RECOMMENDATION ITU-R SM.1633-0*

Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands

(2003)

Scope

This Recommendation serves as a basis for methodology of compatibility analysis between a passive service and an active service operating in allocated in adjacent and nearby bands.

Keywords

Compatibility, unwanted emissions, threshold, active service band, passive service band

The ITU Radiocommunication Assembly,

considering

a) that the radio astronomy service (RAS), the Earth exploration-satellite service (EESS) (passive) and space research service (SRS) (passive) are based on the reception of natural emissions at much lower power levels than are generally used in other radiocommunication services;

b) that, due to these low received power levels, these passive services are generally more susceptible to interference from unwanted emissions than other services;

c) that general limits for spurious emissions contained in Appendix 3 of the Radio Regulations (RR) may not protect to the desired extent the passive services from interference; however, depending on the separation between the bands allocated to the active and passive services actual spurious emission levels falling in a passive band may be lower;

d) that general levels for emissions in the out-of-band (OoB) domain contained in Recommendation ITU-R SM.1541 may not protect operations of the passive services from interference;

e) that there are various operational practices and mitigation techniques that can be used by the passive and active services to minimize the impact of interference on the passive services;

f) that there may be practical and economic limitations on the applicability of these mitigation measures;

g) that the burden of achieving compatibility between active and passive services should be equitably borne;

h) that Recommendation 66 (Rev.WRC-2000) requests in *recommends* 5 that ITU-R "study those frequency bands and instances where, for technical or operational reasons, more stringent spurious emission limits than the general limits in Appendix 3 may be required to protect passive services such as radio astronomy, and the impact on all concerned services of implementing or not implementing such limits";

j) that Recommendation 66 (Rev.WRC-2000) requests in *recommends* 6 that ITU-R "study those frequency bands and instances where, for technical or operational reasons, out-of-band limits may be required to protect passive services such as radio astronomy, and the impact on all concerned services of implementing or not implementing such limits";

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* Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2018 and 2019 in accordance with Resolution ITU-R 1.

k) that the situations of greatest potential difficulty to the passive services are those listed in Table 1,

recommends

1 that the methodology in Annex 1 should be used in conducting compatibility analysis between a passive service and an active service operating in allocated bands listed in Table 1;

2 that other methodologies that lead to a compatibility solution could be used where appropriate;

3 that the results of band-by-band studies, described in Annexes 2 through 21, should be considered in developing solutions to interference problems between the indicated services.

TABLE 1

Reference list of relevant frequency bands for band-by-band studies

Passive service band	**Active service band**	**Annex**
1 400-1 427 MHz (RAS)	1 452-1 492 MHz (BSS)↓	2
1 400-1 427 MHz (EESS)	1 350-1 400 MHz (Radiolocation)	3
1 400-1 427 MHz (EESS/RAS)	1 525-1 559 MHz (MSS)↓	4
1 610.6-1 613.8 MHz (RAS)	1 559-1 610 MHz (RNSS)↓	5
1 610.6-1 613.8 MHz (RAS)	1 613.8-1 626.5 MHz (MSS↓)	6
1 610.6-1 613.8 MHz (RAS)	1 525-1 559 MHz (MSS)↓	7
2 690-2 700 MHz (RAS)	2 655-2 690 MHz (BSS, FSS)↓	8
10.6-10.7 GHz (EESS)	10.7-10.95 GHz (FSS)↓	9
10.6-10.7 GHz (RAS)	10.7-10.95 GHz (FSS)↓	10
21.2-21.4 GHz (EESS)	20.2-21.2 GHz (MSS, FSS)↓	11
22.21-22.5 GHz (RAS)	21.4-22 GHz (BSS)↓	12
23.6-24 GHz (EESS)	22.55-23.55 GHz (ISS)	13
31.3-31.5 GHz (EESS)	30-31 GHz (FSS, MSS)↑	14
31.3-31.5 GHz (EESS)	31.0-31.3 GHz (FS)	15
31.5-31.8 GHz (EESS)	31.8-33.4 GHz (FS)	16
31.5-31.8 GHz (EESS)	31.8-33.4 GHz (RN)	17
42.5-43.5 GHz (RAS)	41.5-42.5 GHz (BSS, FSS)↓	18
50.2-50.4 GHz (EESS)	47.2-50.2 GHz (FSS)↑	19
50.2-50.4 GHz (EESS)	50.4-51.4 GHz (FSS, MSS)↑	20
52.6-52.8 GHz (EESS)	51.4-52.6 GHz (FS)	21

RNSS: radionavigation satellite service.

ISS: inter-satellite service.

FS: fixed service.

Annex 1

Methodology

1 General

The following general methodology defines a systematic means for deriving mutually acceptable compatibility criteria between operators of active and passive services operating in their allocated bands. The flow diagram (Fig. 1) summarizes the methodology with each individual step described in detail in § 2 of this Annex. As the procedure is iterative, several cycles might be required before a solution is found.

The first step is to determine the transmission parameters of the active service (box (i)). The starting point is the worst-case scenario that is used to determine whether there is the potential for detrimental interference to passive services by any and all types of active services operating in an adjacent or nearby band. This worst-case power level could often be determined from existing regulatory limits (box (1)), such as the pfd's found in RR Article 21. Such regulatory limits for the power transmitted by the active service must then be used to determine the worst-case level of unwanted emission into the passive band (box (ii)).

The following step is to determine if this worst-case interference level is higher than the passive service interference threshold for the band under consideration (diamond (a)). These threshold levels are given in various ITU-R Recommendations (box (2)) such as Recommendations ITU-R RA.769, or ITU-R SA.1029. If this interference threshold is higher than the worst-case level of unwanted emissions in the band, then there is no adverse impact to the passive service operations. In this case the methodology follows the "Yes" line and the process terminates. At this point, as at all other end points in the methodology, the assumptions used to achieve the end point form the technical basis for a compatible working arrangement between the active and passive services involved. How these technical assumptions and their resulting conclusions are used is a regulatory exercise and is beyond the technical scope of this Recommendation. However, for the case of diamond (a), if the interference is assessed to be greater than the passive service criteria, then it is necessary to follow the "No" branch to diamond (b). On the first iteration, no new information is available so the path continues to box (iii). On later iterations, the threshold in diamond (b) may be different from the passive service criteria used in diamond (a) as a consequence of modified or additional parameters and burden sharing. These modified or additional parameters may result from diamonds (c), (d) or (e). Diamond (b) allows a further assessment whether compatibility has been achieved.

If such is the case the process follows along the "Yes" branch, and the procedure ends. If such is not the case, the discrepancy has to be assessed, whereby in reaching diamonds (c), (d) or (e) the following alternatives should be investigated:

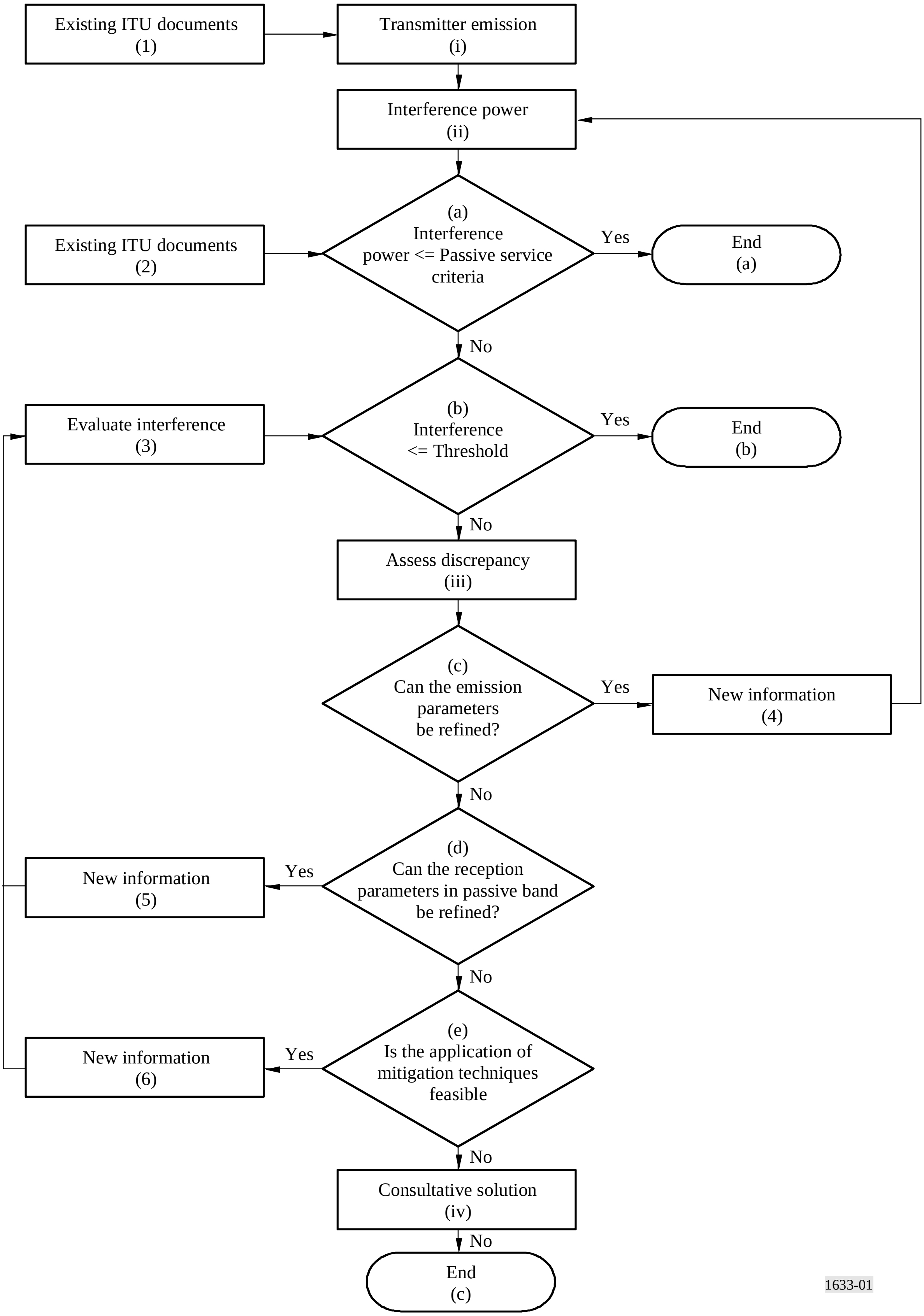
– refine the emission parameters of the active service such as the actual system parameters, available prime power, etc. and/or;

– refine the reception parameters in the passive band, and/or;

– develop further mitigation techniques for both the active and passive services, which may include both alternatives (a) and (b).

FIGURE 1

Process for the evaluation of adjacent and nearby band operation of passive and active services



When during the assessment of discrepancies, as indicated in box (iii), it is shown that the divergence between the two levels is large, then it is clear that the assumptions used in the first iteration are insufficient to resolve the issue and more detailed assumptions about the characteristics and operations of both services must be made. However, if the divergence is small, it may be possible to modify slightly one of the underlying assumptions so as to enable converging on a solution on the next iteration. A review of the data at hand may suggest what additional assumptions might be beneficial.

From this consideration, either one or more of the active service parameters, passive service parameters, the compatibility criteria or possible mitigation methods can be considered for modification in successive iterations. As many iterations will take place as necessary to either completely close the gap or to have exhausted all potential solutions. If all possible solutions have been exhausted and no compatible operation appears to be possible, then the method ends with a "consultative solution". This implies that the only possible solution is for a specific active system to consult with a specific passive service system operator, in order to achieve a one-to-one solution, if that is possible. Specifics of such a consultative solution are outside the purview of this Recommendation.

This methodology only addresses the potential interference from a single active service operating in its allocated band. Noting that EESS (passive) may receive interference simultaneously from multiple services, additional consideration may be required to account for the aggregate effects of multiple active services.

2 Detailed description of the flow chart

2.1 Box (1): Existing ITU documents

This box refers to documents that may be relevant for determining transmitter emissions. The following Articles of the RR and ITU-R Recommendations and Reports are relevant to determining transmitter power that may fall into passive bands, and are provided for reference. These regulations and recommendations are to be used as the starting point in the evaluation of potential active service unwanted emissions into passive service bands.

Radio Regulations

Articles 1, 5, 21, 22, Appendix 3.

Recommendations

ITU-R F.758: Considerations in the development of criteria for sharing between the terrestrial fixed service and other services

ITU-R F.1191: Bandwidths and unwanted emissions of digital fixed service systems

ITU-R SM.326: Determination and measurement of the power of amplitude-modulated radio transmitters

ITU-R SM.328: Spectra and bandwidth of emissions

ITU-R SM.329: Unwanted emissions in the spurious domain

ITU-R SM.1446: Definition and measurement of intermodulation products in transmitter using frequency, phase, or complex modulation techniques

ITU-R SM.1539: Variation of the boundary between the out-of-band and spurious domains required for the application of Recommendations ITU-R SM.1541 and ITU-R SM.329

ITU-R SM.1540: Unwanted emissions in the out-of-band domain falling into adjacent allocated bands

ITU-R SM.1541: Unwanted emissions in the out-of-band domain.

Some data may be needed beyond what these Recommendations provide. This includes:

– the duty cycle of the systems;

– the geographic distribution and densities of the emitters including deployment densities;

– the antenna aiming or scanning for radiodetermination systems or Earth-to-space transmissions;

– the beam coverage for space-to-Earth transmissions;

– relevant spectral masks; and

– antenna patterns.

Not all of the required data may be available for all items listed above. Assumptions may be necessary for some parameters. Other information such as deployment may require the development of models.

2.2 Box (2): Existing ITU documents

This box refers to documents relevant to the selection of the appropriate passive service criteria for protection from interference. The various passive service criteria, each developed by the working party responsible for the respective passive services, serve as the input of diamond (a) on the flowchart. These Recommendations have been developed, over time, in order to assist other working parties dealing with active services in evaluating the potential for interference from their respective services into the passive services. The list of Recommendations to be considered is as follows:

Recommendations

ITU-R RA.769: Protection criteria used for radioastronomical measurements

ITU-R RA.1513: Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis

ITU-R SA.1028: Performance criteria for satellite passive remote sensing

ITU-R SA.1029: Interference criteria for satellite passive remote sensing.

2.3 Box (3): Evaluate interference

The function of this box is to allow for the passive service to generate a new sharing criterion based on the information provided from boxes (5) and (6). As an example, lower side lobe levels might be assumed than the 0 dBi receive antenna gain figure currently assumed for the RAS. If this were the case, the process of re-calculating the sharing criteria would be done in box (3).

To evaluate interference from non-GSO FSS systems to stations in the RAS, the methodology of Recommendation ITU-R S.1586 should be used. Likewise, to evaluate interference from non-GSO MSS and RNSS systems to stations in the RAS, the methodology of Recommendation ITU-R M.1583 should be used.

2.4 Boxes (4), (5) and (6): New information

The function of the box is to accommodate new information brought into the sharing study while it proceeds through multiple iterations. An example of such a situation would be the making usage of RR Appendix 4 information submitted to the Radiocommunication Bureau (BR) in box (4) to justify the use of an in-band pfd less than the regulatory figure. Other information may consist of filter or antenna information in any of boxes (4), (5) and (6) that is brought into the process in order to close the gap. New information may also consist of additional input not considered previously, such as specific ITU-R Recommendations, regional recommendations, or regional standards. Examples for the relevant boxes are as follows:

Box (4)

At higher frequencies, transmit antenna patterns can have a significantly narrower beamwidth in order to maximize the power in a limited service area so as to increase throughput and overcome atmospheric effects. As a result, the majority of the surface of the Earth may receive an unwanted emission pfd level that is well below the detrimental level of the passive service. Instead of having the level applicable over the entire surface of the Earth, it may be possible to relax the level over a fraction of the Earth’s surface. As a result, the probability that an RAS station will receive detrimental interference from a specific direction becomes very small.

In the band 40-42.5 GHz, Recommendation ITU-R S.1557 – Operational requirements and characteristics of fixed-satellite service systems operating in the 50/40 GHz bands for use in sharing studies between the fixed-satellite service and the fixed service, contains parameters that may be used for studies relevant to this band.

Box (5)

Characteristics such as band-specific receive antenna patterns are characteristics that could be used to decrease the difference between the passive service detrimental interference level and the received unwanted emission level.

Box (6)

Many mitigation methods that may minimize the impact of the active service on the passive service are listed in Recommendation ITU-R SM.1542. In any specific case, only some of the mitigation methods listed may apply to the situation at hand. In applying certain mitigation methods, it may often be necessary to determine how the burden resulting from its application will be partitioned.

2.5 Box (i): Transmitter emission

The purpose of this box is to establish the transmit in-band power density at the antenna flange.

2.5.1 General case

Generally the value can be found by:

$$p_{density} = e.i.r.p._{density} - G_t \qquad (1)$$

where:

$p_{density}$: transmit power density into the transmit antenna (dBW/Hz)

$e.i.r.p._{density}$: transmit e.i.r.p. density (dBW/Hz)

G_t: transmission antenna gain (dBi).

Transmit power density can also be computed as:

$$p_{density} = 10 \log(p_t) - OBO - 10 \log(BW_{nb}) - L_c \qquad (2)$$

where:

p_t: transmission amplifier maximum rated power (W)

OBO: output back off (dB)

BW_{nb}: necessary bandwidth (Hz)

L_c: circuit loss between the transmission amplifier and transmission antenna (dB).

It should be noted in equation (2) that the transmit power density is assumed to be uniformly distributed over the necessary bandwidth. If this assumption is erroneous, a correction can be introduced by appropriately modifying the bandwidth.

2.5.2 In-band satellite transmitted power level based on RR Table 21-4

To derive the transmit power density from the pfd limits, then:

$$P_{density} = pfd + 10 \log(4\pi d^2) - G_t + L_c \qquad (3)$$

where:

pfd: downlink power flux-density (dB(W/(m^2 · MHz)))

d: slant path, from satellite to earth station (km)

G_t: transmission antenna gain (dBi)

L_c: circuit loss between the transmission amplifier and transmission antenna (dB).

If these values are used, the result will yield the highest possible transmitter emission level, which is in many cases unrealistic. This is because various factors such as the actual transmit antenna roll-off and spectral waveforms are not taken into the consideration. In making the above calculations, it should be kept in mind that the transmit antenna gain depends on each system and its applications. Typically, the satellite transmit antenna gain varies as follows:

– for non-GSO MSS systems the gain varies over a range from 17 dBi to 31 dBi depending on the satellite altitudes, elevation angles;

– for GSO MSS systems the gain varies over the range from 41 dBi to 45 dBi;

– for FSS satellite antenna gain of existing 4/6 GHz and 12/14 GHz, the gain varies in a range from 20 dBi to 42 dBi. However, the antenna gain of the future 4/6 GHz and 12/14 GHz satellite systems may be significantly higher than those of the existing systems; and

– for FSS satellite systems in the 20/30 GHz and 40/50 GHz bands, the satellite transmit antenna gain is in a range from 44 dBi to 60 dBi.

2.5.3 Power density based on total space station RF power

Calculating the transmit e.i.r.p. density depends on a satellite total transmit RF power, circuits loss between a transmit power amplifier and transmit antenna, transmit antenna gain, frequency re-use scheme, assigned bandwidth, number of beams, etc. The average transmits e.i.r.p. density can be computed as:

$$P_{density} = 10 \log (P_{total}) - 10 \log (N_{beam}) - 10 \log \left(\frac{BW_{as}}{N_{freq}} \right) - OBO \tag{4}$$

where:

p_{total}: total RF transmit power (W)

N_{beam}: number of beams

BW_{as}: assigned bandwidth (Hz)

For example: 500 MHz for 4/6 GHz-band; 1 000 MHz for 12/14 GHz-band, etc.

N_{freq}: frequency re-use scheme

OBO: output back off (dB).

2.5.4 Power density based on ITU satellite filings

The satellite transmit power density can be obtained directly from RR Appendix 4 filings.

2.6 Box (ii): Interference power

The aim of this step is to derive the level of unwanted emission received by the passive service based on the in-band pfd determined in box (i). How this is assessed will vary depending on the characteristics of the transmitting service and those of the passive service receiving the interference. The potential interference to the passive service due to the unwanted emissions of the active service systems could be computed based on the following:

$$pfd_{(unwantedemissions)} = pfd_{in\text{-}band\_active} - OoB - L \tag{5}$$

where:

$pfd_{(unwanted\ emissions)}$: power flux-density level at the RAS receive sites

$pfd_{in\text{-}band\_active}$: in band pfd levels of the active service systems. The maximum allowable pfd limits shown in RR Table 21-4 may be used in the calculation. In some cases, there are no downlink pfd limits, and the maximum downlink pfd limits of the active system may be used

OoB: out-of-band rejection mask (for example, based on Recommendation ITU-R SM.1541)

L: the attenuation by atmospheric gases and scintillation loss (Recommendation ITU-R P.676 – Attenuation by atmospheric gases).

RR No. 1.153 and Recommendation ITU-R SM.1541 suggest methods for determining active services emissions within the OoB domain. In applying Recommendation ITU-R SM.1541, the range of the OoB domain is determined through the application of Recommendation ITU-R SM.1539. Recommendation ITU-R SM.329 is used to derive levels of unwanted emissions from active services that occur in the spurious domain.

2.6.1 EESS receiver

The EESS is vulnerable to interference from terrestrial transmitters, including single high level transmitters and the aggregate emissions of densely deployed low power level transmitters. Space-borne transmitters could add to the energy received by the sensor via reflections off the Earth into the antenna main beam, or directly through the side or back of the antenna.

Inputs that are required to evaluate the resulting power from active systems at an EESS receiver, include:

– the gain of the EESS system;

– the pointing characteristics of the EESS system;

– the altitude of the EESS system; and

– the atmospheric absorption.

2.6.1.1 Transmitter geographical density

Systems deployed on the surface of the Earth are essentially stationary during the measurement period of the sensor. The interference potential increases when several transmitters appear in the main beam of the sensor antenna. The information required for the evaluation of the power received from active systems deployed within the EESS pixel is as follows:

– the size of the EESS pixel;

– the number of terminals to be deployed in the pixel size using the same frequency at the same time;

– an approximation of the gain of the terrestrial systems in the direction of the EESS satellite. Recommendation ITU-R F.1245 provides antenna pattern for FS P-P systems and Recommendation ITU-R F.1336 provides reference radiation patterns for point-to-multipoint (P-MP) systems. Since FS terminals are pointing in direction close to the horizon, the probability to have a FS system pointing directly within the main beam of an EESS satellite antenna is very low. As a first step approach, the average gain of FS systems in the direction of the EESS satellite to be used in the calculation of the aggregate power received at the EESS satellite, may be approximated by taking for each of the FS terminals a gain which is the gain calculated for a 90° off-axis angle.

In case of FS systems, the following parameters should be considered:

– the channel arrangement (if available) as a first step approach(examine the “closest” channels to the EESS band);

– Recommendation ITU-R F.1191 states that for digital FS systems, the necessary bandwidth is to be considered to have the same value as the occupied bandwidth and that the FS power outside the occupied bandwidth (lower and upper) should not exceed 0.5% of the total mean power of the given emission (RR No. 1.153). Total mean power values are given in Recommendation ITU-R F.758.

2.6.1.2 Transmitter pointing toward sensors

In some cases, individual transmitters could interfere with measurements while the sensor is in the main lobe of the terrestrial station. Information required for the evaluation of the power received from the active system is as follows:

– the gain of the transmitter in the EESS direction; and

– the link path.

2.6.1.3 Satellite downlinks

In some cases, interference is possible from reflected signals off the surface of the Earth that could enter the main beam of the space station. Information required for the evaluation of the power received from the active system:

– the reflection coefficient of terrain or body of water;

– the gain of the space system in the direction of the Earth;

– the altitude of the space system or the pfd at the Earth.

2.6.2 RAS receiver

2.6.2.1 Unwanted emissions from the fixed service

Potential interference from high altitude platform station (HAPS) systems to the RAS is expected. No other issues, related to terrestrial sources of interference to radio astronomy bands have been identified in Recommendation ITU-R SM.1542.

2.6.2.2 Unwanted emissions from space systems

Interference power incident on the RAS station comes from either GSO or non-GSO satellite service downlinks. In the first case the interference will generally not vary in either location or time. In the second case, the interference power will vary both in time and location in the sky. As a result, both are treated separately.

2.6.2.2.1 Unwanted emissions from GSO satellite systems (downlink)

The level of unwanted emissions can be assessed as follows:

$$I = \int_{f_1}^{f_2} \frac{p(f) \cdot g(f)}{SL \cdot ATM} \, \mathrm{d}f \qquad (6)$$

where:

- I: interference power at the RAS station (W/m^2)
- f_1, f_2: lower and upper edge respectively of the RAS receiver band (Hz)
- $p(f)$: unwanted emission power at the transmission antenna flange (W)
- $g(f)$: gain of the transmission antenna in the direction of the radio astronomy site
- SL: spreading loss (dB)
- $ATM(f)$: atmospheric absorption in the band $f_1 – f_2$ as a function of frequency.

It should be noted that both the power of the transmitted signal as well as the gain of the antenna sub-system vary with frequency and as such are represented as functions of frequency. The total interference at the location of the RAS station is the integral of these functions as shown above over the passband frequency of the receiver. In cases where the unwanted emission level and the antenna gain are constant throughout the bandwidth of the passive service receiver, the function can be simplified as follows:

$$I = \frac{p \cdot g}{SL \cdot ATM} \tag{7}$$

In cases where the active band is adjacent to the passive band, it may be possible to assume that the transmission antenna gain remains constant in both the transmission band and the passive band. However this may often not be the case, particularly when the passive band is below the cut-off frequency of the waveguide feed network in the antenna sub-system.

2.6.2.2.2 Unwanted emissions from non-GSO satellite systems (downlink)

To evaluate interference from non-GSO FSS systems to stations in the RAS, the methodology of Recommendation ITU-R S.1586 should be used. Likewise, to evaluate interference from non-GSO MSS and RNSS systems to stations in the RAS, the methodology of Recommendation ITU-R M.1583 should be used.

2.7 Box (iii): Assess discrepancy

The purpose of this box is to provide for a review of the input data and the discrepancy before proceeding with another iteration of the methodology. If this box has been reached then the interference received is greater than the threshold, implying that changes must be made in the next iteration to close the gap between the two numbers.

In the first iterations through the loop, the focus should be on improving the accuracy of assessing the interference into the passive service. As preliminary sharing studies involve coarse assumptions about both systems, these will need to be refined so as to be able to appropriately assess the interference potential. More detailed system descriptions and calculation methodologies may require a greater degree of computational complexity, but in the end may reveal that interference potential is significantly less than coarser assumptions had indicated.

Once the study is deemed to be sufficiently precise and a gap still exists, it will be necessary for either or both sides to take restrictions in order to clear the problem. These restrictions may take the form of operational restrictions, characteristic changes of the equipment or a modification in the sharing criteria.

Once the possible areas for changes in the next have been identified in this box, the appropriate decision box will effect the change and lead to a new interference assessment.

2.8 Box (iv): Consultative solution

After several iterations of the methodology, there may still exist a gap between the active and passive service. If no further changes can be made to any of the system parameters, criteria or mitigation methods then there is no general solution that allows all users of the active band to share with all the passive service users. The only remaining solution that can then be explored is for sub-sets of the active band and passive band users to enter discussions and possibly achieve an agreement among them. For example, between two adjacent bands it may not be possible to find a solution between the FSS and RAS. However, a solution may be possible between the non-GSO FSS and the RAS.

The methodology in Fig. 1 may prove useful in carrying out the discussions in this section between sub-sets of operators sharing the band.

However, if smaller consultation groups cannot achieve an agreement, then the methodology comes to an end without having closed the gap. The resulting progress from the iterations through the methodology may have proved helpful in closing the gap and suggesting future areas for study. It may also serve as a basis for multiple solutions among which regulators may have to select.

2.9 Diamond (a): Interference power ≤ passive service criteria

The interference power assessed in box (ii) is compares to the appropriate passive service protection criteria from box (2). If the interference is greater then the detrimental level, the methodology proceeds to decision diamond (b). This method ends if the interference is less than or equal to these criteria.

2.10 Diamond (b): Interference power ≤ threshold

On later iterations the threshold in diamond (b) may indicate that the operating arrangement that provides adequate protection for passive service while minimizing the restrictions upon the active service is possible. Parameters used may result from the procedures in diamonds (c), (d) or (e). The burden following this arrangement would be distributed equitably between two services. In the case of multiple interfering active services, the iteration procedure should be followed for each individual service, possible resulting in different operating arrangements for each. The guiding principle is that the total burden on all parties involved should not render any of these parties incapable of operating effectively.

2.11 Diamond (c): Can the emission parameters be refined?

Following the review done in box (iii), it may be possible to modify the emission parameters of the active service. For example, regulatory limits used as lower levels that are more representative of current may replace the worst-case assumptions for future planned systems. These modified assumptions can then be taken into account in subsequent iterations.

2.12 Diamond (d): Can the reception parameters in passive band be refined?

Following the review done in box (iii), it may be possible to modify reception parameters of the passive service. For example, actual antenna patterns may be used instead of more conservative patterns. These modified assumptions can then be taken into account in subsequent iterations.

2.13 Diamond (e): Is the application of mitigation techniques feasible?

Once the parameters of the active and passive service can no longer be refined and there still remains a gap between the interference and sharing threshold, then mitigation methods can be considered as a way of reducing the gap. Three likely methods are included in this section, although additional methods do exist (e.g. the list in Annex 3 of Recommendation ITU-R SM.1542).

2.13.1 Active system

2.13.1.1 Filtering by the active system

One method of adequately protecting the passive services is the introduction of additional filtering in the RF chain of the transmitter to reduce the level of unwanted emissions. In some cases this may pose a minimal burden as the architecture of the transmitter allows for the insertion of a filter or the improvement of an existing filter. However in some cases, the applicability of filters may be affected by considerations of cost, weight and/or reduction in capacity.

2.13.1.2 Use of a guardband

One method of reducing the level of the unwanted emission from active service transmitter into the passive band is to introduce a guardband. The guardband allows reducing the interference power received by the passive service operator. Although this may be effective when both systems share adjacent bands, it may be of little value when the separation between the bands is large, as the additional bandwidth may not provide any substantial improvement in filter attenuation. Furthermore, the insertion of a guardband reduces the bandwidth available to one or both services.

To assess the impact of a guardband the following calculations should be undertaken. The interference power (W) received by the passive service is as follows:

$$I = \int_{f_1}^{f_2} \frac{p(f) \cdot g_1(f) \cdot g_2(f) \cdot r(f)}{FSL \cdot ATM} \, \mathrm{d}f \qquad (8)$$

where:

- I: interference power received by the passive service receiver within its receive bandwidth (W/m^2)
- f_1, f_2: lower and upper edge respectively of the passive service receiver band (Hz)
- $p(f)$: unwanted emission power density as a function of frequency at the transmission antenna flange (W/Hz)
- $g_1(f)$: gain of the transmission antenna as a function of frequency in the direction of the passive service antenna
- $g_2(f)$: gain of the passive service antenna as a function of frequency in the direction of the transmission antenna
- FSL: free space loss (m^2)
- $ATM(f)$: atmospheric absorption in the band as a function of frequency
- $r(f)$: transfer characteristics of passive service receive filters as a function of frequency.

Implementing a guardband involves shifting both the receiver and transmitter curves. As a result of the frequency shift some of the curves may change shape to accommodate the bandwidth available.

2.13.1.3 Use of geographic isolation

Another method to avoid detrimental interference is to make sure that the Earth-based passive service station is sufficiently removed from the boresight of the active service transmitter. If the Earth-based passive service stations are located in areas, which are removed from the space station service area then the interference, is minimized. Furthermore, if the Earth-based passive service stations are few in number and their positions are well known then it should be possible for the space station designer to position the beams so as to avoid the Earth-based passive service stations.

2.13.2 Passive system

See Recommendation ITU-R SM.1542.

2.14 End circles (a), (b), (c)

End (a): The methodology ending at this point has determined that compatibility has been demonstrated between the initial passive service parameters and the initial or refined active service parameters. It is a possible outcome at his point that no modifications were needed and the initial parameters analysed represent compatible systems.

End (b): The methodology ending at this point has determined that compatibility has been demonstrated between the initial or refined passive service parameters and the initial or refined active service parameters or by the consideration of other mitigation techniques.

End (c): The methodology ending at this point has determined that compatibility cannot be demonstrated with the initial or refined parameters for each service. It is necessary that the administrations sponsoring specific systems enter into negotiations relative to these systems.

Appendix 1
to Annex 1

This technical Appendix to Annex 1 collects information on technical topics. They are retained either because they are of interest for future calculations (e.g. the propagation coefficients in § 3), or are the subject of further studies.

1 Interference power calculations

Use of RR No. 1.153 and Recommendation ITU-R SM.1541 allows evaluation of interference to passive sensors in passive bands from active services operating in adjacent or nearby active service bands. Assuming that the occupied bandwidth of an emission, as defined in RR No. 1.153, does not overlap the passive service band, would limit the unwanted emission power in the passive band to no greater than 0.5% of the total mean power of the emission. Recommendation ITU-R SM.1541 provides a worst-case analysis in which the OoB emissions from the active service are overstated.

Equation (9) provides a spectral representation to serve as guidance on unwanted emissions in the FSS. The spectral representation is referenced to the necessary bandwidth in terms of percentage. If the mask is integrated to determine the amount of power beyond some range from the centre frequency it will provide a curve as shown in Fig. 2. (The Figure assumes a sliding integration domain of 400% of the necessary bandwidth.). An integration of the FSS mask from Recommendation ITU-R SM.1541 indicates that 17% of the in-band energy is transmitted on either side of the necessary bandwidth, and the problem is even further exacerbated when its use is coupled with that of the spurious domain mask in RR Appendix 3 which is flat for all bands, leading to a value of infinite power on integration. To assist in determining the interference power in passive bands, it was proposed that a spectral representation, based on a raised cosine filter that gives the response in the frequency domain:

$$A = [\text{sinc}(2f/B_N)]^2 \,/\, [1 - (2f/B_N)^2]^2 \qquad (9)$$

where:

$$\text{sinc}(2f/B_N) = \text{sinc}(2\pi f/B_N) \,/\, (2\pi f/B_N) \qquad \text{for } 2\pi f/B_N \neq 0$$

and:

$$\text{sinc}(2f / B_N) = 1 \qquad \text{for } 2\pi f/B = 0$$

where:

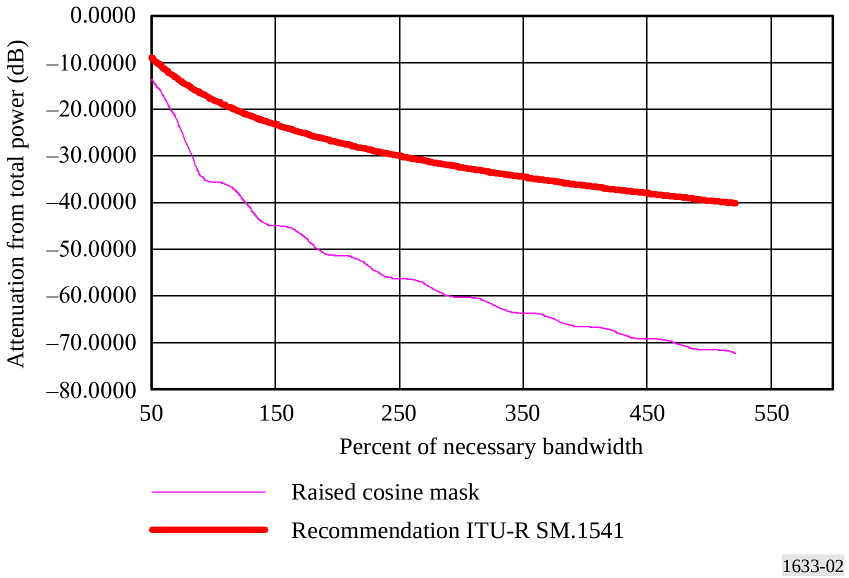
A: attenuation

f: frequency, from centre of necessary bandwidth

B_N: necessary bandwidth.

FIGURE 2

Integration of spectral representation



This preliminary spectral representation of the unwanted emissions, intended for the band-by-band studies, represents in a very general way the typical mean power distribution through the OoB and spurious domains in an adjacent or nearby allocation. The raised cosine mask has been used in calculations in some of the Annexes; its use in such cases is clearly indicated in the text. The applicability of this spectral representation to various services and stations (e.g. space or terrestrial) as well as the frequency range of its validity should be the subject of further studies before its use becomes widespread.

In cases where the scenario is not static, and the worst-case static analysis results in potential interference, a determination of the statistical distribution of interference events will be required. Performing a dynamic analysis, which accounts for the time varying characteristics of the scenario, can do this. The steps that should be followed are as follows:

Step 1: When power predicted by the static analysis exceeds the interference threshold, there is potential for interference in the worst-case static sense. A dynamic simulation should be run in cases where the scenario is time varying to determine the statistical distribution of the interference. A dynamic simulation could show that there is an insignificant occurrence of interference as defined by Recommendation ITU-R SA.1029 or from Recommendation ITU-R RA.1513. If this is the case, then no further analysis is required.

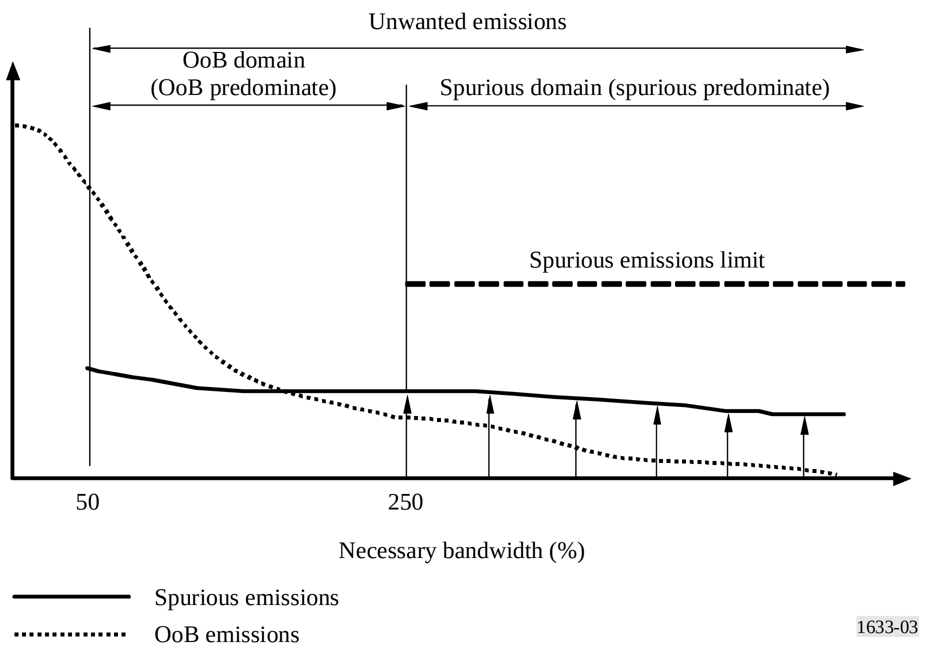
Step 2: If the simulation shows that the interference is significant, the process should be repeated using mitigation techniques such as a different satellite operating centre frequency further separated from the passive band or a filter to the satellite emissions and repeat the calculations until the interfering partial power at the passive service system is less than the required protection. This step could also include modification of other satellite parameters.

2 Possible refinement of the interference power calculation in the case of unwanted emissions from FS systems that may fall within EESS bands

In cases where the unwanted emissions level from FS systems at the edge of the OoB domain (derived from Recommendation ITU-R SM.1541) is significantly below the limit within the spurious domain given in Recommendation ITU-R SM.329 or in RR Appendix 3, the evaluation of the interference power falling in the EESS band calculated by using limits given in Recommendation ITU-R SM.329 or RR Appendix 3, will lead to significantly overestimate the power falling in a wide reference bandwidth (see Fig. 3).

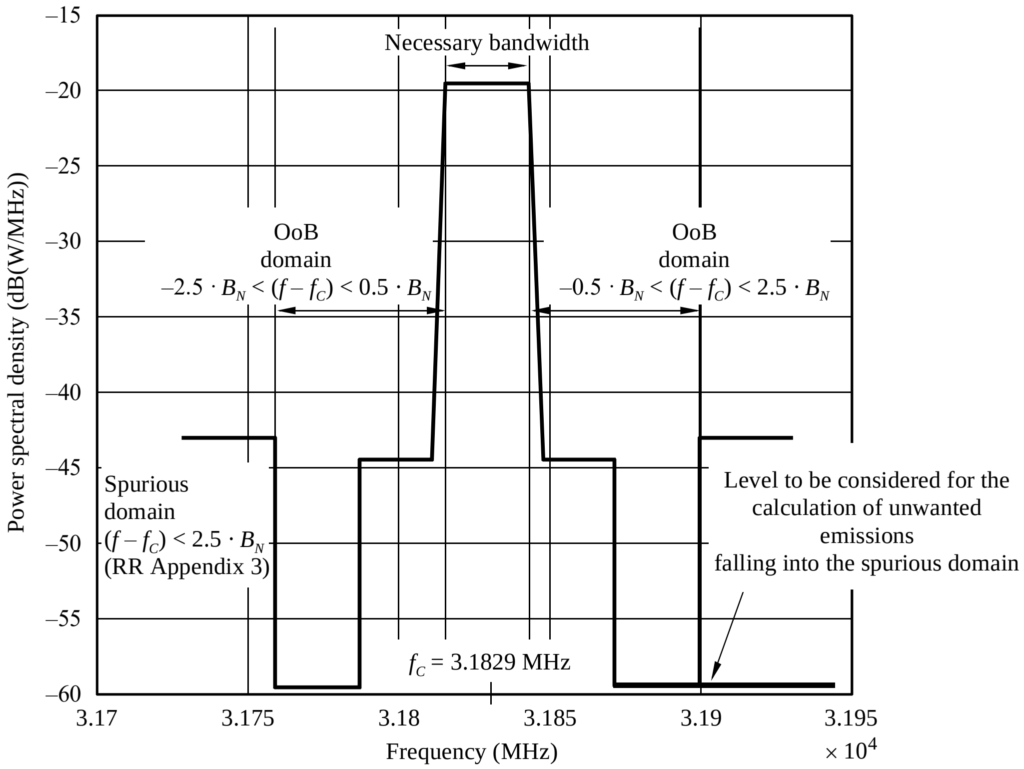
FIGURE 3

Realistic spurious emissions vs. spurious emissions limit



Therefore, calculation of the interference power due to the unwanted emissions of the FS system falling into wide reference bandwidths may be refined by assuming that the spurious emission level does not exceed the level reached at the edge of the OoB domain (see Fig. 4).

FIGURE 4



Unwanted emission mask for an FDMA system (–5 dBW/28 MHz/f_C = 31 829 MHz)

1633-04

3 Minimum Earth-to-space propagation attenuation due to atmospheric gases for use in compatibility studies between passive services and active services

3.1 Introduction

Earth-to-space propagation attenuation between a terrestrial station and a space station (GSO or non-GSO) resulting from absorption due to atmospheric gases including water vapour is an important factor in compatibility studies between passive services and active services. This slant path attenuation depends on the distribution along the path of meteorological parameters such as temperature, pressure and humidity, and thus varies with the geographical location of the site, the month of the year, the height of a terrestrial station above sea level and the elevation angle of the slant path and the operating frequency. The procedure for calculating the slant path attenuation is the line-by-line procedure given in Annex 1 to Recommendation ITU-R P.676.

The detailed calculation of atmospheric absorption attenuation may utilize local information of average water vapour content in the driest month and of other meteorological parameters along with the atmospheric models of Recommendation ITU-R P.835. When this information is not available, the following results provide a simple procedure for estimating atmospheric attenuation.

The equations given below consider each of the frequency bands of interest that are allocated to passive services and are presented for five representative geographical areas of the world (northern and southern hemispheres).

3.2 Estimation of Earth-to-space path attenuation

For the purpose of this simplified estimation, a station on the surface of the Earth is identified as being within one of three climate areas depending only on the latitude (absolute value) of the station:

– low-latitudes within 22.5° of the Equator;

– mid-latitudes greater than 22.5°, but less than 45° from the Equator;

– high-latitudes of 45° or more from the Equator.

Table 2 shows the climate parameters for each of these areas. Note that the sea-level water vapour density for the low-latitude area is lower than that prescribed in Recommendation ITU-R P.835 corresponding to the dry season. The attenuation values for these areas have been determined as a function of the elevation angle of the actual transmission (or reception) path from the station on the surface of the Earth to the position of a space station (GSO or non-GSO). The numerical formulae for atmospheric attenuation, which approximate the theoretical values, are given in the following sections, where:

$A_L(h, \theta)$, $A_M(h, \theta)$, $A_H(h, \theta)$: total atmospheric absorption loss (dB) for the low-latitude, mid-latitude and high-latitude areas, respectively;

h and θ: altitude above sea level of the station on the surface of the Earth (km) and elevation angle (degrees), respectively.

TABLE 2

Parameters at sea level for the climate areas

Climate area	Temperature (K)	Atmospheric pressure (hPa)	Water vapour density (g/m^3)
Low-latitude	300.4	1 012.0	10.0
Mid-latitude	272.7	1 018.9	3.5
High-latitude	257.4	1 010.8	1.23

The line-by-line method in Annex 1 to Recommendation ITU-R P.676 was used for integration. The height profiles of temperature, pressure and water vapour density as defined in Recommendation ITU-R P.835 were used in calculating the loss. Since the bandwidth of each frequency band allocated to passive services is relatively narrow, the centre of the band was used as a representative frequency, assuming that the attenuation is almost constant over each band. The approximation was carried out for $0 \leq h \leq 3$ km and $0° \leq \theta \leq 90°$. Some of the formulae listed appear in Recommendations ITU-R SF.1395 and ITU-R F.1404, but are included here for completeness.

If the interference path is one between two space stations, the atmospheric absorption attenuation should be regarded as 0 dB.

Frequency band 1 400-1 427 MHz

$$A_L(h, \theta) = 1.59 / [1 + 0.6294\,\theta + h\,(0.2258 + 0.1220\,\theta)] \quad (1a)$$

$$A_M(h, \theta) = 1.89 / [1 + 0.6813\,\theta + h\,(0.2828 + 0.1580\,\theta)] \quad (1b)$$

$$A_H(h, \theta) = 2.09 / [1 + 0.7106\,\theta + h\,(0.3057 + 0.1718\,\theta)] \quad (1c)$$

Frequency band 1 610.6-1 613.8 MHz

$$A_L(h, \theta) = 1.63 / [1 + 0.6348\,\theta + h\,(0.2323 + 0.1250\,\theta)] \quad (2a)$$

$$A_M(h, \theta) = 1.95 / [1 + 0.6870\,\theta + h\,(0.2908 + 0.1621\,\theta)] \quad (2b)$$

$$A_H(h, \theta) = 2.16 / [1 + 0.7172\,\theta + h\,(0.3148 + 0.1767\,\theta)] \quad (2c)$$

Frequency band 2 690-2 700 MHz

$$A_L(h, \theta) = 1.78 / [1 + 0.6527\,\theta + h\,(0.2552 + 0.1355\,\theta)] \quad (3a)$$

$$A_M(h, \theta) = 2.11 / [1 + 0.7022\,\theta + h\,(0.3123 + 0.1730\,\theta)] \quad (3b)$$

$$A_H(h, \theta) = 2.33 / [1 + 0.7331\,\theta + h\,(0.3371 + 0.1881\,\theta)] \quad (3c)$$

Frequency band 10.6-10.7 GHz

$$A_L(h, \theta) = 3.38 / [1 + 0.8346\,\theta + h\,(0.2690 + 0.2738\,\theta) + 0.09948\,h^2] \quad (4a)$$

$$A_M(h, \theta) = 3.00 / [1 + 0.7507\,\theta + h\,(0.3983 + 0.2147\,\theta)] \quad (4b)$$

$$A_H(h, \theta) = 2.97 / [1 + 0.7476\,\theta + h\,(0.3734 + 0.2072\,\theta)] \quad (4c)$$

Frequency band 21.2-21.4 GHz

$$A_L(h, \theta) = 39.24 / [1 + 0.8450\,\theta + 0.06450\,\theta^2 - 0.002107\,\theta^3 + 0.1657 \times 10^{-4}\,\theta^4 + h\,(0.2902 + 0.3773\,\theta) + h^2\,(0.09362 + 0.1667\,\theta) + 0.03977\,h^3] \quad (5a)$$

$$A_M(h, \theta) = 17.15 / [1 + 0.8101\,\theta + 0.02691\theta^2 + h\,(0.2374 + 0.2727\,\theta) + h^2\,(0.1157 + 0.08487\,\theta)] \quad (5b)$$

$$A_H(h, \theta) = 9.87 / [1 + 0.6239\,\theta + 0.04358\,\theta^2 + h\,(0.07017 + 0.3633\,\theta) + 0.1166\,h^2] \quad (5c)$$

Frequency band 22.21-22.5 GHz

$$A_L(h, \theta) = 47.63 / [1 + 0.7826\,\theta + 0.1060\,\theta^2 - 0.009088\,\theta^3 + 0.0002975\,\theta^4 - 0.3991 \times 10^{-5}\,\theta^5 + 0.1853 \times 10^{-7}\,\theta^6 + h\,(0.2959 + 0.3016\,\theta) + h^2\,(0.06740 + 0.1773\,\theta) + 0.03795\,h^3] \quad (6a)$$

$$A_M(h, \theta) = 20.26 / [1 + 0.7215\,\theta + 0.05983\,\theta^2 - 0.001961\,\theta^3 + 0.1555 \times 10^{-4}\,\theta^4\; h\,(0.2047 + 0.2338\,\theta) + h^2\,(0.1088 + 0.08897\,\theta)] \quad (6b)$$

$$A_H(h, \theta) = 11.48 / [1 + 0.6065\,\theta + 0.04355\,\theta^2 + h\,(0.05653 + 0.3470\,\theta) + 0.1096\,h^2] \quad (6c)$$

Frequency band 23.6-24.0 GHz

$$A_L(h, \theta) = 41.78 / [1 + 0.8705\,\theta + 0.06699\,\theta^2 - 0.002203\,\theta^3 + 0.1743 \times 10^{-4}\,\theta^4 + h\,(0.3132 + 0.4079\,\theta) + h^2(0.09824 + 0.1906\,\theta) + 0.04830\,h^3] \quad (7a)$$

$$A_M(h, \theta) = 18.42 / [1 + 0.8311\,\theta + 0.02870\,\theta^2 + h\,(0.2517 + 0.2995\,\theta) + h^2\,(0.1330 + 0.09409\,\theta)] \quad (7b)$$

$$A_H(h, \theta) = 10.73 / [1 + 0.6427\,\theta + 0.04402\,\theta^2 + h\,(0.08210 + 0.3840\,\theta) + 0.1273\,h^2] \quad (7c)$$

Frequency band 31.3-31.5 GHz

$$A_L(h, \theta) = 19.52 / [1 + 0.9294\,\theta + 0.02495\,\theta^2 + h\,(0.3409 + 0.4368\,\theta) + h^2\,(0.1938 + 0.07732\,\theta)] \quad (8a)$$

$$A_M(h, \theta) = 11.89 / [1 + 0.8124\,\theta + 0.01982\,\theta^2 + h\,(0.2738 + 0.3876\,\theta) + 0.1181\,h^2] \quad (8b)$$

$$A_H(h, \theta) = 9.70 / [1 + 0.8149\,\theta + h\,(0.2388 + 0.2699\,\theta) + 0.08830\,h^2] \quad (8c)$$

Frequency band 42.5-43.5 GHz

$$A_L(h, \theta) = 33.54 / [1 + 0.7690\,\theta + 0.04472\,\theta^2 - 0.001416\,\theta^3 + 0.1072 \times 10^{-4}\,\theta^4 + h\,(0.2675 + 0.3897\,\theta) + 0.1253\,h^2] \quad (9a)$$

$$A_M(h, \theta) = 26.58 / [1 + 0.6859\,\theta + 0.04579\,\theta^2 - 0.001451\,\theta^3 + 0.1108 \times 10^{-4}\,\theta^4 + h\,(0.2418 + 0.3068\,\theta) + 0.07381\,h^2] \quad (9b)$$

$$A_H(h, \theta) = 25.01 / [1 + 0.6552\,\theta + 0.04585\,\theta^2 - 0.001450\,\theta^3 + 0.1109 \times 10^{-4}\,\theta^4 + h\,(0.2219 + 0.2734\,\theta) + 0.06186\,h^2] \quad (9c)$$

Frequency band 50.2-50.4 GHz

$$A_L(h, \theta) = 91.86 / [1 + 0.65929\,\theta + 0.055368\,\theta^2 - 0.0039239\,\theta^3 + 0.00011109\,\theta^4 - 0.13407 \times 10^{-5}\,\theta^5 + 0.57041 \times 10^{-8}\,\theta^6 + h\,(0.24505 + 0.18790\,\theta + 0.0016855\,\theta^2) + h^2\,(0.055349 + 0.026631\,\theta)] \quad (10a)$$

$$A_M(h, \theta) = 90.25 / [1 + 0.64981\,\theta + 0.059840\,\theta^2 - 0.0043911\,\theta^3 + 0.00012737\,\theta^4 - 0.15609 \times 10^{-5}\,\theta^5 + 0.67150 \times 10^{-8}\,\theta^6 + h\,(0.23568 + 0.17708\,\theta + 0.0022801\,\theta^2) + h^2\,(0.052633 + 0.033709\,\theta)] \quad (10b)$$

$$A_H(h, \theta) = 93.17 / [1 + 0.65343\,\theta + 0.061286\,\theta^2 - 0.0045343\,\theta^3 + 0.00013177\,\theta^4 - 0.16120 \times 10^{-5}\,\theta^5 + 0.69120 \times 10^{-8}\,\theta^6 + h\,(0.24860 + 0.16341\,\theta + 0.0027123\,\theta^2) + h^2\,(0.047282 + 0.035113\,\theta)] \quad (10c)$$

Frequency band 52.6-52.8 GHz

$$A_L(h, \theta) = 243.6 / [1 + 0.61184\,\theta + 0.035912\,\theta^2 - 0.0018265\,\theta^3 + 0.40052 \times 10^{-4}\,\theta^4 - 0.41231 \times 10^{-6}\,\theta^5 + 0.15890 \times 10^{-8}\,\theta^6 + h\,(0.16591 + 0.16486\,\theta + 0.0016442\,\theta^2 - 0.26154 \times 10^{-4}\,\theta^3) + h^2\,(0.045789 + 0.022061\,\theta)] \quad (11a)$$

$$A_M(h, \theta) = 243.8 / [1 + 0.63597\,\theta + 0.037426\,\theta^2 - 0.0019080\,\theta^3 + 0.41762 \times 10^{-4}\,\theta^4 - 0.42823 \times 10^{-6}\,\theta^5 + 0.16431 \times 10^{-8}\,\theta^6 + h\,(0.17376 + 0.18234\,\theta + 0.0018276\,\theta^2 - 0.29487 \times 10^{-4}\,\theta^3) + h^2\,(0.053692 + 0.028670\,\theta)] \quad (11b)$$

$$A_H(h, \theta) = 249.9 / [1 + 0.64303\,\theta + 0.038850\,\theta^2 - 0.0019901\,\theta^3 + 0.43669 \times 10^{-4}\,\theta^4 - 0.44802 \times 10^{-6}\,\theta^5 + 0.17189 \times 10^{-8}\,\theta^6 + h\,(0.18620 + 0.18810\,\theta + 0.0019179\,\theta^2 - 0.31541 \times 10^{-4}\,\theta^3) + h^2\,(0.052809 + 0.030444\,\theta)] \quad (11c)$$

NOTE 1 – If propagation attenuation is actually calculated and included in each compatibility analysis where the propagation attenuation was not considered, it is possible that results of the compatibility analysis slightly change. Calculations of Earth-to-space propagation attenuation are, of course, not necessary between two earth stations and between two space stations, but necessary between earth and space stations. In this last case, effect of attenuation is rather small for high elevation angles, but the effect is relatively large for low elevation angles. Further study is necessary in future for the case of low elevation angles.

