered as typical in an operational scenario. Lower values would lead to an increase in the size of the interference areas. Characteristics of the LEO D/HIBLEO 4 earth stations are contained in Recommendation ITU-R S.1328 and the characteristics used in the analysis are given in Table 3.1-3. The parameters in italics are assumptions for the purpose of this study.

TABLE 3.1-3

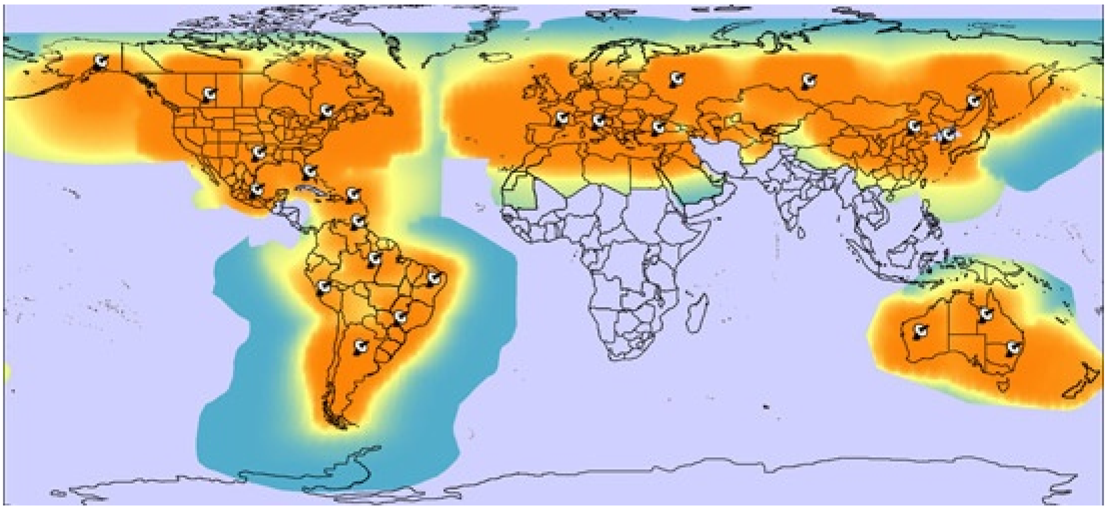
LEO D/HIBLEO 4 feeder-link earth station characteristics

Uplink e.i.r.p./carrier (dBW)	54
Earth station antenna gain (Tx) (dBi)	47.5
Tx power (dBW)	6.5
Antenna radiation pattern	Rec. ITU-R S.465
Minimum elevation angle (degrees)	10
Carrier bandwidth (kHz)	1 230
Antenna height a.g.l. (m)	*5*

For the HIBLEO 4 system, there are 24 feeder-link earth stations located throughout the world, as shown in Fig. 3.1-4[3].

FIGURE 3.1-4

HIBLEO 4 feeder-link earth station (gateway) locations

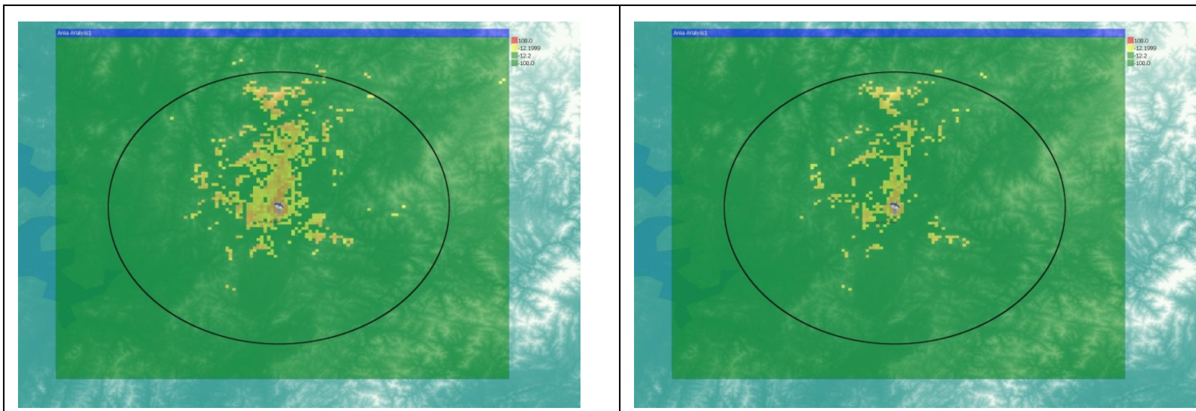


From the earth station antenna pattern and the minimum elevation angle, the horizon antenna gain of the feeder link earth station varies from 7 dBi (10° off-axis angle) to −10 dBi (> 48° off-axis angle). As an example, the feeder-link earth station located in Yeo Ju, South Korea is used. The two plots in Fig. 3.1-5 show the areas where the interference criterion for the MES is exceeded, indicated by the yellow and orange shading. Both plots use the Recommendation ITU-R P.452 propagation model with $p = 20\%$, which is appropriate for the long-term interference criterion used. In the first case (a), the horizon antenna gain is 7 dBi and in second case (b), the horizon antenna gain is −10 dBi. The black circle is radius 50 km.

[3] Source: http://www.globalstar.com/en/satellite/.

FIGURE 3.1-5

Interference from HIBLEO-4 feeder-link earth station into "pocket" MES



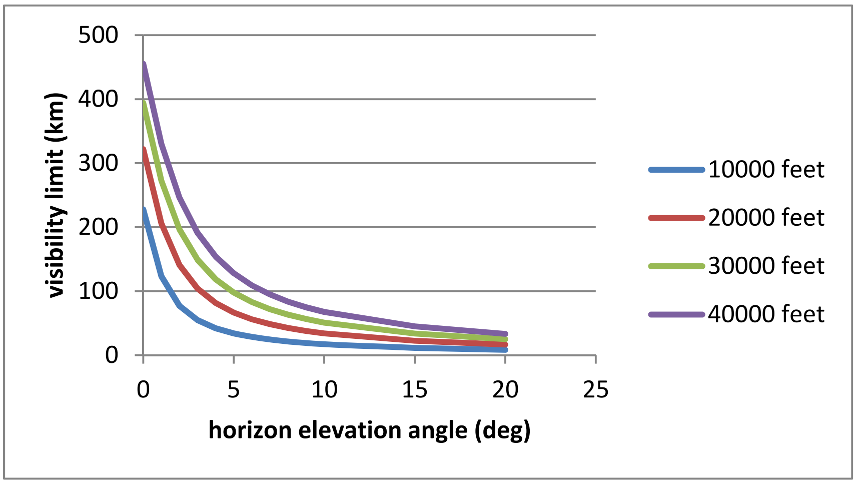
(a) horizon antenna gain = 7 dBi | (b) horizon antenna gain = −10 dBi

The locations for which the MES would receive interference above the criterion extend up to about 50 km from the gateway earth station. However in both cases, the majority of the region within the 50 km circle is green, indicating that the interference is below the criterion for most locations. The MES may be able to operate successfully within a few km of the earth station. These results are conservative in that no clutter losses from buildings, trees, etc. is included, which would reduce the interference caused to the MES and would therefore increase the likelihood of successful operation close to the feeder link earth station.

In the case of aircraft earth stations (AESs), it is apparent that there would be a large interference zone around the feeder link earth station since no terrain benefit will exist. The interference zones are probably defined by the visibility limit which is defined by the horizon elevation angle at the feeder-link earth station and the height of the aircraft. The visibility limit (km), shown in Fig. 3.1-6 is the ground separation distance at which the aircraft is just on the horizon (assuming 4/3 earth radius, to account for refraction effects). For example for an aircraft at 40 000 feet altitude, the separation with respect to a feeder link earth station with 5° horizon elevation angle is 128 km.

FIGURE 3.1-6

Aircraft visibility limits



In the case of the Yeo Ju feeder link station, the horizon elevation angle as a function of azimuth is given in the ITU notification. The horizon elevation angle varies within the range 0.1° to 5°.

3.1.3 Sharing with the mobile service

3.1.3.1 Interference from MSS downlinks to RLAN systems

Recommendation ITU-R M.1828 also includes protection guidelines for protection of the mobile service in the band 5 150-5 250 MHz from aircraft emissions used in an aeronautical telemetry system. The recommended limit is −79.4 dB(W/(m^2 · 20 MHz)) − $G_r(\theta)$ where θ is the elevation angle of the mobile service receiver antenna. The maximum antenna gain is given as 0 dBi for elevation angles between 0° and 35°. The pfd limit is equivalent to −92.4 dB(W/m^2) in a bandwidth of 1 MHz, well above the maximum expected pfd of −116 dB(W/m^2 · MHz).

Recommendation ITU-R M.1739 also contains protection criteria for radio local area networks (RLANs) in the band 5 150-5 250 MHz. Using the characteristics given in this Recommendation, the maximum pfd from MSS downlink can be determined, as shown in Table 3.1-4.

TABLE 3.1-4

Interference MSS downlink to RLAN receiver

Ae iso (dBm^2)	−35.7
Reference bandwidth (MHz)	1
Noise figure (dB)	5
Receiver noise (dBW)	−139.0
I/N criterion (dB)	−6
Margin for aggregate interference (dB)	3
I_{max} (dBW)	−148.0
Rx antenna gain (dBi)	0
Max permissible pfd (dB(W/m^2))	−112.3

The downlink pfd expected from MSS systems in this band is about −116 dBW/m^2 in 1 MHz, less than the maximum permissible pfd determined above. Further losses from buildings (RLANs are limited to indoor use) and polarization benefits would increase the margin.

These results suggest that MSS downlinks would not cause excessive interference to mobile service receivers.

3.1.3.2 Interference from RLAN systems to MES receivers

It is also necessary to consider interference from mobile stations to MES receivers. The band 5 150-5 250 MHz is used by RLANs which operate as part of the mobile service. Characteristics are contained in Recommendation ITU-R M.1454. For this band, RLAN devices are limited to indoor operation only. The power limits vary from one Region to another but the worst case seems to be for Europe and Canada, where the power limits are: 200 mW e.i.r.p. and 10 dBm/MHz e.i.r.p. An important assumption is the indoor-outdoor wall loss. Recommendation ITU-R P.1411 contains figures for “building entry loss” at 5.2 GHz. Measurements taken of losses for an office building are given as 12 dB mean, with a standard deviation of 5 dB. Measurements of loss due to a stone block wall for incident angles between 0° and 75°. The losses range from 28 dB (with a standard deviation of 4 dB) to 50 dB (with a standard deviation of 5 dB). The MES antenna gain in the direction of the RLAN transmitter is taken as 10.9 dBi, which is the gain 25° off-axis for the “pocket” MES (with a peak gain of 20 dBi, and assuming the Recommendation ITU-R F.699

antenna pattern) Table 3.1-5 shows the required separation between an RLAN device and an MES with mean building loss figures of 12 dB, 28 dB and 50 dB. The separation distances are calculated using a propagation model for urban, suburban and rural environments described in Annex 2.

TABLE 3.1-5

Interference from RLAN transmitter to MES receiver

	Case 1	**Case 2**	**Case 3**
RLAN e.i.r.p. (dBm/MHz)	10		
RLAN e.i.r.p. (dBW/MHz)	−20		
MES antenna gain (dBi)	10.9		
MES temp (K)	400		
Noise in 1 MHz (dBW)	−142.6		
I/N criterion (dB)	−12.2		
I_{max} (dBW)	−154.8		
Polarization isolation (dB)	3		
Building entry loss (dB)	12	28	50
Minimum coupling loss (dB)	**131**	**115**	**93**
Separation distance (urban) (m)	900	380	110
Separation distance (suburban) (m)	1 750	650	160
Separation distance (rural) (m)	3 800	1 250	190

These results suggests that MSS operations could be subject to excessive interference in areas where RLANs are most likely to operate, most likely to be urban areas.

3.1.3.3 Interference from MSS downlinks to broadband disaster relief systems

In some CEPT countries, part of the band 5 150-5 250 MHz is available for broadband disaster relief systems (BBDR). Applications are used temporarily by emergency services in all aspects of disaster situations, including disaster prevention and post-event scenarios. For instance, they provide incident communications, video or robotic data applications, telecommand and telemetry parameters, critical data base queries, field reporting, data and location information exchange.

Table 3.1-6 gives the system characteristics[4].

[4] Source: ECC Report 110 (see http://www.erodocdb.dk/doks/doccategoryECC.aspx?doccatid=4).

TABLE 3.1-6

BBDR system characteristics

Receiver characteristics	Value for BS	Value for UE	Remark
Receiver bandwidth (MHz)	10	10	Single frequency band for the whole mesh
Receiver sensitivity (dBm)	−82 (−88 to −69)	−82 (−88 to −69)	Corresponding bit rate of 3-27 Mbit/s
Receiver sensitivity at antenna input (dBm/MHz)	−101 (−107 to −88)	−85 (−91 to −72)	Ignoring the cable loss
C/*I* (dB)	6	6	
Allowable interfering power at receiver antenna input (dBm/MHz)	−107	−91	
Transmitter characteristics			
Bandwidth (MHz)	10	10	
Transmitter e.i.r.p. (dBm)	36	23	(See Note)
Assumed value for TPC (dB)	0	6	
Antenna gain (dBi)	9	0	
Body loss (dB)	0	6	
Antenna loss due to portable usage (dB)	0	1	

NOTE − e.i.r.p. level specified is for a 10 MHz channel.

For other possible channel bandwidths (between 1.25 and 20 MHz), the maximum e.i.r.p. is derived from the power spectral density of 26 dBm/MHz for BS and 13 dBm/MHz for UE.

Using the above parameter values, Table 3.1-7 assesses the interference from the MSS downlink to the BBDR base station and user equipment.

TABLE 3.1-7

Maximum MSS pfd to BBDR receiver

BBDR	Base station	User equipment
Ae iso (dBm^2)	−35.7	−35.7
Allowable interference power (dBm/MHz)	−107	−91
Max Rx antenna gain (dBi)	9	2
Margin for aggregate interference (dB)	3	3
Max permissible pfd (dB(W/m^2 · MHz))	−113.3	−90.3

The maximum MSS pfd is anticipated is approximately −116 dBW/m^2 in 1 MHz, lower than the maximum permissible values.

3.1.3.4 Interference from broadband disaster relief systems to MES receivers

Table 3.1-8 assesses the separation distance from a BBDR transmitter to an MES receiver using the same propagation model as used in the similar case for RLANs above.

TABLE 3.1-8

Interference from BBDR transmitter to MES receiver

BBDR	**Base station**	**User equipment**
Bandwidth (MHz)	10.0	10
Transmitter e.i.r.p. (dBm)	36	23
Assumed value for TPC (dBm)	0	6
Transmitter e.i.r.p. after TPC (dBW/MHz)	−4.0	−23.0
MES antenna gain (dBi)	10.9	10.9
MES temp (K)	400	400
Noise in 1 MHz (dBW)	−142.6	−142.6
I/*N* criterion (dB)	−12.2	−12.2
I_{max} (dBW)	−154.8	−154.8
Pol isolation (dB)	3	3
Minimum coupling loss (dB)	147.8	128.8
Separation distance (urban) (km)	2.3	0.8
Separation distance (suburban) (km)	4.9	1.6
Separation distance (rural) (km)	12.6	3.3

The resulting separation distances are between 0.8 km and 12.6 km. Therefore, MESs operating in the vicinity of a BBDR network would have to accept interference.

3.1.4 Interference from MSS downlinks to aeronautical telemetry systems

Through RR No. 5.447C, the band 5 150-5 250 MHz is available in some countries for aeronautical mobile telemetry (AMT) applications. The protection criterion for the aeronautical telemetry ground station is derived assuming the aircraft is at its maximum separation distance of 300 km. AMT characteristics and a corresponding link budget for a particular system used in one administration are set forth in Table 3.1-9 below. Table 3.1-10 uses these characteristics to quantify the protection shortfall to the AMT system referenced in Table 3.1-9. More general characteristics applicable to AMT systems used in other administrations are set forth in the text immediately following Table 3.1-10.

TABLE 3.1-9

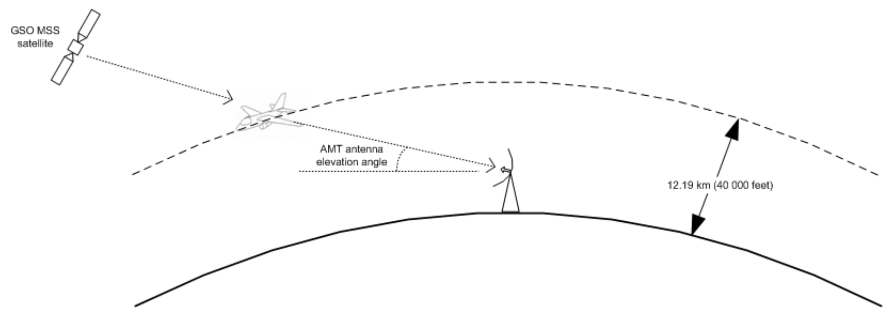
AMT characteristics for one Region 2 administration in 5 091-5 250 MHz, including the sub-band 5 150-5 250 MHz

Type of parameter	
Modulation type	PCM/FM
Transmitter output level (dBm)	46
Transmitter aircraft antenna gain: omni (dBi)	0
Cable/guide and diplexer insertion losses (dB)	3
Transmitted e.i.r.p /10 MHz (dBm)	43
Propagation losses at LoS horizon range (dB)	156.22 @ 300 km
Receiving ground station antenna gain (dBi)	40
Polarization losses (dB)	3
Receiver carrier level, *C*, in 10 MHz (dBm)	−76.22
Receiver bandwidth (MHz)	10
Receiver noise level (dBm)	−99.72
Achieved *C*/*N* (dB)	23.5
Required fade margin (dB)	13
S/*N* ratio requirement (SNR) (dB)	10
Margin (dB)	0.5 dB
Permissible *I*/*N* for 0.5 dB margin (dB)	−9.2
Permissible interference power at receiver input (dBm)	−108.9
Permissible pfd due to interference at AMT receive antenna ((dBW/m^2) in 4 kHz)	−177

As shown in Fig. 3.1-7, interference may be received by the aeronautical telemetry receiving station as it tracks the aircraft.

FIGURE 3.1-7

Interference from MSS downlink to aeronautical telemetry receiver



3.1.4.1 Co-frequency sharing between MSS and AMT

Table 3.1-10 shows the interference for three example elevation angles of the aeronautical telemetry ground station (0°, 30° and 90°). In each case, the aircraft is assumed to be at its maximum separation distance, assuming a maximum altitude of 40 000 feet and the MSS satellite is assumed to be aligned with the aeronautical telemetry receiver.

TABLE 3.1-10

Interference from MSS downlink to aeronautical telemetry receiver for the example link budget given in Table 3.1-9

TABLE 3.1-10a

MSS characteristics

Elevation angle to satellite (degrees)	**0**	**30**	**90**
MSS downlink e.i.r.p. (dBW/MHz)	45.4	45.4	45.4
MSS downlink e.i.r.p. (dBW/10 MHz)	55.4	55.4	55.4
Distance to satellite (km)	41 679	38 612	35 786
Free space loss (dB)	199.1	198.4	197.8
MSS pfd at AMT ground station ((dBW/m^2) in 4 kHz)	–142	−141.3	−140.6
Permissible interference (per Recommendation ITU-R M.1459, but reduced at 0 degree elevation by 2 dB)* ((dBW/m^2) in 4 kHz)	−178*	−162	−162
Additional MSS attenuation required to protect AMT per Recommendation ITU-R M.1459 (dB)	36	20.7	21.4

* It should be noted that, when AMT facilities operate in a higher frequency band, the beamwidth and antenna gain typically remain the same. This yields an inverse relationship between the pfd protection values set forth in Rec. ITU-R M.1459 and the wavelength of the interfering signal. The Rec. ITU-R M.1459 levels should be scaled accordingly. This scaling is most important at low elevation angles due to the long distance to the flight test aircraft, and is reflected by the 2 dB reduction noted in the table above. (For other elevation angles in the table, the pfd protection levels given in Recommendation ITU-R M.1459 for the band 2 310-2 360 MHz are used in the table.)

TABLE 3.1-10b

AMT system characteristics

Aircraft cable/guide and diplexer insertion losses (dB)	3	3	3
Transmitter's output 12 W on-board a/c, 2 dB on-board losses (dBW)	16	16	16
Transmit aircraft antenna gain: omni (dBi)	0	0	0
Transmitted e.i.r.p./10 MHz (dBW)	13	13	13
Aircraft distance (km)	300	21.1	12.2
Propagation losses (LoS) (dB)	156.2	133.2	128.4
Receiving ground station antenna gain (dBi)	40	40	40
Polarization losses (dB)	3	3	3
Ground station cable/guide and diplexer insertion losses (dB)	0	0	0
Received carrier level, C, in 10 MHz (dBW)	−106.2	−83.2	−78.4
Receiver bandwidth (MHz)	10	10	10
Receiver noise level (dBW)	−129.7	−129.7	−129.7
Additional fade margin* (dB)	13	13	13
Achieved S/N (dB)	10.5	33.5	38.3
$S/(I+N)$ ratio requirement* (dB)	10	10	10
Margin (dB)	0.5	23.5	28.3

* Other systems may use different modulations and have different SNR requirements.

TABLE 3.1-10c

Link budget analysis

Permissible $N + I_{Agg}$ ($N + I = C - S/N$) with S/N 10 dB (dBW)	−129.2	−106.2	−101.4
Permissible aggregate interference at receiver input (dBW/10 MHz)	−138.9	−115.3	−110.5
Inter-service factor apportionment (dB)	6	6	6
I_{max} (dBW/10 MHz)	−144.9	−112.2	−107.4
I (boresight, no pol loss, assuming the above "Permissible interference" pfd value is just met) (dBW/10 MHz)	−139.7	−123.7	−123.7
Margin between maximum permissible interference and interference assuming the permissible pfd value is met for this example (= $I_{max} - I$ boresight...) (dB)	−5.15	11.5	16.3
MSS pfd at ground, per Table 3.1-9, assuming no constraints on MSS (dBW/m^2) in 4 kHz	−142	−141.3	−140.6
MSS pfd at ground, in 10 MHz (dBW/m^2) in 10 MHz	−108	−107.3	−106.6
Effective area of AMT 40 dBi ground station antenna at 5 200 MHz (m^2)	2.68	2.68	2.68
Actual MSS received power (assuming no constraints on MSS) (dBW/10 MHz)	−104	−103.3	−102.6
Shortfall between permitted and achieved MSS interference power (= actual MSS received power − I_{max}) (dB)	40.9	8.9	4.8

For cases involving more general characteristics applicable to AMT systems used in other administrations, the following parameters are suggested. A single composite result based on 19 dB of additional margin for the low elevation case is used, to account for:

– additional SNR required for AMT receivers that use high spectral efficiency modulation: 3-5 dB;

– additional fade margin to account for signal blockage by aircraft structures, the angular dependence of aircraft telemetry antenna gain during manoeuvres, ground multipath, etc.: 10-20 dB.

In the first case, where the aeronautical telemetry antenna is at 0° elevation, interference is 36 dB above the Recommendation ITU-R M.1459 criterion assuming, as in Table 3.1-10, that the MSS space station operates at its maximum e.i.r.p. toward the horizon. For the specific example based on the parameters given in Table 3.1-9, the pfd exceedence is 40.9 dB, a result specific to this example and may not apply to other systems.

The pfd exceedences might be acceptable if it can be assured that the aeronautical telemetry antenna does not point towards the MSS satellite. However, due to flight test airspace limitations, air traffic control constraints, and weather factors, this can represent a significant constraint on flight test operations.

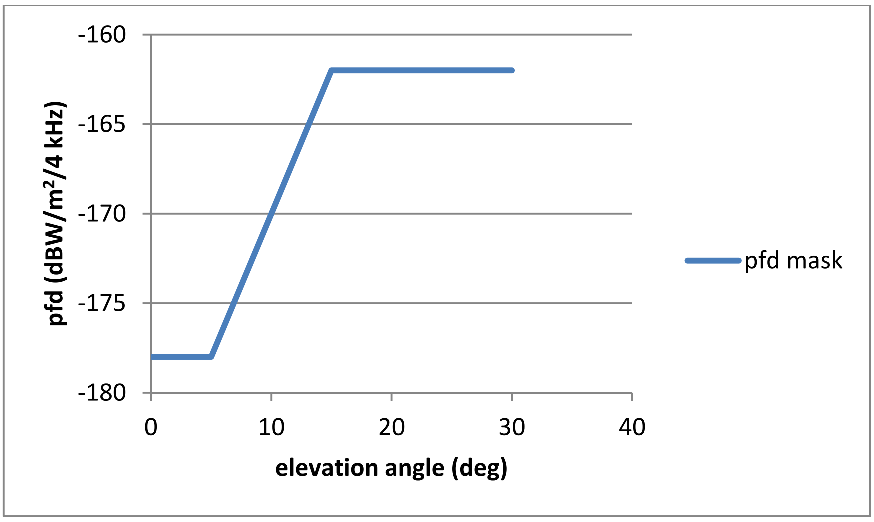
For elevation angles above about 30°, the aircraft is much closer to the ground station which leads to a higher carrier level at the receiver, and hence less additional attenuation of the MSS signal is required compared to the situation for lower MSS signal arrival angle. Without this additional attenuation, the link will be lost if the AMT ground station antenna should point in the direction of an MSS satellite, as would likely be the case. If the MSS satellite were to meet the above pfd values, the AMT protection criterion would be met with a margin of between 11.5 and 16.3 dB.

However, as noted, in Table 3.1-10, MSS signal attenuation of about 20 dB would be required to meet the applicable pfd values.

The requirements of Recommendation ITU-R M.1459 are captured in the following mask of MSS pfd at the aperture of an AMT ground station antenna, as a function of the elevation angle to the MSS satellite. This mask, shown in Fig. 3.1-8, provides protection of AMT for the entire band 5 091-5 250 MHz.

FIGURE 3.1-8

Example pfd mask for protection of aeronautical telemetry stations as a function of the elevation angle to the MSS satellite



3.1.4.2 Adjacent band compatibility between MSS and AMT

In addition to the in-band interference considered above, in regions where administrations use the adjacent band, 5 091-5 150 MHz, the effects of out-of-band (OoB) interference to AMT systems operating must also be considered. Permitted out-of-band emissions (OoBE) from satellites are such that, when an adjacent band system uses high gain antennas to receive weak signals, as is the case for AMT, the likelihood of interference from satellites is high.

OoBE are addressed in Recommendation ITU-R SM.1541-3, "Unwanted emissions in the out-of-band domain". Section 3 of Annex 5 of the Recommendation is titled "OoB masks for mobile-satellite service (MSS) earth and space stations," and states:

> Attenuation of OoB emissions in the reference bandwidth of 4 kHz for MSS systems below 15 GHz … is
>
> $$40 \log\left(\frac{F}{50}+1\right) \text{dBsd (i.e. dB spectral density)}$$
>
> "Where *F* is the frequency offset from the edge of the total assigned band, expressed as a percentage of necessary bandwidth. It is noted that the OoB domain starts at the edges of the total assigned bandwidth."

Because of the logarithmic term in the above equation, OoBE from the MSS satellite would fall extremely slowly with respect to frequency offset *F*. Hence, this ITU-R Recommendation provides very little protection to AMT. Assuming a mid-range value of 36 MHz for transponder bandwidth on a geostationary MSS satellite, the attenuation as a function of frequency into the band 5 091-5 150 MHz is given in Table 3.1-11 below. Note that the out of band roll-off does very little to provide the attenuation required to meet the protection levels specified in Recommendation

ITU-R M.1459. For elevation angles lower than 30 degrees, OoBE roll-off would produce interfering signals to AMT throughout the entire band. Even for elevation angles of 30 degrees or greater, MSS interference would be experienced down to 5 110 MHz, i.e. −40 MHz of the 59 MHz allocation.

TABLE 3.1-11

Attenuation of MSS emissions into the AMT band 5 091-5 150 MHz for a necessary bandwidth of 36 MHz

Frequency (MHz)	5 100	5 110	5 120	5 130	5 140	5 150
OoBE attenuation	23.9 dB	20.3 dB	17.0 dB	13.0 dB	7.7 dB	0 dB
Protection shortfall for low elevation angle	12.1 dB	15.7 dB	19 dB	23.0 dB	28.3 dB	36 dB

To meet the AMT protection requirements for low elevation angles, the MSS pfd would need to be attenuated by 36 dB, as shown in Table 3.1-10A. Consequently, to meet the requirements for protection of AMT systems operating on frequencies adjacent to 5 150-5 250 MHz, the MSS emissions would have to be attenuated by 36 dBc. Administrations are of different views concerning the feasiblity and practicality of meeting this requirement through the use of new technology.

Recommendation ITU-R M.1459 references various mitigation techniques to reduce interference. For example, AMT ground station site diversity might possibly be used by an administration to avoid or minimize pointing of the AMT ground station antenna towards the satellite. However, for some administrations, and some test ranges, this and other mitigation techniques entail impractical or unrealistic constraints on AMT. Receive site diversity, for example, results in unacceptable "keep-out" zones within test ranges. As additional MSS satellites are placed into orbit within view of AMT ground stations, the aggregate effect of multiple satellites with different designs introduces an escalating complexity to any such zones.

This difficulty is compounded by the fact that the air space typically in use at ranges is already constrained by air traffic patterns, civil aviation authorities, and weather conditions. In addition, safety considerations, e.g. not flying over populated areas or in commercial airspace, preclude flying only in certain directions to avoid AMT-MSS conjunction.

Other mitigation techniques, such as the use of post-processing to recover lost data, are already in use. Error correction is used in the coding of digital flight test data prior to transmission, and in any event, the performance advantage derived from such techniques is minimal (~5 dB), especially compared to the magnitude of the interference deficit discussed previously.

3.1.4.3 Summary regarding sharing between MSS and AMT

Range safety is critical for flight testing and may not be compromised by impractical sharing methods. In conclusion, unless an administration is prepared to accept less protection for its AMT than specified in Recommendation ITU-R M.1459, or mitigation measures for that administration are deemed acceptable, co-channel operation of MSS systems in 5 150-5 250 MHz can cause harmful interference to, and represent a significant constraint upon, AMT in 5 150-5 250 MHz. The above pfd mask (derived from Recommendation ITU-R M.1459, and exemplified in Fig. 3.1-8) would adequately protect AMT systems, but its attainment would entail significant limitations on any MSS use of the band.

With regard to adjacent band compatibility, operation of MSS systems in 5 150-5 250 MHz can likewise cause harmful interference to, and represent a significant constraint upon, AMT in 5 091-5 150 MHz.

Regulatory provisions would be required with any new MSS downlink allocation to ensure adequate protection of AMT systems in both the co-frequency range 5 150-5 250 MHz and the adjacent frequency range 5 091-5 150 MHz in accordance with the pfd levels contained in Recommendation ITU-R M.1459.

3.1.5 Sharing with the radiodetermination-satellite service

The band 5 150-5 216 MHz is allocated to the radiodetermination-satellite service (RDSS) (space-to-Earth) through RR No. 5.446. No characteristics of RDSS systems currently or planned to be in operation have been identified.

3.2 Frequency band 7 055-7 250 MHz

The range 7 055-7 250 MHz and parts of this range have been considered for MSS downlinks. This band is allocated to the FS and MS on a primary basis. The sub-band 7 055-7 075 MHz is allocated to the FSS (Earth-to-space) and (space-to-Earth). The band 7 145-7 235 is allocated to the SRS for Earth-to-space links. The bands 7 100-7 155 MHz and 7 190-7 235 MHz are allocated to the SOS (Earth-to-space) in one country through RR No. 5.459. The band 7 055-7 250 MHz may be used by passive sensors under the conditions given in RR No. 5.458.

The band 7 055-7 250 MHz is heavily used for the deployment of FS, including broadcasting auxiliary services (BAS) applications in many administrations. In at least one administration, the band 7 125-7 250 MHz for the FS is used for point-to-point microwave links that carry data for en-route and terminal surveillance radars, voice communications, and other application that are used for air traffic control. These links are critical for maintaining separation of aircraft during all phases of flight and under all weather conditions.

3.2.1 Fixed service, fixed wireless systems

The band 7 055-7 250 MHz is used for various types of fixed wireless systems (FWS).

In the case of new MSS allocations, restrictions will have to be applied to pointing of the FS links towards the GSO. Studies identified a gain reduction of 40 dB for the FS antenna in order to be compatible. Pfd limits or thresholds would be required to reduce interference to FS receivers. The existing pfd mask contained in RR Article 21, applicable to the band 6 825-7 075 MHz, is -134 dBW/m^2 · MHz (angles below 5°), rising to -124 dBW/m^2 · MHz (for angles above 25°). An alternative pfd mask is between -140 dBW/m^2 · MHz (angles below 5°) rising to -115 dBW/m^2 · MHz for angles above 20°. Either option will still require some FS off-pointing from the GSO. For the elevation angle of 0°, the interference from the MSS satellite which must meet the pfd mask of -140 dBW/m^2 · MHz will require an additional signal reduction of 13 dB. For the mask starting at -134 dBW/m^2 · MHz, the additional required signal reduction will be 19 dB. This number will increase as a function of the elevation angle up to 40 dB, requiring off-pointing of the FS station between ±1° and ±15°. This will be a significant constraint for countries at higher latitudes. Another study also showed that some systems used to support air traffic control equipment may need off-pointing angles significantly exceeding the above range of angles, depending on the pfd mask applied. This will be a severe and safety related constraint.

In the case of mandatory pfd masks, MSS operations would be restricted to areas where the elevation angle of the MES towards the MSS satellite is above approximately 20°, which would reduce the MSS service area by more than 30% when compared to an area with a minimum elevation angle of 5°. This may be a severe constraint for MSS operations and, moreover, may represent an inefficient use of orbit/spectrum resources.

Interference could be caused by FWS transmitters to MESs. The separation distance between FWS transmitter and MES is highly dependent on the terrain around the FWS station. Using some assumptions (including non-worst-case alignment of antennas, no clutter loss), separation distances are in the range of about 5 km to 30 km. In cases where the FWS and the MES antenna are pointing towards each other, the separation distances calculated in accordance with Recommendation ITU-R P.452 will exceed 100 km. MESs may be able to coexist with such interference if designed with mitigation features as described above.

3.2.2 Broadcasting auxiliary services

The band 7 055-7 250 MHz is used by BAS, which operate as part of the FS or MS. Widespread use has been identified in some countries. Characteristics are contained in Recommendations ITU-R F.1777 and ITU-R M.1824.

Studies have shown that acceptable interference from MSS satellites into BAS would require an off-pointing angle of the BAS up to ±15° in some cases, in other cases probably more. This may be considered as an undesirable constraint for fixed BAS operations and would generally not be feasible for a mobile BAS. Pfd limits or thresholds would be required to reduce interference to BAS receivers. One potential mask proposed is −158 dBW/m^2 · MHz (angles below 3°), rising to −124 dBW/m^2 · MHz (for angles above 25°). An alternative pfd mask is between −140 dBW/m^2 · MHz (angles below 5°) rising to −115 dBW/m^2 · MHz for angles above 20°. Considering the difference between the two values, the pfd mask of −140 dBW/m^2 · MHz (angles below 5°) rising to −115 dBW/m^2 · MHz for angles above 20° causes interference levels of 18 dB above recognized protection criteria with a large parabolic antenna with tilt angles up to 3 degrees. Either option will require some BAS off-pointing from the GSO.

In the case of mandatory pfd masks, MSS operations would be restricted to areas where the elevation angle of the MES towards the MSS satellite is above approximately 20°, which would reduce the MSS service area by more than 30% when compared to an area with a minimum elevation angle of 5°. This may be a severe constraint for MSS operations and, moreover, may represent an inefficient use of orbit/spectrum resources.

Interference could be caused by BAS transmitters to MESs. The separation distance between BAS transmitter and MES is highly dependent on the terrain around the FS station. Using some assumptions (including non-worst-case alignment of antennas, no clutter loss), separation distances are in the range of a few km to about 40 km in the worst case. In cases where the BAS and the MES antenna are pointing towards each other, the separation distances calculated in accordance with Recommendation ITU-R P.452 will exceed 100 km. MESs may be able to coexist with such interference if designed with mitigation features as described above. This would only work for narrow-band BAS links as no interference-free channels will be available in case of broadband BAS signals.

3.2.3 Mobile service (excluding BAS)

The band 7 055-7 250 MHz is currently allocated on a primary basis to the MS. However, characteristics of mobile applications other than BAS to enable sharing studies with MSS downlinks are not available.

3.2.4 Fixed-satellite service

The band 7 055-7 075 MHz is used by GSO FSS systems for uplinks. There are currently six systems notified in the band 7 025-7 075 MHz. Interference could be caused by MSS satellites to FSS satellites for orbital separation of less than about 0.3 degree. In the case that the GSO MSS satellite is in a near antipodal position with respect to the FSS satellite (at almost opposite locations in the geostationary arc, but just visible to one another), the MSS satellite would have to limit its e.i.r.p. in the direction of the FSS satellite. MSS satellite antenna discrimination of about 12 dB would be required, which would mean that MSS spot beams must avoid intersecting the geostationary arc. This would be a minor constraint on MSS operations. Therefore, coordination between MSS and FSS systems would be feasible with minor constraints on both the MSS and the FSS. MESs could receive interference from FSS uplink earth stations. However, this band is used mostly for feeder links to BSS systems and hence the number of earth stations globally is small, so this would not be a major constraint on MSS operations. The use of the band 7 055-7 075 MHz by non-GSO FSS systems for MSS feeder downlinks and BSS feeder uplinks has not been studied.

3.2.5 Earth exploration-satellite service

In accordance with provision No. 5.458 of the RR the frequency band 6 425-7 250 MHz is also used for passive microwave sensor measurements carried out in the Earth exploration-satellite service (EESS). Studies available show that interference from MSS downlinks is likely to exceed the relevant ITU-R protection criteria, by up to 15 dB, thus causing harmful interference. However, current and planned passive sensors would operate below 7 100 MHz and hence MSS operations above 7 100 MHz would not cause excessive interference to those sensors.