4 Note on reflection coefficient

One form of interference power into the EESS passive bands arises from unwanted emissions of FSS downlinks that are reflected upwards from the Earth's surface towards a nearby EESS sensor. For frequencies around 10-20 GHz, this reflected energy has a significant time-varying component. Reflections by this mode contribute to the worst-case interference that can be expected. Other reflection modes also exist. These would be more frequent in occurrence but at a lower level. Recommendation ITU-R SA.1449 describes a model for the reflection coefficient that may be used as the foundation in developing a reflection coefficient model applicable to these studies. Further work is planned within the ITU-R to develop a bi-static microwave scattering model for interference assessment using this approach.

Annex 2

Compatibility analysis between RAS systems operating in the 1 400-1 427 MHz band and BSS (space-to-Earth) systems operating in the 1 452-1 492 MHz band

1 RAS

1.1 Allocated band

The 1 400-1 427 MHz band is allocated to passive services only, on a primary basis: the RAS, the EESS (passive), and the SRS (passive).

RR No. 5.340 prohibits all emissions in this band.

1.2 Type of observations

The 1 400-1 427 MHz band is used more intensely than any other, in all ITU-R Regions. The main radio-astronomical use of band is to make spectral line observations of cosmic neutral atomic hydrogen (also referred to as HI), which has a rest frequency of 1 420.406 MHz. This material is by far the main constituent of our Galaxy and other galaxies, and occurs in huge, complex-structured clouds. This line is observed in both emission and absorption, and is broadened and shifted in frequency by Doppler shifts due to local and bulk motions in the cloud structures. Accordingly, HI observations can be used to map the distribution of material and its motions in our and other galaxies. In this way we can map the structure of our Galaxy, and how material is moving.

The 1 400-1 427 MHz allocation is sufficiently broad to encompass the Doppler-shifted emission from clouds in our galaxy and in nearby galaxies. Measurements of the polarization of the HI emission or absorption yield important information on galactic magnetic fields and thence an increased understanding of galactic structure.

The 1400-1427 MHz band is also used for continuum observations of broadband emissions produced by hot plasma formed when stars heat the surrounding clouds, and by the interaction of high-energy (fast-moving) electrons in the galactic magnetic field (synchrotron emission).

1.3 Required protection criteria

The threshold levels for detrimental interference to radio astronomical observations are given in Recommendation ITU-R RA.769, which lists the levels of unwanted emissions that will increase the measurement error by 10%. The band is used for both spectral line and continuum observations. In the 1400-1427 MHz band, for single-dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 20 kHz, the threshold pfd limit is –196 dB(W/m^2). For making single-dish continuum observations, the whole 27 MHz width of the band is used, for which case the threshold pfd limit for detrimental interference is –180 dB(W/m^2).

Very long baseline interferometry (VLBI) observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, –166 dB(W/m^2), for a bandwidth of 20 kHz.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

The 1400-1427 MHz band is the most intensely used radio astronomy band of all. It is used worldwide, in all ITU Regions, and some radio telescopes, such as the Synthesis Radio Telescope at the Dominion Radio Astrophysical Observatory (DRAO), Penticton, Canada observe full-time in this band. Single-antenna radio telescopes are used to measure the integrated spectral pfd (spfd) of sources of small angular diameter and to map structures of large angular size that cannot be mapped using synthesis telescopes.

The higher angular resolution offered by synthesis telescopes make it possible to map the finer structure in the hydrogen clouds and sources of continuum emissions such as supernova remnants. These maps are then combined with the lower-resolution maps obtained using single-antenna radio telescopes to make high-quality 3-D images of our Galaxy and others. Synthesis radio telescopes, using multi-antenna arrays may require between one and a dozen 12 h "exposures" to make a complete map of an area of sky. In order to facilitate mapping comparatively large source structures, some synthesis radio telescopes, such as the DRAO instrument, use arrays of comparatively small antennas. Instruments of this kind do not have the option of optimum side-lobe suppression and are therefore more vulnerable to interference.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the hydrogen cloud(s) in the antenna beam.

In general, observations are made differentially. In the case of continuum emissions, the area of sky containing the source may be mapped and the background emission subtracted, or measurements made of the power coming from the direction from the source (on-source) and at one or more nearby positions in the sky (off-source). By subtracting the off-source values from the on-source values, the emission originating in the source is separated from other contributions to the receiver output.

In the case of spectral line observations, spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

Since the Galaxy is filled with clouds of neutral hydrogen, radio telescopes detect not only the emission or absorption in the clouds in the antenna main beam, but also a very significant contribution through the antenna side lobes. This "stray radiation" distorts spectra and reduces map detail. Removing this from the data involves large-scale measurement of the whole antenna beam (as far as possible), and estimation of the stray radiation correction. Interference and large "blocked" areas of sky will therefore affect the ability to make maps at parts of the sky large angles from interference sources.

Extended areas of radio emission can be mapped by recording the emission from a grid of points covering the region of interest. Both continuum and spectral line observations may be made. In the case of single antenna radio telescopes, each grid point observation is an indication of the total power (in the continuum case) or the emission spectrum (in the spectral line case) coming from that position in the sky; the spacing between the grid points should not be more than half the antenna beamwidth. When observations are made using a synthesis radio telescope, where the area to be mapped exceeds the instantaneous mapping field, the grid points should not be further apart than half the beamwidth of one of the radio telescope antennas.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without demodulation, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data have been processed.

2 BSS

2.1 Allocated transmit band

The 1 452-1 492 MHz band is allocated to the BSS.

2.2 Application

Broadcasting of audio-only transmissions.

2.3 Levels based upon regulatory provisions

Not assessed.

2.4 Operational characteristics

The following characteristics were communicated as the expected maximum values and typical necessary bandwidth based on characteristics of BSS sound systems already implemented or most likely to be implemented. In addition, this Recommendation proposes typical values for antenna gains.

TABLE 3

Frequency band (MHz)	Notified system	Necessary bandwidth (MHz)	Satellite antenna gain (dBi)	Expected maximum in-band pfd (dB(W/(m^2 · 4 kHz)))
1 452-1 492	Digital System A	1.536	30	–128
	Digital System DS	1.84	30	–138

NOTE 1 – The results in this Annex are limited to GSO systems.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

With respect to non-GSO systems, the protection criteria for radio astronomy and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems.

The OoB emission mask that was used for the calculation is described in § 4.3.1.

4.2 Calculation of interference level

See § 4.3.

4.3 Values achieved

It should be noted that the following sections cover only the case of GSO systems.

4.3.1 Spectral line observations

Based on the necessary bandwidth given in Table 3, and on the separation of the BSS and passive service bands, it appears that for the BSS allocation, the spurious limit applies: 43 + 10 log *P* or 60 dBc, whichever is less stringent, where *P* is the mean power (W) supplied to the antenna transmission line. This is detailed in Table 4.

TABLE 4

BSS allocation (MHz)	Closest passive service allocation (MHz)	Notified system	Necessary bandwidth (MHz)	Start of OoB domain (MHz)	End of OoB domain (MHz)	Required attenuation in the passive allocation
1 452-1 492	1 400-1 427	Digital System A	1.536	1 452	1 448.928	43 + 10 log *P* or 60 dBc
		Digital System DS	1.84	1 452	1 448.32	43 + 10 log *P* or 60 dBc

The expected unwanted emission level is deduced from the parameters in Table 5.

TABLE 5

BSS allocation (MHz)	Necessary bandwidth (MHz)	Expected maximum in-band pfd (dB(W/(m^2 · 4 kHz)))	Satellite antenna gain (dBi)	Total mean output power of the transmitter (dBW)	Required attenuation in the passive allocation (dBc)	Expected maximum unwanted emission levels (dB(W/(m^2 · 4 kHz)))
	(1)	(2)	(3)	(4)	(5)	(6)
1 452-1 492	1.536	–128	30	29.8	60	–162.4
	1.84	–138	30	20.6	60	–171.4

where the columns are related as follows:

$$(4) = (2) + 162 \text{ (free space loss)} - (3)_{in\text{-}band} - 36 + 10 \log((1))$$

The level of (4) determines the required attenuation in the case of the spurious limit:

$$(6) = (4) - (5) + (3)_{out\text{-}of\text{-}band} - 162$$

It was assumed that the satellite antenna gains at the frequencies of the passive allocation are the same as at the operating frequencies of the satellite allocation (i.e. $(3)_{in\text{-}band} = (3)_{out\text{-}of\text{-}band}$ with the notations used below). One should keep in mind that this corresponds to a worst case.

The passive band is used for both spectral line and continuum observations. Spectral line observations are made using a channel bandwidth (one of the spectrometer channels) of (typically) 20 kHz, the threshold pfd is then –196 dB(W/m^2). This protection criteria needs to be compared with the following values:

$$-162.4 + 10 \log ((20/4)) = -155.4 \text{ dB(W/(m}^2 \cdot 20 \text{ kHz))}$$

and with:

$$-171.4 + 10 \log ((20/4)) = -164.4 \text{ dB(W/(m}^2 \cdot 20 \text{ kHz))}$$

It means that at the end of the OoB domain, the discrepancy between the protection criteria and the spurious limit is of the order of 40 dB. Since the end of the OoB domain occurs at 1 448.928 MHz and the RAS allocated band starts at 1 427 MHz (more than 10 times the necessary bandwidth), it is likely that at the beginning of the RAS band, the discrepancy between the level of spurious emissions and the protection criteria will be significantly lower.

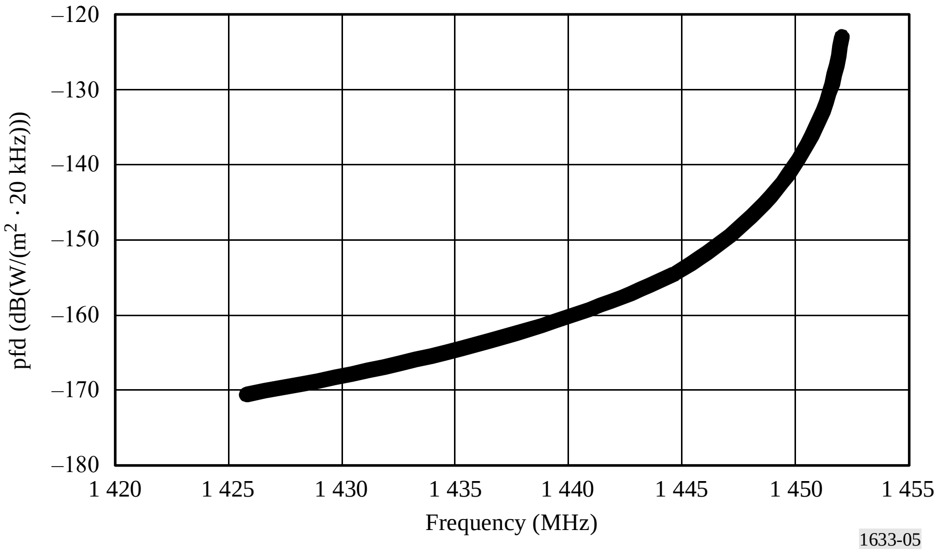
In particular, if we make the assumption that the decrease of the signal, within the spurious domain, will follow the new OoB mask as developed for BSS system (see Recommendation ITU-R SM.1541), then the attenuation will be given by:

$$32 \log \left(\frac{F}{50} + 1 \right) \qquad \text{dBsd}$$

FIGURE 5

pfd level integrated over 20 kHz depending on the frequency

Digital System A



In such a case the discrepancy at the edge of the RAS allocation is about 25 dB (about 20 dB in case of Digital System DS). This remaining interference would have to be avoided by additional mitigation technique (geographical isolation and filtering).

4.3.2 VLBI observations

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −166 dB(W/m^2), for a bandwidth of 20 kHz.

According to the calculation conducted in § 4.3.1, the VLBI protection criteria are likely to be met.

4.3.3 Continuum observations

For making single-dish continuum observations, the whole 27 MHz width of the band is used, for which case the threshold pfd limit for detrimental interference is –180 dB(W/m^2).

Taking into account the two systems given in Table 3, the maximum in band pfd level is:

$$-128 + 10 \log_{10} (1.536 \text{ MHz}/4 \text{ kHz}) = -102 \text{ dB(W/(m}^2 \cdot 1.536 \text{ MHz}/4 \text{ kHz))}$$

If this system follows the same decrease of the signal than the one proposed by Radiocommunication Working Party 4A in Document 1-7/149, then the rejection between the in-band power and the power integrated over 27 MHz will be higher than 80 dB. This means that the continuum observation protection criteria will be met. This also confirms that the VLBI protection criteria will be met.

5 Mitigation techniques

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna sidelobe performance: The aperture illumination of radio telescopes is usually optimized for *G*/*T*, i.e. telescope gain divided by system temperature. This is to maximize the *S*/*N* for point sources. A key element of this approach is to reduce ground radiation entering through far sidelobes. Inevitably this leads to some corresponding increase in the levels of near sidelobes. Experience has shown that the majority of radio telescopes meets the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in some cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

5.2 BSS

This service involves continuous transmission of signals continually or for long periods of time, with constant power and spectrum. Possible mitigation procedures are to avoid transmitting unwanted emissions in the direction of the radio astronomy stations that use this band, or to use filters to appropriately suppress unwanted emissions to a level where detrimental interference to radio astronomical observations in the 1 400-1 427 MHz is not caused.

5.3 Potential impact

5.3.1 RAS

Antenna sidelobe performance: Attempts to decrease the sensitivity of the radio astronomy antenna to unwanted emissions coming from space stations are likely to increase the sensitivity of the radio astronomy telescope to ground radiation, and possibly reduce its main beam gain. Both of these effects will reduce the telescope's channel capacity of and thus lead to an increase of the total required integration time.

Blanking in time and/or frequency: Blanking involves a risk of compromising the integrity of the data and may lead to errors in their scientific interpretation. Blanking also causes a concomitant increase in the total integration time required to make the observation, this is equivalent to a loss in the channel capacity of the telescope.

5.3.2 BSS

Filters are an obvious way to suppress unwanted emissions, but the addition of such filters may affect the satellite design in a substantial manner. If a phased array active antenna is used, filters may be required for every driven antenna element. This will increase the weight of the satellite. Compensating for filter losses will require more powerful transmitters, which in turn will require more bus power, and so, larger solar power arrays. The increase in weight could be sufficient to require a larger launcher. The cost impact could be large. Consequently the implementation of filters can be considered only at the design stage of a system. However, continuing technical improvements in the design of filters and active antennas may in time reduce the problem of implementing such solutions to manageable proportions.

6 Results of studies

6.1 Summary

The calculations provided in the previous section address compatibility between GSO BSS systems operating in the band 1 400-1 427 MHz and the RAS operating in the band 1 400-1 427 MHz. Further studies will be needed to address the case of non-GSO systems.

The calculations provided in the above sections show that BSS systems will meet the protection criteria of VLBI and continuum observations, as discussed in § 1.3. However, to meet the spectral line protection criteria, it is likely that mitigation techniques such as filtering would have to be implemented. Taking into account the fact that the existing guardband between the RAS and the BSS allocated bands is large compared to necessary bandwidth used by BSS systems, it is expected that the RAS protection criteria are technically achievable by using mitigation techniques such as filtering and geographical isolation. It should be noted that the economic impact of implementing such techniques is significant.

6.2 Conclusions

The protection criteria for radio astronomical observations in this band can be met for continuum and VLBI observations, and for spectral line observations when appropriate mitigation techniques are used.

Annex 3

Compatibility analysis between the EESS (passive) systems operating in the 1 400-1 427 MHz band and radiolocation service systems operating in the 1 350-1 400 MHz band

1 EESS (passive)

1.1 Allocated band

This Annex presents a band-by-band study between the radiolocation service allocated in the 1 350-1 400 MHz adjacent to the 1 400-1 427 MHz passive band allocated to the Earth exploration-satellite (passive) service. It should be noted that according to RR No. 5.340, all emissions are prohibited in the band 1 400-1 427 MHz. The allocations are shown in Table 6.

TABLE 6

Adjacent band allocations

Services in lower allocated band	Passive band	Service in upper allocated band
1 350-1 400 MHz	**1 400-1 427 MHz**	**1 427-1 429 MHz**
FIXED (Region 1) MOBILE (Region 1) RADIOLOCATION (All) 5.399	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	SPACE OPERATION (Earth-to-space) FIXED MOBILE except aeronautical mobile

1.2 Application

NASA/JPL is currently developing an instrument for measuring soil moisture (the HYDROS mission), which will collect measurements in the entire passive microwave band under consideration (1 400 to 1 427 MHz). The European Space Agency (ESA) is developing a separate instrument (the SMOS mission), using a different technological approach, for measurements of soil moisture and ocean salinity. HYDROS and SMOS are complementary missions, both requiring high-precision radiometric measurements globally and continuously in time. Frequencies near 1 400 MHz are ideal for measuring soil moisture, and also for measuring sea surface salinity and vegetation biomass. Soil moisture is a key variable in the hydrologic cycle with significant influence on evaporation, infiltration and runoff. In the vadose zone, soil moisture governs the rate of water uptake by vegetation. Sea surface salinity has an influence on deep thermohaline circulation and the meridional heat transport. Variations in salinity influence the near surface dynamics of tropical oceans. To date, there is no capability to measure soil moisture and sea surface salinity directly on a global basis, so the protection of this passive band is essential.

1.3 Required protection criteria

The following Recommendations establish the interference criteria for passive sensors:

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

There are two criteria for this band. First there is a power threshold of −171 dBW in 27 MHz. This is a maximum interference level from all sources.

Secondly there is a frequency-of-occurrence limit on the threshold being exceeded. The number of measurement cells lost due to the threshold being exceeded must not exceed 5% in cases where the interference events are random, and 1% when the interference events are systematic. Since the radiolocation service is not random (fixed sites and 100% of time operational), the 1% criterion applies.

1.4 Operational characteristics

TABLE 7

EESS characteristics

Parameter	SMOS	HYDROS
EESS maximum antenna gain (dBi)	9	35
EESS altitude (km)	757	670
EESS –3 dB antenna aperture (degrees)	71.6	2.6
EESS pointing direction (degrees)	25 off nadir (fixed)	40 off nadir (rotating 6 r.p.m.)
Swath width (km)	620	45

FIGURE 6

SMOS antenna pattern

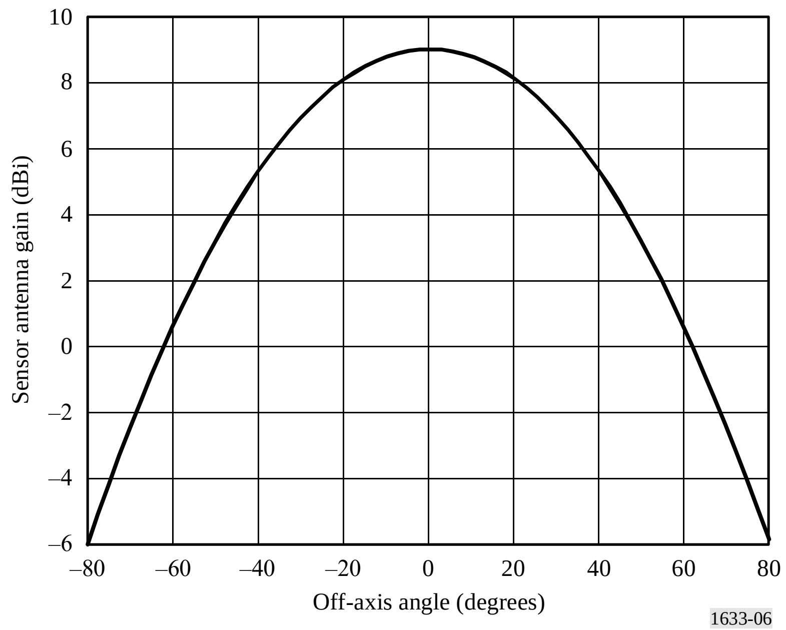
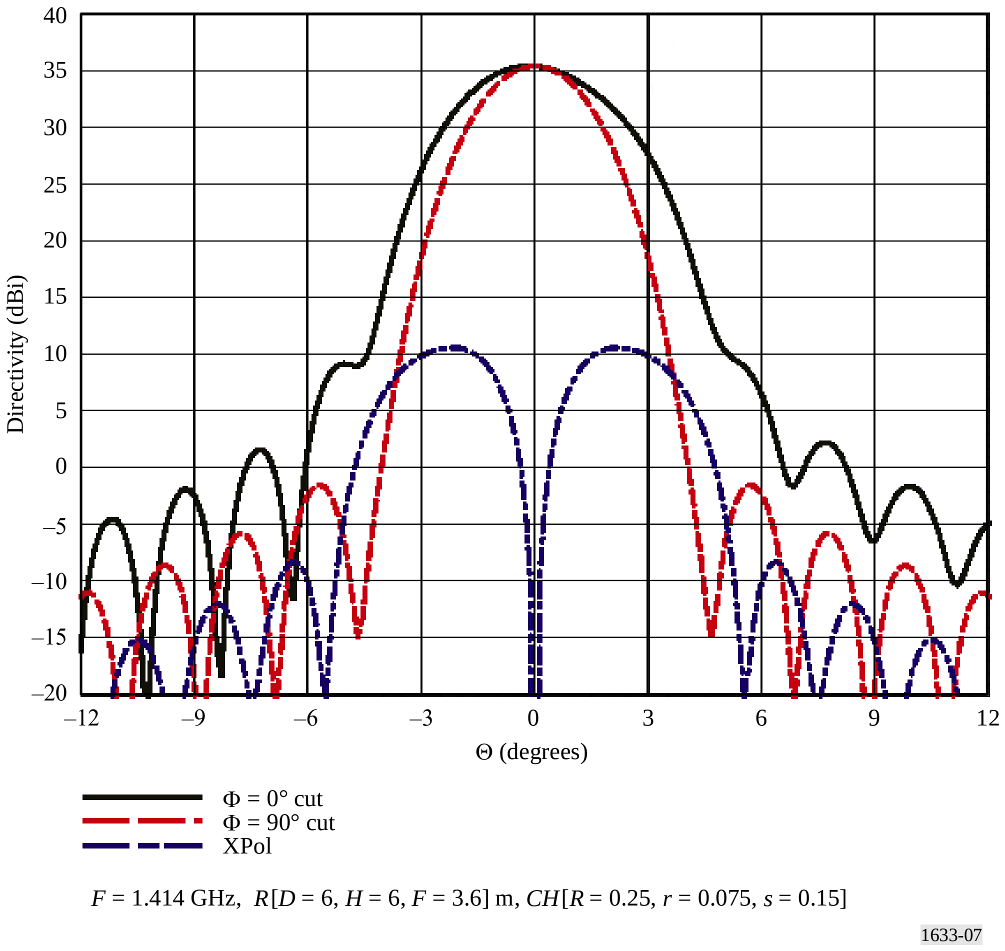


FIGURE 7

HYDROS antenna pattern



2 Radiolocation service

2.1 Allocated transmit band

The active service band is the radiolocation band 1 350-1 400 MHz.

2.2 Application

The set of radar characteristics that are taken into account in this compatibility analysis are derived from Recommendation ITU-R M.1463 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz.

2.3 Levels based on ITU-R provisions and Recommendations

2.3.1 RR No. 1.153

The RR define *occupied bandwidth* as follows:

“**1.153** *occupied bandwidth:* The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage β/2 of the total *mean power* of a given *emission*.

Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of β/2 should be taken as 0.5%.”

If the upper edge of the occupied bandwidth were at or below the upper limit of the radiolocation allocation, the total power of unwanted emissions at frequencies above the allocated bandwidth would be no greater than 0.5% of *P*, where *P* is the in-band power. Therefore, the total power of unwanted emission at frequencies in the EESS band and above is no greater than $P - 23$ dB.

2.3.2 Recommendation ITU-R SM.1541

Annex 8 of Recommendation ITU-R SM.1541 specifies a generic mask for OoB emissions for primary radars. This is repeated below as a segmented relationship. The dependent variable *F* is the frequency offset from band centre as a percent of the –40 dB bandwidth of the radar, as illustrated in Fig. 8.

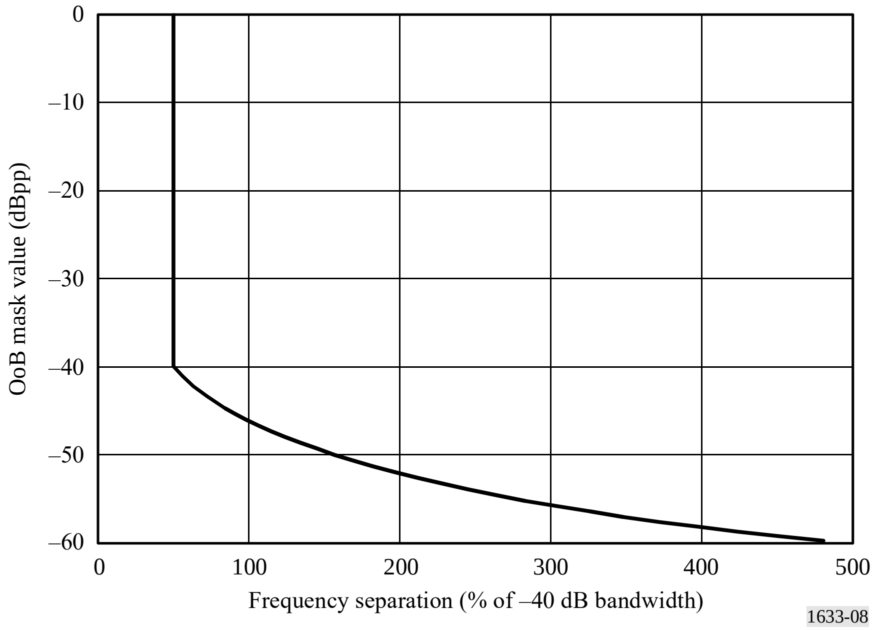
F: frequency offset from band centre as a per cent of the –40 dB bandwidth of the radar.

dBpp: decibels relative to the maximum value of the peak power, measured with the reference bandwidth within the occupied bandwidth.

It provides the minimum attenuation for OoB emission power, within a reference bandwidth, relative to the in-band peak power.

FIGURE 8

OoB mask for primary radars



2.4 Transmitter characteristics

The transmitter characteristics are described in Table 8. This Table has been extracted from Recommendation ITU-R M.1463.

2.5 Operational characteristics

See Table 8.

2.6 In-band transmit level

See Table 8.

TABLE 8

1 215-1 400 MHz radiodetermination system characteristics

Parameter	System 1	System 2	System 3	System 4
Peak power into antenna (dBm)	97	80	76.5	80
Pulse duration (μs)	2	88.8; 58.8 (1)	0.4; 102.4; 409.6 (2)	39 single frequency 26 and 13 dual frequency (3)
Pulse repetition rate (pps)	310-380 staggered	291.5 or 312.5 average	200-272 long range 400-554 short range	774 average
Chirp Bandwidth for frequency modulated (chirped) pulses	Not applicable	770 kHz for both pulse widths	2.5 MHz for 102.4 μs 625 kHz for 409.6 μs	Not applicable
Phase-coded sub-pulse width (μs)	Not applicable			1
Compression ratio	Not applicable	68.3:1 and 45.2:1	256:1 for both pulses	
RF emission bandwidth (3 dB) (MHz)	0.5	1.09	2.2; 2.3; 0.58	1
Output device	Klystron	Transistor		Cross field amplifier
Antenna type	Horn-fed reflector	Stack beam reflector	Rotating phased array	Parabolic cylinder
Antenna polarization	Horizontal, vertical, LHCP, RHCP	Vertical, circular	Horizontal	Vertical
Antenna maximum gain (dBi)	34.5, transmit 33.5, receive	32.4-34.2, transmit 31.7-38.9, receive	38.9, transmit 38.2, receive	32.5
Antenna elevation beamwidth (degrees)	3.6 shaped to 44	3.63-5.61, transmit 2.02-8.79, receive	1.3	4.5 shaped to 40
Antenna azimuthal beamwidth (degrees)	1.2	1.4	3.2	3.0

TABLE 8 (*end*)

Parameter	System 1	System 2	System 3	System 4
Antenna horizontal scan characteristics	360° mechanical at 5 r.p.m.		360° mechanical at 6 r.p.m. for long range and 12 r.p.m. for short range	360° mechanical at 6, 12 or 15 r.p.m.
Antenna vertical scan characteristics	Not applicable	–7° to +30° in 12.8 or 13.7 ms	–1° to +19° in 73.5 ms	Not applicable
Receiver IF bandwidth	780 kHz	0.69 MHz	4.4 to 6.4 MHz	1.2 MHz
Receiver noise figure (dB)	2		4.7	3.5
Platform type	Fixed		Transportable	
Percentage of time system operates (%)	100			

LHCP: left hand circular polarization.

RHCP: right hand circular polarization.

(1) The radar has 44 RF channel pairs with one of 44 RF channel pairs selected in normal mode. The transmitted waveform consists of an 88.8 μs pulse at frequency f_1 followed by a 58.8 μs pulse at frequency f_2. Separation of f_1 and f_2 is 82.854 MHz.

(2) The radar has 20 RF channels in 8.96 MHz increments. The transmitted waveform group consists of one 0.4 μs P0 pulse (optional) which is followed by one 102.4 μs linear frequency modulated pulse (if 0.4 μs P0 is not transmitted) of 2.5 MHz chirp which may be followed by one to four long range 409.6 μs linear frequency modulated pulses each chirped 625 kHz and transmitted on different carriers separated by 3.75 MHz. Normal mode of operation employs frequency agility whereby the individual frequencies of each waveform group are selected in a pseudo-random manner from one of the possible 20 RF channels within the 1 215-1 400 MHz band.

(3) The radar has the capability of operating single frequency or dual frequency. Dual RF channels are separated by 60 MHz. The single channel mode uses the 39 μs pulse width. In the dual channel mode, the 26 μs pulse is transmitted at frequency f, followed by the 13 μs pulse transmitted at $f + 60$ MHz.

3 Compatibility threshold

The passive service interference threshold from Recommendation ITU-R SA.1029 is –171 dBW in 27 MHz for sensors operating near 1 400 MHz.

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service.

Further work is needed to address the impact of these multiple active services operating above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

The first step is to analyse the co-channel interference case. From this, the required attenuation is found to satisfy the EESS (passive) protection criteria. The second step is to calculate the attenuation when the EESS (passive) band is falling just outside the –40 dB bandwidth of the radar.

4.2 Calculation of interference level

4.2.1 Required attenuation in passive band

The required attenuation for the four radiolocation systems is given in Table 9.

TABLE 9

Compatibility analysis with radar

	System 1		**System 2**		**System 3**		**System 4**	
Peak power (dBW)	67		50		46.5		50	
Radar antenna gain (dBi)	34.5		34.2		38.9		32.5	
Duty cycle allowance (dB)	–31.2		–15.7		–10.9		–15.2	
Free space loss SMOS/HYDROS (dB)	152.9	154.4	152.9	154.4	152.9	154.4	152.9	154.4
Sensor ant gain SMOS/HYDROS (dBi)	9	35	9	35	9	35	9	35
Co-channel received power (dBW)	–73.6		–75.4		–69.4		–76.6	
Interference threshold (dBW)	–171		–171		–171		–171	
Required attenuation (dB)	97.4	121.9	95.6	120.1	101.6	126.1	94.4	118.9

Of course, these values result from a worst-case situation. But even when the radar antenna gain would be 0 dBi, the required attenuation would be 62.9, 61.4, 62.7 and 61.9 dB for Systems 1 to 4, respectively for SMOS and would be 87.4, 85.9, 87.2 and 86.4 for Systems 1 to 4, respectively for HYDROS.

4.2.2 Calculation of unwanted emissions from radar Systems 1 and 2

An assumption used in this analysis is that the –40 dB bandwidth of the radar is located within the 1 350-1 400 MHz and that the EESS-band is located from the 50% value of the –40 dB bandwidth as depicted in Fig. 8.

For Systems 1 and 2 the attenuation levels have been calculated. This has been done using the mask and equations in Annex 8 of Recommendation ITU-R SM.1541. For the calculations of both the necessary bandwidth and the –40 dB bandwidth the pulse rise-time is needed.

Regarding pulse rise time, the value of this parameter will vary as a function of radar type, and so it is not possible to assign a single value to this parameter for radars in the 1 350-1 400 MHz band. A value of 50 ns may however be of use as a reasonable approximation for systems in this band.

Accordingly, this parameter has been estimated at 50 ns for both Systems 1 and 2. For System 1, this resulted in a B_N of 3.18 MHz and a B_{-40} of 19.6 MHz. For System 2, B_N is 2.39 MHz and B_{-40} is 8.68 MHz.

The EESS (passive) band 1 400-1 427 MHz runs from 50% to 187.75% in Fig. 7 for System 1 and from 50% to 361% for System 2. The unwanted emission power falling into the reference bandwidth of 27 MHz is −45.8 dBpp for System 1 and −48.7 dBpp for System 2.

4.3 Values achieved

For SMOS, the resulting margins for a radar side-lobe level of 0 dBi are 17.1 and 12.7 dB for Systems 1 and 2, respectively (for maximum radar antenna gains the analysis results in 51.6 and 46.9 dB).

For HYDROS, the resulting margins for a radar side-lobe level of 0 dBi are 41.6 and 37.2 dB for Systems 1 and 2, respectively (for maximum radar antenna gains the analysis results in 76.1 and 71.4 dB).

Obviously, the difference between the values achieved for the two EESS (passive) instruments can be explained by the different maximum antenna gains. However, the instantaneous antenna foot-prints of the two sensors counteract for this in the way that for SMOS, since it has a larger antenna swath (but lower antenna gain), the likelihood of being interfered at a given instance is higher.

This study has used the assumption that the –40 dB bandwidth is completely comprised within the radiolocation band, which does not need to be valid for all systems. Also, one administration has performed detailed measurements on emissions from a number of radar types in the band 1 350-1 400 MHz, and has measured emission levels from those radars across adjacent bands. These measurements have shown that, in compliance with the RR, the radars occupy the necessary bandwidth at the band edge of 1 400 MHz. The measured peak emission levels have been found to be approximately –20 dB at 1 400 MHz as measured in a bandwidth of 1 MHz, relative to the maximum of the fundamental radar emission within the band. The same measurements show that a −40 dB emission level is achieved at frequencies near 1 420 MHz, as measured in a 1 MHz bandwidth.

5 Mitigation techniques

5.1 EESS (passive)

Due to the smallness of the allocated band of 27 MHz, no mitigation technique such as an effective guardband can be utilized for the EESS (passive) band.

5.2 Radiolocation service

Mitigation techniques for systems that are currently in use may be used from a practical point of view. Most of the radars used in the range 1 215-1 400 MHz are frequency agile and have relatively small RF emission bandwidths compared to allocated band. A possibility to avoid emissions in the upper part of the spectrum need to be investigated and could resolve the discrepancy. For example, it is likely that the compatibility analysis would result in a positive scenario when the closest radar channel with respect to the existing edge of the passive band has a frequency separation of approximately 2 to 2.5 times the −40 dB bandwidth of the radiolocation systems.

5.3 Potential impact

5.3.1 EESS (passive)

Since no mitigation techniques have been identified for the EESS (passive) in this specific band, the potential impact of these mitigation techniques will be null.

5.3.2 Radiolocation service

The feasibility to keep the complete –40 dB radar bandwidth within the radiolocation band combined with either an additional frequency separation or a lower peak power limit (i.e. future radars for the band 1 350-1 400 MHz may have different parameters) would need further investigation.

6 Results of studies

6.1 Summary

This compatibility analysis has calculated the potential interference from radiolocation systems in the lower adjacent band in the band 1 400-1 427 MHz allocated to the EESS (passive).

6.2 Conclusions

For the SMOS passive sensor, this compatibility analysis resulted in a discrepancy of 17.1 dB and 12.7 dB for a single system of radiolocation Systems 1 and 2, respectively, assuming an antenna side-lobe gain of 0 dBi. For the HYDROS passive sensor, this resulted in a discrepancy of 41.6 dB and 37.2 dB for a single system of radiolocation Systems 1 and 2, respectively, assuming an antenna side-lobe gain of 0 dBi.

This compatibility assessment has used assumptions, which are relaxed and not valid for all radiolocation systems.

It is likely that the compatibility analysis would result in a positive scenario when the closest radar channel with respect to the existing edge of the passive band has a frequency separation of approximately 2 to 2.5 times the –40 dB bandwidth of the radiolocation systems.

Annex 4

Compatibility analysis between the RAS in the 1 400-1 427 MHz band and GSO mobile-satellite systems (space-to-Earth) operating in the 1 525-1 559 MHz band

1 RAS

1.1 Allocated band

The 1 400-1 427 MHz band is allocated to passive services only, on a primary basis: the RAS, the EESS (passive) and the SRS (passive). This Annex discusses the radio astronomy case only.

RR No. 5.340 prohibits all emissions in this band.

1.2 Type of observations

The 1 400-1 427 MHz band is used more intensely than any other, in all ITU-R Regions. The main radio-astronomical use of band is to make spectral line observations of cosmic neutral atomic hydrogen (also referred to as HI), which has a rest frequency of 1 420.406 MHz. This material is by far the main constituent of our Galaxy and other galaxies, and occurs in huge, complex-structured clouds. This line is observed in both emission and absorption, and is broadened and shifted in frequency by Doppler shifts due to local and bulk motions in the cloud structures. Accordingly, HI observations can be used to map the distribution of material and its motions in our and other galaxies. In this way we can map the structure of our Galaxy, and how material is moving.

The 1 400-1 427 MHz allocation is sufficiently broad to encompass the Doppler-shifted emission from clouds in our galaxy and in nearby galaxies. Measurements of the polarization of the HI emission or absorption yield important information on galactic magnetic fields and thence an increased understanding of galactic structure.

The 1 400-1 427 MHz band is also used for continuum observations of broadband emissions produced by hot plasma formed when stars heat the surrounding clouds, and by the interaction of high-energy electrons in the galactic magnetic field (synchrotron emission).

1.3 Required protection criteria

The threshold interference levels for detrimental interference to radio astronomical observations are given in Recommendation ITU-R RA.769, which lists the levels of unwanted emissions that will increase the measurement error by 10%. The band is used for both spectral line and continuum observations. In the 1 400-1 427 MHz band, for single-dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 20 kHz, the threshold pfd for detrimental interference is –196 dB(W/m^2). For making single-dish continuum observations, the entire 27 MHz width of the band is used, for which case the threshold pfd for detrimental interference is –180 dB(W/m^2).

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, –166 dB(W/m^2), for a bandwidth of 20 kHz.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics, type of observations

The 1 400-1 427 MHz band is the most intensely used radio astronomy band of all. It is used worldwide, in all ITU Regions, and some radio telescopes, such as the Synthesis Radio Telescope at the DRAO, Penticton, Canada, observe full-time in this band. Single-antenna radio telescopes are used to measure the integrated spfd of sources of small angular diameter and to map structures of large angular size that cannot be mapped using synthesis telescopes.

The higher angular resolution offered by synthesis telescopes makes it possible to map the finer structure in the hydrogen clouds and sources of continuum emissions such as supernova remnants. These maps are then combined with the lower-resolution maps obtained using single-antenna radio telescopes to make high-quality 3-D images of our Galaxy and others. Synthesis radio telescopes, using multi-antenna arrays may require between one and a dozen 12 h “exposures” to make a complete map of an area of sky.

In order to facilitate mapping comparatively large source structures, some synthesis radio telescopes, such as the DRAO instrument, use arrays of comparatively small antennas. Instruments of this kind do not have the option of optimum side-lobe suppression and are therefore more vulnerable to interference.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the hydrogen cloud(s) in the antenna beam.

In general, observations are made differentially. In the case of continuum emissions, the area of sky surrounding the sky may be mapped, and the background emission subtracted, or measurements made of the power coming from the direction from the source (on-source) and at one or more nearby positions in the sky (off-source). By subtracting the off-source values from the on-source values, the emission originating in the source is separated from other contributions to the receiver output.

In the case of spectral line observations, spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

Since the Galaxy is filled with clouds of neutral hydrogen, radio telescopes detect not only the emission or absorption in the clouds in the antenna main beam, but also a very significant contribution through the antenna side lobes. This “stray radiation” distorts spectra and reduces map detail. Removing this from the data involves large-scale measurement of the whole antenna beam (as far as possible), and estimation of the stray radiation correction. Interference and large “blocked” areas of sky will therefore affect the ability to make maps at parts of the sky large angles from interference sources.

An extended area of radio emission can be mapped by recording the emission from a grid of points covering the region of interest. Both continuum and spectral line observations may be made. In the case of single antenna radio telescopes, each grid point observation is an indication of the total power (in the continuum case) or the emission spectrum (in the spectral line case) coming from that position in the sky; the spacing between the grid points should not be more than half the antenna beamwidth. When observations are made using a synthesis radio telescope, where the area to be mapped exceeds the instantaneous mapping field, the grid points should not be further apart than half the beamwidth of one of the radio telescope antennas.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data has been processed.

2 Mobile-satellite systems

2.1 Allocated transmit band

The allocated transmit band is 1 525-1 559 MHz (space-to-Earth).

2.2 Application

Mobile-satellite service.

2.3 Levels based on regulatory provisions

The required attenuation is 43 + 10 log *P* dBc or 60 dBc whichever is less stringent where *P* is the peak power at the input to the antenna (W) in any 4 kHz.

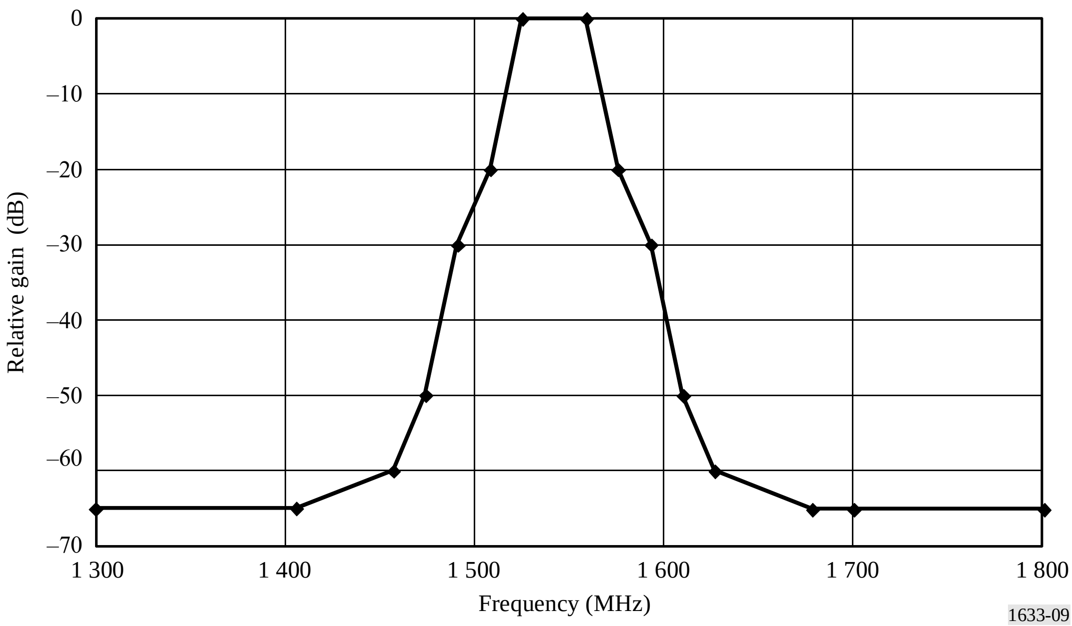
2.4 Transmitter characteristics

The antenna gain is 41 dBi.

The transmitter (Tx) output filter characteristic is shown in Fig. 9.

FIGURE 9

Tx output filter characteristics



2.5 Operational characteristics

The typical peak power into GSO MSS satellite spot beam at input to the antenna is 16 dBW over a bandwidth of 5 MHz.

2.6 In-band transmit level

The in-band transmit level is –15 dBW in a 4 kHz bandwidth.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

The parameters peak in band power spectral density, the peak antenna gain and the measured attenuation of the Tx output filter at different frequencies are used to determine the pfd at the surface of the Earth.

4.2 Calculation of interference level

Based on the expected performance of the Tx filter used for the 1 525-1 559 MHz band, the typical power levels at the output of this filter, e.i.r.p. density levels at the antenna output and the pfd at the surface of the Earth at different frequencies are as shown in Table 10.

TABLE 10

Expected values of the power spectral density (PSD), e.i.r.p. density and pfd at the surface of the Earth of Inmarsat-4 satellite

Frequency (MHz)	PSD at the output of filter (dB(W/4 kHz))	e.i.r.p. density at the output of the antenna (dB(W/4 kHz))	pfd at the surface of the Earth (dB(W/(m^2 · 4 kHz)))
1 300	–80	–39	–202
1 406	–80	–39	–202
1 457	–75	–24	–197
1 474	–65	–14	–187
1 491	–45	–4	–167
1 508	–35	6	–157
1 525	–15	26	–137
1 559	–15	26	–137
1 576	–35	6	–157
1 593	–45	–4	–167
1 610	–65	–14	–187
1 627	–75	–24	–197
1 678	–80	–39	–202
1 700	–80	–39	–202
1 800	–80	–39	–202

4.3 Values achieved

The value is –202 dB(W/m^2) in a 4 kHz bandwidth.

Translating these values for the continuum and spectral line observations, we obtain the following values:

– for single-dish continuum observations: –163 dB(W/m^2) in a 27 MHz bandwidth;

– for single-dish spectral line observations: –195 dB(W/m^2) in a 20 kHz bandwidth.

Based on the above parameters of one GSO mobile-satellite system of one operator the following margins/deficits are derived:

– for single-dish line observations there is a deficit of 1 dB in meeting the protection criterion given in Recommendation ITU-R RA.769;

– for single-dish continuum observations there is a deficit of 17 dB in meeting the protection criterion given in Recommendation ITU-R RA.769.

5 Mitigation techniques

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna sidelobe performance: The aperture illumination of radio telescopes is usually optimized for *G*/*T*, i.e. telescope gain divided by system temperature. This is to maximize the *S*/*N* for point sources. A key element of this approach is to reduce ground radiation entering through far sidelobes. Inevitably this leads to some corresponding increase in the levels of near sidelobes. Experience has shown that the majority of radio telescopes meets the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in some cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

5.2 MSS

In order to improve the levels given in Table 10, the following mitigation techniques should be taken into account in the design of new space station:

– the wideband frequency response of the antenna;

– the attenuation characteristics of intermediate filters;

– the gain frequency response of solid state power amplifiers;

– the modulation characteristics of individual carriers;

– the attenuation of inter-modulation products with respect to the power of the carriers.

5.3 Potential impact

The mitigation techniques in § 5.2 are deemed technically feasible for GSO systems.

5.3.1 MSS

The mitigation techniques in § 5.2 are deemed technically feasible for GSO systems.

6 Results of studies

6.1 Summary

Based on the parameters of one GSO mobile-satellite system of one operator and taking into account the mitigation factors listed in § 5.2, it is very likely that the unwanted emission levels from this satellite system meet the threshold levels for detrimental interference to single-dish radio astronomical observations as discussed in § 1.3.

6.2 Conclusions

The protection criteria are likely to be met for continuum, VLBI and spectral lines observations, with the use of appropriate mitigation measures.

Annex 5

Compatibility analysis between RAS systems operating in the 1 610.6-1 613.8 MHz band and RNSS systems operating in the 1 559-1 610 MHz band

1 RAS

1.1 Allocated band

The 1 610.6-1 613.8 MHz band is allocated to the RAS on a primary basis.

RR No. 5.149 urges administrations to take all practicable steps to protect the RAS.

1.2 Type of observations

The 1 610.6-1 613.8 MHz band is used for spectral line observations of the hydroxyl radical (OH). The OH line, which has a rest frequency of 1 612 MHz, is one of the most important spectral lines for radio astronomy, and is listed as such in Recommendation ITU-R RA.314. OH was the first cosmic radical to be detected at radio frequencies (1963), and continues to be a powerful research tool. OH produces four spectral lines, at frequencies of approximately 1 612, 1 665, 1 667 and 1 720 MHz, all of which have been observed in our own galaxy, as well as in external galaxies. The study of OH lines provides information on a wide range of astronomical phenomena, e.g. the formation of protostars and the evolution of stars. To interpret most observations made in the OH lines, it is necessary to measure the relative strength of several of these lines. Loss of the ability to observe any one of these lines may prevent the study of some classes of physical phenomena.