3.2.6 Space operation service

The bands 7 100-7 155 MHz and 7 190-7 235 MHz are allocated to the SOS (Earth-to-space) in the Russian Federation through RR No. **5.459**. Studies have shown that interference from MSS downlinks would not cause excessive interference to space operation spacecraft provided the pfd from the MSS system does not exceed −115 dB(W/(m^2 · MHz)). However, for the case of the omnidirectional antenna, interference is only 0.5 dB below the *I*/*N* criterion of −10 dB. The effect of a directional antenna tracking a ground station and possible main beam coupling may yield different results and conclusions.

Also, only a low-Earth orbit space operation system was considered. Sharing with other SOS systems with higher orbits (medium Earth orbit or GSO) is more difficult but has not been studied. It is expected that similar results for these orbits would be obtained as for SRS systems as indicated below.

3.2.7 Space research service

The band 7 145-7 235 MHz is allocated to the space research service (SRS) (Earth-to-space).

Sub-band: 7 145-7 190 MHz

The use of the lower part of the band: 7 145-7 190 MHz by the space research service (SRS) is limited to deep-space[5] use through RR No. 5.460. This band is also used for near-Earth operations of deep-space missions.

MESs operating close to a deep-space earth station could receive interference above the MES protection criterion. For the studies based on space research stations transmitting with the maximum permitted e.i.r.p. in the direction of the horizon, the required separation distances range from several tens of km to several hundred km (600 km in the worst case). For the studies based on space research earth stations transmitting with lower power, consistent with practical operations, and a typical reference bandwidth for the MES of 1 MHz, the separation distances range from several tens of km to about 200 km in the worst case. If the MSS satellite is geostationary, the worst-case

5 Deep space is defined as space at distances from the Earth equal to, or greater than 2×10^6 km. (See RR No. 1.177.)

separation distances may only be required for certain azimuths. MESs operating in this band will require accurate pointing/tracking mechanisms to maintain a predictable off-axis angle with respect to SRS earth stations.

Despite the relatively low number of SRS earth stations, the required separation distances would make large areas unavailable for MSS use. Any MESs operating at less than the calculated separation distances from the space-research earth stations would have to accept interference or switch to an interference-free channel. However, free channels may not be available if the MSS system is operating close to saturation. Moreover, if a free channel is available momentarily, it will have to take into account the dynamic nature of the SRS signal in this band. An SRS deep-space earth station frequently starts with the transmission of an unmodulated carrier during acquisitions, then switches to a much wider band signal with command subcarrier and modulation, and finally may switch to a ranging signal, with multiple tones, which will spread over an even larger band.

Additionally, during a single track, a SRS earth station may switch its frequency in order to support more than one deep-space mission. Moreover, while tracking a deep-space mission, an SRS station continuously changes the frequency of its signal to compensate for the Doppler shift caused by the relative movement of the earth station and the SRS space station.

There are thirteen deep-space earth stations identified in Recommendation ITU-R SA.1014, but additional stations are currently under construction and new earth stations will be deployed in the future. Considering the relatively small number of space-research earth stations, particularly in the band 7 145-7 190 MHz, which is used for deep-space missions, this might be an acceptable constraint on MSS operations. To avoid constraints on operation of current and future SRS earth stations, the MSS would not claim protection from the SRS.

Studies for AESs using the IF-77 program show that separation distances as much as 825 km are required to avoid interference from the SRS earth station uplinks to the MSS aircraft earth stations. Required separation distances are smaller if the MSS aircraft terminals can correctly track the MSS satellite and, in particular, if the MSS satellite is geostationary, which will ensure large antenna off-axis angles between the MES terminals and the SRS sites for most azimuths.

For situations in the band 7 145-7 190 MHz where the SRS spacecraft is beyond 2×10^6 km from the Earth, the worst-case situation arises when the SRS spacecraft is close to the edge of the Earth and in the spot beam of the MSS satellite (the spot beam would intersect the edge of the Earth and the power would "overspill" into space). For this situation, the e.i.r.p. from the proposed MSS satellite would exceed the limit by about 3.6 dB. Hence, limits on the power radiated by the MSS satellite to deep space would be necessary, but would not be a significant constraint. The pfd in the direction of deep-space spacecraft would need to be limited to meet the protection levels in Recommendation ITU-R SA.1157-1. This protection level translates to a pfd value of −199.5 dB(W/m^2) in a bandwidth of 20 Hz, as shown in Table 3.2-1.

TABLE 3.2-1

SR space stations protection criterion (Recommendation ITU-R SA.1157-1) (dBW/20 Hz)	−190
SR satellite antenna gain (dBi)	48.0
Frequency (MHz)	7 145
Ae_iso (dBm^2)	−38.5
max pfd at SRS spacecraft (dB(W/m^2)/20 Hz)	−199.5

The above derived pfd level is based on an SRS satellite antenna diameter of around 4 m. There are currently plans to use larger antennas, such as inflatable antennas with diameters of up to 18 m, reducing the allowable pfd level by at least 10 dB. In the case where deep-space SRS satellites have occasional perigees near Earth, interference could be experienced in excess of up to 30 dB. The SRS satellite would need full protection from MSS transmissions in case of rare but very critical mission phases such as launch and early operations phase (LEOP), Earth fly-bys or sample returns, where excessive interference could result in a loss of the mission. Hence, MSS satellites would be required to interrupt operation on the affected frequencies. The restrictions on MSS operations would be rare events and would be limited to a small bandwidth (up to 3 MHz for the ranging signal). This would require complex procedures whereby the notifying administration of the SRS mission has to contact the notifying administrations of all respective MSS operators to ensure that affected MSS channels are switched off. Such a procedure requires that MSS satellites would have to interrupt their operation during launch, LEOP, Earth fly-by, and sample return phases of the SRS missions (when they operate below the GSO) on the affected frequency channel. Any interference avoidance technique between SRS missions and MSS satellites would require operational coordination when the SRS mission is below 2×10^6 km which would be difficult for SRS operators to accept (noting that such operational coordination would have to be effected with all MSS operators and the responsible administrations around the world). These constraints on the MSS should be acceptable because of the limited number of deep-space earth stations and the limited time period of deep-space SRS missions operating below the GSO. However, if the process is not successful, it may hamper the SRS missions.

It should be noted that some SRS deep-space missions may operate at near-Earth distances for several months after launch. Also, the launch of many deep-space missions is frequently delayed due to weather anomalies or equipment malfunction. If an MES operates in 7 145-7 190 MHz and 8 400-8 450 MHz as paired downlink/uplink bands and interference mitigation techniques are implemented to give an MES greater flexibility in operating near a 7 GHz SRS earth station, it should be noted that the MES would not be able to receive in 7 GHz within an exclusion zone for an 8 GHz SRS earth station because it could not transmit using the 8 GHz uplink band. Thus, in this case, the 8 GHz exclusion zone would also lead to constraints on use of the 7 GHz band.

Sub-band: 7 190-7 235 MHz

MESs operating close to a near-Earth earth station in the band 7 190-7 235 MHz could receive interference above the MES protection criterion. For the studies based on space research earth stations transmitting with the maximum permitted e.i.r.p. in the direction of the horizon, the required separation distances range from several tens of km to several hundred km (300 km in the worst case). The required separation distances would make large areas unavailable for MSS use. However, it should be pointed out that, if the MSS satellite is geostationary, large antenna off-axis angles between the MES terminals and the SRS sites will exist for most azimuths, and consequently the worst-case separation distances will only be required for certain azimuths. Any MESs operating at less than the calculated separation distances from a near-Earth space-research earth station would have to accept interference or to adopt measures to avoid interference. There are more near-Earth earth stations than for deep-space, but these constraints might be acceptable for MSS operations. To avoid constraints on operation of current and future SRS earth stations, the MSS would not claim protection from the SRS.

Studies have shown that the sub-band 7 190-7 235 MHz is more difficult to share than the band 7 145-7 190 MHz due to a larger number of earth stations in this part of the band, as well as orbital configurations where interference excess up to 20 dB could be caused repeatedly to SRS satellites when flying through the main beam of the MSS satellite.

Some earth stations are deployed close to large bodies of water. Separation distances for maritime MESs can range between 460 and 510 km for earth stations in the band 7 145-7 190 MHz and between 370 and 420 km for earth stations in the band 7 190-7 235 MHz. Studies for AESs show that separation distances as much as 875 km are required to avoid interference from the SRS earth station uplinks to the MSS aircraft earth stations.

If an MES operates in 7 190-7 235 MHz and 8 450-8 500 MHz as paired downlink/uplink bands and interference mitigation measures are implemented to give an MES greater flexibility in operating near a 7 GHz SRS earth station, it should be noted that the MES would not be able to receive in 7 GHz within an exclusion zone for an 8 GHz earth station because it could not transmit using the 8 GHz uplink band. Thus, in this case, the 8 GHz exclusion zone could also lead to constraints on use of the 7 GHz band.

Regarding sharing with space research earth stations in the band 7 145-7 190 MHz, it appears to be potentially feasible, subject to the MSS accepting interference when operating in the vicinity of space-research earth stations. However, the required large exclusion zones and the dynamic nature of the SRS transmissions may render sharing impractical unless sufficient MSS channels are available for dynamic reassignment of interference-free channels. This is primarily a function of the frequency reuse scheme and the SRS channel bandwidth. If the SRS channel has a bandwidth of approximately equal size or larger than the bandwidth per MSS beam, this mitigation technique would not be available.

3.2.8 Summary for all affected services

An allocation of parts of this band to the MSS would require the establishment of numerous and complex regulatory provisions to provide for the protection of the existing services, or coordination procedures or other approaches in order to ensure protection of MES and would not allow for MSS operations in many and, in some cases, large areas around existing stations due to excessive interference.

Mandatory MSS pfd limits would be required to protect FS/BAS systems and would restrict MSS operations to areas where the elevation angles of the MES towards the MSS satellite is above 20°, reducing the MSS service area by more than 30% when compared to an area with a minimum elevation angle of 5°.

FS stations would be required to off-point between ±1° and ±15° from the GSO to protect FS stations from MSS interference, and for fixed BAS stations occasionally more than ±15° to protect BAS stations which would generally not be feasible for a mobile BAS. FS systems used to support air traffic control equipment may need off-pointing angles significantly exceeding the above range of angles depending on the pfd mask applied.

MES could not claim protection from current and future fixed and mobile stations, and therefore would need to be designed to accept interference from them.

Interference to SRS satellites could in some cases be up to 30 dB in excess of applicable ITU-R Recommendations in the band 7 145-7 235 MHz, being particularly critical for deep space missions in the band 7 145-7 190 MHz, where interference during essential orbital manoeuvres may result in loss of the mission. A similar situation may occur for the space operation service in the bands 7 100-7 155 MHz and 7 190-7 235 MHz operating in accordance with RR No. 5.459.

Operational coordination and disruption of MSS services would be required during operations of the near-Earth SRS missions in 7 190-7 235 MHz and operations of the deep space SRS missions during near-Earth phases in 7 145-7 190 MHz, and the resultant burden that would be difficult for SRS operators to accept (noting that such operational coordination would have to be effected with all MSS operators around the world to ensure that affected MSS channels are switched off, noting that the number of MSS systems is inherently limited by the small earth station antenna size, e.g. 20 cm earth stations would lead to around 12 co-frequency systems). During launch of SRS satellites and their early orbit phases, an additional complexity is added as launch dates may shift at short notice. MSS operators would have to be prepared to switch off affected channels at very short notice many times over an extended period of days or weeks.

MES would be required to perform real-time channel scanning and channel switching in the band 7 145-7 235 MHz, which is complicated by the dynamic nature of the signal from SRS earth stations. MES may suffer loss of service occasionally because they cannot claim protection from current and future SRS earth stations. Alternatively, required separation distances of several tens of km to several hundreds of km to SRS earth stations would make large areas unavailable for MSS use. MSS aircraft earth stations (AES) may need separation distances up to 875 km away from SRS earth stations.

3.3 Frequency band 8 400-8 500 MHz

This band has been considered for MSS uplinks. The band is allocated to the fixed and mobile (except aeronautical mobile) services on a primary basis. The band is also allocated to the SRS (space-to-Earth), with the band 8 400-8 450 MHz limited to use in deep space through RR No. 5.465.

Sharing in the band 8 400-8 500 MHz would require MESs to avoid causing interference to receiving earth stations in the SRS.

3.3.1 Space research service in the band 8 400-8 450 MHz

For the band 8 400-8 450 MHz, adequate protection of SRS earth stations would require separation distances up to several hundred km for transmission paths over land and much longer distances, between 350 and 500 km, when the SRS earth stations are deployed near large bodies of water. Separation distances for AESs would range between 720 and 835 km. The separation distances would have to be based on minimum elevation angles of the SRS earth station as the actual angle is generally not known to the MSS operator.

For a majority of SRS earth stations, the entire frequency sub-band 8 400-8 450 MHz or 8 450-8 500 MHz would have to be taken into account for the separation distance as SRS earth stations generally support several missions per day. In addition, cross-support agreements are in existence and any SRS station could be called upon for support on any of the frequencies in the sub-band over limited time periods. All SRS earth stations can tune to any frequency in the band 8 400-8 500 MHz. Near-Earth SRS stations often support SRS deep-space missions for orbital phases where the perigee is close to Earth as fast movements of large antennas are limited.

In view of the sensitivity of the operations in the band 8 400-8 450 MHz, space agencies have international agreements not to exceed the levels of Recommendation ITU-R SA.1157 at any time as mission objectives could be lost for which a satellite has been cruising for years to far distant locations to encounter a comet or planet.

In the event of harmful interference from MES transmissions into an SRS earth station, the required reacquisition times of the SRS signal may be much longer than the interference burst itself.

Despite the relatively low number of SRS earth stations in the band 8 400-8 450 MHz, the required separation distances would make large areas unavailable for MSS use. MESs would be required to avoid operating in the areas around SRS earth stations where interference would be caused to SRS earth stations. If the MSS satellite is geostationary, the worst-case separation distances may only be required for certain azimuths. MESs operating in this band will require accurate pointing/tracking mechanisms to maintain a predictable off-axis angle with respect to SRS earth stations. Given the relatively small number of space-research earth stations globally, this might be an acceptable constraint on MSS operations.

Procedures and assumptions would need to be agreed for the determination of the required separation distances. Several studies have used propagation models including terrain models and have assumed that the MES is permanently operating at any location, to ensure worst-case assumptions are used. The studies have not included clutter losses, which may reduce the separation distances, but caution is required as clutter losses may vary over time. The ability of MESs to comply with exclusion areas would be an important consideration as the consequences of operation of an MES within the separation distance could be very serious.

It would in practice be difficult for an SRS earth station operator to determine if an MES is the source of interference. A report of infringement (in accordance with RR Appendix 9) could not be filed as the location of the MES is generally unknown.

Appropriate provisions are required to ensure protection of future deep-space SRS earth stations. No constraints should be placed on deployment of future SRS space stations.

Studies for AESs using the IF-77 program show that separation distances as much as 835 km are required to avoid interference from the AES to the receiving SRS earth stations. Required separation distances are smaller if the AES can correctly track the MSS satellite and, in particular, if the MSS satellite is geostationary, which will ensure large antenna off-axis angles between the MESs and the SRS sites for most azimuths. Moreover, the effect of emissions from multiple MESs in the separation distances around SRS earth stations has been analysed and found to have negligible effect on the required distances.

For those cases where the SRS satellite remains above 2×10^6 km, the protection requirements for MSS satellites can be met but, for the case analysed, would require constraints on the MSS satellite antenna, to avoid pointing towards the edge of the earth. During the near-Earth operations of deep-space SRS spacecraft, interference from the SRS spacecraft could cause the protection requirements for MSS satellites to be exceeded by many dB, unless affected MSS channels can be swapped with non-interfered with channels which may be difficult considering the high velocity of the SRS spacecraft traversing the MSS beams. These constraints on MSS would be acceptable because of the limited time period of deep-space SRS missions operating below 2×10^6 km. It should be noted, however, that some SRS deep-space missions may stay in near-Earth for several months after launch. Also, the launch of many deep-space missions is frequently delayed due to weather anomalies or equipment malfunction. However, any operational coordination during a critical phase of those missions would be difficult for SRS operators to accept (noting that such operational coordination would have to be effected with all MSS operators around the world). However, it should be recognized that the number of co-frequency MSS systems will inherently be limited by the antenna discrimination of the small MSS earth station antennas.

3.3.2 Space research service in the band 8 450-8 500 MHz

The band 8 450-8 500 MHz is used for near-Earth applications in the SRS.

For the band 8 450-8 500 MHz, most of the above conclusions regarding SRS earth stations in the band 8 400-8 450 MHz apply similarly. Studies have determined that separation distances up to about 300 km may be required over land. Distances will increase to around 400 km near large bodies of water. AESs would require separation distances up to around 800 km. Exclusion areas around each SRS earth station would be required where MES operations would not be permitted to operate. Given the number of space research earth stations in use throughout the world (currently around 40, but growing), such exclusion areas might be an acceptable constraint on MSS operations. However, it should be pointed out that, if the MSS satellite is geostationary, large antenna off-axis angles between the MES terminals and the SRS sites will exist for most azimuths, and consequently the worst-case separation distances will only be required for certain azimuths. Appropriate provisions are required to ensure protection of future SRS earth stations. No constraints should be placed on deployment of future SRS space stations.

While a majority of near-Earth space research satellites will be able to meet typical MSS protection requirements, there is a limited number of near-Earth SRS satellites that will have regular or even permanent orbit heights underneath the GSO and could use higher power density (well within the RR pfd limits). For these systems, which like all SRS missions typically transmit in a bandwidth of no more than 10 MHz, MSS protection criteria may not be met. Transmissions are often effected via the omnidirectional antenna so that excessive interference levels occurring at the MSS satellite may interrupt the link from MESs.

A number of near-Earth SRS satellites will have orbits below the MSS orbit between several times a day and once every few days. Based on past experience, even mission anomalies would have to be taken into account where the satellite may not reach the desired orbit and may have apogees close to the GSO twice a day for many years. The results of dynamic simulations of hypothetical cases were confirmed by static analyses which showed that protection criteria of MSS satellites can be exceeded by up to 60 dB. Complexity is added by the fact that there are no standard SRS orbits as they always depend on mission objectives. It is therefore not possible to draw general conclusions from a few orbit examples. A general assessment of potential SRS satellites operating in compliance with the RR is needed and such assessments indicate that MSS protection criteria can be exceeded by orders of magnitude. It would be unacceptable to exclude a range of SRS orbits or severely limit their currently allowed pfd.

The effect of emissions from multiple MSS MESs in the separation distances around SRS earth stations has been analysed and found to have little effect on the required distances.

3.3.3 Sharing with the fixed and mobile service

In the band 8 400-8 500 GHz, the FS is widely used for FWS. In at least one administration, links are used to carry data for en-route and terminal surveillance radars, voice communications, and other application that are used for air traffic control. These links are critical for maintaining separation of aircraft during all phases of flight and under all weather conditions.

There is potential for interference from MESs to FWS receivers. In the case of land MESs, the required separation distance varies depending on the terrain. Using some assumptions (including non-worst-case alignment of antennas, no clutter loss), on the worst-case azimuth, the distance may be up to about 30 km, and on other azimuths the distance may be less than 10 km. In cases where the FWS and the MES antenna are pointing towards each other, the separation distances calculated in accordance with Recommendation ITU-R P.452 will be up to 200 km. Regarding interference to FS systems used to support air traffic control equipment, even higher separation distances may be needed in some cases.

All of these estimates do not consider benefits from terrain clutter (e.g. trees and buildings), which would reduce the required separation in cases where diffraction is the main propagation mode but would have little impact in case tropospheric scatter or layer ducting are the main propagation modes.

For aircraft earth stations, the required separation distance may be determined by the visibility limits between the aircraft and FWS station. In such case, the maximum required separation, for an aircraft at 12 200 m (40 000 feet), is about 450 km. Separation distances taking into account beyond line-of-sight propagation modes are expected to be much larger. The exact numbers need further study.

Up to ±10° off-pointing from the GSO will be required to protect MSS satellites from transmitting FS stations which will be a significant constraint for countries at high latitudes. Another study also showed that some FS systems used to support air traffic control equipment may need off-pointing angles significantly exceeding the above range of angles depending on the pfd mask applied. This will be a severe and safety related constraint.

A single FS station could cause interference above an $I/N = 30$ dB and would disable operation of an entire MSS beam. Provided the off-pointing angle to the MSS satellite exceeds about 10°, interference from an FWS station would be at least 4 dB below the interference criterion (−12.2 dB I/N). There may be several co-frequency FWS stations within an MSS satellite spot beam; however, it is likely that there is sufficient margin such that the interference from all FWS stations would not exceed the criterion. The band 8 400-8 500 MHz is used in some countries for fixed BAS. Characteristics are described in Recommendation ITU-R F.1777. With regard to interference from BAS transmitters to MSS satellite receivers, an off-pointing angle to the MSS satellite of about 15° would be necessary to ensure that interference is at least 2 dB below the criterion. Similarly, this will be a significant constraint for countries at higher latitudes.

There is potential for interference from MESs to BAS receivers. In the case of land MESs, the required separation distance varies depending on the terrain. Using some assumptions (including non-worst-case alignment of antennas, no clutter loss), on the worst-case azimuth, the distance may be up to about 30 km, and on other azimuths the distance may be less than 10 km. In cases where the BAS and the MES antenna are pointing towards each other, the separation distances calculated in accordance with Recommendation ITU-R P.452 will be more than 100 km. These estimates do not consider benefits from terrain clutter (e.g. trees and buildings), which would reduce the required separation in many cases where diffraction is the main propagation mode but would have little impact in case tropospheric scatter or layer ducting are the main propagation modes. For aircraft earth stations, the required separation distance is determined by the visibility limits between the aircraft and BAS station. In such cases, the maximum required separation, for an aircraft at 12 200 m (40 000 feet), is about 450 km. Separation distances taking into account beyond LoS propagation modes are expected to be much larger. The exact numbers would need further study. Sharing with mobile BAS links is generally not feasible in view of their unknown locations and pointing directions.

For those countries that operate terrestrial services (including FWS and BAS) in this band, exclusion areas would be required to ensure that MESs do not cause harmful interference. If there are a large number of terrestrial stations, it may be impractical to define an exclusion area for each one, and alternatively, the exclusion area might need to be defined for a group of terrestrial stations within a specific area or an entire country. In countries where there is little use of the band 8 400-8 500 MHz by terrestrial services, this band may be used by MESs with few constraints with respect to the terrestrial services. Coordination may still be required for stations close to borders in view of the large separation distances. The use of AESs in a particular country would require consideration of terrestrial usage in neighbouring countries, within a distance of at least 450 km based on LoS propagation. Separation distances taking into account beyond LoS propagation modes are expected to be much larger. The exact numbers need further study.

3.3.4 Summary for all affected services

An allocation in this band to the MSS would require the establishment of numerous and complex regulatory provisions to provide for the protection of the existing services, or coordination procedures or other approaches in order to ensure protection of MSS space stations. Coordination would be required for MES operations in the vicinity of current and future SRS earth stations and countries operating terrestrial systems in this band. This could result in large exclusion areas of up to several hundreds of km for MESs around SRS earth stations and even greater separation distances up to 835 km for AESs. FS and BAS stations would require worst case separation distances up to 200 km in case the MES is pointing towards them with no antenna discrimination. FS systems used to support air traffic control equipment may need higher separation distances in some worst-case situations.

FS stations would be required to off-point between ±1° and ±10° from the GSO to protect MSS satellites from FS interference. FS systems used to support air traffic control equipment may need off-pointing angles significantly exceeding the above range of angles depending on the pfd mask applied. Fixed BAS stations would require up to ±15° to protect MSS satellites. In case of BAS using horn antennas, the required off-pointing could be even higher. Sharing with mobile BAS links would not be feasible as their locations are generally not known.

SRS would need to coordinate with MSS systems to prevent SRS satellites operating in the near-Earth distances from interfering with MSS satellites. The resultant coordination burden would be difficult for SRS operators to accept, recognizing that such operational coordination would have to be effected with all MSS operators around the world. It should also be noted that the number of MSS systems is inherently limited by the small earth station antenna size, e.g. 20 cm earth stations, which would lead to around 12 co-frequency systems.

In the 8 450-8 500 MHz band, studies of interference from SRS satellites operating in compliance with the RR indicate that MSS protection criteria can be exceeded by several orders of magnitude for a limited number of SRS orbits in a typical SRS mission transmit bandwidth of no more than 10 MHz. Sharing with transmitting SRS satellites would not be possible in these cases.

Compilation and maintenance of dynamic databases would be required to establish and ensure the viability of large exclusion zones around current and future SRS earth stations requiring protection. It may be difficult to enforce proper implementation and maintenance of such safeguards by all MSS systems, potentially exposing extremely sensitive SRS earth stations to interference whose source cannot easily be determined.

3.4 Frequency band 10.5-10.6 GHz

The allocation of this band in RR Article 5 is indicated below.

10.5-10.55 FIXED MOBILE Radiolocation	**10.5-10.55** FIXED MOBILE RADIOLOCATION
10.55-10.6	FIXED MOBILE except aeronautical mobile Radiolocation

This band is considered for possible MSS downlink operations.

The MES receiver characteristics given in Table 3.4-1 are used.

TABLE 3.4-1

MES characteristics for the band 10.5-10.6 GHz

MES	"pocket"	"suitcase"
Antenna gain (dBi)	25	33
Antenna pattern	Rec. ITU-R F.699	Rec. ITU-R F.699
MES receiver temperature (K)	400	250
Interference criterion (I/N, dB)	−12.2	−12.2
MES height a.g.l. (m)	1	1

3.4.1 Sharing with fixed-service systems

The sections below reflect several studies. Section 3.4.1.1 reflects static studies while that in § 3.4.1.2 is dynamic, and takes account of statistics of the systems in relation to each other. Section 3.4.1.3 addresses interference from the terrestrial systems to the MSS.

3.4.1.1 Interference from MSS downlinks to fixed radio-relay stations − Static

Regarding sharing with fixed-service systems, characteristics are contained in Recommendation ITU-R F.758. Example characteristics of point-to-point systems have been taken and included in Table 3.4-2. For one study, the MSS downlink pfd is assumed to be −116 dBW/m^2 in 1 MHz. The FS antenna gain in the direction of the MSS satellite is determined from the pattern in Recommendation ITU-R F.699 using the equation in *recommends* 3 of Recommendation ITU-R F.699 to estimate the D/λ and an off-axis angle of 10°, which is the minimum angle at which the FS protection requirements are just met.

TABLE 3.4-2

Interference from MSS satellite downlinks to FS receivers in the band 10.5-10.6GHz

Frequency band (GHz)	10.55-10.68	
Modulation	FSK, QPSK	FSK, QPSK
Capacity	8 Mbit/s	16 Mbit/s
Channel spacing (MHz)	7	14
Antenna gain (maximum) (dBi)	49	49
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna type	Dish	Dish
Maximum Tx output power (dBW)	−2	−2
e.i.r.p. (maximum) (dBW)	47	47
Receiver IF bandwidth (MHz)	7	14
Receiver noise figure (dB)	3	3
Receiver thermal noise (dBW)	−135.5	−129.5
Nominal Rx input level (dBW)	−60	−60
Rx input level for 1×10^{-3} BER (dBW)	−117	−114
Nominal long-term interference (dBW)	−142.5	−139.5
Spectral density (dB(W/MHz))	−151	−148
Off-axis gain in direction of satellite (dBi)	7.0	7.0
I at input of receiver (dBW/MHz)	−150.9	−150.9
Excess interference from MSS downlink (dB)	0.1	−2.9

The study in Table 3.4-2 shows that interference from MSS downlinks would not exceed the protection criterion considered in the Table 3.4-2, provided the off-axis angle to the MSS satellite exceeds about 10°. The feasibility or impact to FS deployment possibilities has been assessed in studies below in § 3.4.1.2.

Data in Table 3.4-2, show that, with the proposed pfd under worst case conditions, there might be some interference into some FS systems.

In addition, the data are derived with the conventional $I/N = -10$ dB protection criterion (corresponding to the possible degradation of error performance and availability objectives of 10% as stated in Recommendation ITU-R F.1094 for co-primary sharing). In this band significant deployment of FS point-to-point and multipoint systems are already in place and are used for public networks. They are designed to comply with the relevant ITU-T and ITU-R Recommendations for error performance and availability. An additional source of interference needs to be evaluated as to its effect on networks containing FS connections to determine its impact on meeting the referenced ITU Recommendations.

There are point-to-multipoint fixed systems used in some countries, but the characteristics to enable similar analysis to that above are not available.

3.4.1.2 Interference from MSS downlinks to fixed radio-relay stations − Statistical

3.4.1.2.1 Analysis description

This additional study implements and evaluates the use of a pfd mask to protect these services from the MSS downlink. The results are shown in terms of achievable I/N for a given percentage of FS and BAS deployments. The intent is to complement the static analysis of above § 3.4.1.1 by way of statistically evaluating the interference of MSS GSO satellites into FS receiving stations. Further, this analysis expands to evaluate the entire pfd mask and not just the single value of −116 dBW/m^2 in 1 MHz.

3.4.1.2.2 FS receiver station random variables

The FS receiver station location is randomly distributed over an area around Seattle, in the United States of America as described in Table 3.4-3. The FS receive antenna pointing azimuth and pointing elevation are also randomly distributed to simulate the unknown nature of these variables. These distributions and their parameters are detailed in Table 3.4-3 as well.

TABLE 3.4-3

Random variables used in analysis

Random variable	Distribution type	Mean	Variance
FS station latitude	Uniform	47.6°N	0.4°
FS station longitude	Uniform	122.3°W	0.3°
FS station pointing azimuth	Uniform	0°	180°
FS station pointing elevation	Gamma	$\alpha = 1$	$\beta = 2$

The simulation is designed to run for a total of 100 000 samples. At each sample, four new random variables are generated from their respective probability distribution function. The gamma distribution of the FS station pointing elevation with a $\alpha = 1$ and $\beta = 2$ means that 36.8% of the stations will have an elevation larger than 2°, and 8.2% will have an elevation larger than 5°.

The FS receiver station parameters used are described in the first column of Table 3.4-2 in § 3.2.1.1 with the addition of the FS receive antenna beamwidth which is derived from the antenna gain and approximated antenna diameter operating at 10.55 GHz. These are needed parameters for the antenna characteristics. As mentioned above, the FS characteristics are contained in Recommendation ITU-R F.758. The reason for using the first column of FS parameters is based on the FS receiver input power levels being the lowest for the given frequency range.

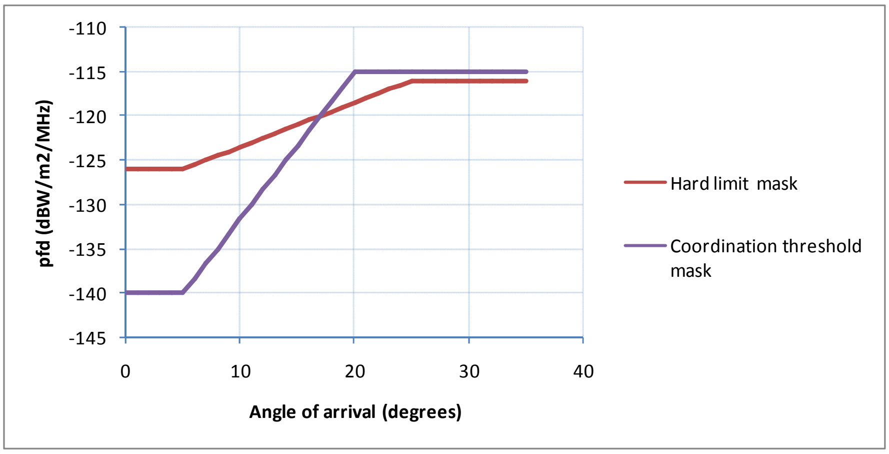
It is noteworthy that there is a bandwidth differential between the GSO MSS and FS carriers. The simulation is designed to take this into account such that multiple GSO MSS carriers (having narrower bandwidth) are combined or stacked together to completely fill the FS receiver bandwidth in order to provide the maximum interference.

3.4.1.2.3 GSO MSS satellite characteristics

In the software used, the GSO MSS satellite is constrained to follow the pfd masks shown in the following graph, Fig. 3.4-1. There are two pfd masks analysed corresponding to two different methods for an allocation of MSS. The first shows the proposed mask for a pfd threshold to be used to establish coordination triggers with the FS. The second illustrates a pfd mask from a neighbouring frequency band in Table 21.4 of RR Article 21 which represents hard pfd limits not to be exceeded.

FIGURE 3.4-1

GSO MSS pfd masks for 1 MHz reference carrier



As mentioned above, each of the three portions of the pfd curves is analysed in order to fully evaluate the FS protection provided from application of the pfd masks. This is achieved by considering FS stations deployed within elevation angles of 0° to 5°, 5° to 20° and lastly, 25° to 90° with respect to the GSO MSS satellite.

3.4.1.2.4 Results

The following three graphs in Fig. 3.4-2 illustrate the *I*/*N* versus percentage of FS deployment for both pfd masks corresponding to three portions of the pfd curves. Beside each graph, the approximate percentage of deployments that would see an *I*/*N* of less than –10 dB is identified for the pfd threshold and hard limit masks.

FIGURE 3.4-2

***I*/*N* ratio corresponding to the % of deployments within a given range of elevation angles**

0°-5° elevation angles

Threshold

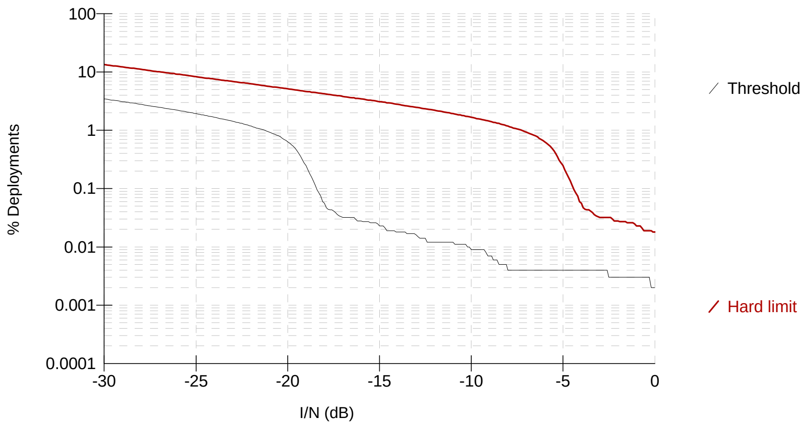
pfd = –140 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.99%

Hard limits

pfd = –126 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 98%



5°-20° elevation angles

Threshold

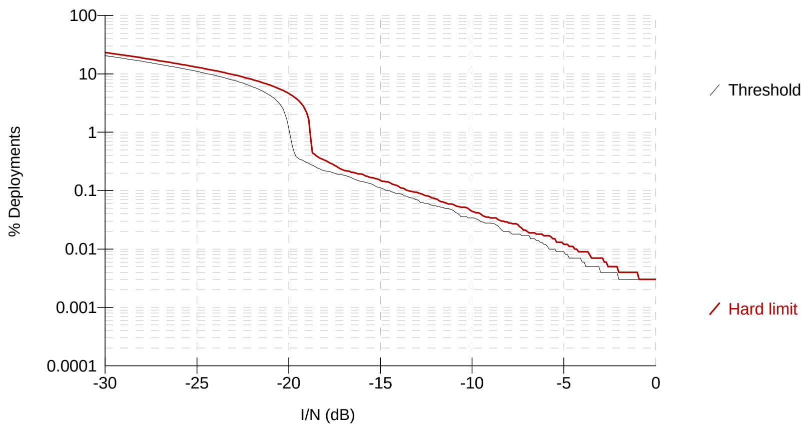
pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.97%

Hard limits

pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.95%



25°-90° elevation angles

Threshold

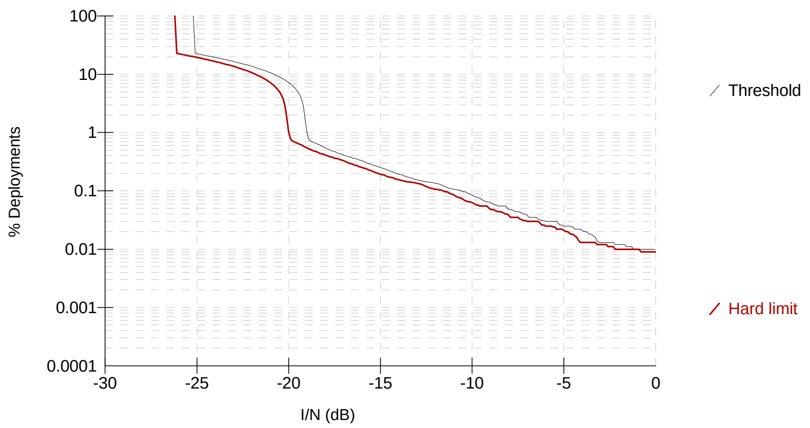
pfd = –115 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.9%

Hard limits

pfd = –116 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.93%



From these graphs, it is clear that the pfd threshold mask provides 99.93% of all FS receiver station deployed with an I/N of better than −10 dB. Conversely, this means that only 70 of the 100 000 FS receiver stations could see an I/N above the desirable −10 dB.

Furthermore, improvements from polarization and benefits from clutter are not considered which could improve the I/N performance for FS stations.

3.4.1.3 Interference from fixed radio-relay stations to MESs

Table 3.4-2 contains FS characteristics applicable to the band 10.55-10.68 GHz. From this information the characteristics given in Table 3.4-4 have been used to assess interference from FS transmitters to MES receivers.