These OH lines are produced by a coherent process, in which a concentration of OH radicals radiate "in step", creating narrow-band emission. They are slightly broadened due to physical conditions in this concentration. Movement of these concentrations with respect to the Earth impose a Doppler shift on the line emission. The presence of several concentrations in the source, which are moving at different velocities, give rise to a more complicated spectrum, consisting of a number of superimposed Gaussian line profiles of different widths and amplitudes, and slightly-different frequencies (due to the different Doppler shifts). The width of the band allocation is required to accommodate the spreading and shifting of the spectrum by differential and total motions of the source.

In some stages of their evolution, certain classes of stars radiate only the 1 612 MHz line. The study of this line allows astronomers to gauge such physical properties of these stars as the rate at which gas is blown off by the stars and recycled into the interstellar medium. Some properties of these stars cannot be inferred from any other astronomical observation. Measurements of OH emitting stars have also been used to estimate the distance to the Galactic Centre, to measure the mass of the central bulge of our galaxy, and to study the spatial distribution of the molecular component in our galaxy and in external galaxies. Finally, extremely strong maser emission has been detected near the nuclei of a number of external galaxies. This OH megamaser emission from galactic nuclei allows astronomers to study the temperature and density of the molecular gas in their centre.

The OH spectral line is also observed in comets; there is little flexibility in scheduling observations of these "targets of opportunity".

Spectral line observations are made using spectrometers that can simultaneously integrate the power in a large number of frequency channels (typically 256-4 096) distributed across the frequency band used. The width and number of channels has to be large enough to accurately reproduce the spectrum of the emission received by the radio telescope. Instantaneous bandwidths of typically ~0.2-20 kHz per frequency channel are used, depending on the scientific program.

The sources are small, and measurements of their size and structure often require observations using the VLBI technique.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. In the 1 610.6-1 613.8 MHz band, for single-dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 20 kHz, the threshold pfd limit is -194 dB(W/m^2). This band is used only for radio line observations, not for continuum observations.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems and in Recommendation ITU-R M.1583 for MSS and RNSS systems.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 1 612 MHz band are carried out at a number of radio astronomy sites in numerous countries, worldwide. Observations in the 1 612 MHz band are sometimes conducted on targets of opportunity, e.g. on objects such as comets, which have been observed to produce transient emissions in this line. VLBI observations are also frequently conducted in this band, sometimes between the North American and European VLBI networks.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −166 dB(W/m^2), for a bandwidth of 20 kHz, which has been developed for VLBI observations, but not included in ITU-R RA.769.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the source(s) in the antenna beam.

In general, observations are made differentially; spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data have been processed.

2 RNSS

2.1 Allocated transmit band

The band 1 559-1 610 MHz is allocated to the RNSS for transmissions from space to Earth.

2.2 Application

Radio navigation satellite systems, which are low power signals compared to most satellite system, are used for position estimation and timing by users, including radio astronomers and space-based passive systems. Therefore both services are intertwined. There are two main types of RNSS systems: non-GSO and GSO. GSO systems are primarily used for aviation navigation. Non-GSO systems are used throughout the world and by multiple administrations for navigation, position estimation, precise timing, and search and rescue.

2.3 Levels based upon regulatory provisions

The levels were not assessed as part of this study.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

See § 1.3 for references to the relevant ITU-R Recommendations regarding the epfd methodology for non-GSO systems.

4.2 Calculation of the interference level

See § 2.3.

4.3 Values achieved

5 Mitigation methods

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna sidelobe performance: The aperture illumination of radio telescopes is usually optimized for *G*/*T*, i.e. telescope gain divided by system temperature. This is to maximize the *S*/*N* for point sources. A key element of this approach is to reduce ground radiation entering through far sidelobes. Inevitably this leads to some corresponding increase in the levels of near sidelobes. Experience has shown that the majority of radio telescopes meets the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in some cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

5.2 RNSS

Two RNSS systems are operating in the 1 559-1 610 MHz band, both of which use spread spectrum modulation. Both systems started their operation without filtering their transmissions, and interference into the 1 610.6-1 613.8 MHz band from both systems was reported at radio astronomy stations.

The unwanted emissions into the 1 610.6-1 613.8 MHz band by one system, which operates at lower frequencies in the RNSS band, was improved to the satisfaction of the radio astronomy community by introducing filters in those satellites that were launched after the interference was reported.

The other system started operating in the 1 610.6-1 613.8 MHz band, while this RAS allocation was still secondary. In order to improve the interference situation in the band, an Agreement was concluded between the satellite operator and the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science (IUCAF), representing the radio astronomy community worldwide. This Agreement contains a phased approach to meet the protection criteria of the RAS after some years. The channel plan has been revised and satellite transmissions switched over to frequencies further below the 1 610.6-1 613.8 MHz band. According to the above-mentioned agreement, filtering in subsequent generations of satellites is expected to suppress the systems' unwanted emissions into the 1 610.6-1 613.8 MHz band to below the single-dish interference threshold levels given in Recommendation ITU-R RA.769.

5.3 Potential impact

5.3.1 RAS

Antenna sidelobe performance: Attempts to decrease the sensitivity of the radio astronomy antenna to unwanted emissions coming from space stations are likely to increase the sensitivity of the radio astronomy telescope to ground radiation, and possibly reduce its main beam gain. Both of these effects will reduce the telescope's channel capacity of and thus lead to an increase of the total required integration time.

Blanking in time and/or frequency: Blanking involves a risk of compromising the integrity of the data and may lead to errors in their scientific interpretation. Blanking also causes a concomitant increase in the total integration time required to make the observation, this is equivalent to a loss in the channel capacity of the telescope.

5.3.2 RNSS

Hardware solutions such as filters may be difficult to implement. In active, multi-element antennas, filters may be needed for every antenna element. This will increase the weight of the satellite. The filter losses will require more powerful transmitters, which will in turn require more bus power, and so larger solar arrays. This will further increase the weight. In addition, a bigger, heavier satellite might need a larger launcher. The cost impact may be large. Technical improvements in filter design may ameliorate this problem. Implementation of filters in the system may be a more manageable task if considered at the design stage of the system.

6 Results of studies

6.1 Summary

In this band, the threshold levels for detrimental interference to radio astronomical observations as discussed in § 1.3 may be met by the active service for the VLBI and single-dish spectral line case, when mitigation methods are taken into account. No single-dish continuum observations are made in this band.

6.2 Conclusions

It is possible that appropriate mitigation techniques planned for future systems may permit VLBI and spectral-line observations in this band.

Annex 6

Compatibility analysis between RAS systems operating in the 1610.6-1613.8 MHz band and MSS (space-to-Earth) systems operating in the 1613.8-1626.5 MHz band

1 RAS

1.1 Allocated band

The 1610.6-1613.8 MHz band is allocated to the RAS on a primary basis.

RR No. 5.149 urges administrations to take all practicable steps to protect the RAS in this band.

1.2 Type of observations

The 1610.6-1613.8 MHz band is used for spectral line observations of the OH. The OH line, which has a rest frequency of 1 612 MHz, is one of the most important spectral lines for radio astronomy, and is listed as such in Recommendation ITU-R RA.314. OH radical was the first cosmic radical to be detected at radio frequencies (1963), and continues to be a powerful research tool. OH produces four spectral lines, at frequencies of approximately 1612, 1665, 1667 and 1720 MHz, all of which have been observed in our own galaxy, as well as in external galaxies. The study of OH lines provides information on a wide range of astronomical phenomena, e.g. the formation of protostars and the evolution of stars. To interpret most observations made in the OH lines, it is necessary to measure the relative strength of several of these lines. Loss of the ability to observe any one of these lines may prevent the study of some classes of physical phenomena.

These OH lines are produced by a coherent process, in which a concentration of OH radicals radiate “in step”, creating narrow-band emission. They are slightly broadened due to physical conditions in this concentration. Movement of these concentrations with respect to the Earth impose a Doppler shift on the line emission. The presence of several concentrations in the source, which are moving at different velocities, give rise to a more complicated spectrum, consisting of a number of superimposed Gaussian line profiles of different widths and amplitudes, and slightly-different frequencies (due to the different Doppler shifts). The width of the band allocation is required to accommodate the spreading and shifting of the spectrum by differential and total motions of the source.

In some stages of their evolution, certain classes of stars radiate only the 1 612 MHz line. The study of this line allows astronomers to gauge such physical properties of these stars as the rate at which gas is blown off by the stars and recycled into the interstellar medium. Some properties of these stars cannot be inferred from any other astronomical observation. Measurements of OH emitting stars have also been used to estimate the distance to the Galactic Centre, to measure the mass of the central bulge of our galaxy, and to study the spatial distribution of the molecular component in our galaxy and in external galaxies. Finally, extremely strong maser emission has been detected near the nuclei of a number of external galaxies. This OH megamaser emission from galactic nuclei allows astronomers to study the temperature and density of the molecular gas in their centre.

The OH spectral line is also observed in comets; there is very little flexibility in scheduling observations of these “targets of opportunity”.

Spectral line observations are made using spectrometers that can simultaneously integrate the power in a large number of frequency channels (typically 256-4 096) distributed across the frequency band used. The width and number of channels has to be large enough to accurately reproduce the spectrum of the emission received by the radio telescope. Instantaneous bandwidths of typically ~0.2-20 kHz per frequency channel are used, depending on the scientific program.

The sources are small, and measurements of their size and structure often require observations using the VLBI technique.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. In the 1 610.6-1 613.8 MHz band, for single dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 20 kHz, the threshold pfd limit is -194 dB(W/m^2). This band is used only for radio line observations, not for continuum observations.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems and in Recommendation ITU-R M.1583 for MSS and RNSS systems.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes

10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 1 612 MHz band are carried out at a number of radio astronomy sites in numerous countries, worldwide. Observations in the 1 612 MHz band are sometimes conducted on targets of opportunity, e.g. on objects such as comets, which have been observed to produce transient emissions in this line. VLBI observations are also frequently conducted in this band, sometimes between the North American and European VLBI networks.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −166 dB(W/m^2), for a bandwidth of 20 kHz, which has been developed for VLBI observations, but not included in ITU-R RA.769.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the source(s) in the antenna beam.

In general, observations are made differentially; spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data have been processed.

2 MSS

2.1 Allocated transmit band

The band 1 613.8-1 626.5 MHz was allocated to the MSS (space-to-Earth) on a secondary basis, worldwide at WARC-92. WARC-92 also took the following actions in regard to the RAS in the 1 610.6-1 613.8 MHz band:

a) an upgrading of the existing radio astronomy allocation from secondary to primary status in the 1 610.6-1 613.8 MHz band; and

b) the adoption of RR No. 5.372, that states: “Harmful interference shall not be caused to stations of the radio astronomy service using the band 1 610.6-1 613.8 MHz by stations of the radiodetermination-satellite and mobile-satellite services (RR No. **29.13** applies).” This footnote applies to the 1 610-1 626.5 MHz band.

2.2 Application

The band 1 610-1 626.5 MHz is allocated to MSS uplinks, worldwide on a primary basis, subject to some constraints.

The band 1 613.8-1 626.5 MHz is allocated to the MSS (space-to-Earth) service on a secondary basis, worldwide. The HIBLEO-2 system is currently the only system using this allocation in both Earth-to-space and space-to-Earth directions, while HIBLEO-4 uses the band in the Earth-to-space direction. HIBLEO-2 is a satellite system capable of operating in the 1 616-1 626.5 MHz band, but authorized to operate in the 1 621.35-1 626.5 MHz band only.

2.3 Levels based upon regulatory provisions

There are no regulatory limits on OoB emissions in the RR. However, the ITU RR states in RR Nos. 5.28-5.31 that, *inter alia*, stations of a secondary service by definition shall not cause harmful interference to stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date nor claim protection from harmful interference from stations of a primary service. This provision applies to protection from both in-band and OoB emissions and would apply to secondary MSS downlinks, regardless of specified pfd levels. Thus there is no obvious reason to codify specific pfd limits.

In RR No. 29.13 it is stated "Administrations shall take note of the relevant ITU-R Recommendations with the aim of limiting interference of the radio astronomy service from other services".

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

See § 2.3 for references to the relevant ITU-R Recommendations dealing with non-GSO systems.

4.2 Calculation of the interference level

Unwanted emissions in terms of aggregate spfd of HIBLEO-2 satellite transmissions in the 1 610.6-1 613.8 MHz band have been theoretically estimated to range between –214 dB(W/(m^2/Hz)) and –223 dB(W/(m^2/Hz)) at some radio astronomy sites, under fully loaded conditions.

4.3 Values achieved

A collaborative test program, conducted by HIBLEO-2 and the United States National Radio Astronomy Observatory (NRAO), in 1998 measured spfd values ranging from –220 to –240 dB(W/(m^2/Hz)) at these sites. These values refer to the so-called voice channels that are turned on when communication takes place. In addition the HIBLEO-2 system was found to radiate broadcast signals at all times. The spectra of the broadcasting channels showed 9-10 narrow (less than 40 kHz wide) peaks within the radio astronomy band. spfd peak values appeared to average -227 dB(W/(m^2/Hz)) over 90 ms. Due to the mismatch between the satellite system transmission and other parameters and the radio astronomy receiver and antenna characteristics (e.g. radio telescopes are not adapted to track satellites; available receiver bandwidths are different from 20 kHz, etc.), it was difficult to estimate the spfd that would result under the conditions in Recommendation ITU-R RA.769, which specifies a detrimental interference level of -238 dB(W/(m^2/Hz)).

5 Mitigation techniques

5.1 RAS

There are various methods that might be used to reduce unwanted emissions from the satellite transmitters at a radio telescope. When such methods are insufficient other solutions, such as an agreement between the operator of a satellite system and radio astronomy observatories may be considered.

No specific provisions for such coordination agreements between the RAS and active services are made in the RR. However, general provisions for coordination and consultation can be found in RR Article 9.

Coordination agreements can only be concluded with the explicit mutual assent of both parties involved, i.e. in principle the satellite operator and an afflicted astronomical observatory. For satellite downlinks, coordination at a national level between a satellite system operator and radio astronomy sites is only practicable when the footprint of the satellite transmission is smaller than the geographical dimensions of the nation in which coordination is sought, and when the visibility of the transmitting space station from a radio astronomy station does not extend beyond that nation’s border. International solutions need to be found when the local geographic density of radio astronomy stations operating at 1.6 GHz is such that at any given moment in time radio astronomy stations in more than one nation lie within the same satellite footprint or visibility of the same satellite.

In general, the conditions of such arrangements are not immutable over time, and need to be reviewed as required, for which milestones must to be defined. In case of disagreement, arbitration arranged by mutual agreement must be defined *a priori* in the text of the Agreement.

Several agreements were reached between the operators of the HIBLEO-2 system and various parts of the radio astronomy community. The common element in these agreements is that the aggregate emissions of the HIBLEO-2 system will meet the threshold levels given in Recommendation ITU-R RA.769 for single-dish observations in the 1 610.6-1 613.8 MHz band at the observatories concerned for a daily period of time, varying in duration from about 4 to 8 h. Some radio astronomy sites agreed to notify in advance their intentions to observe in this band.

5.2 MSS

There are various methods, such as filtering, that may be employed to reduce unwanted emissions. These should be considered in the design of new space station.

When such methods are insufficient, other solutions, such as an agreement between the operator of a satellite system and radio astronomy observatories may be considered (see § 5.1).

5.3 Potential impact

5.3.1 RAS

Coordination agreements between the operator of a satellite system and radio astronomy observatories, if feasible at all, may have a negative impact on the scheduling of observations, the flexibility of the observatory to accommodate the needs of the user community, and increase the administrative overhead. The net impact of a coordination arrangement upon the operability of an observatory should not render it ineffective of meeting required productivity standards.

5.3.2 MSS

Hardware solutions such as filters may be difficult to implement. In active, multi-element antennas, filters may be needed for every antenna element. This will increase the weight of the satellite. The filter losses will require more powerful transmitters, which will in turn require more bus power, and so larger solar arrays. This will further increase the weight. In addition, a bigger, heavier satellite might need a larger launcher. The cost impact may be large. Technical improvements in filter design may ameliorate this problem. Implementation of filters in the system is a more manageable task if considered at the design stage of the system.

It should be noted, however, that according to the coordination agreement signed between the operator of the HIBLEO-2 satellite system and the European radio astronomy community, the aggregate pfd level of the HIBLEO-2 system will not exceed the levels specified in Recommendation ITU-R RA.769 for radio astronomy stations within Europe from 1 January 2006. This indicates that adequate mitigation techniques are expected to be implemented by that date.

However, if satellite replenishment is extended beyond 1 January 2006 it will be difficult to use improved filtering on the inadequately filtered satellites still in orbit and the implementation of other mitigation techniques could have an adverse economic impact.

6 Results of studies

6.1 Summary

The mitigation of interference issues has been addressed by the setting up of agreements between the operators of the HIBLEO-2 system and various radio astronomy facility operators. Using such mitigation techniques, it should be possible for the protection criteria to be met for spectral line operations, as described in § 1.3, and for VLBI observations. No single-dish continuum observations are made in this band.

6.2 Conclusions

Appropriate mitigation techniques should make it possible to make effective spectral line and VLBI observations in this band.

Annex 7

Compatibility analysis between RAS systems operating in the 1 610.6-1 613.8 MHz band and GSO MSS (space-to-Earth) systems operating in the 1 525-1 559 MHz band

1 RAS

1.1 Allocated band

The 1 610.6-1 613.8 MHz band is allocated to the RAS on a primary basis.

RR No. 5.149 urges administrations to take all practicable steps to protect the radio astronomy service in this band.

1.2 Type of observations

The 1 610.6-1 613.8 MHz band is used for spectral line observations of the OH. The OH line, which has a rest frequency of 1 612 MHz, is one of the most important spectral lines for radio astronomy, and is listed as such in Recommendation ITU-R RA.314. OH was the first cosmic radical to be detected at radio frequencies (1963), and continues to be a powerful research tool. OH produces four spectral lines, at frequencies of approximately 1 612, 1 665, 1 667 and 1 720 MHz, all of which have been observed in our own galaxy, as well as in external galaxies. The study of OH lines provides information on a wide range of astronomical phenomena, e.g. the formation of protostars and the evolution of stars. To interpret most observations made in the OH lines, it is necessary to measure the relative strength of several of these lines. Loss of the ability to observe any one of these lines may prevent the study of some classes of physical phenomena.

These OH lines are produced by a coherent process, in which a concentration of OH radicals radiate "in step", creating narrow-band emission. They are slightly broadened due to physical conditions in this concentration. Movement of these concentrations with respect to the Earth impose a Doppler shift on the line emission. The presence of several concentrations in the source, which are moving at different velocities, give rise to a more complicated spectrum, consisting of a number of super-imposed Gaussian line profiles of different widths and amplitudes, and slightly-different frequencies (due to the different Doppler shifts). The width of the band allocation is required to accommodate the spreading and shifting of the spectrum by differential and total motions of the source.

In some stages of their evolution, certain classes of stars radiate only the 1 612 MHz line. The study of this line allows astronomers to gauge such physical properties of these stars as the rate at which gas is blown off by the stars and recycled into the interstellar medium. Some properties of these stars cannot be inferred from any other astronomical observation. Measurements of OH emitting stars have also been used to estimate the distance to the Galactic Centre, to measure the mass of the central bulge of our galaxy, and to study the spatial distribution of the molecular component in our galaxy and in external galaxies. Finally, extremely strong maser emissions have been detected near the nuclei of a number of external galaxies. This OH megamaser emission from galactic nuclei allows astronomers to study the temperature and density of the molecular gas in their centre.

The OH spectral line is also observed in comets; there is little flexibility in scheduling observations of these "targets of opportunity".

Spectral line observations are made using spectrometers that can simultaneously integrate the power in a large number of frequency channels (typically 256-4 096) distributed across the frequency band used. The width and number of channels has to be large enough to accurately reproduce the spectrum of the emission received by the radio telescope. Instantaneous bandwidths of typically ~0.2-20 kHz per frequency channel are used, depending on the scientific program.

The sources are small, and measurements of their size and structure often require observations using the VLBI technique.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. For single dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 20 kHz, the threshold pfd for detrimental interference is −194 dB(W/m^2).

This band is used only for radio line observations, not for continuum observations.

The thresholds of detrimental interference levels to the RAS as defined and calculated in Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 1 612 MHz band are carried out at a number of radio astronomy sites in numerous countries, worldwide. Observations in the 1 612 MHz band are sometimes conducted on targets of opportunity, e.g. on objects such as comets, which have been observed to produce transient emissions in this line. VLBI observations are also frequently conducted in this band, sometimes between the North American and European VLBI networks.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −166 dB(W/m^2), for a bandwidth of 20 kHz, which has been developed for VLBI observations, but not included in ITU-R RA.769.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the source(s) in the antenna beam.

In general, observations are made differentially; spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data has been processed.

2 MSS

2.1 Allocated transmit band

1 525-1 559 MHz (space-to-Earth).

2.2 Application

MSS.

2.3 Levels based upon regulatory provisions

RR Appendix 3.

The required attenuation is 43 + 10 log *P* dBc or 60 dBc, whichever is less stringent, where *P* is the peak power at the input to the antenna (W) in any 4 kHz bandwidth.

2.4 Transmitter characteristics

The antenna gain is 41 dBi. The Tx output filter characteristic is shown in Fig. 10.

2.5 Operational characteristics

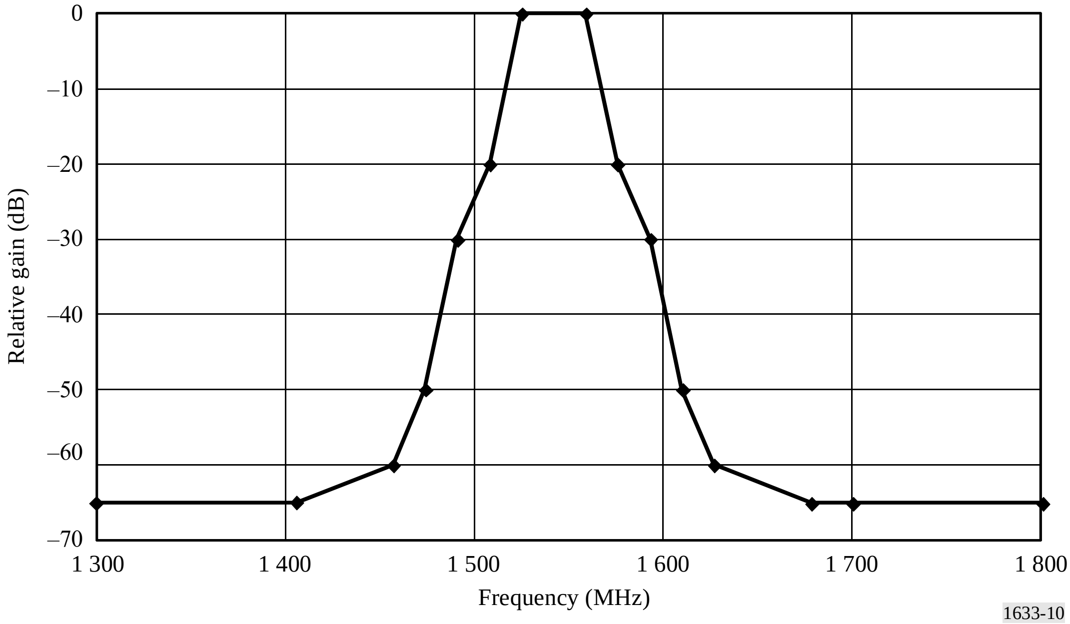
The typical peak power into an MSS GSO satellite spot beam at input to the antenna is 16 dBW over a bandwidth of 5 MHz.

2.6 In-band transmit level

The in-band transmit level is –15 dBW in a 4 kHz bandwidth.

FIGURE 10

Tx output filter characteristic



3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

The parameters peak in band PSD, the peak antenna gain and the measured attenuation of the 1 525-1 559 MHz band output filter at different frequencies are used to determine the pfd at the surface of the Earth.

4.2 Calculation of the interference level

Based on the expected performance of the 1 525-1 559 MHz band, the typical power levels at the output of the Tx L band filter, e.i.r.p. density levels at the antenna output and the pfd at the surface of the Earth at different frequencies are as shown in Table 11.

4.3 Values achieved

The value achieved is –192 dB(W/m^2) in 4 kHz bandwidth.

Translating these values for single-dish spectral line observations, we obtain a pfd value of −185 dB(W/m^2) in a 20 kHz bandwidth for spectral line observations: Based on the above parameters of one GSO mobile-satellite system of one operator, it follows that there is a deficit of 9 dB in meeting the protection criteria for single-dish spectral line observations.

TABLE 11

Expected values of the PSD, e.i.r.p. density, and the pfd at the surface of the Earth of an Inmarsat-4 satellite in the frequency band 1 525-1 559 MHz

Frequency (MHz)	PSD at the output of filter (dB(W/4 kHz))	e.i.r.p. density at the output of the antenna (dB(W/4 kHz))	pfd at the surface of the Earth (dB(W/(m^2 · 4 kHz)))
1 300	–80	–39	–202
1 406	–80	–39	–202
1 457	–75	–24	–197
1 474	–65	–14	–187
1 491	–45	–4	–167
1 508	–35	6	–157
1 525	–15	26	–137
1 559	–15	26	–137
1 576	–35	6	–157
1 593	–45	–4	–167
1 610	–65	–14	–187
1 627	–75	–24	–197
1 678	–80	–39	–202
1 700	–80	–39	–202
1 800	–80	–39	–202

5 Mitigation techniques

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna sidelobe performance: The aperture illumination of radio telescopes is usually optimized for G/T, i.e. telescope gain divided by system temperature. This is to maximize the S/N for point sources. A key element of this approach is to reduce ground radiation entering through far sidelobes. Inevitably this leads to some corresponding increase in the levels of near sidelobes. Experience has shown that the majority of radio telescopes meets the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in some cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

5.2 MSS

In order to improve the levels given in Table 11, the following mitigation techniques should be taken into account in the design of a new space station:

– the wideband frequency response of the antenna;

– the attenuation characteristics of intermediate filters;

– the gain frequency response of solid state power amplifiers;

– the modulation characteristics of individual carriers;

– the attenuation of inter-modulation products with respect to the power of the carriers.

5.3 Potential impact

5.3.1 RAS

On the basis of the analysis in § 4, and the nature of the mitigation techniques listed in § 5.1, there could be some loss of observing time when satellites travel through the main or inner sidelobes of the antenna. The extent of this loss will depend upon the radio telescope antenna and the number of satellites. The data loss issue is discussed in Recommendation ITU-R RA.1513.

5.3.2 SMS

The mitigation techniques in § 5.2 are deemed technically feasible for GSO systems.

6 Results of studies

6.1 Summary

Based on the parameters of one GSO mobile-satellite system of one operator and taking into account the mitigation factors listed in § 5.2, it is likely that the unwanted emission levels from this satellite system meet the criteria discussed in § 1.3. No single-dish continuum observations are made in this band.

6.2 Conclusions

Protection criteria are met for the single-dish spectral-line case and for VLBI.

Annex 8

Compatibility analysis between the RAS systems (space-to-Earth) operating in the 2 690-2 700 MHz band and the BSS, and FSS (space-to-Earth) systems operating in the 2 655-2 690 MHz band

1 RAS

1.1 Allocated band

The 2 690-2 700 MHz band was allocated on a primary basis to the RAS, EESS (passive) and SRS (passive).

RR No. 5.340 states that in this band "all emissions are prohibited".

1.2 Type of observations

This band is primarily of interest for the study of continuum emission of radio sources.

A general consideration for the study of the continuum emission of radio sources is the requirement of sampled observations of these sources throughout a very wide frequency range. Observations at many different frequencies help to define the shape of the spectra of the emission from these sources, which in turn can give information on the physical parameters of the radiating sources such as densities, temperatures and magnetic fields, while they also give information on their lifetimes. The knowledge of these physical parameters is essential for our understanding of the physical processes that produce radio radiation. Many extragalactic radio sources show a "break" in their non-thermal spectrum in the region between 1 to 3 GHz and continuum measurements at ~2.7 GHz are essential to define such a spectral characteristic accurately.

This is a good frequency band for continuum measurements partly because the galactic background radiation is low, and also because radio astronomy receivers are of excellent quality and have very low noise at such frequencies.

It is also useful for galactic studies of ionized hydrogen clouds and the general diffuse radiation of the Galaxy. Since at such frequencies available radio telescopes have adequate angular resolutions (narrow beams, of the order of 10 arc min for large telescopes), many useful surveys of the galactic plane have been performed, including the regions of the galactic centre, which is invisible at optical wavelengths because of the interstellar absorption by dust particles. The centre of our Galaxy is perhaps its most important region and yet it can only be observed at infrared and radio wavelengths, since these wavelengths are not affected by the dust particles in the interstellar space (optical wavelengths are absorbed and scattered by such dust particles). The study of the nuclei of galaxies, including the nucleus of our own Galaxy, is emerging as an extremely important and fundamental topic in astronomy.

Problems that can be studied in these objects include the state of matter and the possibilities of the existence of black holes in galactic nuclei; the explosive activities and the production of intense double radio sources from galactic nuclei; the influence of galactic nuclei on the morphological structure of galaxies; the formation of galaxies and quasars; and many other major astrophysical subjects.

An important study at radio wavelengths is the polarization of the radiation that is observed from radio sources. It is often found that radio sources are weakly linearly polarized, with a position angle that depends on frequency. This effect is due to the fact that the propagation medium in which the radio waves travel to reach us is composed of charged particles, electrons and protons, in the presence of magnetic fields. The determination of the degree and angle of polarization gives us information on the magnetic fields and electron densities of the interstellar medium and in certain cases on the nature of the emitting sources themselves. The degree of polarization of radio waves is higher at higher frequencies. The 2 690-2 700 MHz frequency band is important for polarization measurements.

1.3 Required service protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. In the 2 690-2 700 MHz band, for single-dish continuum observations making use of the entire 10 MHz bandwidth, the threshold pfd limit is −177 dB(W/m^2).

This band is used only for continuum observations, not for spectral line observations.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −161 dB(W/m^2), for a bandwidth of 20 kHz.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 2 690-2 700 MHz band are carried out at a number of radio astronomy sites in numerous countries, worldwide. Observations in this band are sometimes conducted on targets of opportunity, e.g. on objects such as comets. VLBI observations are also frequently conducted in this band, sometimes between the North American and European VLBI networks.

Radio astronomical measurements are usually made differentially, the area of sky containing the source may be mapped, and the background emission subtracted, or measurements made of the power coming from the direction from the source (on-source) and at one or more nearby positions in the sky (off-source). By subtracting the off-source values from the on-source values, the emission originating in the source is separated from other contributions to the receiver output.

Extended areas of emission can be mapped by recording the emission from a grid of points covering the region of interest. In the case of single antenna radio telescopes, each grid point observation is an indication of the total power coming from that position in the sky; the spacing between the grid points should not be more than half the antenna beamwidth. When observations are made using a synthesis radio telescope, where the area to be mapped exceeds the instantaneous mapping field, the grid points should not be further apart than half the beamwidth of one of the radio telescope antennas.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data has been processed.

2 Active band

2.1 Allocated transmit band

The sub-band 2 655-2 670 MHz was allocated to the BSS on a primary basis.

The sub-band 2 670-2 690 MHz was allocated on a primary basis to the MSS (Earth-to-space), to the FSS (Earth-to-space) in Regions 2 and 3, and to the FSS (space-to-Earth) in Region 2.

The following relevant footnotes apply to the sub-band 2 655-2 670 MHz: RR Nos. 5.149, 5.413, 5.415, 5.416 and 5.420, and the following footnotes apply to the sub-band 2 670-2 690 MHz: RR Nos. 5.149, 5.419 and 5.420. Most relevant to the issue at hand are the following of these footnotes:

RR No. 5.149 states that in this band "In making assignments to stations of other services ... administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference."

RR No. 5.413 states that "In the design of systems in the broadcasting-satellite service in the bands between 2 500 MHz and 2 690 MHz, administrations are urged to take all necessary steps to protect the radio astronomy service in the band 2 690-2 700 MHz."

RR No. 5.415 states that in this band, for the FSS operating in Regions 2 and 3. "In the direction space-to-Earth the power flux-density at the Earth's surface shall not exceed the values given in Article **21**, Table **21-4**."

2.2 Application

There are operational BSSs in this band especially serving India. These services fall under the distribution definition of the BSS.

2.3 Levels based on regulatory provisions

pfd limits exist for BSS for community reception and for FSS systems, as set forth in RR Table 21-4.

2.4 Transmitter characteristics

2.4.1 FSS/MSS systems

Based upon the typical characteristics of systems operating in this band, FSS/MSS systems are supposed to use a necessary bandwidth of 20 MHz and to operate using the pfd limit given in RR Article 21: –137 dB(W/(m^2 · 4 kHz)) (i.e. –100 dB(W/(m^2 · 20 MHz))).

2.4.2 BSS systems

Based upon the typical characteristics of systems operating in this band, FSS/MSS systems are supposed to use a necessary bandwidth of 18 MHz and to operate using the pfd limit given in RR Article 21: –137 dB(W/(m^2 · 4 kHz)) (i.e. –100.5 dB(W/(m^2 · 20 MHz))).

2.5 Operational characteristics

Only GSO systems are addressed in the following calculations.

2.6 In-band transmit level

The BSS community reception and FSS pfd levels conform to the levels in RR Table 21-4.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

4.1.1 MSS/FSS cases

Recommendation ITU-R SM.1541 provides a mask for unwanted emissions within the OoB domain covering the case of FSS/MSS systems.

4.1.2 BSS case

The BSS is a full-time service, in that the areas served will be provided the signal all the time, with the same spectrum and power. On the other hand, there are no radio astronomy stations that use the band under consideration all the time. If interference problems arise, the GSO satellite systems will be steady emitters at unchanging positions in the sky, while celestial sources will be carried past them by the Earth’s rotation, so the interference may not completely preclude the observation of the sources.

Interference to single-antenna radio telescopes will degrade the observations by an amount that is a function of the angle between the satellite(s) and the antenna boresight, and can be evaluated using methodologies such as the epfd approach (see § 1.3).

Calculation of levels of unwanted emissions using the OoB mask for BSS systems which are now retained within Recommendation ITU-R SM.1541 have shown that, following this dBc mask, in some cases the level of emissions within the OoB domain may be higher than the emissions levels within the necessary bandwidth. Therefore, a new OoB mask was developed for BSS system.

The OoB emissions of a station operating in the bands allocated to the BSS should be attenuated below the maximum PSD, in a reference bandwidth of 4 kHz (for systems operating above 15 GHz a reference bandwidth of 1 MHz may be used in place of 4 kHz) within the necessary bandwidth, by the following:

$$32 \log \left(\frac{F}{50} + 1 \right) \qquad \text{dBsd}$$

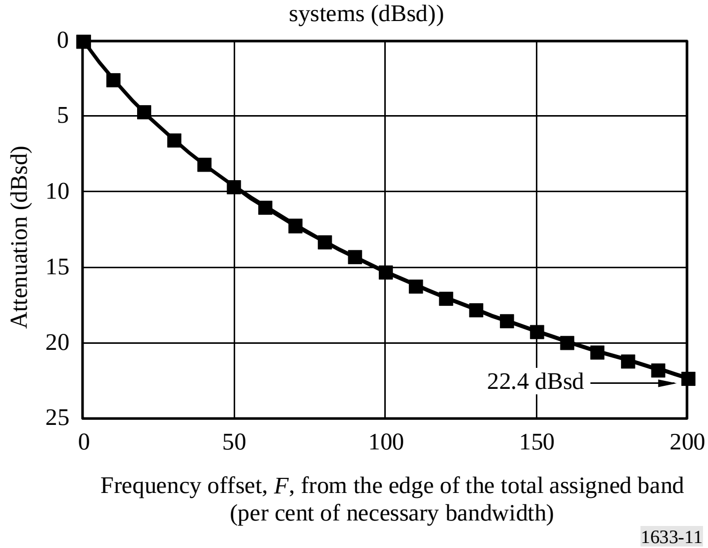
where F is the frequency offset from the edge of the total assigned band, expressed as a percentage of necessary bandwidth. It is noted that the OoB emission domain starts at the edges of the total assigned band.

The OoB emission mask rolls off to the spurious boundary or the point where it is equal to the RR Appendix 3 spurious emission limit, whichever is less attenuation. The spurious emission attenuation for space services is 43 + 10 log P or 60 dBc in a reference bandwidth of 4 kHz, whichever is less attenuation, or equivalently, 19 + 10 log P or 36 dBc in a reference bandwidth of 1 MHz, whichever is less attenuation.

FIGURE 11

OoB mask for BSS systems

(Attenuation within the OoB domain for BSS systems (dBsd))



4.2 Calculation of the interference level

In cases where application of RR No. 1.153 provides improvements in the consideration of compatibility, this footnote should be taken into account:

"**1.153** *occupied bandwidth*: The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage $\beta/2$ of the *mean power* of a given *emission*.

Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of $\beta/2$ should be taken as 0.5%."

If the lower edge of the occupied bandwidth was at or above the lower limit of the satellite service allocation, the total power of the unwanted emissions at frequencies below the allocated bandwidth would be no greater than 0.5% of P, where P is the in-band power. Therefore, the total power of unwanted emission at frequencies in the 50.2-50.4 GHz EESS band would be no greater than P – 23 dB.

4.3 Values achieved

4.3.1 FSS/MSS case

The application of Recommendation ITU-R SM.1541 for the FSS/MSS systems using a necessary bandwidth lead to an integrated pfd over the whole RAS band of 108.5 dB(W/(m^2 · 10 MHz)). The application of RR No. 1.153 leads to a total pfd of –123 dB(W/(m^2 · 10 MHz)). This means the protection criteria for continuum observations will not be met.

The pfd integrated over 20 kHz, at the edge of the RAS band, is equal to –130 dB(W/(m^2 · 20 kHz)), i.e. about 30 dB above the VLBI protection criteria.

4.3.2 BSS case

Based on the pfd limit given in RR Article 21 (–137 dB(W/(m^2 · 4 kHz))), assuming a necessary bandwidth of 18 MHz and by applying the mask described in § 4.1.2, for a BSS system operating below 2 670 MHz, the maximum pfd falling into a 10 MHz reference bandwidth is equal to –121 dB(W/(m^2 · 10 MHz)), i.e. about 56 dB above the criteria given for continuum observations. The application of RR No. 1.153 leads to a pfd of –123.5 dB(W/(m^2 · 10 MHz)). This means the protection criteria for continuum observations will not be met.

The pfd due to a BSS system operating below 2 670 MHz and integrated over 20 kHz, at the edge of the RAS band, is equal to –146 dB(W/(m^2 · 20 kHz)), which is about 15 dB above the VLBI protection criteria.

5 Mitigation techniques

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna side lobe performance: The aperture illumination of radio telescopes is usually optimized for *G*/*T*, i.e. telescope gain divided by system temperature. This is to maximize the *S*/*N* for point sources. A key element of this approach is to reduce ground radiation entering through far side lobes. Inevitably this leads to some corresponding increase in the levels of near side lobes. Experience has shown that the majority of radio telescopes meet the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

Guardband: A guardband is a technique to provide adequate separation in frequency between the active and passive services. In general, it will equitably straddle the boundary between the frequency bands of the active and passive services.

Geographical isolation: The geographic isolation of specific radio astronomy sites can be a factor in favour of protecting observations at these sites, given the orbital location of a specific BSS/FSS satellite, as there will be relatively few satellites.

5.2 FSS/BSS service

This service involves continuous transmission of signals continually or for long periods of time, with constant power and spectrum. Possible mitigation procedures are to avoid transmitting unwanted emissions in the direction of the radio astronomy stations that use this band, or to use filters to appropriately suppress unwanted emissions to a level where detrimental interference to radio astronomical observations in the 2 690-2 700 MHz is not caused.

5.3 Potential impact

5.3.1 RAS

Antenna sidelobe performance: Attempts to decrease the sensitivity of the radio astronomy antenna to unwanted emissions coming from space stations are likely to increase the sensitivity of the radio astronomy telescope to ground radiation, and possibly reduce its main beam gain. Both of these effects will reduce the telescope’s channel capacity of and thus lead to an increase of the total required integration time.

Blanking in time and/or frequency: Blanking involves a risk of compromising the integrity of the data and may lead to errors in their scientific interpretation. Blanking also causes a concomitant increase in the total integration time required to make the observation, this is equivalent to a loss in the channel capacity of the telescope.

Guardband: In the case of broadband continuum measurements, the use of a guardband would effectively lead to a loss of channel capacity, since the integration time would need to be increased to compensate for the loss of bandwidth.

Geographical isolation: When considered on a case-by-case basis it is likely that there would be little impact on the radio astronomy sites concerned. This does necessarily provide protection of radio astronomy as a service, however.

5.3.2 FSS/BSS

Filters are an obvious way to suppress unwanted emissions, but the addition of such filters may affect the satellite design in a substantial manner. If a phased array, active antenna is used, filters may be required for every driven antenna element. This will increase the weight of the satellite. Compensating for filter losses will require more powerful transmitters, which in turn will require more bus power, and so, larger solar power arrays. The increase in weight could be sufficient to require a larger launcher. The cost impact could be large. Consequently filters can be considered only at the design stage of a system. However, continuing technical improvements in the design of filters and active antennas may in time reduce the problem of implementing such solutions to manageable proportions.

Since some multi-beam satellite systems are planned for operation in the frequency range of interest, the number of beams in the multi-beam system or the number of elements multiplies the cost and weight implications of additional RF filtering in the phased-array antenna system. This is due to the fact that in a multi-beam system the output amplifiers are generally not shared between beams, and so would have to be filtered separately. In a phased array type system the final stage of amplification takes place at the various elements of the array, each of which would have to be filtered separately. In this way the weight impact of an individual filter is multiplied by the number of beams in the system or the number of elements in the phased array. The filter insertion loss could impact system capacity.

Geographic isolation would involve the use of satellite antenna pattern roll-off to achieve the required isolation to meet an agreed sharing criterion at a particular radio astronomy receiver site. This technique tacitly assumes that an FSS system will not have a global, or even regional, coverage area, which is a limiting assumption in itself. Many systems have regional or sub-regional beams where geographic isolation is not feasible. Other spot beam systems may be able to use geographic isolation; however, this is not an attractive solution from the satellite system perspective as it could result in areas of the Earth being unavailable to the satellite service. Such limitations of the FSS service area could have serious revenue-generating implications. However, this solution does have the benefit of taking into account the actual protection requirements of specific radio astronomy sites, without the need to resort to the worst-case criteria at every radio astronomy site.

6 Results of studies

6.1 Summary

The interference calculation performed shows that, on the basis of the protection criteria discussed in § 1.3, if no mitigation techniques are applied, there is a possibility of detrimental interference to radio astronomy observations in the 2 690-2 700 MHz band by services in the adjacent band, at a level that would effectively prevent any useful astronomical measurements being made in that band.

Satellite operators will continue to work closely with the radio astronomy community to minimize the impact of satellite OoB emissions. In many instances normal satellite transponder filtering will be sufficient to ensure there is no harmful impact to the radio astronomy bands. When this is not the case, the impact of additional satellite filtering will be considered along with other mitigating techniques such as geographical pattern isolation and radio astronomy ground station isolation. This can be accomplished on a case-by-case basis depending on the radio astronomy site location and the orbital location.

6.2 Conclusion

Protection criteria are not met for single-dish continuum or spectral-line observations, or for VLBI.

Annex 9

Compatibility analysis between the EESS (passive) systems operating in the 10.6-10.7 GHz band and FSS (space-to-Earth) systems operating in the 10.7-10.95 GHz band

1 EESS (passive)

1.1 Allocated band

The band 10.6-10.68 GHz is allocated to the EESS (passive), RAS and SRS (passive) as well as terrestrial services (fixed and mobile).

The band 10.68-10.7 GHz has a footnote, RR No. 5.340, relevant for passive services.

TABLE 12

Adjacent band allocations

Services in lower allocated bands		**Passive band**	**Services in upper allocated band**
10.55-10.6 GHz	**10.60-10.68 GHz**	**10.68-10.7 GHz**	**10.70-11.7 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	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) 5.484 MOBILE except aeronautical mobile

1.2 Application

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

1.3 Required protection criteria

The following Recommendations establish the interference criteria for passive sensors:

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

The first criterion is the acceptable interference power received by the EESS sensor, which is –163 dBW in the reference bandwidth of 20 MHz. This is a maximum interference level from all sources.

The second criterion is the frequency of occurrence limit on the threshold being exceeded. The number of measurement cells lost due to the threshold being exceeded must not exceed 5% in cases where the interference events are random, and 1% when the interference events are systematic. Since the FSS is not random, the 1% criterion applies.

1.4 Operational characteristics

Table 13 shows specifications for two microwave radiometric systems: MEGHA-TROPIC and EOS AMSR-E.

TABLE 13

Preliminary specifications for two microwave radiometric applications

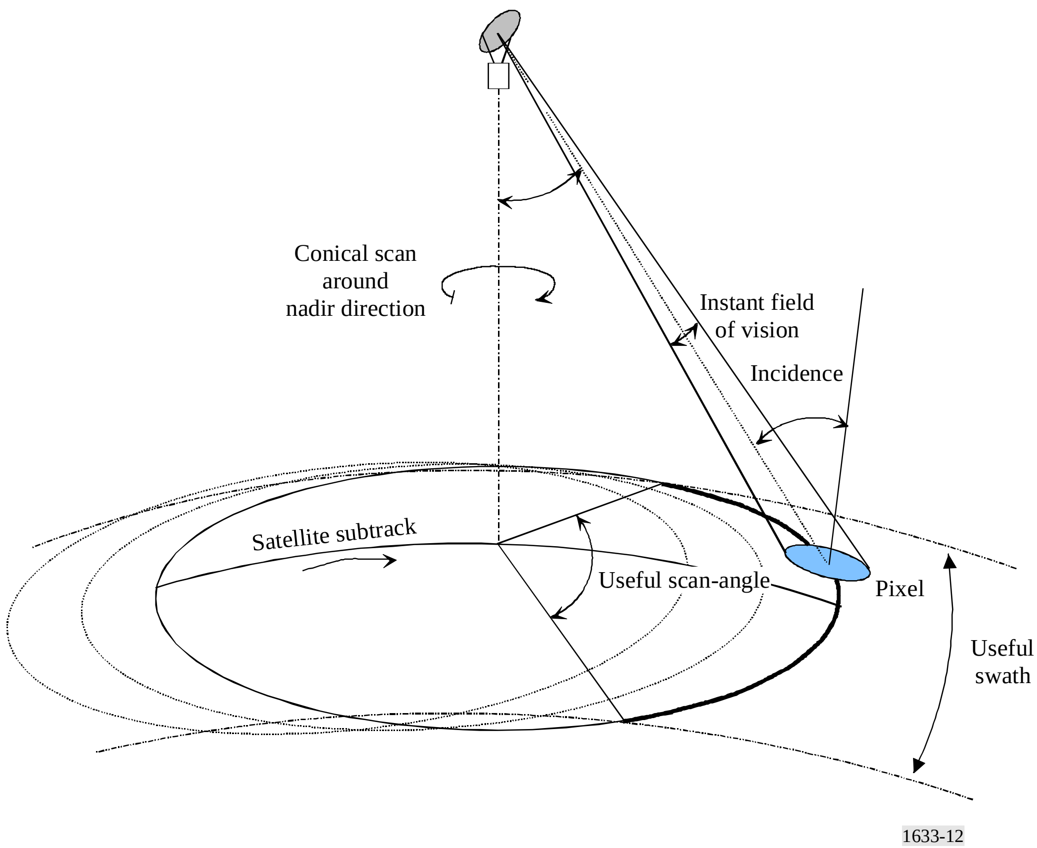
Channel 10.6-10.7 GHz	MEGHA-TROPIC	EOS AMSR-E
Channel bandwidth (MHz)	100	100
Pixel size across track (km)	56.7	28
Incidence angle *i* at footprint centre (degrees)	52	55
Polarization (linear)	H, V	H, V
Altitude of the satellite (km)	817	705
Maximum antenna gain (dBi)	36	37
Half power antenna beamwidth $\theta_{3\ dB}$ (degrees)	2.66	1.4

The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle *i* of the beam boresight.

The above EESS sensors are not nadir satellites, but EESS sensors having a conical scan configuration centred around the nadir direction. It is important for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The geometry of conically scanned instruments is described in Fig. 12. The rotation speed of the instrument (and not the satellite) is w = 20 r.p.m. for the MEGHA-TROPIC satellite and 40 r.p.m. EOS AMSR-E.

FIGURE 12

Geometry of conically-scanned passive microwave radiometers



The typical geometry characteristics of this kind of instruments are the following (for an altitude of about 850 km).

– the ground incidence angle i at footprint centre is about 50°;

– the EESS offset angle to the nadir or half cone angle α to the nadir direction: about 44°;

– the useful swath is about 1 600 km; and

– the scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

Figure 13 shows the antenna pattern planned for the MEGHA-TROPIC satellite: the first side lobe has a level around –35 dB below the maximum antenna gain, and the level of the back lobe radiation is around –50 dB.

FIGURE 13

Antenna pattern of the MEGHA-TROPIC passive microwave radiometer

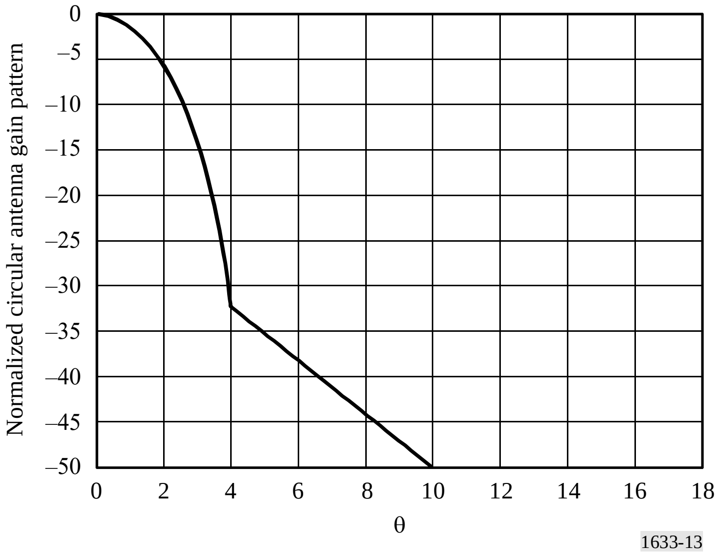
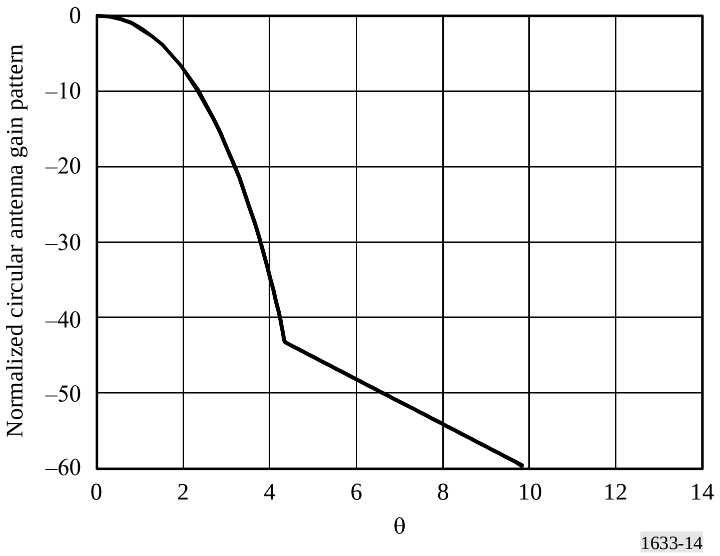


Figure 14 shows the antenna pattern planned for the EOS AMSR-E satellite: the first side lobe has a level around –45 dB below the maximum antenna gain, and the level of the back lobe radiation is around –60 dB.

FIGURE 14

Antenna pattern of the EOS AMSR-E passive microwave radiometer



2 FSS (space-to-Earth)

2.1 Allocated transmit band

The active service band is the FSS (space-to-Earth) 10.7-11.7 GHz band.

2.2 Application

The whole set of transmitter characteristics that are taken into account in this Annex are derived from Recommendation ITU-R S.1328-3 – Satellite system characteristics to be considered in frequency sharing analyses between geostationary-satellite orbit (GSO) and non-GSO satellite systems in the fixed-satellite service (FSS) including feeder links for the mobile-satellite service (MSS). This Recommendation gives some relevant information about typical systems.