TABLE 3.4-4

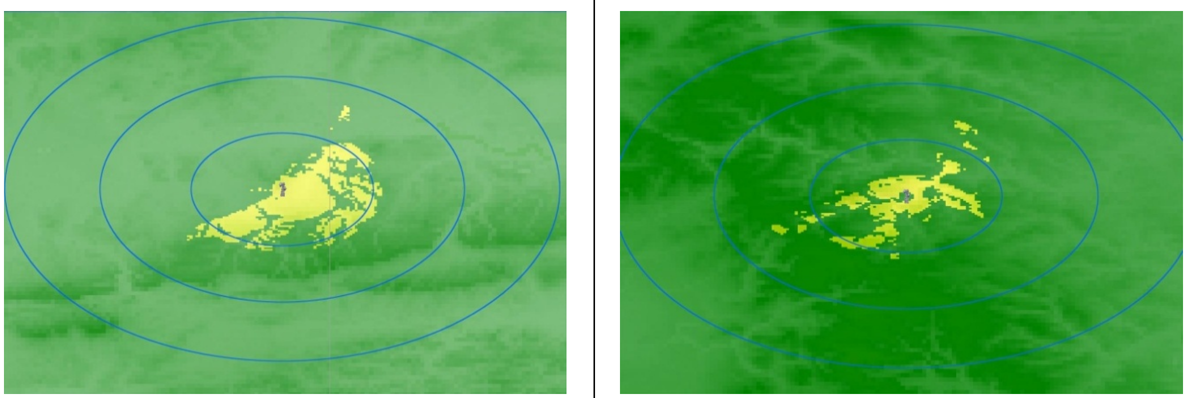
FS radio-relay characteristics used in the interference assessment

Antenna gain (dBi)	49
e.i.r.p. (dBW)	47
Emission bandwidth (MHz)	7
Antenna height a.g.l. (m)	*30*
Antenna azimuth (degrees)	*270*
Antenna elevation (degrees)	*0*

The parameters in italics are assumptions for the purpose of this study. The antenna azimuth of 270° was chosen arbitrarily to represent a typical situation. For an FS station pointing due north, interference may be higher due to the higher horizon antenna gain of the MES which is assumed to be pointing due south. Figures 3.4-3 and 3.4-4 show the locations in yellow and orange where the MES would receive interference above the criterion given above. The Recommendation ITU-R P.452 propagation model is used with $p = 20\%$, in keeping with the interference criterion which should be considered as "long term". Note that no losses due to local clutter from trees, buildings, etc. are included. The blue circles have radius 10 km, 20 km and 30 km.

FIGURE 3.4-3

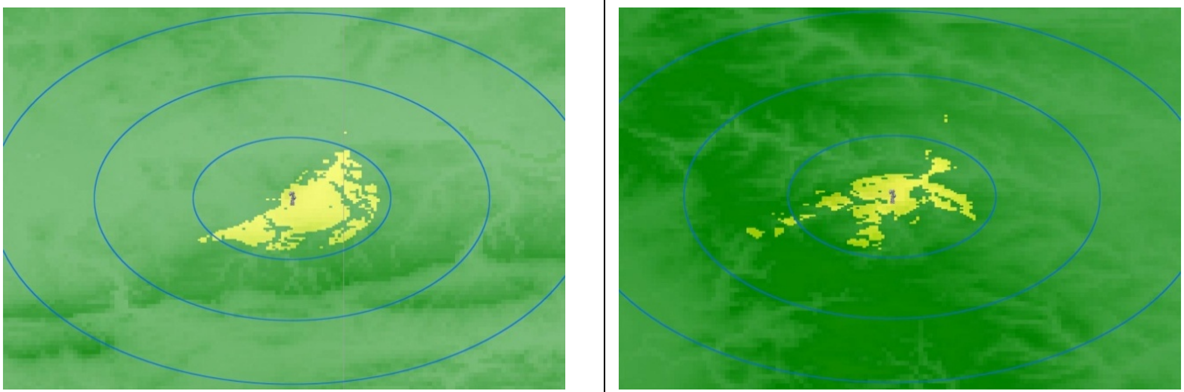
Interference from FS station to "pocket" MES



(a) FS station at Crystal Palace (b) FS station in Huddersfield

FIGURE 3.4-4

Interference from FS station to "suitcase" MES



(a) FS station at Crystal Palace (b) FS station in Huddersfield

The results show that interference above the criterion is received up to about 15 km from the FS station in the worst case. However operation much closer to the FS station is possible. In both examples, within a radius of 5 km from the FS station, about 30% locations are green. No local clutter losses (from trees, buildings, etc.) are included and the worst case FS characteristics have been chosen.

There is a possibility that the MES would receive interference above the recommended criterion from an FS transmitter. Considering the ubiquitous nature of the MES, some administrations consider that MES terminals should not claim protection from FS stations or limit further deployment of FS links in this band if there will be a new allocation for MSS (downlink).

3.4.2 Sharing with broadcasting auxiliary services

BAS are globally used in the band 10.5-10.6 GHz in fixed and mobile services. A typical use of BAS in FS is for one of the primary distribution link of nationwide terrestrial broadcasting networks.

3.4.2.1 Interference from MSS downlinks to BAS stations − Static

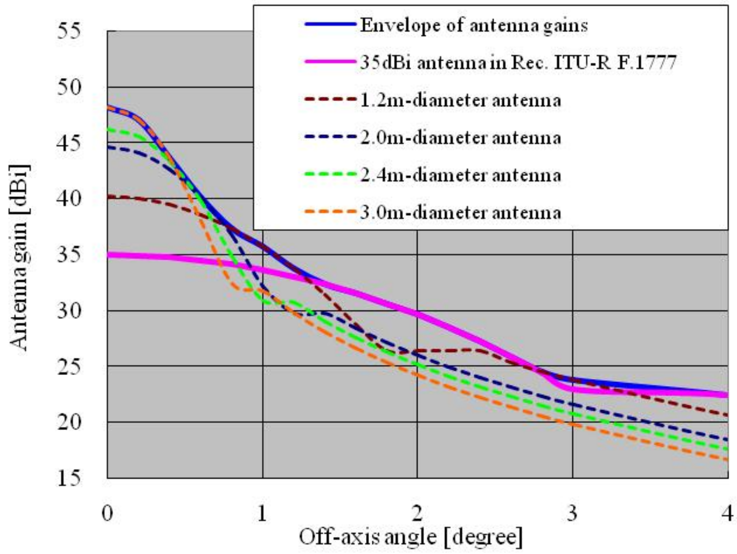
The characteristics are contained in Recommendation ITU-R M.1824 and Recommendation ITU-R F.1777. The off-axis gain of the parabolic antenna is determined from Recommendation ITU-R F.699 and using the equation in *recommends* 3 of Recommendation ITU-R F.699 to estimate the D/λ. Compared to the case for the FS above, a higher elevation angle is necessary to ensure that MSS downlink emissions do not exceed the criterion for BAS systems.

For the sharing of BAS in FS with MSS, –150 dB(W/MHz), which corresponds to I/N of −10 dB, should be applied as described in Recommendation ITU-R F.1777.

Various types of receiving antennas are used for both digital and analogue systems. The range of antenna gains differs from those in Recommendation ITU-R F.1777 depending on conditions such as location, distance, terrain, and affordable propagation loss. In particular, large-diameter receiving antennas are deployed for stations with long-distance networks to construct nationwide terrestrial broadcasting networks effectively. The receiving antenna characteristics, which correspond to the envelope of the antenna gains of various antennas, are used for the sharing study of BAS in the band 10.5-10.6 GHz as shown in Figure 3.4-5 below. The antenna gain based on the off-axis angle is calculated by using Recommendation ITU-R F.699-7. The combined envelope upper bound of these antenna patterns represents the collective peak and off-axis gain values of the various BAS antennas. In the following static analysis, the peak gain of a 3 metre antenna is assumed based on the maximum size of antennas in use in some countries.

FIGURE 3.4-5

Receiving antenna characteristics of BAS in FS in the band 10.5-10.6 GHz to be used for the sharing studies



To ensure adequate protection of BAS, permissible interference level, *Pper*, is derived from the following equation.

$$Pper \geq pfd_{int} + G_r + 10\log(\lambda^2/(4\pi)) - L \quad \text{dB(W/MHz)} \qquad (1)$$

where:

pfd_{int} :	interference pfd from MSS space station	dB(W/m^2 · MHz)
Gr :	receiving antenna gain	dBi
L :	feeder loss	dB

Where, −150 dB(W/MHz) of *Pper* and 1dB of *L* are used based on Recommendation ITU-R F.1777. G_r is derived from the figure above.

The pfd mask to prevent space station of MSS in the band 10.5-10.6 GHz from exceeding the permissible interference level is given as follows.

Limits in dB(W/m^2) for angles of arrival, δ, above the horizontal plane in the reference bandwidth of 1 MHz is as follows.

−156	dB(W/m^2 · MHz)	for 0°−3°	
$-156 + 8(\delta - 3)$	dB(W/m^2 · MHz)	for 3°−5°	
$-140 + 1.66(\delta - 5)$	dB(W/m^2 · MHz)	for 5°−20°	
−115	dB(W/m^2 · MHz)	for 20°−90°	(2)

Assuming that GSO MSS satellite downlinks exactly meet this mask as shown in Figure 3.4-6, the resulting interference to BAS systems is as shown in Tables 3.4-5 and 3.4-6. For each of three examined BAS station types, the interference is determined for example elevation angles of 0°, 5°, 10°, 15° and 20°.

FIGURE 3.4-6

Pfd mask for protection of BAS systems in the band 10.5-10.6GHz

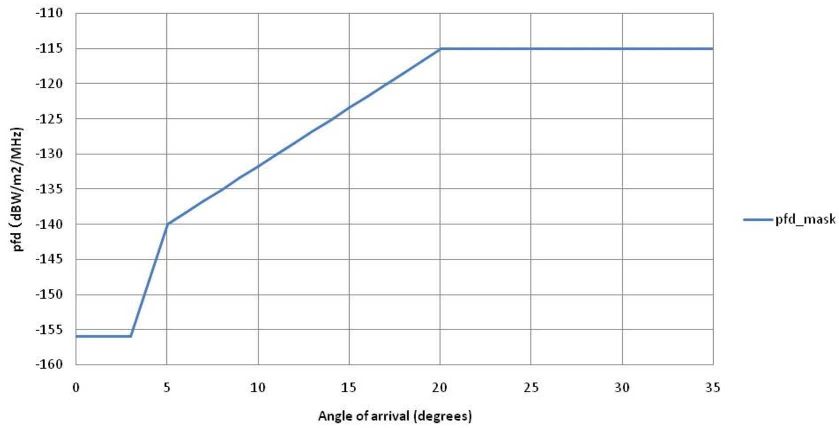


TABLE 3.4-5

Interference to BAS stations from MSS satellite which just meets the pfd mask (10.5-10.6 GHz)

Frequency band (GHz)	10.5-10.6		
References	Rec. ITU-R F.1777 (Fixed BAS)		
Capacity (Mbit/s)	Up to 30	Up to 60	Up to 66
Channel spacing (MHz)	9	18	18
Antenna gain (maximum) (dBi)	48.2	48.2	48.2
Antenna type	Parabolic	Parabolic	Parabolic
Angles of arrival, δ, above the horizontal plane = 0°, pfd = −156 dB(W/m^2 · MHz)			
Off-axis gain in direction of satellite (dBi)	48.2	48.2	48.2
I at input of receiver (dB(W/MHz))	−150.8	−150.8	−150.8
Excess interference from MSS downlink (dB)	−0.8*	−0.8 *	−0.8*
Angles of arrival, δ, above the horizontal plane = 5°, pfd = −140 dB(W/m^2 · MHz)			
Off-axis gain in direction of satellite (dBi)	29.6*	29.6*	29.6*
I at input of receiver (dB(W/MHz))	−153.4*	−153.4*	−153.4*
Excess interference from MSS downlink (dB)	−3.4*	−3.4*	−3.4*
Angles of arrival, δ, above the horizontal plane = 10°, pfd = −131.7 dB(W/m^2 · MHz)			
Off-axis gain in direction of satellite (dBi)	17.2*	17.2*	17.6*
I at input of receiver (dB(W/MHz))	−157.5*	−157.5*	−157.5*
Excess interference from MSS downlink (dB)	−7.5*	−7.5*	−7.5*

TABLE 3.4-5 (*end*)

Angles of arrival, δ, above the horizontal plane = 15°, pfd = −123.4 dB(W/m² · MHz)			
Off-axis gain in direction of satellite (dBi)	11.4*	11.4*	11.4*
I at input of receiver (dB(W/MHz))	−155.0*	−155.0*	−155.0*
Excess interference from MSS downlink (dB)	−5.0*	−5.0*	−5.0*
Angles of arrival, δ, above the horizontal plane = 20°, pfd = −115 dB(W/m² · MHz)			
Off-axis gain in direction of satellite (dBi)	7.6*	7.6*	7.6*
I at input of receiver (dB(W/MHz))	−150.4*	−150.4*	−150.4*
Excess interference from MSS downlink (dB)	−0.4*	−0.4*	−0.4*

* Here, the off-axis angles of BAS receivers are 3 degrees smaller than the angles of arrival, δ, above the horizontal plane of MSS downlink considering the BAS receiving antenna with the elevation angle of 3°.

TABLE 3.4-6

Interference from MSS satellite downlinks to BAS receivers in the band 10.5-10.6 GHz

Frequency band (GHz)	10.55-10.68			
Capacity (Mbit/s)	60	60	60	30
Channel spacing (MHz)	18	18	18	9
Antenna gain (maximum) (dBi)	2	20	35	48.2
Feeder/multiplexer loss (minimum) (dB)	1	1	1	1
Antenna type	Omnidirectional	Horn	Parabolic	Parabolic
Maximum Tx output power (dBW)	7	7	7	4
e.i.r.p. (maximum) (dBW)	8	26	41	51.2
Receiver thermal noise (dBW)	−127.4	−127.4	−127.4	−130.5
Rx input level for 1×10^{-3} BER (dBW)	−116.9 to −105.1	−116.9 to −105.1	−116.9 to −105.1	−120 to −108.2
Nominal long-term interference (dBW)	−137.4	−137.4	−137.4	−140.5
Spectral density (dB(W/MHz))	−150	−150	−150	−150
Off-axis gain in direction of satellite (dBi)	2.0	10.0[6]	8.9	29.6[7]
I at input of receiver (dB(W/MHz))	−156.9	−148.9	−149.9	−129.4
Excess interference from MSS downlink (dB)	−6.9	1.1	0.1	20.6

6 Assuming a parabolic roll-off and 15° off-axis angle.

7 Assuming an off-axis angle of 5° with off-set elevation angles of 3°.

Interference would just exceed the criterion in the case of the horn and parabolic antennas. With the inclusion of 3 dB polarization isolation between the MSS and BAS systems the interference would be below the criterion for horn and small parabolic antennas. However, large parabolic antennas with low elevation angles would receive harmful interference that exceeds the criterion. It is also necessary to consider potential interference to and from MESs to BAS stations. For this purpose, information on the deployment of BAS systems would be desirable.

3.4.2.2 Interference from MSS downlinks to BAS stations − Statistical

3.4.2.2.1 Analysis description

The objective of this analysis is to complement the static analysis of above § 3.4.2.1 by way of statistically evaluating the interference MSS GSO satellites into BAS stations in the band 10.5-10.6 GHz. The analysis is performed using Monte-Carlo simulations. Two antenna diameters of 0.7 m (antenna gain of 35 dBi) and 3.0 m (antenna gain of 48.2 dBi) are assumed for BAS.

3.4.2.2.2 BAS station random variables

The BAS station location is randomly distributed over an area around Seattle, in the United States of America as described in Table 3.4-7. The BAS receive antenna pointing azimuth and pointing elevation are also randomly distributed to simulate the unknown nature of these variables. These distributions and their parameters are also detailed in Table 3.4-7.

TABLE 3.4-7

Random variables used in analysis

Random variable	Distribution type	Mean	Variance
BAS station latitude	Uniform	47.6°N	0.4°
BAS station longitude	Uniform	122.3°W	0.3°
BAS station pointing azimuth	Uniform	0°	180°
BAS station pointing elevation	Gamma	$\alpha = 1$	$\beta = 2$

The simulation is designed to run for a total of 100 000 samples. At each sample, four new random variables are generated from their respective probability distribution function. The gamma distribution of the BAS station pointing elevation with a $\alpha = 1$ and $\beta = 2$ means that 36.8% of the stations will have an elevation larger than 2°, and 8.2% will have an elevation larger than 5°. These parameters were agreed inputs for this simulation. It is noted however that the parameters of this probability distribution function play a significant role in the results of the analysis.

The BAS station parameters used are described in the third and fourth columns of Table 3.4-6 in § 3.4.2.1 with the addition of the BAS antenna beamwidth which is derived from the antenna gain and approximated antenna diameter operating at 10.55 GHz. As mentioned above, the BAS characteristics are contained in Recommendation ITU-R F.1777. The reason for choosing these two columns of Table 3.4-6 is based on the availability of the parabolic antenna types with the simulation software.

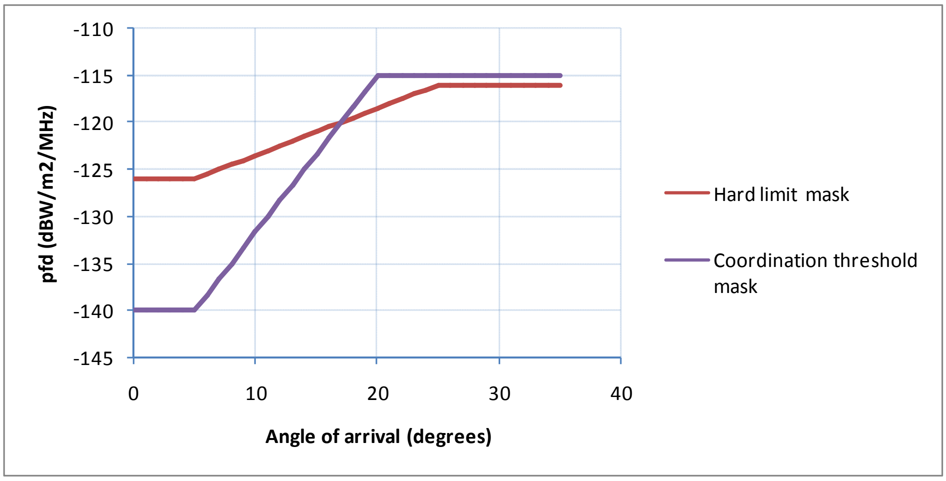
It is noteworthy that there is a bandwidth differential between the GSO MSS and BAS carriers. The simulation is designed to take this into account such that multiple GSO MSS carriers (having narrower bandwidth) are combined or stacked together to completely fill the BAS receiver bandwidth in order to provide the maximum interference. The simulation software calls this the "Bandwidth adjustment factor" between the wanted and interfering carriers.

3.4.2.2.3 GSO MSS satellite characteristics

In the software, the GSO MSS satellite is constrained to follow the pfd masks shown in the following graph, Fig. 3.4-7. There are two pfd masks analysed corresponding to two different methods for an allocation of MSS. The first shows the proposed mask for a pfd threshold to be used to establish coordination triggers with the BAS. The second illustrates a pfd mask for a neighbouring frequency band in from Table 21.4 of RR Article 21 which represents hard pfd limits not to be exceeded.

FIGURE 3.4-7

GSO MSS pfd masks for 1 MHz reference carrier



As mentioned above, each of the three portions of the pfd curves is analysed in order to fully evaluate the BAS protection provided from application of the pfd masks. This is achieved by considering BAS stations deployed within elevation angles of 0° to 5°, 5° to 20° and lastly, 25° to 90° with respect to the GSO MSS satellite.

3.4.2.2.4 Results for small BAS antenna sizes

The following three graphs in Fig. 3.4-8 illustrate the *I*/*N* versus percentage of BAS deployment of small antenna sizes (0.7m) for both pfd masks. Beside each figure, the approximate percentage of deployments that would see an *I*/*N* of less than −10 dB is identified for the pfd threshold and hard limit pfd masks.

FIGURE 3.4-8

I/N ratio corresponding to the % of deployments within a given range of elevation angles

0°-5° elevation angles

Threshold

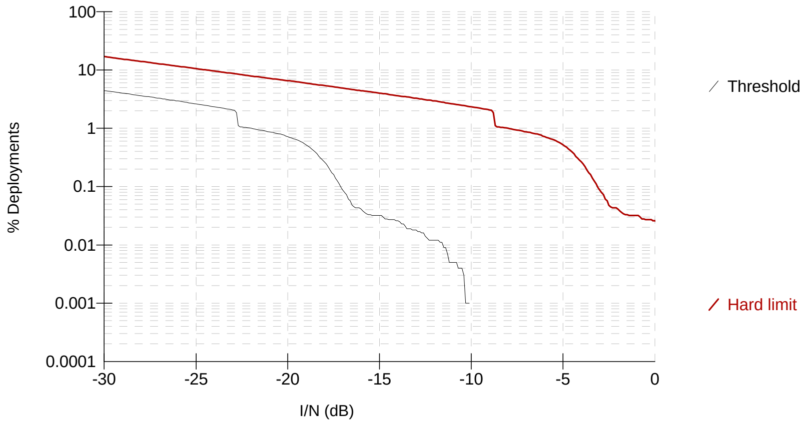
pfd = –140 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 100%

Hard limits

pfd = –126 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 97.5%



5°-20° elevation angles

Threshold

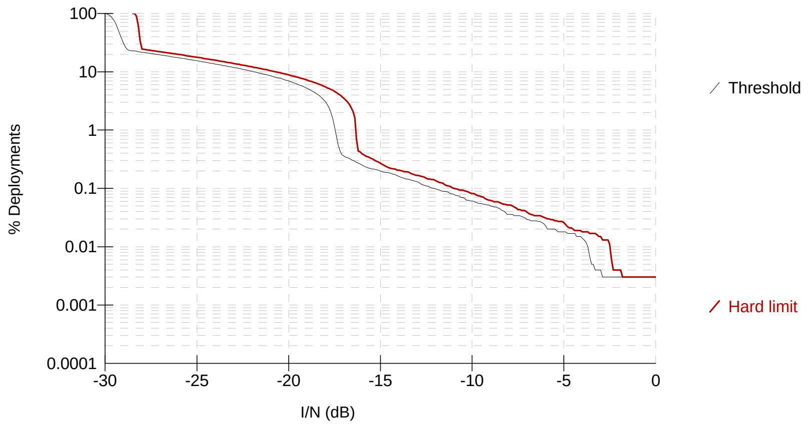
pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.94%

Hard limits

pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.91%



25°-90° elevation angles

Threshold

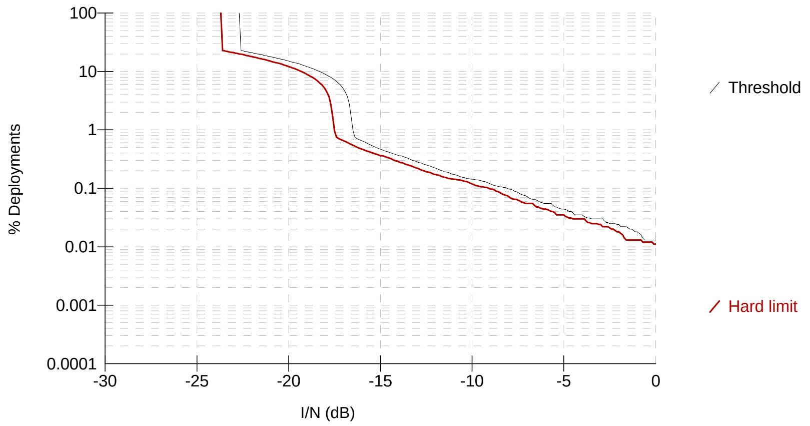
pfd = –115 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.85%

Hard limits

pfd = –116 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.9%



From these graphs, it is clear that the pfd threshold mask provides 99.85% of all BAS stations deployed with an I/N of better than −10 dB. This means that only 150 of the 100 000 BAS stations could see an I/N above the desirable −10 dB.

3.4.2.2.5 Results for large BAS antenna sizes

The following three graphs in Fig. 3.4-9 illustrate the *I*/*N* versus percentage of BAS deployment of larger antenna sizes (3.0m) for both pfd masks. Beside each figure, the approximate percentage of deployments that would see an *I*/*N* of less than −10 dB is identified for the pfd threshold and hard limit pfd masks.

FIGURE 3.4-9

***I*/*N* ratio corresponding to the % of deployments within a given range of elevation angles**

0°-5° elevation angles

Threshold

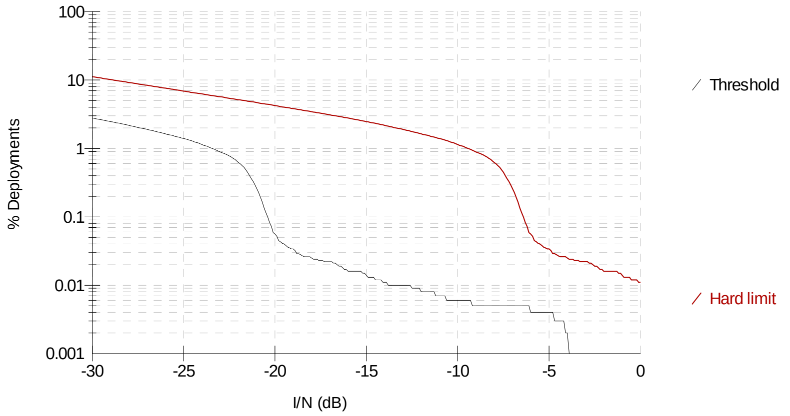
pfd = –140 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.993%

Hard limits

pfd = –126 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99%



5°-20° elevation angles

Threshold

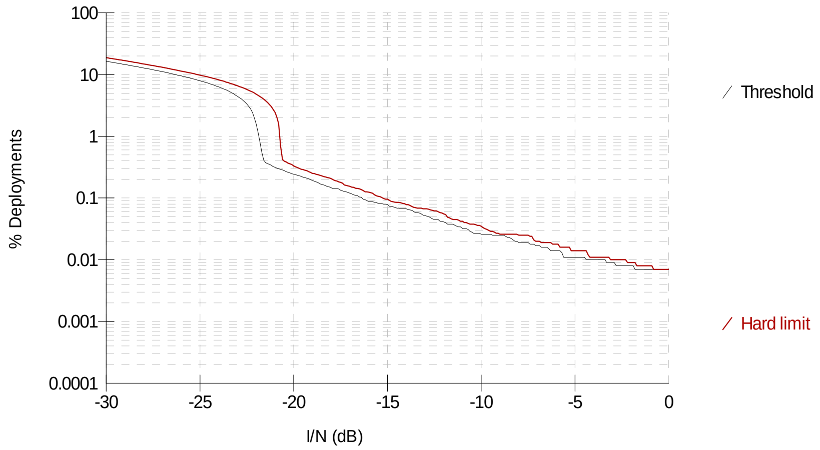
pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.97%

Hard limits

pfd ≈ –121 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.96%



25°-90° elevation angles

Threshold

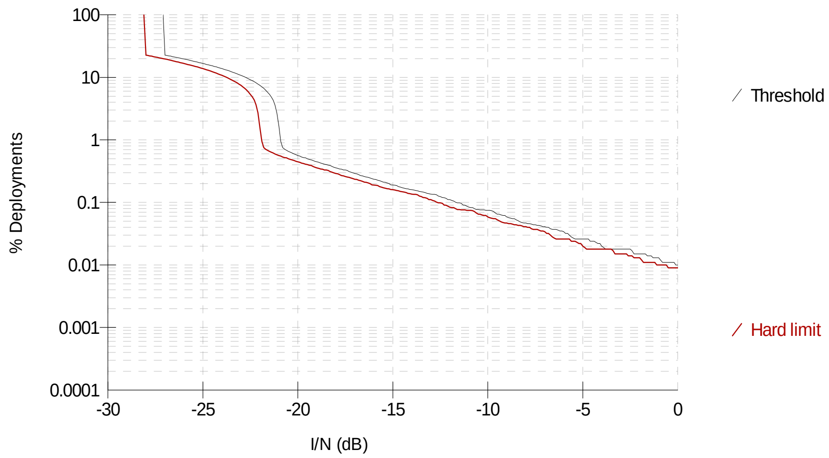
pfd = –115 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.92%

Hard limits

pfd = –116 dB(W/m^2 · MHz)

$I/N \leq -10$ dB ≈ 99.94%



From these graphs, it is clear that the pfd threshold mask provides 99.92% of all BAS stations deployed with an *I*/*N* of better than −10 dB. This means that only 80 of the 100 000 BAS stations could see an *I*/*N* above the desirable −10 dB. It should be noted that the worst cases would sometimes not be shown in the graphs as these portions of the curves extend beyond the right edge of the graphs in Fig. 3.4-8.

Furthermore, independent of the BAS receive antenna size used, improvements from polarization and benefits from clutter are not considered which could improve the *I*/*N* performance for BAS stations.

Comparing the results from the small BAS receive antennas with the large antennas shows that the impact of the MSS into BAS is more a function of the off-axis antenna pattern rather than the peak on-axis gain of the antenna itself. These statistical results show that the likelihood of interference to the BAS is going to occur to a very small percentage of the BAS deployments and that the BAS receive antenna size does not play a critical role in the results.

Although the probability of BAS stations receiving interference is shown to be quite low, this probability cannot be ignored. Degradation of service availability of a BAS system could cause the interruption of broadcasting service potentially affecting a large number of viewers. As stated above, choosing different parameters for the probability distribution function will alter the outcome of the statistical analysis. The parameters should be chosen dependent on the area being considered. To ensure the protection of BAS, it is appropriate to establish a pfd limit taking into account both the static and statistical analyses.

3.4.2.3 Interference from BAS stations to MESs

Table 3.4-6 contains BAS characteristics applicable to the band 10.55-10.68 GHz band. From this information the characteristics given in Table 3.4-8 have been used to assess interference from BAS transmitters to MES receivers. The figures in italics are assumptions made for the purpose of this analysis.

TABLE 3.4-8

Fixed and mobile BAS transmitter station characteristics

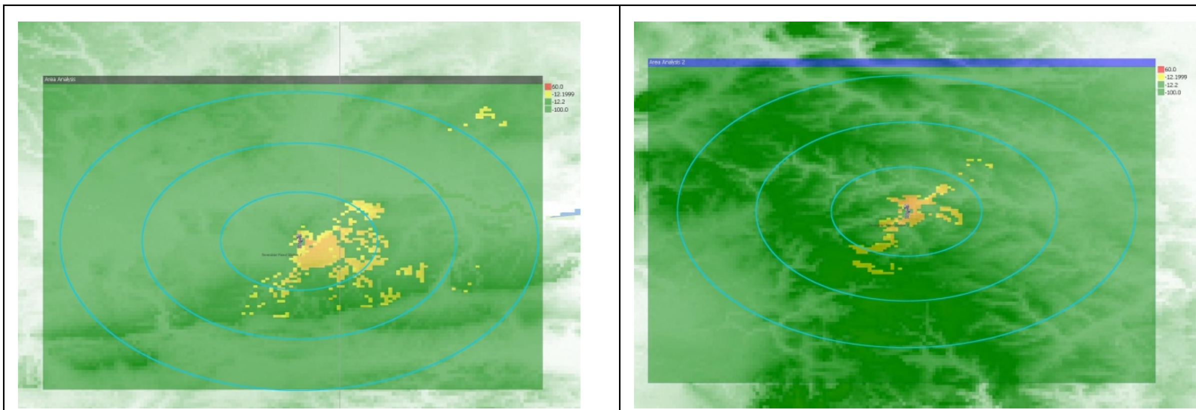
Frequency band (GHz)	10.5-10.6 (Fixed BAS)			10.55-10.68 (Mobile BAS)		
Antenna type	Parabolic	Parabolic	Parabolic	Omni-directional	Horn	Parabolic
Capacity (Mbit/s)	Up to 30	Up to 60	Up to 66	60	60	60
Emission bandwidth (MHz)	9	18	18	18	18	18
Antenna gain (maximum) (dBi)	48.2	48.2	48.2	2	20	35
Antenna pattern	Rec. ITU-R F.699	Rec. ITU-R F.699	Rec. ITU-R F.699	Omni	Parabolic roll-off to 31°, then −10 dBi	Rec. ITU-R F.699
Feeder/multiplexer loss (minimum) (dB)	1	1	1	1	1	1
Maximum Tx output power (dBW)	4	7	1.76	7*	7*	7*
e.i.r.p. (maximum) (dBW)	51.2	54.2	49.0	8	26	41
Antenna height a.g.l. (m)	*10 to 70*			*2*	*2*	*30*
Antenna azimuth (degrees)	*0 to 360*			*N/A*	*0 to 360*	
Antenna elevation (degrees)	*–3 to 3*			*N/A*	*–10 to 90*	

* –3dBW in the band 10.6-10.68 GHz.

Regarding mobile BAS transmitter station, the parameters in italics are assumptions for the purpose of this study. The antenna azimuth of 270° was chosen arbitrarily to represent a typical situation. For an FS station pointing due north, interference may be higher due to the higher horizon antenna gain of the MES which is assumed to be pointing due south. Figures 3.4-10 to 3.4-12 show the locations where interference from the BAS station would exceed in *I*/*N* criterion of −12.2 dB as the yellow and orange shaded areas. The blue circles have radius 10 km, 20 km and 30 km.

FIGURE 3.4-10

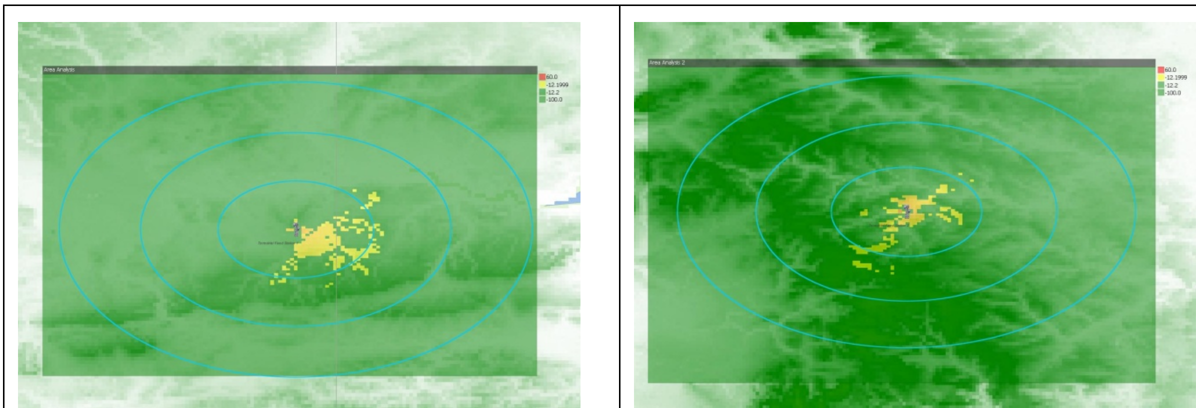
Interference from BAS station with omnidirectional antenna to "pocket" MES



(a) FS station at Crystal Palace | (b) FS station in Huddersfield

FIGURE 3.4-11

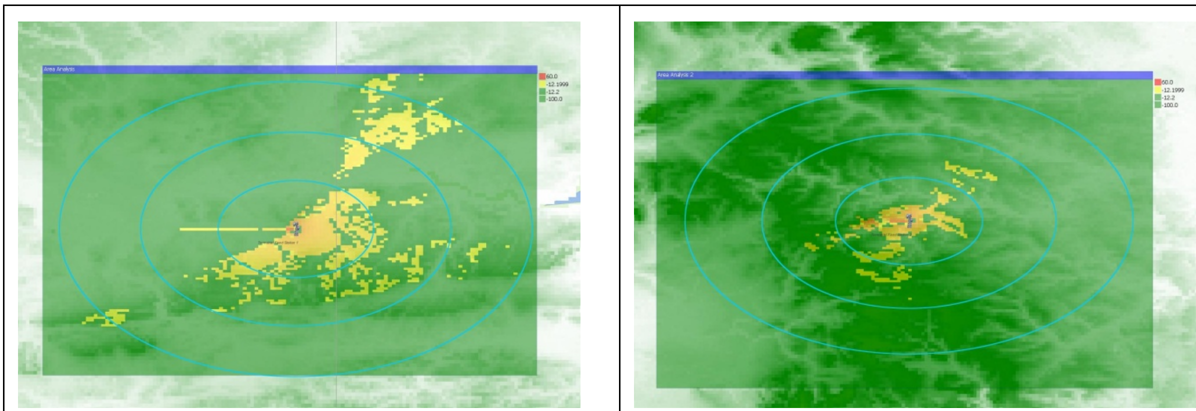
Interference from BAS station with horn antenna to "pocket" MES



(a) FS station at Crystal Palace | (b) FS station in Huddersfield

FIGURE 3.4-12

Interference from BAS station with parabolic antenna to "pocket" MES



(a) FS station at Crystal Palace | (b) FS station in Huddersfield

There is a possibility that the MES would receive interference above the recommended criterion from a BAS transmitter. Considering the ubiquitous nature of the MES, some administrations consider that MES terminals should not claim protection from BAS stations or limit further deployment of BAS links in this band if there will be a new allocation for MSS (downlink).

3.4.3 Sharing with radiolocation systems

In the band 10.5-10.55 GHz, the radiolocation service is allocated on a secondary basis in Region 1 and on a primary basis in Regions 2 and 3. In the band 10.55-10.6 GHz, the radiolocation service is allocated on a secondary basis in all three Regions.

In the European Community, EC Decision 2009/381/EC[8] identifies the band 8.5-10.6 GHz for Tank Level Probing Radar applications. Such devices are restricted to use inside tanks and are limited in power to 30 dBm inside the tank. The tank will provide attenuation to interference which might enter the tank (e.g. from MSS downlinks) and will provide attenuation to interference from the radars to MES. It is therefore assumed that the interference risks are sufficiently small as to be ignored here.

Radiolocation devices for other applications are included in Recommendation ERC/REC 70-03[9] with a recommended peak power of 500 mW e.i.r.p. These radar applications (tank level probing radars and those included in Recommendation ERC/REC 70-03) are called system type-1. It is possible to protect radiolocation type-1 systems through the same pfd limits for MSS as those applicable for terrestrial services in the band 10.5-10.6 GHz.

With regard to the radiolocation service, there are no ITU-R Recommendations which include characteristics of radiolocation systems used in the band 10.55-10.6 GHz. However, Recommendation ITU-R M.1796, which contains the characteristics and protection criteria of radiolocation system in the band 8.5-10.5 GHz, is currently being revised to include the band 10.5-10.68 GHz. These radar applications of Recommendation ITU-R M.1796 are called system type-2 in this study.

Four radars which are described in proposed revisions to Recommendation ITU-R M.1796 have been studied Those radars: G17, G18, G19 and G20, may operate in the frequency band 10.5-10.6 GHz.

8 Official Journal of the European Union L 119 of 14.05.2009, page 32.

9 Recommendation ERC/REC 70-03 can be downloaded from the CEPT webpage on www.cept.org.

3.4.3.1 Interference from MSS satellite transmitters (downlink) to radar receivers

Recommendation ITU-R M.1461 is about procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services. According to the Recommendation, the signal level I_T at which the radar receiver performance starts to degrade (i.e. turning point) is decided by the following equation:

$$I_T = I/N + N \tag{3}$$

where:

I/N : interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria (dB)

N : receiver inherent noise level

$$N(\text{dBm}) = -114 \text{ dBm} + 10 \log B_{IF}(\text{MHz}) + NF$$

or:

$$N(\text{dBW}) = -144 \text{ dBW} + 10 \log B_{IF}(\text{MHz}) + NF$$

where:

B_{IF} : receiver IF bandwidth (MHz)

NF : receiver noise figure (dB).

$$I_R = P_T + G_T + G_R - L_T - L_R - L_P - FDR_{IF} \tag{4}$$

where:

I_R : peak power of the undesired signal at the radar receiver input (dBm or dBW)

P_T : peak power of the undesired transmitter under analysis (dBm or dBW)

G_T : antenna gain of the undesired system in the direction of the radar under analysis (dBi)

G_R : antenna gain of the radar station in the direction of the system under analysis (dBi)

L_T : insertion loss in the transmitter (dB)

L_R : insertion loss in the radar receiver (dB)

L_P : propagation path loss between transmitting and receiving antennas (dB)

FDR_{IF} : frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB). For co-frequency analysis, FDR_{IF} can be set to 0 dB.

This analysis takes an assumption of MSS downlink power density of 45.4 dBW/MHz at 35 786 km

Analysis of interference to Radars G18, G17, G19 and G20

Radar characteristics herein assumed in the interference assessment are shown in Table 3.4-9.

TABLE 3.4-9

Radar characteristics

Radar type	System G18	System G17	System G19	System G20
Tuning range (GHz)	10.5-10.6	10.5-10.6	10.5-10.6	10.5-10.6
Antenna main beam gain (dBi)	43	35.5	42.2	46
Antenna 1st side-lobe levels (dBi)	23	22.5	29.2	33
Antenna back-lobe level (dBi)	−7	5.5	12.2	16
Antenna elevation (degrees)	+83/−30	±60	±90	+85/−10
Receiver IF 3 dB bandwidth (MHz)	0.5	0.48	0.52	10
Receiver noise figure (NF) (dB)	3.5	3.6	3.4	4.5
L_R (dB)	2	2	2	2
Interference criterion I/N (dB)	−6	−6	−6	−6
N (dBW)	−143.5	−143.6	−143.4	−129.5
I_T (dBW)	−149.5	−149.6	−149.4	−135.5

The analysis of interference from MSS satellite downlink to radar receivers shows System G18 will receive the most interference (of the four radars in Table 3.4-9). The analysis results for System G18 are given in Table 3.4-10.

Table 3.4-10 shows three cases. The first case is in which the MSS downlink signal falls into the main beam of the radar, i.e. main beam coupling, and the peak power of the undesired signal at the radar receiver input is about −122.1 dBW, 27.4 dB higher than the signal level of −149.5 dBW at which the radar receiver performance starts to degrade. The result indicates that MSS downlinks could cause interference to the radar receiver.

The second is the case in which the MSS downlink signal falls into the side lobe of the radar, and the peak power of the undesired signal at the radar receiver input is 7.4 dB higher than the signal level of the protection criterion, which also means there is interference to the radar receiver.

The third is the case in which the MSS downlink signal falls into the back-lobe of the radar antenna, and the peak power of the undesired signal at the radar receiver input is much lower than the signal level of the protection criterion, which means no interference to the radar receiver.

TABLE 3.4-10

Interference from MSS satellite downlink to System G18

MSS downlink e.i.r.p. density (dBW/MHz)	45.4		
Free-space loss (dB)	203.5		
L_T (dB)	2		
Signal power density to the Earth (dBW/MHz)	−160.1		
	Main beam coupling	Side-lobe coupling	Back-lobe coupling
I_R density (dBW/MHz)	−119.1	−139.1	−169.1
I_R (dBW)	−122.1	−142.1	−172.1
Excess interference from MSS downlink (dB)	27.4	7.4	−22.6

The pfd level from MSS satellite at the Earth's surface is −118.6 dBW/m^2 in 1 MHz. In accordance with the conducted calculations, the required pfd level from the MSS satellite shall be −146.0 dBW/m^2 in 1 MHz to protect the type-2 radars.

Calculations identical to those shown in Table 3.4-10 were done for all systems, and the results are summarized in text below. Table 3.4-11 summarizes the interference results for these four systems.

TABLE 3.4-11

Summary of analysis results

Interferer	**Victim**	**Antenna coupling configurations causing interference**
GSO MSS	System G17	Main lobe to main lobe antenna coupling cases GSO MSS main lobe to RLS side lobe coupling case
GSO MSS	System G18	Main lobe to main lobe antenna coupling cases GSO MSS main lobe to RLS side lobe coupling case
GSO MSS	System G19	Main lobe to main lobe antenna coupling cases GSO MSS main lobe to RLS side lobe coupling case
GSO MSS	System G20	Main lobe to main lobe antenna coupling cases GSO MSS main lobe to RLS side lobe coupling case

In the worst case (system G18), the MSS downlink pfd would have to be reduced by 27.4 dB to meet the criterion, assuming main lobe-to-main lobe alignment.

This study used Recommendation ITU-R M.1461, a static analyses, to determine if interference will occur. Antenna coupling is dependent on the geometry between the systems and there is not enough information about the deployment and operation of the two systems to make accurate geometric simulations.

A statistical analysis could lead to improved results.

3.4.3.2 Interference from type-2 radar transmitters into MES receivers

Since higher power radiolocation applications may be used as included in Recommendation ITU-R M.1796, it is necessary to consider the potential interference from radar transmitters to MES receivers. This interference mechanism occurs when the energy emitted from the radar transmitter falls within the IF passband of the MES receiver. When the radar emission levels in the receiver passband are high relative to the desired signal level, performance degradation to the receiver can occur.

Equations (3) and (4) as contained in Recommendation ITU-R M.1461 can also be used for analysing the interference from radar transmitters to MES receivers. In equation (3), N can be calculated in another way as below:

$$N\,(\text{dBW}) = -168.6 \text{ dBW} + 10 \log B_{IF}\,(\text{MHz}) + 10 \log T$$

where:

T : system noise temperature (K).

Table 3.4-12 contains assumed radar characteristics for assessing the potential interference from the radar transmitter to the MES receiver. These are provided by one administration. The worst interference case occurs when the radar main beam points to the MES receiver, but the remote side lobe of the radar with high power and high gain may also cause the interference to the MES receiver, which is perhaps more likely case. Therefore, the interference effect of the remote side lobe to the MES receiver is analysed herein under the mean transmitter power considering the operation of the radar with high power and high gain.

TABLE 3.4-12

Radar characteristics assumed in the interference assessment

Tuning range (GHz)	10.5-10.6
Peak power into antenna (W)	25 000
Mean power into antenna (W)	250
RF emission bandwidth (MHz)	10
Antenna main beam gain (dBi)	42
Antenna altitude (m)	5
Remote side-lobe attenuation (dB)	40
L_T (dB)	2

Table 3.4-13 is the "pocket" MES characteristics in Annex 1. This kind of MES may be the worst case in terms of being subject to interference among the four example MES types (pocket, notebook, briefcase, suitcase).

TABLE 3.4-13

Receiving "pocket" MES characteristics

MES antenna gain (dBi)	22.2
MES antenna pattern	Rec. ITU-R F.699
Antenna elevation angle (degrees)	25
Antenna azimuth angle (degrees)	180
MES noise temperature (K)	400
Antenna diameter (m)	0.2
Antenna altitude (m)	1
L_R (dB)	2
Interference criterion I/N (dB)	−12.2
Noise in 1 MHz (dBW/MHz)	−142.6
I_T density (dBW/MHz)	−154.8

Under the above assumed parameters and Recommendation ITU-R P.452/ITU-R P.526 propagation model, separation distances between a radar transmitter and a MES receiver under various MES antenna off-axis gains and receiving power densities are obtained respectively by simulation, as shown in Table 3.4-14. The results of simulation indicate that the radar transmitter with high power and high antenna gain would likely cause serious interference to the MES receiver when the MES is within the beam of the radar antenna, and even the separate distance for preventing remote side-lobe interference is at least over 20 km. That is to say, it is not possible for MES receivers and radar transmitters with high power and high antenna gain to operate compatibly within hundreds sq. km. of area in the same frequency band at the same time even only considering the effect of the radar side lobe.

TABLE 3.4-14

Interference from radar transmitters into MES receivers

Mean power density (dBW/MHz)	MES antenna off-axis angle (degrees)	MES antenna gain (dBi)	I_R density (dBW/MHz)	Propagation loss (dB)	Separate distance (km)
14	0	22.2	−100	132.2	2.9
			−130	162.2	14.3
			−154.8	187	31.2
	10	17	−100	129	2.7
			−130	159	13.2
			−154.8	183.8	28.5
	30	5	−100	117	1.5
			−130	147	6.2
			−154.8	171.8	21

3.4.3.3 Summary

This section presents sharing studies between MSS and radiolocation service in the band 10.5-10.6 GHz under certain assumptions based on ITU-R Recommendations applicable to the adjacent band 8.5-10.5 GHz and possible applications of radiolocation services in the band 10.5-10.6 GHz.

For tank level probing radar applications and similar low power devices (type-1), it is assumed that the interference risks are sufficiently small as to be ignored here.

For other radiolocation applications which use high gain antennas (type-2), the carried out studies show that interference from MSS satellite to RLS station exceeds the permissible level by 27.4 dB. Therefore, shared operation of these services is difficult in the considered frequency band. The pfd level from the MSS satellite at the Earth's surface is −118.6 dBW/m^2 in 1 MHz. In accordance with the conducted calculations the required pfd level from the MSS satellite shall be −146.0 dBW/m^2 in 1 MHz.

To address the situation of all countries, it would be possible:

– to protect radiolocation type-1 systems through the same limits as those applicable for terrestrial services in the band 10.5-10.6 GHz;

– to protect radiolocation type-2 systems through a pfd level of −146 dBW/m^2 in 1 MHz where such systems are in operation.

Also MES receivers could receive interference from radar transmitters with high power and high antenna gain within hundreds of square kilometres of area in the same frequency band, even considering only the effect of the radar side-lobe emissions.

3.4.4 Compatibility with the radio astronomy service operating in the band 10.6-10.7 GHz

The band 10.5-10.6 GHz is considered for MSS downlink operations. This leads to potential interference to radio astronomy stations receiving in the adjacent band 10.6-10.7 GHz. The threshold values for protection of radio astronomy stations are in Recommendation ITU-R RA.769. From Recommendation ITU-R RA.769, it is understood that the band 10.6-10.7 GHz band is used for continuum measurements and very long baseline interferometry (VLBI) measurements.

The criterion for continuum measurements is a pfd value −160 dBW/m^2 in an assumed bandwidth of 100 MHz. Table 3.4-15 shows the interference relative to the recommended threshold value for continuum observations.

TABLE 3.4-15

Adjacent band interference from MSS downlink to radio astronomy station

MSS e.i.r.p. (dBW/MHz)	46
Adjacent band power ratio (dB)	35
e.i.r.p. in adjacent band (dBW/MHz)	11
Minimum e.i.r.p. to pfd (dB)	162.1
Maximun pfd at earth surface (adjacent band) (dBW/m^2)	−151.1
Continuum	
Assumed bandwidth (MHz)	100
Threshold pfd in assumed bandwidth (dBW/m^2)	−160
Threshold pfd in 1 MHz (dBW/m^2)	−180
Required discrimination (dB)	28.9
VLBI	
Reference bandwidth (Hz)	1
Threshold pfd in assumed bandwidth (dBW/m^2)	−193
Threshold pfd in 1 MHz (dBW/m^2)	−133
Required discrimination (dB)	−18.1

With respect to the radio astronomy service, compatibility is feasible with some conditions on MSS operations. Additional filtering would be required to meet the threshold level for continuum measurements. Based on these assumptions, the average reduction in O.B emissions from the MSS satellite would be 28.9 dB in the band 10.6-10.7 GHz. This would require filtering to be included in the satellite design, but is not major technical challenge. No special requirements would be needed with respect to the VLBI threshold level as the predicted pfd is lower than the threshold level.

3.4.5 Compatibility with remote passive sensors operating in the band 10.6-10.7 GHz

The band 10.6-10.68 GHz is allocated to the EESS passive, radio astronomy and space research (passive) services and also terrestrial services (fixed and mobile). The band 10.68-10.7 GHz has a provision, RR No. 5.340, relevant for passive services (see Table 3.4-16).

At the WRC-07, RR No. 5.482A was added, which introduces the limits applicable for the fixed and mobile services in order to protect the EESS (passive) for the band 10.6-10.68 GHz (Resolution 751 (WRC-07) applies).

TABLE 3.4-16

Adjacent band allocations

Services in lower allocated bands		Passive band	Service in upper allocated band
10.55-10.6 GHz	**10.6-10.68 GHz**	**10.68-10.7 GHz**	**10.7-11.7 GHz**
FIXED MOBILE except aeronautical mobile radiolocation	EARTH EXPLORATION-SATELLITE (Passive) FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY SPACE RESEARCH (Passive) Radiolocation 5.149 5.482 5.482A	EARTH EXPLORATION-SATELLITE (Passive) RADIO ASTRONOMY SPACE RESEARCH (Passive) 5.340 5.483	FIXED FIXED-SATELLITE (space-to-Earth in all Regions) 5.441 5.484A (Earth-to-space in Region 1) MOBILE except aeronautical mobile

The band 10.6-10.7 GHz is of primary interest to measure rain, snow, sea state and ocean wind.

3.4.5.1 Required protection criteria

The following three documents establish the interference criteria for passive sensors:

1) Recommendation ITU-R RS.515-4, "Frequency bands and bandwidths used for satellite passive services".
2) Recommendation ITU-R RS.1028-2, "Performance criteria for satellite passive remote sensing".
3) Recommendation ITU-R RS.1029-2, "Interference criteria for satellite remote sensing".

The first criterion is the permissible interference power received by the EESS sensor which is −166 dBW in the reference bandwidth of 100 MHz. This is a maximum interference level from all sources.

The second criterion is the frequency of occurrence limit on the threshold being exceeded. These interference levels should not be exceeded for more than 0.1% of sensor viewing area (data availability of 99.9%) for measurement area defined as a square on the Earth of 10 000 000 km^2.

3.4.5.2 Operational characteristics

According to Recommendation ITU-R RS.1861, Table 3.4-17 shows specifications for five microwave radiometric systems (see also Figures 3.4-13 and 3.4-14).

TABLE 3.4-17

EESS (passive) sensor characteristics in the 10.6-10.7 GHz band

	Sensor C1	**Sensor C2**	**Sensor C3**	**Sensor C4**	**Sensor C5**
Sensor type	Conical scan				
Orbit parameters					
Altitude	817 km	705 km	833 km	835 km	699.6 km
Inclination	98°	98.2°	98.7°	98.85°	98.186°
Eccentricity	0	0.0015	0	0	0.002
Repeat period	N/A	16 days	17 days	N/A	16 days
Sensor antenna parameters					
Number of beams	1		2	1	
Reflector diameter	0.9 m	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	36 dBi	42.3 dBi	45 dBi	36 dBi	44.1 dBi
Polarization	H, V		H, V, R, L	H, V	
−3 dB beamwidth	2.66°	1.4°	1.02°	3.28°	1.2°
Instantaneous field of view	56 km × 30 km	51 km × 29 km	48 km × 28 km	76 km × 177 km	41 km × 21 km
Main beam efficiency		94.8%	95%		93%
Off-nadir pointing angle	44.3°	47.5°	47°	55.4°	47.5°
Beam dynamics	20 rpm	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	52°	55°	58.16°	65°	55°
−3 dB beam dimensions	56.7 km (cross-track)	27.5 km (cross-track)	42.9 km (cross-track)	N/A	23 km (cross-track)
Swath width	1 594 km	1 450 km	1 600 km	2 000 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813	Fig. 8a	Fig. 8b	See Rec. ITU-R RS.1813	
Cold calibration ant. gain	N/A	29.1 dBi	N/A		29.6 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5°	N/A		115.5°
Cold calibration angle (degrees re. nadir direction)	N/A	97.0°	N/A		97.0°
Sensor receiver parameters					
Sensor integration time	1 ms	2.5 ms	2.47 ms	N/A	2.5 ms
Channel bandwidth	100 MHz	100 MHz centred at 10.65 GHz			
Measurement spatial resolution					
Horizontal resolution	38 km	27 km	15 km	38 km	23 km
Vertical resolution	38 km	47 km	15 km	38 km	41 km

FIGURE 3.4-13

Sensor C1 antenna pattern envelope for the 10.6-10.7 GHz band

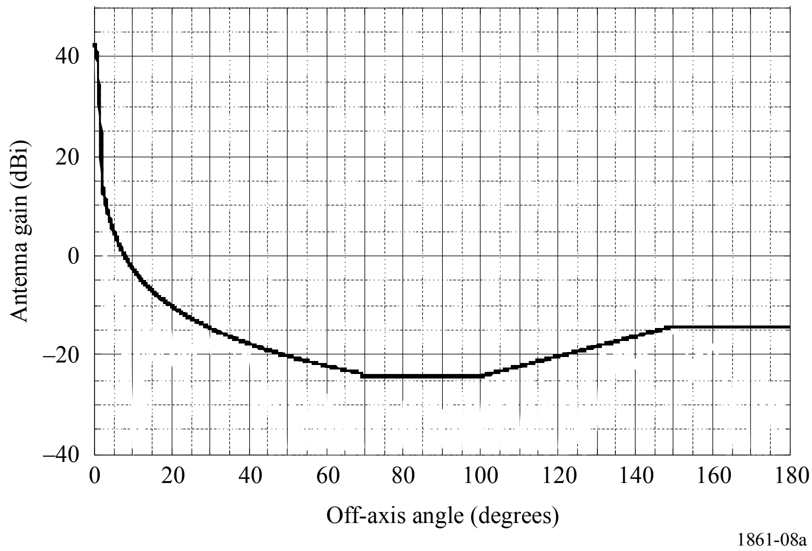
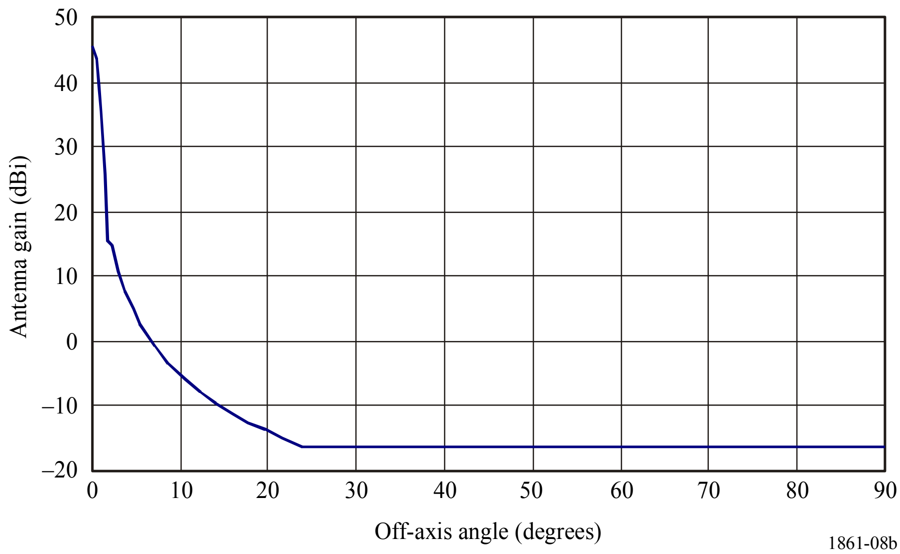


FIGURE 3.4-14

Sensor C2 antenna pattern envelope for the 10.6-10.7 GHz band



3.4.5.3 Methodology and analysis

The purpose of this study computes the potential amount of MSS downlink unwanted emissions received by the EESS passive sensors. The methodology consists of the following steps.

Step 1: compute the MSS unwanted emission level within the passive band 10.6-10.7 GHz.

Step 2: compare the computed level of unwanted emission with the protection level of EESS (passive) for this band.

Following the results of step 2, specific conclusions would be drawn.

3.4.5.4 Analysis of three different geometric situations

Tables 3.4-18 to 3.4-20 show link budget analysis based on three different geometric situations.

The first situation is when the EESS (passive) sensor receives all the MSS downlink energy through the back lobe.

TABLE 3.4-18

Interference to EESS (passive) sensor through the back lobe

Interference level: Rec. ITU-R RS.1029-2 | −186 | dBW/MHz

EESS (passive) sensor	SENSOR-5	AMSR-E SENSOR-2	CMIS SENSOR-3	SENSOR-1
Forward link e.i.r.p (dBW/MHz)	47.9	47.9	47.9	47.9
Distance GSO MSS − Satellite EESS passive (km)	35 084	35 079	34 951	34 967
Space attenuation (dB)	203.9	203.9	203.9	203.9
Back lobe sensor satellite antenna gain (dBi)	−17	−17	−17	−15
Received power at the EESS sensor (dBW/MHz)	−173.0	−173.0	−173.0	−171.0
Margin (dB)	−13	−13	−13	−15

The second situation is when the EESS (passive) sensor directly receives MSS downlink energy in a tangential configuration.

TABLE 3.4-19

Interference to EESS (passive) sensor in a tangential configuration

Interference level: Rec. ITU-R RS.1029-2 | −186 | dBW/MHz

EESS (passive) sensor	AMSR-E SENSOR-2
MSS output power (dBW)	33.5
MSS antenna gain (dBi)	14.4
Distance GSO MSS − Satellite EESS passive (km)	44 976
Space attenuation (dB)	206.0
EESS (passive) angle off nadir (degrees)	64.2
Passive sensor satellite antenna gain (dBi)	−6.0
Received power at the EESS sensor (dBW/MHz)	−164.1
Margin (dB)	−21.9

The third situation is when the EESS (passive) sensor receives downlink MSS backscattered energy.

TABLE 3.4-20

Interference to EESS (passive) sensor from MSS backscattered energy

Interference level: Rec. ITU-R RS.1029-2 −166 dBW/100 MHz

EESS (passive) sensor	AMSR-E SENSOR-2
Reflected area (km^2)	2000
MSS ground pfd (dB(W/m^2/4 kHz))	−140.0
Backscatter coeff (%)	10
Power reflected (100 MHz)	−13.0
Distance ground − Satellite EESS passive (km)	1 124
Space attenuation (dB)	174.0
Passive sensor satellite antenna gain (dBi)	42.3
Received power at the EESS sensor (dBW/100 MHz)	−144.7
Margin (dB)	−21.3

Interference is predicted to be 21.3 dB above the recommended criterion. This would require filtering to be included in the satellite design, but is not a major technical challenge. This indicates that MSS satellites should have no difficulty in meeting the protection requirements for remote passive sensor operating in the band 10.6-10.7 GHz.

3.4.5.5 Analysis of an aggregation situation

It is anticipated that multiple GSO MSS satellites will be in operation and therefore, may provide additional interference for the EESS satellite. The geometric satellite configuration which is envisaged here is that 2 GSO MSS in operation and using the same frequency bands are separated by 50° within the GSO arc.

The EESS (passive) satellite is located right below one GSO MSS satellite and therefore receives interference according to first (back lobe energy) and third situation (backscattered energy).

The second GSO MSS is located 50° away in longitude and the EESS (passive) radiometer may receive interference from such other MSS GSO according to the link budget shown in Table 3.4-21.

TABLE 3.4-21

Interference to EESS (passive) sensor from aggregate MSS interference

Interference level: Rec. ITU-R RS.1029-2 −186 dBW/MHz

EESS (passive) sensor	AMSR-E SENSOR-2
MSS output power (dBW)	33.5
MSS antenna gain (dBi)	14.4
Distance GSO MSS − Satellite EESS passive (km)	38 212
Space attenuation (dB)	204.6
EESS(passive) angle off nadir (degrees)	121.8
Passive sensor satellite antenna gain (dBi)	−17.0
Received power at the EESS sensor (dBW/MHz)	−173.7
Margin (dB)	−12.3

In total, the overall negative margin equals −21.3 dB for SENSOR 2.

3.4.5.6 Summary of the study and conclusion

− This study addresses GSO satellites only, since no MSS parameters have been provided for MEO and/or LEO MSS constellations for this frequency band.

− MSS satellite filtering may be required to protect remote sensors from interference via earth reflections. Additional MSS signal attenuation of about 22 dB would be required, but this is not a major technical challenge. The natural modulation roll-off plus some minor additional filtering is expected to achieve the required MSS signal attenuation.

− In order to achieve compatibility, it is necessary that MSS satellite pfd within the passive band 10.6-10.7 GHz would not exceed −118 dB(W/m^2/100 MHz) on the ground.

3.4.6 Summary of conclusions for the band 10.5-10.6 GHz

Regarding the feasibility of sharing with fixed radio-relay systems and BAS systems, it is confirmed that:

− the limits of RR Article 21 currently applicable in the band 10.7-11.7 GHz, i.e. between −126 dB(W/m^2 · MHz) (angles below 5°) rising to −116 dB(W/m^2 · MHz) for angles above 25°, are generally appropriate for the protection of FS links in the band 10.5-10.6 GHz;

− however, some countries also operate BAS systems in the band 10.5-10.6 GHz where it can be shown that different pfd protection levels could be required. As derived from a static evaluation, the proposed pfd values are −156 dB(W/m^2 · MHz) (angles below 3°) rising to −140 dB(W/m^2 · MHz) (angles 3-5°) and rising up to −115 dB(W/m^2 · MHz) for angles above 20°. Alternatively, through a statistically evaluation of the same limits of RR Article 21 currently applicable in the band 10.7-11.7 GHz, the protection of 99% of BAS deployments in the 10.5-10.6 GHz band would be achieved.

− comparing proposed two pfd limits, the pfd limit of RR Article 21 may cause interference levels of 30 dB above recognized protection criteria with the limit of −156/−115 dB(W/m^2 · MHz) with a large parabolic antenna under worst case conditions.

Interference could be caused by FS system and BAS systems to receiving earth stations. Example cases have been presented which show that interference above the criterion could be received up to about 15 km from an FS station, and about 30 km from a BAS station.

Regarding the feasibility of sharing with the radiolocation service, to address the situation of all countries, it would be possible:

− to protect radiolocation type-1 systems through the same limits as those applicable for terrestrial services in the band 10.5-10.6 GHz;

− to protect radiolocation type-2 systems through a pfd level of −146 dBW/m^2 in 1 MHz where such systems are in operation.

Also MES receivers could receive interference from radar transmitters with high power and high antenna gain within hundreds of square kilometres of area in the same frequency band, even considering only the effect of the radar side-lobe emissions.

With respect to the radio astronomy service, compatibility is feasible with some conditions on MSS operations. Additional filtering would be required to meet the threshold level for continuum measurements. Based on these assumptions, the average reduction in OoB emissions from the MSS satellite would be 28.9 dB in the band 10.6-10.7 GHz. This would require filtering to be included in the satellite design, but is not major technical challenge. No special requirements would be needed with respect to the VLBI threshold level as the predicted pfd is lower than the threshold level.

With respect to the EESS (passive) service operating in the band 10.6-10.7 GHz, the OoB emissions from MSS downlinks should not exceed −118 dB(W/m^2/100 MHz) on the ground to ensure no harmful interference to remote passive sensors.

3.5 Frequency band 13.25-13.4 GHz

The allocation of this band in RR Article **5** is indicated below.

13.25-13.4	EARTH EXPLORATION-SATELLITE (active) AERONAUTICAL RADIONAVIGATION 5.497 SPACE RESEARCH (active) 5.498A 5.499

This band is considered as a possible MSS downlink band.

3.5.1 Sharing with the aeronautical radionavigation service

This frequency band is used by the aeronautical radionavigation service (ARNS) on a primary basis. This use is limited to Doppler Navigation Aids (RR No. 5.497). According to the Handbook on Radio Frequency Spectrum Requirements for Civil Aviation (Doc. 9718-AN/957), 4th edition 2007 version, this band is widely used by Airborne Doppler navigation systems.

Airborne Doppler navigation systems are installed in aircraft (helicopters as well as certain airplanes) and used for specialized applications such as continuous determination of ground speed and drift angle information of an aircraft with respect to the ground. The Radio Technical Commission for Aeronautics (RTCA) has developed a standard for this equipment: DO-158 - Minimum Performance Standards − Airborne Doppler Radar Navigation Equipment.

Table 3.5-1 shows the technical and operational characteristics of ARNS systems in the band 13.25-13.4 GHz. Key technical characteristics of additional Doppler radar navigation equipment (DRNE) manufactured and used in one administration are given below in Table 3.5-2.

Another type of ARNS Doppler radar system is under development and will be used for Sense and Avoid (S&A) operations for Unmanned Aircraft (UA). This S&A radar will be used to provide information on near-by aircraft in order to maintain flight safety for UA's operating in non-segregated airspace.

The ARNS systems in this band, including S&A, have a safety of life mission.

TABLE 3.5-1

Technical and operational characteristics of radars operating in the aeronautical radionavigation service in the frequency band 13.25-13.40 GHz

Parameter	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6
Platform	Aircraft (helicopter)	Aircraft (helicopter)	Aircraft (airplane and helicopter)	Aircraft (airplane and helicopter)	Aircraft (helicopter)	Aircraft
Platform operational altitude (m)	3 000	2 800	10 400	15 000	0-4 500	0-4 500
Radar type	Doppler navigation radar	Doppler navigation radar	Doppler navigation radar	Doppler navigation radar	Doppler radar velocity sensor	Doppler radar velocity sensor
Frequency tuning range between 13.25-13.4 GHz	Fixed single channel	Fixed single channel	Fixed single channel	Fixed single channel	Fixed single channel	Fixed single channel
Emission type	Continuous wave Doppler (CW)	Intermittent continuous wave Doppler	Frequency modulated-continuous wave (FM-CW)	Continuous wave Doppler (CW)	Frequency modulated-continuous wave (FM-CW)	Unmodulated pulse
Pulse width (μs)	Not applicable	1 to 4	Not applicable	Not available	Not applicable (FM)	4 to 7
Pulse rise and fall times (ns)	Not applicable	20	Not available	Not available	Not applicable (FM)	0.2, 0.2
RF emission bandwidth at −40 dB (kHz)	Not applicable	20 000	350	Not available	150	60
Pulse repetition frequency (pps)	Not applicable	Not available	Not available	Not available	Not applicable (FM)	80 000
Peak transmitter power (W)	0.85	0.132	0.18	1.0	0.050	40 20 Average

TABLE 3.5-1 (*continued*)

Parameter	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6
Receiver IF bandwidth (−3 dB) (kHz)	1.4 Estimated	1.6 Estimated	55 000	2.9 Estimated	14	2 500
Sensitivity (dBm)	−135 for 0 dB *S/N*	−135	−134 for 0 dB *S/N*	−138 for 3 dB *S/N*	−130 for 3 dB *S/N* (v = 100 m/s) −160 for 3 dB *S/N* (v = hover)	−96 for 3 dB *S/N* (v = 100 m/s)
Receiver noise figure (dB)	22 (Homodyne Receiver)	22 (Dual Conversion Homodyne Receiver)	12 (Double Conversion Superhet Receiver)	22 (Homodyne Receiver)	22 (Homodyne Receiver)	7.5
Antenna type	Parabolic reflector	Phased array	Phased array	Phased array	Printed circuit array	Printed circuit array
Antenna placement	Points towards Earth	Points towards Earth	Points towards Earth	Points towards Earth	Points towards Earth	Points towards Earth
Antenna gain (dBi)	27	27	26	29.5	26.5	18
First antenna side lobe (dB)	5.5	Not available	9	14.2° at 4°	−10	−10
Horizontal beamwidth (degrees)	7	3.3	9	4.7	4.0	20
Vertical beamwidth (degrees)	4.5	5	3	2.5	3.4	4.2
Polarization	Linear	Not available	Not available	Linear	Linear	Linear
Number of beams	4	4	4	4	4	2
Antenna beam configuration	Employs Janus system. Approximate four corners of a pyramid with each 18° from vertical	Not available	Employs Janus system. Approximate four corners of a pyramid with each 16° from vertical	Employs Janus system	Employs Janus system. Approximate four corners of a pyramid with each 20° from vertical	Two beams

TABLE 3.5-1 (*end*)

Parameter	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6
Antenna scan	Scan is one beam at a time for each corner of the pyramid	Scan is one beam at a time for each corner of the pyramid	Scan is one beam at a time for each corner of the pyramid	Not available	Scan is one beam at a time for each corner of the pyramid	Not available
Protection criteria (dB)	−10	−10	−10	−10	−10	−10

NOTE 1 − The service ceiling of helicopters is generally lower than 7 000 m MSL, while the service ceiling of fixed-wing maritime patrol aircraft is approximately 15 000 m MSL.

NOTE 2 − The sensitivity calculation (assuming a minimum 3 dB *S*/*N* requirement for tracking) for a Doppler system must account for the bandwidth of the receiver's tracker. Sensitivity calculated with respect to the wide-open receiver bandwidth will yield a relatively low figure compared with the sensitivity based on the tracker's dynamic bandwidth. In a current-generation tracker, this bandwidth is comparable to the bandwidth of the back-scattered radar signal's spectrum, which itself varies with the velocity of the aircraft.

NOTE 3 − The actual instantaneous pointing direction of individual antenna beams depends on the installation attitude of the airborne Doppler radar with respect to the aircraft reference axes (it is not always level), as well as the pitch and roll state of the aircraft. Helicopters flying search patterns or making abrupt acceleration/deceleration manoeuvres will often have roll and pitch values in excess of 30° for short periods of time. The attitude excursions for high-performance military helicopters are even higher.

NOTE 4 − For systems where no noise figure is available, assume a value of 12 dB for systems employing IF receivers and 22 dB for Homodyne (zero IF) receivers. Reference Fried, W. R.: Principles and Performance Analysis of Doppler Navigation Systems, IRE Trans., Vol. ANE-4, pp.176-196, December 1957.

TABLE 3.5-2

Additional ARNS system characteristics

Parameter	Typical value	
	Airplane DRNE	**Helicopter DRNE**
The range of measured ground speed (km/h)	180 − 1 300	50 − 399
Operating altitude range (m)	Up to 15 000	Up to 3 500
Frequency band (MHz)	13 249-13 401	13 295-13 355
Type of emission	Non modulated	Non modulated
Transmitter power (W)	0.125-10	0.15-10
Capture sensitivity of receiver (dB/mW)	−110 in search mode −120 in tracking mode	No less than −114
UHF band pass (MHz)	No more than 15	100
Uninterrupted working time	During the whole flight (up to 24 h)	During the whole flight (up to 6 h)
Antenna	Slotted-waveguide	Horn-reflector antenna
Number of beams	3 or 4	3
Antenna gain (beam) (dBi)	No less than 20	No less than 27.8
Side lobe level (relative) (dB)	−13	−35
Back lobe level (relative) (dB)	–	−50
Off-nadir angle (degrees)	9… 11	18
Antenna placement	Bottom of aircraft fuselage	Bottom of aircraft fuselage (tail boom)

The proposed characteristics for the S&A ARNS Doppler radar on future UA are shown in Table 3.5-3.

TABLE 3.5-3

Characteristics of proposed UA S&A system

Parameter	Victim S&A ARNS
Centre frequency (MHz)	13325
Receiver IF bandwidth (MHz)	1.1
Bandwidth correction factor (dB)	0 (tx bw < rx bw)
Receiver noise figure (dB)	3
Protection criterion (*I*/*N*) (dB)	−10
Calculated receiver noise power (dBW)	−140.6
Interference threshold value (dBW)	−150.6

TABLE 3.5-3 (*end*)

Parameter	Victim S&A ARNS
Antenna parameters	
Polarization type	Linear
Antenna pattern	Sine
Polarization loss (dB)	3
Antenna cable losses (dB)	2
Antenna height (km)	20
Peak antenna gain (dBi)	32
Peak antenna side lobe gain (dB)	19
Antenna back lobe gain (dB)	2

Two interference scenarios should be considered:

− *Scenario 1:* interference from MSS space station towards airborne ARNS receivers and

− *Scenario 2:* interference from ARNS transmitters towards MSS (user terminals).

3.5.1.1 Analysis of potential interference from MSS downlink to ARNS receivers

Interference by direct coupling

The MSS transmitter characteristics are:

− Frequency: 13 325 MHz

− e.i.r.p.: 45.4 dBW

− Transmitter bandwidth: 1 MHz

− Transmitter cable loss: 2 dB

− MSS altitude: 35 786 km.

The ARNS radars have different maximum altitudes, but the differences are not enough to appreciably change the free space loss, which is calculated in all cases as 206.0 dB. The transmitter signal power density on the Earth is therefore the same in all cases, calculated as −162.6 dBW/MHz.

For Radars 1-6, the ARNS antenna is directed to the ground (typically 16-20° off-nadir), therefore interference will be received in the side lobe of the ARNS antenna. The antenna patterns for the ARNS receivers are not given, so the assumed value is −3.5 dBi in the direction of the MSS satellite.

The interference analysis methodology follows Recommendation ITU-R M.1461. The results are shown in Table 3.5-4.