According to RR No. 5.441, the use of the bands 10.7-10.95 GHz and 11.2-11.45 GHz by GSO satellites in the FSS shall be in accordance with RR Appendix 30B.

In the above Recommendation, any information concerning systems that would use in Region 1 the uplink allocation 10.7-11.7 GHz (Earth-to-space) through footnote RR No. 5.484 (limited to feeder links for the BSS) is not mentioned. Therefore, it was not possible to undertake any interference analysis between such FSS systems and EESS systems in the 10.6-10.7 GHz passive band.

2.3 Levels based on provisions and ITU-R Recommendations

2.3.1 RR No. 1.153

The RR defines *occupied bandwidth* as follows:

"**1.153** *occupied bandwidth*: The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage β/2 of the total *mean power* of a given *emission*.

Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of β/2 should be taken as 0.5%."

If the lower edge of the occupied bandwidth were assumed to be at or above the lower limit of the FSS allocation, the total power of unwanted emissions at frequencies below the allocated bandwidth would be no greater than 0.5% of P, where P is the in-band power. Therefore, the total power of unwanted emission at frequencies below 10.7 GHz, including those in the 10.6-10.7 GHz EESS band, would be no greater than P – 23 dB.

Although maintaining the occupied bandwidth within the allocated band is often an effective means of achieving the EESS interference criteria, meeting this assumption may be difficult and expensive for some FSS systems, requiring the use of either a guardband or space station filters.

2.3.2 Recommendation ITU-R SM.1541

Recommendation ITU-R SM.1541 – Unwanted emissions in the out-of-band domain.

The OoB domain emissions of a station operating in the bands allocated to the FSS should be attenuated below the maximum PSD (in a reference bandwidth of 4 kHz for systems operating below 15 GHz, in a reference bandwidth, is given in Annex 5 of Recommendation ITU-R SM.1541 (see Fig. 15). This curve is based on the following expression:

$$40 \log \left(\frac{F}{50} + 1 \right) \qquad \text{dBsd}$$

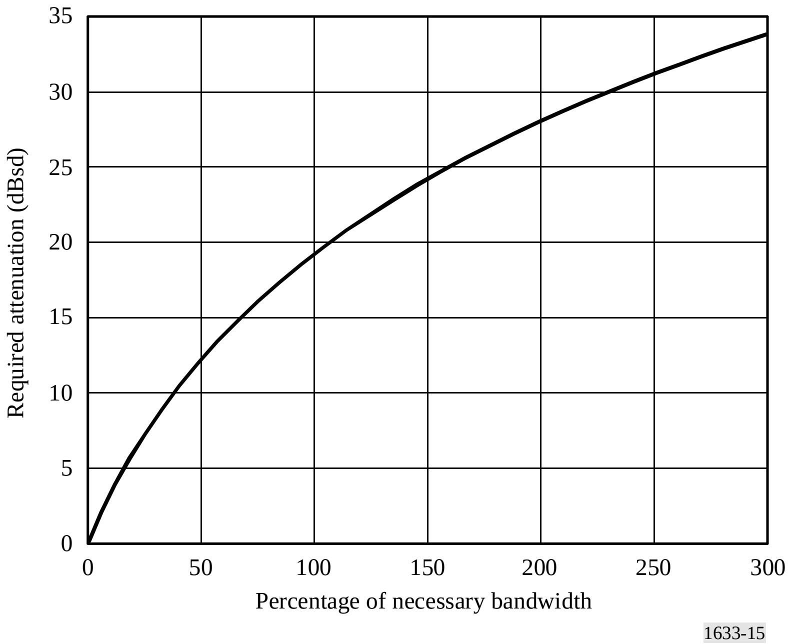
where:

F: frequency offset from the edge of the total assigned band, expressed as a percentage of necessary bandwidth. The OoB emission domain starts at the edges of the total assigned band

dBsd: dB relative to the maximum value of PSD within the necessary bandwidth.

FIGURE 15

Required attenuation for FSS earth and space stations according to Annex 5 of Recommendation ITU-R SM.1541



2.4 Transmitter characteristics

2.4.1 GSO satellite networks

TABLE 14

GSO-VX characteristics

Parameters	GSO-VX: planned GSO FSS network
Downlink frequency range (GHz)	10.7-10.95
Orbital parameters	14 GSO with at least 2° separation
Carrier transmission parameters	
Bandwidth (MHz)	250: 1 bandwidth per channel (1 channel/beam)
Downlink e.i.r.p./carrier (dBW)	47
Tx satellite antenna parameters	
Peak gain (dBi)	33.5
Side lobe gain or pattern	18 dB below peak (back lobes at 25 dB below peak)

2.4.2 Non-GSO networks

TABLE 15

Technical characteristics of a non-GSO FSS network, FSAT-MULTI 1-B

Orbital parameters	Shape of the orbit	Circular
	Height (km)	1 457
	Inclination angle (degrees)	55
	Number of satellites per plane	4
	Number of orbital planes	16
	Satellite separation within plane (degrees)	90
Downlink frequency (GHz)	11-12	
Spectrum requirement (MHz)	1 000	
Carrier Tx parameters	Downlink e.i.r.p./carrier (dBW)	At 90°: 17.5 and 4.8 At 75°: 19.7 and 7.1 At 50°: 21.2 and 8.6 At 32°: 23.1 and 10.2
Tx satellite antenna gain (dBi)	At 90°: 17.2 At 75°: 19.8 At 50°: 21.7 At 32°: 23	

2.4.3 Highly elliptical orbit (HEO) networks

TABLE 16

USAKU-H1 characteristics

Parameters	USAKU-H1
Downlink frequency range (GHz)	10.7 to 12.7
Orbital parameters	HEO/Elliptical: 41 449 km (apogee)/ 4 100 km (perigee)
Spectrum requirements (MHz)	
Carrier modulation technique	QPSK
Bandwidth (MHz)	24
Overall C/N_0 (dB/Hz)	86
Downlink e.i.r.p./carrier (dBW)	58
Tx satellite antenna parameters	
Peak gain (dBi)	38

3 Compatibility threshold

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor. Therefore, the compatibility threshold is –163 dBW in a bandwidth of 20 MHz for 99% of the time as indicated in § 1.3.

This Annex provides an analysis of the interference generated by a single active service. Therefore further work is needed to address the impact of these multiple active services above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

The hereunder analysis is based on some static geometric cases which are quite significant.

For each case, the applied methodology is divided into three steps:

Step 1: consists of computing the difference between the power produced by an FSS system and the EESS interference criteria when the particular FSS downlinks are co-frequency with the EESS (passive) band. The interference received from one carrier is then compared with the sensor interference threshold. The calculated difference between these values is the roll-off of OoB emissions that must be achieved to protect the EESS.

Step 2: consists of computing the pfd produced by the particular satellite at the Earth's surface, and comparing this level to the maximum pfd level permitted by RR Article 21 in the 10.7-10.95 GHz band to determine the maximum allowable increase in e.i.r.p. density that just complies with this limit. The interference received from one carrier operating at this maximum permissible e.i.r.p. density is then compared with the sensor interference criteria. The difference between the two values indicates whether the interference received meets or exceeds the EESS interference criteria.

Step 3: consists of assuming levels of unwanted emissions based on Recommendation ITU-R SM.1541 and RR No. 1.153, as described above. The calculated levels of OoB FSS emissions assuming the spectrum roll-off characteristics indicated in these sources are then compared to the EESS interference criteria to determine if compatibility is achieved under these assumptions.

4.2 Calculation of interference level

4.2.1 Calculations with the GSO networks (back lobe reception)

A very simple geometric situation is when the EESS sensor is located directly below the transmitting FSS satellite.

The difference between interference level and EESS criteria is calculated in Table 17 when the FSS downlinks are co-frequency with the EESS (passive) sensor.

TABLE 17

Compatibility analysis with GSO-VX network

Parameter	MEGHA-TROPIC	EOS AMSR-E
Downlink frequency range (GHz)	10.7-10.95	10.7-10.95
e.i.r.p./carrier (dBW)	47	47
Bandwidth (MHz)	250	250
Distance GSO-EESS (km)	34 969	35 081
Free space loss (dB)	204	204
EESS paraboloid offset angle to the nadir (degrees)	44	47.5
EESS antenna gain (dBi)	–14	–23
Received power at the EESS in the above bandwidth (dBW)	–171	–180
Corresponding received power at the EESS in a bandwidth of 20 MHz (dBW)	–182	–191
Interference threshold in a bandwidth of 20 MHz (dBW)	–163	–163
Difference between interference power and EESS protection criterion (dB)	0	0
Reference bandwidth for pfd limit (kHz)	4	4
Maximum permitted pfd by RR Article 21 (dB(W/(m^2 · 4 kHz)))	–140	–140
pfd produced by operating e.i.r.p. density at Earth's surface (dB(W/(m^2 · 4 kHz)))	–163	–163
Allowable increase in e.i.r.p. density (dB)	23	23
Difference between interference power and EESS protection criterion at the maximum permitted e.i.r.p. (dB)	4	0

According to Recommendation ITU-R S.1328-3[1], system GSO-VX[2] proposes to operate six satellites located at the three adjacent orbital locations of 99º W, 101º W and 103º W, assuming that agreement can be reached with other administrations on the necessary modifications to the RR Appendix 30B Plan. Therefore, assuming that co-located satellites do not have overlapping service areas and that the individual received power at the EESS is more or less the same (i.e. −182 dBW for a bandwidth of 20 MHz for MEGHA-TROPIC or –191 dBW for EOS AMSR-E), the calculated power produced by three co-coverage, co-frequency FSS satellites equals $10 \log_{10} (3 \times 10^{-18.2}) = -177$ dBW into MEGHA-TROPIC and $10 \log_{10} (3 \times 10^{-19.1}) = -186$ dBW into EOS AMSR-E. In both cases, the interference criterion of the passive service is met.

For the worst-case assumption that a GSO FSS satellite operating with an e.i.r.p. density that produces the maximum pfd at the Earth's surface permitted by RR Article 21 can be incorporated into the RR Appendix 30B Plan, the calculated power level at the MEGHA-TROPIC satellite exceeds the EESS interference criteria by 4 dB. With respect to the lower altitude EOS AMSR-E passive sensor, the EESS interference criterion is not exceeded.[3]

4.2.2 Calculations with the non-GSO networks

It should be noted that these results are based on simple analyses that do not take into account the percentage of time that the EESS interference criteria is exceeded. A more complex simulation would be required to find out if a non-GSO FSS system that exceeds the EESS criteria for the particular geometric configuration considered in these analyses does so as well for the 99% of time value indicated in Recommendation ITU-R SA.1029.

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[1] Recommendation ITU-R S.1328-3 consists of a database of FSS characteristics and link budget information to be used for sharing studies. This Recommendation has been replaced by Recommendation ITU-R S.1328-4, which as well as an electronic database, contains a format for the electronic submission of link budgets and a validation tool to ensure links are internally consistent. At this time, only a few validated link budgets are available in the Recommendation ITU-R S.1328-4 database, none of which are applicable to the band in question. Consequently, sharing studies were done with the link information available in the previous version of this Recommendation.

[2] System GSO-VX, as described in Recommendation ITU-R S.1328-3, does not provide any information as to the service area of each space station. There are no filings on record at the BR consistent with GSO-VX which would provide additional detail concerning this system. Although the pfd produced by the satellites of this system are significantly below the levels typically produced satellites consistent with the RR Appendix 30B Plan, no finding has been made by the BR on this system and it is unclear as to whether it could be successfully notified as described.

[3] The e.i.r.p. density required to achieve the pfd limits in RR Table 21-4 is 7 to 19 dB higher than that of allotment entries in the RR Appendix 30B Plan. Any such system with a service area sufficient to provide viable commercial service is likely to exceed the *C*/*I* aggregate criterion of 26 dB on numerous allotments in the RR Appendix 30B Plan, and it is not certain that such a system would receive the approval of all the impacted administrations required to notify the proposed system. However, this worst-case interference case has been presented in order to be consistent with the methodology used in this Recommendation.

4.2.2.1 Case 1 – Non-GSO networks (back lobe reception)

For case 1, the geometric situation is such that the EESS sensor is located directly below the transmitting FSS satellite.

The difference between interference level and EESS criteria is calculated in Table 18 when the FSS downlinks are co-frequency with the EESS (passive) sensors.

TABLE 18

Compatibility analysis with FSAT-MULTI 1-B

Parameter	MEGHA-TROPIC	EOS AMSR-E
Downlink frequency range (GHz)	11-12	11-12
e.i.r.p./carrier for one beam (dBW)	17.5	17.5
Bandwidth (MHz)	41	41
Distance FSAT-EESS (km)	640	752
Free space loss (dB)	169	170.5
EESS paraboloid offset angle to the nadir (degrees)	44	47.5
EESS antenna gain (dBi)	–14	–23
Received power at the EESS in the above bandwidth (dBW)	–166	–176
Corresponding received power at the EESS in a bandwidth of 20 MHz (dBW)	–169	–179
Interference threshold in a bandwidth of 20 MHz (dBW)	–163	–163
Difference between interference power and EESS protection criterion at the proposed operating e.i.r.p. (dB)	0	0
Reference bandwidth for pfd limit (kHz)	1 000	1 000
Maximum permitted pfd by RR Article 21 (dB(W/(m^2 · MHz)))	–116	–116
pfd produced by operating e.i.r.p. density at Earth's surface (dB(W/(m^2 · MHz)))	–133	–133
Allowable increase in e.i.r.p. density (dB)	17	17
Difference between interference power and EESS protection criterion (dB) at the maximum permitted e.i.r.p.	11	1

For one FSAT-MULTI-1B satellite, the calculated interference level does not exceed the EESS interference criteria. The total constellation for FSAT-MULTI-1B is composed of 64 satellites.

Assuming that:

– it is possible to have up to two satellites in visibility of the EESS sensor; and

– the individual received power at the EESS is more or less the same (i.e. –169 dBW for a bandwidth of 20 MHz for MEGHA-TROPIC and –179 dBW for EOS AMSR-E), the resulting power valid for two satellites equals 10 $\log_{10}(2 \times 10^{-16.9}) = -166$ dBW for MEGHA-TROPIC and 10 $\log_{10}(2 \times 10^{-17.9}) = -176$ dBW for EOS AMSR-E. In both cases, the interfering power is also below the required interference threshold.

For the worst case of a similar non-GSO FSS satellite operating with an e.i.r.p. density that produces the maximum permissible pfd at the Earth's surface, the calculated power level at the MEGHA-TROPIC satellite exceeds the EESS interference criteria by 11 dB. For the same assumption that two such satellites are simultaneously visible, the calculated interference level exceeds the EESS criteria by $(11 + 10 \log_{10} 2) = 14$ dB if each satellite is operating at the maximum permitted pfd level. For the lower altitude EOS AMSR-E passive sensor, the calculated interference level exceeds the EESS criteria by $(1 + 10 \log_{10} 2) = 4$ dB for this two satellite case.

4.2.2.2 Case 2 – Non-GSO networks (near-grazing path)

For case 2, the geometric situation is such that the FSS satellite is in the direction of the maximum antenna gain of the EESS sensor. This case does not exist because:

– the full antenna beamwidth of the main beam equals 6.7º and concentrates more than 90% of the energy;

– the actual and operational off-nadir angle of the EESS sensor is 44º;

– the minimum off-nadir of the EESS satellite where the sky is seen is about 60º; and

– the EESS antenna side lobes above this minimum off-nadir angle are already below –30 dB.

4.2.3 Calculations with the HEO/Elliptical networks (back lobe reception)

The geometric situation, which is under consideration is such that the EESS sensor is located directly below the transmitting FSS satellite.

The difference between interference level and EESS criteria is calculated in Table 19 when the FSS downlinks are co-frequency with the EESS (passive) sensors. In the case of perigee operations, the e.i.r.p./carrier has been adjusted to the level that would just produce the maximum pfd permitted at the Earth's surface.

TABLE 19

Compatibility analysis with elliptical networks

Parameter	MEGHA-TROPIC		EOS AMSR-E	
Downlink frequency range (GHz)	10.7-11.7		10.7-11.7	
e.i.r.p./carrier for one beam (dBW)	58		58	
Bandwidth (MHz)	24		24	
Distance FSAT-EESS (km)	40 632 (apogee)	3 283 (perigee)	40 744 (apogee)	3 395 (perigee)
pfd limit adjusted e.i.r.p./carrier at perigee for one beam (dBW)	58	41	58	41
Free space loss (dB)	205	183	205	184
EESS paraboloid offset angle to the nadir (degrees)	44	44	47.5	47.5

TABLE 19 (*end*)

Parameter	MEGHA-TROPIC		EOS AMSR-E	
EESS antenna gain (dBi)	–14	–14	–23	–23
Received power at the EESS in the above bandwidth (dBW)	–161	–156	–170	–166
Corresponding received power at the EESS in a bandwidth of 20 MHz (dBW)	–162	–157	–171	–167
Interference threshold in a bandwidth of 20 MHz (dBW)	–163	–163	–163	–163
Difference between interference power and EESS protection criterion at the proposed operating e.i.r.p. (dB)	1	6	0	0
Reference bandwidth for pfd limit (kHz)	1 000	1 000	1 000	1 000
Maximum permitted pfd by RR Article 21 (dB(W/(m^2 · MHz)))	–116	–116	–116	–116
pfd produced by operating e.i.r.p. density at Earth's surface (dB(W/(m^2 · MHz)))	–119	–116	–119	–116
Allowable increase in e.i.r.p. density (dB)	3	0.0	3	0.0
Difference between interference power and EESS protection criterion at the maximum permitted e.i.r.p. (dB)	4	6	0	0

In the case of the MEGHA-TROPIC passive sensor, the EESS interference criteria is exceeded by 1 dB for the USAKU-H1 satellite when it is at apogee and the threshold is exceeded by 6 dB when it is at apogee and operating at the maximum permitted pfd level. If the satellite e.i.r.p. density at apogee is increased to the maximum allowable under RR Article 21, the interference criteria is exceeded by 4 dB.

4.2.4 Calculations for both GSO and non-GSO networks in the case of scattering

One form of interference power into the passive service comes from the unwanted emissions of the FSS that are scattered from the Earth's surface upward toward a nearby EESS sensor.

For frequencies around 10-20 GHz, the scattered energy has a significant specular component. Scattering by this mode would constitute the worst-case interference. Hence, the maximum interference would occur when:

– the sensor views a FSS coverage area;

– the FSS satellite, the sensor, the Earth's centre, and the intersection of the FSS and sensor beams all lie in the same plane;

– the intersection of the FSS satellite and sensor beams lie between the FSS satellite and sensor nadirs; and

– the FSS satellite beam axis and the sensor beam axis intersect the Earth at the same angle.

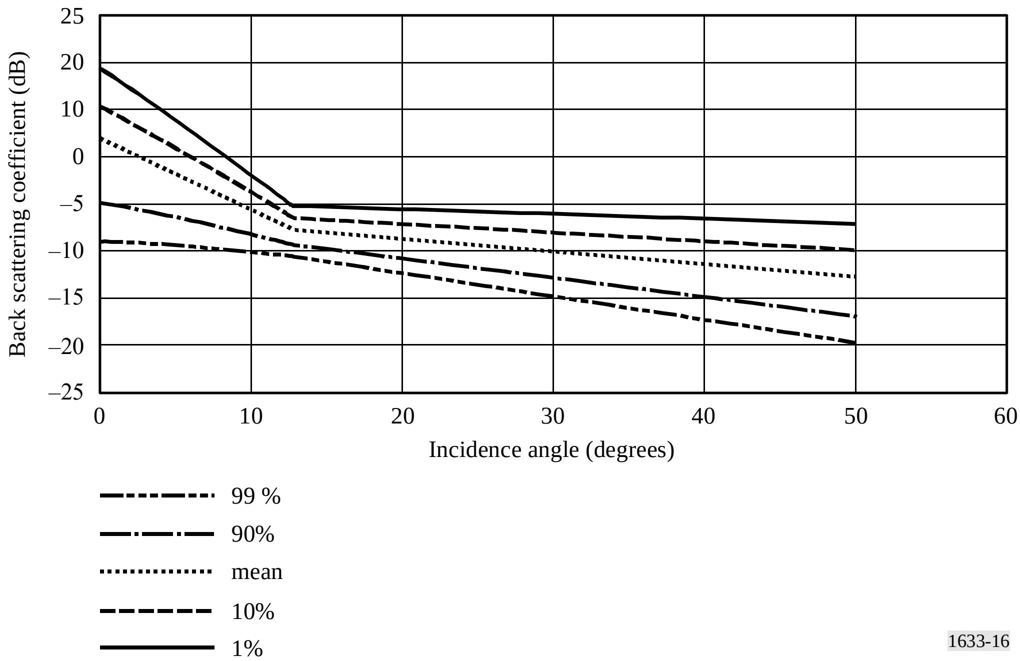
Other scattering modes also exist. These would be more frequent in occurrence but at a lower level.

4.2.4.1 Scattering coefficient

Annex 1 of Recommendation ITU-R SA.1449 describes a model for the scattering coefficient that enables one to estimate the direction and intensity of scattering from the Earth's surface. Experiments from Skylab have determined the Earth surface radar scattering coefficient at 13.9 GHz over the Conterminous United States (CONUS) including the 48 contiguous States and the District of Columbia. Extrapolating across frequency and assuming that the probability density of the scattering coefficient has a log-normal form, it is estimated that the scattering coefficient, for the worst-case geometry described above, has a mean value of about 2 dB. However, 10% of the time the scattering coefficient can exceed 5.2 dB and 1% of the time can exceed 9.4 dB at 10.65 GHz as illustrated in Fig. 16. Further work is planned within the ITU-R to develop a bi-static microwave scattering model for interference assessment using this approach.

FIGURE 16

Scattering coefficient model



Most of the time, however, scattering would be via a more non-directional mode with an average scattering coefficient range of –12.8 to –5.7 dB depending on incidence angle (lesser value for 50° incidence/40° elevation). Recall from § 3.2.2, the interference threshold is coupled with a frequency of occurrence. This factor is a combination of the statistics of the scattering coefficient and the dynamics of relative motion of the FSS satellite and the EESS satellite. Coupling of both factors requires further study. For, herein, we only examine the worst-case scenario of interception of a specular reflection at the 1% occurrence level.

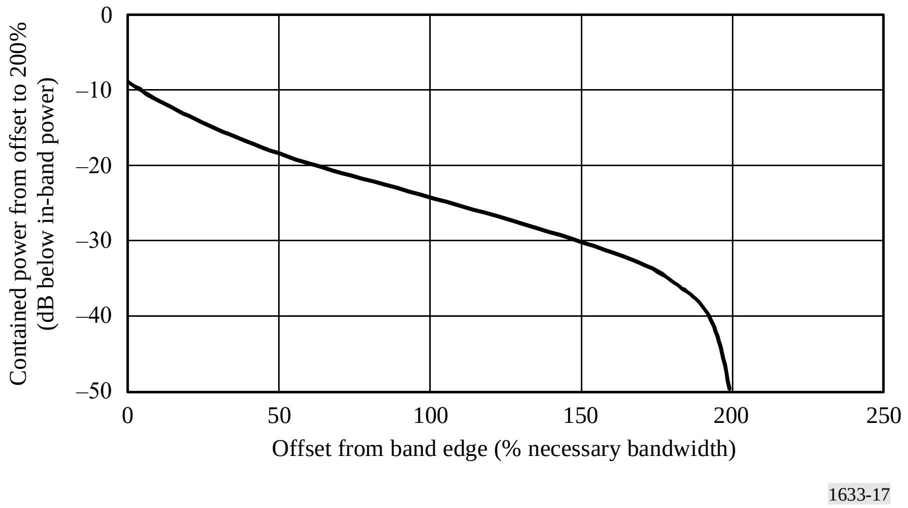
4.2.4.2 OoB interference using the OoB mask of Recommendation ITU-R SM.1541

Appendix 1, Annex 1 of Recommendation ITU-R SM.1541 describes the procedure for calculating the unwanted emission power between any two frequencies within the OoB domain.

Two equivalent methods are included, which essentially estimate the integral of the spectral mask over the frequency span defined by the two frequencies. Consequently, in order to determine the impact of this mask, it is integrated to provide the results in Fig. 17.

FIGURE 17

Relative power in Recommendation ITU-R SM.1541 mask from reference to 200% of necessary bandwidth



If it were assumed the total power within an adjacent band service includes the OoB emissions on either side of the necessary bandwidth, integration of the above relation would indicate that about 12.5% (–9 dB) of the energy would be emitted into the OoB domain on either side of the necessary bandwidth. Therefore, if no allowance is made for a guardband between two adjacent assigned bands (both services operate at band edge), an active service in the 10.7-11.7 GHz band could contribute interfering unwanted emissions into the passive service up to the amount of 12.5% of the total transmitter power (P – 9.0 dB). Of course, use of guardbands with either service could reduce this interference greatly. However, for this initial assessment, it will be assumed no guardbands are used.

Table 20 provides power budgets for the three representative satellite systems showing interference threshold margins for each. With the OoB mask of Recommendation ITU-R SM.1541, the level of the unwanted emissions into the passive band is obtained by integration over the OoB mask between the two edges of the passive band. For the GSO case with 250 MHz bandwidth and the sensor having a bandwidth of 100 MHz, the appropriate integration boundaries range from 0-40% of the necessary bandwidth of the active service. An equivalent operation would simply take the difference of the antilog at 0% and 40% taken from Fig. 17, and convert that to dBs. Doing so would indicate an unwanted emission level of about 9.8 dB below the average in-band power of the active service. This result is indicated in Table 20 as the OoB factor. For both the LEO-N and USAKU-H1 systems, the upper boundary of the integration percentage extends beyond the ITU-R SM.1541 mask (which terminates at the spurious boundary of 200% of the necessary bandwidth). For these we account only for the unwanted emissions defined by the OoB mask and exclude those due to spurious emissions. The total contribution from the OoB domain is 9 dB below the average power in the active service. Both the GSO-VX and LEO-N systems can meet the conditions for alignment of a specular reflection along the axis of the sensor antenna (elevation angle = 35°). However, the USAKU-H1 system is designed to operate at high elevation angles on the order of 70º. Consequently, there would never be such an alignment with this system. At the point on the Earth where the sensor axis intersects the axis of the active service antenna, there will be an offset of ε – φ = 35° as shown in Fig. 18.

TABLE 20

Estimated interference margins for typical FSS systems using the OoB mask of Recommendation ITU-R SM.1541

	FSS System		
	GSO-VX	**LEO-N**	**USAKU-H1**
e.i.r.p. (dBW)	47.0	17.6	58.0
FSS transponder bandwidth (MHz)	250.0	4.9	24.0
Sensor bandwidth (MHz)	100	100	100
Percent frequency offset from band edge	0-40	–(1)	–(1)
OoB power factor	–9.8	–9.0	–9.0
Unwanted power in sensor band (dBW)	37.2	8.6	49.0
Threshold bandwidth adjustment (dB)(2)	–7.0	–7.0	–7.0
Unwanted emission psd (dB(W/20 MHz))	30.2	1.6	42.0
Elevation to active service satellite (degrees)	35.0	35.0	70.0(3)
FSS range (km)	38 180	1 117	41 784
Beam spreading loss (dB)	162.5	132.0	163.4
OoB pfd centre of projected area (dB(W/(m^2 · 20 MHz)))	–134.7	–131.4	–123.8
Scattering coefficient (dB)	9.4	9.4	–5.5(4)
Sensor beamwidth (degrees)	1.4	1.4	1.4
Sensor range (km)	1 124	1 124	1 124
Sensor beam area (million m^2)	592	592	592
Elevation to sensor (degrees)	35	35	35
Projected beam area (million m^2)	1 033	1 033	1 033
Scattered power (dB(W/20 MHz))	–35.3	–33.2	–37.0
Path to sensor (dB)	–174	–174	–174
Sensor antenna gain (dBi)	41	41	41
Received psd (dB(W/(m^2 · 20 MHz)))	–168.3	–166.2	–170.0
Interference threshold (dB(W/20 MHz))	–163	–163	–163
Margin (dB)	5.3	3.2	7.0

(1) As explained in the text, the percentage range exceeds the range of validity of the OoB mask, and the integration of the OoB mask ignores the interference contribution from the region beyond the spurious boundary at 200% necessary bandwidth.

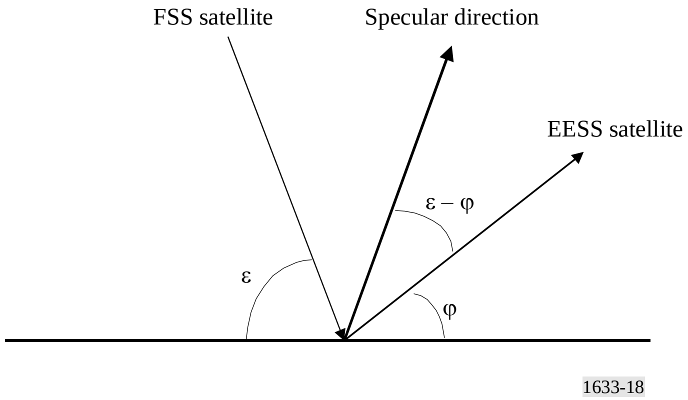
(2) Threshold reference bandwidth is 1/5 the sensor bandwidth.

(3) HEO systems are usually designed for high elevation angles, 70° assumed.

(4) The closest approach to specular is a 12.5° offset, which gives the smaller coefficient.

FIGURE 18

Offset of EESS sensor axis from specular reflection



From § 3.2 of Annex 1 of Recommendation ITU-R SA.1449, the scattering coefficient appropriate for this offset would be the value corresponding to one-half this offset taken from Fig. 12 at the frequency-of-occurrence of interest. With a 70° FSS satellite elevation and 35° EESS satellite elevation, the one-half offset would be 17.5° and the scattering coefficient at the 1% frequency-of-occurrence from Fig. 16 would be about –5.5 dB.

The scattered PSD has a variation of about 4 dB among the three systems. The net margin against interference is positive in each case with the LEO-N system having the least margin.

4.2.4.3 OoB interference using RR No. 1.153

The intent of this provision is to provide a definition of occupied bandwidth in the RR that is based on the power of an emission. In this study, it is assumed that the occupied bandwidth is entirely within the allocated band and that no more than 0.5% of the power falls either above or below the allocated band. If this were the case, the mean power either above or below the allocated band would be no greater than –23 dB relative to the total power of the emission. Herein, we assume the distribution of this unwanted emission power is uniform over a bandwidth equal to the active service bandwidth. Consequently, the OoB unwanted emission into the passive band from the GSO-VX case would be further adjusted by the ratio 10 log(100/250). Since the LEO-N and USAKU-H1 cases have bandwidths less than the passive band, the passive band is subject to the entire unwanted emission allocation.

Since the interference threshold is referenced to 20 MHz, we make the further bandwidth adjustment of 10 log (20/100) = –7 dB.

With these considerations, a power budget showing the margins against interference is shown in Table 21.

4.3 Values achieved

The interference criterion is met for the cases of the studied GSO and non-GSO systems operating at their proposed e.i.r.p. levels. For cases where the FSS systems operate at the maximum pfd limits allowed under RR Article 21, the calculations presented in § 4.2.2.1 indicate that the EESS interference criteria is exceeded by up to 14 dB when considering the impact of two non-GSO satellites.

TABLE 21

Estimated interference margins for typical FSS systems using RR No. 1.153

	FSS System		
	GSO-VX	**LEO-N**	**USAKU-H1**
e.i.r.p. (dBW)	47.0	17.6	58.0
OoB factor (dB)[(1)]	–23.0	–23.0	–23.0
FSS transponder bandwidth (MHz)	250.0	4.9	24.0
Sensor bandwidth (MHz)	100	100	100
OoB bandwidth adjustment (dB)[(2)]	–4.0	0.0	0.0
Threshold bandwidth adjustment (dB)	–7.0	–7.0	–7.0
OoB equivalent e.i.r.p. (dB(W/20 MHz))	13.0	–12.4	28.0
FSS range (km)	38 180	1 117	41 784
Beam spreading loss (dB)	162.5	132.0	163.4
Reference incidence angle (degrees)	55.0	55.0	20.0
OoB pfd at scattering point (dB(W/m^2))	–149.9	–136.0	–129.2
Scattering coefficient (dB)	9.4	9.4	–5.5
Sensor beamwidth (degrees)	1.4	1.4	1.4
Sensor range (km)	1 124	1 124	1 124
Sensor beam area (million m^2)	592.5	592.5	592.5
Elevation to sensor (degrees)	35.0	35.0	35.0
Projected beam area (million m^2)	1 033	1 033	1 033
Scattered power (dB(W/20 MHz))	–52.5	–47.2	–51.0
Path to sensor (dB)	–172.6	–172.6	–172.6
Sensor antenna gain (dBi)	41	41	41
Received psd (dB(W/(m^2 · 20 MHz)))	–185.5	–180.2	–184.0
Interference threshold (dB(W/20 MHz))	–163.0	–163.0	–163.0
Margin (dB)	22.5	17.2	20.4

(1) Assumes 0.5% outside allocation on each side.

(2) Assumes OoB power uniformly distributed over bandwidth equal to active service bandwidth.

Compatibility will occur in all of the cases considered above if the occupied bandwidth of the FSS emission lies wholly within the allocated band. However, this may not be possible for the active service, or may require that the FSS bear the burden of the use of mitigation methods such as filtering or a guardband.

For consideration of the application of Recommendation ITU-R SM.1541, Table 22 summarizes the exceedance of interference criteria calculated for each of the cases addressed in § 4.2.1, 4.2.2 and 4.2.3 above and the frequency separations implied by Fig. 15 for the specified necessary bandwidth considered.

TABLE 22

Summary of interference exceedance threshold and frequency separation calculations

	Interference threshold exceedance (dB)	**Calculated frequency offset (%)**	**Carrier bandwidth (MHz)**	**Calculated guardband (MHz)**
GSO-VX	0	–	–	–
Maximum pfd GSO FSS	4	34	36[(1)]	5
FSAT-MULTI 1-B	0	–	–	–
Maximum pfd non-GSO FSS	14	63	41	26
USAKU-H1	1 (apogee) 6 (perigee)	3 (apogee) 20 (perigee)	24	1 (apogee) 5 (perigee)
Maximum pfd HEO FSS	4 (apogee) 6 (perigee)	13 (apogee) 20 (perigee)	24	3 (apogee) 5 (perigee)

(1) Typical FSS transponder bandwidth.

5 Mitigation techniques

The proposed GSO and non-GSO satellite designs considered above that operate at e.i.r.p. density levels substantially below the maximum levels permitted by RR Article 21 do not require mitigation techniques. However, mitigation techniques may be required in the case of the proposed HEO elliptical orbit FSS system considered, as well as for all types of FSS systems operating with higher e.i.r.p. densities than the particular FSS networks considered above if they produce pfd levels at the Earth’s surface that approach the limits in RR Table 21-4.

In such cases, having the occupied bandwidth contained completely within the band allocated to the FSS would lead to compatibility between the two services. However the impact on the FSS of this obligation could be significant either in loss capacity through the application of a guardband in the RR Appendix 30B band or in the implementation of additional filtering.

This is because the addition of an output filter to a space station results in additional construction costs and time delays resulting from the design construction and testing of the filter. In addition filters cause an insertion loss after the high power amplifier (HPA), which implies the selection of a larger HPA in order to maintain the same network capacity. A larger HPA impacts the weight and power requirements on the space station bus that impacts space station cost. In addition, the insertion of a filter increases phase delay that can result in a need for equalization at the terminal impacting terminal cost.

Compatibility in these cases may also be achieved by means less onerous than full compliance with RR No. 1.153. For example, controlling the percentage of total OoB power to less than 4% appears to be sufficient to satisfy the EESS interference criteria under the worst-case assumptions in the calculations presented above. Employing emissions in the FSS whose OoB spectra roll-off faster than the Recommendation ITU-R SM.1541 mask would result in a smaller frequency offset as a percentage of the necessary bandwidth being needed to achieve the passive service criteria. It should be noted that the values of guardband calculated in Table 20 are based on the carrier bandwidths specified for the specific systems considered and that smaller carrier bandwidths might require smaller guardbands in order to achieve the protection criterion of the EESS. Further study is required to establish if FSS systems can reasonably employ the mitigation methods mentioned above.

6 Results of studies

6.1 Summary

This study addressed a compatibility analysis between the EESS (passive) in the band 10.6-10.7 GHz and the FSS (space-to-Earth) in the band 10.7-10.95 GHz.

Two different microwave radiometers from the EESS (passive) were taken into account and three different types of satellite networks from the FSS were considered in this study, i.e. GSO, non-GSO (including HEO/elliptical) satellite networks. Calculations were performed using the e.i.r.p./carrier levels specified for the proposed systems as well as for worst-case e.i.r.p./carrier levels that produce the maximum level of pfd at the Earth's surface permitted by RR Article 21.

Mitigation techniques resulting in a reduction of unwanted emissions of up to 14 dB for non-GSO and 4 dB for GSO would be required by certain FSS systems operating at the maximum e.i.r.p. density levels that comply with the RR Article 21 pfd limits in order to meet the EESS protection criterion for 100% of time. This reduction could possibly be achieved via compliance with RR No. 1.153 (assuming that the overall occupied bandwidth is within the allocated FSS band and that no more than 0.5% of the power falls either above or below the allocated band), or by some combination of controlling the total OoB power of the FSS emission that falls with the EESS (passive) band, and/or employing frequency offsets within the allocated FSS band. Whether all FSS systems can meet this constraint remains to be studied. For the particular cases considered in this analysis, frequency offsets of up to 63% of the necessary bandwidth were calculated on the basis of the OoB emission mask in Recommendation ITU-R SM.1541.

As indicated in § 2.2, it was not possible to undertake an interference analysis dealing with FSS systems that would use in Region 1 the uplink allocation 10.7-11.7 GHz through RR No. 5.484 (limited to feeder links for the broadcasting service), because no information is currently available on such systems. If such systems were to be deployed, it would be a major concern for EESS (passive) sensors since these links are planned for Earth-to-space. There might be a significant amount of time during which the signal sent by such FSS earth stations be in the main beam or the first sidelobe of the EESS antenna.

6.2 Conclusions

The interference criteria of the EESS are met for the cases of GSO and non-GSO systems operating at the proposed e.i.r.p./carrier levels. An additional 14 dB of reduction of the unwanted emission power may be required by certain FSS systems operating at the maximum e.i.r.p. density levels that comply with the RR Article 21 pfd limits. In all such cases, having the occupied bandwidth contained completely within the band allocated to the FSS would lead to compatibility between the two services. In the special case of HEO satellites, since they are transmitting mostly in the apogee position and are switched off in the perigee position, it is unlikely that this interference event will occur. Applying the unavailability criteria of Recommendation ITU-R SA.1029 may modify this scattering.

Annex 10

Compatibility analysis between RAS systems operating in the 10.6-10.7 GHz band and FSS (space-to-Earth) systems operating in the 10.7-10.95 GHz band

1 RAS

1.1 Allocated band

The 10.6-10.7 GHz band is allocated to the RAS, EESS (passive) and SRS (passive) on a primary basis; the 10.68-10.7 GHz sub-band is allocated exclusively to these services, worldwide.

The following footnotes are of relevance to these bands: RR No. 5.149 for the band 10.6-10.68 GHz and RR No. 5.340 for the band 10.68-10.7 GHz.

1.2 Type of observations

1.2.1 Single dish observations

Astronomical uses of the band include the observation of non-thermal synchrotron sources that are just detectable at this frequency range. These observations provide information at the highest frequency where such sources can be easily detected, and this allows the determination of some physical parameters of these sources. The 10.6 GHz band is also extremely important for monitoring the intensity variability of radio galaxies, including quasars. These objects, believed to be the most distant celestial objects that astronomers can detect, have been found to vary in intensity with periods varying from hours to years, and to produce surprisingly large amounts of energy. The energy emitted during one such burst from a quasar is equivalent to the complete destruction of a few hundred million stars in a period of a few weeks or months. The fundamental physics that can produce such events are not yet fully understood and observations of the size and variability of these sources are crucial in solving these enigmas. Such observations are best performed in the frequency range 10 to 15 GHz.

The variability of quasars is pronounced at these frequencies, and their observation facilitates the discovery and the monitoring of such events, the physics of which is as yet poorly understood by astronomers. Observations lead us to estimate the sizes of these sources, which turn out to be very small for the amount of energy they produce. The 10.6 GHz band provides some of the best angular resolutions (~2 arc min) for many large, single-dish radio telescopes.

1.2.2 VLBI observations

The extremely small sizes of quasars (as small as milliarcseconds) are revealed from the VLBI observations. Such observations are also being made in the frequency band 10.6-10.7 GHz, though at present the 8.4 GHz is a more frequently used band for VLBI observations. The 8-10 GHz range provides a better angular resolution than observations made at lower frequencies and enable scientists to determine more accurately the sizes and small-scale structure of radio galaxies.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. In the 10.6-10.7 GHz band, for single-dish continuum observations making use of the entire 100 MHz bandwidth, the threshold pfd limit is –160 dB(W/m^2) This band is used only for continuum observations, not for radio line observations.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, –145 dB(W/m^2), for a bandwidth of 50 kHz.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems and in Recommendation ITU-R M.1583 for MSS and RNSS systems.

The thresholds of detrimental interference levels to the radio astronomy service as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealised circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 10.6-10.7 GHz band are carried out at a number of radio astronomy sites worldwide; these are made using single-antenna and array radio telescopes.

In general, observations are made differentially. In the case of continuum emissions, the area of sky containing the source may be mapped and the background emission subtracted, or measurements made of the power coming from the direction of the source (on-source) and at one or more nearby positions in the sky (off-source). By subtracting the off-source values from the on-source values, the emission originating in the source is separated from other contributions to the receiver output.

Extended areas of radio emission can be mapped by recording the emission from a grid of points covering the region of interest. In the case of single antenna radio telescopes, each grid point observation is an indication of the total power coming from that position in the sky; the spacing between the grid points should not be more than half the antenna beamwidth. When observations are made using a synthesis radio telescope, where the area to be mapped exceeds the instantaneous mapping field, the grid points should not be further apart than half the beamwidth of one of the radio telescope antennas.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data have been processed.

2 FSS

2.1 Allocated transmit band

The active service band considered is from 10.7 to 10.95 GHz.

2.2 Application

The band 10.7 to 10.95 GHz is allocated to the FSS on a primary basis. This allocation is governed by RR Appendix 30B that uses a plan to assign and guarantee capacity to all member nations. Given the general policy of first-come, first-served in unplanned bands, the creation of the RR Appendix 30B Plan allowed developing nations to preserve access to the GSO arc at a future time. Any imposition of constraints such as guardbands or filtering on the FSS would impact the RR Appendix 30B Plan allotments.

2.3 Levels based upon regulatory provisions

Levels of unwanted emissions into the band 10.6-10.7 GHz from the FSS are based on regulatory in-band pfd limits. The conversion from in band to OoB power is done using the RR Appendix 3 spurious emission levels and the OoB emission levels from Recommendation ITU-R SM.1541. A level of –154 dB(W/(m^2 · 4 kHz)) is the level of unwanted emissions that would be received in the band 10.6 to 10.7 GHz based on regulatory levels. A level of −166 dB(W/(m^2 · 4 kHz)) was provided, which is based on practical experience.

2.4 Transmitter characteristics

FSS GSO systems operating in the band are governed by RR Appendix 30B. FSS non-GSO systems operating in the band are governed by RR Article 22.

2.5 Operational characteristics

In order to share with the terrestrial fixed service, the in-band pfd limit from RR Table 21-4 for the FSS ranges from −116 to −126 dB(W/(m^2 · MHz)) which represents a range from −176 to −186 dB(W/(m^2 · Hz)) between 0° and 90° above the horizontal plane.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

Based on experience acquired with some radio astronomy sites and some satellite systems in these bands, information was provided by the radio astronomy community and satellite operators on unwanted levels that could be expected in the band 10.6-10.7 GHz.

4.2 Calculation of the interference level

The calculations performed are all based on information provided in § 4.3, as indicated in § 4.1.

4.3 Values achieved

4.3.1 European example for GSO satellite systems

In Europe, the RAS in the frequency band 10.6-10.7 GHz experiences severe harmful interference by OoB emissions from one FSS system. Specifically, this harmful interference has effectively rendered observations in this band completely impossible at the Effelsberg radio observatory in Germany. The issue has been brought to the attention of the German Administration, which confirmed the observed interference by observations at the Leeheim Satellite Monitoring Station of the German Administration and supported by this evidence also to the attention of the operator.

For example, one real case of interference to RAS operations is described below, with a particular GEO FSS satellite system operating at lower nominal centre frequency of 10.714 MHz with a transponder bandwidth of 26 MHz.

Figure 19 shows the results of RAS measurement at 10.6 GHz by the Effelsberg 100 m radio telescope, looking towards 3C84, one of the strongest point-like cosmic radio sources. This measurement was made before 1995. The field size is 30' × 12', the flux from the source is 20.5 Jy (~ -247 dB(W/(m^{-2} · Hz^{-1}))).

FIGURE 19

Map of the galactic object "3C84" in the 10.6-10.7 GHz band with the Effelsberg 100 m radio telescope *

1633-19

* The source 3C84 has an angular diameter much smaller than the antenna beamwidth, so the image above shows the antenna beam profile, including sidelobes. Since the map has been made to measure the source brightness and not its structure, this is not a problem.

Then in the year 1995 a GSO FSS satellite was put into operation at certain orbital position, where other satellites had been already operating for some time. The satellite has a lower transmitting centre frequency of 10.714 GHz and a transponder bandwidth of 26 MHz. The resulting noise fluctuation generated by unwanted FSS emissions from that orbital position into adjacent RAS band 10.6-10.7 GHz was so strong, that it completely masked any astronomical signals.

Therefore, Fig. 20 shows a consequent map in the same 30' × 12' field of the sky as shown in Fig. 19, but after the satellite was put into operation in the year 1995, its orbital position being spaced 10° from the mapped field of the sky. For comparison, the 3C84 picture from Fig. 19 has been added onto the map in Fig. 20. However, this very strong point source is now no longer visible against the flux caused by the satellite's emissions.

To investigate this case of interference, the satellite monitoring station at Leeheim of the German Regulatory Authority measured a spectrum of the FSS transmissions from the given satellite orbital location (see Fig. 21), in order to determine the level of unwanted emissions into the RAS band. However it should be noted, that the sensitivity and the dynamic range of the monitoring station are not sufficient to verify interference at the levels given as protection criteria for the RAS in Recommendation ITU-R RA.769.

NOTE 1 – In Fig. 20, the galactic object is no longer visible due to interference received.

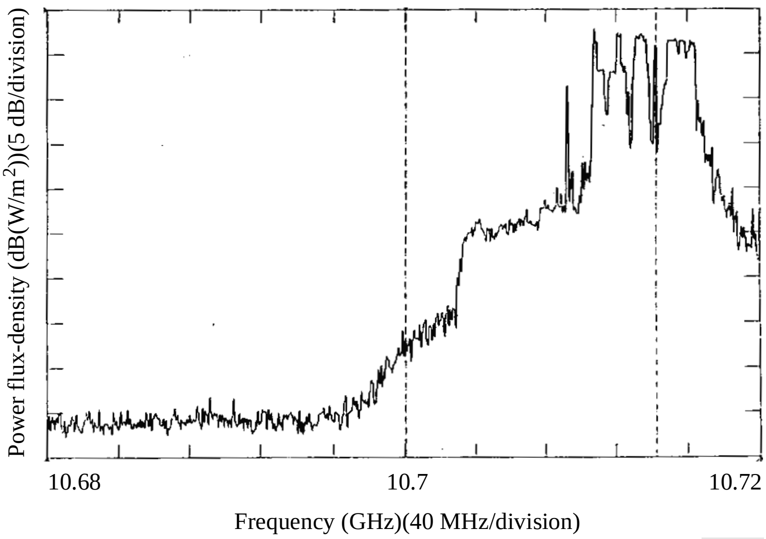
FIGURE 20

Map of the same sky field as in Fig. 19, but with interference received at Effelsberg radio telescope

1633-20

FIGURE 21

Measurement of interference source conducted at Leeheim monitoring station (1995)



1633-21

It may be seen from Fig. 21 that at the 10.7 GHz edge of the RAS allocation, in the passive exclusive band, the unwanted emission level is measured to be –151 dB(W/m^2) in a reference bandwidth of 100 kHz. This corresponds to –201 dB(W/(m^2 · Hz)), whereas Recommendation ITU-R RA.769 gives a 39 dB lower number, –240 dB(W/(m^2 · Hz)), as interference threshold, and additionally considers desirable that more stringent limits of 15 dB be applied in case of GSO satellites. This huge discrepancy occurs at the high edge of the 10.6-10.7 GHz band, and is lower in the rest of the band.

Down from the edge of 10.7 GHz until about 10.69 GHz, where the interfering signal reaches the noise floor of the Leeheim monitoring station (pfd ~ –160 dB(W/m^2)), its roll-off is about 10 dB per 4 MHz. If one assumes that this roll-off rate continues down to 10.6 GHz, the estimated total power emitted from that orbital location into the 10.6-10.7 GHz band would be –145.6 dB(W/m^2), which is 14.4 dB above the –160 dB(W/m^2) threshold given in Recommendation ITU-R RA.769 for the 10.6-10.7 GHz band, and therefore renders the entire 10.6-10.7 GHz completely unusable for radio astronomy observations, as shown in Fig. 20.

Though the operator of the satellite system did improve the system to some extent and filters were installed at the Effelsberg radio telescope an effective solution of this problem is not yet possible.

The following values of levels of unwanted emissions from typical FSS systems falling into the RAS band were provided. Two operators identified that any limit lower than the levels in Table 23 would impose undue constraint on FSS systems currently operating in the 10.7-10.95 GHz frequency band.

TABLE 23

Levels of unwanted emissions falling into the 10.57-10.7 GHz frequency band at specific points

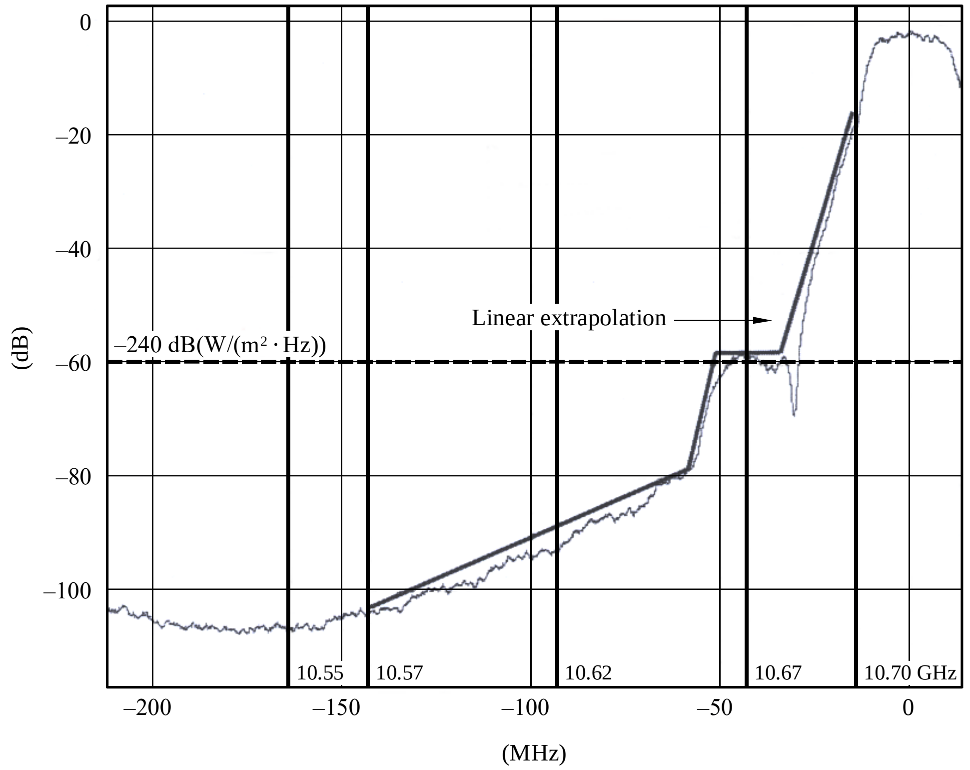
Boundary (GHz)	**Unwanted emission spfd level (dB(W/(m^2 · Hz)))**
10.570	–285
10.656	–256
10.662	–237
10.680	–237
10.700	–195

Figure 22 shows the spfd levels of a digital modulation with a symbol rate of 22 Msymbol/s, a roll-off of 35% and a transponder bandwidth of 26 MHz operating at 10 714 MHz. For practical reasons, the real power decrease was extrapolated by a linear power decrease in order to estimate the power falling into the entire 100 MHz radio astronomy band depending of the frequency offset.

Due to the nature itself of the digital modulation, the digital modulation necessary bandwidth is very close to the transponder bandwidth. Therefore, the spfd levels falling into the upper part of the RAS frequency band is much greater than the spfd levels observed for an analogue modulation (see Fig. 23).

FIGURE 22

Digital OoB emission mask

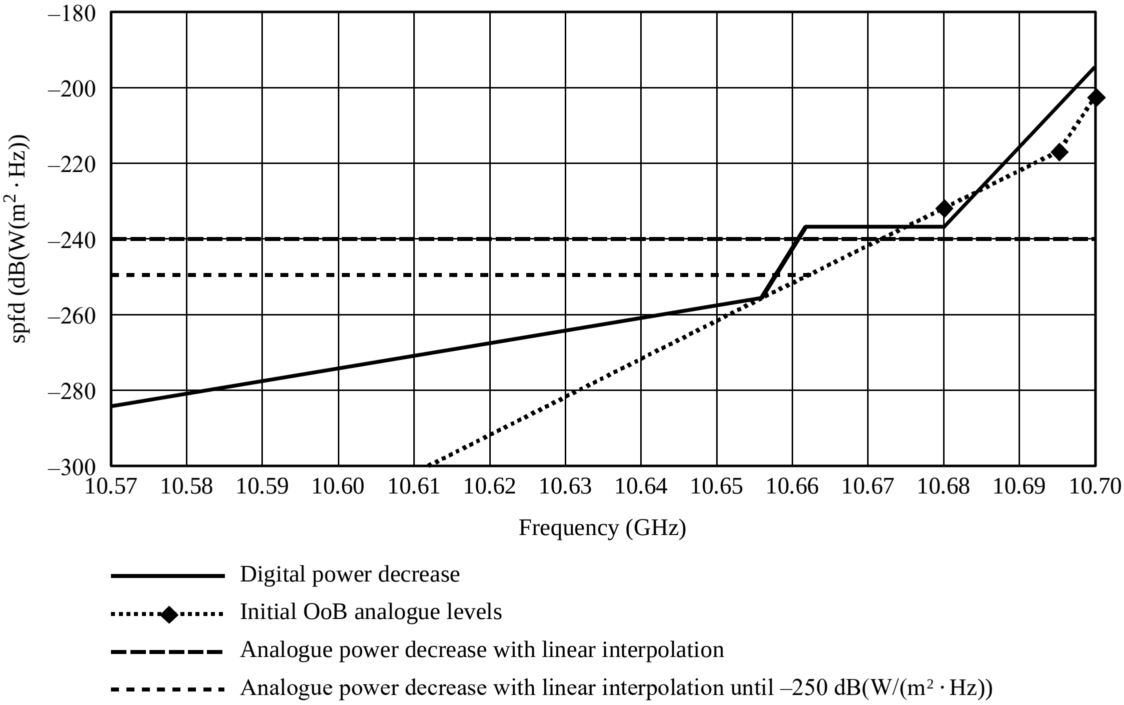


Symbole rate: 22 Msymbol/s, 35% roll-off

1633-22

FIGURE 23

Comparison of spfd levels depending on the type of modulation

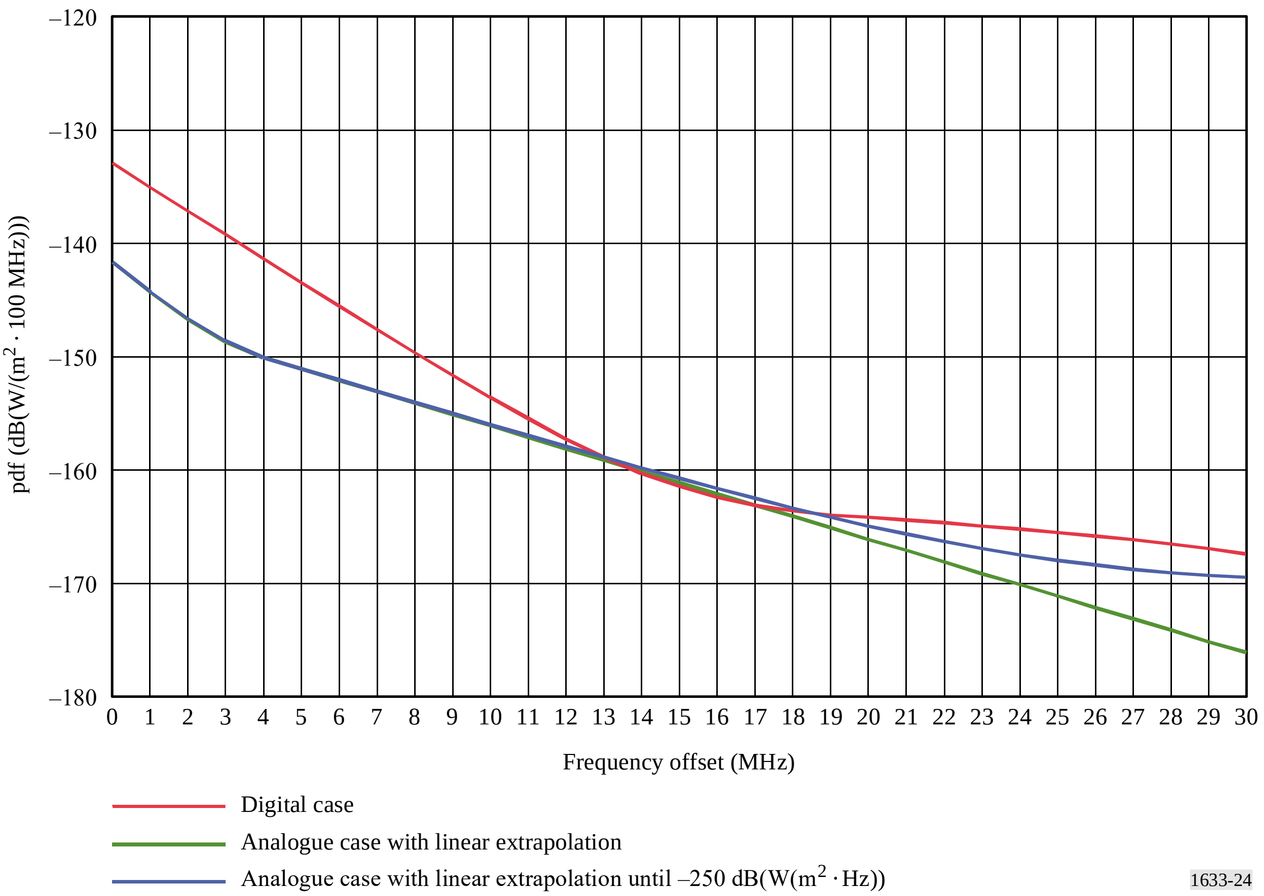


1633-23

From Fig. 23, it is possible to calculate the power falling into a 100 MHz reference bandwidth depending on the frequency where the integrations starts (see Fig. 24).

FIGURE 24

pfd integrated over a 100 MHz bandwidth depending on the type of modulation



In Fig. 24, a frequency offset of 0 MHz means that the integration over 100 MHz starts from 10.7 GHz (and thus ends up at 10.6 GHz), similarly a frequency offset of 30 MHz means that the integration over 100 MHz starts from 10.67 GHz (and thus ends up at 10.57 GHz).

From Fig. 24, under the assumptions that were made with regard to the signal decrease, the threshold level for continuum observations, i.e. –160 dB(W/(m^2 · 100 MHz)), would be met with the implementation of a guardband of at least 15 MHz between the two services. A different assumption with regard to the signal decrease could result in a larger required guardband.

Therefore, to reach a conclusion on a possible frequency separation that would make both services compatible in this example, the assumptions in terms of signal decrease should be validated.

4.3.2 Region 2 example for GSO satellite systems

In November, 1993 the United States National Radio Astronomy Observatory (NRAO) conducted a survey of the geostationary belt from 152° W to 7° W in the 10.68-10.7 GHz band, using its 43 m telescope at Green Bank, West Virginia, (since decommissioned) to determine the levels of emission that may be present, and determined that this portion of the sky was free of emissions to at least the –250 dB(W/(m^2 · Hz)) level.

One case in Region 2 concerns two identical GSO satellites operating in the 10.75-10.95 GHz band, and using the 10.75-10.95 GHz band in accordance with RR Appendix 30B to provide feeder links for an MSS application. In another case, an operator provided data on the expected performance of their space station in the 10.6-10.7 GHz band.

In the case of the two identical GSO satellites mentioned above, special filters providing attenuation just over 40 dB in the 10.6-10.7 GHz band were installed at significant expense to the operators, to satisfy domestic concerns of protection of the passive services. The satellites generate interference into the 10.68-10.7 GHz band from two independent sources:

– radiated thermal noise generated in a travelling wave tube amplifier (TWTA). The worst case thermal tube noise e.i.r.p. was measured to be –27 dB(W/4 kHz) at the peak of the antenna pattern in the 10.68-10.7 GHz band, resulting in a spfd of –226.2 dB(W/(m^2 · Hz)), after subtraction of a spreading loss of –163.2 dB(W/m^2); and

– intermodulation (IM) products among carriers generated by non-linearities in the TWTA. The 10.75 to 10.95 GHz downlink band is subdivided into 27 sub-bands, each carrying varying numbers of radio carriers. Under peak loading conditions, approximately 600 carriers will be on simultaneously and distributed across the sub-bands. In order to estimate the level of IM falling in the radio astronomy band, a worst-case simulation was done in which the sub-bands were filled with Gaussian noise to simulate the presence of many carriers, and the TWTA was run at maximum loading level. The simulation used measured TWTA input-output transfer characteristics and resulted in a peak IM product spfd level (including all IM product orders) in the 10.69-10.70 GHz band of –223.0 dB(W/(m^2 · Hz)). The average worst case IM spfd over this band is –231 dB(W/(m^2 · Hz)). Values for the remainder of the RAS band are approximately 5 dB less (i.e. peak of –228.0 and average of –236.0 dB(W/(m^2 · Hz)).

The IM is generated by hundreds of independent radio carriers that are modulated by random, independent bit streams. Each modulator applies a 24-bit maximal pseudo-random noise sequence on top of the information stream, assuring minimal cross-correlation between carriers. There are thousands of individual independent products distributed across the radio astronomy band. The radio carriers themselves are turned on only when speech is present, further adding to the randomness of the composite IM signal. It therefore appears that the IM products will behave very much like wideband Gaussian noise.

The radio carriers are demand assigned when needed, otherwise they are turned off. As a result, these worst-case conditions will occur during normal business day busy hours typically occurring in a twelve-hour period during the day. At night, weekends and holidays the peak loading will be greatly reduced. This reduction in loading moves the operation of the TWTA into a more linear region, reducing the IM level. Fewer radio carriers also reduce the number of IM products. During these off-peak periods the IM spfd is reduced by at least 40 dB, or in the vicinity of –260 dB(W/(m^2 · Hz)).

Total interference estimate: the tube noise and IM noise combined are wideband Gaussian distributed. The worst-case average spfd across the 10.6 to 10.69 GHz band is estimated to be –225.6 dB(W/(m^2 · Hz)), rising to –221.3 dB(W/(m^2 · Hz)) at 10.7 GHz. During light traffic loading periods the average spfd across the entire band is estimated to be –226.2 dB(W/(m^2 · Hz)).

4.3.2.1 Computer simulation

One study based on a computer simulation demonstrated that the bringing into use of any RR Appendix 30B allotment would cause interference above the continuum pfd threshold level listed in § 1.3 for all radio telescopes having visibility of the space station. The study highlighted the fact that the largest portion of the unwanted emission power falling into the 10.6-10.7 GHz band occurs on the band edge. It should be pointed out that the use of Recommendation ITU-R SM.1541 to establish the OoB level overestimates the unwanted emission level, as this represents integration over a worst-case mask. Additional studies are required based on a mask representing typical unwanted emission performance.

4.3.3 Non-GSO satellite systems

As yet no non-GSO satellite system operates in the 10.7-10.95 GHz band, but several are planned to begin operations in the near future. Preliminary calculations were performed for one of these systems (F-SATMULTI1 B), using the epfd method (see Recommendations ITU-R RA.1513 and ITU-R S.1586). These calculations show that using the assumptions in Recommendation ITU-R RA.769, filtering values between 30 dB and 40 dB, would be required to protect the RAS in the 10.7 GHz band from spurious emissions of this system to the –240 dB(W/(m^2 · Hz)) level within a 100 MHz bandwidth. This result is consistent with the first GSO example described above.

5 Mitigation techniques

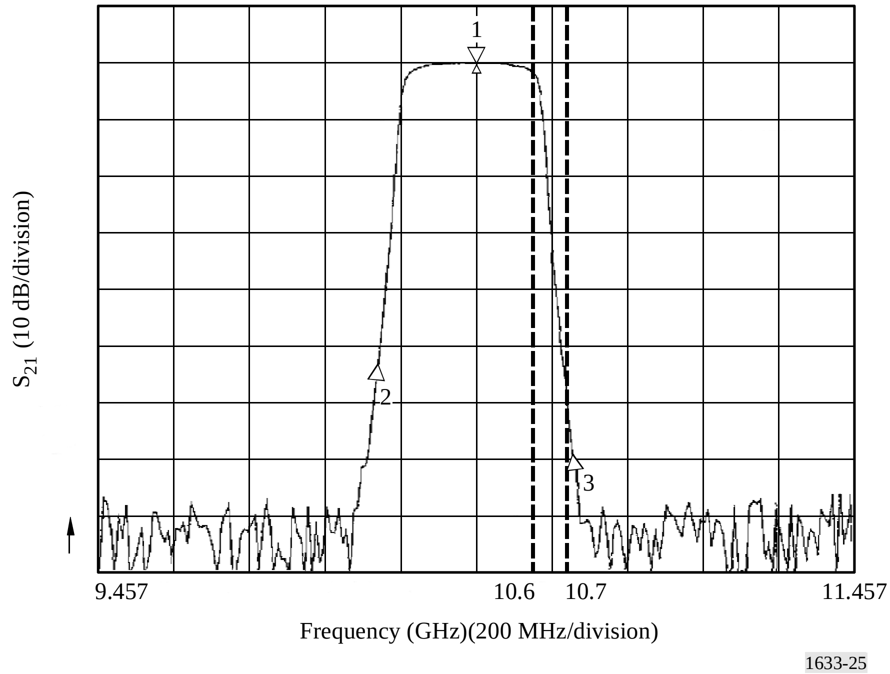
5.1 RAS

In order to continue RAS observations in the interference situation described in § 4.3.1, a filter was introduced into the receiver front-end of the radiotelescope. The specification for the filter was designed so as to suppress the main transmission from an interference source by 70 dB, while leaving sufficient pass-band with minimal insertion loss.

Amplifiers based on field effect transistors could be retuned to the somewhat lower frequency without loss of gain or increase in noise figure and a good commercially available filter design could be found. Figure 25 shows the transfer function for the filter, as provided by the filter manufacturer.

FIGURE 25

Filter attenuation curve of the band-rejection filter implemented at the radiotelescope mentioned in § 4.3.1



Marker 3 in Fig. 25 is set to the nominal centre frequency of interfering satellite transmission, that is 10.714 GHz. Note that the RAS band allocation, 10.6-10.7 GHz is marked by the dashed lines.

It should be noted that the above-described filter, which has been designed to protect the RAS receiver, provides minimal insertion loss at a frequency separation of roughly 200 MHz from the centre frequency of a rejected signal. As filter technology progresses, better figures may be achievable, but the currently available instrumentation requires a frequency shift of at least 100 MHz to be made.

It should be also noted that usable RAS observations could be made at Effelsberg in a frequency band around 10.5 GHz, which is allocated to the terrestrial fixed service, and in which interference is reported only occasionally. This may not be applicable in other countries due to their particular use of the fixed service in this band.

5.2 The active service

A number of possible mitigation methods may be implemented to minimize the impact on the passive service. These are listed in Recommendation ITU-R SM.1542. Certain specific cases that have been applied to protect the passive services operating in the band 10.6-10.7 GHz are listed below:

– One administration found that, while interference limits in Recommendation ITU-R RA.769 provided protection against interference to RAS operations, more flexibility could be exercised by requiring that non-GSO FSS service providers coordinate and reach a mutually acceptable agreement with the RAS facilities that use the 10.6-10.7 GHz band, that ensure that these facilities are adequately protected from interference. To that effect, a footnote was added to the relevant National Table of Allocations. The text of this footnote is as follows:

  "In the band 10.7-11.7 GHz, non-geostationary satellite orbit licensees in the fixed-satellite service (space-to-Earth), prior to commencing operations, shall coordinate with the following radio astronomy observatories to achieve a mutually acceptable agreement regarding the protection of the radio telescope facilities operating in the band 10.6-10.7 GHz" (NOTE 1 – In this place in the footnote, a Table of Radio Astronomy sites follows).

– One contribution suggests that the possibility to set a guardband between the FSS band and the RAS band should be considered (see considerations on this issue in § 4.3.1). Results of the band-by-band studies may conclude that the only option is to seek the implementation of a guardband between the FSS and RAS. However, the apportionment of the burden of the guardband between the services needs consideration.

  It should be kept in mind that any guardband imposed on the FSS would impact the RR Appendix 30B Plan. Similarly, any guardband imposed on the RAS would result in an increase in measurement time thus reducing the usage of RAS stations.

  Similarly, if an extension of the RAS allocation below 10.6 GHz is considered to allow the RAS service to operate properly in a 100 MHz bandwidth, this may impact services operating below 10.6 GHz.

5.3 Potential impact

5.3.1 RAS

From the radio astronomy side, it is technically not possible to filter the interference mentioned in § 4.3.1. Even a well designed BSS/FSS system would force radio astronomy observatories to insert filters into the receiver front ends. The receiver front ends in use today at radio observatories normally contain cooled high electron mobility transistor (HEMT) amplifiers, which are inherently broadbanded. The passband of the first stage amplifier drops slowly outside the edge of the designed bandwidth. Satellite transmitters, especially, which come close enough to the observing direction, may cause non-linearity of the receiving system and therefore filtering may be required before the first amplifier stage of the receiver front-end. In designing radio astronomy receivers, however, one always tries to avoid transmission loss, which raises the receiver noise temperature. This loss would occur when insufficient guardband is taken into account to protect radio astronomy observations, also because at the frequencies under consideration the filter technology is not developed sufficiently.

5.3.2 FSS

Filters may be used to suppress unwanted emissions, but the addition of filters may affect the satellite design in a substantial manner:

– The insertion loss introduced by the filter can result in a loss of capacity. To compensate for the loss requires an increase in HPA size, with consequential impacts to the space station design (cost, weight, power, reliability).

– The insertion of a filter impacts the phase response of the in-band signal. If the phase tolerance levels of the receiver are exceeded, the performance of the link will be impacted even though there is sufficient power at the receiver.

– The addition of a filter increases the complexity of the space station design and testing program.

Furthermore, if a phased-array active antenna is used, filters may be required for every antenna element.

For multi-beam satellite systems planned for operation in the frequency range of interest, the number of beams or the number of elements in the phased-array antenna system multiplies the cost and weight implications of additional RF filtering in the multi-beam system. This is due to the fact that in a multi-beam system the output amplifiers are generally not shared between beams, and so would have to be filtered separately. In a phased array type system the final stage of amplification takes place at the various elements of the array, each of which would have to be filtered separately. In this way the number of beams multiplies the weight impact of an individual filter in the system, or number of elements in the phased array. The filter insertion loss could impact system capacity.

Geographic isolation would involve the use of satellite antenna pattern roll-off to achieve the required isolation to meet an agreed sharing criterion at a particular radio astronomy receiver site. This technique tacitly assumes that an FSS system will not have a global, or even regional, coverage area, which is a limiting assumption in itself. Many 10-14 GHz band systems have regional or sub-regional beams where geographic isolation is not feasible. Other spot beam systems may be able to use geographic isolation; however, this is not an attractive solution from the satellite system perspective at is could result in areas of the Earth being unavailable to the satellite service. Such limitations of the FSS service area could have serious revenue-generating implications. However, this solution does have the benefit of taking into account the actual protection requirements of specific radio astronomy sites, without the need to resort to the worst-case criteria at every radio astronomy site.

6 Results of studies

6.1 Summary

In Region 2, currently available design practices and mitigation methods have protected the radio astronomy service in the 10.6-10.7 GHz band from the limited number of FSS space stations currently deployed. In cases where the usage of the RR Appendix 30B Plan may have interfered with radio astronomy observations, domestic pressure in another country ensured that the situation was corrected. However the deployment of future space stations that do not intentionally seek to protect radio telescopes could adversely impact their operations.

In Region 1, the juxtaposition of bands allocated to the RAS and the FSS or BSS, for use in transmitting signals in the space-to-Earth direction, has given rise to a difficult interference situation in some countries - one that can only be solved through the provision of a guardband between the two services. In this band, the protection criteria listed in § 1.3 are satisfied by the active service for the VLBI case, but not for the single-dish continuum case. Mitigation methods have been used in Region 2 to meet the single-dish continuum level. However, in Region 1 there are currently persistent cases of detrimental interference.

No data was received and no studies were done for Region 3.

6.2 Conclusion

In Region 1 the protection criteria are met for the VLBI case, but not for single-dish continuum or spectral line observations. In Region 2 the protection criteria are met for the VLBI case.

Annex 11

Compatibility analysis between the EESS (passive) in the 21.2-21.4 GHz band and both FSS (space-to-Earth) and MSS (space-to-Earth) systems in the 20.2-21.2 GHz band

1 EESS (passive)

1.1 Allocated band

Table 24 provides a listing of the services in the 21.2-21.4 GHz band and the bands adjacent to it.

TABLE 24

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
20.2-21.2 GHz	21.2-21.4 GHz	21.4-22 GHz
FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) Standard frequency and signal satellite (space-to-Earth) 5.524	EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE SPACE RESEARCH (passive)	FIXED MOBILE BROADCASTING SATELLITE (Regions 1 and 3) 5.530 5.531

NOTE 1 – Different from other bands, this allocation is not exclusive. The BSS will not come into effect until 1 April 2007.

1.2 Application (type of observation)

This band was used on the Nimbus-7 experimental satellite. On the advanced microwave sounder unit (AMSU) instrument the 23.6 to 24 GHz band is used. The AMSU antenna characteristic will be assumed for this band because this band would be used in support of other measurements on this instrument and because it is an alternate band to the 23.6-24 GHz band.

This band and the 23.6 to 24 GHz bands are used for measurements of water vapour and liquid water. Therefore they are used for both surface and atmospheric measurements. They are on either side of the 22.235 GHz water-vapour spectral line. Atmospheric measurements are used with oxygen, O_2, temperature measurements to remove the effect of water vapour on temperature profiles.

1.3 Required protection criteria

The following Recommendations establish the interference criteria for passive sensors.

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

1.4 Operational characteristics

Table 25 provides the operating characteristics of the sensor under study.

TABLE 25

Parameters of the advanced microwave sounding unit scanning sensor

Parameter	Value
Altitude (km)	850
Orbit	Sun-synchronous polar
Main lobe antenna gain (dBi)	36
Antenna 3 dB beamwidth (degrees)	3.3
Backlobe and side-lobe gain (dBi)	–10
Pixel diameter at nadir (km)	49
Pixels per scan	90
Scan width (km)	2 300

2 FSS (space-to-Earth) and MSS (space-to-Earth)

2.1 Allocated transmit band

Refer to Table 24.

2.2 Application

The active services under consideration for this Annex are the FSS (space-to-Earth) and the MSS (space-to-Earth) in the 20.2-21.2 GHz band.

2.3 Levels based on RR provisions and ITU-R Recommendations

2.3.1 RR No. 1.153

The RR defines *occupied bandwidth* as follows:

"1.153 *occupied bandwidth*: The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage β/2 of the total *mean power* of a given *emission*.

Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of β/2 should be taken as 0.5%."

If the upper edge of the occupied bandwidth were at or below the upper limit of the satellite service allocation, the total power of unwanted emissions at frequencies above the allocated bandwidth would be no greater than 0.5% of P, where P is the in-band power. Therefore, the total power of unwanted emission at frequencies in the EESS band and above is no greater than $P - 23$ dB.

2.3.2 Recommendation ITU-R SM.1541

Recommendation ITU-R SM.1541 provides guidance on unwanted emissions falling outside the allocated bandwidth.

2.3.3 Recommendation ITU-R SM.329

Recommendation ITU-R SM.329 provides information on unwanted emissions falling into the spurious domain.

Even though levels are provided for narrowband and broadband spurious emissions it is noted that, except for spurious components, emissions roll off beyond the OoB domain. This analysis will consider the emissions to roll off at 40 dB per decade. The impact of spurious emissions will be handled as accumulative components of several emitters.

2.4 Transmitter characteristics

The transmitter characteristics are derived from Recommendation ITU-R S.1328-3 – Satellite system characteristics to be considered in frequency sharing analyses between geostationary-satellite orbit (GSO) and non-GSO satellite systems in the fixed-satellite service (FSS) including feeder links for the mobile-satellite service (MSS). This Recommendation tabulates a variety of satellite systems that are representative of systems that are being considered for deployment in various bands.

2.5 Operational characteristics

Twenty-six FSS or MSS systems were specified in the reference for use in the 20.2-20.4 GHz band. Both GSO and non-GSO systems are included.

No non-GSO systems listed in the reference operate between 19.7-20.3 GHz. The list below shows characteristics for systems that operate below 19.7 GHz. In spite of the lack of listings, non-GSO operation is not prohibited in this band.

2.6 In-band transmit level

See Tables 26 and 27.

TABLE 26

Downlink characteristics of GSO space stations

System	**GSO-20**	**GSO-30**	**GSO-F**	**GSO-13**
Service	FSS/MSS	FSS	MSS	FSS
Polarization	LHCP/RHCP	LHCP/RHCP		RHCP/LHCP
Modulation	FDMA/QPSK	Phase	FDM/TDM/QPSK	
Bandwidth (MHz)	1.8	3 200	125	81
e.i.r.p. (dBW)	57	74	61.8	59.5
Antenna gain (dBW)	40.9	55	49.0	46.5
Number of satellites	Unknown	12	Unknown	17

TABLE 27

Downlink characteristics of non-GSO space stations

System	**LEO A**	**LEO B**	**LEO SAT-1**	**Quasi-GSO 31**
Service	MSS	MSS	FSS	FSS
Orbit	Circular	Circular	Circular	Elliptical
Altitude (km)	780	10 355	700	1 000-43 000
Inclination (degrees)	86	50	98.2	63
Satellites in plane	11	4	40	1
Planes	6	3	21	8
Satellite in plane (degrees)	32.7	90	9	–
Plane phasing (degrees)	31.6	30	Random	Varies
Polarization	LHCP	RHCP	LHCP/RHCP	LHCP/RHCP
Modulation	FDMA/QPSK	CDMA	Shaped QPSK FDMA	Phase
Bandwidth (MHz)	4.37	2.5	500	3 200
e.i.r.p. (dBW)	15	5.31	47.5	74
Antenna gain (dBi)	26.9	35.7	28.9	55

3 Compatibility threshold

There are two criteria for the 21.2-21.4 GHz band. First there is a power threshold of −163 dBW in 100 MHz. This is a maximum interference level from all sources. Secondly the availability criterion is 99% of all measurement cells or 1% loss of measurement pixels.

Interference is potentially received from several sources arising from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service. Therefore further work is needed to address the impact of multiple active services above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

The interference level of unwanted emissions is calculated for each FSS satellite in § 4.2.2.

4.1.1 Use of the mask presented in Recommendation ITU-R SM.1541 for determination of OoB emissions

Annex 5 of Recommendation ITU-R SM.1541 specifies a generic mask for OoB emissions for FSS earth and space stations. It is of the form:

$$40 \log \left(\frac{F}{50} + 1 \right) \quad \text{dBsd}$$

where F is the frequency offset from the edge of the total assigned band, normalized as a percentage of the necessary bandwidth of the allocation or the lower transponder, whichever is least. The mask rolls off to the spurious boundary or to the point where it is equal to the RR Appendix 3 spurious limits (see Annex 5, Recommendation ITU-R SM.1541). It provides the minimum attenuation for OoB emissions relative to the maximum PSD in-band of the adjacent assigned band. The integration of this mask for power OoB is shown in Fig. 26. This Figure also includes the integral of a rectangular pulse and a raised cosine shaped pulse.

The integration above is the power from the specified percent of the necessary bandwidth out to infinity. However in cases where the necessary bandwidth of the emissions is broad, the passive sensor bandwidth is a small percentage of it. For a 500 MHz bandwidth, the passive sensor covers only 20% of its bandwidth. For the system with a 3 200 MHz bandwidth the passive sensor is only 3% of the necessary bandwidth. The power in the passive sensor bandwidth is less than indicated on the Figure. To adjust for this the power can be adjusted. For the situation where the necessary bandwidth only is in the active band the passive band extends from the 50% point to the 70% point for the 500 MHz system and from the 50% point to the 53% point for the 3 200 MHz system. For these cases the powers are as shown in Table 28.

FIGURE 26

Relative power depending of frequency offset

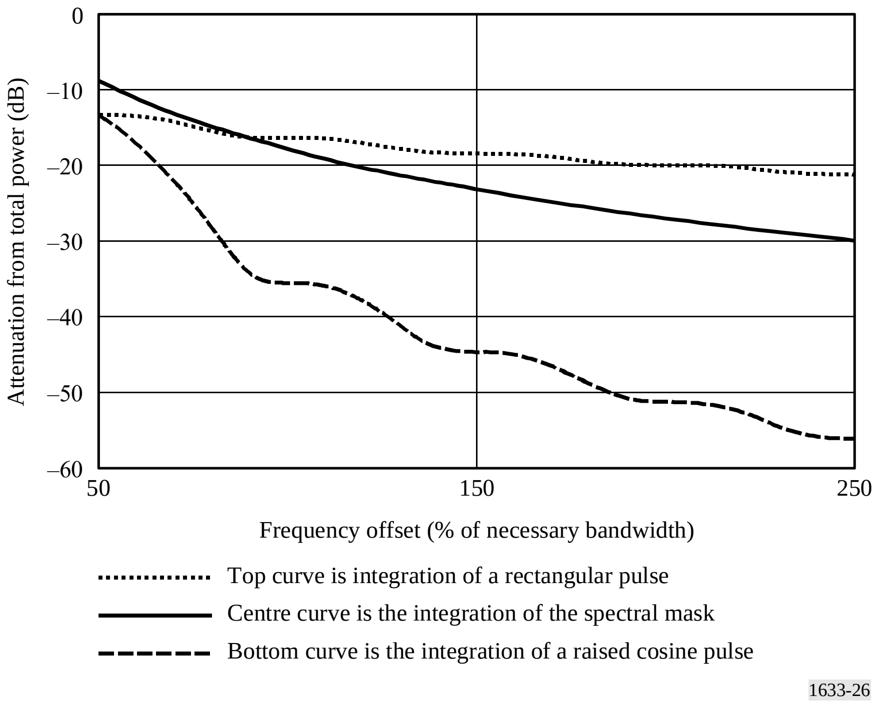


TABLE 28

Relative power in a passive sensor bandwidth

Necessary bandwidth (MHz)	Spectral mask from Recommendation ITU-R SM.1541 (dB)	Rectangular pulse (dB)	Raised cosine pulse (dB)
125	–9.1	–15.4	–13.7
500	–10.8	–20.5	–14.4
3 200	–16.7	–44.4	–21.8

4.1.2 Assumption that the occupied bandwidth does not extend beyond the space service band

If an unwanted emission power level of *P* – 23 dB does not cause excessive interference, a potential interference mitigation solution is to keep the occupied bandwidth within the allocated band. (See RR No. 1.153.)

4.1.3 Interference threshold

The passive service interference threshold from Recommendation ITU-R SA.1029 is –163 dBW in 100 MHz for sensors operating near 20 GHz.

4.2 Calculation of interference level

4.2.1 Direct interference path

An assessment of the levels of unwanted emissions produced by FSS satellites into EESS receivers via a direct radio path from the FSS transmitter via the backlobe of the EESS sensor antenna is provided in Table 29 for GSO FSS systems and Table 30 for non-GSO FSS systems. These calculations indicate the level amount of spectral attenuation, if any, that would be required if the emissions were co-channel.

TABLE 29

Interference power levels from GSO FSS satellite networks

FSS satellite network	**GSO-20**	**GSO-30**	**GSO-F**	**GSO-13**
FSS altitude (km)	35 786	35 786	35 786	35 786
EESS altitude (km)	850	850	850	850
Separation distance (km)	34 936	34 936	34 936	34 936
FSS transmit power (dBW)	16	19	13	13
FSS antenna gain (dBi)	40.9	55.0	49.0	46.5
FSS e.i.r.p. (dBW)	57	74	61.8	59.5
FSS bandwidth (MHz)	1.8	3 200	125	81
EESS bandwidth (MHz)	100	100	100	100
e.i.r.p. in EESS bandwidth (dBW)	74.4	58.9	60.8	60.4
EESS backlobe antenna gain (dBi)	–10	–10	–10	–10
Free space loss at 23.6 GHz (dB)	210.8	210.8	210.8	210.8
Co-channel interference level (dBW)	–146.3	–161.8	–159.9	–160.4
EESS interference criterion (dBW)	–163	–163	–163	–163
Difference between interference level and EESS criterion (dB)	–16.7	–1.2	–3.1	–2.6

These calculations assume that the FSS satellite is directly above the EESS satellite and the unwanted emissions are received via the backlobe of the EESS sensor antenna, except in the case of LEO A and LEOSAT-1 where the non-GSO satellites have a lower altitude than the EESS satellite. In these cases, a value of –10 dBi was assumed for the backlobe gain of the non-GSO satellite in the direction of the EESS directly above it. However, the effects of shielding by the body of the satellite were not taken into account in these calculations. Although the calculations for these two non-GSO FSS satellites are based on the –10 dBi EESS sensor sidelobe gain, the possibility exists in these cases that the EESS main beam can be pointed at the non-GSO FSS satellite below it producing very high levels of interference in the EESS receiver for short periods of time.

TABLE 30

Interference power levels from non-GSO FSS satellite networks

FSS satellite network	**LEO A**	**LEO B**	**LEO SAT-1**	**Quasi-GSO 31**	
FSS altitude (km)	780	10 355	700	1 000	43 000
EESS altitude (km)	850	850	850	850	850
Separation distance (km)	70[(1)]	9 505	150[(1)]	150	42 150
FSS transmit power (dBW)	–12	–30	19	19	19
FSS antenna gain (dBi)	–10.0	35.7	–10.0	55.0	55.0
FSS e.i.r.p. (dBW)	15	5.31	47.5	74	74
FSS bandwidth (MHz)	4.37	2.5	500	3 200	3 200
EESS bandwidth (MHz)	100	100	100	100	100
e.i.r.p. in EESS bandwidth (dBW)	28.6	21.3	40.5	58.9	58.9
EESS backlobe antenna gain (dBi)	–10	–10	–10	–10	–10
Free space loss at 23.6 GHz (dB)	156.8	199.5	163.4	163.4	212.4
Co-channel interference level (dBW)	–138.2	–188.1	–132.9	–114.5	–163.5
EESS interference criterion (dBW)	–163	–163	–163	–163	–163
Difference between interference level and EESS criterion (dB)	–24.8	25.1	–30.1	–48.5	0.5

(1) The non-GSO FSS satellite is below the EESS satellite in this case.

4.2.2 Backscatter interference

Another form of interference power into the passive service to be considered is the case where the OoB emissions of the FSS are scattered from the Earth's surface upwards toward a nearby EESS sensor. For frequencies around 20 GHz, the scattered energy has a significant specular component. Hence, the maximum interference would occur when:

– the sensor views a FSS coverage area;

– the FSS satellite, the sensor, the Earth's centre, and the intersection of the FSS and sensor beams all lie in the same plane;

– the intersection of the FSS satellite and sensor beams lie between the FSS satellite and sensor nadirs; and

– the FSS satellite beam axis and the sensor beam axis intersect the Earth at the same angle.

Although models were constructed to evaluate the potential levels of unwanted FSS emissions into EESS receivers due to this back-scatter propagation mode, the accuracy of such models requires further review. (See technical Appendix to Annex 1.)

4.3 Values achieved

The discrepancy between the EESS interference protection criteria and the co-channel interference power for non-GSO satellites ranges from –48.5 dB to no interference. The discrepancy between the EESS interference protection criteria and the co-channel interference power for GSO systems are in the −1.2 to −16.7 dB range.

The levels of unwanted emissions falling within the EESS bandwidth can be reduced by the application of the OoB emission masks described in § 4.1.1 or by keeping the occupied bandwidth within the allocated band as described in § 4.1.2.

5 Mitigation techniques

5.1 EESS (passive)

The passive service is not providing any interference to other services therefore it cannot apply any mitigation techniques to reduce interference. The only mitigation technique for the passive services is the sacrifice of data quality and availability. However this band is one of four bands that are so sensitive and critical for weather forecasting that any compromise in the quality and reliability of the data resulting from excessive OoB emissions could jeopardize public safety during dangerous weather conditions (e.g. flooding, storms).

5.2 FSS and MSS

– Guardbands – This is an offset of the closest channel from the allocation band edge.

– Reduced spectral emissions through the use of more efficient modulation techniques and filtering. Note in Fig. 26 that the raised cosine pulse waveform has far less interference potential than the rectangular pulse or the spectral mask.

– Revision of the recommended mask to conform more closely to the actual spectrum and provide a limit for the passive service to guarantee no interference.

5.3 Potential impact

5.3.1 EESS (passive)

The loss of this data due to excess OoB emissions would be considered irrevocable and permanent since RF contamination almost never gets better, only worse. This data is so critical to weather and climate forecasting that it cannot be compromised without some impact on public safety.

5.3.2 FSS and MSS

Mitigation techniques for systems that are currently in use may not be practical. Improvement of the spectral efficiency or the use of guardbands may come at a cost in equipment or channel capacity, but may also have the effect of improving the efficiency and channel capacity. The ultimate impact is likely to be financial in the extra cost of doing business and reduced customer services.

6 Results of studies

6.1 Summary

This study addressed compatibility between EESS (passive) in the 21.2-21.4 GHz band and both MSS and FSS (space-to-Earth) in the 20.2-21.2 GHz band. The characteristics of the mobile and fixed systems in the band 21.2-22 GHz are not available. Further studies are required.

6.2 Conclusions

Based on this compatibility analysis, assuming that an appropriate OoB emission mask is applied or that the FSS occupied bandwidth is contained wholly within the FSS allocated band, it appears that compatibility can be achieved in all but two cases involving non-GSO FSS satellites. Dynamic analysis of these two cases to determine the EESS availability may resolve the compatibility issue in these cases.

Annex 12

Compatibility analysis between RAS systems operating in the 22.21-22.5 GHz band and BSS (space-to-Earth) systems operating in the 21.4-22 GHz band

1 Radio astronomy

1.1 Allocated band

The 22.21-22.5 GHz band is allocated on a primary basis to the RAS.

RR No. 5.149 states that in this band "In making assignments to stations of other services ... administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference".

1.2 Type of observations

The frequency band is used by the RAS for both continuum observations as well as spectroscopic line observations of the water molecule, whose spectroscopic band in this frequency range is one of the most important for radio astronomy (see Recommendation ITU-R RA.314, Table 31 and the List of Important Spectral Lines of the International Astronomical Union).

The water molecule transitions in this band are observed using both single-dish and VLBI techniques.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands.

For the 22.21-22.5 GHz band, the pfd threshold limit given in Recommendation ITU-R RA.769 for single-dish line observations made using a channel bandwidth (one of the spectrometer channels) of 250 kHz is −162 dB(W/m^2). A pfd threshold limit of −146 dB(W/m^2) is defined for single-dish continuum observations in this band, made using the entire 290 MHz bandwidth.

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, −128 dB(W/m^2), for a bandwidth of 250 kHz.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems and in Recommendation ITU-R M.1583 for MSS and RNSS systems.

The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealised circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

1.4 Operational characteristics

Observations in the 22.21-22.5 GHz band are carried out at a number of radio astronomy sites in numerous countries, worldwide. They may be of continuum emissions, spectral lines, or VLBI experiments. Observations in this band are sometimes conducted on targets of opportunity, e.g. on objects such as comets. VLBI spectral line observations are also frequently conducted in this band.

Spectral line observations are made using multichannel spectrometers that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band. The number of channels and their individual bandwidths are chosen to adequately sample the spectrum of the net emission from the sources in the antenna beam.

In general, observations are made differentially. In the case of continuum emissions, a map may be made of the area of sky containing the source, and the background emission subtracted, measurements are made of the power coming from the direction from the source (on-source) and at one or more nearby positions in the sky (off-source). By subtracting the off-source values from the on-source values, the emission originating in the source is separated from other contributions to the receiver output.

In the case of spectral line observations, spectra are recorded at frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). By subtracting the reference spectra from the line spectra, unwanted noise contributions and other contaminants can be removed from the data.

Extended areas of radio emission are mapped by recording the emission from a grid of points covering the region of interest. Both continuum and spectral line observations may be made. In the case of single antenna radio telescopes, each grid point observation is an indication of the total power (in the continuum case) or the emission spectrum (in the spectral line case) coming from that position in the sky; the spacing between the grid points should not be more than half the antenna beamwidth. When observations are made using a synthesis radio telescope, where the area to be mapped exceeds the instantaneous mapping field, the grid points should not be further apart than half the beamwidth of one of the radio telescope antennas.

VLBI observations are made by down-converting the signals to a baseband, digitizing them without rectification, and recording them on tape or other storage media, along with precise timing signals. The data are then taken to a VLBI data processing centre, where the signals are synchronized and correlated. Consequently, the full impact of interference might not be known until the observing period is over and the data has been processed.

2 BSS

2.1 Allocated transmit band

The frequency range of the active service allocation is from 21.4 to 22 GHz.

2.2 Service

WARC-92 has reallocated the band 21.4-22.0 GHz in Regions 1 and 3 to the BSS high definition digital television (HDTV) service to be implemented after 1 April 2007. This band has been identified for the development of a future allotment plan.

2.3 Levels based on regulatory provision

Annex to Resolution 525 (WARC-92), Section III – Interim procedure relating to operational BSS (HDTV) systems introduced before 1 April 2007.

For the purpose of introducing operational BSS (HDTV) systems in the band 21.4-22.0 GHz in Regions 1 and 3 before 1 April 2007, the procedure contained in Resolution 33 (WARC-79) shall be applied if the pfd at the Earth's surface produced by emissions from a space station, on the territory of any other country, exceeds:

– −115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0° and 5° above the horizontal plane; or

– −105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25° and 90° above the horizontal plane; or

– values to be derived by linear interpolation between these limits for angles of arrival between 5° and 25° above the horizontal plane.

Annex to Resolution 525 (WARC-92) Section IV – Interim procedure relating to BSS (HDTV) systems introduced after 1 April 2007.

For the purpose of introducing and operating BSS (HDTV) systems in the band 21.4-22.0 GHz in Regions 1 and 3 after 1 April 2007, and before a future conference has taken decisions on definitive procedure, the procedure in Sections B (Coordination procedure between space stations in the broadcasting-satellite service and space systems of other administrations) and C (Notification, examination and recording in the Master Register of assignments to space stations in the broadcasting-satellite service dealt with under this resolution) of Resolution 33 (Rev.WRC-97) shall be applied.

2.4 Transmitter characteristics

The following assumptions were made:

– the antenna gain of the BSS system is the same in the BSS and in the RAS band;

– maximum spfd/pfd levels are used for the unwanted emissions from BSS systems falling into the radio astronomy band.

These represent worst-case assumptions that could be refined through further studies.

In addition, this study was based on a single BSS system only because of lack of information for other systems by the time of this study. These characteristics could be refined through further studies.

2.5 Operational characteristics

This Annex only addresses the case of GSO systems. The case of non-GSO systems would have to be further studied.

2.6 In-band transmit level

See § 2.3.

3 Compatibility threshold

See § 1.3.

4 Interference assessment

4.1 Methodology used to assess the interference level

See § 2.4.

4.2 Calculation of interference level

Maximum levels of unwanted emissions from considered BSS systems operating in the band 21.4-22 GHz and falling into the 22.21-22.5 GHz radio astronomy band are given in Table 31.

TABLE 31

Maximum levels of unwanted emissions from BSS systems

Band (GHz)	Maximum unwanted narrow-band emission spfd level (dB(W/(m^2 · Hz)))	Maximum unwanted wideband emission pfd level (dB(W/(m^2 · 290 MHz)))
22.21-22.5	–199	–145

4.3 Values achieved

A comparison between the threshold pfd levels for the protection of the RAS in the 22.21-22.5 GHz band, as given in Recommendation ITU-R RA.769 (see § 1.3) and the unwanted emission levels produced by BSS systems provided in Table 31 lead to the results given in Table 32. Negative values in Table 32 indicate that the protection criteria for the RAS have not been met, by the listed margin in dB.

TABLE 32

Discrepancy between Recommendation ITU-R RA.769 RAS threshold pfd levels and BSS unwanted emission levels

Type of observation	Continuum observations	Spectral line observations	VLBI observations
Discrepancy between Recommendation ITU-R RA.769 RAS threshold pfd levels and BSS unwanted emission levels (dB)	–1	–17	+15

From this calculation it follows that for single-dish continuum and single-dish spectral line observations, the threshold levels of Recommendation ITU-R RA.769 are not met, by margins of 1 dB and 17 dB respectively. In the case of single-dish spectral line observations, such a shortfall would effectively preclude any useful observations in the band. It should be noted however, that the estimated levels for the unwanted emissions from BSS systems are maximum spfd values.

If a more realistic calculations were to be made, including for example filter rejection, intermodulation product rejection and the actual gains of the transmitter amplifiers in the radio astronomy band, and taking atmospheric absorption into account, the discrepancy would diminish, at least to where the protection criteria for VLBI and single-dish continuum observations would be met.

5 Mitigation methods

5.1 RAS

There are various methods, including those described below, which might be considered to reduce unwanted emissions from the satellite transmitters at a radio telescope.

Antenna sidelobe performance: The aperture illumination of radio telescopes is usually optimized for *G*/*T*, i.e. telescope gain divided by system temperature. This is to maximize the *S*/*N* for point sources. A key element of this approach is to reduce ground radiation entering through far sidelobes. Inevitably this leads to some corresponding increase in the levels of near sidelobes. Experience has shown that the majority of radio telescopes meets the envelope sidelobe mask given in Recommendation ITU-R SA.509 over most directions.

Blanking in time and/or frequency: This technique may be applied in cases where interference into the radio astronomy frequency band can be fully and unambiguously identified in time and/or frequency.

5.2 BSS

Filters: This would involve the active system implementing additional RF filtering.

5.3 Potential impact

5.3.1 RAS

Antenna sidelobe performance: Attempts to decrease the sensitivity of the radio astronomy antenna to unwanted emissions coming from space stations are likely to increase the sensitivity of the radio astronomy telescope to ground radiation, and possibly reduce its main beam gain. Both of these effects will reduce the telescope’s channel capacity of and thus lead to an increase of the total required integration time.

Blanking in time and/or frequency: Blanking involves a risk of compromising the integrity of the data and may lead to errors in their scientific interpretation. Blanking also causes a concomitant increase in the total integration time required to make the observation, this is equivalent to a loss in the channel capacity of the telescope.

5.3.2 BSS

For multi-beam satellite systems planned for operation in the frequency range of interest, the number of beams in the multi-beam system, or number of elements, multiplies the cost and weight implications of additional RF filtering in the phased-array antenna system. This is due to the fact that in a multi-beam system the output amplifiers are generally not shared between beams, and so would have to be filtered separately. In a phased array type system the final stage of amplification takes place at the various elements of the array, each of which would have to be filtered separately. In this way the number of beams or number of elements in the phased array multiplies the weight impact of an individual filter in the system. The filter insertion loss could impact system capacity.

6 Results of studies

6.1 Summary

The calculation suggests that the protection criteria discussed in § 1.3 are met for VLBI observations, nearly met for single-dish continuum observations, and not met for spectral line observations. However, this is a worst-case calculation. Refinement of the calculation could lead to significant improvements in those margins. Since the short-fall in meeting the protection criteria for single-dish, continuum observations in only 1 dB in this worst case, which is already within reasonable measurement tolerances, any improvement would lead to the criteria for single-dish continuum observations being met. This consideration is reflected in the conclusions.

6.2 Conclusion

The protection criteria are met for VLBI and single-dish continuum observations, but not for single-dish spectral line observations.

Annex 13

Compatibility analysis between the EESS (passive) in the 23.6-24 GHz band and the ISS in the 22.55-23.55 GHz band

1 EESS (passive)

1.1 Allocated band

The band 23.6-24 GHz is allocated to the EESS (passive), RAS and SRS (passive). It should be noted that the band 23.6-24 GHz is covered by RR No. 5.340. The allocations adjacent to the 23.6-24 GHz passive band are shown in Table 33.

1.2 Application

Passive measurements around frequencies 23.8 GHz (total water vapour content), 31.5 GHz (window channel) and 90 GHz (liquid water) provide auxiliary data which play a predominant role in the retrieval process of temperature measurements performed in the O_2 absorption spectrum. These auxiliary measurements must have radiometric and geometric performances and availability criteria consistent with those of the temperature measurements.

TABLE 33

Adjacent band allocations

Services in lower allocated bands		Passive band	Services in upper allocated band
22.55-23.55 GHz	**23.55-23.6 GHz**	**23.6-24 GHz**	**24-24.05 GHz**
FIXED INTER-SATELLITE MOBILE 5.149	FIXED MOBILE	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	AMATEUR AMATEUR-SATELLITE 5.150

NOTE 1 – The Inter-satellite allocation could be used for GSO and non-GSO systems.

1.3 Required protection criteria

The following three Recommendations below establish the interference criteria for passive sensors:

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

The criteria, which are applicable to measurements, are the following:

– the first criteria is the maximum interfering power received by the EESS sensor from all potentially interfering sources. The interference threshold is –163 dBW in a reference bandwidth of 100 MHz;

– the second one is the maximum tolerable proportion of measurement cells lost due to interference.

For conically scanned instruments, the proportion of measurement cells lost due to the threshold being exceeded must not exceed 5% in cases where the interference events are random, and 1% when the interference events are systematic. Since the ISS is not random, the 1% criteria applies.

For nadir sounders used for three-dimensional measurements of atmospheric temperature or gas concentration, the proportion of measurement cells lost due to interference must not exceed 0.01%. This frequency of occurrence limit is valid for mechanically scanned and push-broom nadir sounders.

1.4 Operational characteristics

1.4.1 Conically scanned instruments

Main characteristics of typical mechanically scanned sensors are given in Table 34.

TABLE 34

Typical characteristics of conically scanned sensors

Channel 23.6-24 GHz	MEGHA-TROPIC	EOS-AMSR-E	ADEOS-II AMSR
Channel bandwidth (MHz)	400	400	400
Pixel size across track (km)	35.4	17.6	16.6
Beam efficiency (%)	96	97	96
Incidence angle *i* at footprint centre (degrees)	52.3	55	55
Altitude of the satellite (km)	817	705	803
Maximum antenna gain (dBi)	40	46	48
Reflector diameter	650 mm	1.6 m	2.0 m
Half power antenna beamwidth $\theta_{3\,dB}$ (degrees)	1.65	0.9	0.75

The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle of the beam boresight.

It is important to note that those kinds of EESS sensors are not nadir pointing satellites, but EESS sensors having a conical scan configuration centred on the nadir direction. It is important for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The geometry of conically scanned instruments is described in Fig. 27. The rotation speed of the instrument (and not the satellite) is w = 20 r.p.m. for MEGHA-TROPIC and 40 r.p.m. for EOS AMSR-E.

The configuration of conically scanned sensors is presented in Fig. 27.