TABLE 3.5-4

Direct interference from MSS downlinks to ARNS receivers

	RADAR 1	RADAR 2	RADAR 3	RADAR 4	RADAR 5	RADAR 6
Rx antenna gain (dB)	−3.5	−3.5	−3.5	−3.5	−3.5	−3.5
Rx insertion loss (dB)	2	2	2	2	2	2
I_R density (dBW/MHz)	−168.1	−168.1	−168.1	−168.1	−168.1	−168.1
Rx IF bandwidth (MHz)	0.0014	0.0016	55	0.0029	0.0014	2.5
On-tune rejection (dB, zero if Rx IF bw > Tx bw)	28.5	28.0	0	25.4	28.5	0
I_R (dBW)	−196.7	−196.1	−168.1	−193.5	−196.7	−168.1
Receiver noise figure (dB)	22	22	12	22	22	7.5
Receiver noise power (dBW)	−150.5	−150.0	−114.6	−147.4	−150.5	−121.7
Protection criteria (dB)	−10	−10	−10	−10	−10	−10
Interference threshold (dBW)	−160.5	−160.0	−124.6	−157.4	−160.5	−131.7
Margin (dB)	36.1	36.1	43.5	36.1	36.1	36.4

For Radars 1-6, in all cases, the positive margin indicates that the transmitting MSS transmission will not interfere with the radars.

For the S&A ARNS system, a pfd level for the protection of UAs S&A radionavigation Doppler radars in the 13.25-13.4 GHz band is derived below based on characteristics of such radars shown in Table 3.5-3. The proposed S&A ARNS radar is mounted on the nose of the aircraft; its vertical antenna scan is ±30° and its horizontal antenna scan is ±110°. Since the operation of the UAs S&A radionavigation radars is such that it could have direct main-beam to main-beam coupling with GSO MSS satellites, the pfd to protect the UAs S&A radionavigation radar must be based on the worst case of direct coupling between the UAs S&A radionavigation radar and the main beam of the MSS downlink.

The ARNS protection criteria of 13.25-13.4 GHz band is $I/N = -10$ dB.

$$P_r = \text{It} + \text{losses}$$

$$P_r = I/N + N + \text{losses}$$

$$P_r = I/N + (-144\text{dBW} + 10\log\text{Bif(MHz)} + \text{NF}) + \text{losses}$$

$$P_r = -10\text{dB} + (-144\text{dBW} + 10\log(1.1\text{MHz}) + 3\text{dB}) + 5\text{ dB}$$

$$P_r = -145.6\text{ dBW}$$

Next the pfd is determined based on the antenna effective area and P_r:

$G = 32$ dBi;

effective diameter = 0.29 m

Area = $\pi r^2 = 0.064\text{ m}^2 = -11.9\text{ dB(m}^2)$

$Pfd = P_r$ − effective antenna area = −145.6 dBW − (−11.9 dB(m^2)) = −133.7 dBW/m^2/1.1 MHz

Then, using a reference bandwidth of 1 MHz, the pfd has to be adjusted for the lower bandwidth (subtract 0.4 dB from the pfd in 1.1 MHz)

$Pfd_{1MHz} = -133.7$ dBW/m^2/1.1 MHz − 0.4 dB = −134 dBW/m^2/1 MHz at the aircraft radar antenna[10].

This pfd level will protect the ARNS UAs S&A radars from harmful interference from the proposed MSS downlinks in the 13.25-13.4 GHz band.

A similar analysis for the additional ARNS systems is shown in Table 3.5-5.

TABLE 3.5-5

Direct interference from MSS downlinks to the additional ARNS receivers

Direct coupling	Airplane	Helicopter
Receiver noise figure (assumption) (dB)	3	3
IF bandwidth (kHz)	10 (Note 1)	10
Receiver noise (dBm)	−131.0	−131.0
Receiver antenna gain in direction of satellite (assumption) (dBi)	0	0
MSS pfd (dBW/m^2 · MHz)	−115	−115
MSS pfd in IF bandwidth (dBW/m^2)	−135	−135
Interference at receiver (dBW)	−178.9	−178.9
I/N (dB)	−17.9	−17.9

NOTE 1 − The IF bandwidth is not available for these systems but a value of 10 kHz has been assumed.

In the two above cases addressing interference to current ARNS systems, the interference is below the criterion of −10 dB.

Interference by ground reflection

Interference may be received from the MSS downlinks to the ARNS antenna via ground reflection of the MSS signal. In this case, interference may be received on the boresight of the ARNS antenna. The radar equation may be used to calculate the interference received which, assuming free-space propagation loss, is given by:

$$P_r = \frac{P_t \, G_t \, A_r \, \sigma}{(4\pi)^2 \, R_t^2 \, R_r^2}$$

where:

P_r : power received

P_t : power transmitted by the MSS satellite

G_t : gain of the transmitting antenna

[10] One administration has a view that the formula $T_r = (L - 1)T_0$ from Recommendation ITU-R V.573-5 should be used for deriving the noise temperature of S&A receivers. That leads to 3dB difference with the calculation above and thus the pfd in 1 MHz = –137 dBW/m^2/1 MHz is proposed by that administration.

A_r : effective area of the receiving antenna

σ : radar cross section

R_t : distance from the transmitter to the ground (m)

R_r : distance from the receiver to the ground (m).

From the information provided in § 3.5.2, the worst case value of the normalized (by the reference area of 1 m^2) radar cross section σ_0 is 6 dB. The GSO MSS altitude is 35 786 km and the altitudes of the ARNS aircraft are used.

The results are shown in Table 3.5-6.

TABLE 3.5-6

Interference from MSS downlinks to ARNS receivers via ground reflection

	Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**
MSS pfd (dBW/m^2 in 1 MHz)	−115	−115	−115	−115	−115	−115
P_t G_t (MSS e.i.r.p.) (dBW in IF bandwidth)	18.6	19.1	64.5	21.7	28.6	51.1
G_r (dBi)	27	27	26	29.5	26.5	18
A_r (effect area of Rx antenna) (dBm^2)	−16.9	−16.9	−17.9	−14.4	−17.4	−25.9
σ (dB)	6	6	6	6	6	6
R_t (km)	35 786	35 786	35 786	35 786	35 786	35 786
R_r (m)	100	100	100	100	100	100
P_r (dBW)	−205.4	−204.8	−160.4	−199.7	−195.9	−181.9
Receiver noise in IF bandwidth (dBW)	−150.5	−149.9	−114.6	−147.4	−140.5	−132.5
I/N (dB)	−54.9	−54.9	−45.9	−52.4	−55.4	−49.4

In all cases, the positive margin indicates that the transmitting MSS transmission will not interfere with the ANRS radars via ground reflection.

A similar analysis for the two additional ARNS system is shown in Table 3.5-7.

TABLE 3.5-7

Interference from MSS downlinks to additional ARNS receivers via ground reflection

	Airplane	Helicopter
MSS pfd (dBW/m^2 in 1 MHz)	−115	−115
P_t G_t (MSS e.i.r.p.) (dBW in IF bandwidth)	27.1	27.1
G_r (dBi)	20	27.8
A_r (effect area of Rx antenna) (dBm^2)	−23.9	−16.1
σ (dB)	6	6
R_t (km)	35 786	35 786
R_r (m)	100	100
P_r (dBW)	−203.9	−196.1
Receiver noise in IF bandwidth (dBW)	−161.0	−161.0
I/N (dB)	−42.9	−35.1

In all cases the interference is below the I/N criterion of −10 dB.

3.5.1.2 Analysis of potential interference from ARNS transmitters to MES receivers

There is a possibility that the ARNS transmissions will cause interference to the MES user terminals. Since the ARNS is a safety-of-life service, the MES user terminals will have to accept interference from the ARNS. However, it is useful to the MSS to characterize the interference.

In view of small beam width of ARNS systems and high airplane speed, the interference from an ARNS transmit antenna main beam into a receive MSS user terminal will be of a short-term nature. Therefore, interference from the ARNS into a receive MSS user terminal is calculated when:

– main lobes of the ARNS transmit antenna and receive antenna of MSS user terminal overlap (worst case);

– side lobes of the ARNS transmit antenna and main lobe of a receive antenna of MSS user terminal overlap (most probable case).

Figure 3.5-2 shows in a generalized view the scenario for interference from the ARNS towards MSS user terminals. However further in this section the interference from and ARNS transmitter into a receive MSS user terminal is considered for and ARNS transmitter installed both on airplane and helicopter (for comparison purposes).

It should be noted that high flight altitudes (up to 15 km) create the "affected" area several times greater for an ARNS system on an airplane compared to a helicopter (operational altitude is up to 3.5 km).

Also it should be taken into account that the receiving MSS user terminal can be located in the visibility area of several aircraft simultaneously.

Worst-case interference calculation (single entry interference from an airborne ARNS transmitter (on board the airplane) to the main beam of an MSS user terminal)

Basic data:

MSS characteristics in the 13.25-13.4 GHz frequency band are shown in Table 3.5-8.

TABLE 3.5-8

	Pocket	Suitcase
Net data rate (kbit/s)	256.0	2 048.0
Carrier noise bandwidth (kHz)	333	1778
MES receiver temperature (K)	400	250
Antenna gain (dBi)	25	33
Interference criterion (I/N) (dB)	−12.2	−12.2

For the ARNS system, the characteristics of the additional ARNS airplane system given in Table 3.5-2 are used.

Calculation:

GSO MSS system

1) Determine the thermal noise power, N:

− for the pocket-size user terminal

$N = KT\Delta f = -228.6 + 10\log(400) + 10\log(333\ 000) = -147.4$ dBW;

− for the suitcase-size user terminal

$N = KT\Delta f = -228.6 + 10\log(250) + 10\log(1\ 778\ 000) = -142.1$ dBW.

2) Allowable interference level for the pocket-size terminal should not exceed: −147.4 dB −12.2 dB = −159.6 dBW.

Allowable interference level for the suitcase-size terminal should not exceed: −142.1 dB −12.2 dB = −154.3 dBW.

3) Calculate propagation path loss from a plane to an MSS user terminal:

- airplane altitude 10 km;
- propagation losses: 134.9 dB (at the frequency 13.325 GHz).

4) Calculate the potential interference level (main beam):

- for the Pocket-size terminal:

  $I = 10 + 20 - 134.9 + 25 = -79.9$ dBW;

- for the suitcase-size terminal:

  $I = 10 + 20 - 134.9 + 33 = -71.9$ dBW.

5) Now determine the calculated interference to the allowable interference level ratio:

- for the pocket-size terminal:

  $-79.9 - (-159.6) = 79.7$ dB.

Side lobe interference from DRNE transmitting antenna (gain is 7 dBi) into the main beam of an MSS user terminal results in excess of the allowable interference level of 66.6 dB.

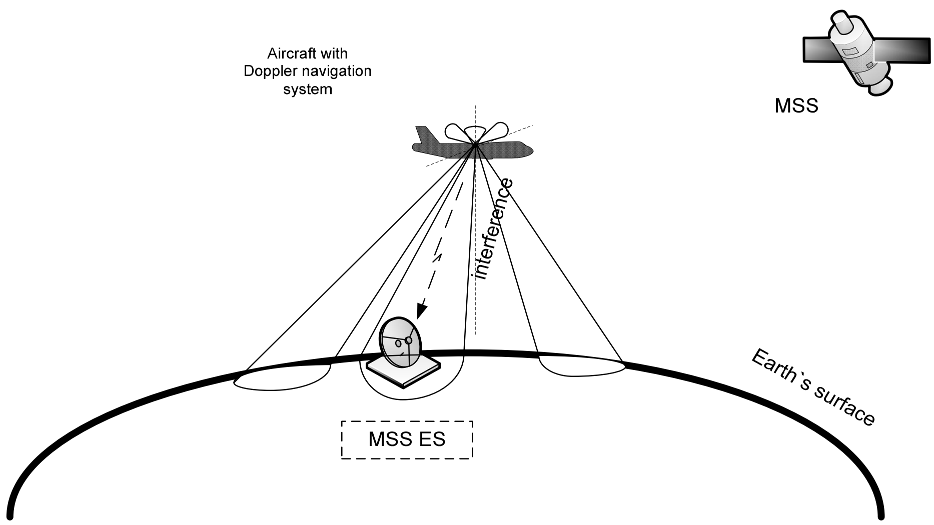
− for the suitcase-size terminal:

$-71.9 - (-154.3) = 82.4$ dB.

Back lobe interference from DRNE transmitting antenna (gain is 7 dBi) into the main beam of an MSS user terminal results in excess of the allowable interference level of 69.4 dB (see Figure 3.5-1).

FIGURE 3.5-1

Simplified scenario of interfering effect



Worst-case interference calculation (single entry interference) from an airborne ARNS transmitter on board a helicopter to the main beam of an MSS user terminal

Calculation:

GSO MSS system:

1) Determine the thermal noise power, N:
   - for the pocket-size terminal:
     $N = K\text{T}\Delta f = -228.6 + 10\log(400) + 10\log(333000) = -147.4$ dBW;
   - for the suitcase-size terminal
     $N = K\text{T}\Delta f = -228.6 + 10\log(250) + 10\log(1778000) = -142.1$ dBW.
2) Allowable interference level for the pocket-size user terminal should not exceed: −147.35 dB − 12.2 dB = −159.6 dBW.

   Allowable interference level for the suitcase -size user terminal should not exceed: −142.1 dB − 12.2 dB = −154.3 dBW.
3) Calculate propagation path loss from the helicopter to MSS earth station:
   - helicopter altitude: 3.5 km;
   - propagation losses: 125.8 dB (at 13.325 GHz).
4) Calculate the potential interference level (main beam):
   - for the pocket-size terminal:
     $I = 10 + 27.8 – 125.82 + 25 = -63.0$ dBW;
   - for the suitcase -size terminal:
     $I = 10 + 27.8 – 125.82 + 33 = -55.0$ dBW.

5) Determine the calculated interference to the allowable interference level ratio:

− for the pocket-size terminal:

−63.0 − (−159.6) = 96.6 dB.

Side lobe interference from DRNE transmitting antenna (gain is −7.2 dBi) into the main beam of an MSS user terminal results in excess of the allowable interference level of: 61.53 dB.

− for the suitcase -size terminal:

−55.0 − (−154.3) = 99.3 dB.

Side lobe interference from DRNE transmitting antenna (gain is −7.2 dBi) into the main beam of an MSS user terminal results in excess of the allowable interference level of: 64.3 dB (see Table 3.5-9).

TABLE 3.5-9

Summary of the results of calculation of the interference level excess (dB)
(single-entry interference)

<table>
<tr><th colspan="3" rowspan="2">Interference scenario</th><th colspan="2">Affected network (into the main beam)</th></tr>
<tr><th>GSO MSS
Pocket-size terminal</th><th>GSO MSS
Suitcase-size terminal</th></tr>
<tr><td rowspan="4">Network generating interference</td><td rowspan="2">DRNE
on board the airplane</td><td>from the main beam</td><td>79.7</td><td>82.4</td></tr>
<tr><td>from the side lobe</td><td>66.6</td><td>69.4</td></tr>
<tr><td rowspan="2">DRNE
on board the helicopter</td><td>from the main beam</td><td>96.6</td><td>99.3</td></tr>
<tr><td>from the side lobe</td><td>61.5</td><td>64.3</td></tr>
</table>

3.5.2 Sharing with EESS (active) and space research (active) satellites

No information is available for SRS (active) for this specific band.

In the band 13.25-13.4 GHz, Report ITU-R RS.2068 describes the use of the band by the various types of EESS (active) sensors. The interference criteria of EESS active sensors can be found in Recommendation ITU-R RS.1166-4. Information has also been gathered with ESA and NASA and is presented hereafter (see also Tables 3.5-10 and 3.5-11).

Three types of instruments are considered under the EESS (active) allocation:

a) Scatterometers (measures winds at the surface of oceans)

Current and planned systems: e.g. Seawinds on board the Quickscat satellite, uses a bandwidth of a few MHz at the edge of 13.4 GHz. Some systems are planned that would operate in the band 13.25-13.4 GHz. Typical bandwidths are around 1 MHz, but higher bandwidths can be found.

For Quickscat, two spot beams are available, one having an incidence angle of 46° (corresponding to an EESS off nadir angle of 40° for the inner beam) and the other one having an incidence angle of 54° (corresponding to an EESS off nadir angle of 46° for the outer beam).

The long-term spectrum needs of scatterometers are for about 100 MHz but no such instrument is planned yet.

Therefore, there is a very limited overlap (of typically a few MHz) with current operational and planned systems.

b) Precipitation radars (i.e. tropical rain)

These systems usually operate over bandwidths around 20 to 30 MHz: currently all systems operate in 13.4-13.75 GHz band (and some in 13.75-14 GHz). The Global Precipitation Mission (GPM) will use two channels at 13.593 and 13.603 GHz each channel being 3 MHz wide.

Therefore, there is no overlap between potential MSS systems with current operational or planned precipitation radar systems. To address the operation of a future potential system, a link budget is provided within this Report.

c) Altimeters (measures oceans' currents): such as Jason, Envisat, Cryosat, Sentinel

These systems usually operate within a bandwidth of around 350 MHz. In addition, Report ITU-R RS.2068 provides a rationale for instruments having bandwidths of up to 600 MHz.

All current systems are centred on 13.575 GHz or 13.6 GHz, i.e. within 13.4-13.75 GHz.

Therefore, there is currently no overlap with current operational or planned systems in the near future.

Furthermore, if future EESS altimeter systems were to extend in the band 13.25-13.4 GHz in order to improve their resolution, MSS and EESS would thereby use overlapping frequencies. As mentioned above, future EESS systems may operate the band 13.25-13.4 GHz, therefore in-band sharing studies have been conducted and are presented below.

TABLE 3.5-10

Receive characteristics of current flying space-borne active sensors in the 13.25-13.75 GHz band

Parameters	**Active sensor type and mission**		
	Altimeter JASON-1/2	**Scatterometer QuickSCAT seawinds**	**Precipitation radar TRMM/GPM DPR**
Orbit altitude (km)	1 336	803	350/400
Orbit inclination (degrees)	66	98.2	35/66
Antenna type	1.2 m diameter parabolic dish	1 m diameter parabolic dish	Planar array
Antenna polarization	Linear	Horizontal (inner), Vertical (outer)	Horizontal
Antenna peak gain (dBi)	43.9	41.0	47.7
Antenna elevation beamwidth (degrees)	1.28	1.6 (inner), 1.4 (outer)	0.71
Antenna azimuth beamwidth (degrees)	1.28	1.8 (inner), 1.7 (outer)	0.71
Antenna beam look angle (degrees)	0	40 (inner), 46 (outer)	−17 to +17
Antenna scan range (degrees)	0	0 to 360	−17 to +17 (cross track)

TABLE 3.5-10 (*end*)

Parameters	Active sensor type and mission		
	Altimeter JASON-1/2	**Scatterometer QuickSCAT seawinds**	**Precipitation radar TRMM/GPM DPR**
Antenna scan period (s)	0	3.33 (18 rpm)	0.7
Antenna pointing	Fixed at nadir	Circular scanning in azimuth	Scanning across nadir track
Centre RF frequency (GHz)	13.575	13.402	13.796; 13.802/ 13.597; 13.602
Receiver bandwidth (MHz)	320	0.40	1.72/3.36
Receiver sensitivity level	−117 dBW/320 MHz (for *I*/*N* of −3 dB) or −142 dBW/MHz	−195 dBW/Hz or −135 dBW/MHz	−150 dBW/600 kHz (for *I*/*N* of −10 dB) or −147.8 dBW/MHz
Comments	Nadir looking	Rotating dish antenna with two spot beams sweeping a circular pattern	Two channel frequency agility; cross track antenna scanning

TABLE 3.5-11

Receive characteristics of space-borne active sensors in the 13.25-13.75 GHz band of additional example systems

Parameters	Active sensor type and mission		
	Altimeter	**Scatterometer**	**Precipitation radar**
Orbit altitude (km)	963	963/836	408
Orbit inclination (degrees)	99.34	99.34/98.75	28
Antenna type	1.3 m dia parabolic dish	1.06 m dia parabolic dish/1.392 × 0.231 m rectangular waveguide	2.4×2.4 m slotted waveguide phased array antenna
Antenna polarization	Linear	H (inner), V (outer)/HH VV	HH
Antenna peak gain (dBi)	42.5	40.5/36.7 (H pol), 36.1(V pol)	47
Antenna elevation beamwidth (degrees)	1.2	1.5/5.0	0.71
Antenna azimuth beamwidth (degrees)	1.2	1.5/0.83	0.71
Antenna beam look angle (degrees)	0	35 (inner), 40.5 (outer)/42	0
Antenna scan range (degrees)	0	0 to 360	–20 to 20
Antenna scan period (s)	0	3.79 (15.83 rpm); 3.43(17.5 rpm)/10 (6rpm)	0.69

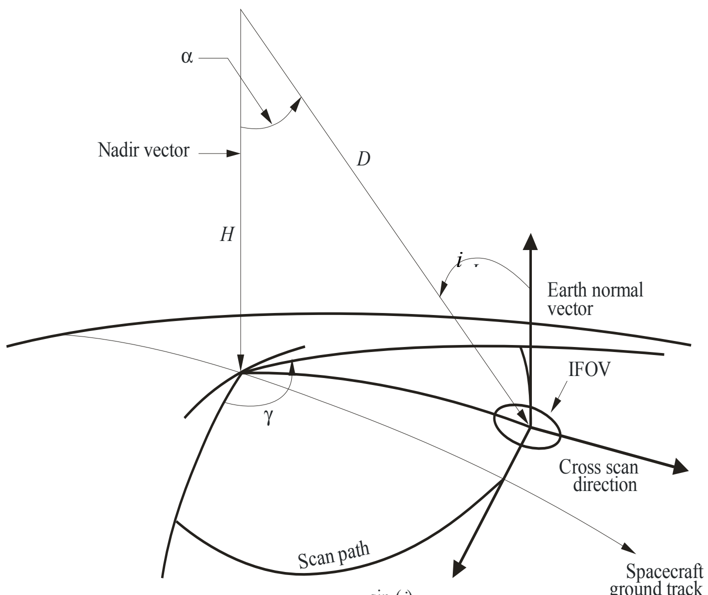
TABLE 3.5-11 (*end*)

Parameters	Active sensor type and mission		
	Altimeter	**Scatterometer**	**Precipitation radar**
Antenna pointing	Fixed at nadir	Circular scanning in azimuth	Across track scanning
Centre RF frequency (GHz)	13.58	13.256	13.6
Receiver bandwidth (MHz)	320	5	TBD
Receiver sensitivity level	−116 dBW/ 320 MHz	−196 dBW/Hz/ –198 dBW/kHz	18 dBZ
Comments	Nadir looking	Rotating dish antenna with two spot beams sweeping a circular pattern/two polarized fan-beam antenna with rotating scanning	

The corresponding definitions of these angles can be found in the schematics shown in Figures 3.5-2 to 3.5-5.

FIGURE 3.5-2

Space-borne active sensor geometry



$$\text{Sin}(\alpha) = \frac{\sin(i)}{1 + \frac{H}{R}}$$

$$D = R\,\frac{\sin(i\text{-}\alpha)}{\sin(\alpha)}$$

i: incidence angle at footprint centre
α: angle off nadir
γ: total scan angle
H: height above mean sea level
D: distance to field of view centre
R: radius of Earth (not shown in diagram)

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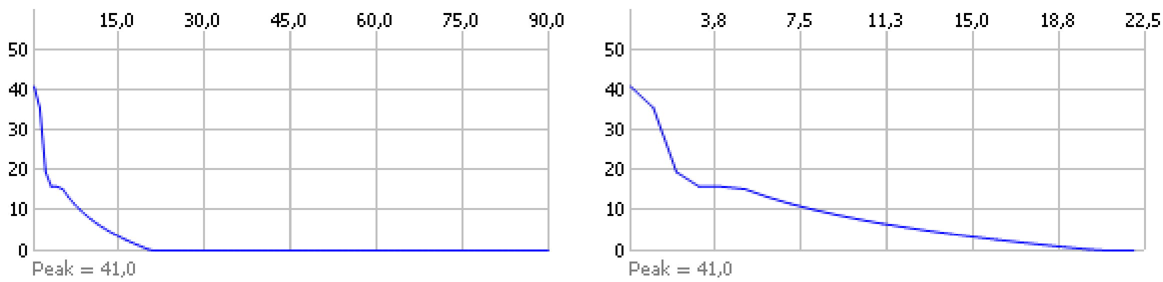
Two interference scenarios are considered below: one whereby the MSS signal is received directly by the active sensor and one whereby the reflected signal is received by the active sensor.

Direct coupling

The following figures show the antenna patterns for the scatterometer active sensors using $L_n = -25$ dB.

FIGURE 3.5-3

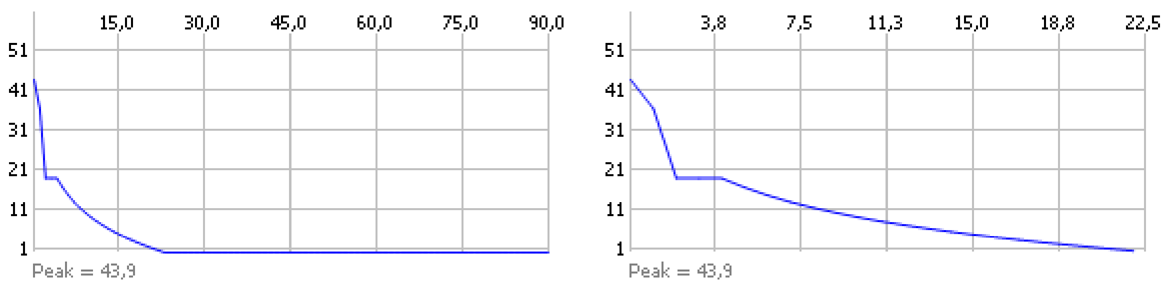
Scatterometer antenna patterns (dBi, 0-90° and 0-22.5° off axis)



For the altimeter, the antenna pattern is as follows, also using a Recommendation ITU-R S.672-3 model with $L_n = -25$ dB.

FIGURE 3.5-4

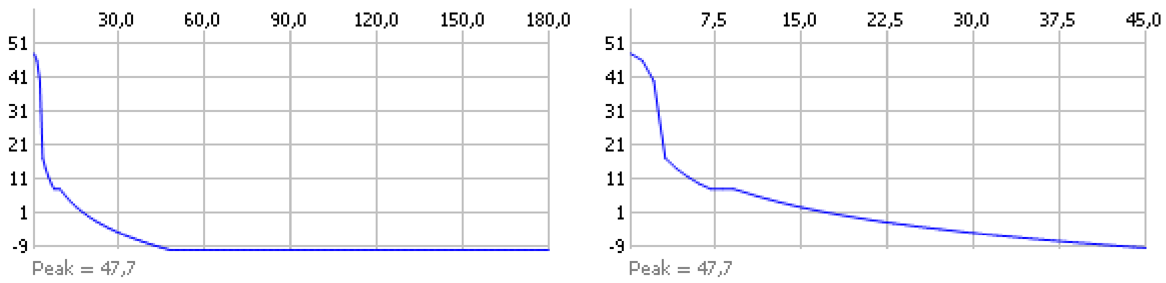
Scatterometer antenna patterns (dBi, 0-90° and 0-22.5° off axis)



For the precipitation radar case, it is noted in Report ITU-R RS.2068 that "*TRMM PR antenna aperture distribution adopts a Taylor weighting with SL = −35 dB to achieve low side-lobe level characteristics*". Therefore, the corresponding antenna pattern for TRMM is as follows (using an available Recommendation ITU-R S.672-3 model with $L_n = -30$ dB).

FIGURE 3.5-5

TRMM antenna patterns (dBi, 0-180° and 0-45° off axis)



Therefore, the link budgets are as shown in Table 3.5-12. It is to be noted that for Quickscat, the worst case vis-à-vis the two spot beams has been retained.

TABLE 3.5-12

In band interference from MSS downlink to EESS active sensor (direct coupling)

Frequency (MHz)	13 250		
Wavelength (m)	0.02		
EESS(active) sensor	**JASON-2 Altimeter**	**QUICKSCAT Scatterometer**	**Precipitation radar**
MSS e.i.r.p. (dBW)	47.9	47.9	47.9
Altitude MSS (km)	36 000	36 000	36 000
EESS altitude (km)	1336	803	350
Maximum active sensor antenna gain (dBi)	43.9	41.0	47.7
EESS (active) protection level (dBW/MHz)	−142.0	−135.0	−147.8
EESS off nadir angle (degrees)	55.7	62.6	71.4
MSS off nadir angle (degrees)	8.6	8.6	8.6
Distance GSO MSS – Satellite EESS (km)	46 234	45 195	44 037
Space attenuation (dB)	208.1	208.0	207.7
Active sensor satellite antenna gain (dBi)	0	4.0	−9.0
Received power at the EESS sensor (dBW/MHz)	−160.2	−156.1	−168.8
Margin (dB)	18.2	21.1	21.0

It is to be noted that parameters for other similar systems in Table 3.5-12 will show similar compatibility results.

In addition, these link budgets show that no harmful interference will occur in the case of direct coupling for each kind of EESS (active) instrument from a potential MSS downlink when using the same frequency band at 13.2 GHz.

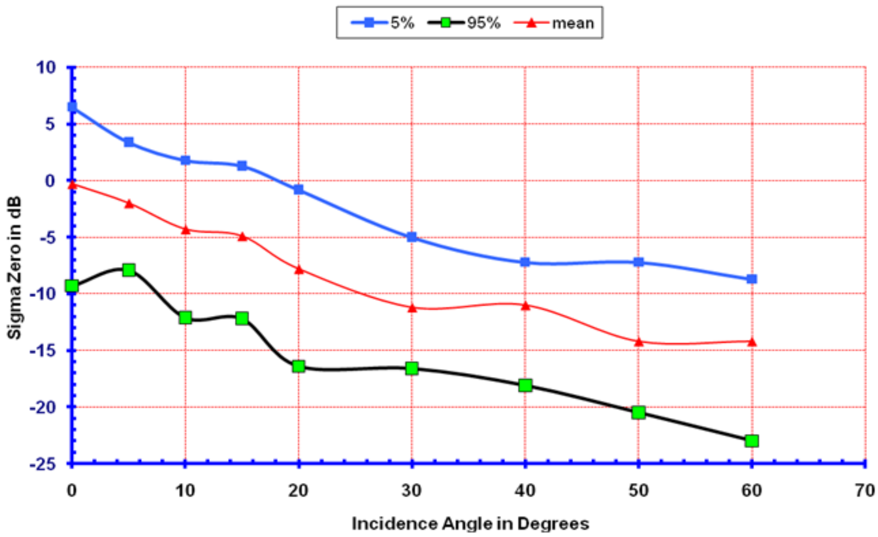
Reflected signal

This case of the MSS reflection of the MSS downlink into the main lobe of the EESS (active) is addressed in this section.

The backscattering coefficients for soils at Ku-band HH polarization for 5%, mean, and 95% are derived from Ulaby files (Handbook of radar scattering statistics for terrain, Ulaby, Dobson, Artech House) which provide probability density functions (PDFs) of the radar backscattering coefficient σ_0 (dB) for nine generalized terrain categories as organized by frequency band, angle of incidence, and linear polarization configuration. The HH polarization and the soil terrain have been selected for computing the curves shown in Figure 3.5-6.

FIGURE 3.5-6

Soils Ku-band HH backscatter curves



The incidence angle is defined in Fig. 3.5-3.

Using the mean curve in Fig. 3.5-6, the backscattering parameters are as follows:

– For the altimeter which is a pure nadir instrument, the backscattering coefficient is −2 dB.

– For the precipitation radar, an average backscattering coefficient of −5 dB has been retained. A precipitation radar has an antenna scan range up to 17°, resulting in a backscattering coefficient between −2 dB and −8 dB.

– For the scatterometer, with antenna beam angles equal to 40° and 46°, the backscattering coefficient is −10 dB.

The reflected area corresponds to a typical area valid for altimeters, scatterometers or precipitation radars in the band 13.25-14 GHz.

Consequently, the link budgets are as shown in Table 3.5-13:

TABLE 3.5-13

In band interference from MSS downlink to EESS (active) sensor (indirect coupling)

Frequency (MHz)	13 250		
Wavelength (m)	0.02		
EESS(active) sensor	**JASON-2**	**QUICKSCAT**	**Precipitation radar**
Reflected area (km^2)	2 000	2 000	2 000
MSS ground pfd (dBW/m^2 · MHz)	−116.0	−116.0	−116.0
Backscatter coeff (dB)	−2.0	−10.0	−5.0
Power reflected in 1 MHz (dBW)	−25.0	−10.0	−28.0
Distance ground – EESS Satellite (km)	1 336	1 200	350
Space attenuation (dB)	177.4	176.4	165.7
Active sensor satellite antenna gain (dBi)	43.9	41.0	47.7
EESS (active) protection level (dBW/MHz)	−142.0	−135.0	−147.8
Received power at the EESS sensor (dBW/100 MHz)	−158.5	−145.4	−146.0
Margin (dB)	16.5	10.4	−1.8

It is to be noted that the precipitation radar is the worst case since the resulting margin equals −1.8 dB. Therefore, MSS downlinks and precipitation radars are not compatible when sharing the same band. This negative margin is mainly due to the low altitude of the satellite (350/400 km) and due to typical high antenna gains. According to Report ITU-R RS.2068 and to the draft EESS handbook, current and future space borne precipitation radars centre frequencies are above 13.5 GHz. Consequently, as MSS are foreseen within the band 13.25 to 13.4 GHz, there are no compatibility issues with rain precipitation radars.

Analysis of an aggregation situation

It is anticipated that multiple GSO MSS satellites will be in operation and therefore, may provide additional interference for the EESS satellite. The geometric satellite configuration which is envisaged here is that 2 GSO MSS in operation and using the same frequency bands are separated by 50° within the GSO arc.

The EESS (active) satellite is located right below one GSO MSS satellite and therefore receives backscattered energy interference.

The second GSO MSS is located 50° away in longitude and the EESS (active) satellite may receive interference from such other MSS GSO according to the link budget shown in Table 3.5-14 (tangent case).

TABLE 3.5-14

Aggregate interference from MSS downlink to EESS (active) sensor

EESS (active) sensor	JASON-2 Altimeter	QUICKSCAT Scatterometer
(dBW)	33.5	33.5
MSS antenna gain (dBi)	14.4	14.4
altitude MSS (km)	36 000	36 000
EESS altitude (km)	1 336	803
Maximum active sensor antenna gain (dBi)	43.9	41.0
EESS(active) protection level (dBW/MHz)	–142	–135
EESS off nadir angle (degrees)	121.0	121.7
MSS off nadir angle (degrees)	9.0	8.3
Distance GSO MSS − Satellite EESS (km)	37 883	38 160
Space attenuation (dB)	206.4	206.5
Active sensor satellite antenna gain (dBi)	0.0	0.0
Received power at the EESS sensor (dBW/MHz)	–158.5	–158.6
Margin (dB)	16.5	23.6

This aggregation case shows that for JASON-2, the backscattered energy case and the tangent case produce similar interference effects.

3.5.3 MSS and FS stations

There is no information available so far about the FS characteristics and use in India, Pakistan and Bangladesh in RR No. 5.499.

3.5.4 Summary of studies for the band 13.25-13.4 GHz

The studies show that interference from MSS downlinks to current ARNS receivers would be below the recommended interference criterion for an MSS maximum pfd value of −115 dB(W/m^2 · MHz). Considering that some ARNS system have receiver bandwidths of a few kHz, any limit should be specified in a bandwidth of 4 kHz, leading to a pfd value of –139 dB(W/m^2/4 kHz).

Furthermore, some administrations have proposed the use of the band 13.25-13.4 GHz for a new ARNS system on board unmanned aircraft. For this proposed new ARNS application, interference could exceed the recommended criterion by up to 19 dB for a main lobe-to-main lobe alignment. The required pfd level to protect the S&A Doppler radars for UA systems is −134 dB(W/m^2 · MHz), equivalent to −158 dB(W/m^2/4 kHz). These pfd values would also protect the current ARNS systems.

Calculations show that considerable interference excess (more than 40 dB for any scenario, see Table 3.5-9 above) also can be expected for the receiving MSS user terminals from the ARNS stations installed both on airplane and helicopter. Taking into account that receiving MSS user terminals can be located in the visibility area of several aircraft simultaneously, the cumulative interfering effect will result in even greater degradation of the interfering situation for receiving MSS user terminals.

With regard to sharing with the EESS (active), three types of instrument are considered under the EESS (active) allocation: scatterometers, altimeters and precipitation radars.

Taking into information provided from Report ITU-R RS.2068, Recommendation ITU-R RS.1166, as well as other information available through space agencies, in the band 13.25-13.4 GHz there is only one operational system (scatterometer) using a few MHz at the edge of 13.4 GHz. It is expected that a potential MSS downlink would not cause harmful interference to EESS (active) scatterometer sensors.

The current altimeters operate in the band 13.4-13.75 GHz with a bandwidth of around 350 MHz. If future EESS altimeters were to extend in the band 13.25-13.4 GHz in order to improve their resolution, MSS and EESS would thereby use overlapping frequencies. Taking into account the previous technical analysis, it is expected that a potential MSS downlink would not cause interference to EESS (active) altimeter sensors.

Some precipitation radars may experience negative margins. However, due to the fact that current and planned precipitation radars will not use the frequency band 13.25-13.4 GHz, it is expected that a potential MSS downlink would not cause interference to EESS (active) precipitation radar sensors if frequencies are not overlapping

Based on the calculations above, in order for altimeters and scatterometers to coexist with potential MSS GSO systems within the band 13.25-13.4 GHz, it is expected that the MSS satellite pfd within the band 13.25-13.4 GHz would not exceed −115 dB(W/m^2 · MHz) on the ground.

No existing or planned use has been identified for the space research (active) service.

3.6 Frequency band 15.43-15.63 GHz

The allocation of this band in the RR Article 5 is indicated below.

15.43-15.63	FIXED-SATELLITE (Earth-to-space) 5.511A AERONAUTICAL RADIONAVIGATION 5.511C

This band is considered for MSS uplinks.

This band is allocated to the aeronautical radionavigation service. This band is also allocated to the FSS limited to feeder links for non-GSO MSS and in both space-to-Earth and Earth-to-space directions, though there are no systems that operate in the band.

This band is also considered under WRC-12 Agenda item 1.21, which investigates a potential radiolocation allocation in the band 15.4-15.7 GHz.

The band 15.4-15.5 GHz might also be studied under WRC-12 Agenda item 1.3 for the terrestrial component of UAs operations (LoS).