The typical geometry characteristics of this kind of instruments are based on the following for an altitude of about 850 km:

– the ground incidence angle *i* at footprint centre is around 50°;

– the EESS offset angle to the nadir or half cone angle α to the nadir direction is about 44°;

– the useful swath is about 1 600 km; and

– the scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

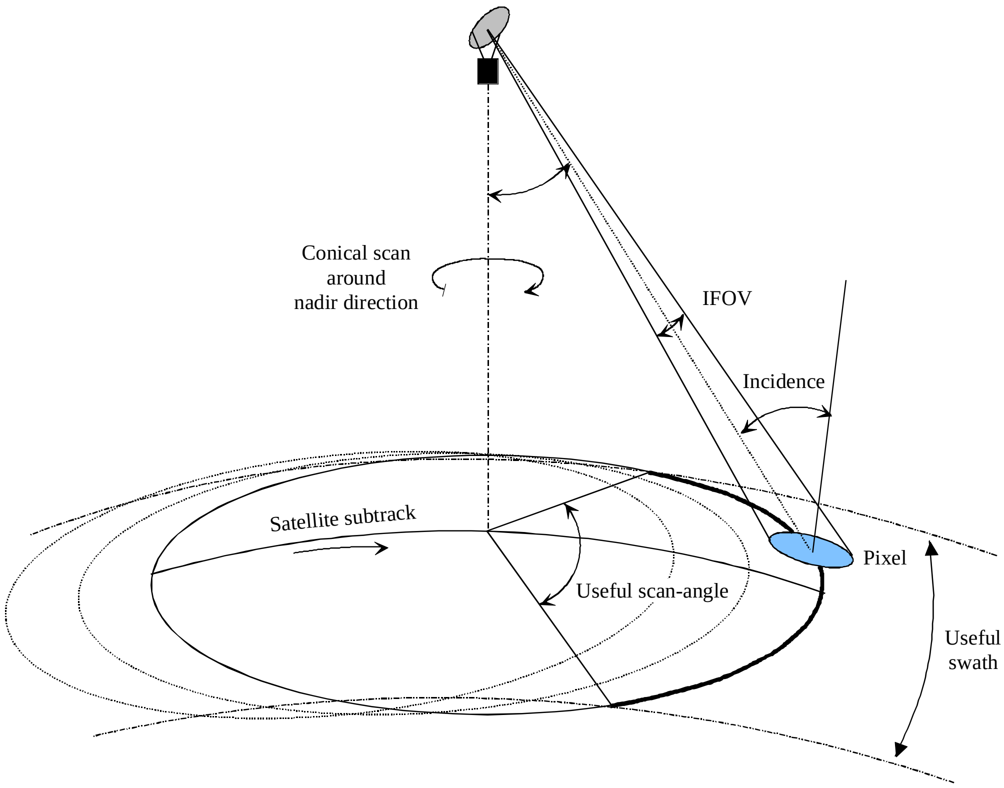
Figures 28 and 29 show the relative antenna gain pattern referred to the maximum gain of the MEGHA-TROPIC satellite and of the EOS AMSR-E, respectively.

1.4.2 Operational characteristics of nadir instruments

The nadir passive sensors retained for this analysis are the AMSU, a mechanically scanned instrument cross-track around nadir direction, and the push-broom vertical sounder. The push-broom is a purely static instrument with no moving parts. The major feature of the push-broom is that all pixels in a scan-line are acquired simultaneously, and not sequentially as for mechanically scanned sensors (i.e. AMSU type), enabling to significantly increase the integration time and the achievable radiometric resolution. The push-broom incorporates one fixed data acquisition antenna pointing in direction of nadir and one dedicated cold space calibration antenna. In the AMSU case, calibration is implemented once per scan revolution by the main antenna when looking in the cold space direction. The main characteristics of these sensors are given in Table 35.

FIGURE 27

Configuration of conically scanned passive sensors

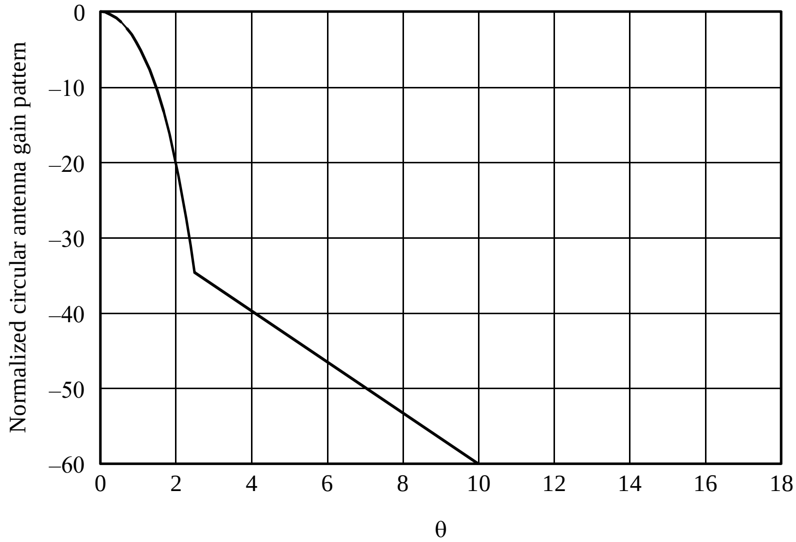


IFOV: Instantaneous field of view

1633-27

FIGURE 28

Antenna gain pattern of the MEGHA-TROPIC sensor



1633-28

FIGURE 29

Antenna gain pattern of the EOS AMSR-E satellite

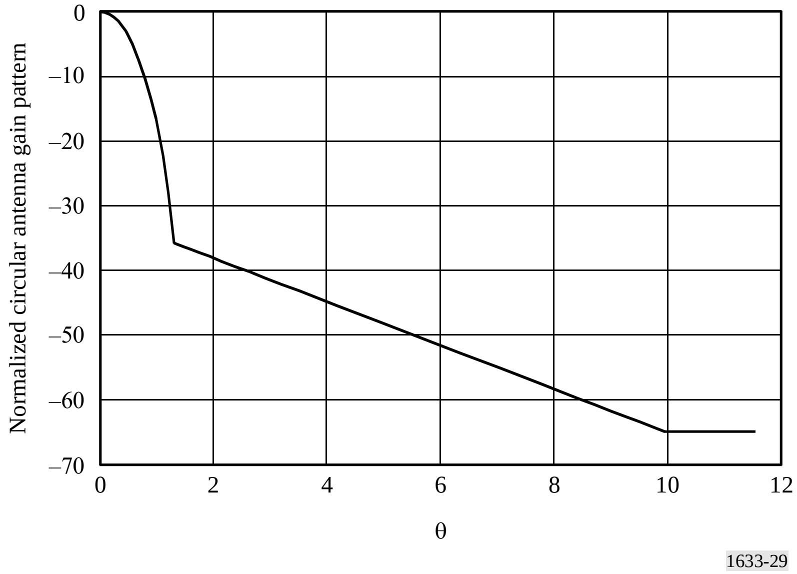


TABLE 35

Nadir sensors' characteristics

Parameters	AMSU	Push-broom
Main antenna gain (dBi)	36	45
Antenna back lobe gain (dBi)	–10	–12
IFOV at –3 dB (degrees)	3.3	1.1
Total FOV cross/along-track (degrees)	100/3.3	100/1.1
Pixel size (km)	45	16
Number of pixels per line	30	90
Radiometric resolution (K)	0.2	0.2
Interference threshold density (dB(W/100 MHz))	–163	–163
Sensor altitude (km)	850	850
Cold calibration antenna gain (dBi)	36	35
Cold calibration angle (degrees re. satellite track)	90	90
Cold calibration angle (degrees re. nadir direction)	83	83
Type of scan	Mechanical	Electronic

FOV: field of view

re: referred to

The orbital configuration for these sensors are illustrated in Figs. 30 and 31.

FIGURE 30

Orbital configuration of the AMSU sensor

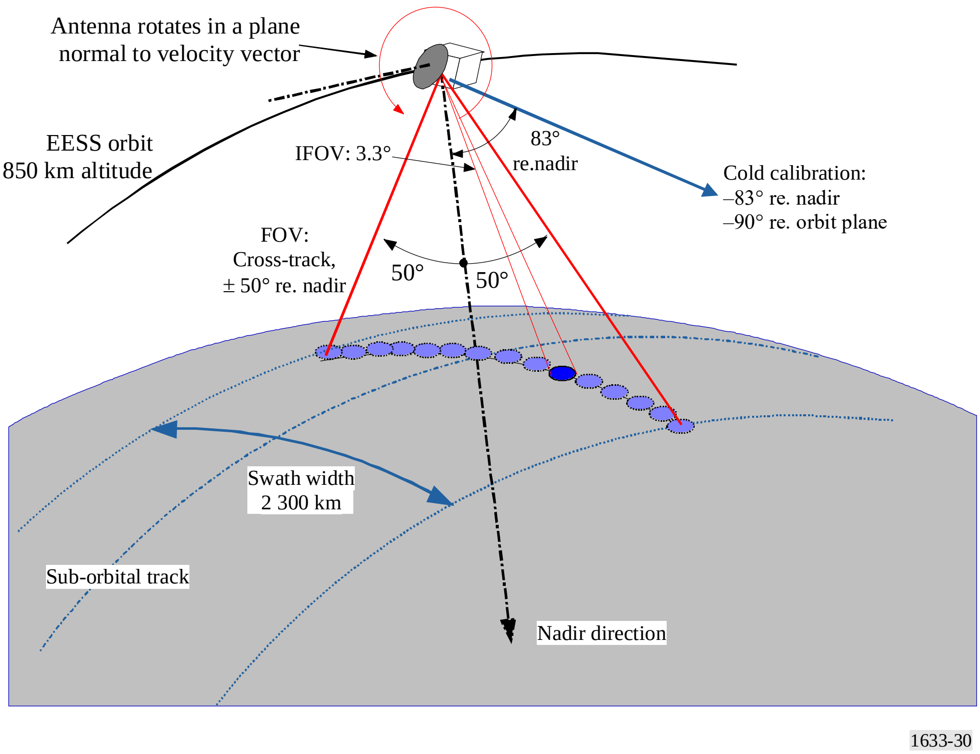
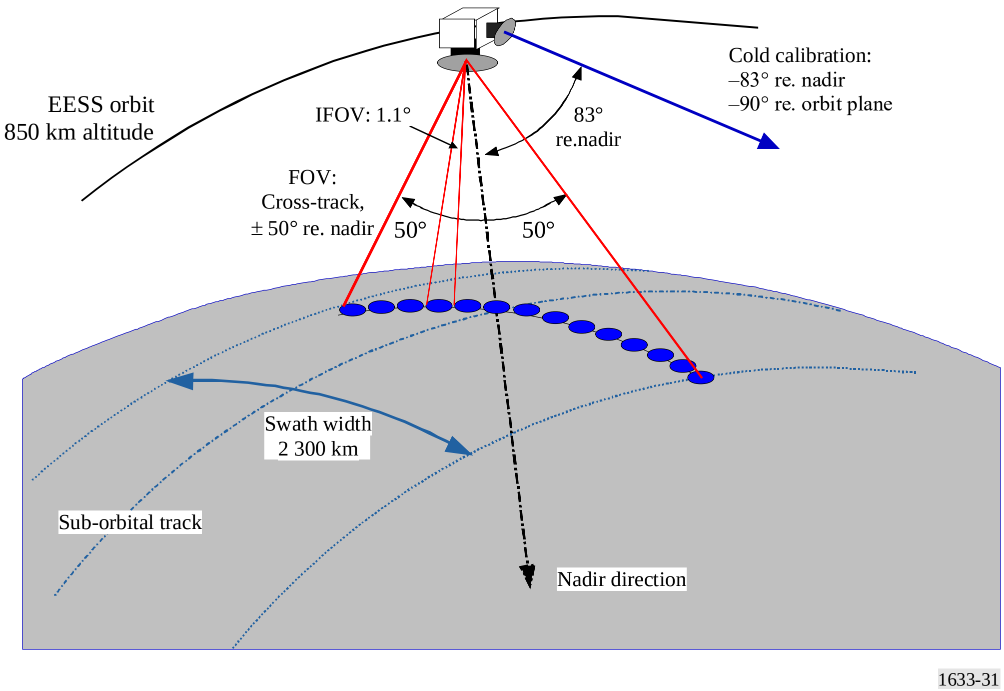


FIGURE 31

Orbital configuration of the push-broom sensor



2 ISS

2.1 Allocated transmit band

The transmit band considered is the 22.55-23.55 GHz band (see Table 33).

2.2 Application

The active service under consideration in this analysis is the ISS. Recommendation ITU-R S.1328 contains satellite system characteristics to be considered in frequency sharing analyses between GSO and non-GSO satellite systems in the FSS including feeder links for the MSS. However, this Recommendation does not contain information on inter-satellite links.

2.3 Levels based on spectral representation

This Annex uses the “raised cosine” spectral representation which is described in Annex 1.

This spectral representation is intended for band-by-band studies and is provisional, pending further review within the ITU-R. It represents in a very general way the typical mean power distribution through the OoB and spurious domains in an adjacent or nearby allocation.

2.4 Transmitter characteristics

2.4.1 Non-GSO satellite network Hib-Leo 2

This system is retained for the compatibility study with conically scanned sensors. The present study, which is based on a worst-case analysis, is purely static and does not consider temporal aspects. However, it will be completed with a dynamic analysis, on the basis on a real constellation. The only known constellation is for the time being the Hib-Leo 2 system. The major characteristics of this system are presented in Table 36.

TABLE 36

Hib-Leo 2 system specifications

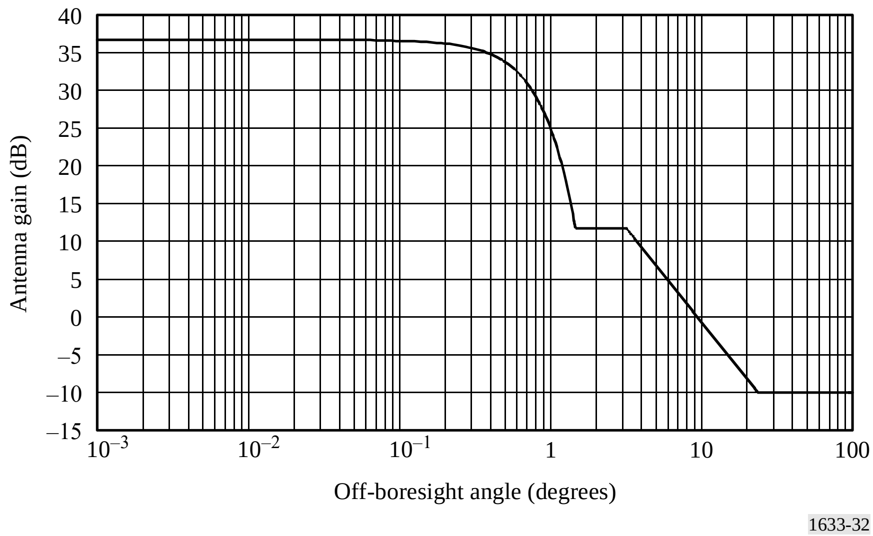
System parameter	Value
Number of satellite planes	6
Number of satellites per plane	11
Nominal altitude	780
Orbit type	Circular polar (inclination angle of 86.5°)
Necessary bandwidth	8 × 19 MHz channels (total bandwidth 194 MHz)
Peak power	3.5 dBW for the total 8 links
Antenna gain	36.7 dBi

Recommendation ITU-R S.672 is applicable for the inter-satellite link antenna. The antenna pattern is presented in Fig. 32.

FIGURE 32

ISS antenna gain pattern

(Antenna mask and average pattern complying with Recommendation ITU-R S.672)



2.4.2 Parametric characteristics of inter-satellite links

Technical characteristics of ISS systems considered for the analysis of nadir instruments are given in Table 37. They have been based on the following assumptions in order to assess the influence of various configuration parameters:

– low, circular polar orbiting systems (LEO-1 to LEO-4) are considered covering altitudes ranging from 700 to 1 000 km, and a system in GSO;

– the transmission characteristics based on Hib-Leo 2 that is currently operating inter-satellite links in this frequency band, are retained and adapted for LEO and GEO systems;

– for the necessary bandwidth three values are considered: 200 MHz (8 channels), 100 MHz (4 channels) and 50 MHz (2 channels) and a total peak power of 3.5 dBW, 0.5 dBW and –2.5 dBW was assumed respectively;

– an antenna gain of 36.7 dBi was assumed for the lowest system (LEO-1); the antenna gains (receive and transmit) for other scenarios are adjusted to compensate for the increased length of the links, considering links such that their minimum altitude is at 200 km above Earth’s surface (1 000 km in the case of the GEO system);

– these characteristics should be updated and the analysis should be re-iterated, whenever those of real existing or planned systems are available.

It is further considered that the upper edge of the necessary bandwidth coincides with the upper limit of the frequency band allocated. Therefore, a minimum guardband of 50 MHz is provided by the allocation to the fixed and mobile services between the ISS and the EESS allocations.

TABLE 37

Parametric inter-satellite link characteristics

System parameters	Values				
	LEO-1	**LEO-2**	**LEO-3**	**LEO-4**	**GEO**
Nominal altitude (km)	700	800	900	1 000	35 900
Orbit type	Circular polar				GSO
Necessary bandwidth (8 × 25 MHz channels)	200				
Total peak power in necessary BW (dBW)	3.5/0.5/–2.5				
Maximum power density (dB(W/MHz))	–7.5				
Antenna gain (dBi)	36.7	37.5	38.2	38.8	48.4
Antenna orientation at longest distance (re. local nadir) (degrees)	68.34	66.41	64.66	63	10
Maximum link distance (km)	5 226	5 746	6 229	6 683	83 460

3 Compatibility threshold

The interference threshold is –163 dBW in a 100 MHz reference bandwidth. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service. Therefore further work is needed to address the impact of multiple active services above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

This is a purely static analysis, which evaluates the worst case interference received from one unique satellite of the Hib-Leo 2 constellation. The interference assessment is implemented in two steps.

As a first step, the power received by the passive sensor from the inter-satellite link is computed in various geometric configurations, under the assumption that the passive sensor and the inter-satellite links are co-frequency. In order to be consistent with the interference threshold which is referred to a 100 MHz reference bandwidth (see Recommendation ITU-R SA.1029), the analysis is performed in the lowest 100 MHz wide part of the EESS passive allocation (23.6-23.7 GHz), which is the closest to the ISS allocation. Therefore, assuming that the necessary bandwidth of the ISS is 200 MHz (see Table 37), only half of the total ISS power is received by the passive sensor in a 100 MHz reference bandwidth. This amount of power is then compared to the interference threshold of the passive sensor. The excess (if any) of the power received by the passive sensor over the interference threshold is the required attenuation of OoB emissions that must be achieved to protect the EESS.

The second step consists of using the OoB emission limits for space services contained in Annex 5 of Recommendation ITU-R SM.1541. The application of this Recommendation provides spectral attenuations in the 100 MHz lowermost part of the EESS allocation that will be compared to the results of the first step. If the interference threshold is still exceeded, then methods for reducing the power in the passive band should be identified.

4.2 Calculations of interference level for conically scanned passive sensor

4.2.1 ISS satellite is right above the passive sensor

A very simple geometric situation is when the ISS satellite is right above the EESS sensor. In that situation, the antenna gain EESS sensor is much lower than the maximum. This case only occurs with the EOS AMSR-E radiometer.

TABLE 38

Compatibility analysis between Hib-Leo 2 and EOS AMSR-E

Parameters	Value achieved
ISS frequency range (GHz)	23.183-23.377
e.i.r.p./carrier (dBW)	12.2
Bandwidth (MHz)	194
Distance ISS space station – EESS sensor (km)	75
Space attenuation (dB)	157.5
EESS antenna gain (dBi)	–19
Received power at the EESS in the above bandwidth (dBW)	–164.3
Corresponding received power at the EESS in a bandwidth of 100 MHz (dBW)	–167.2
Interference threshold in a bandwidth of 100 MHz (dBW)	–163
Required spectral attenuation	0

4.2.2 ISS satellite is right below the passive sensor

A very simple geometric situation is when the ISS satellite is right below the EESS sensor. In that situation, the antenna gain EESS sensor at its maximum. This case only occurs with the MEGHA-TROPIC radiometer.

TABLE 39

Compatibility analysis between Hib-Leo 2 and MEGHA-TROPIC

Parameters	MEGHA-TROPIC
ISS frequency range (GHz)	23.183-23.377
e.i.r.p./carrier (dBW)	12.2
Bandwidth (MHz)	194
Distance ISS space station – EESS sensor (km)	56
Space attenuation (dB)	154.7
EESS antenna gain (dBi)	40
Received power at the EESS (dB(W/MHz))	–125.4
Received power at the EESS (dB(W/100 MHz))	–105.4
Interference threshold in a bandwidth of 100 MHz (dBW)	–163
Required spectral attenuation	57.6

TABLE 40

Compatibility analysis between Hib-Leo 2 and ADEOS-II AMSR

Parameters	ADEOS-II AMSR
ISS frequency range (GHz)	23.183-23.377
e.i.r.p./carrier (dBW)	12.2 (8 links activated)
Bandwidth (MHz)	194
Distance ISS space station – EESS sensor (km)	36
Space attenuation (dB)	150.8
EESS antenna gain (dBi)	40
Received power at the EESS (dB(W/MHz))	–121.5
Received power at the EESS (dB(W/100 MHz))	–101.5
Interference threshold in a bandwidth of 100 MHz (dBW)	–163
Required spectral attenuation	61.5

4.2.3 Calculations when the ISS satellite is at the limb of the EESS sensor

A very simple geometric situation is when the ISS satellite is at the limb of the EESS sensor. In that situation, the antenna gain of the EESS sensor is also at a very low level, but the antenna ISS gain is near close to the maximum (a few degrees of angle from boresight).

No specific allowance has been made on the effect of the body of the satellite.

TABLE 41

Compatibility analysis between Hib-Leo 2 and MEGHA-TROPIC

Parameters	Value achieved
ISS frequency range (GHz)	23.183-23.377
Bandwidth (MHz)	194
EESS off nadir angle	61.9
ISS off nadir angle	62.4
ISS e.i.r.p. (dBW)	18.2
Distance ISS space station – EESS sensor (km)	6 660
Space attenuation (dB)	196.4
EESS antenna gain (dBi)	–20
Received power at the EESS within the above bandwidth (dBW)	–198.2
Corresponding received power at the EESS in a bandwidth of 100 MHz (dBW)	–201
Interference threshold in a bandwidth of 100 MHz (dBW)	–163
Required spectral attenuation	0

When the ISS satellite is seen at the limb by the EESS satellite, the integrated power in a 100 MHz reference bandwidth is below the interference threshold.

4.3 Calculation of interference level for nadir passive sensor

4.3.1 Identification of the worst configurations

Five geometric configurations involving the passive sensor in a 850 km circular sun-synchronous orbit, and one unique satellite of the ISS constellation in circular orbits of various altitudes that are described in Table 37 are analysed.

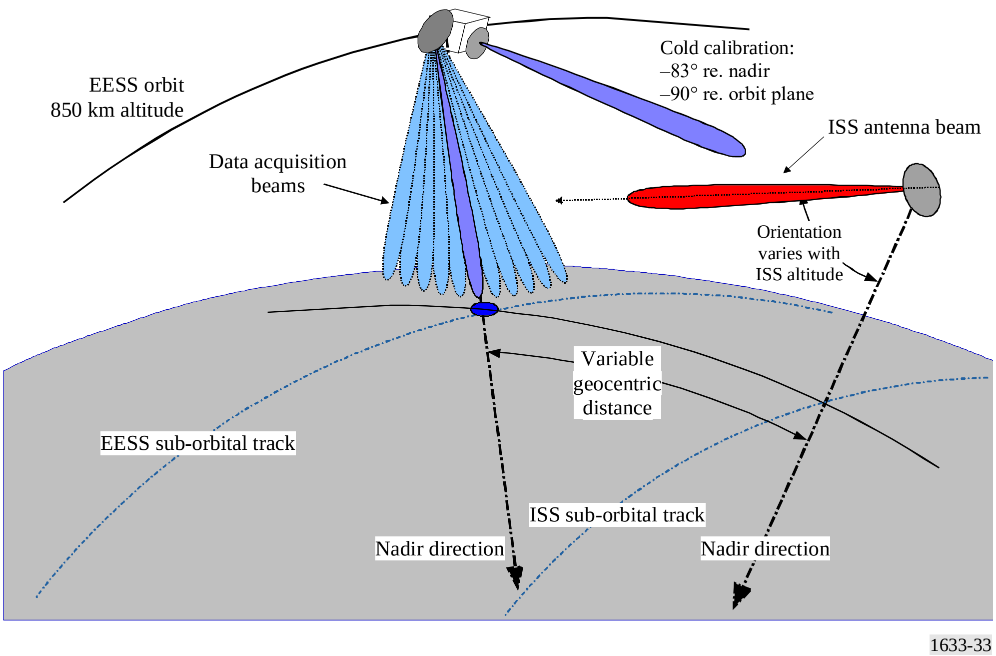
The nadir beam of the passive sensor (the data acquisition antenna) is considered as the worst case when ISS satellites are lower than the EESS satellite. Data acquisition and calibration modes are considered simultaneously.

Considering that the nadir sounder scanning and cold space calibration are implemented in a plane normal to the velocity vector of the Earth exploration-satellite which contains the main beams of the data acquisition antenna and of the calibration antenna, it is recognized that the worst potentially interfering conditions are met when the ISS links are implemented in this plane, because interference paths involving the main beams of the passive sensor and/or ISS antennas are then becoming possible. The geocentric distance between the EESS and the ISS satellites being a variable parameter, the present analysis explores such configurations to identify those, which cause interference.

The antenna model given in Recommendation ITU-R F.1245 is adopted to simulate the EESS and the ISS antennas.

FIGURE 33

Orbital configuration of EESS-ISS potential interference analysis



It is noted that in case of similar EESS and ISS orbits (similar inclination, similar altitude) as it is the case for the two low orbiting ISS systems considered, their relative velocity may be low, enabling long-lasting potentially interfering situations to happen.

The results of the co-frequency link budgets for the sounding and for the cold space calibration are plotted in Figs. 34, 35, 36, 37 and 38 (push-broom case). These Figures are valid for 200 MHz and 100 MHz necessary bandwidth; they should be decreased by 3 dB in case of 50 MHz necessary bandwidth. They clearly indicate the geometric conditions, which create interference. They are also mostly applicable to the AMSU case.

FIGURE 34

Power received by the passive sensor (co-frequency, LEO-1 at 700 km)

(Co-frequency link budgets) (EESS altitude 850 km-ISS altitude 700 km)

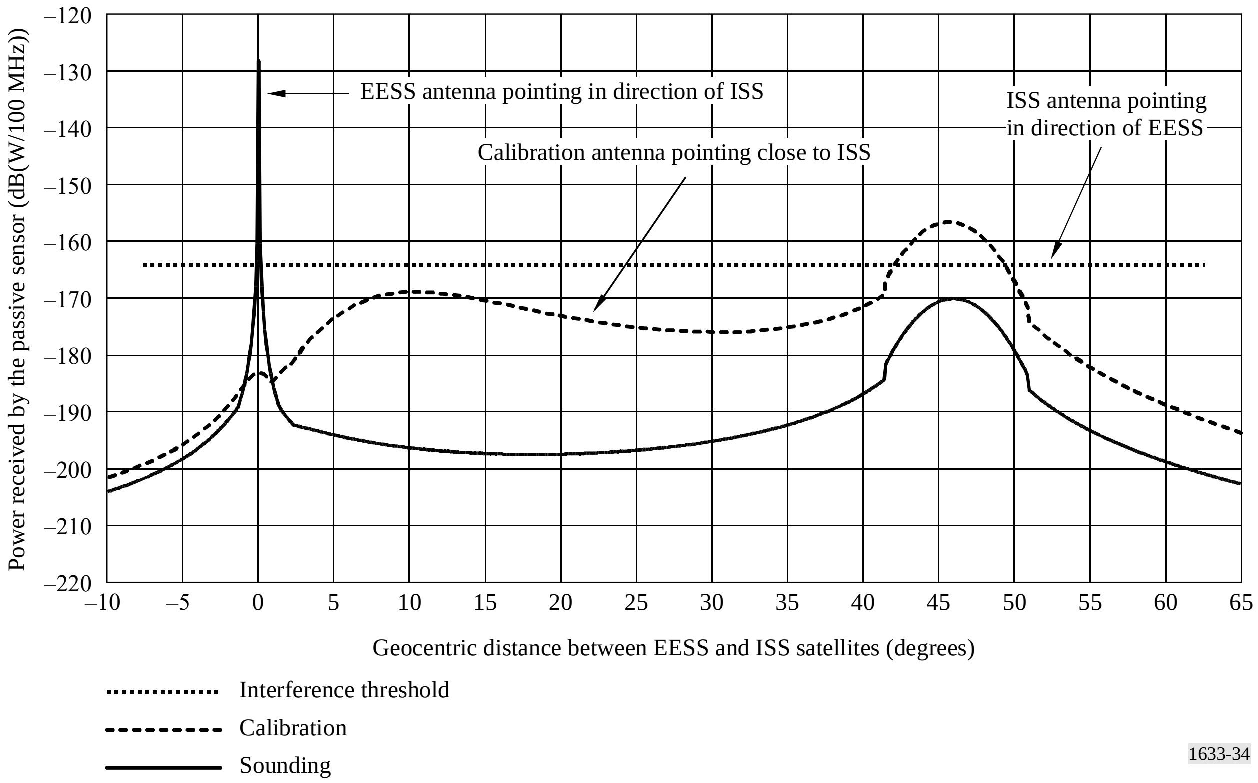


FIGURE 35

Power received by the passive sensor (co-frequency, LEO-2 at 800 km)

(Co-frequency link budget) (EESS altitude 850 km-ISS altitude 800 km)

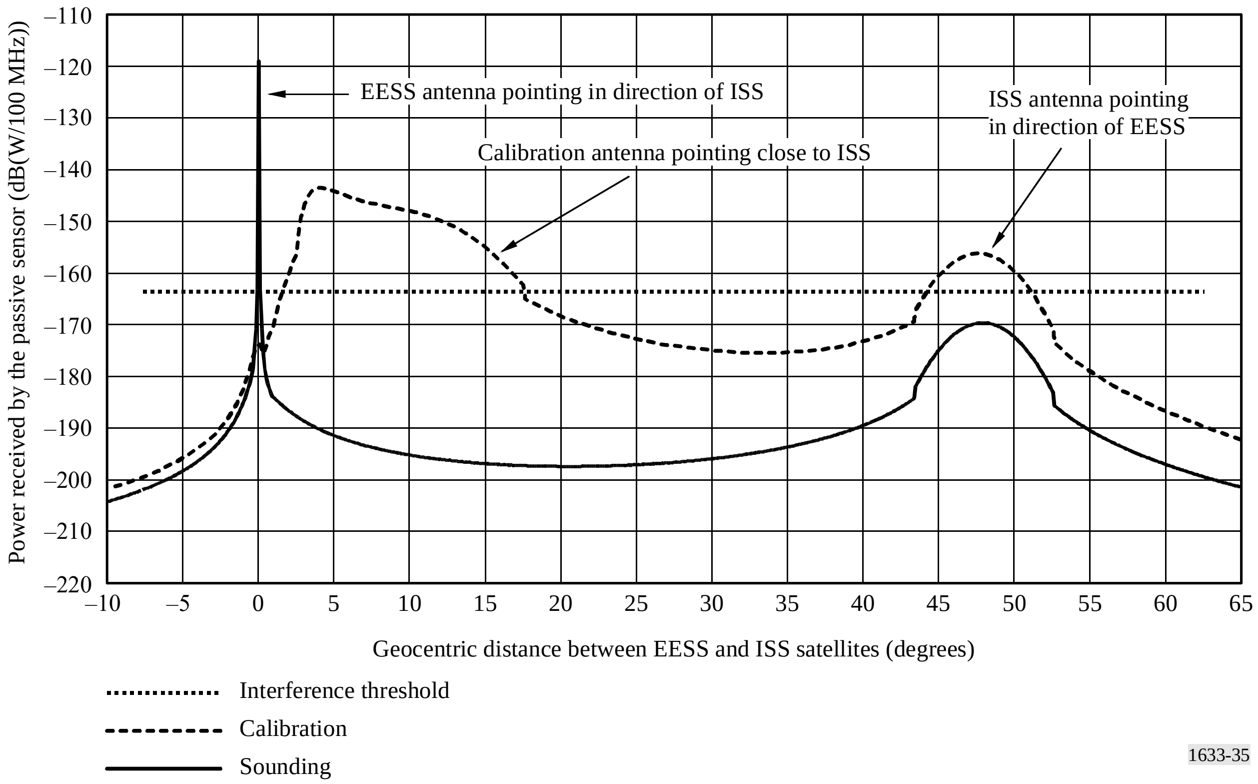


FIGURE 36

Power received by the passive sensor (co-frequency, LEO-3 at 900 km)

(Co-frequency link budget) (EESS altitude 850 km-ISS altitude 900 km)

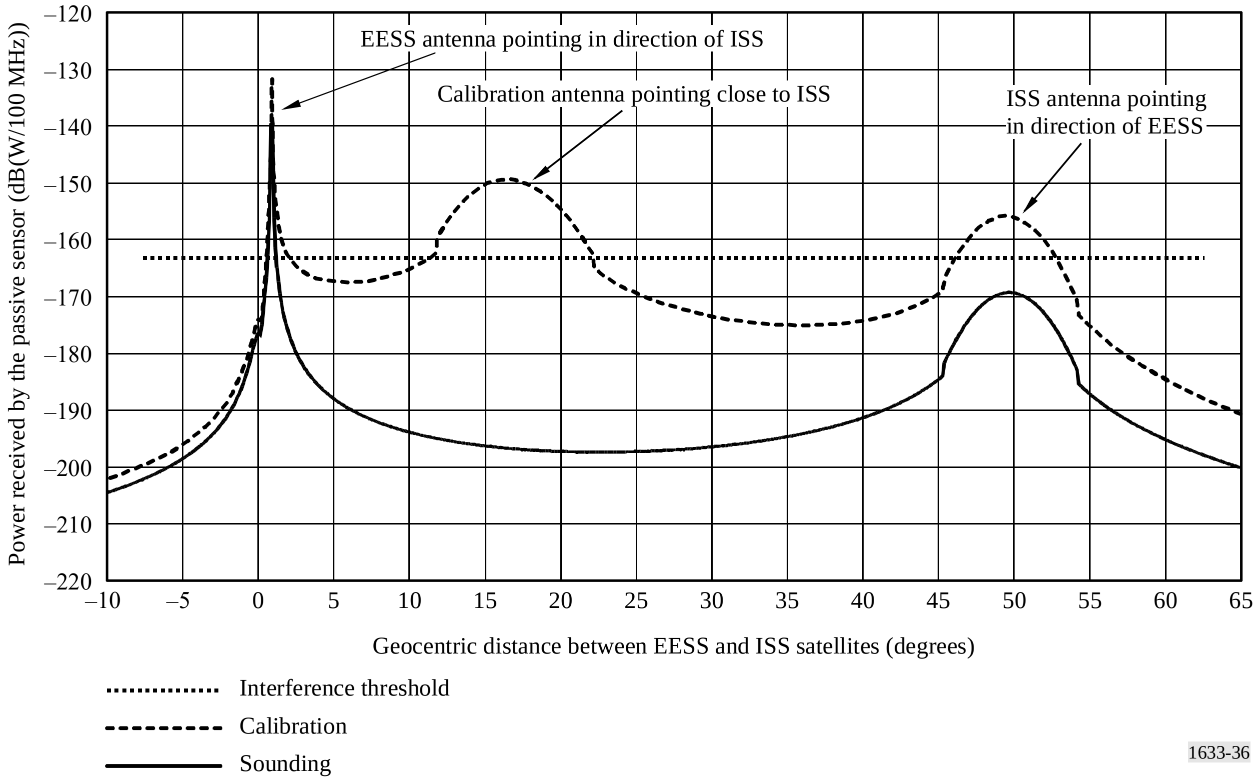


FIGURE 37

Power received by the passive sensor (co-frequency, LEO-4 at 1 000 km)

(Co-frequency link budgets) (EESS altitude 850 km-ISS altitude 1 000 km)

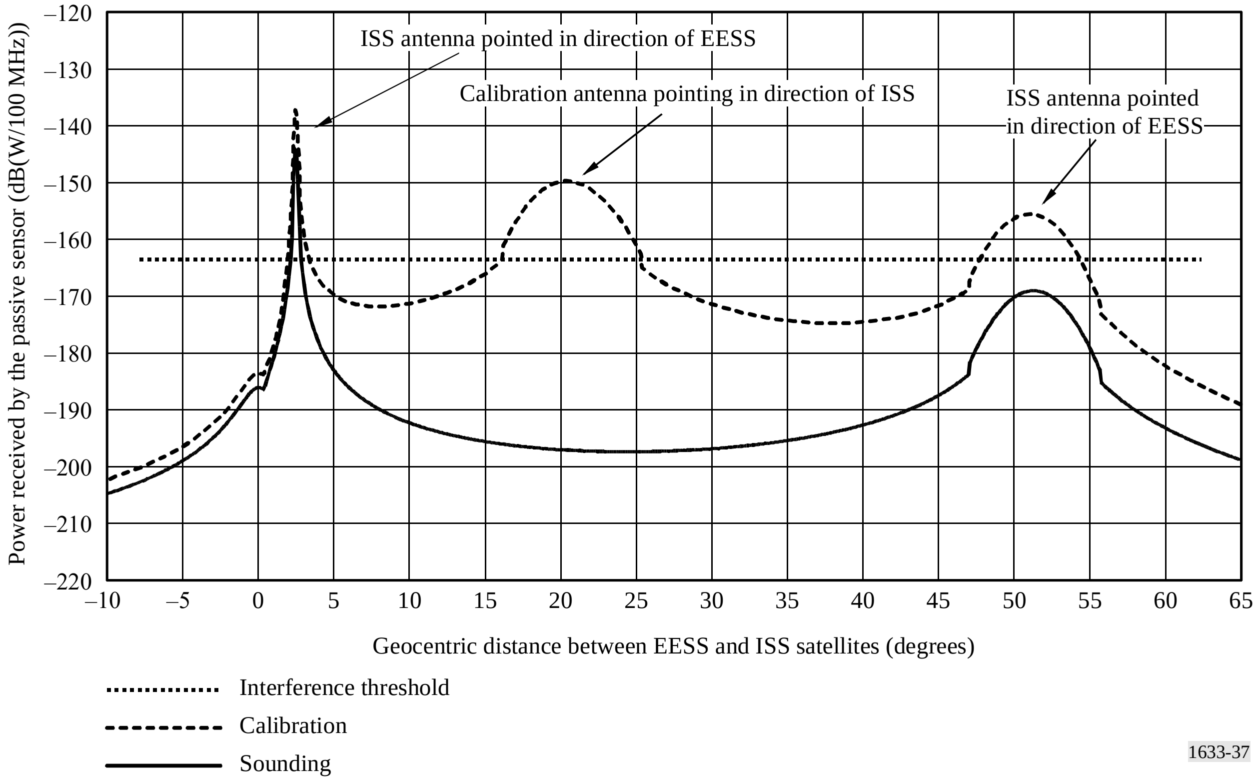
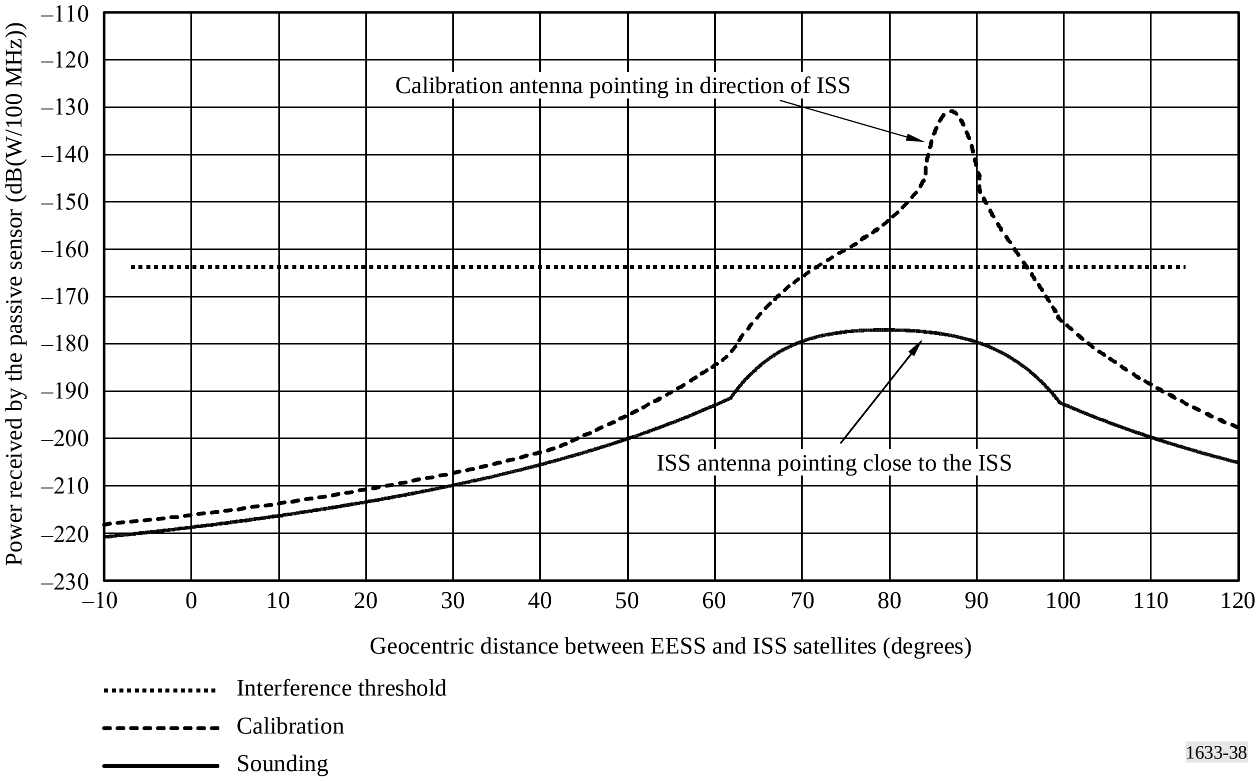


FIGURE 38

Power received by the passive sensor (co-frequency, GEO at 35 900 km)

(Co-frequency link budgets) (EESS altitude 850 km-ISS altitude 35 900 km)



4.3.2 Summary of co-frequency link budgets and comments

The worst-case excesses of received power over the interference threshold (co-frequency link budgets) are summarized in Tables 42 and 43, for the data acquisition and for the cold space calibration modes, and for the five configurations analysed. All results were obtained in semi-static configurations involving interference from one unique satellite of the ISS constellation. Negative margins indicate that the interference threshold is exceeded.

TABLE 42

Worst-case margins referred to the interference threshold (co-frequency assumption) (AMSU case)

Worst-case margins referred to sensor's interference threshold – AMSU case (co-frequency assumption)						
	LEO-1 (700 km)		**LEO-2 (800 km)**		**LEO-3 (900 km)**	
	Sounding	**Calibration**	**Sounding**	**Calibration**	**Sounding**	**Calibration**
Angular distance (degrees)	0.00	45.70	0.00	4.20	0.90	0.90
Distance (km)	150.00	5 557.00	50.00	530.25	124.42	124.42
Path-loss (dB)	–163.50	–194.87	–153.96	–174.47	–161.87	–161.87
Sensor antenna gain (dBi)	36.00	0.99	36.00	–4.19	–10.08	–5.09
ISS antenna gain (dBi)	–10.25	36.59	–10.45	35.57	34.22	34.22
ISS Tx power (dB(W/100 MHz))	0.50	0.50	0.50	0.50	0.50	0.50
Received power (dB(W/100 MHz))	–137.25	–156.79	–127.91	–142.59	–137.23	–132.24
Margin/threshold B_N = 200/100 MHz (dB)	–25.75	–6.21	–35.09	–20.41	–25.77	–30.76
Margin/threshold B_N = 50 MHz (dB)	–22.75	–3.21	–32.09	–17.41	–22.77	–27.75
	LEO-4 (1 000 km)		**LEO-5 (35 900 km)**			
	Sounding	**Calibration**	**Sounding**	**Calibration**		
Angular distance (degrees)	2.40	2.40	79.30	87.10		
Distance (km)	340.67	340.67	41 547.55	42 529.43		
Path-loss (dB)	–170.62	–170.62	–212.35	–212.55		
Sensor antenna gain (dBi)	–10.08	–5.68	–10.08	35.97		
ISS antenna gain (dBi)	38.31	38.31	47.13	46.13		
ISS Tx power (dB(W/100 MHz))	0.50	0.50	0.50	0.50		
Received power (dB(W/100 MHz))	–141.89	–137.49	–174.80	–129.95		
Margin/threshold B_N = 200/100 MHz (dB)	–21.11	–25.51	11.80	–33.05		
Margin/threshold B_N = 50 MHz (dB)	–18.11	–22.51	14.80	–30.05		

In all configurations analysed, the interference threshold can be considerably exceeded.

Note that the unwanted power within the 100 MHz reference bandwidth is identical for 200 MHz and 100 MHz necessary bandwidth, because it is assumed that the power density within the necessary bandwidth is the same. The unwanted power is 3 dB lower in the case of a 50 MHz necessary bandwidth.

For the data acquisition antenna beam looking down to the Earth, interference occurs over relatively short ranges of geocentric distances, when ISS or EESS antennas are pointing in the direction of the other satellite. The worst-case values are obtained when the passive sensor and the ISS satellite are at a short distance, and the ISS satellite lower than the passive sensor. It must be emphasized that with such an important negative margins, many adjacent pixels in the line are likely to be also contaminated, although to a lesser extent (for instance about 20 pixels in case of a negative margin of –40 dB). Dynamic analysis will be essential to determine the importance of the temporal dimension.

TABLE 43

Worst-case margins referred to the interference threshold (co-frequency assumption) (push-broom case)

Worst-case margins referred to sensor's interference threshold – Push-broom case (co-frequency assumption)						
	LEO-1 (700 km)		**LEO-2 (800 km)**		**LEO-3 (900 km)**	
	Sounding	**Calibration**	**Sounding**	**Calibration**	**Sounding**	**Calibration**
Angular distance (degrees)	0.00	45.70	0.00	45.70	0.90	0.90
Distance (km)	150.00	5 557.00	50.00	517.74	124.42	124.42
Path-loss (dB)	–163.50	–194.87	–153.96	–174.26	–161.87	–161.87
Sensor antenna gain (dBi)	45.00	1.24	45.00	–4.27	–12.33	–4.84
ISS antenna gain (dBi)	–10.25	36.70	–10.45	34.54	34.22	34.22
ISS Tx power (dB(W/100 MHz))	0.50	0.50	0.50	0.50	0.50	0.50
Received power (dB(W/100 MHz))	–128.25	–156.43	–118.91	–143.49	–139.48	–131.99
Margin/threshold B_N = 200/100 MHz (dB)	–34.75	–6.57	–44.09	–19.51	–23.52	–31.01
Margin/threshold B_N = 50 MHz (dB)	–31.75	–3.57	–41.09	–16.51	–20.52	–28.01
	LEO-4 (1 000 km)		**LEO-5 (35 900 km)**			
	Sounding	**Calibration**	**Sounding**	**Calibration**		
Angular distance (degrees)	2.40	2.40	87.10	87.10		
Distance (km)	340.67	340.67	42 529.43	42 529.43		
Path-loss (dB)	–170.62	–170.62	–212.55	–212.55		
Sensor antenna gain (dBi)	–12.33	–5.43	–12.33	34.98		
ISS antenna gain (dBi)	38.31	38.31	46.13	46.13		
ISS Tx power (dB(W/100 MHz))	0.50	0.50	0.50	0.50		
Received power (dB(W/100 MHz))	–144.14	–137.24	–178.25	–130.94		
Margin/threshold B_N = 200/100 MHz (dB)	–18.86	–25.76	15.25	–32.06		
Margin/threshold B_N = 50 MHz (dB)	–15.86	–22.76	18.25	–29.06		

For the cold space calibration mode, interference threshold is significantly exceeded over a wide range of geocentric distances. The cold space calibration mode is more vulnerable to emissions from ISS systems due to the specific orientation of the dedicated calibration antenna, in the direction of ISS orbits. Note that if calibration is contaminated by interference, the data acquired are also totally invalidated.

Interference produced by the GSO system depends strongly on the length of the link and on the orientation of the ISS antenna. Under the hypothesis adopted, there is no interference if the centre of the link is at an altitude higher than 8 000 km above the Earth's surface.

It must be emphasized that depending on the orbit of the ISS, the geometric conditions which generate interference may be met during a considerable time. Clearly a dynamic simulation will be necessary to evaluate the relative importance of interfering configurations over a certain period of time.

4.4 Dynamic interference analysis

In addition to the above static and semi-static cases, a dynamic analysis is necessary in order to take into consideration the percentage of time when the interference occurs. As indicated above, the threshold of −163 dBW must not be exceeded no more than 0.01% of time in a bandwidth of 100 MHz.

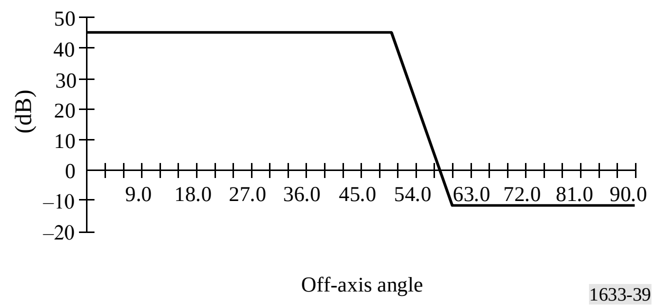
Simulations were conducted to determine the probability of interference using a time increment (sampling) of 5 s in order to get accurate results. Simulations stopped when the cumulative distribution function becomes stable. Furthermore, it has to be noted that all these simulations presented hereunder only deal with the nadir sounder "push-broom" satellite, because the above static and semi-static cases have shown that it is the worst case.

4.4.1 Modelling of the push-broom antenna

As explained above, the push-broom antenna is able to see a whole line of pixels located around the nadir at ± 50° for the azimuth, and in ± 0.55° for the elevation. The maximum antenna gain is 45 dBi, and as usual for radiometer antennas, there is a steep decrease to the side lobe level of −12 dBi. Figure 39 shows the antenna pattern according to the azimuth off-axis angle.

FIGURE 39

Push-broom composite antenna pattern



4.4.2 Dynamic calculations with Hib-Leo 2 system

The simulation which has been conducted, is based upon a simple assumption: each satellite tries to communicate with the nearest 4 within the constellation. The use of the full bandwidth is assumed, and the 8 links on each satellite are supposed to be in use (4 links to transmit and 4 links to receive).

TABLE 44

Dynamic analysis between the inter-satellite links of the non-GSO system Hib-Leo 2 and one EESS sensor push-broom type

Cumulative distribution (%)	100	23.2	10	1	0.1	0.01	0.008
Push-broom: corresponding interference power received by EESS (dBW) (194 MHz bandwidth)	−177	−163	−160	−154	−146	−105	−102

According to Table 44, there is a risk that the EESS satellite experiences interference when the inter-satellites links are in operation (or the percentage of data interfered is above the acceptable one). Taking into account the relative bandwidth, the required spectral attenuation is 55.1 dB for Hib-Leo 2.