The interference scenarios to be considered are:

- MSS and aeronautical radionavigation
  - Potential interference from MESs into aeronautical radionavigation.
  - Potential interference from aeronautical radionavigation into MSS satellites.
- MSS and FSS
  - Potential interference from MESs into FSS.
  - Potential interference from FSS into MSS satellites.
- MSS and radiolocation
  - Potential interference from MESs into radiolocation.
  - Potential interference from radiolocation into MSS satellites.

- MSS and UAVs (terrestrial component, LoS)
  - Potential interference from MESs into UAVs.
  - Potential interference from UAVs into MSS satellites.
- MSS and radio astronomy in the nearby band 15.35-15.4 GHz
  - Potential interference from MESs at radio astronomy sites.

3.6.1 Information on system characteristics, current operational and planned systems

The MSS system characteristics to be used are contained in Annex 1 of this Report.

3.6.1.1 MSS and aeronautical radionavigation

The 15.4-15.7 GHz band is allocated on a primary basis to the ARNS. There are no International Civil Aviation Organization (ICAO)-standard ARNS systems that currently operate in this band although ICAO standards exist for aircraft weather radar systems. ARNS is recognized as a safety service as delineated in No. 4.10 of the Radio Regulations.

There are existing aeronautical radionavigation systems operating in the band 15.4-15.7 GHz. Systems used for aircraft landing require special protection in relation to MSS. Variable or temporary service requirement for ARNS require that the ground stations of this service are re-locatable and used at unspecified points.

3.6.1.1.1 Recommendation ITU-R S.1340 aeronautical radionavigation radars

A survey of ITU-R M-series Recommendations revealed that currently there are no systems characteristics available for study. However, Recommendation ITU-R S.1340 has aeronautical radionavigation systems in the 15.4 to 15.7 GHz band that are studied in the two following sections.

3.6.1.1.2 Aeronautical radionavigation systems in the 15.4-15.7 GHz band

The aeronautical system descriptions are copied from Recommendation ITU-R S.1340. The systems studied are:

1) Surface Based Radar (SBR) is a land- and ship-based system used for the detection, location and movement of aircraft and other vehicles on the surface of airports and other aircraft landing areas;
2) Aircraft Landing System (ALS) is a general purpose system used on ships, as portable or permanent land-based systems and for shuttle landings. The microwave scanning beam landing system (MSBLS) is one such system. Some of the characteristics vary with the particular applications;
3) Aircraft Multipurpose Radar (MPR) is a radionavigation, radiolocation and weather radar; and
4) Radar Sensing and Measurement System (RSMS) that uses radar technology at 15 GHz are particularly suited to smaller aircraft, including helicopters, offering the benefits of compact, light, equipment with good antenna directivity. This system is widely used in certain parts of the world where they make an important contribution to the safety of aircraft operation. RSMS are essentially used in low level operations up to a nominal height of around 1 500 m. An antenna mounting which transmits and receives vertically downwards would be used in the great majority of applications. Power reduction proportional to height above terrain is employed to reduce scatter and other undesirable effects.

A summary of technical characteristics of these systems are found in Table 3.6-1.

TABLE 3.6-1

Recommendation ITU-R S.1340 summary of technical characteristics

System	SBR	ALS	MPR	RSMS
Reference	Rec. ITU-R S.1340 Annex 1, § 1	Rec. ITU-R S.1340 Annex 1, § 2	Rec. ITU-R S.1340 Annex 1, § 3	Rec. ITU-R S.1340 Annex 1, § 4
Frequency range (GHz)	15.65-16.7	15.4-15.7	15.4-15.7	15.63-15.65
Peak power (dBW)	43	38	40	0
Antenna pattern	Elevation pattern Annex 1, § 1.1.1	Rec. ITU-R S.1340	Rec. ITU-R S.1340 (§ 3.1)	Rec. ITU-R S.1340
Transmit antenna gain (dBi)	43	Az 33 El 28	30	13
Receiver antenna gain (dBi)	43	8 (on the landing aircraft)	30	5 (back lobe)
Maximum side-lobe level below peak gain (dB)	25		14	
Nominal 3 dB Receive antenna pattern beamwidth (degrees)	3.5	Omnidirectional	4.5	Omnidirectional
Antenna polarization	Circular	Horizontal and vertical	Vertical	Vertical (assumed)
Vertical tilt range (degrees)	+1.5	Omnidirectional	±20	Omnidirectional
Maximum horizontal scan range for receive antenna (degrees)	360	Omnidirectional	±45	Omnidirectional
Receiver IF bandwidth (MHz)	25	3	0.50	2
Noise figure (dB)	6.5	8	8	6

With regard to the "surface based radars" described in Recommendation ITU-R S.1340, these are expected to be operate outside of the band 15.43-15.63 GHz[11]. Consequently, sharing studies with MSS uplinks are not addressed in this report, although there may be adjacent band compatibility issues to be addressed.

With regard to the "aircraft landing systems" (ALS) described in Recommendation ITU-R S.1340, these could operate in the band 15.43-15.63 GHz and hence sharing studies are required. Studies are included below and are based on the characteristics of ALS systems and sharing methodology contained in Recommendation ITU-R S.1340.

[11] See *recommends* 6 of Recommendation ITU-R S.1340.

With regard to the “aircraft multipurpose radars” (MPR) which is described in Recommendation ITU-R S.1340, this system could operate in the band 15.4-15.7 GHz, and hence sharing studies are included below. However the extent of current and planned use of MPR systems in the band 15.43-15.63 GHz is not known.

With regard to the “radar sensing and measurement system (RSMS)” which is described in Recommendation ITU-R S.1340, the frequency range for this system is 15.63-15.65 GHz. Consequently, sharing studies with MSS uplinks are not addressed in this contribution, although there may be adjacent band compatibility issues to be addressed at a later date.

3.6.1.1.3 Characteristics of the Aircraft Landing Systems (ALS)

The technical characteristics of ALS systems that operate in the 15.4-15.7 GHz band are not found in ITU Recommendations or Reports. This section provides an overview and characteristics of an ALS system that operates in the 15.4-15.7 GHz band which is implemented by some administrations. The system consists of azimuth and elevation transmitters, including separate azimuth and elevation antennae, located at the landing site. The receiver is located in the aircraft. The aircraft system receives coded transmissions on a number of selectable channels from the ground-based azimuth and elevation transmitters; it decodes the received signals for display on a cross-pointer indicator in the aircraft cockpit. A centre-line display of both elevation and azimuth on the cross-pointer indicator depicts the flight path the pilot must follow to line up accurately with the runway. By consecutively scanning through azimuth and elevation, the system provides continuous measurement of the lateral and vertical deviations of the aircraft in space from the optimum approach line. The aircraft receiver local oscillator (LO) is a crystal-controlled solid-state unit employing multipliers, amplifiers, and filters, which provide rejection of spurious signals. Filters in the detector circuit remove the IF component, so that only video is passed to the decoder.

Table 3.6-2 below lists the technical characteristics of the ALS transmitter and receiver (see also Figure 3.6-1).

TABLE 3.6-2

Aircraft landing systems characteristics in the 15.4-15.7 GHz band

Characteristics	**Aircraft landing system**	
Function	**Transmitter**	**Receiver**
Platform type	Located at the landing site	Airborne platform
Tuning range (GHz)	15.4-15.7	15.4-15.7
Modulation	Pulse	Not applicable
Transmit peak power (W)	2 200	Not applicable
Pulse width (μs)	0.3	Not applicable
Pulse rise/fall time (ns)	100/100	Not applicable
Pulse repetition rate (pps)	3 334	Not applicable
Maximum duty cycle	0.001	Not applicable
Output device	Magnetron	Not applicable
Antenna pattern type	Beam	Beam (assumed)
Antenna gain (dBi)	Az 31 El 26	4
Antenna elevation beamwidth (degrees)*	±20 horizontal 1.25 vertical	30
Antenna azimuthal beamwidth (degrees)*	Az 2 horizontal 6 vertical	70

TABLE 3.6-2 (*end*)

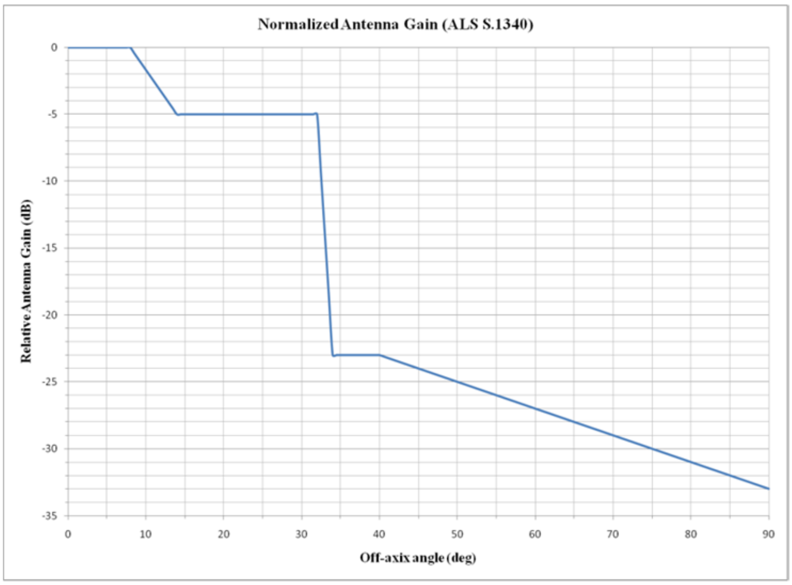
Characteristics	Aircraft landing system	
Function	**Transmitter**	**Receiver**
Antenna horizontal scan rate	5 Hz	Not applicable
Antenna horizontal scan type	Sector	Not applicable
Antenna vertical scan rate	5 Hz	Not applicable
Antenna vertical scan type	Sector	Not applicable
Antenna 1st side-lobe level	20 dB down from the main lobe peak	20 dB minimum (assumed)**
Antenna height (m)	Ground level	1 000 (typical landing sequence initiation)
1st/2nd receiver IF −3 dB bandwidths (MHz)		15
Receiver noise figure (dB)		10
Minimum discernible signal (MDS) (dBm)		−72

* There are two antennae systems: one for azimuth and one for elevation.

** The receiver antenna 1st side-lobe level needs to be verified.

FIGURE 3.6-1

Normalized antenna elevation pattern for ALS (15 GHz band)



3.6.1.2 Characteristics of FSS systems

The band is also allocated to the FSS limited to feeder links for non-GSO MSS and in both space-to-Earth and Earth-to-space directions, though there are no systems that operate in the band.

The technical characteristics of FSS systems that operate uplinks and downlinks in the 15.4-15.7 GHz band were found in Recommendation ITU-R S.1328-3. From Recommendation ITU-R S.1328-3, Table 3.6-3 below provides characteristics and includes some added technical assumptions that are required to perform the simulation.

TABLE 3.6-3

FSS systems characteristic in the 15.4-15.7 GHz band

Parameters	**Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E**	**Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO N feeder link**	**Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS**	**Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1**
1 Orbital parameters				
Shape of orbit	Elliptical	Circular	Circular	Elliptical
Height (km)	7 846 × 520	700	1 500	44 641 × 26 932
Inclination angle (degrees)	116.6	82	74	42.5
Coherence (track repeat)	3 h	46 h		23 h 56 min
Number of satellites per plane	5	13	12	1
Number of orbital planes	2	7	4	3-5
Satellite separation within plane (degrees)	72	27.7	30	–
Satellite phasing between planes (degrees)	36	25.7	90	Variable
2 Targeted frequency range and polarization				
Uplink frequency (GHz)	15.45-15.65	19.3-19.6	19.3-19.6	17.7-18.1
Uplink polarization	–	Circular	LHCP	Circular
Downlink frequency (GHz)	6.875-7.075	15.43-15.63	15.45-15.65	15.43-15.63
Downlink polarization	–	Circular	RHCP	Circular
3 Spectrum required in each direction (MHz)	200	300(1)/200(2)	200	400(1)/200(2)
4 Carrier transmission parameters				
Modulation type	QPSK	TDMA/QPSK		CDM, TDM, CDM/FDM (QPSK)
Number of service link beams	61	–		1
Number of feeder-link segments/polarization	31	1		–
Segment bandwidth (MHz)	12	–		–
Receiver bandwidth (kHz)	3 000/7 000	20 000(1); 20 000(2)	48 000	2 500, 6 000, N/A, N/A
Transmission bandwidth (kHz)	3 000/7 000	20 000(1); 20 000(2)	48 000	15 000, 700, 17 800, 6 000
Overall C/N_0 per user (dB/Hz) or C/N (dB)	–	6.5 dB (E_b/N_0)	46	8, 8 6, 6

TABLE 3.6-3 (*continued*)

Parameters	**Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E**	**Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO N feeder link**	**Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS**	**Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1**
Uplink e.i.r.p./carrier (dBW) Maximum Minimum	50	67.2	67 29.6	74.4, 46.9, 74.8, 77.3
Downlink e.i.r.p./carrier (dBW) Maximum Minimum	–	15.8	24.9 −3.8	48.5, 52.2, N/A, N/A
Type of satellite transponder	Transparent	Processing		Transparent
5 Satellite antenna parameters				
Tx maximum gain (dBi)	11	5.2	22	41.9
Rx maximum gain (dBi)	11	5.2	22	44.5
Main lobes	–	–		–
Side lobes (dB)	−16	–		–
Back lobes (dB)	−38	–		–
Steerable antenna or not	No	No	Yes	Steerable
Receiver noise temperature (degrees Kelvin) (assumed)	520			
Antenna pattern for analysis (assumed)	Rec. ITU-R S.672-4 −20 dB side lobe			
6 Earth station antenna parameters				
Peak Tx gain (dBi)	55.3	48.4	49	62.4
Peak Rx gain (dBi)	48.2	48.4	49	60.5
Radiation pattern	–	Rec. ITU-R S.465-5	Rec. ITU-R S.465-5 (assumed)	Rec. ITU-R S.580-6
Antenna noise temperature from Rec. ITU-R SF.1006 (1993) (degrees Kelvin) (assumed)		300	300	300
Minimum operating elevation angle (degrees)	5	10	10	70
Steerable antenna				
7 Number of earth stations and distribution	20-40	Up to several dozens	6 or more	Up to 100

TABLE 3.6-3 (*end*)

Parameters	Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E	Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO N feeder link	Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS	Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1
8 Earth station switching strategy	Highest and 2nd highest elevation angle	Maximum duration of communication session	Minimum elevation angle	Minimum operating elevation angle

ARC: automatic range compensation.

LHCP: left-hand circular polarization.

RHCP: right-hand circular polarization.

(1) Uplink.

(2) Downlink.

The interference protection criteria for the FSS satellite and earth station are defined below.

Interference criteria for satellite station

The interference protection criteria for the satellite is obtained using Figure 1 of Recommendation ITU-R S.1432-1, "Apportionment of the allowable error performance degradations to FSS hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz". Interference allowance, in terms of percentage of system noise power, can be converted into corresponding values of *I*/*N* ratios. For the satellite receiver case, a 6.0% increase in the receiver noise, due to interference from other systems having a co-primary status; like, potentially, MSS in this case, yields *I*/*N* of −12.2 dB for 100% of the time of any month. Therefore, the interference protection value of −12.2 dB is used to assess the interference.

Interference criteria for earth station

To develop short-term and long-term interference criteria for the earth stations, the method in Recommendation ITU-R SF.1006 (1993) described by equations (3) and (4) in Annex 1 of the Recommendation, can be used for this analysis.

3.6.1.3 Characteristics of the radiolocation systems

This band is also considered under WRC-12 Agenda item 1.21 for a potential allocation to the radiolocation service. Sharing with the radiolocation service seems to be difficult, however both allocations (radiolocation, MSS) could be considered taking into account the respective spectrum requirements.

Recommendation ITU-R M.1730-1 contains the technical characteristics and protection criteria for radiolocation radars in the band 15.4-17.3 GHz and Recommendation ITU-R M.1372-1 identifies interference reduction techniques which enhance compatibility among radar systems.

The following section contains the radiolocation technical characteristics that will be used in the compatibility analysis.

Recommendation ITU-R M.1730-1 contains technical characteristics and protection criteria for radiolocation radars in the band 15.4-17.3 GHz only, where the band 15.7-17.3 GHz is already allocated to the radiolocation service on a primary basis. The added radiolocation System-6 is used in the compatibility analysis for this Report and the characteristics are shown in Table 3.6-4 below (see also Figure 3.6-2).

TABLE 3.6-4

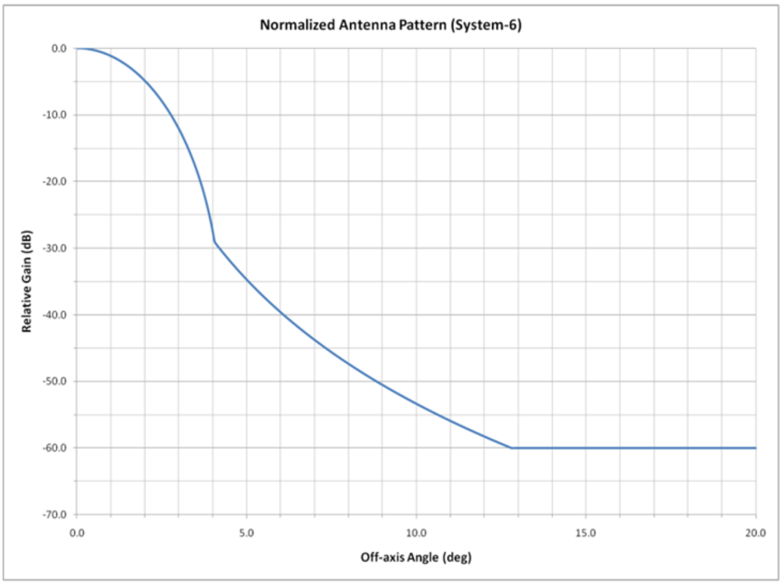
Radiolocation systems characteristic in the 15.4-17.3 GHz band

Characteristics	System-6 (Rec. ITU-R M.1730-1)
Function	**Search, track and ground-mapping (multi-function)**
Platform type	Airborne (typical operational height = 8 500 m)
Tuning range (GHz)	15.4-17.3
Modulation	Linear FM chirp
Transmit peak power (W)	500
Pulse width (μs)	0.05-50
Pulse rise/fall time (ns)	5-100
Pulse repetition rate (pps)	200-20 000
Maximum duty cycle	Up to 0.2(1)
Output device	Travelling wave tube
Antenna pattern type	Pencil
Antenna type	Phased array
Antenna polarization	Linear
Antenna gain (dBi)	35
Antenna elevation beamwidth (degrees)	3.2
Antenna azimuthal beamwidth (degrees)	3.2
Antenna horizontal scan rate	1-30 degrees/s
Antenna horizontal scan type (continuous, random, sector, etc.)	±45° (electronic)
Antenna vertical scan rate	1, 5 degrees/s
Antenna vertical scan type	+5° to −45° (electronic)
Antenna 1st side-lobe level	3.5 dBi at 5.2°
Antenna height	Aircraft altitude
1st/2nd receiver IF −3 dB bandwidths (MHz)	25
Receiver noise figure (dB)	5
Minimum discernible signal (dBm)	−100
Chirp bandwidth (MHz)	< 1 900
Transmitter RF emission bandwidth (MHz): • −3 dB • −20 dB	 1 850 1 854

(1) Sharing analysis was done for 100% duty cycle.

FIGURE 3.6-2

Normalized antenna elevation pattern for System-6 (15 GHz band)



3.6.1.4 Characteristics of UAVs (terrestrial component)

The band 15.4-15.5 GHz might also studied under WRC-12 Agenda item 1.3 for the terrestrial component of UAs operations (LoS). However, the need for such terrestrial component had been estimated to be 2 × 17 MHz (plus a duplex gap). Sharing studies would need to be conducted to assess the conditions for compatibility between these services. In any case, both allocations (AM(R)S, MSS) could be considered taking into account the respective spectrum requirements.

3.6.1.5 Characteristics of radio astronomy stations in the nearby band 15.35-15.4 GHz

The radio astronomy service (RAS) is a service with a primary status in the band 15.35-15.4 GHz in the RR Article 5 with Nos. 5.340 and 5.511A. During an observation, a radio astronomy telescope points towards a celestial radio source at a specific right ascension and declination corresponding with a specific azimuth and elevation at a given moment in time, and the pointing direction of the telescope is continuously adjusted to compensate for the rotation of the Earth. A brief survey found the following RAS system that may use the 15.35-15.4 GHz band. See Table 3.6-5 for details.

TABLE 3.6-5

Brief RAS survey results for the 15.35 to 15.4 GHz band

Location	Geographic longitude	Geographic latitude	Altitude above sea level (m)	Diameter telescope (m)	Minimum elevation (degrees)	Reference
Effelsberg, Germany	06° 53′ 00″	50° 31′ 32″	369	100	7°	1
Medicina, Italy	11° 38′ 49″	44° 31′ 14″	28	32	5°	1 and 2
Sardinia, Italy	09° 14′ 40″	39° 29′ 50″	650	64	5°	1
Badari, Russia	102° 13′ 16″	51° 45′ 27″	832	32	−5°	1
Kalyazin, Russia	37° 54′ 01″	57° 13′ 22″	195	64	0°	1
Pushchino, Russia	37° 40′ 00″	54° 49′ 00″	200	22	6°	1
Svetloe, Russia	29° 46′ 54″	61° 05′	80	32	−5°	1
Zelenchukskaya, Russia	41° 35′ 32″	43° 49′ 53″	1 000	32	−5°	1 and 2
Onsala, Sweden	11° 55′ 35″	57° 23′ 45″	10	25	0°	1
Cambridge, UK	00° 02′ 20″	52° 09′ 59″	24	13	0°	1
National Radio Astronomy Observatory − Green Bank, W VA, USA	−79° 50′ 23″	38° 25′ 59″	807	105	0°	3
National Radio Astronomy Observatory − VLA, San Agustin, NM, USA	−107° 37′ 06″	34° 04′ 44″	2115	27 antennas 25 m (each antenna)	0°	3
National Radio Astronomy Observatory − VLBA				25 m (each)	0°	3
Pie Town, NM, USA	−108° 07′ 09″	34° 18′ 04″	2 371			
Kitt Peak, AZ, USA	−111° 36′ 45″	31° 57′ 23″	1 916			
Los Alamos, NM, USA	−106° 14′ 44″	35° 46′ 30″	1 967			
Fort Davis, TX, USA	−103° 56′ 41″	30° 38′ 06″	1 615			
North Liberty, IA, USA	−91° 34′ 27″	41° 46′ 17″	241			
Brewster, WA, USA	−119° 41′ 00″	48° 07′ 52″	255			
Owens Valley, CA, USA	−118° 16′ 37″	37° 13′ 54″	1 207			
St. Croix, VI, USA	−64° 35′ 01″	17° 45′ 24″	16			
Mauna Kea, HI, USA	−155° 27′ 20″	19° 48′ 05″	3 725			
Hancock, NH, USA	−71° 59′ 12″	42° 56′ 01″	309			

TABLE 3.6-5 (*end*)

Location	**Geographic longitude**	**Geographic latitude**	**Altitude above sea level (m)**	**Diameter telescope (m)**	**Minimum elevation (degrees)**	**Reference**
Parkes, Australia	148° 15′ 494″	−33° 00′ 00″	400	64	30°	3
MIYUN50, China	116° 58′	40° 33′	115	50	5°	3
Nobeyama, Japan	138° 28′ 32″	35° 56′ 29″	1 350	45	10°	4
Kashima, Japan	140° 39′ 58″	35° 57′ 03″	35	34	6°	4
K-SRBL, Korea	127.37°	36.40°	120	2	10°	3
KVN-Yonsei, Korea	126° 56′ 35″	37° 33′ 44″	120	21	5°	3
KVN-Ulsan, Korea	129° 15′ 04″	35° 32′ 33″	160	21	5°	3
KVN-Tamna, Korea	126° 27′ 43″	33° 17′ 18″	450	21	5°	3

RAS protection criteria

Consideration of possible interference to the RAS in the band 15.35-15.4 GHz caused by the operation of MES of MSS in the band 15.43-15.63 GHz (Earth-to-space) is not a sharing scenario because the prospective MSS allocation is in a different, nearby band from that which is allocated to RAS; the interference arises from spurious emissions. Therefore, this is a case where impact and compatibility, not sharing, is being considered. In addition, it should be noted that provision RR No. 5.340 applies in the band 15.35-15.4 GHz, explicitly prohibiting all emissions there.

Recommendation ITU-R RA.769 contains general protection criteria and interference thresholds for RAS observations (including the thresholds cited below). The protection criteria given in Recommendation ITU-R RA.769-2 assume that the interferer is in the antenna far field of a radio telescope, and that it is received in the side lobe of the RAS antenna pattern, at a level of 0 dBi at relative angles greater than 19 degrees from the antenna boresight (see also Recommendation ITU-R SA.509-2). It should also be noted that a radio telescope typically uses an antenna with a very high gain, on the order of 76 dB for a telescope with a diameter of 50 metres, or higher. As recommended, a RAS antenna gain of 0 dBi is used in the calculation.

The sensitivity levels given in Recommendation ITU-R RA.769-2 employ values for the bandwidth and integration time for which these other factors usually are insignificant, as shown in Table 3.6-6.

TABLE 3.6-6

RAS protection criteria

	System sensitivity (noise fluctuations)		**Threshold interference levels**		
	Temperature	**Power spectral density**	**Input power**	**pfd**	**Spectral power flux-density**
Single dish	0.095 mK	−269 dB (W/Hz)	−202 dBW/50MHz	−156 dB (W/m^2)	−233 dB $(W/(m^2 Hz))$

Recommendation ITU-R RA.1513 indicates that any one active service network should not detrimentally interfere with RAS observations more than 2% of the time in a spectrum band that is allocated to RAS on a primary basis, as is the case for the passive band at 15.35-15.4 GHz. Recommendation ITU-R RA.1513 also develops the idea that it is appropriate to use 0 dBi as the receiving RAS antenna gain for the purpose of calculating interference.

Recommendation ITU-R RA.1031 uses the 2% data-loss criterion developed in Recommendation ITU-R RA.1513 to consider situations where RAS has a primary allocation in a band that is shared with active services (that is, allocated to both). Sharing between RAS and active services is generally impossible when the active service transmits within line of sight of an RAS antenna, owing to the very sensitive protection criteria for RAS given in Recommendations ITU-R RA.769 and RA.1513. Therefore, Recommendation ITU-R RA.1031 discusses the construction of coordination zones about RAS sites where active service transmissions are prevented, such that the 2% data-loss criterion may be observed. Although some of the techniques used in Recommendation ITU-R RA.1031 can also be used to study compatibility in cases where interference to RAS arises from spurious emissions in nearby or adjacent frequency bands not allocated to RAS, Recommendation ITU-R RA.1031 is not applicable in the present case.

3.6.2 Sharing studies

3.6.2.1 Sharing between MSS uplinks and aircraft landing systems

ALS use a ground based transmitter positioned at the aircraft landing site. The system consists of azimuth and elevation transmitters, including separate azimuth and elevation antennas, located at the landing site. The receiver is located in the aircraft. The aircraft system receives coded transmissions on a number of selectable channels from the ground-based azimuth and elevation transmitters; it decodes the received signals for display on a cross-pointer indicator in the aircraft cockpit.

The characteristics applicable to these sharing studies are shown in Tables 3.6-1 and 3.6-2. A fuller set of characteristics are contained in Recommendation ITU-R S.1340 and Report ITU-R M.2170. Recommendation ITU-R S.1340 addresses sharing between ALS systems and FSS earth stations, which is limited to non-GSO MSS feeder links, and this methodology is used in this Report to calculate the required separation distance between ALS systems and MESs. Report ITU-R M.2170 addresses sharing between ALS systems and proposed new radiolocation systems where specific parameters are used. Some administrations have the view that the methodology and assumptions used in Report ITU-R M.2170 are also applicable to sharing between ALS and the MSS and that some of the assumptions used in Recommendation ITU-R S.1340 are not applicable, e.g. the aircraft altitude of 7.6 km (which should rather be in the order of 1-2 km). The use of the methodology and assumptions in Report ITU-R M.2170 would lead to significantly lower separation distances, of the order of 20 km.

The methodology used here to address interference between proposed MES and incumbent ALS is based on Recommendation ITU-R S.1340. The value of $I/N = -10$ dB is used for the protection of ALS. The aircraft altitude is 7.6 km. The main technical parameters of MSS transmit mobile earth stations are shown in Table 3.6-7.

TABLE 3.6-7

11/14 GHz band return link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate, R_{ndr} (kbit/s)	128.0	128.0	128.0	128.0
Uplink				
Assumed central frequency (GHz)	14.5	14.5	14.5	14.5
Terminal e.i.r.p. (dBW)	28.0	30.5	33.5	36.5
e.i.r.p in bandwidth (dB(W/3 MHz))	42.5	45.0	48.0	51.0

Values of e.i.r.p. in 3 MHz bandwidth (ALS receiver bandwidth) showed in Table 3.6-10 were calculated as follows (shown by an example of transmit pocket MES):

Calculation of the frequency bandwidth required through conversion net data rate of the terminal (R_{ndr} = 128.0 kbit/s), taking the following assumptions:

– signal modulation QPSK

– FEC code rate 3/4

– roll-off factor, α 0.25

Then, according to the known expression:

$$BW = \frac{R}{FEC\,QPSK}(1+\alpha) \quad \text{MHz}$$

$$BW = \frac{128}{3/4 \times 2} \times (1+0.25) = 0.1067 \text{ MHz}$$

Recalculate MES e.i.r.p. for 3 MHz bandwidth:

28.0 dBW − 10log (0.1067 MHz) + 4.8= 42.5 dBW/3 MHz.

Necessary separation distance is calculated by an example of transmit "pocket" MES type as shown below:

1) Calculation of the total radio LoS distance (km).

According to expression (6) in Recommendation ITU-R S.1340 we get:

$$D_{fsl} = (2 \cdot 8500 \cdot 7.6)^{0.5} + (2 \cdot 8500 \cdot 0.01)^{0/5} = 372.5 \text{ km}.$$

2) Calculation of free space loss (FSL) computed for D_{fsl}.

Basic transmission losses − due to LoS propagation and due to over-the-horizon propagation as well as the distance corresponding to these losses are calculated by expressions in Rec. ITU-R S.1340:

$$L_{fsl} = 20 \log (15530 \text{ MHz}) + 20 \log (372.5 \text{ km}) + 32.45 = 167.7 \text{ dB}.$$

$$L_{oth} = 42.5 + 168.6 - 167.7 + (-22.7) - (-10) = 30.7 \text{ dB}.$$

$$D_{oth} = 25 + 25((30.7 - 24) / (45 - 24)) = 33.0 \text{ km}.$$

3) Then separation distance, D_c, necessary to ensure protection against interference from MES into ALS:

$$D_c = 372.5 + 33.0 + 100 = 505.5 \text{ km}.$$

Coordination distances for other types of MES have been similarly calculated. Results of calculation are presented in Table 3.6-8.

Results of the calculation of coordination distance between MES in the band 15.43-15.63 GHz (Earth-to-space) and ALS system, carried out in accordance with the methodology specified in Recommendation ITU-R S.1340 (for various types of MES) are shown in the Table 3.6-8 below.

TABLE 3.6-8

Coordination distances between MES (Earth-to-space) and ALS system

MES Type	Coordination distance (km)
Pocket	505.5
Notebook	508.1
Briefcase	511.5
Suitcase	515.1

It is seen from the table that the coordination distance is up to 515.1 km.

Interference from the ALS transmitter to the MSS satellite

The interference from the ALS transmitter to the MSS satellite is shown in Table 3.6-9. The worst-case situation is clearly when the MSS satellite sees the ALS transmitter at a low elevation, aligned with the maximum antenna gain of the ALS transmitter. In the assessment below, the elevation angle of the ALS transmitter to the MSS satellite is assumed to be 10°.

TABLE 3.6-9

Interference from ALS transmitter (peak power) to MSS satellite

Parameter	**Value**
	Rec. ITU-R S.1340
ALS transmitter power (dBW)	38
ALS peak antenna gain (maximum of the elevation and azimuth antennas) (dBi)	33
ALS bandwidth (MHz)	3
e.i.r.p. in 1 MHz (dBW/MHz)	66.2
MSS satellite antenna gain (dBi)	44
MSS satellite temperature (K)	500
I/N criterion (dB)	−12.2
I_{max} (dBW/MHz)	−153.8
Slant range elevation (10 degrees elevation) (km)	40 586
FSL (dB)	208.4
Interference at MSS sat (main beam coupling) (dBW)	−98.2
Excess of the permissible interference level (main beam-to-main beam coupling) (dB)	**55.6**

Table 3.6-10 shows the interference to the GSO satellite based on the ALS average power, taking into account the duty cycle of the transmitter.

TABLE 3.6-10

Average power analysis results: Interference from ALS to GSO MSS

		ALS interferer antenna	**Main lobe**	**Side lobe**	**Side lobe**	**Back lobe**
		GSO victim antenna	**Main lobe**	**Main lobe**	**Side lobe**	**Main lobe**
ALS latitude (degrees)	**Distance interferer to GSO MSS (km)**	**FSL (dB)**	$I_{Th} = I - (N + (I/N)_{max})$ ***NOTE – Values greater than zero indicate interference potential***			
0	35 786.0	207.3	16.3	11.3	−14.1	−6.7
75	40 979.1	208.5	15.1	10.1	−15.3	−7.9

The carried out calculations showed that in the worst-case interference from ALS to the MSS satellite exceeds the permissible level by 55.6 dB.

For the interference from the ALS transmitter to meet the criterion, 55.6 dB antenna discrimination in the case of ALS conforming to Recommendation ITU-R S.1340 would be required from the ALS and/or MSS antenna. The ALS azimuth antenna has a peak gain of 31 dBi, so about 30 dB discrimination is realistic provided the ALS antenna is not aligned with the MSS satellite or if the MSS satellite is at a high elevation from the ALS transmitter. As the ALS antenna discrimination alone may not be sufficient to avoid excessive interference, MSS antenna discrimination may also be required, which suggests that the MSS spot beam would have to avoid coverage of the ALS location. Since the ALS antennas are scanned in elevation and azimuth, any interference to the MSS satellite is likely to have a strong temporal variation, which might allow a more relaxed criterion to be used.

Further study of the interference from ALS to MSS satellites would be necessary, including information on the ALS system deployment and operational characteristics.

3.6.2.2 Sharing between MSS uplinks and aircraft multipurpose radars

The characteristics of aircraft multipurpose radars (MPR) are described in Annex 1 to Recommendation ITU-R S.1340. Table 3.6-11 shows the interference for main beam-to-main beam coupling, using an I/N criterion at the MPR of $I/N = -10$ dB although it may be noted that Recommendation ITU-R M.1730 recommends an I/N protection level of −6 dB for multiple interferers.

TABLE 3.6-11

Interference from a ground-based MES to an airborne MPR

Parameter	Value
MES e.i.r.p. in Rx bandwidth (dBW)	37.0
Receiver bandwidth (MHz)	0.5
Receiver noise figure (dBW)	8
Receiver noise power (dBW)	−139.0
I/N criterion (dB)	−10
I_{max} (dBW)	−149.0
Receiver antenna gain (dBi)	30
Polarization loss (dB)	3.0
Separation distance (aircraft height) (m)	15 000
FSL (dB)	139.8
Interference from MES (dBW)	−65.8
Required antenna discrimination Excess of the permissible interference level (dB)	73.1
Minimum separation distance[12] (km)	570

[12] The methodology specified in Recommendation ITU-R S.1340 was used in calculations of separation distance between MES and ARNS stations.

The conducted studies show that the interference from MES exceeds the permissible level for MPR by 73.1 dB. For providing protection of operating MPR stations of the aeronautical radionavigation service from the unacceptable interferences of MES it is required to provide the separation distance of 570 km.

The bandwidth requirements of the MPR are relatively modest (0.5 MHz) so frequency separation between MES uplinks and MPRs may be feasible.

Table 3.6-12 shows the interference from an MPR to an MSS satellite receiver.

TABLE 3.6-12

Interference from an airborne MPR to an MSS satellite receiver

Parameter	Value
MPR peak antenna gain (dBi)	30
MPR e.i.r.p. (dBW)	70.0
MPR bandwidth (MHz)	0.5
e.i.r.p. in 1 MHz (dBW/MHz)	70.0
MSS satellite antenna gain (dBi)	44
MSS satellite temperature (K)	500
I/N criterion (dB)	−12.2
I_{max} (dBW/MHz)	−153.8
Slant range elevation (10 degrees elevation) (km)	40 586
FSL (dB)	208.4
Interference at MSS sat (main beam coupling) (dBW)	−94.4
Required antenna discrimination (dB)	59.4

Table 3.6-13 show the interference to the GSO satellite based on the MPR average power, taking into account the duty cycle of the transmitter.

TABLE 3.6-13

Average power analysis results MPR and GSO MSS

		MPR interferer antenna	**Main lobe**	**Side lobe**	**Side lobe**	**Back lobe**
		GSO victim antenna	**Main lobe**	**Main lobe**	**Side lobe**	**Main lobe**
ALS latitude (degrees)	**Distance interferer to GSO MSS (km)**	**FSL (dB)**	$I_{Th} = I - (N + (I/N)_{max})$ ***NOTE – Values greater than zero indicate interference potential***			
0	35 786.0	207.3	6.3	−6.7	−32.1	−23.7
75	40 979.1	208.5	5.1	−7.9	−33.3	−24.9

As for the case of interference from the MES to the MPR, a high antenna discrimination would be required. Assuming the maximum MPR antenna discrimination, additional MSS spot beam antenna discrimination of about 27 dB would be required. This result also suggests that co-frequency co-coverage sharing is not feasible but frequency separation between MSS systems and MPRs may allow sharing.

Information on the deployment numbers and characteristics of MPRs would be desirable to enable more definite conclusions.

3.6.2.3 Sharing between MSS and surface-based radars, and between MSS and radar sensing and measurement systems

Studies have shown difficulties in co-frequency sharing between MSS uplinks and surface-based radars (SBR) and radar sensing and measurement systems. However, as explained in § 3.6.1.1, surface-based radars and radar sensing and measurement systems are not expected to operate in the band 15.43-15.63 GHz.