4.5 Application of OoB mask to the ISS transmission

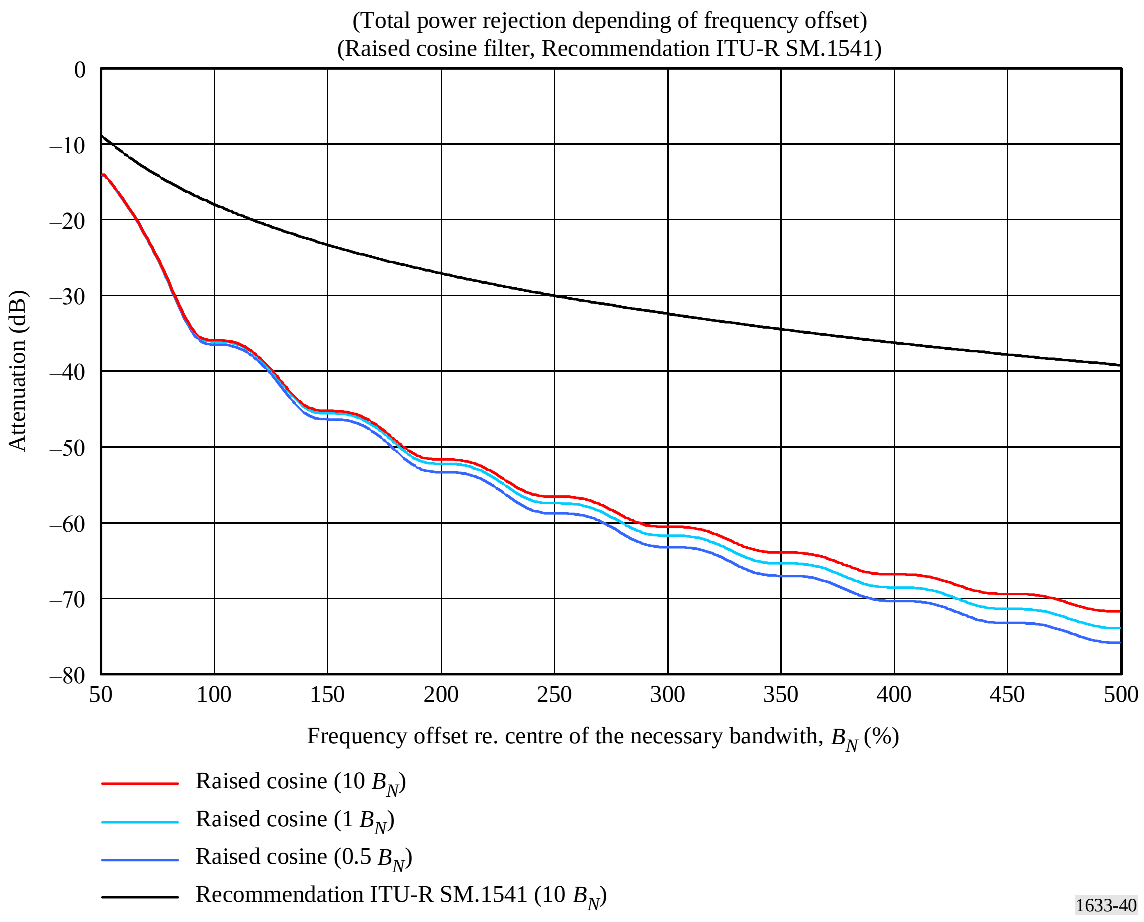
Considering now that the ISS systems are transmitting in their own frequency band, the rejection of their transmitter power within the neighbouring EESS (passive) allocated band should be sufficient to avoid harmful interference, for instance 61 dB for the MEGHA-TROPIC sensor (see Table 39) and up to 35 dB for the push-broom sensor (see Table 41).

Figure 40 represents the power falling within the EESS allocation, depending on guardband. To cover the varying characteristics of the ISS emissions, the sliding integration is performed for three values of the passive band, expressed in terms of percentage of the ISS necessary bandwidth (1 000%, 100% and 50%). There is only a minor difference between the three curves.

Note that, in Fig. 40, the frequency offset is taken from the centre of the necessary bandwidth. Therefore the minimum frequency offset is half the necessary bandwidth, i.e. 50%. This curve will be used to determine the minimum separation between the centre of the necessary bandwidth and the lower limit of the EESS allocated band, which is required to protect the passive sensor from unwanted FSS emissions.

FIGURE 40

Attenuation of OoB power contained within the EESS bandwidth



Furthermore, a 50 MHz separation is provided by the fixed and mobile allocation between the ISS and the EESS allocated bands, in the 23.55-23.6 GHz band. Therefore the minimum frequency separation between the centre of the necessary bandwidth which is the reference in the mask, is $B_N/2 + 50$ MHz. Therefore, the required additional guardband is:

$$\text{Offset from centre } B_N - (B_N/2 + 50 \text{ MHz})$$

4.5.1 Conically scanned sensor

On the basis of the results presented in Tables 38 and 39, Tables 45 and 46 present the minimum frequency offset that is required to protect the passive sensor from interference generated by the Hib-Leo 2 system.

TABLE 45

Summary of necessary guardbands to protect AMSR-E from Hib-Leo 2 links

	Hib-Leo2
Required power rejection (dB)	0
Necessary bandwidth (MHz)	200
Passive band (% B_N)	200
Offset from centre B_N (% B_N)	50
Offset from centre B_N (MHz)	100
Required additional guardband (MHz)	0

TABLE 46

Summary of necessary guardbands to protect MEGHA-TROPIC from Hib-Leo 2 links

	Hib-Leo 2
Required power rejection (dB)	57.6
Necessary bandwidth (MHz)	200
Passive band (% B_N)	200
Offset from centre B_N (% B_N)	250
Offset from centre B_N (MHz)	500
Required additional guardband (MHz)	350

TABLE 47

Summary of necessary guardbands to protect ADEOS-II AMSR from Hib-Leo 2 links

	Hib-Leo 2
Required power rejection (dB)	61.5
Necessary bandwidth (MHz)	200
Passive band (% B_N)	200
Offset from centre B_N (% B_N)	275
Offset from centre B_N (MHz)	550
Required additional guardband (MHz)	400

4.5.2 Nadir sensors

On the basis of the results presented in Tables 42 and 43, Tables 48 to 50 and 51 to 53 present the minimum frequency offset that is required to protect the passive sensor from interference generated by the hypothetical systems presented in Table 37. In each case, the worst of the two configurations, sounding or calibration, was selected to determine the minimum required frequency offset.

TABLE 48

Summary of necessary guardbands to protect AMSU-A from ISS links (200 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	25.75	35.09	30.76	25.51	33.05
Necessary bandwidth (MHz)	200				
Passive band (% B_N)	200				
Offset from centre B_N (% B_N)	76	92	84	76	87
Offset from centre B_N (MHz)	152	184	168	152	174
Required additional guardband (MHz)	2	34	18	2	14

TABLE 49

Summary of necessary guardbands to protect AMSU-A from ISS links (100 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	25.75	35.09	30.76	25.51	33.05
Necessary bandwidth (MHz)	100				
Passive band (% B_N)	400				
Offset from centre B_N (% B_N)	76	92	84	76	87
Offset from centre B_N (MHz)	76	92	84	76	87
Required additional guardband (MHz)	0	0	0	0	0

TABLE 50

Summary of necessary guardbands to protect AMSU-A from ISS links (50 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	22.75	32.09	27.76	22.51	30.05
Necessary bandwidth (MHz)	50				
Passive band (% B_N)	800				
Offset from centre B_N (% B_N)	71	85	79	70	83
Offset from centre B_N (MHz)	36	43	40	35	42
Required additional guardband (MHz)	0	0	0	0	0

TABLE 51

Summary of necessary guardbands to protect the "push-broom" from ISS links (200 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	34.75	44.09	31.01	25.76	32.06
Necessary bandwidth (MHz)	200				
Passive band (% B_N)	200				
Offset from centre B_N (% B_N)	91	138	84	76	86
Offset from centre B_N (MHz)	182	276	168	152	172
Required additional guardband (MHz)	32	126	18	2	22

TABLE 52

Summary of necessary guardbands to protect the "push-broom" from ISS links (100 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	34.75	44.09	31.01	25.76	32.06
Necessary bandwidth (MHz)	100				
Passive band (% B_N)	400				
Offset from centre B_N (% B_N)	91	138	84	76	86
Offset from centre B_N (MHz)	91	138	84	76	86
Required additional guardband (MHz)	0	38	0	0	0

TABLE 53

Summary of necessary guardbands to protect the "push-broom" from ISS links (50 MHz necessary bandwidth)

	LEO-1	LEO-2	LEO-3	LEO-4	GEO
Required power rejection (dB)	31.75	41.09	28.01	22.76	29.06
Necessary bandwidth (MHz)	50				
Passive band (% B_N)	800				
Offset from centre B_N (% B_N)	85	129	80	71	81
Offset from centre B_N (MHz)	43	65	40	36	41
Required additional guardband (MHz)	0	0	0	0	0

NOTE 1 – In case of LEO-1 and LEO-2, the worst case is obtained in the data acquisition mode. It is obtained in the calibration mode in case of LEO-3, LEO-4 and GEO.

The dynamic simulations have shown that a 55.1 dB rejection is required: such a rejection corresponds to a 320 MHz guardband.

5 Mitigation techniques

5.1 EESS (passive)

This subject needs further investigation.

5.2 ISS

The results of the analysis (see Tables 45 to 53) indicate that, under the working assumptions adopted, the application of the raised cosine mask is not sufficient in cases of a 200 MHz necessary bandwidth. Other mitigation techniques may also be employed in addition in order to comply with the interference threshold of the passive sensor.

5.2.1 Necessary bandwidth limits and guardbands

The benefits of decreasing the necessary bandwidth are clearly indicated in Tables 48 and 53.

5.2.2 Baseband filtering

It has to be noted that most of the OoB suppression would take full benefit of the roll off of the modulation waveform and of the analogue filter, if it is on-board implemented. In order to resolve practical cases of OoB interference in passive bands, it becomes urgent to get typical spectrum of transmitting active services out of their own bandwidth. If those spectrums are not available, the alternative way is to get a spectrum of the transmitting active services at the edges of their own bandwidths: the knowledge of these spectrums might give us enough information to predict the decrease of the spectrums in adjacent bands.

5.2.3 Lower emission power and/or reduction of necessary bandwidth

Reduction of power and/or necessary bandwidth could be accomplished by placing lower data rate applications near the upper band edge. Shorter ISS links would lead to a reduction of the necessary e.i.r.p.. In addition, a reduction of the antenna side lobes would also be beneficial.

5.2.4 Geometric separation and ISS orbits

If a minimal geocentric separation between the passive sensor and active satellites is maintained, this separation would enable either to decrease the power received by the sensor or to reduce the temporal interference impact. Such a separation could be in terms of orbital distance, longitudinal separation for systems in polar or geostationary orbits, or separation in the orbit inclination. ISS orbits above the EESS orbit may also improve compatibility

5.3 Potential impact

5.3.1 EESS (passive)

A reduction of the measurement bandwidth due to unacceptable interference in the lowest part of its allocated spectrum may degrade the quality of data below the required level. Alternatively, change of sensor's design to maintain its performance at the required level will inevitably considerably increase the development and production costs of the instrument.

5.3.2 ISS

Mitigation techniques for systems that are currently in use may not be practical. Introduction of guardbands will reduce the available spectrum. Possible modification of the channel configuration to decrease the occupied bandwidth, adoption of improved modulation techniques and in band filtering may be feasible for new systems, but are likely to increase the cost.

ISS constellations using a wide necessary bandwidth might be placed as far as practicable from the EESS (passive) allocation, in the lowest part of the ISS allocation.

6 Results of studies

6.1 Summary

Studies, which have been conducted, conclude that, using the raised cosine mask, mitigation techniques described above would need to be applied simultaneously to ensure compatibility.

6.2 Conclusions

Interference to a passive sensor can occur at several locations in its orbit from ISS links depending on many parameters of the active system. The probability of interference is highly dependent on the relative orbital characteristics of the sensor and the ISS system, and on the number of satellites that compose the ISS system. Dynamic simulations involving the passive sensor and ISS constellations should be pursued to consider the case of ISS networks having characteristics different from those of Hib-Leo 2.

The above mitigation techniques need to be investigated and reviewed within the ITU-R.

It must be noted that satellite systems with orbits similar to the sensor could cause longer periods of interference because their relative positions do not change quickly. Even if the interference occurs for 0.01% of the time over a month, it may be almost 100% of the time for a few hours. This does not meet the criterion of only interfering with 0.01% of the measurement pixels.

Annex 14

Compatibility analysis between the EESS (passive) in the 31.3-31.5 GHz band and the FSS (Earth-to-space) and the MSS (Earth-to-space) in the 30-31 GHz band

1 EESS (passive)

1.1 Allocated band

The band 31.3-31.5 GHz is allocated to the EESS (passive), RAS and SRS (passive). It should be noted that the band 31.3-31.5 GHz is covered by RR No. 5.340. The allocations adjacent to the 31.3-31.8 GHz passive bands are shown in Table 54.

TABLE 54

Adjacent band allocations

Space services in lower allocated band	Services in lower allocated band	Passive band	Services in upper allocated band
30-31 GHz	**31-31.3 GHz**	**31.3-31.5 GHz**	**31.5-31.8 GHz**
FIXED-SATELLITE (Earth-to-space) MOBILE-SATELLITE (Earth-to-space) Standard frequency and time signal-satellite (space-to-Earth) 5.542	FIXED MOBILE Standard frequency and time signal satellite (space-to-Earth) Space research 5.544 5.545 5.149	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed (Regions 1 and 3) Mobile except aeronautical mobile (Regions 1 and 3) 5.149 5.546 (Region 1) 5.340 (Region 2) 5.149 (Region 3)

1.2 Application

Passive measurements around frequencies 23.8 GHz (total water vapour content), 31.5 GHz (window channel) and 90 GHz (liquid water) provide auxiliary data which play a predominant role in the retrieval process of temperature measurements performed in the O_2 absorption spectrum. These auxiliary measurements must have radiometric and geometric performances and availability criteria consistent with those of the temperature measurements.

1.3 Required protection criteria

The following three Recommendations below establish the interference criteria for passive sensors:

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

The first criterion is the acceptable interference power received by the EESS sensor, which is –163 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. For conically scanned sensors, the number of measurement cells lost due to the threshold being exceeded must not exceed 5% in cases where the interference events are random, and 1% when the interference events are systematic. Since the FSS is not random, the 1% criteria apply.

For nadir sounders used for three dimensional measurements of atmospheric temperature or gas concentration, the proportion of measurement cells lost due to interference must not exceed 0.01%. This frequency of occurrence limit is valid for mechanically scanned and push-broom nadir sounders.

1.4 Operational characteristics

1.4.1 Conically scanned sensors

TABLE 55

Specifications for microwave radiometric applications

	Conical sensor
Channel bandwidth (MHz)	100
Pixel size across track (diameter) (km)	26.7
Beam efficiency (%)	95
Incidence angle *i* at footprint centre (degrees)	52
Polarization (linear)	H,V
Altitude of the satellite (km)	817
Maximum antenna gain (dBi)	42
Reflector diameter (mm)	650
Full width of the main beam (degrees)	3.12
Half power antenna beamwidth $\theta_{3\,dB}$ (degrees)	1.25

Beam efficiency is defined as the energy (main polarization component only) within the main beam, relative to the total energy within all angles (4π steradians). Main beam is defined as the cone 2.5 $\theta_{3\ dB}$ full angle (2.5 $\theta_{3\ dB}$ is the half power beamwidth full angle).

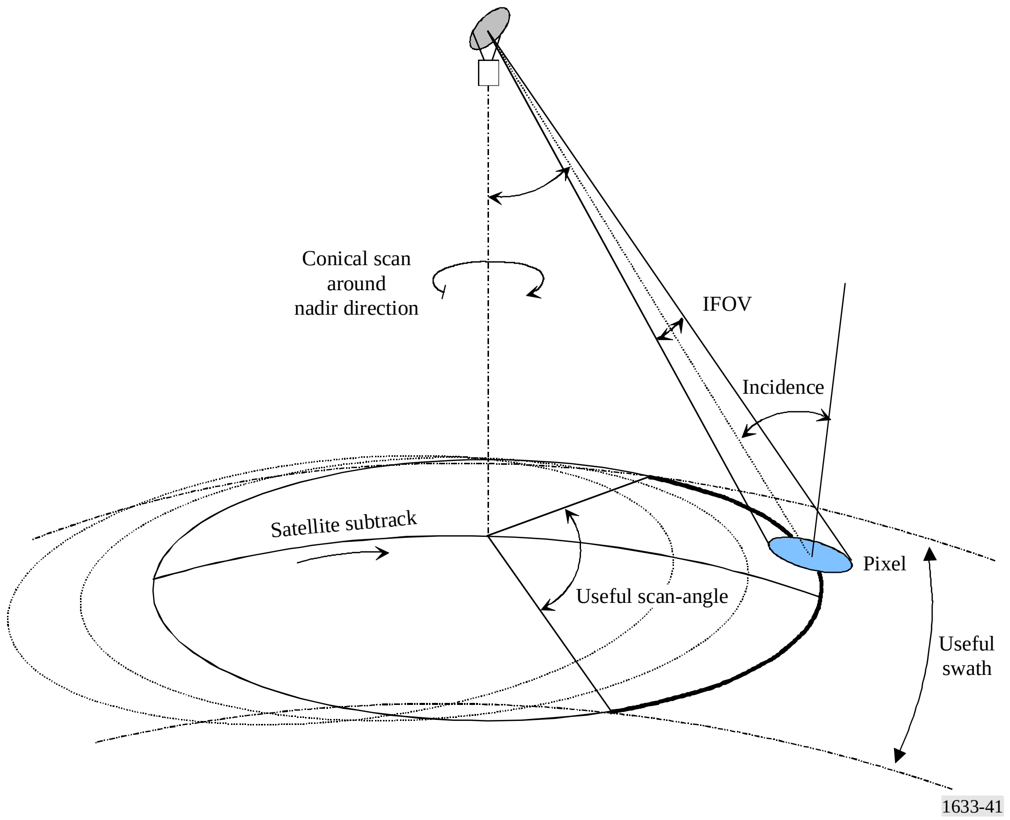
The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle *i* of the beam boresight.

From a general point of view, the antennas currently used within radiometric applications have high beam efficiency. The main lobe is able to concentrate a very high amount of energy. The first side-lobes have a level around –30 dB, which means that the level of the back lobe radiation should be at least –35 dB. AMSU-A measurements show a back lobe level that is 56 dB below the main beam.

It is important to note that the conical scanning sensor is not a nadir sensor, but has a conical scan configuration centred on the nadir direction. It is desirable for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The nadir sensor has different size pixels. The geometry of conical scanned instruments is described in Fig. 41. The rotation speed of the instrument (and not the satellite) is w = 20 r.p.m.

FIGURE 41

Geometry of conical-scanned microwave radiometers



The typical geometry characteristics of this kind of instruments are the following for an altitude of about 850 km:

– the ground incidence angles *i* at footprint centre is around 50°;

– the EESS offset angle to the nadir or half cone angle α to the nadir direction is about 44°;

– the useful swath of about 1 600 km; and

– the scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

1.4.2 Nadir scanning sensor

The nadir mechanically-scanned sensor (AMSU-A) has been in operation for several years and is the system presently in use. It has the following characteristics:

– scans across the track through nadir to ± 48.5°;

– 30 pixels per scan;

– swath width of 2 300 km;

– incident angle with the Earth varies with pixel.

A "push-broom" sensor has been proposed that has fixed beams in a swath similar to the AMSU-A. The nadir passive sensor retained for this analysis is the "push-broom" vertical sounder, because it is the most vulnerable to interference. The "push-broom" is a purely static instrument with no moving parts. The major feature of the push-broom is that all pixels in a scan-line are acquired simultaneously, and not sequentially as for mechanically scanned sensors (i.e. AMSU type), enabling to significantly increase the integration time and the achievable radiometric resolution. The push-broom incorporates one fixed data acquisition antenna pointing in direction of nadir and one dedicated cold space calibration antenna. The main characteristics of this sensor are given in Table 56.

TABLE 56

Nadir sensor characteristics

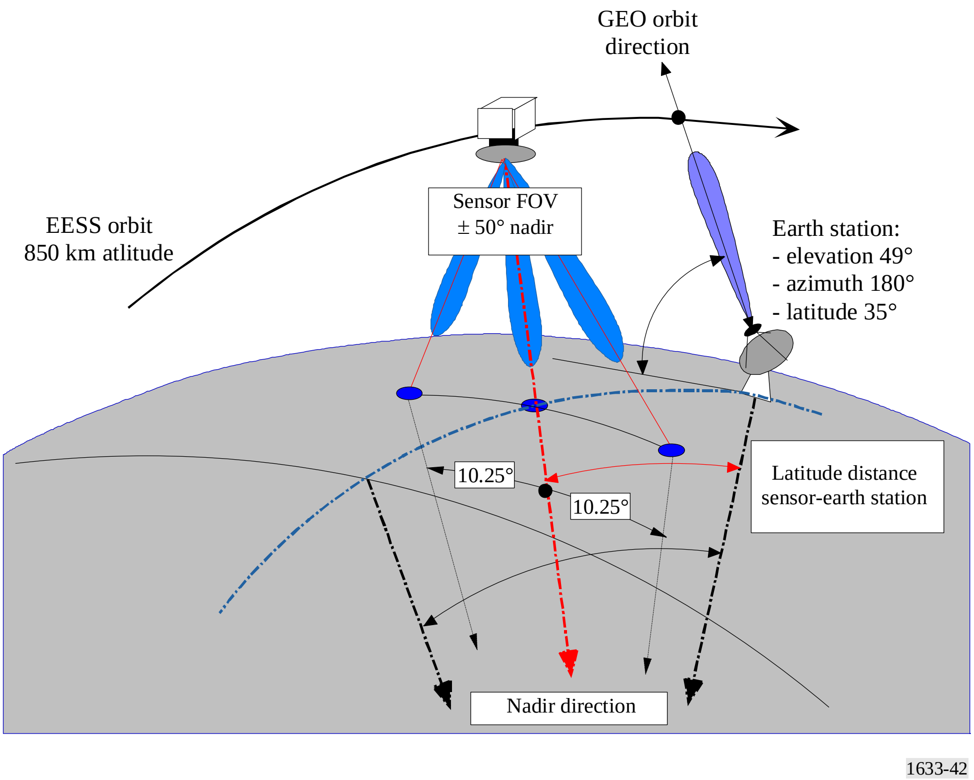
Parameters	Push-broom
Main antenna gain (dBi)	45
Antenna back lobe gain (dBi)	–12
IFOV at –3 dB (degrees)	1.1
Total FOV cross/along-track (degrees)	100/1.1
Pixel size (km)	16
Number of pixels per line	90
Radiometric resolution (K)	0.2
Interference threshold density (dB(W/100 MHz))	–163
Sensor altitude (km)	850
Cold calibration antenna gain (dBi)	35
Cold calibration angle (degrees re. satellite track)	90
Cold calibration angle (degrees re. nadir direction)	83
Type of scan	Electronic

The orbital configuration of this sensor is illustrated in Fig. 42.

FIGURE 42

Configuration of GSO FSS/MSS earth station to passive sensor interferences

(Configuration of FSS/MSS earth station interference to a nadir sensor)



2 FSS and MSS

2.1 Allocated transmit band

The active service band is the FSS uplink and MSS feeder links in the 30-31 GHz band (refer to Table 54).

2.2 Application

The whole set of transmitter characteristics that are taken into account in this Annex are derived from Recommendation ITU-R S.1328-3 – Satellite system characteristics to be considered in frequency sharing analyses between geostationary-satellite orbit (GSO) and non-GSO satellite systems in the fixed-satellite service (FSS) including feeder links for the mobile-satellite service (MSS). This Recommendation gives some relevant information about typical systems.

NOTE 1 – Most of the systems found in the Recommendation ITU-R S.1328-3 having FSS uplinks in the 30 GHz range have a frequency range generally ending at 30 GHz. Despite this fact, it is assumed that FSS satellites having uplinks in the range 30-31 GHz have similar characteristics to those operating below 30 GHz.

2.3 Levels based on spectral representation

This Annex uses the raised cosine spectral representation which is described in Annex 1.

This spectral representation is intended for band-by-band studies and is provisional, pending further review by the ITU-R. It represents in a very general way the typical mean power distribution through the OoB and spurious domains in an adjacent or nearby allocation.

2.4 Transmitter characteristics

2.4.1 GSO satellite networks

The characteristics used for the GSO earth stations are given in Table 57. Each of the GSO satellite networks consists of a single GSO satellite. Information for all of the GSO system parameters was not available. These parameters are indicated in the Tables by the entry “N/A”.

TABLE 57

Characteristics of GSO uplink earth stations

System	**Ka-1**	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Service		FSS/MSS	MSS	MSS	MSS	FSS
Polarization		LHCP/RHCP	N/A	N/A	N/A	RHCP/LHCP
Modulation		FDMA/QPSK	FDM/TDM/QPSK	QPSK	QPSK	N/A
Bandwidth (MHz)	186.6	500	125	0.0768	0.0768	0.340
e.i.r.p. (dBW)	77	62	53.2	67.5	61.5	44.3
Antenna gain (dBW)	63.7	43.9	57.2	45.7	55.2	44.3
Transmitter power (dBW)	13.3	18.1	–4	21.8	6.3	0
Number of stations		10	Unlimited	–	–	600 000

2.4.2 Non-GSO networks

The characteristics for the non-GSO earth stations are given in Table 58.

TABLE 58

Characteristics of non-GSO uplink earth stations

System	**LEO-A**	**LEO-B**	**LEOSAT-1**	**LEOSAT-2**
Service	MSS	MSS	FSS	FSS
Orbit	Circular	Circular	Circular	Circular
Altitude (km)	780	10 355	700	1 400
Inclination (degrees)	86	50	98.2	48
Satellites in plane	11	4	40	9
Planes	6	3	21	7
Separation in plane (degrees)	32.7	90	9	
Plane phasing (degrees)	31.6	30	Random	
Polarization	RHCP	LHCP	LHCP/RHCP	
Modulation	FDMA/QPSK	CDMA	Shaped QPSK FDMA	
Bandwidth (kHz)	4 370	2 500	500 000	311 000
e.i.r.p. (dBW)	43.5	54.25	15.2-33.6	50.8-60.4
Antenna gain (dBi)	56.3	64.8	36	
Transmitter power (dBW)	–12.8	–10.55	–2.4	

3 Interference threshold

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor. Therefore, the compatibility threshold is –163 dBW in a bandwidth of 100 MHz. This Annex provides an analysis of the interference generated by a single active service. Further work is needed to address the impact of these multiple active services above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

The following analysis is based on some static geometric cases, which are quite significant.

For each case, the applied methodology is divided into two steps.

The first step consists of computing the required attenuation when the FSS uplinks are co-frequency with the EESS (passive) band. The interference received from one carrier is then compared with the sensor interference threshold. The difference is the required roll-off (attenuation) of OoB emissions that must be achieved to protect the EESS. Moreover, in the hereunder analysis, we assume that the received spectral interference power density is constant, throughout the 200 MHz EESS band (31.3-31.5 GHz).

The second step consists of using the raised cosine spectral representation described in Annex 1, and to determine the minimum guardband that would be required (separation between the passive and the active allocations) to protect the passive sensor.

4.2 Calculation of interference level in case of conically-scanned sensors

Tables 59 and 60 calculate the e.i.r.p. of a single transmitter vertically radiating power on the Earth that corresponds to the sensors interference threshold. Two scenarios are addressed: sensor antenna main-lobe and sensor side-lobe.

4.2.1 Determine power on Earth at threshold level

Table 59 provides the parameters for calculation of the interference thresholds of the sensor main beam and side-lobes at the surface of the Earth.

TABLE 59

Translation of interference threshold to Earth – sensor main beam and side-lobes

Conically scanned sensor	Sensor main beam	Sensor sidelobes
Interference threshold (dB(W/100 MHz))	–163	–163
Antenna gain (dBi)	42	0
Altitude (km)	815	815
Range (km)	1 081	815
Free space loss (dB)	–182.8	–180.4
Atmospheric attenuation (dB)	–1	–1
Polarization loss (circular to linear) (dB)	–3	–3
e.i.r.p. at the Earth corresponding to the sensor threshold (dB(W/100 MHz))	–18.2	21.5

4.2.2 Calculations with the GSO and non-GSO networks

Results are presented in Tables 60 and 61.

TABLE 60

On tune interference margin for GSO systems

System	GSO-Ka-1	GSO residential terminal	GSO-20	GSO-F	GSO-G	GSO-B	GSO-13
Case 1 – Transmitter mainbeam							
Conical scan mainbeam (dB)	–92.3	–66.8	–73.3	–70.5	–85.8	–79.8	–62.6
Conical scan side-lobe (dB)	–52.5	–27	–33.5	–30.7	–46	–40	–22.8
Case 2 – Transmitter side-lobe							
Conical scan mainbeam (dB)	–18.9	–11.3	–19.4	–3.3	–30.1	–14.6	–8.3
Conical scan side-lobe (dB)	+20.9	+28.5	+20.4	+36.5	+9.7	+15.4	+31.5

TABLE 61

On tune interference margin for non-GSO systems

System	LEOSAT-2	LEO-A	LEO-B	LEOSAT-1
Case 1 – Transmitter mainbeam				
Conical scan mainbeam (dB)	–73.8	–61.8	–72.55	–44.9
Conical scan side-lobe (dB)	–34.0	–22.0	–32.75	–5.1
Case 2 – Transmitter side-lobe				
Conical scan mainbeam (dB)	N/A	–5.5	–7.75	–8.9
Conical scan side-lobe (dB)	N/A	+34.3	+32.05	+30.9

4.3 Nadir sounder "push-broom": Calculation of interference level

The following basic hypothesis are adopted for the analysis:

– Interference occurs via direct coupling between the passive sensor and the FSS earth station antennas.

– Both antennas are modelled using Recommendation ITU-R F.1245.

– In an attempt to identify possibly worst-case configurations, it is assumed that the pointing direction of the FSS/MSS earth station (aiming at the geostationary orbit in case of GSO FSS/MSS system is contained in the orbit plane of the Earth exploration-satellite. This configuration renders possible sensor side-lobe to earth station main-lobe and sensor main-lobe to earth station side-lobe interfering paths. Main-lobe to main-lobe interfering paths are also possible; in case of GSO systems, this can occur only with earth stations located near the equator; in case of non-GSO systems, this can occur everywhere. Their probability of occurrence should be studied further in a dynamic analysis which is not implemented in this study.

– The FSS earth station is assumed to be located at a latitude of 35°. This value was selected as a fair compromise to represent a "worst case" sensor side-lobe to earth station main-lobe scenario, because it may represent the lower latitude above which earth stations are the most densely distributed and where, due to the relatively high incidence angle of the interfering path (about 49°), the natural protection due to the path-loss plus atmospheric absorption losses is the lowest.

– The dynamic analysis in § 4.4 will consider latitudes between 0° and 50° N in order to get an extended range of results.

4.3.1 Calculation with the GSO and non-GSO networks

Noting that the most critical scenarios are those involving simultaneously a high e.i.r.p. and/or a wide necessary bandwidth, three GSO systems are selected on these criteria for detailed analysis; these are the "GSO-G", the "GSO-Ka-1" and the "GSO-20" systems (see Table 57).

Considering only the nadir beam of the push-broom passive sensor, the following parameters are computed, depending on the latitudinal distance between the passive sensor and the FSS/MSS earth station:

– linear distance between the sensor and the earth station (km);

– off-set angles between the line-of-sight sensor/earth station and the antennas main axis;

– mutual gains in direction of each other, of the sensor and earth station antennas;

– space loss;

– atmospheric absorption depending on the elevation angle of the path;

– power received by the passive sensor;

– margin referred to the interference threshold;

– size of the area on the Earth's surface, where sounding data are contaminated by interference.

The problem is more complex in case of non-GSO earth stations, because in this case the pointing direction of the earth station is a varying parameter: A specific earth station may be pointing in any direction (elevation and azimuth angles).

For convenience, the present study is limited to a configuration similar to that adopted for the GSO FSS case, where main-lobe to main-lobe scenarios are not considered. It is clear however that this will result in a very optimistic evaluation of the real situation.

In case of GSO FSS systems, main-lobe to main-lobe configurations may occur only with earth stations located near the equator.

In case of non-GSO FSS systems, this configuration may occur everywhere in the FSS satellite coverage.

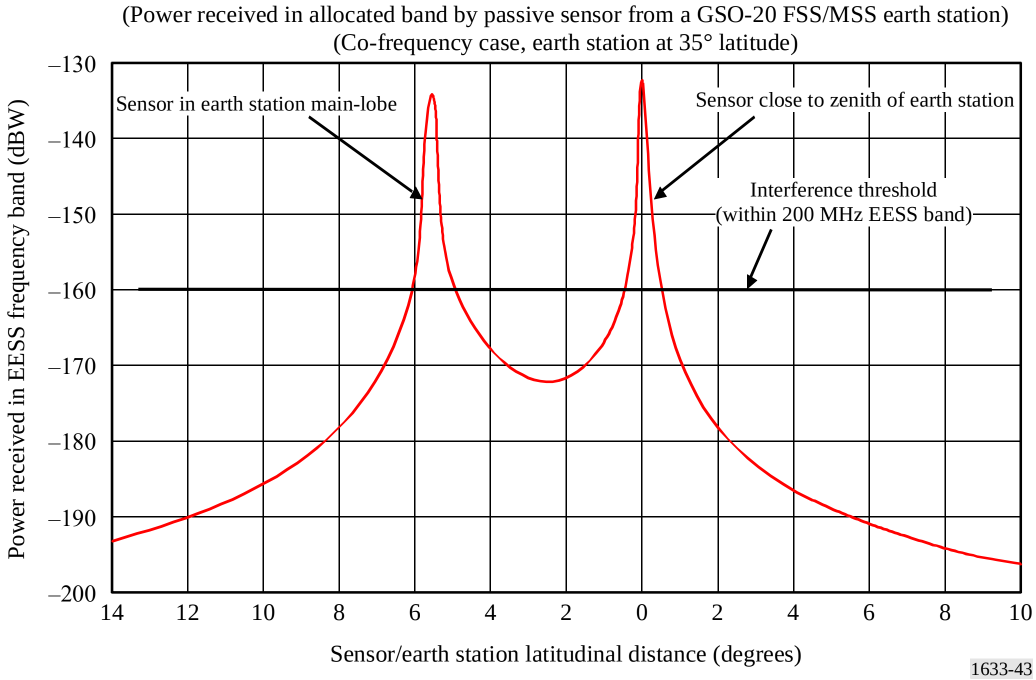
The configuration is described on Fig. 42, where the major geometric parameters of the analysis are indicated.

4.3.2 Result of the analysis

Detailed results are plotted in Figs. 43, 44 and 45, for the three GSO systems selected. While the Earth exploration-satellite is moving in direction of the earth station, a first event appears when the sensor is crossing the earth station's main-lobe; Then a second event occurs when the sensor is near the zenith of the earth station. Main-lobe to main-lobe configurations are possible near the zenith of earth stations located close to the equator. In that case, the power excess is augmented by the discrimination of the earth station antenna (difference between main-lobe and far-lobes).

FIGURE 43

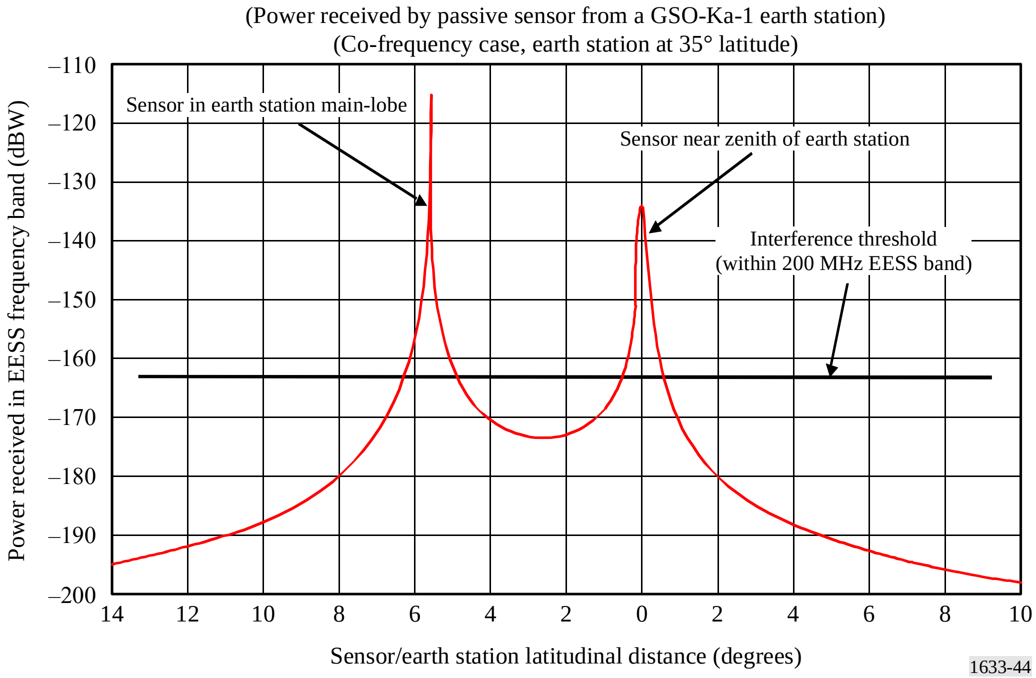
Power received by the passive sensor from a GSO-20 earth station



1633-43

FIGURE 44

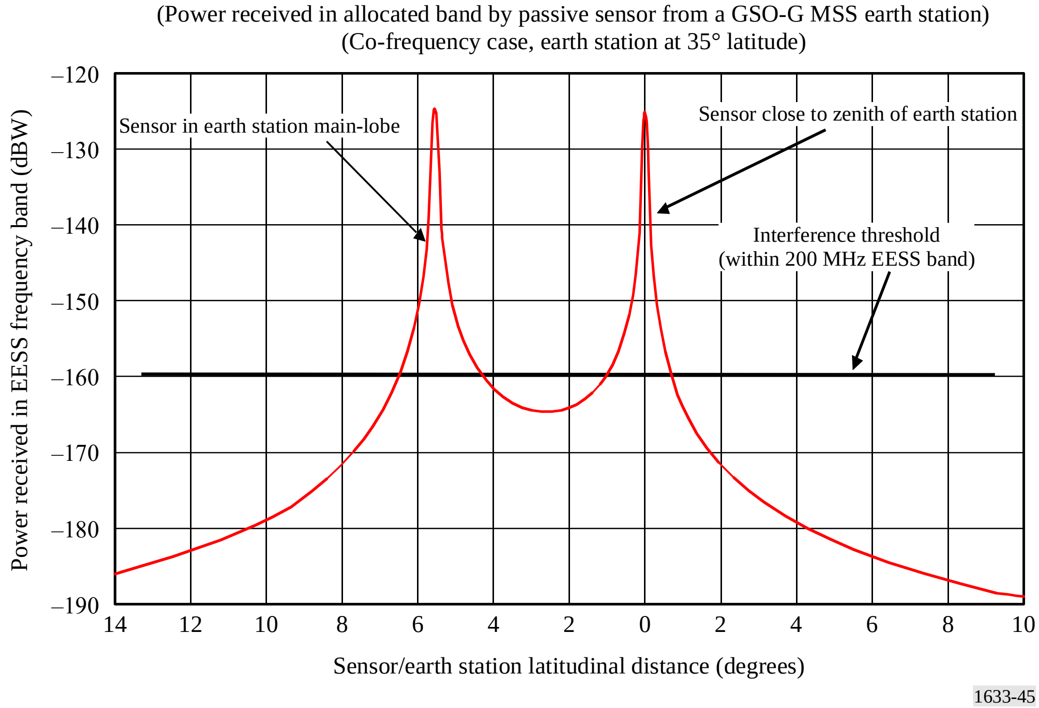
Power received by the passive sensor from a GSO-Ka-1 earth station



1633-44

FIGURE 45

Power received by the passive sensor from a GSO-G earth station



Results for other GSO and non-GSO systems, not analysed in detail, are deduced from the results above by comparing the respective antenna gain and transmitter power.

4.3.3 Discussion of results

Interference events which occur when the passive sensor is in the main-lobe of the FSS earth station (Table 62).

TABLE 62

Power excess over interference threshold – Sensor in main-lobe of earth station (co-frequency assumption)

	GSO FSS/MSS systems					
	GSO-Ka-1	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Excess in all antenna beams (dB)	44.8	25.8	21	35.3	29.3	12.1
Contaminated zone (km^2)	100 × 2 200	120 × 2 200	18 × 2 200	245 × 2 200	42 × 2 200	40 × 2 200
Contaminated pixels/event	6 scan-lines	7.5 scan-lines	1 scan-lines	16 scan-lines	2.6 scan-lines	2.5 scan-lines
Duration of one event (s)	15	18	2.7	37	6.3	6

They are up to 35.3 dB (GSO-G system) above the interference threshold of the passive sensor. They last up to 37 s, which is to be compared to the passive sensor orbital period of 100 min. Since all antenna beams of the sensor are permanently activated, several complete scan-lines (90 pixels each) may be lost at each event; this leads to about 1 440 pixels being lost per event in case of the GSO-G network. Since the Earth exploration-satellite is in an almost polar orbit, the condition required for interference is a coincidence within ± 0.6° around the longitude of the earth station. The probability of occurrence of such events should be further studied, considering in particular the passive sensor drifting-orbit parameters, the density and latitude of earth stations and the availability criteria of passive sensors. Owing to the magnitude of the events, it is doubtful however, that their probability of occurrence may be neglected.

Interference which occurs when the passive sensor is close to the zenith of the FSS earth station (Table 63).

TABLE 63

Power excess over interference threshold – Sensor close to zenith of earth station (co-frequency assumption)

	GSO FSS/MSS systems					
	GSO-Ka-1	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Nadir beam (dB)	25.9	27.7	8.7	34.9	17.1	13.5
± 50° off-nadir beams (dB)	22.1	23.86	4.86	31.06	13.26	9.7
Contaminated zone (km)	Φ: 78	Φ: 94	Φ: 23	Φ: 191	Φ: 34	Φ: 27
Contaminated pixels/event	24	35	2	143	4.4	2.8
Duration of one event (s)	12	14	3.4	29	5	4

They are up to 35 dB above the sensor's interference threshold. They appear also a most serious matter of concern, because the 100° FOV of the push-broom sensor (cross-track) is composed of about 90, permanently activated, adjacent antenna beams, creating a ±10.25° longitudinal zone around the earth station position, where the sensor can receive harmful interference in any of it antenna beams.

Therefore interference will occur whenever the two following geometric conditions are met:

– the sensor is crossing the latitude of the earth station;

– the sensor is at a longitudinal distance within ±10.25° from the earth station.

This configuration is described in Fig. 46.

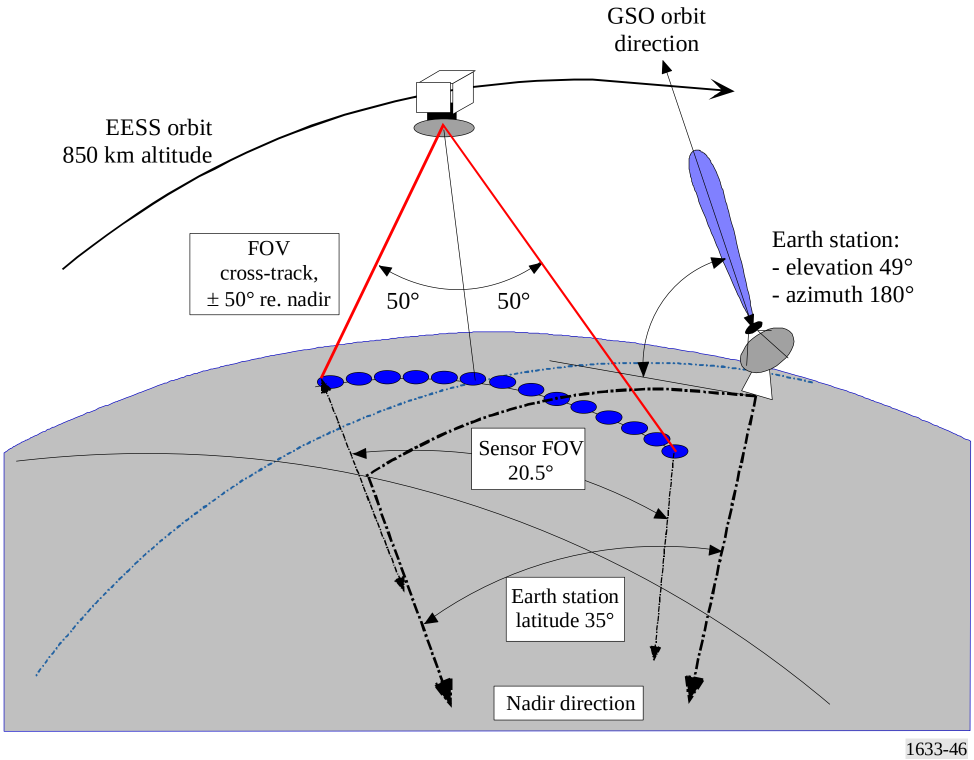
Considering that the longitudinal distance between two successive orbits is about 25° at the equator, the consequence is that passive sensor operation will be hampered by one interference event about twice a day from a unique earth station, considering both ascending and descending orbital paths.

The probability is 100%. The number of events increases with the latitude of the earth station, as the distance between successive orbits decreases with the cosine of the latitude. It is directly proportional to the number of earth stations.

FIGURE 46

Specific case of the push-broom sensor

(Configuration of FSS/MSS earth station interference to push-broom sensor)



The main characteristics of each interference event are the following, in the case of a GSO-G FSS earth station:

– the duration is about 29 s;

– a circular area on the Earth's surface of about 191 km in diameter around each earth station position, is contaminated by harmful interference;

– this 28 600 km^2 zone, corresponding to 140 pixels is to be compared to the 2 000 000 km^2 reference sensor's service area which is stipulated in the Recommendations ITU-R SA.1028 and ITU-R SA.1029;

– the non-availability criterion of 0.01% is by far exceeded in the vicinity of earth stations.

Note that the power excess may exceed 100 dB in case of earth stations located near the equator (main-lobe to main-lobe coincidences). Besides the massive loss of data, this might cause damages to the passive sensor's receivers.

Interference from non-GSO FSS earth stations (Table 64).

TABLE 64

Power excess over interference threshold (co-frequency assumption)

	Non-GSO FSS/MSS systems		
Sensor close to zenith of earth station	**LEO-A**	**LEO-B**	**LEOSAT-1**
Minimum excess, sensor nadir beam (dB)	12.7	4.5	12
Peak excess, sensor nadir beam (dB)	80	70	80
Minimum excess, ±50° off-nadir beams (dB)	6.7	none	6

As for the GSO FSS case, the “close to zenith” event (see Fig. 47) occurs twice a day over all earth stations with, in addition, the possibility of main-lobe to main-lobe interfering path for which a dynamic analysis is required.

Table 64 summarizes the results, showing the “bottom” case where main-lobe to far lobe (earth station) interference occurs, and the “peak” case where a main-lobe to main-lobe coincidence is established.

Clearly if the bottom case induces relatively minor interference similar to the lowest GSO FSS cases, the possible occurrence of “peak excess” is a serious matter of concerns with systems having a wide necessary bandwidth. Further consideration of the peak case is likely to lead to a difficult situation where application of OoB masks may be insufficient.

4.4 Dynamic interference analysis

In addition to the above static and semi-static cases, a dynamic analysis is necessary in order to take into consideration the percentage of time when the interference occurs. As indicated above, the threshold of –163 dBW must not be exceeded no more than 0.01% of time in a bandwidth of 100 MHz.

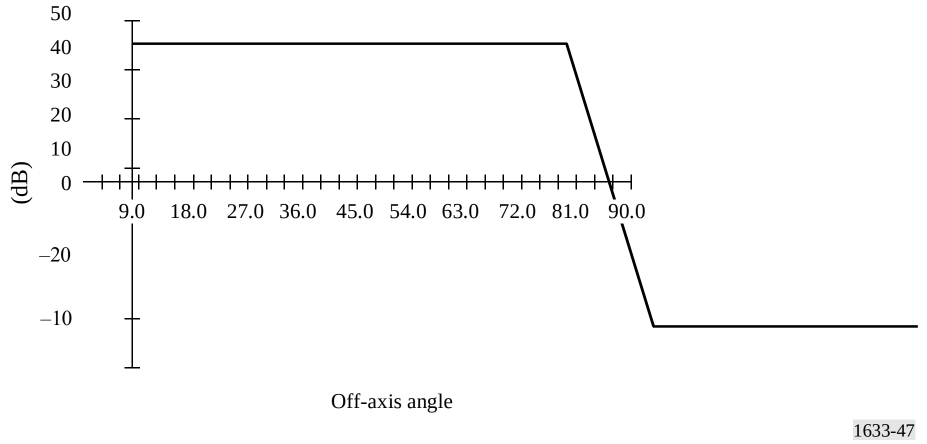
Simulations were conducted to determine the probability of interference using a time increment of 5 s in order to get accurate results. Simulations stopped when the cumulative distribution function becomes stable. Furthermore, it has to be noted that all these simulations presented hereunder only deal with the nadir sounder “push-broom” satellite, because the above static and semi-static cases have shown that it is the worst case.

4.4.1 Modelling of the push-broom antenna

As explained above, the push-broom antenna is able to see a whole line of pixels located around the nadir at ±50° for the azimuth, and in ±0.55° for the elevation. The maximum antenna gain is 45 dBi, and as usual for radiometer antennas, there is a steep decrease to the side-lobe level of –12 dBi. Figure 47 shows the antenna pattern according to the azimuth off-axis angle.

FIGURE 47

Push-broom composite antenna pattern used for the dynamic analysis



4.4.2 Dynamic calculations with GSO systems

TABLE 65

Dynamic analysis between GSO system GSO-20 and EESS with only one earth station operating at the location N0, E0

Cumulative distribution (%)	4.2	1	0.1	0.08	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (500 MHz bandwidth)	–210	–193	–175	–163	–134	–75

Table 65 shows that it is possible to find a 88 dB difference between the threshold of –163 dBW and the maximum power received by the radiometer of –75 dBW. Such a level has a potential to cause damage to the sensor.

TABLE 66

Dynamic analysis between GSO system GSO-20 and EESS with only one earth station operating at the location N50, E0

Cumulative distribution (%)	6.8	1	0.09	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (500 MHz bandwidth)	–212	–188	–163	–134	–129

TABLE 67

Dynamic analysis between GSO system Ka-1 and EESS with only one earth station operating at the location N0, E0

Cumulative distribution (%)	4.2	1	0.07	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (186.6 MHz bandwidth)	–212	–197	–163	–136	–129

According to the above Tables, there is a risk that the EESS satellite experiences interference when only one earth station is in operation (or the percentage of data interfered is above the acceptable one). Taking into the relative bandwidth, the required spectral attenuations are 22 dB for GSO-20 and 24.3 dB for Ka-1.

It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Tables 65 to 67. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criterion is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.4.3 Dynamic calculations with non-GSO systems

TABLE 68

Dynamic analysis between non-GSO system MSS-LEO-B and EESS with six earth stations evenly operating along the equator

Cumulative distribution (%)	24.2	1	0.1	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (2.5 MHz bandwidth)	–236	–208	–163	–152	–150

According to Table 68, there is a risk that the EESS satellite experiences interference when six earth stations are in operation (or the percentage of data interfered is above the acceptable one). In that case, the required spectral attenuation is 11 dB for MSS-LEO-B.