3.6.2.4 Sharing between MSS uplinks and proposed radiolocation system "System-6"

The band 15.4-15.7 GHz is being studied for a potential radiolocation allocation under WRC-12 Agenda item 1.21. Studies have been based on the characteristics of the proposed "System-6", described in Recommendation ITU-R M.1730-1, which would operate in the band 15.4-17.3 GHz. This system is an airborne system, typically operate at an altitude of 8 500 m, used for search, track and ground-mapping.

Study 1

Interference from a ground based MES to a radiolocation receiver is assessed in Table 3.6-14 for the worst-case situation of main beam-to-main beam coupling. Note that the radiolocation system has a very large receiver bandwidth (1 850 MHz) but it is assumed that the interference from the MES (which has a 1 MHz bandwidth) is the only interference source.

System-6 has a peak antenna gain of 35 dBi which suggests that about 40 dBi antenna discrimination is available when interference is received on the far side lobes. The MES antenna can provide a maximum of about 41 dBi antenna discrimination between main beam and the far side lobes. Hence, provided the MES and System-6 receiver are aligned such that interference is via the side lobes of both the MES and radiolocation antenna, interference should be below the criterion. Conversely, interference could occur above the criterion if the MES is within the beam of the radiolocation antenna or if the System-6 aircraft is within the beam of the MES. Since the radiolocation system is deployed on an aircraft, any interference would be transitory.

TABLE 3.6-14

Interference from a ground-based MES to "System-6" receiver

Parameter	Value
MES e.i.r.p. (dBW)	40
Receiver bandwidth (MHz)	1 850
Receiver noise figure (dBW)	5
Receiver noise power (dBW)	−106.3
I/N criterion (dB)	−10
Imax (dBW)	−116.3
Receiver antenna gain (dBi)	35
Polarization loss (dB)	3
Separation distance (aircraft height) (m)	8 500
FSL (dB)	134.8
Interference from MES (dBW)	−62.8
Excess of the permissible interference level (main beam-to-main beam coupling) (dB)	53.5
Minimum separation distance[13] (km)	461

Table 3.6-15 shows the interference from a System-6 aircraft transmitter to an MSS satellite receiver assuming main beam-to-main beam antenna coupling.

TABLE 3.6-15

Interference from a "System-6" transmitter to an MSS satellite receiver

Parameter	Value
Transmitter power (dBW)	27.0
e.i.r.p. (dBW)	62.0
Bandwidth (MHz)	1 850
e.i.r.p. in 1 MHz (dBW/MHz)	29.3
MSS satellite antenna gain (dBi)	44
MSS satellite temperature (K)	500
I/N criterion (dB)	−12.2
I_{max} (dBW/MHz)	−153.8
Slant range elevation (10 degrees elevation) (km)	40 586
FSL (dB)	208.4
Interference at MSS sat (main beam coupling) (dBW)	−135.1
Excess of the permissible interference level (main beam-to-main beam coupling) (dB)	18.7

[13] The methodology specified in Recommendation ITU-R S.1340 was used in calculations of separation distance between MES and ARNS stations.

As System-6 uses a ground scanning antenna, discrimination of at least 18.7 dB in the direction of any MSS satellite is a realistic assumption.

Hence from these preliminary studies, excessive interference may be caused by an MES to a System-6 radiolocation receiver. The conducted studies show that the interference from MES exceeds the permissible level for System 6 receiver by 53.5 dB. For providing protection of operating RLS System 6 stations from the unacceptable interferences of MES it is required to provide the separation distance of 461 km. Interference from System-6 to an MSS satellite may be acceptable.

Study 2

For this analysis, the interference to noise ratio, I/N will be calculated to assess compatibility between the radiolocation System-6 planned to operate in the 15.4-17.3 GHz band and proposed MESs.

An initial step in assessing compatibility is to determine noise power as follows:

$$N = -228.6 \text{ dBW} + 10 \log(B_{IF} \text{ (Hz)}) + 10 \log(290^*(10^\wedge (NF/10)-1)) \quad (5)$$

where:

- B_{IF} : receiver IF bandwidth (Hz) is 25 MHz for System-6
- NF : receiver noise figure (dB) is 5 dB for System-6.

The equation to determine if interference into System-6 from MESs is likely to occur is given by:

$$I = P_{Tx} + G_{Tx} + G_{Rx} - L_{Trans} - FDR_{IF} \quad (6)$$

where:

- I : interference, peak power of the radar pulses at the receiver (dBW)
- P_{Tx} : peak power of the interfering system (dBW)
- G_{Tx} : antenna gain of the interfering transmitter in the direction of the victim receiver (dBi)
- G_{Rx} : antenna gain of the victim receiver in the direction of the interfering transmitter (dBi)
- L_{Trans} : transmission loss between transmitting and receiving antennas (dB)
- FDR_{IF} : frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

The FDR_{IF} value can be determined from Recommendation ITU-R SM.337. FDR_{IF} is zero for this case since the receiver bandwidth (25 MHz for System-6) is much larger than the transmitter bandwidth (1 MHz). The transmission loss is calculated using Recommendation ITU-R P.525 using free space loss and Recommendation ITU-R P.676 for attenuation by atmospheric gases. The one way attenuation due to atmospheric gases is assumed to be 0.0275 dB/km according to Fig. 5 of Recommendation ITU-R P.676.

Study 2a – Static interference analysis

For the static interference analysis case, the link budget is shown in Tables 3.6-16 and 3.6-17. Table 3.6-16 shows the case for peak-to-peak antenna coupling and Table 3.6-17 shows the results for the combinations of peak and side lobe antenna gains.

TABLE 3.6-16

Static link budget for interference analysis for peak-to-peak antenna coupling

Parameter	System-6 Rx	MES Tx
Frequency (MHz)	15 530.0	15 530.0
Wavelength (m)	0.019	0.019
Peak transmit power (W)		15.7
Peak transmit power (dBW)		4.5
e.i.r.p. (dBW)		28
Pulse bandwidth (MHz)		1.0
Polarization loss (dB)	3.0	
Receiver IF bandwidth (MHz)	25.0	
Receiver noise figure (assumed) (dB)	5.0	
System noise temperature (degrees K)	627.1	
Calculated receiver noise power (dBW)	−126.6	
Protection criterion, I/N (dB)	–6.0	
Bandwidth correction factor (OTR) if $Rx\_BW <= Tx\_BW$ (dB)	0.0	
Received signal power excluding propagation loss and antenna gains (dB)	9.0	
Antenna gain (dBi)	35.0	23.5
Received signal power excluding propagation loss (dBW)		60
Sys-6 Antenna 3-dB elevation beamwidth (degrees)	3.2	5.49
Slant range Rx to interferer (km)		706
Atmospheric attenuation 0.0275 dB/km (dB)		19.4
Free-space propagation loss (dB)		173.2
Peak received power including propagation loss (dBW)		−132.7
Interference or signal-to-noise ratio (I/N) (dB)		−6.0

TABLE 3.6-17

Static link budget for interference analysis for antenna coupling combination

Antenna coupling case	Interference from MES antenna peak gain into System-6 antenna peak gain	Interference from MES antenna 1st side lobe into System-6 antenna peak gain	Interference from MES antenna peak gain into System-6 antenna 1st side lobe gain	Interference from MES antenna 1st side lobe into System-6 antenna 1st side lobe
System-6 antenna gain value (dBi)	35	35	3.5	3.5
MES antenna gain value (dBi)	28	14	28	14
Required separations distance between the victim System-6 and MESs interferers to meet the required protection criteria $I/N = -6$ dB (km)	706	482	120	50

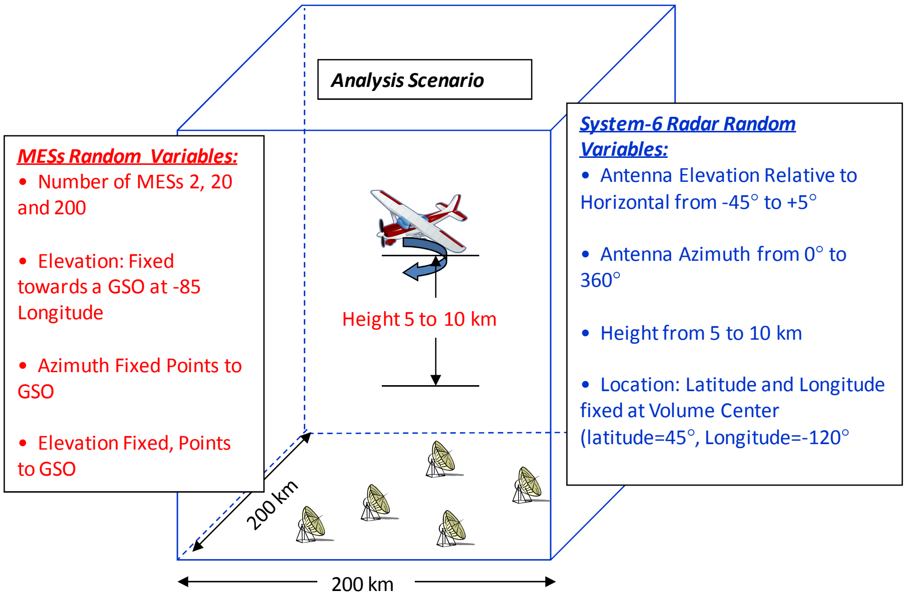
The results shown in Table 3.6-17 indicate the difficulties in achieving co-frequency compatibility between System-6 and the MESs. In the best case, the minimum required separation distance for the 1st side lobe to 1st side lobe case in 50 km, and in the worst case the minimum required separation distance is 706 km.

Study 2b − Dynamic simulation

The interference analysis for radiolocation systems does not call for dynamic simulation. Interference protection criteria for these systems is $I/N = -6$ dB for any interferer or a combination of interferers at any time. However, it is necessary to show the effect of multiple MES devices on System-6. In the following paragraphs the results of the interference of 2, 20 and 200 MESs randomly distributed in a 400 000 cubed kilometre, corresponding to 0.000005, 0.00005 and 0.0005 MESs per cubed kilometre, are provided as cumulative distribution function (CDF). The CDF results are plotted as a function of System-6 I/N in dB. In all cases the required System-6 I/N protection criteria is exceeded. Figure 3.6-3 shows the compatibility analysis scenario for the dynamic simulation.

FIGURE 3.6-3

Compatibility analysis scenario for dynamic simulation



The following analysis assumptions are made:

1) *I*/*N* of −6 dB is the protection criteria for System-6;

2) MES systems points towards a geostationary satellite located at longitude of −85° and has an inclination of zero;

3) the analysis scenario is centred at latitude of 45° and longitude of −120°;

4) main lobe-to-main lobe antenna coupling between MESs transmitters and System-6 receiver will regularly occur;

5) transmission loss is calculated using Recommendations ITU-R P.525 and ITU-R P.676;

6) the assumed antenna pattern for the MESs is Recommendation ITU-R F.699 (Annex 11 to Document 4C/436);

7) System-6 typical operational height is between 5 000 to 10 000 m;

8) System-6 antenna angles orientations range from 0° to 360° in azimuth and from +5° to −45° relative to the horizontal line of the flight vector;

9) all MESs are randomly distributed over a 200 × 200 km (40 000 km^2) area on the surface of the Earth;

10) the densities of MESs are 0.00005, 0.0005 and 0.005 MES per km^2. These correspond to using 2, 20 and 200 randomly distributed MESs.

Study 2b − Simulation parameters

Dynamic simulations were performed using a software analysis tool to determine the statistics of the interference levels from MESs into System-6 radar operating in the same frequency band. System-6 and the MESs in this analysis are contained in a 400 000 km^3 volume. This cube has dimensions of 200 km (width) by 200 km (length) by 10 km (height). Some systems characteristics vary randomly over a specified range of values inside that cube. The random variable ranges of the parameters simulated in the software as shown in Table 3.6-18.

TABLE 3.6-18

Simulation analysis random values range

Parameter	Minimum value	Maximum value	Notes
Simulation			
Terrain data			Terrain data is not used
Number of samples			The number of samples for each analysis is 200 000
System-6 radar parameters			
Ground distance to interference	Centre of analysis cube	Radius is 100 km	The volume where the MESs are located is 400 000 km^3
Antenna height above terrain (km)	5	10	
Antenna elevation angle (degrees)	−45	+5	
Antenna azimuth angle (degrees)	0	360	To accommodate the aircraft azimuthal orientation
Antenna pattern			Rec. ITU-R M.1851 with cosine cubed pattern
Frequency (GHz)	15.53	15.53	Fixed frequency. Same as MESs
Receiver IF bandwidth (MHz)	25	25	
Polarization mismatch (dB)	−3.0	−3.0	Typical value used in many ITU Recommendations
Earth stations parameters			
Antenna elevation angle (degrees)	Fixed towards GSO	Fixed towards GSO	Toward a satellite in geostationary satellite orbit at longitude of −85° and inclination of zero
Antenna azimuth angle (degrees)	Fixed towards GSO	Fixed towards GSO	Toward a satellite in geostationary satellite orbit at longitude of −85° and inclination of zero
Antenna height (m)	1.5	1.5	Nominal value for antenna height is 1.5 m
Antenna patterns			Rec. ITU-R F.699 for 0.2 m diameter antenna (gain = 23.5 dBi)
Analysis volume (km^3)			A 200 km by 200 km by 10 km^3 volume centred on the earth station. The analysis volume is 0.4 million km^3

Study 2b − Dynamic simulation results

The result of the dynamic simulation shows that System-6 protection criteria of $I/N = -6$ dB is regularly exceeded and that the aggregate interference is excessive.

Figures 3.6-4, 3.6-6 and 3.6-8 show the simulation results for 2, 20 and 200 MES devices where the per cent of time System-6 *I*/*N* protection criteria is exceed for 0.5% for two MESs, 5% for 20 MESs and 30% for 200 MESs.

The number of times System-6 *I*/*N* protection criteria is exceeded, in a 5 second duration, is large as shown in Figs. 3.6-5 for 2 MES, Fig. 3.6-7 for 20 MESs and Fig. 3.6-9 for 200 MESs.

Figures 3.6-5 to 3.6-9 assume the co-frequency interference and is within the 25 MHz IF bandwidth 100% of the time every time the radar is in receive mode.

FIGURE 3.6-4

Per cent of time *I*/*N* is exceeded for 2 MES devices

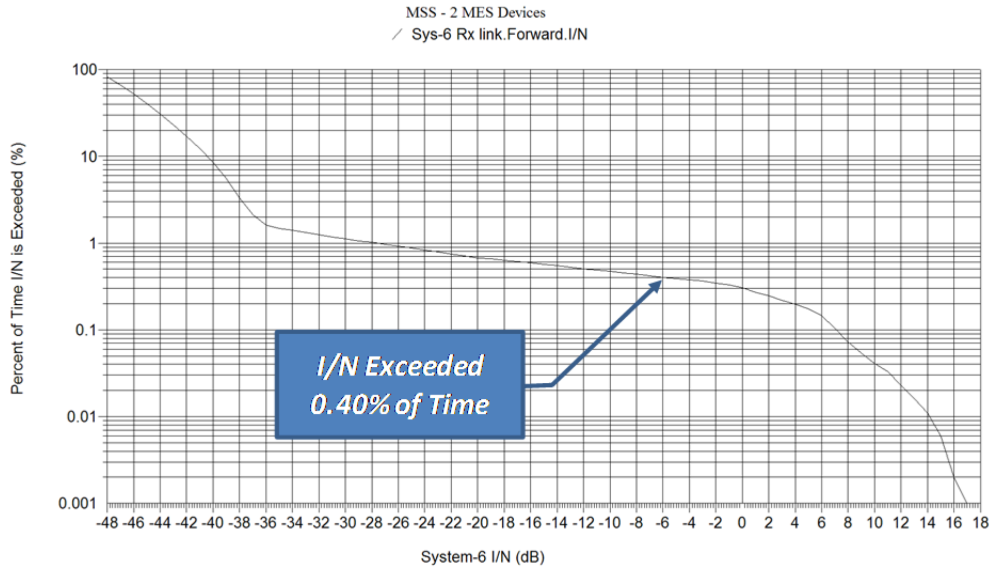


FIGURE 3.6-5

Number of times System-6 *I*/*N* protection criteria is exceeded in the last 5 seconds (1 000 samples) of the simulation for 2 MES devices

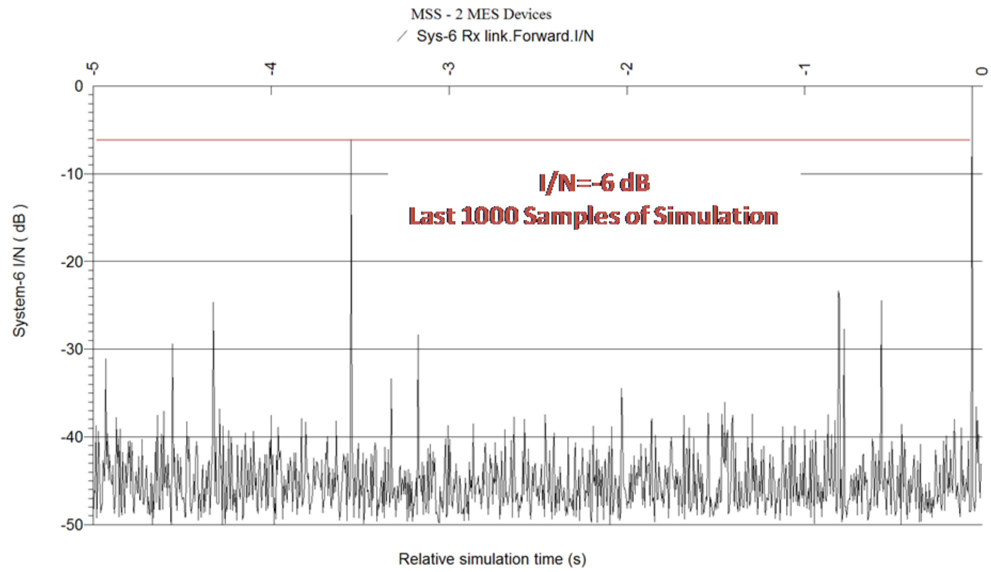


FIGURE 3.6-6

Per cent of time *I*/*N* is exceeded for 20 MES devices

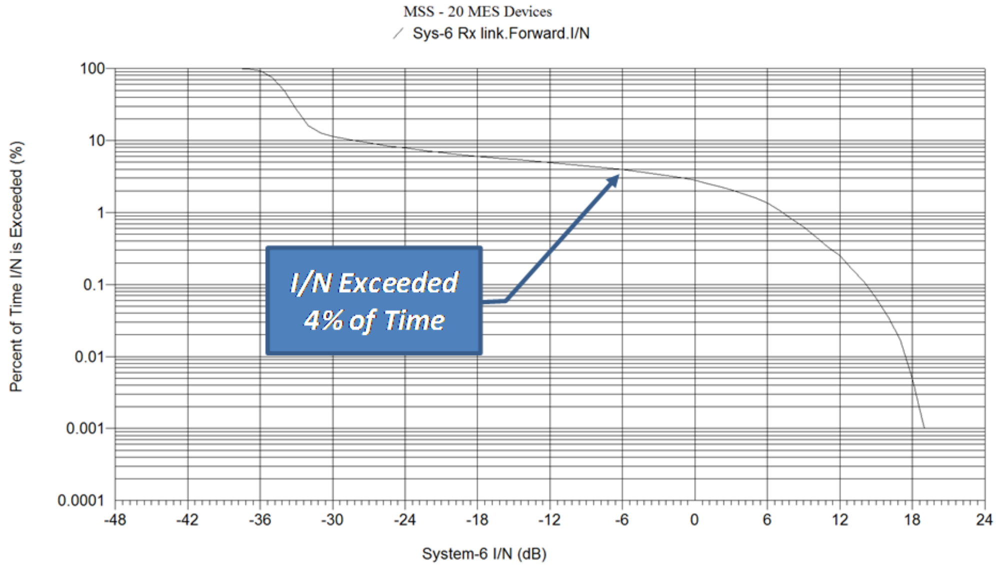


FIGURE 3.6-7

Number of times System-6 *I*/*N* protection criteria is exceeded the last 5 seconds (1 000 samples) of the simulation for 20 MES devices

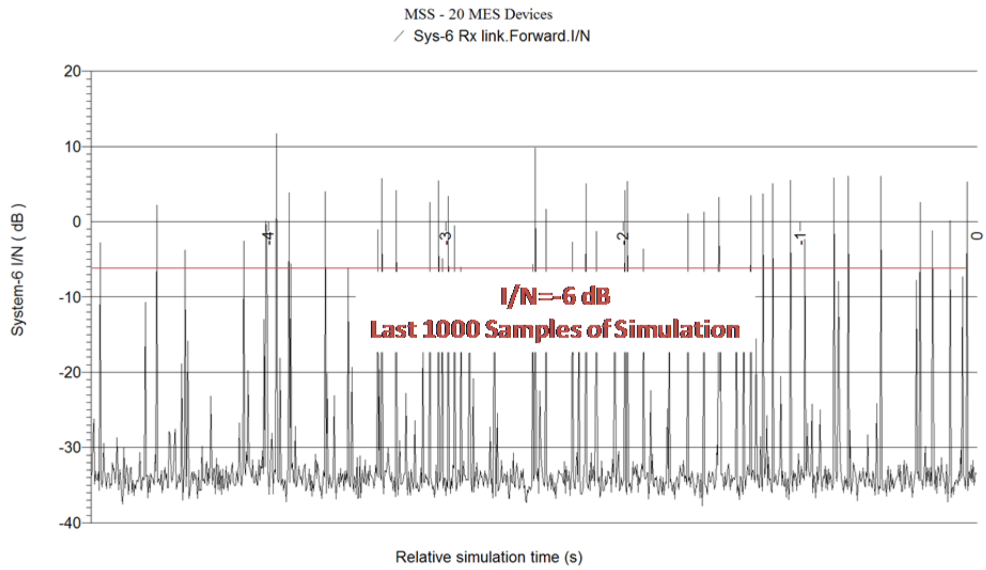


FIGURE 3.6-8

Per cent of time *I/N* is exceeded for 200 MES devices

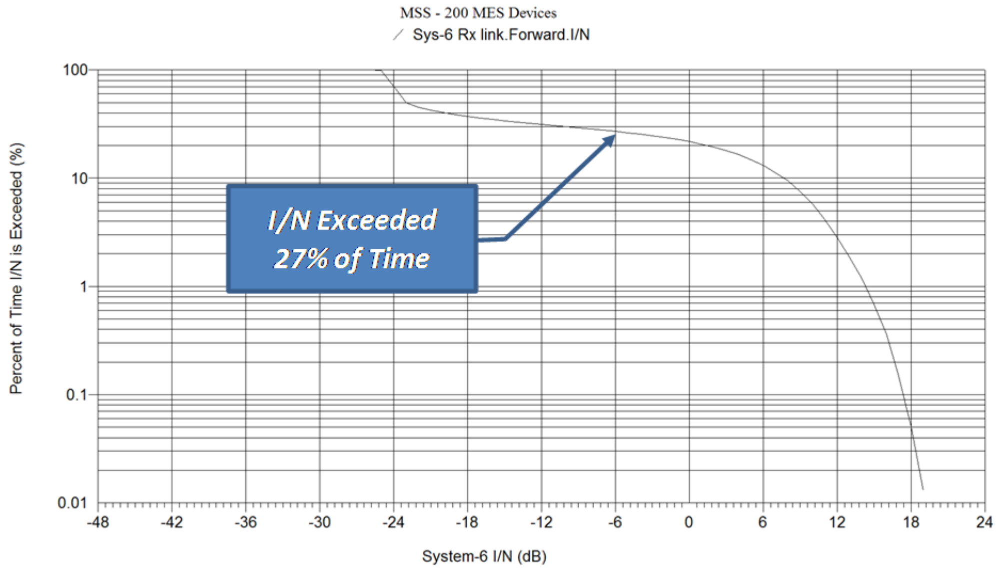
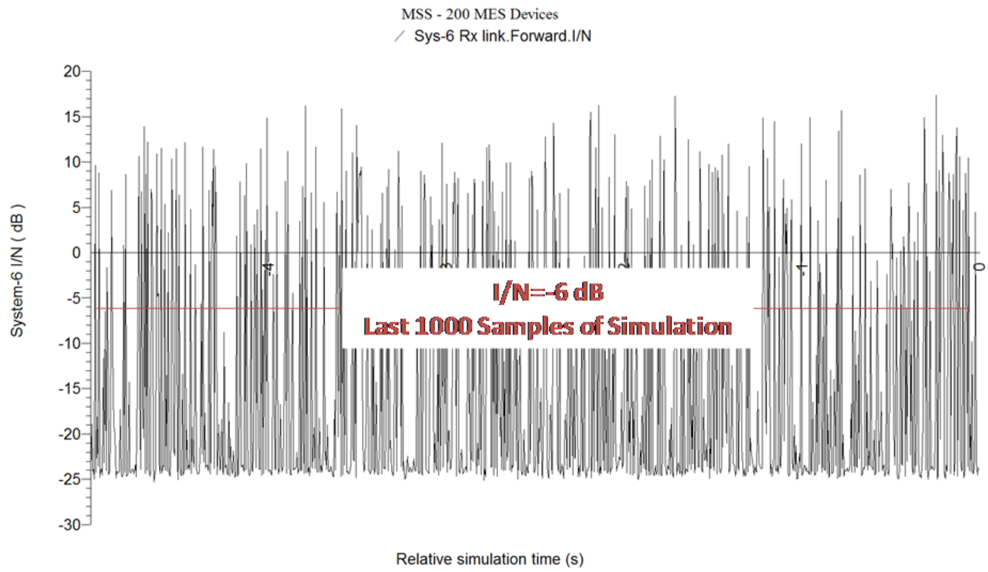


FIGURE 3.6-9

Number of times System-6 *I/N* protection criteria is exceeded the last 5 seconds (1 000 samples) of the simulation for 200 MES devices



Analysis of interference into the MSS space station and mitigation techniques to reduce interference from MSS into radars

Interference into the MSS space station:

The maximum permissible pfd level into a MSS space station receiver can be computed from the following formula:

$$pfd = I/N + 10\log(4\pi/\lambda^2) - (G/T) + k$$

Applying a required *I/N* of −12.2 dB and a *G/T* of 15 dB/K from Annex 1 to this Report, the pfd to protect the MSS space station is −174.6 dB(W/m^2/4 kHz).

Given that the System 6 radar is airborne and has a limited pointing range towards the ground, that meeting a pfd level at the GSO arc is not expected to be constraining on the planned radar systems

Possible mitigation techniques to reduce interference from MSS into radars

There are a number of possible mitigation techniques that could be considered. For example, interference levels into the radar antenna could be reduced by maintaining a minimum separation distance between the MES and radar stations. Such a technique might be applicable in a cross-border situation. Another possible technique is restricting the radar pointing toward the MES stations also can significantly reduce the interference levels. This technique would result in a small limitation to the area to which the radar can point and requires that the radar system to have information on the location of the MES transmitters. Another technique that could be considered to reduce interference into the radar could be by improving the side-lobe performance of the MES antennas. Another possible mitigation technique is for the radar system to implement signal rejection techniques to remove unwanted signals from the radar data.

Study 2 − Conclusions

Similar to the static analysis, Tables 3.6-16 and 3.6-17 results, the dynamic simulation Figures 3.6-3 to 3.6-9 show difficulties in achieving compatibility between MES devices and System-6 on a co-frequency basis. Figures 3.6-3 to 3.6-9 also show that the percentage of time *I*/*N* criteria is exceeded is highly dependent on the expected density of MES deployment.

3.6.2.5 Sharing between MSS uplinks are FSS systems

The use of this band by the FSS (Earth-to-space) is limited to feeder links for non-GSO MSS systems. It is believed that there are is no current or planned use of this band for such applications, and hence sharing studies with respect to FSS systems have not been included.

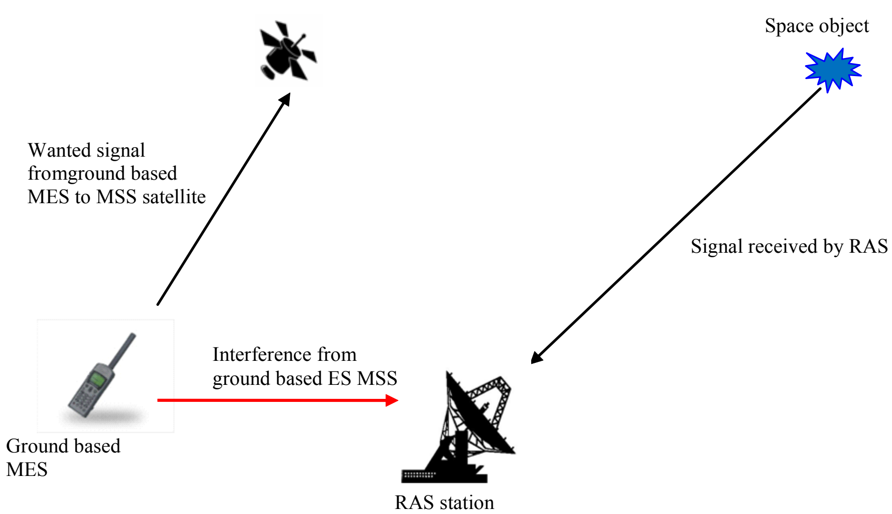
3.6.2.6 Compatibility between MSS uplinks and radio astronomy stations

3.6.2.6.1 Interference from mobile earth stations (except AESs) to radio astronomy stations

The interference scenario is shown in Figure 3.6-10.

FIGURE 3.6-10

Interference scenario



As noted in Table 3.6-6, the threshold level of interference to RAS in the 15.35-15.4 GHz band is –202 dBW in a 50 MHz bandwidth. This is equivalent to -219 dBW/MHz.

The in-band e.i.r.p. from a single MES is +40 dBW/MHz.

For a receive antenna gain of 0 dBi and assuming that the MES antenna directs its main beam at the radioastronomy station without any adjacent channel rolloff, the required propagation loss would be 259 dB, leading to very large separation distances if LoS interference is assumed. There are, however, additional significant mitigating factors:

- there is a separation of 30 MHz between the RAS band and the proposed MSS band and it is reasonable to expect that the adjacent band power ratio will be at least 35 dB and possibly as much as 75 dB;
- interference from an MES to a radio astronomy station would typically be via the MES side lobes. As noted in Table 3.6-17, the gain of the MES station is 28 dBi, but a sidelobe level of 0 dBi is a reasonable assumption.

Using a 0 dBi antenna sidelobe level and given an atmospheric attenuation of 0.03 dB/km in wet air (Recommendation ITU-R P.676, Fig. 6; 0.009 dB/km in dry air) Table 3.6-19 shows the separation distances which would be required to keep interference below the threshold level for various values of the adjacent band power ratio.

TABLE 3.6-19

Terrestrial coordination radii required to prevent interference from individual terrestrial MES (0 dBi sidelobe) to RAS (0 dBi sidelobe) assuming LoS

Adjacent band power ratio	Coordination radius in wet air (dry air)
35 dB	747 km (1 697 km)
45 dB	518 km (1 050 km)
55 dB	322 km (552 km)
65 dB	172 km (242 km)
75 dB	76 km (90 km)

However, at these distances, it is highly unlikely that there will be a LoS between the RAS and the MES and so terrain shielding and diffraction loss will reduce the received signal level, reducing these distances. Using smooth earth diffraction, the distances above for 75 dB adjacent band power ratio could be reduced to about 25 km. However exact distances will depend on the heights of the MES and the radioastronomy receiver, as well as the terrain on the path.

3.6.2.6.2 Interference from aircraft earth stations to radio astronomy stations

Two compatibility studies are presented in this section. The first calculates the minimum distance at which an AES would exceed the Recommendation ITU-R RA.769 protection criterion. The second study is based on modelling the movement of aircraft visible to an RAS station, and determines the required filtering of the AES emissions to meet the recommended protection criteria.

Study 1

In this compatibility study the interference scenario shown at Fig. 3.6-11 was considered with the following assumptions:

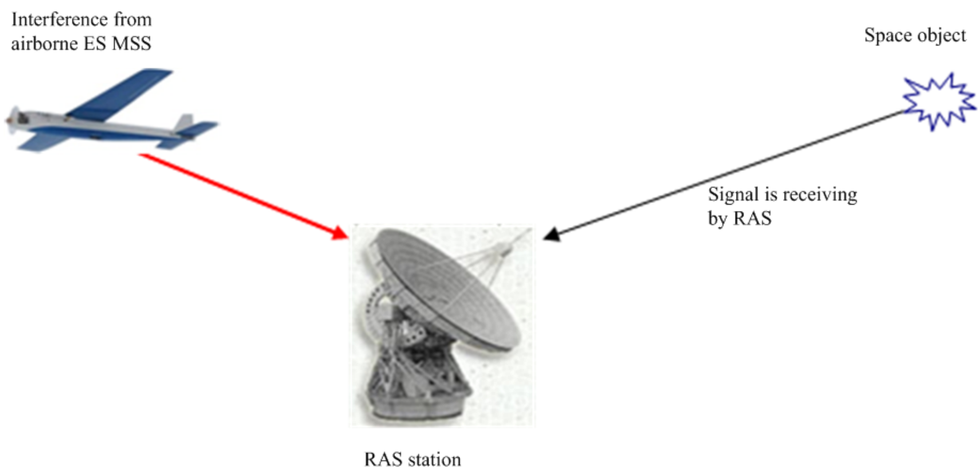
1) The interference from AES transmitter to the RAS receiver may pass through the main RAS antenna beam as well as through the side lobe and back lobe of this antenna.

2) The free space propagation model in accordance with Recommendation ITU-R P.528 was used.

3) The technical characteristics and protection criteria of RAS correspond to Recommendation ITU-R RA.769.

FIGURE 3.6-11

Interference scenario



The threshold interference levels I_{max} at the RAS receiver input was used for the compatibility analysis of the RAS receiver and airborne ES MSS transmitter:

$$I <= I_{max} \tag{7}$$

For the frequency range 15.35-15.4 GHz this level is −202 dBW/50 MHz.

The list of RAS stations operating in the band 15.35-15.4 GHz is presented in the Table 3.6-5.

Power of spurious interference I(W) from an AES transmitter at the input of RAS receiver is calculated by using the following formula:

$$I = P_{ua} \cdot G_{ras}(\theta) \cdot \lambda^2 / (4\pi R)^2 \tag{8}$$

where:

P_{ua} : power of spurious interference of an AES transmitting in the frequency band of RAS receiver (W)

$G_{ras}(\theta)$: RAS receiving antenna gain in direction to the source of interference (θ − it is an angle between direction of maximum RAS receiving antenna gain and direction to the source of interference)

λ : length of wave (m)

R : separation distance between AES transmitter and RAS receiver (m).

To assess P_{ua} values the information from Annex 1 was used for the case of AES input parameters operating in the band 15.43-15.63 GHz (see Table 3.6-20).

TABLE 3.6-20

AES parameters

	Pocket	Notebook	Briefcase	Suitcase
Net data rate (kbit/s)	128.0	256.0	512.0	1 024.0
Terminal e.i.r.p. (dBW)	28.0	30.5	33.5	36.5
RF power (dBW)	4.5	2.7	2.7	5.7

The radiation antenna pattern of the AES was taken from Fig. 1-2 in Annex 1 of this Report.

The analysis of the parameters presented in Table 3.6-20 and Fig. 1-2 have shown that there is a contradiction between the e.i.r.p. value in Table 3.6-20 and the calculated e.i.r.p. value (RF power + antenna gain) following the data from Table 3.6-20 and Fig. 1-2. Therefore in this Report it was assumed that the e.i.r.p. of the AES corresponds to the Table 3.6-21 values when transmitter power is 0 dBW for any net data rate, that is:

TABLE 3.6-21

AES parameters

	Pocket	Notebook	Briefcase	Suitcase
Net data rate, *R*, (kbit/s)	128.0	256.0	512.0	1 024.0
Terminal e.i.r.p. (dBW)	28.0	30.5	33.5	36.5
RF power (dBW)	0	0	0	0

Furthermore, it is assumed that the AES will use:

– phase modulation − QPSK

– channel coding FEC – 3/4

– demodulator roll-off factor – $a = 0.25$

and use the following formula:

$$BW = \frac{R}{FEC * \log_2(QPSK)} * (1 + a) \qquad \text{kHz} \tag{9}$$

The required bandwidth of AES signals (BW) was calculated for different data rates, *R*, and corresponding values of spectral e.i.r.p. density (see Table 3.6-22):

TABLE 3.6-22

Values of spectral e.i.r.p. density of ES MSS

	Pocket	Notebook	Briefcase	Suitcase
Net data rate, *R*, (kbit/s)	128.0	256.0	512.0	1 024.0
Bandwidth of signals BW (kHz)	106.7	213.3	426.7	853.3
Spectral e.i.r.p. density ($e.i.r.p._{Sp\_es\_mss}$) (dBW/Hz)	−22.28	−22.79	−22.8	−22.81

Also it was assumed that:

a) the AES signal is shifted from the upper edge of the RAS allocation thereby that the level of its unwanted emissions in the RAS band does not exceed −60 dB in relation to the maximum transmitting power ($K_{es\_mss} = S_{es\_mss}/S_{unwanted\_es\_mss}$ = 60 dB);

b) the RAS receiver has 50 MHz receiving bandwidth ΔF_{ras} (in the range 15.35-15.4 GHz) as mentioned in Recommendation ITU-R RA.769;

c) the AES antenna gain towards RAS is always towards the back lobe (see Fig. 1-2) and equal 0 dB (for antenna with diameter 0.2 m) or −4.5 dB (for antenna with diameter 0.5 m). It leads to a reduced unwanted e.i.r.p. value of AES due to antenna discrimination ($\Delta G_{es\_mss}(\theta)$) towards the RAS station at 28 dB (for antenna with diameter 0.2 m) and at 41 dB (for antenna with diameter 0.5 m) from the values presented in the Table 3.6-25 above.

Compatibility assessment

Taking into account the above mentioned assumptions the formula for definition of AES unwanted emissions level ($P_{unwanted\ es\_mss}$) towards RAS with 50 MHz receiving band is the following (see Table 3.6-23):

$$P_{unwanted\ es\_mss} = E.I.R.P_{Sp\_es\_mss} - \Delta G_{es\_mss}(\theta) - K_{es\_mss} + 10 \cdot \lg \Delta F_{ras}\,. \tag{10}$$

TABLE 3.6-23

Unwanted emissions level of ES MSS ($P_{unwanted\ es\_mss}$) in the receiving band of RAS

	Pocket	Notebook	Briefcase	Suitcase
Net data rate, R, (kbit/s)	128.0	256.0	512.0	1 024.0
$P_{unwanted\ es\_mss}$ (dBW/50 MHz)	−33.3	n/d	n/d	−46.82

Using equations (7), (8) and (9) the following ratio to calculate the minimum protection distance R (km) for providing compatibility of the both systems will be used:

$$R = 10^{(P_{unwanted\ es\_mss} + G_{ras}(\theta) - 20*\mathrm{Log}(F) - I_{max} - 92.44)/20} \tag{11}$$

where corresponding variables have the following dimensions: $P_{unwanted\ es\_mss}$ (dBW/50 MHz), $G_{ras}(\theta)$ (dBi), F (GHz), K_{es_mss} (dB), ΔF_{ras} (MHz), θ (degree), I_{max} (dBW/50 MHz).

In calculation the following input data was used: $P_{unwanted\ es\_mss}$ (see Table 3.6-23) dBW/50 MHz; I_{max} = −202 dBW/50 MHz; ΔF_{ras} = 50 MHz; F = 15.375 GHz. It was assumed that the AES is located at the aircraft flying at 10 000 m and the height of the RAS antenna is 10 m. In this case the LoS distance between the AES and the RAS receiver is 425 km. These results apply to an example study against one aircraft only.

The results of study are shown in Table 3.6-24.

TABLE 3.6-24

The value of protection distance, *R*, (km) to provide compatibility between an AES and RAS

θ (degree)	0	1	2	3	5	10	15	20	25	30	34-80	80-120	120-180
$G_{ras}(\theta)$ (dBi)	84	29	21.5	17	11.5	4	−1.3	−5	−8	−10.3	−12	−7	−12
R − *min* protection distance (km) (when $P_{unwanted\ es\_mss}$ = −33.3 dBW/50 MHz)	*	11 930	5 031	2 997	1 591	671	364	238	169	129	106	**189**	106
R − *min* protection distance (km) (when $P_{unwanted\ es\_mss}$ = −46.8dBW/50 MHz)	*	2 513	1 060	631	335	141	77	50	35	27	22	**40**	22

* More than 1 million km.

Conclusions of Study 1

The analysis of the Study 1 results (Table 3.6-24) have shown that it is difficult to achieve compatibility between airborne ES MSS (E-s) and the RAS receiver:

− it will not be provided even at line of sight distance of 425 km between the stations which are under consideration (AES and RAS) for a big enough possible observation directions of the RAS station (more than ±10° from RAS antenna main beam direction when the AES unwanted e.i.r.p in the direction of the RAS station is −33.3 dBW/50 MHz and around ±4° − when the AES unwanted e.i.r.p in the direction of the RAS station is −46.8 dBW/50 MHz);

− an exclusion zone needs to be established around RAS stations for flight of aircrafts equipped with an AES transmitter of at least 189 km (when the AES unwanted e.i.r.p in the direction of the RAS station is −33.3 dBW/50 MHz) or 40 km (when the AES unwanted e.i.r.p in the direction of the RAS station is −46.8 dBW/50 MHz).

At the same time it should be mentioned:

− that the above conclusions were derived based on the assumption that attenuation of AES unwanted emissions will be at least 60 dB down to the main emissions of this station. However, in accordance with RR Appendix **3** the value of unwanted emissions attenuation in the spurious domain for ES MSS with power 1 W should not exceed the value 43 + 10Log(1W) = 43 dBc. This value of 17 dB is less than the value which has been used in this study;

− that due to the simplicity of the study it was assumed that airborne ES MSS antenna is always pointed towards the RAS back lobe; notably, the possible aircraft manoeuvres were not considered;

− that following the data from Table 3.6-20 the e.i.r.p. value of ES MSS may increase by at least 4.5 dB (from "Pocket" station type) and 5.7 dB (from "Suitcase" station type). That leads to an increase of the required protection distance and exclusion zones around the RAS station.

Study 2

The scope of this study is to determine the level of unwanted emissions of an AES necessary to provide adequate protection to a radio astronomy station. As a result, the required filtering of out-of-band emissions of the AES terminal is determined.

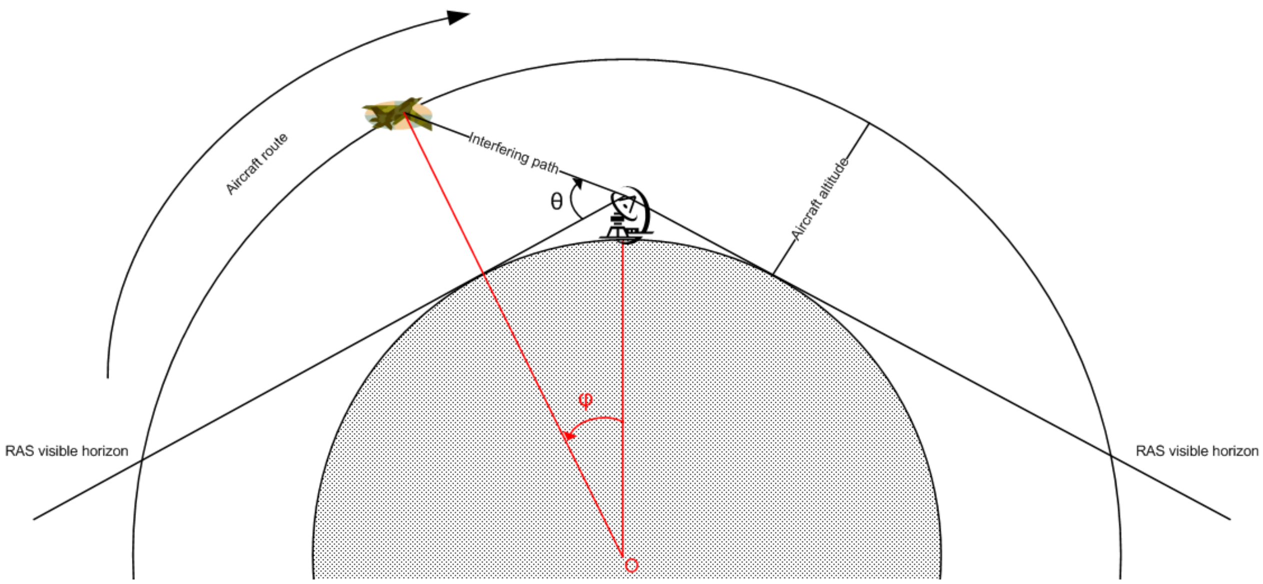
As a worst-case scenario, the interferer is considered being a terminal mounted on an aircraft flying over the RAS station, directly overhead; furthermore, according to the information contained in

Table 3.6-5, the RAS station is considered to be situated at an altitude of 400 (m). The reference period of time starts at the time the aircraft is just visible on one horizon and ends when the aircraft just disappears at the opposite horizon. Effectively, one aircraft equipped with an AES is permanently visible to the RAS (see Figure 3.6-12).

A certain number of RAS sites are local to major airports and below major air routes for which aggregate interference from AESs could be a significant factor. This aspect would require further studies, and could lead to the need for more stringent filtering requirements on AESs.

FIGURE 3.6-12

Geometrical scenario



The parameters shown in Table 3.6-25 are considered to be applicable to the AES:

TABLE 3.6-25

Parameters for AES

Parameter	High Gain UT
Antenna peak gain (dBi)	37
Antenna type	Directive
Antenna diameter (m)	0.5
Max output power (dBm)	33
Polarisation	Circular
Centre frequency (MHz)	15 530
Channel bandwidth (MHz)	1
Typical Elevation (degrees)	20

It should be noted that a lower gain UT may have higher side lobe emissions than the high gain UT, which would lead to higher unwanted emissions in the direction of the RAS. With no change to the other assumptions, the required filtering would need to be increased by the corresponding amount.

The threshold level of interference shown in Table 3.6-6 is considered to be applicable to a RAS station. As indicated in Recommendation ITU-R RA.1513, a criterion of 2% has been applied for assessing the interference affecting the RAS.

An atmospheric path attenuation loss as defined in Annex 2 of Recommendation ITU-R P.676-8 is used in the calculations; the atmospheric parameters shown in Table 3.6-26 are taken into account for the area in which the scenario is simulated[14]:

TABLE 3.6-26

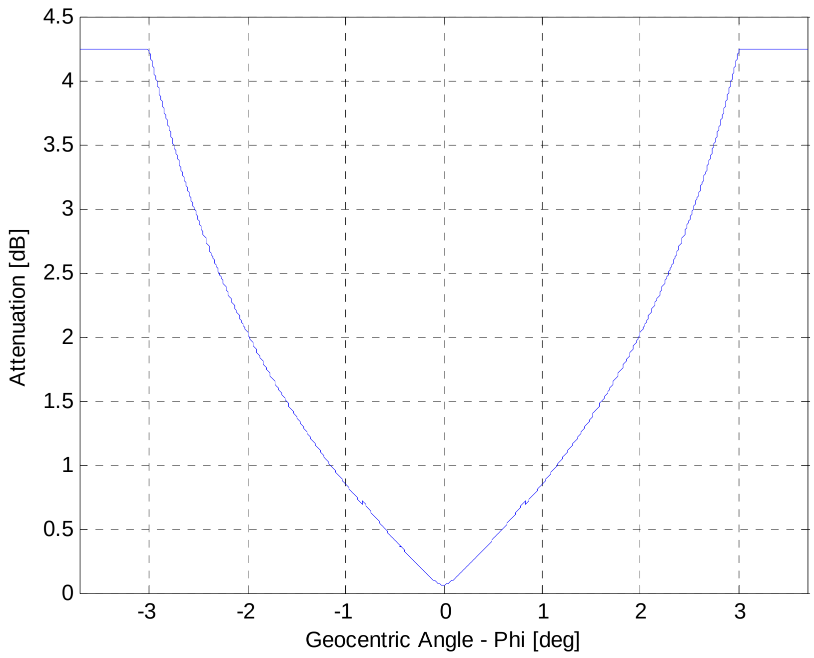
Parameters for atmospheric attenuation

Parameter	Value
Temperature (°K)	272.7
Atmospheric pressure (hPa)	1 018.9
Water vapour density (g/m^3)	3.5

Taking into account the parameters listed in the previous table, the following Fig. 3.6-13 illustrates the attenuation due to the atmospheric loss for the geometrical scenario depicted in Fig. 3.6-12 when one aircraft is flying at a cruise altitude of 30 000 ft:

FIGURE 3.6-13

Attenuation due to atmospheric loss



Considering that the AES antenna is typically installed on the top of the fuselage or the bottom of the vertical stabilizer (i.e. on the upper and back part of the aircraft), the attenuation due to the fuselage must be taken into account. With no official study being available about this matter, a

[14] In the absence of any other reference, the parameters listed in the table are taken from Table 1 – row "Mid-latitudes" of Recommendation ITU-R SF.1395.

measurement campaign run by an aeronautical Internet Service Provider has been considered as reference. In this particular study, the attenuation due to the aircraft body on the roll-plane (i.e. for azimuth = 90°) has been measured when an antenna was mounted on top of a full cylinder with radius of curvature approximately equal to that of a Boeing 737 fuselage. Although all the measurements were made at 14.2 GHz, it is assumed that they can be extended to the band this Report is referring to.

The following Fig. 3.6-14 visualizes the path loss over the roll plane considered in the simulations of this study; Φ = 0 = 180° is the aircraft horizontal axis.

FIGURE 3.6-14

Attenuation due to the fuselage of the aircraft

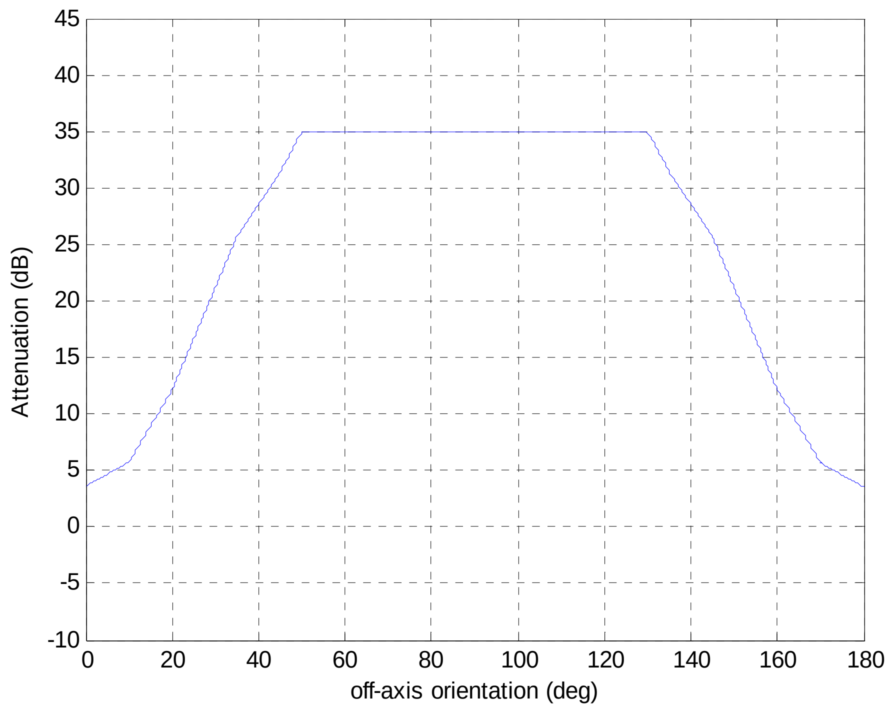


Figure 3.6-15 illustrates the level of the received interfering power at the RAS station as a function of the geocentric angle between the RAS and the aircraft-mounted transmitter. It is assumed that the aircraft is flying at an altitude of 30 000 ft and that the transmitter's adjacent channel leakage ratio[15] is 65 dB.

[15] The ACLR is defined as the ratio between the power spectral density in the assigned channel and the power spectral density of the OoB emissions in the adjacent channel.

FIGURE 3.6-15

Interfering power at RAS station during the transit of the aircraft. The red line highlights the interference threshold in 1 MHz as indicated in Table 3.6-6

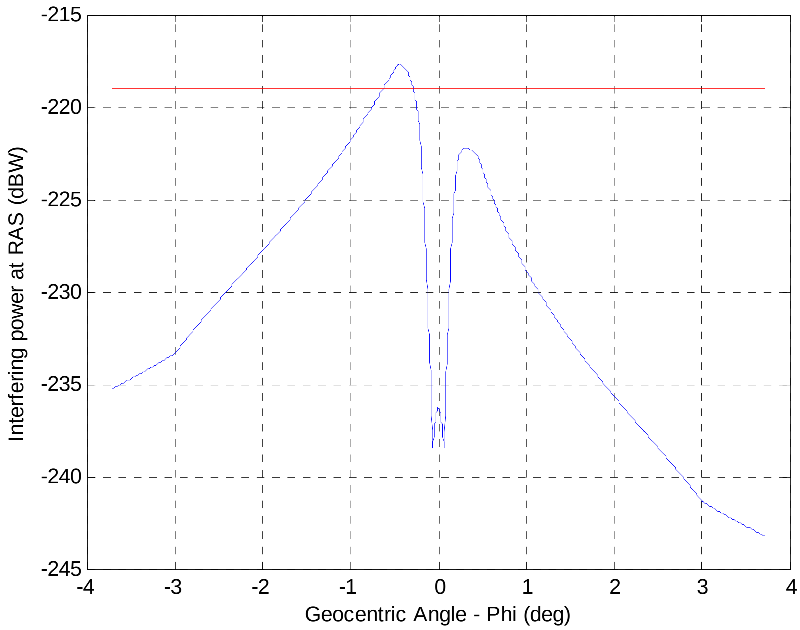


Table 3.6-27 shows the required ACLR (Adjacent Channel Leakage Ratio) for different cruise altitudes of the aircraft on which one AES is operating in order to comply with the interference criteria described above:

TABLE 3.6-27

Required values of ACLR for an AES

Aircraft altitude (ft)	Required ACLR (dB)
10 000	75
12 000	74
14 000	72
16 000	71
18 000	70
20 000	69
22 000	68
24 000	67
26 000	67
28 000	66
30 000	65
32 000	65
34 000	64
36 000	64
38 000	63
40 000	63

A typical value of ACLR for a device with no special filtering is 30-35 dB. Hence to meet the ACLR requirements shown in Table 3.6-27, additional reduction of the OoB emissions by around 40-45 dB would be required to meet the RAS protection requirements. Such a requirement can be achieved by filter technologies available today.

Conclusions of Study 2

The results of this study show that the recommended interference threshold into the RAS station can be met if a proper filtering is applied to the AES.

Furthermore, the values obtained can be reached by technologies available today, also recognizing that a minimum separation of 30 MHz would exist between the MSS emissions and the RAS band.

ITU-R Working Party 7D, in charge of the radio astronomy service, considers that study 2 contains only an exceedingly rare case of a single aircraft passing directly overhead of a radio telescope. Because the radio horizon from an aircraft at 10 km is several hundred km, by far the greatest number of aircraft will not fly directly overhead and it is likely that there will be numerous aircraft within line-of-sight at a given time. While the minimum propagation loss to these planes will be greater, the shielding due to the body of the aircraft will be considerably less, potentially by an amount that more than compensates for the additional propagation loss due to increased distance. Study 2 only contains aircraft shielding data along the axis of the direction the plane is moving. Properly treating the case of airborne MSS interference into radio astronomy requires off-axis models of airplane body shielding and a Monte-Carlo simulation that includes a reasonable density and frequency of air traffic, and is simulated over a long enough duration in time to be statistically meaningful. Unless such studies are performed, no useful conclusion about compatibility can be reached.

3.6.3 Summary of conclusions for the band 15.43-15.63 GHz

Sharing with the FSS

Although the band is allocated to the FSS, it is understood that there is no current or planned use for such applications in this band.

Sharing with the radiolocation service

It has been proposed that this band be used for new radiolocation applications. Sharing with the radiolocation service seems to be difficult. The conducted studies show that the interference from MES exceeds the permissible level for System 6 receiver by 53.5 dB. Therefore for providing protection of RLS System 6 stations from MESs it is required to provide the separation distance of 461 km. Another study showed that for ensuring protection of operating RLS System 6 stations from the MES unacceptable interference it is required to provide the separation distance of 706 km.

Sharing with the ARNS

The study of interference from ground based MESs to ALS systems has shown that a maximum separation distance of 515.1 km is required. Regarding interference from ALS to MSS satellites, in the worst-case interference exceeds the permissible level by 55.6 dB. From this result the conclusion that co-coverage and co-frequency operation of MSS and ALS is not feasible.

Co-coverage and co-frequency operation of MSS and aircraft MPR is also not feasible. The carried out calculations show that the interference from MES exceeds the permissible level for the ARNS systems by up to 73.1 dB. For ensuring protection of the operating MPR stations from the unacceptable interference of the MES, it is required to provide the separation distances of 570 km.

Further study is required for the case of interference from an AES to ARNS systems. For such scenario the separation distance will correspond to the line-in sight distance between the airborne stations and may be up to 900 km.

Compatibility with the radio astronomy service

To protect the radio astronomy service operations in the band 15.35-15.4 GHz from unwanted emissions of ground based MESs operating in the band 15.43-15.63 GHz, appropriate filtering would be required for MESs to meet the threshold level of Recommendation ITU-R RA.769. With the implementation of appropriate filtering at the MES (feasible with existing filtering technology) to reduce MSS spurious emissions in the band 15.35-15.4 GHz, coordination zones of some hundreds of kilometres around the limited number of RAS stations in the world (about 20 sites) would achieve compatibility between MSS in the band 15.43-15.63 GHz and RAS in the band 15.35-15.4 GHz.

Studies have been conducted related to protection of radio astronomy stations from AESs. One study has identified that a separation distance of several hundred km is required to protect RAS stations (when back lobe-to-back lobe coupling is considered), the actual distance depending on the level of out-of-band emissions from the AES. This study did not consider shielding from the aircraft fuselage or atmospheric absorption. Another study considered these factors and determined the AES filtering required to meet the radio astronomy protection criteria. The precise figure depends on, among other things, the minimum operating altitude of the AES and on the respective position of the AES with regard to the radio telescope. Neither study considered the potential effects of aggregate interference from multiple AES simultaneously visible to the RAS station. Further study is required on this issue.

Annex 1

GSO MSS system technical characteristics

1 Overview

Link budgets for example bands are shown in the tables below. The 4/6 GHz band system differs from the 11/14 GHz band system in that the reduction of spreading loss and fading loss is compensated by reducing the gain of the terminals (reduction of G/T and e.i.r.p. of terminals in the link budget), while satellite G/T and e.i.r.p. are the same in the two cases. The same approach is used to adjust the above parameters for other bands. For some specific cases of sharing in the 7/8 GHz bands, as indicated in the main part of the report, the GSO MSS network parameters were derived based on the link budgets presented in § 1.4 of this Annex.

2 Link budget for the 11/14[16] GHz bands

Table 1-1 shows the link budget assumed for the 11/14 GHz band system.

[16] The frequency range 11/14 GHz is just an example for these systems.

TABLE 1-1

11/14 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	256.0	512.0	1024.0	2 048.0
Uplink				
Assumed frequency (GHz)	14.5	14.5	14.5	14.5
SAS e.i.r.p. (dBW)	62.2	60.9	62.2	64.0
Spread loss (dB)	206.7	206.7	206.7	206.7
Fading + atmospheric loss (dB)	3.0	3.0	3.0	3.0
Satellite G/T (dB/K)	−2.0	−2.0	−2.0	−2.0
Boltzmann constant (dBW/K Hz)	−228.6	−228.6	−228.6	−228.6
Uplink C/N_0 (dB/Hz)	79.1	77.8	79.1	80.9
Downlink				
Assumed frequency (GHz)	11	11	11	11
Satellite e.i.r.p. (dBW)	43.5	42.2	43.5	45.4
Spread loss (dB)	204.4	204.4	204.4	204.4
Fading + atmospheric loss (dB)	4.5	4.5	4.5	4.5
UT G/T (dB/K)	−1.0	4.0	7.0	10.0
Boltzmann constant (dBW/K.Hz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	62.2	65.9	70.2	75.1
Other				
IM C/N_0 (dB/Hz)	72.3	71.0	72.3	74.2
Other beams C/N_0 (dB/Hz)	74.3	73.0	74.3	76.2
Other systems C/N_0 (dB/Hz)	75.4	77.8	80.8	83.8
Total				
C/N_0 (dB/Hz)	61.5	63.9	66.9	70.0
E_b/N_0 (dB)	4.9	7.3	7.3	7.3
11/14 GHz band return link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	128.0	256.0	512.0	1 024.0
Uplink				
Assumed frequency(GHz)	14.5	14.5	14.5	14.5
Terminal e.i.r.p. (dBW)	28.0	30.5	33.5	36.5
RF power (dBW)	4.5	2.7	2.7	5.7
Spread loss (dB)	206.7	206.7	206.7	206.7
Fading + atmospheric loss (dB)	4.5	4.5	4.5	4.5
Satellite G/T (dB/K)	15.0	15.0	15.0	15.0
Boltzmann constant (dBW/K.Hz)	−228.6	−228.6	−228.6	−228.6
Uplink C/N_0 (dB/Hz)	60.4	62.9	65.9	68.9

TABLE 1-1 (*end*)

11/14 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Downlink				
Assumed frequency (GHz)	11	11	11	11
Satellite e.i.r.p. (dBW)	13.8	16.3	19.3	22.3
Spread loss (dB)	204.4	204.4	204.4	204.4
Fading + atmospheric loss (dB)	3.0	3.0	3.0	3.0
SAS G/T (dB/K)	38.0	38.0	38.0	38.0
Boltzmann constant (dBW/K.Hz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	73.0	75.5	78.5	81.5
Other				
IM C/N_0 (dB/Hz)	74.5	77.0	80.0	83.0
Other beams C/N_0 (dB/Hz)	70.5	73.0	76.0	79.0
Other systems C/N_0 (dB/Hz)	73.5	76.0	79.0	82.0
Total				
C/N_0 (dB/Hz)	59.5	62.0	65.0	68.0
E_b/N_0 (dB)	3.0	5.5	5.5	5.5

SAS : satellite access station
UT : user terminal
IM : intermodulation

3 Link budget for the 4/6[17] GHz bands

Table 1-2 shows the link budget assumed for the 4/6 GHz band system.

TABLE 1-2

4/6 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	256.0	512.0	1 024.0	2 048.0
Uplink				
Assumed frequency (GHz)	6.3	6.3	6.3	6.3
SAS e.i.r.p. (dBW)	54.2	52.9	54.2	56.0
Spread loss (dB)	200.7	200.7	200.7	200.7
Fading + atmospheric loss (dB)	1.0	1.0	1.0	1.0
Satellite G/T (dB/K)	−2.0	−2.0	−2.0	−2.0
Boltzmann constant (dBW/K.Hz)	−228.6	−228.6	−228.6	−228.6

[17] The frequency range 4/6 GHz is just an example for these systems.

TABLE 1-2 (*continued*)

4/6 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Uplink C/N_0 (dB/Hz)	79.1	77.8	79.1	80.9
Downlink				
Assumed frequency (GHz)	4.5	4.5	4.5	4.5
Satellite e.i.r.p. (dBW)	43.5	42.2	43.5	45.4
Spread loss (dB)	197.7	197.7	197.7	197.7
Fading + atmospheric loss (dB)	1.0	1.0	1.0	1.0
UT G/T (dB/K)	−11.2	−6.2	−3.2	−0.2
Boltzmann constant (dBW/K·Hz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	62.2	65.9	70.2	75.1
Other				
IM C/N_0 (dB/Hz)	72.3	71.0	72.3	74.2
Other beams C/N_0 (dB/Hz)	74.3	73.0	74.3	76.2
Other systems C/N_0 (dB/Hz)	75.4	77.8	80.8	83.8
Total				
C/N_0 (dB/Hz)	61.5	63.9	66.9	70.0
E_b/N_0 (dB)	4.9	7.3	7.3	7.3
4/6 GHz band return link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	128.0	256.0	512.0	1 024.0
Uplink				
Assumed frequency (GHz)	6.3	6.3	6.3	6.3
Terminal e.i.r.p. (dBW)	18.5	21.0	24.0	27.0
RF power (dBW)	4.5	4.5	4.5	4.5
Spread loss (dB)	200.7	200.7	200.7	200.7
Fading + atmospheric loss (dB)	1.0	1.0	1.0	1.0
Satellite G/T (dB/K)	15.0	15.0	15.0	15.0
Boltzmann constant (dBW/K·Hz)	−228.6	−228.6	−228.6	−228.6
Uplink C/N_0 (dB/Hz)	60.4	62.9	65.9	68.9
Downlink				
Assumed frequency (GHz)	4.5	4.5	4.5	4.5
Satellite e.i.r.p. (dBW)	7.1	9.6	12.6	15.6
Spread loss (dB)	197.7	197.7	197.7	197.7
Fading + atmospheric loss (dB)	1.0	1.0	1.0	1.0
SAS G/T (dB/K)	36.0	36.0	36.0	36.0
Boltzmann constant (dBW/K·Hz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	73.0	75.5	78.5	81.5
Other				

TABLE 1-2 (*end*)

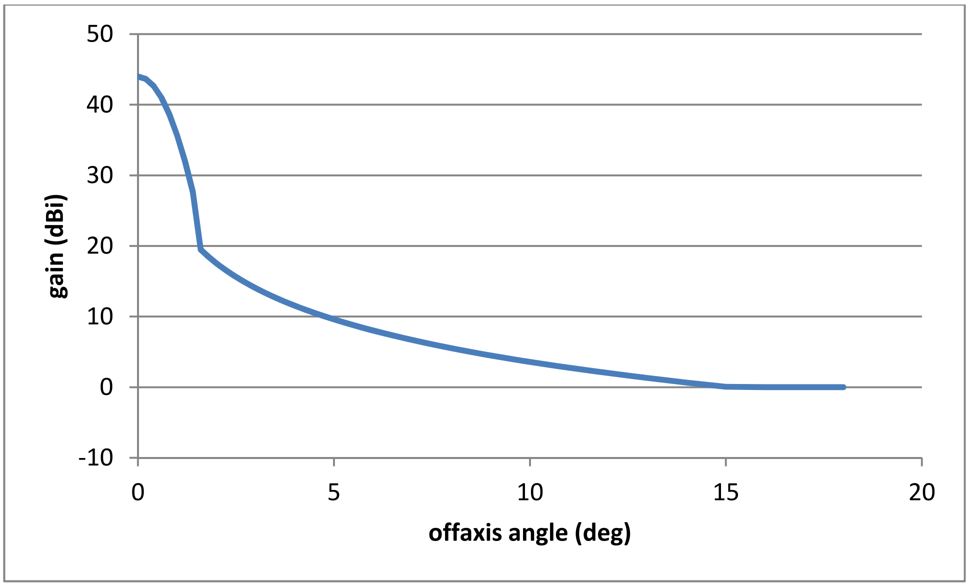
4/6 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
IM C/N_0 (dB/Hz)	74.5	77.0	80.0	83.0
Other beams C/N_0 (dB/Hz)	70.5	73.0	76.0	79.0
Other systems C/N_0 (dB/Hz)	73.5	76.0	79.0	82.0
Total				
C/N_0 (dB/Hz)	59.5	62.0	65.0	68.0
E_b/N_0 (dB)	3.0	5.5	5.5	5.5

SAS : satellite access station
UT : user terminal
IM : intermodulation

The antenna pattern assumed for the MSS satellite spot beams is that given in RR Appendix 30 for Region 2. This is shown in Fig. 1-1 and is applicable for all frequencies.

FIGURE 1-1

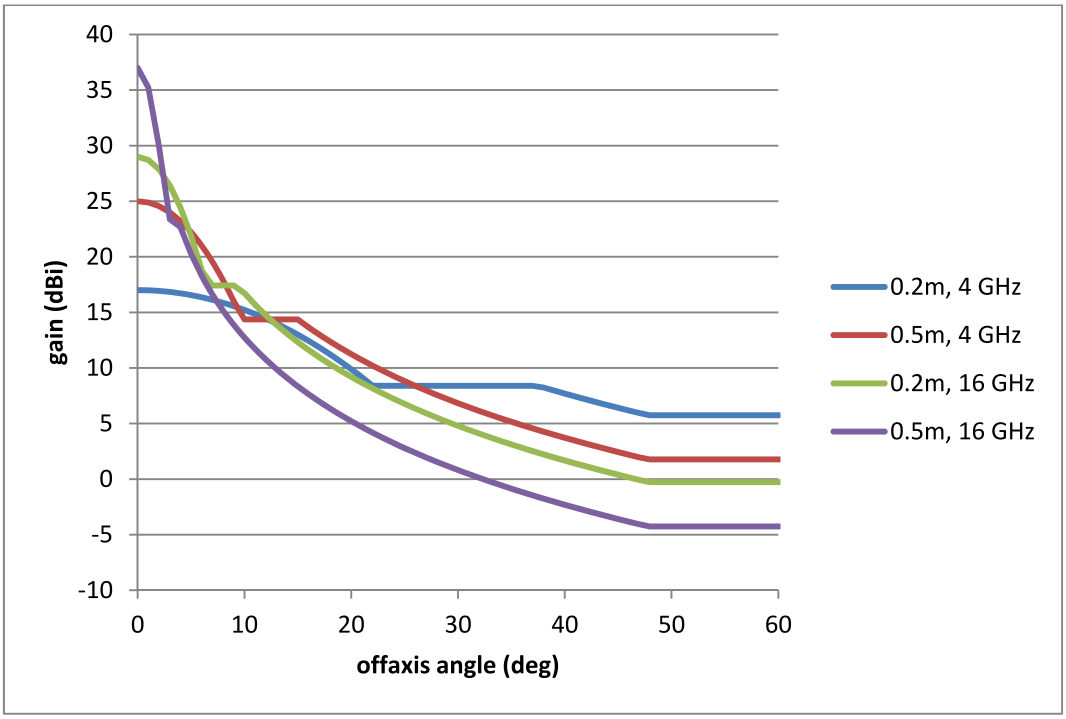
Assumed antenna pattern for MSS spot beam



The MES antenna patterns are determined using Recommendation ITU-R F.699. The patterns vary with the frequency being considered. As examples, Fig. 1-2 shows the antenna patterns for the 0.2 m MES and the 0.5 m MES at frequencies of 4 GHz and 16 GHz.

FIGURE 1-2

Assumed antenna patterns for MESs



4 Link budget for the 7/8 GHz bands

Table 1-3 shows the link budgets assumed for the 7/8 GHz band GSO MSS network.

TABLE 1-3

7/8 GHz band forward link – Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	256.0	512.0	1 024.0	2 048.0
Carrier noise bandwidth (kHz)	333	445	889	1778
Uplink				
Carrier frequency (MHz)	8.450	8.450	8.450	8.450
SAS e.i.r.p. (dBW)	56.9	56.9	56.9	56.9
SAS side lobe pattern	Rec. 580	Rec. 580	Rec. 580	Rec. 580
Spread loss (dB)	202.5	202.5	202.5	202.5
Fading + atmospheric loss (dB)	2.0	2.0	2.0	2.0
Satellite *G*/*T* (dB/K)	−2.0	−2.0	−2.0	−2.0
Boltzmann constant (dBW/KHz)	−228.6	−228.6	−228.6	−228.6
Uplink C/N_0 (dB/Hz)	79.0	79.0	79.0	79.0
Downlink				
Carrier frequency (MHz)	7.150	7.150	7.150	7.150
Satellite e.i.r.p. (dBW)	39.3	40.9	42.7	46.8
Spread loss (dB)	201.0	201.0	201.0	201.0

TABLE 1-3 (*continued*)

7/8 GHz band forward link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Fading + atmospheric loss (dB)	1.8	1.8	1.8	1.8
UT *G*/*T* (dB/K)	–4.4	–0.3	2.9	5.6
UT side lobe pattern	Rec. 699	Rec. 699	Rec. 699	Rec. 699
UT pointing loss (dB)	0.5	0.5	0.5	0.5
Boltzmann constant (dBW/KHz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	60.2	66.0	70.9	77.7
Other				
IM C/N_0 (dB/Hz)	72.9	73.2	72.0	73.1
Other beams C/N_0 (dB/Hz)	70.0	71.3	74.3	77.3
Total				
C/N_0 (dB/Hz)	59.6	64.1	67.1	70.1
Interference allowance %	20	20	20	20
E_b/N_0 (dB)	4.7	6.2	6.2	6.2
7/8 GHz band return link − Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
Net data rate (kbit/s)	128.0	256.0	512.0	1 024.0
Carrier noise bandwidth (kHz)	167	222	445	889
Uplink				
Carrier frequency (MHz)	8.450	8.450	8.450	8.450
UT e.i.r.p. (dBW)	22.1	25.6	28.1	30.0
RF power (dBW)	–1.0	–1.0	–1.0	–1.0
UT side lobe pattern	Rec. 699	Rec. 699	Rec. 699	Rec. 699
UT pointing loss (dB)	0.5	0.5	0.5	0.5
Spread loss (dB)	202.4	202.4	202.4	202.4
Fading + atmospheric loss (dB)	2.9	2.9	2.9	2.9
Satellite *G*/*T* (dB/K)	16.5	16.5	16.5	16.5
Boltzmann constant (dBW/KHz)	−228.6	−228.6	−228.6	−228.6
Uplink C/N_0 (dB/Hz)	61.4	64.9	67.4	69.3
Downlink				
Carrier frequency (MHz)	7,150	7,150	7,150	7,150
Satellite e.i.r.p. (dBW)	–5.9	0.6	4.4	9.9
Spread loss (dB)	201.0	201.0	201.0	201.0
Fading + atmospheric loss (dB)	1.3	1.3	1.3	1.3
SAS *G*/*T* (dB/K)	38.8	38.8	38.8	38.8
Boltzmann constant (dBW/KHz)	−228.6	−228.6	−228.6	−228.6
Down C/N_0 (dB/Hz)	59.2	65.7	69.5	75.0
Other				

TABLE 1-3 (*end*)

7/8 GHz band forward link – Link budget				
	Pocket	**Notebook**	**Briefcase**	**Suitcase**
IM C/N_0 (dB/Hz)	73.2	74.5	77.5	80.5
Other beams C/N_0 (dB/Hz)	67.0	68.3	71.3	74.3
Total				
C/N_0 (dB/Hz)	56.6	61.1	64.1	67.1
Interference allowance (%)	20	20	20	20
E_b/N_0 (dB)	4.7	6.2	6.2	6.2

SAS : satellite access station
UT : user terminal
IM : intermodulation

Annex 2

Propagation model for the band 5 150-5 250 MHz

The propagation model used to assess the interference from RLAN systems into MES receivers in the band 5 150-5 250 MHz is taken from ECC Report 110[18]. The model has been used in the assessment of interference from broadband disaster relief (BBDR) systems to other services in frequency bands around 5 GHz. The propagation loss is given by the following formula.

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & d \le d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d}{d_0}\right) & \text{if } d_0 < d \le d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d_1}{d_0}\right) - 10n_1 Log\left(\frac{d}{d_1}\right) & d > d_1 \end{cases} \quad (12)$$

The parameter values for the formula are given in Table 2-1.

[18] Available at http://www.erodocdb.dk/doks/doccategoryECC.aspx?doccatid=4.

TABLE 2-1

Parameter values for propagation model

	Urban	Suburban	Rural
Breakpoint distance d_0 (m)	64	128	256
Path loss factor n_0 beyond the first break point	3.8	3.3	2.8
Breakpoint distance d_1 (m)	128	256	1 024
Path loss factor n_1 beyond the second breakpoint	4.3	3.8	3.3

Figure 2-1 shows the loss given by the above equation.

FIGURE 2-1

Propagation loss for urban, suburban and rural environments