It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Table 68. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criteria is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.5 Application of OoB masks to the FSS earth station transmission

Considering now that the FSS earth stations are transmitting in their own frequency band, the rejection of their transmitter power within the adjacent EESS (passive) allocated band should be, for example:

– 25.9 to 44.8 dB for the GSO Ka-1 system (24.3 dB using dynamic analysis), disregarding the possible occurrence of main-lobe to main-lobe configurations in case of earth stations close to the equator;

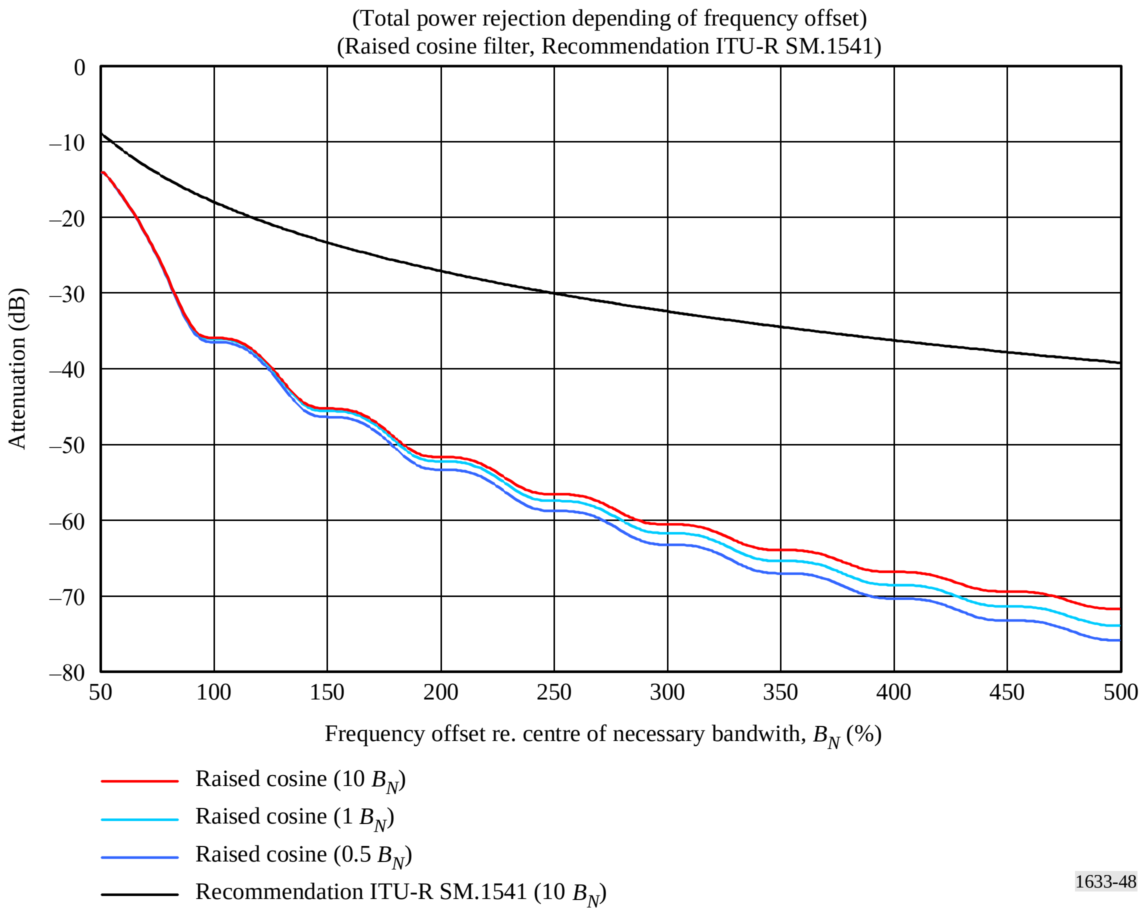
– 12.7 dB for the LEO-A non-GSO system;

– 11 dB for the LEO-B non-GSO system.

Figure 48 represents the power falling within the EESS allocation, depending on guardband. To cover the varying characteristics of the FSS emissions, the sliding integration is performed for three values of the passive band, expressed in terms of percentage of the FSS necessary bandwidth (1 000%, 100% and 50%). There is only a minor difference between the three curves.

FIGURE 48

Attenuation of OoB power contained within the EESS bandwidth



Note that in Fig. 48, the frequency offset is taken from the centre of the necessary bandwidth. This will be used to determine the minimum distance between the centre of the necessary bandwidth and the upper limit of the FSS allocated band, which is required to protect the adjacent EESS allocated band from unwanted FSS emissions.

Furthermore, a 300 MHz separation is provided by the fixed and mobile allocation between the FSS and the EESS allocated bands, in the 31-31.3 GHz band. Therefore the minimum frequency separation between the centre of the necessary bandwidth, which is the reference in the mask, is defined as $B_N/2 + 300$ MHz.

Therefore the required additional guardband has an offset from centre of $B_N - (B_N/2 + 300$ MHz).

4.5.1 Nadir sounder push-broom

Assuming that this mask will be adopted and is representing reliably the real spectral characteristics of the FSS transmitters, the following conditions can be derived, which are summarized in Tables 69 and 70 for GSO FSS systems, and in Table 71 for non-GSO FSS Systems (bottom and peak cases). The last line in these Tables indicates additional guardband, which would be necessary to protect the passive sensors from unwanted emissions in the band 31.3-31.5 GHz.

TABLE 69

Summary of necessary guardbands to protect passive sensors from GSO FSS earth stations (sensor far-lobes in earth station main-lobe)

	GSO-Ka-1	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Required power rejection (dB)	44.8	25.8	21	35.3	29.3	12.1
Necessary bandwidth (MHz)	186.6	500	125	0.0768	0.0768	0.340
Passive band (% BN)	107	40	160	> 1 000	> 1 000	> 1 000
Offset from centre BN (% BN)	145	75	70	90	80	50
Offset from centre BN (MHz)	271	375	88	Negligible	Negligible	Negligible
Required additional guardband (MHz)	0	0	0	0	0	0

TABLE 70

Summary of necessary guardbands to protect passive sensors from GSO FSS earth stations (sensor close to zenith of earth station)

	GSO-Ka-1	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Required power rejection (dB)	25.9	27.7	8.7	34.9	17.1	13.5
Necessary bandwidth (MHz)	186.6	500	125	0.0768	0.0768	0.340
Passive band (% BN)	107	40	160	> 1 000	> 1 000	> 1 000
Offset from centre BN (% BN)	80	80	50	–	–	–
Offset from centre BN (MHz)	150	400	63	–	–	–
Required additional guardband (MHz)	0	0	0	0	0	0

TABLE 71

Summary of necessary guardbands to protect passive sensors from non-GSO FSS earth stations (sensor close to zenith of earth station)

	LEO-A	**LEO-B**	**LEOSAT-1**
Minimum required power rejection (dB)	12.7	4.5	12
Necessary bandwidth (MHz)	4.37	2.5	500
Passive band (% B_N)	> 1 000	> 1 000	40
Offset from centre B_N (% B_N)	50	< 50	50
Offset from centre B_N (MHz)	Negligible	Negligible	250
Required additional guardband (MHz)	0	0	0
Maximum required power rejection (dB)	80	70	80
Offset from centre B_N (% B_N)	550	450	550
Offset from centre B_N (MHz)	24	6.25	2 750
Required additional guardband (MHz)	0	0	2 200

– For all GSO systems considered in this study, the application of a "raised cosine" mask resolves most potential interference problems caused by Earth-to-space links between earth stations and satellites. However, the probability of main-lobe to main-lobe configurations which exists for earth stations located near the equator which would lead to very significant augmentation of the interfering levels indicated in Table 65 (up to about 88 dB), must be investigated further (dynamic analysis);

– The conclusion is similar with non-GSO networks, except for systems having a wide necessary bandwidth due to the higher probability of main-lobe to main-lobe coincidences. The LEOSAT-1 system raises particular concerns because of its wide necessary bandwidth and because of its orbit, close to an EESS orbit. This might result in long duration main-lobe to main-lobe coincidences leading to unacceptable interference events and possibly damages to the sensor's receivers, even under application of the raised cosine mask. However, in view of the large number of satellites specified in the above system concept, the actual implementation of this network is unlikely within this configuration (840 satellites initially planned).

4.5.2 Conically scanned sensors

On the basis of the results presented in Tables 60 and 61, Tables 72 and 73 present the minimum frequency offset between the centre of the necessary bandwidth and the lower limit of the allocated band, that is required to protect the passive sensor from interference generated by the FSS uplinks. The frequency offsets are computed on the basis of a raised cosine mask.

Note that the minimum frequency offset is half the necessary bandwidth, i.e. 50%.

It should be noted that there is a 300 MHz separation between the FSS/MSS allocation and the EESS (passive) allocation. Therefore, the minimum frequency separation between the centre of the necessary bandwidth, which is the reference in the mask, is $B_N/2 + 300$ MHz.

Shaded areas in the tables indicate that the margins are positive and no harmful interference is predicted. They are provided as a visual aid to assess the extent of the interference problem.

TABLE 72

Calculation of the frequency offset required to protect the allocated passive band using the raised cosine mask (GSO systems)

System	**GSO-Ka-1**	**GSO residential terminal**	**GSO-20**	**GSO-F**	**GSO-G**	**GSO-H**	**GSO-13**
Necessary bandwidth (MHz)	186.6	3	500	125	0.0768	0.0768	0.340
Case 1 – Transmitter mainbeam							
Conical scan mainbeam (dB)	–92.3	–66.8	–73.3	–70.5	–85.8	–79.8	–62.6
Offset from centre B_N (%)	> 1 000	394	533	475	957	725	329
Offset from centre B_N	> 1.9 GHz	11.8 MHz	2.7 GHz	594 MHz	0.8 MHz	0.6 MHz	1.2 MHz
Required additional guardband	> 1.5 GHz	0	2.15 GHz	232 MHz	0	0	0
Conical scan side-lobe (dB)	–52.5	–27	–33.5	–30.7	–46	–40	–22.8
Offset from centre B_N (%)	217	78	88	83	165	125	71
Offset from centre B_N (MHz)	405	2.4	440	104	0.13	0.96	0.25
Required additional guardband (MHz)	12	0	0	0	0	0	0
Case 2 – Transmitter side-lobe							
Conical scan mainbeam (dB)	–18.9	–11.3	–19.4	–3.3	–30.1	–14.6	–8.3
Offset from centre B_N (%)	65	50	70	50	80	50	50
Offset from centre B_N (MHz)	122	1.5	350	125	0.07	0.04	0.17
Required additional guardband (MHz)	0	0	0	0	0	0	0
Conical scan side-lobe (dB)	+20.9	+28.5	+20.4	+36.5	+9.7	+15.4	+31.5

TABLE 73

Calculation of the frequency offset required to protect the allocated passive band using the raised cosine mask (N-GSO systems)

System	**LEOSAT-2**	**LEO-A**	**LEO-B**	**LEOSAT-1**
Necessary bandwidth (MHz)	311	4.37	2.5	500
Case 1 – Transmitter mainbeam				
Conical scan mainbeam (dB)	–73.8	–61.8	–72.55	–44.9
Offset from centre B_N (%)	547	323	523	142
Offset from centre B_N (MHz)	1 700	14.2	13.1	710
Required additional guardband (MHz)	1 250	0	0	160
Conical scan side-lobe (dB)	–34.0	–22.0	–32.75	–5.1
Offset from centre B_N (%)	89	75	87	50
Offset from centre B_N (MHz)	277	3.3	2.2	250
Required additional guardband (MHz)	0	0	0	0
Case 2 – Transmitter side-lobe				
Conical scan mainbeam (dB)	N/A	–5.5	–7.75	–8.9
Offset from centre B_N (%)		50	50	50
Offset from centre B_N (MHz)		2.2	1.25	250
Required additional guardband (MHz)		0	0	0
Conical scan side-lobe (dB)	N/A	+34.3	+32.05	+30.9

In most cases, it appears that application of the raised cosine mask is a satisfactory solution to protect the passive sensors against unwanted emissions generated by the FSS non-GSO and GSO earth stations, except in case of main-lobe to main-lobe coincidences and aggregate impact of multiple earth stations in dynamic simulations which still require further investigations.

However, a few systems using simultaneously a wide necessary bandwidth and a high e.i.r.p. raise serious concerns in case of main-lobe to main-lobe configurations. These are the GSO Ka-1, the GSO-20 and the LEOSAT-2 for which the frequency offset required to protect the passive band is not practicable. Further consideration should be given to these systems.

5 Mitigation technique

5.1 EESS (passive)

This subject needs further investigation.

5.2 FSS and MSS

The results of the analysis (see Tables 60 and 61 for the conically scanned sensor, and Tables 62 to 64 for the nadir sensor) indicate that, in most cases, the 300 MHz separation between the FSS and the EESS allocations and the application of the raised cosine mask offer adequate protection of the passive sensors. Some critical issues involving main-lobe to main-lobe alignment with systems implementing simultaneously high e.i.r.p. and wide necessary bandwidth remain unsolved and require further consideration. Because the likelihood of main-lobe to main-lobe coincidences may be high in case of non-GSO FSS systems and in case of GSO FSS earth stations close to equator, no additional frequency offset can be implemented with such systems, with a view of providing protection for the adjacent passive allocation.

5.3 Potential impact

5.3.1 EESS (passive)

The potential impact on the EESS (passive) cannot be assessed until the mitigation techniques (see § 5.1) are finalized.

5.3.2 FSS and MSS

This Annex is based upon the use of the raised cosine spectral representation. The implication of such a spectral representation is being reviewed within the ITU-R.

6 Results of studies

6.1 Summary

This Annex has addressed the protection issue of the passive band 31.3-31.5 GHz taking into account various EESS sensors. Depending on the FSS characteristics, the level above the threshold may be in the order of 88 dB in the case of main-lobe to main-lobe alignment: such a level has the potential to cause damage to the sensors.

It has to be noted that for most of the GSO and non-GSO networks which have been considered in the study, the protection of the EESS (passive) band 31.3-31.5 GHz takes advantage of the 300 MHz separation between the two services if an appropriate attenuation is used. However, further investigation will be required for other kinds of networks.

It should be noted that due to the lack of information on the current use of the 30-31 GHz band by FSS/MSS systems and the appropriate system characteristics, characteristics of FSS/MSS systems used in a nearby band have been assumed for the purpose of this study. Therefore, it may be expected that some of the conclusions of this Annex may be changed.

6.2 Conclusions

This analysis shows that further work on applicable mitigation techniques is necessary. Except for the specific case of main-lobe to main-lobe alignment which has a probability below 0.01% to occur according to the dynamic analysis, and the aggregate impact of multiple earth stations in the dynamic simulation which still requires some further investigation, based on the known characteristics of the FSS/MSS systems used in the study, the band 31.3-31.5 GHz may be protected if the raised cosine attenuation is used or any modulation technique providing a similar or better attenuation.

Annex 15

Compatibility analysis between EESS (passive) systems operating in the 31.3-31.5 GHz band and fixed service (FS) systems operating in the 31-31.3 GHz band

1 EESS (passive)

1.1 Allocated band

The 31-31.3 GHz band is allocated to FS and this band is adjacent to the 31.3-31.5 GHz band allocated to the EESS. This Annex provides calculations of levels of unwanted emissions from FS systems operating below 31.3 GHz that may fall within the 31.3-31.5 GHz band.

It should be noted that according to RR No. 5.340, all emissions are prohibited in the 31.3-31.5 GHz band.

The allocations adjacent to the 31.3-31.5 GHz passive bands are shown in Table 74.

TABLE 74

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
31-31.3 GHz	**31.3-31.5 GHz**	**31.5-31.8 GHz**
FIXED MOBILE Standard frequency and time signal-satellite (space-to-Earth) Space research 5.544	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive)	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed (Regions 1 and 3) Mobile except aeronautical mobile (Regions 1 and 3)

1.2 Application

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with the bands such as 23.8 GHz and 50.3 GHz for the characterization each layer of the Earth's atmosphere.

In the band 31 GHz, a 416 MHz bandwidth is required to get 0.2 K of accuracy in the 31 GHz band. That means the passive microwave users community needs to protect both the 31.3-31.5 GHz band and the 31.5-31.8 GHz band.

This band will also be used in conjunction with the band 31.5-31.8 GHz as a “split window”. This will allow a comparison of the measurements conducted in the two sub-bands to check the quality of the data. This will then allow using the full band when the quality is expected good to increase the sensitivity of the sensor.

1.3 Required protection criteria

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

1.4 Operational characteristics

The following operational characteristics are considered for the EESS system:

– The EESS sensor is assumed to have an antenna with a peak gain of 45 dBi.

– The EESS sensor is pointing in the nadir direction.

– The pixel size for a sensor at an altitude of 850 km is 201 km^2 (16 km diameter).

2 FS

2.1 Allocated band

See Table 74.

2.2 Application

This band may be used for both point-to-point (P-P) FS systems and P-MP FS systems.

2.3 Levels based on existing ITU documents

The following ITU-R Recommendations provide information on unwanted emissions of FS systems:

Recommendation ITU-R F.1191 – Bandwidths and unwanted emissions of digital fixed service systems.

Recommendation ITU-R SM.329 – Unwanted emissions in the spurious domain.

Recommendation ITU-R SM.1541 – Unwanted emissions in the out-of-band domain.

2.4 Transmitter characteristics

The following characteristics were considered for P-P and P-MP FS systems operating in this band.

TABLE 75

Characteristics of P-P systems
(Recommendation ITU-R F.758)*

Channel spacing (MHz)	56	3,5
Antenna gain (maximum) (dBi)	45	45
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna type	Dish	Dish
Maximum Tx output power (dBW)	0	0
e.i.r.p. (maximum) (dBW)	45	45

* Since Recommendation ITU-R F.758 does not provide any information on P-P systems to be deployed in this band, these parameters are based on those of systems to be deployed in the band 37-39.5 GHz, with the appropriate antenna gain.

TABLE 76

Characteristics of P-MP systems
(Recommendation ITU-R F.758)

Channel spacing (MHz)	50	2,5
Direction of transmission	Hub to RT	RT to Hub
Antenna gain (maximum) (dBi)	15	36
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna type	15° × 90° horn	2° × 2° Dish
Maximum Tx output power (dBW)	10	4
e.i.r.p. (maximum) (dBW)	25	40

RT: remote terminal.

2.5 Operational characteristics

2.5.1 P-MP operational characteristics

It is proposed to use as a first step a density of terminals of 1 terminal per km^2[*].

2.5.2 P-MP operational characteristics

It is proposed to use as a first step a density of terminals of 0.3 terminals per km^2[*].

– *Frequency reuse*: a frequency reuse of 2 is commonly used and is considered as a typical scenario. A frequency reuse factor of 1 is to be considered as a worst-case situation, which occurs rarely.

[*] It should be noted that these numbers represent a worst-case approach and will be refined to obtain a realistic number of FS systems in each of the considered bands.

– *Sector antenna*: the typical sector antenna width is 90°. In some cases, 45° sector antennas are foreseen where high amount of traffic capacities have to be transported from one station location.

Based on these considerations, a hub of a P-MP cell may serve typically two co-channel subscribers within a given cell.

2.6 In band transmit power

See Tables 75 and 76.

3 Compatibility threshold (if applicable)

The passive sensor protection criterion is −163 dBW in a 100 MHz bandwidth (not to be exceeded for more than 0.01% of time as stipulated by Recommendation ITU-R SA.1029).

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service.

Further work is needed to address the impact of these multiple active services operating above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess the interference level

The first step of this approach is to calculate the acceptable power resulting from a deployment of FS systems that may fall within an EESS pixel.

Aggregate power at the Earth in 100 MHz = EESS protection criteria (dB(W/100 MHz)) –
EESS gain + free space loss

Then it is possible to derive the unwanted level of emissions per FS system falling into the EESS 100 MHz reference bandwidth:

Power per Tx (dB(W/100 MHz)) **=** Aggregate power at the Earth in 100 MHz –
N_b Tx (in EESS pixel) – FS Gain in the EESS direction

4.2 Calculation

For P-P systems, Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. The density of terminals operating at the same frequency is assumed to be one terminal per km^2.

For P-MP terminal stations, Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. For P-MP central stations, Recommendation ITU-R F.1336 was used to derive the antenna gain in the zenith direction. The density of site of central station operating at the same frequency is assumed to be 0.3 terminals per km^2. On the same site, two central stations may use the same frequency assuming 90°sector antenna. Therefore within the same cell two terminal stations may use the same frequency.

TABLE 77

Acceptable unwanted emissions level per P-P FS system falling into the EESS band

Frequency (GHz)	31.3	
Interference criteria (dB(W/100 MHz))	–163	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	181	
Aggregate at the Earth (dB(W/100 MHz))	–27	
Aggregate at the Earth in dB(W/MHz)	–47.1	
Station type	CS	TS
Channel spacing (MHz)	56	3.5
FS antenna gain	45	45
FS gain in the EESS direction	–12.3	–12.3
Aggregate power (dB(W/MHz))	–34.8	–34.8
Density of systems per km^2	1.0	1.0
Pixel size (km^2)	201	201
N_b Tx	201	201
Power per Tx (dB(W/MHz))	–57.8	–57.8
Power per Tx (dB(W/100 MHz))	–37.8	–37.8

CS: Central station.

TS: Terminal station.

TABLE 78

Acceptable unwanted emissions level per P-MP FS system falling into the EESS band

Frequency (GHz)	31.3	
Interference criteria (dB(W/100 MHz))	–163	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	181	
Aggregate at the Earth (dB(W/100 MHz))	–27	
Aggregate at the Earth (dB(W/MHz))	–47.1	
Station type	CS	TS
Channel spacing (MHz)	50	2.5
FS antenna gain	15	36
FS gain in the EESS direction	–11.6	–10.1
Aggregate power (dB(W/MHz))	–35.5	–37.0
Density of systems per km^2	0.6	0.6
Pixel size (km^2)	201	201
N_b Tx	121	121
Power per Tx (dB(W/MHz))	–56.3	–57.8
Power per Tx (dB(W/100 MHz))	–36.3	–37.8

4.3 Value achieved

4.3.1 Level of unwanted emissions based on ITU-R Recommendations

As a first step approach, only unwanted emissions falling into the spurious domain are considered (if the guardband is larger than the OoB domain). Then, levels of attenuation provided in RR Appendix 3 and Recommendation ITU-R SM.329 are used to derive the levels of unwanted emissions from FS falling within the spurious emission domain (offset higher than 250% of the necessary bandwidth or channel separation compared to the centre frequency of the FS signal). In the case of FS systems, the attenuation specified in RR Appendix 3 should be in dBc, the minimum of 70 dBc or (43 + 10 log (P)).

Based on the first step approach, for a system operating with an output power of 0 dBW and a channel spacing of 56 MHz (see Table 74).

The spurious emission limits for this system is:

$$P \text{ (dBW)} - (43 + P) \qquad \text{dB in a 1 MHz reference bandwidth}$$

Table 79 provides the level of unwanted emissions that may fall in a 100 MHz reference bandwidth.

TABLE 79

Calculation of the level of unwanted emissions that may fall within a 100 MHz bandwidth

FS System	Level of spurious emissions per 1 MHz (dBW)	Level of spurious emissions per 100 MHz (dBW)
P-P 56 MHz (Table 75)	–43	–23
P-P 3.5 MHz (Table 75)	–43	–23
P-MP 50 MHz (Table 76)	–43	–23
P-MP 2.5 MHz (Table 76)	–43	–23

This first step approach leads to the conclusion that even if only unwanted emissions falling into the spurious domain are considered then the EESS protection criteria is not met.

4.3.2 Refinement of the calculations

Since the first step of the calculation has shown that the EESS interference criteria will not be met, the refinement of the calculations will take into account characteristics of unwanted emissions systems that will be deployed in this band. In particular, the following sections are based on characteristics of systems provided in the European Telecommunications Standard Institute (ETSI). The approach, which is described in the following sections, was used within the European Conference of Postal and Telecommunications Administrations (CEPT) to derive the required guardband so that the unwanted emissions from FS systems falling into the EESS band met the EESS interference criteria given in § 4.2 (–37.8 dB(W/100 MHz)). These results were taken into account to develop channel arrangements for FS systems operating in the 31-31.3 GHz band.

4.3.2.1 P-P FS systems

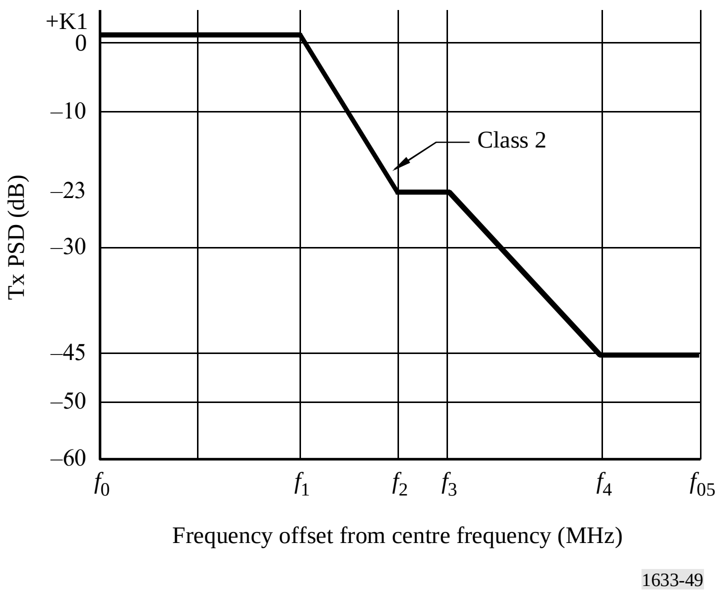
4.3.2.1.1 OoB emissions masks for P-P systems

For the purpose of these analyses, we consider OoB mask given in ETSI Standard EN 300 197 provides OoB mask for fixed radio systems; P-P equipment; parameters for radio systems for the transmissions of digital signal operating at 32 GHz and 38 GHz.

The analysis considers the worst case of OoB emissions masks given in the ETSI Standard EN 300 197, this leads to consider the following masks (see Fig. 49).

FIGURE 49

OoB emission mask



NOTE 1 – The 0 dB level shown on the spectrum masks relates to the spectral power density of the nominal centre frequency disregarding residual carrier.

Table 80 provides the values of f_i depending on channel spacing, which may extend from 3.5 MHz to 56 MHz according to EN 300 197.

TABLE 80

Break points of the OoB emissions mask

Channel spacing (MHz)	K1 (dB)	f_1 (MHz)	f_2 (MHz)	f_3 (MHz)	f_4 (MHz)	f_5 (MHz)
3.5	+1	1.3	2	2.3	4.3	8.75
7	+1	2.8	5.6	7	14	17.5
14	+1	5.6	11.2	14	28	35
28	+1	11	19	25	45	70
56	+1	18	32	40	70	140

4.3.2.1.2 Spurious emissions levels for P-P systems

Recommendation ITU-R SM.329 gives information on the levels of spurious emissions, in particular, this analysis consider levels adopted in Europe and used by some other countries (Category B levels).

For P-P system operating with a channel spacing, C_s, higher than 10 MHz, the spurious emission limit is −60 dB(W/MHz).

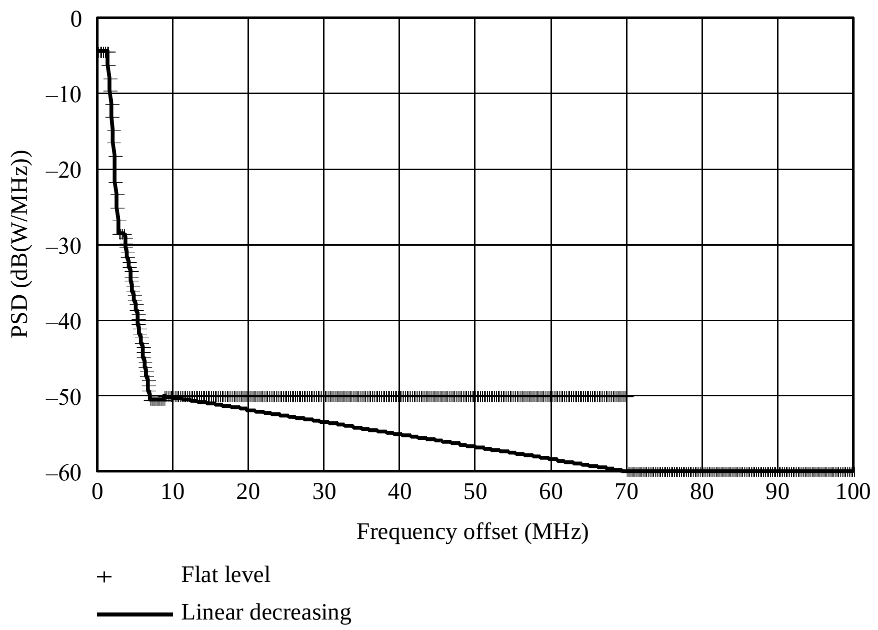
In case of P-P systems operating with a C_s lower than 10 MHz, there is a step before reaching this −60 dB(W/MHz) value. From an offset of 2.5 × C_s compared to the centre frequency to an offset of 70 MHz, the limit is equal to −50 dB(W/MHz) (or −60 dBW in a 100 kHz reference bandwidth).

In case of P-P systems operating with a C_s lower than 10 MHz, to obtain more realistic results we made the assumption that there is a linear decreasing between the –50 dB(W/MHz) point on the mask and the point corresponding to the level of −60 dB(W/MHz).

Figure 50 provides an example of unwanted emissions mask for system using a C_s of 3.5 MHz.

FIGURE 50

Level of unwanted emission for 3.5 MHz system



Unwanted emission mask for an FDMA system (0 dB/3.5 MHz/f_c = 31 250 MHz)

1633-50

4.3.2.1.3 Results of the calculations for P-P systems

The following sections derived the levels of unwanted emissions, which may be received by the EESS system in a 100 MHz reference bandwidth, depending on the guardband.

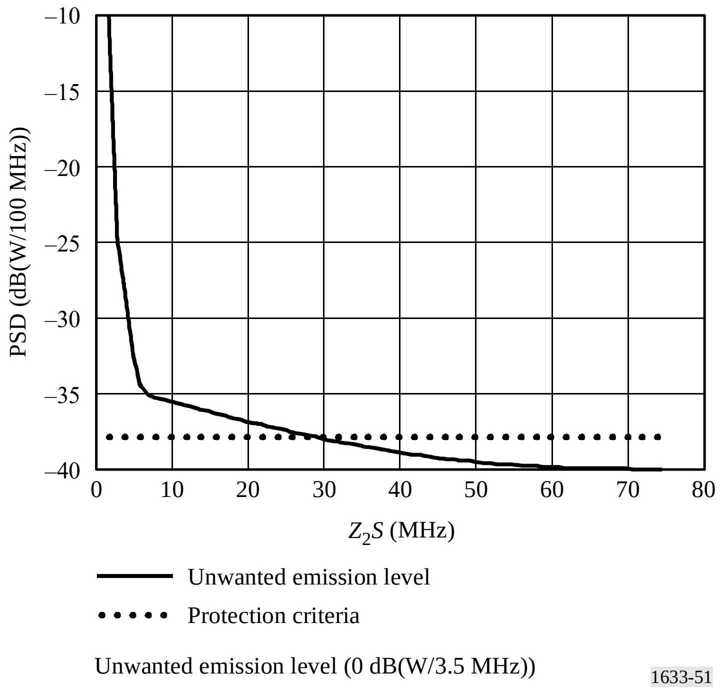
It should be noted that ETSI standards provide a maximum output power of 0 dBW for P-P systems to be deployed in this band.

4.3.2.1.3.1 3.5 MHz channel P-P spacing

Figure 51 provides the result of the calculation for a 3.5 MHz C_s P-P system.

FIGURE 51

Z_2S for FS P-P system using a 3.5 MHz C_s



The term Z_2S, is defined in Recommendation ITU-R F.746 as the upper separation between the centre frequency of the final channel and the upper edge of the band. This leads to a guardband of 28.75 – 3.5/2 = 27 MHz assuming that there is a linear decrease between the –50 dB(W/MHz) point on the mask and the point corresponding to the level of –60 dB(W/MHz).

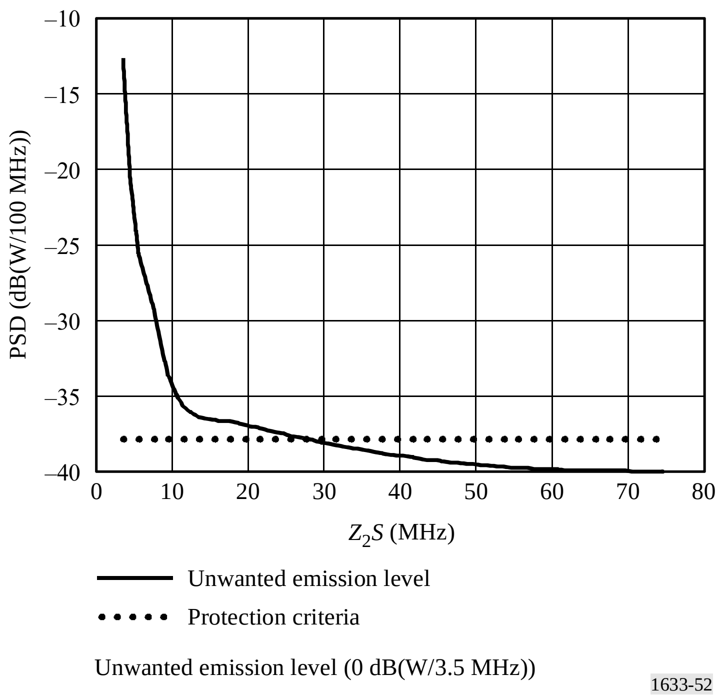
In this case, the guardband is larger than the OoB domain, and then only spurious emissions will fall in the EESS band.

4.3.2.1.3.2 7 MHz channel spacing P-P systems

Figure 52 provides the result of the calculation for a 7 MHz C_s P-P system.

FIGURE 52

Z_2S for FS P-P system using a 7 MHz C_s



The term Z_2S, is defined in Recommendation ITU-R F.746 as the upper separation between the centre frequency of the final channel and the upper edge of the band. This leads to a guardband of 27.5 – 7/2 = 24 MHz assuming that there is a linear decreasing between the –50 dB(W/MHz) point on the mask and the point corresponding to the level of –60 dB(W/MHz).

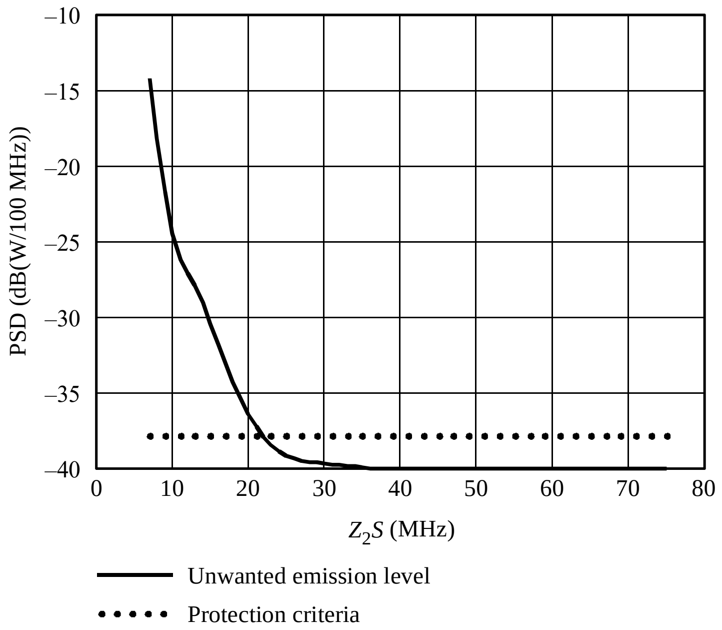
In this case, the guardband is larger than the OoB domain, and then only spurious emissions will fall in the EESS band.

4.3.2.1.3.3 14 MHz channel spacing P-P systems

Since the channel spacing is larger than 10 MHz, in this case there is no need make the assumptions considered in the previous part for spurious emissions. Figure 53 provides the result of the calculation for a 14 MHz C_s P-P system.

FIGURE 53

Z_2S for a 0 dBW FS P-P system using a C_s of 14 MHz



Unwanted emission level (0 dB(W/14 MHz))

1633-53

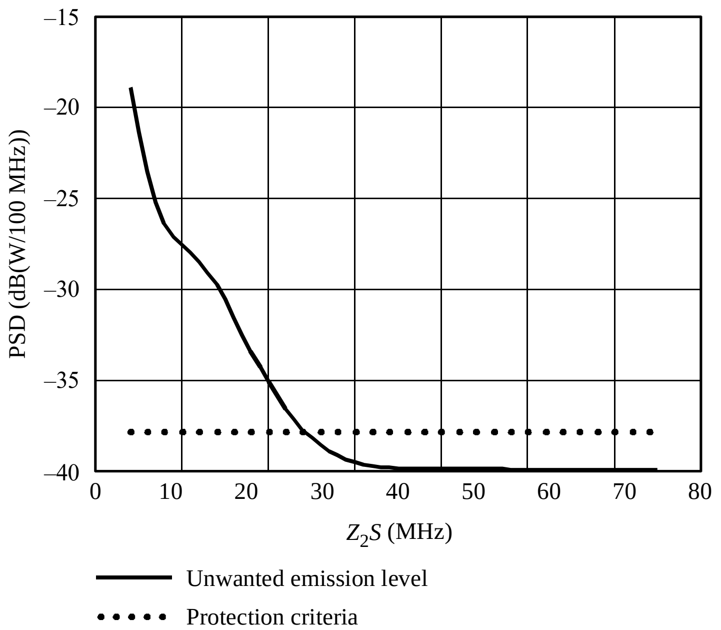
This leads to a guardband of 22 – 14/2 = 15 MHz.

4.3.2.1.3.4 28 MHz channel spacing P-P systems

Figure 54 provides the result of the calculation for a 28 MHz C_s P-P system.

FIGURE 54

Z_2S for a 0 dBW FS P-P system using a C_s of 28 MHz



Unwanted emission level (0 dB(W/14 MHz))

1633-54

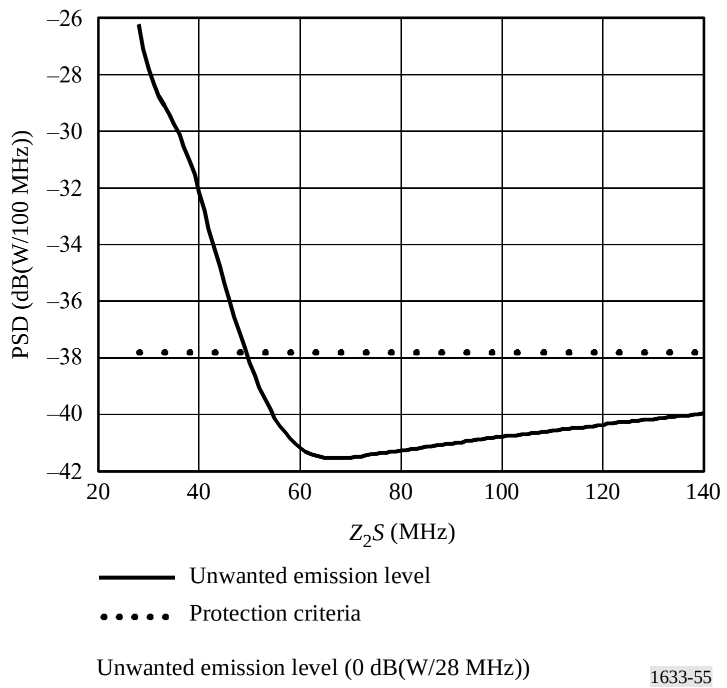
This leads to a guardband of 34 – 28/2 = 20 MHz.

4.3.2.1.3.5 56 MHz channel spacing P-P systems

Figure 55 provides the result of the calculation for a 56 MHz C_s P-P system.

FIGURE 55

Z_2S for a 0 dBW FS P-P system using a C_s of 56 MHz



This leads to a guardband of 49 – 56/2 = 21 MHz.

4.3.2.1.3.6 Summary of the results for P-P systems

Table 81 provides a summary of the results calculated for P-P systems using a C_s ranging from 3.5 MHz to 56 MHz.

TABLE 81

Guardband depending on the C_s

Channel spacing (MHz)	Z_2S (MHz)	Guardband (MHz)
3.5	28.75	27
7	27.5	24
14	22	15
28	34	20
56	49	21

4.3.2.2 P-MP FS systems

It should be noted that the acceptable unwanted emissions level per P-MP FS system level, which is obtained in case of terminal station (see Table 79) is the same as the acceptable unwanted emissions level per P-P FS system level (see Table 78).

4.3.2.2.1 OoB emissions masks for P-MP systems

For the purpose of these analyses, we consider the OoB masks given in the ETSI standard which provides information on fixed radio systems; multipoint equipment, and multipoint digital radio systems operating in the 31 GHz to 33.4 GHz (32 GHz) frequency range. The first step of the analysis is to determine the worst-case OoB emissions masks. This leads to consider the following cases shown in Fig. 56.

FIGURE 56

Spectrum masks, Types A and B

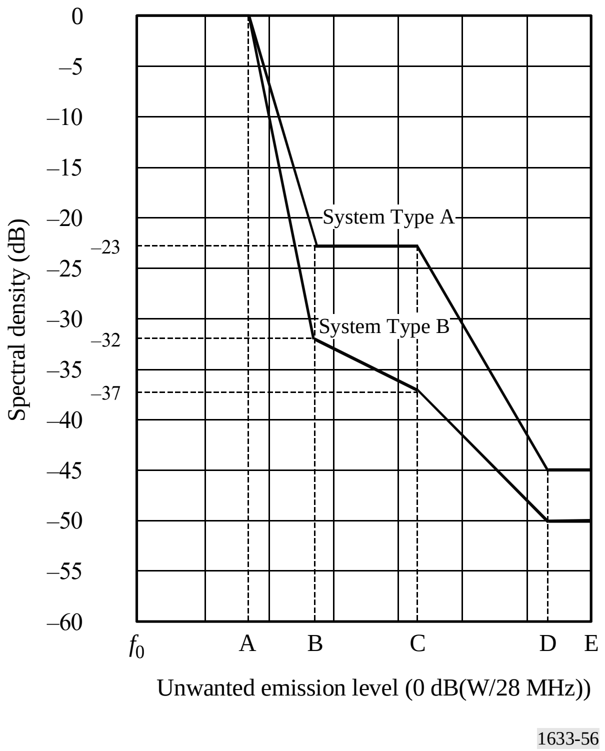


Table 82 provides the corresponding break points for type A systems, depending on the C_s, which may extend from 3.5 MHz to 112 MHz according to the ETSI standard.

TABLE 82

Break points of the OoB emissions mask

Co-polar channel spacing Points in Fig. 56 (MHz)	0 dB Point A (MHz)	–23 dB Point B (MHz)	–23 dB Point C (MHz)	–45 dB Point D (MHz)	–45 dB Point E (MHz)
3.5	1.5	2.8	3.7	7	8.75
7	2.8	5.6	7	14	17.5
14	5.6	11.2	14	28	35
28	11.2	22.4	28	56	70
56	22.5	45	56	112	140
112	45	90	112	224	280

It should be noted that these masks are applicable both for terminal stations and for base stations.

4.3.2.2.2 Levels of spurious emissions for P-MP systems

EN 301 390 provides the levels of spurious emissions for P-P systems (the same as those given in Recommendation ITU-R SM.329 under Category B) and for P-MP systems.

Tables 83 and 84 provide the comparison of limits depending on the type of system.

TABLE 83

Spurious limits in case of systems using a C_s smaller than 10 MHz

Frequency offset	2.5 × C_s – 56 MHz	56-70 MHz	70-112 MHz	> 112 MHz
P-P limit (Category B) (dB(W/MHz))	–50	–50	–60	–60
P-MP limit (EN 301 390) (dB(W/MHz))	–50	–60	–60	–70

TABLE 84

Spurious limits in case of systems using a C_s higher than 10 MHz

Frequency offset	2.5 × C_s – max (112 MHz; 4.5 × C_s)	> max (112 MHz; 4.5 × C_s)
P-P limit (Category B) (dB(W/MHz))	–60	–60
P-MP limit (EN 301 390) (dB(W/MHz))	–60	–70

4.3.2.2.3 Results of the calculations for P-MP systems

The same approach as for P-P system is used.

4.3.2.2.3.1 3.5 MHz and 7 MHz channel spacing P-MP systems

According to the calculations made in § 4.3.2.1.3.1, only spurious emissions will fall in the EESS band (the calculated guardband for P-P systems is larger than the OoB domain).

Since:

– the acceptable unwanted emissions level which is obtained in case of P-MP systems (see Table 79) is the same as the acceptable unwanted emissions level which was considered in the analyses for P-P systems (see Table 78);

– the spurious emissions limits for P-MP systems are more stringent than for P-P systems,

it can be directly concluded that the guardband, which was derived for P-P systems, will also cover the case of P-MP systems.

4.3.2.2.3.2 14 MHz channel spacing P-MP systems

Since:

– the OoB emissions mask for P-P systems and for P-MP systems are the same (see Table 80 and Table 82);

– the acceptable unwanted emissions level which is obtained in case of P-MP systems (see Table 79) is the same as the acceptable unwanted emissions level which was considered in the analyses for P-P systems (see Table 78),

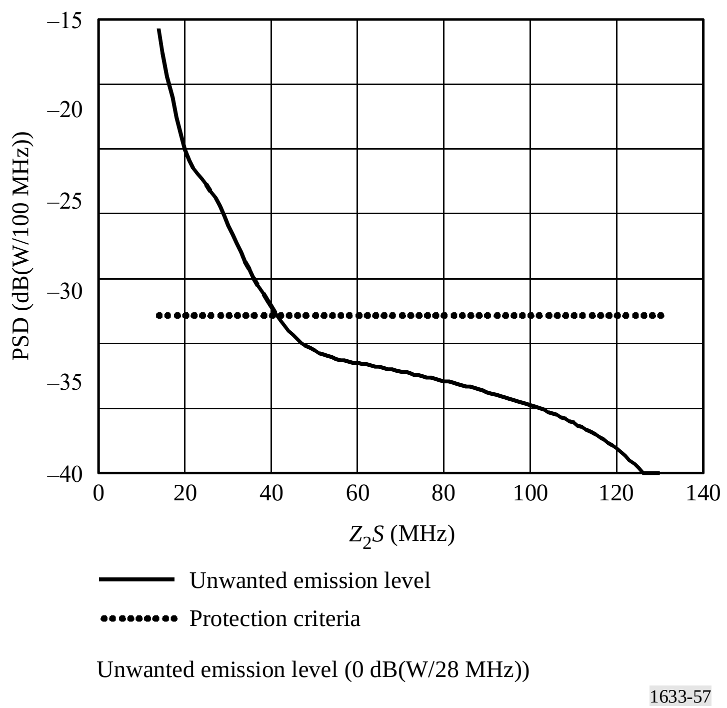
it can be directly concluded that the guardband, which was derived for P-P systems, will also cover the case of 14 MHz channel spacing P-MP systems.

4.3.2.2.3.3 28 MHz channel spacing P-MP systems

Figure 57 provides the result of the calculation for a 28 MHz C_s P-MP system.

FIGURE 57

Z_2S for a 0 dBW FS P-MP system using a C_s of 28 MHz



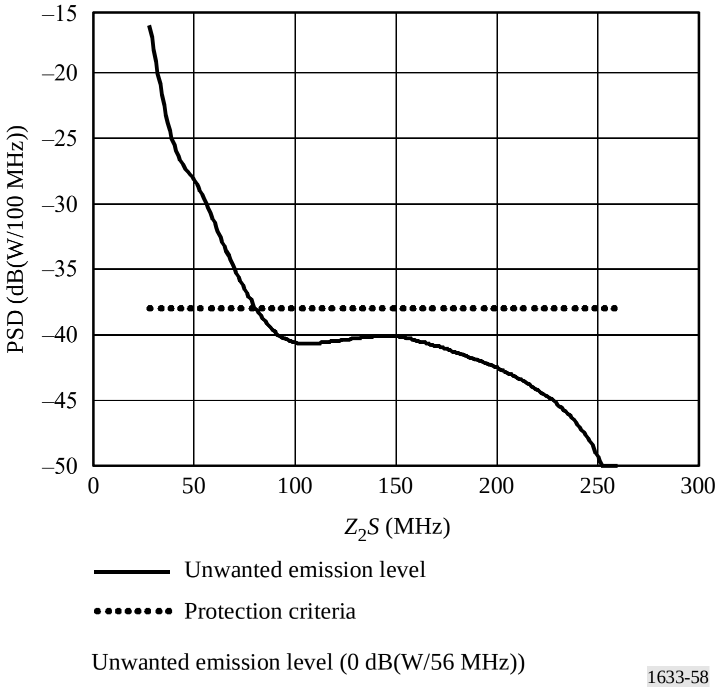
The term Z_2S, is defined in Recommendation ITU-R F.746 as the upper separation between the centre frequency of the final channel and the upper edge of the band. This leads to a guardband of 41 – 28/2 = 27 MHz.

4.3.2.2.3.4 56 MHz C_s P-MP systems

Figure 58 provides the result of the calculation for a 56 MHz C_s P-MP system.

FIGURE 58

Z_2S for a 0 dBW FS P-MP system using a C_s of 56 MHz



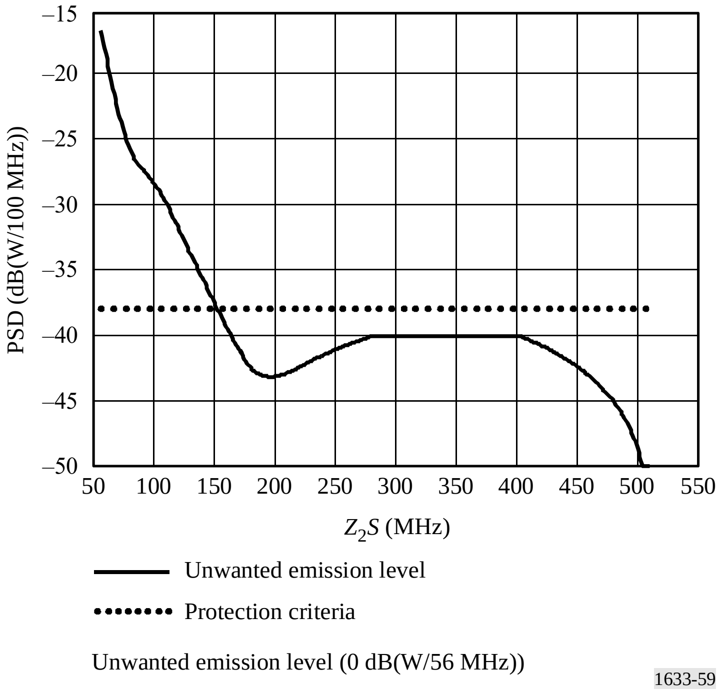
This leads, for an output power of 0 dBW, to a guardband of 80 – 56/2 = 52 MHz.

4.3.2.2.3.5 112 MHz C_s P-MP systems

Figure 59 provides the result of the calculation for a 112 MHz C_s P-MP system.

FIGURE 59

Z_2S for a 0 dBW FS P-P system using a C_s of 112 MHz



This leads, for an output power of 0 dBW, to a guardband of 152 – 112/2 = 96 MHz.

4.3.3 Summary and conclusions for P-P and P-MP systems

Table 85 provides a summary of the results. Table 85 provides a summary of the results calculated for P-P and P-MP systems using a C_s from 3.5 MHz to 112 MHz (including the results provided in Table 81).

TABLE 85

Guardband depending on the C_s

C_s (MHz)	Z_2S (MHz)	Guardband (MHz)
3.5	28.75	27
7	27.5	24
14	22	15
28	41	27
56	80	52
112	152	96

The 56 MHz and 112 MHz channel spacing plans are not included in the channel arrangement given in Annex 8 to Recommendation ITU-R F.746 due to the limited number of channels they would allow for. Specifically, they would allow for only one frequency division duplex (FDD) channel for 56 MHz spacing and one time division duplex (TDD) channel for 112 MHz C_S. The channel arrangement of Annex 8 to Recommendation ITU-R F.746 includes a guardband of 31 MHz in the upper part of the band 31-31.3 GHz.

It should be noted that since the guardband included in Annex 8 to Recommendation ITU-R F.746 is larger than the minimum one required for channel spacing of 3.5, 7, 14 and 28 MHz, this gives an additional margin compared to the acceptable power given in Tables 77 and 78.

5 Mitigation techniques

5.1 EESS (passive)

EESS systems cannot implement guardband at the lower edge of the EESS band since they need to operate in the whole 200 MHz allocation.

5.2 FS

The use of a guardband of 31 MHz for systems deployed in accordance with Annex 8 to Recommendation ITU-R F.746 and, which use more stringent mask for OoB emissions than those given in Recommendation ITU-R SM.1541 and limits for spurious emissions given in Recommendation ITU-R SM.329 (Category B) ensure that the levels of unwanted emissions from FS systems falling into the band 31.3-31.5 GHz meet the acceptable power given in Tables 77 and 78 (about –38 dB(W/100 MHz)).

Other mitigation techniques such as filtering may also be used to ensure that the maximum acceptable power within the passive band may be met.

5.3 Potential impact

5.3.1 EESS

No impact.

1. FS

If the FS systems implement mitigation techniques using both OoB limits, as well as limits for spurious emissions given in Recommendation ITU-R SM.329 (Category B) then the impact has yet to be determined for FS in countries that do not follow such limits. If other techniques are implemented by the FS to meet –38 dB(W/100 MHz), then the impact of those techniques needs to be determined as well.

6 Results of the studies

6.1 Summary

In this Annex, it was shown that FS systems operating in the band 31-31.3 GHz deployed in Europe using more stringent mask for OoB emissions than those given in Recommendation ITU-R SM.1541 and limits for spurious emissions given in ITU-R SM.329 (Category B) will meet the protection maximum acceptable power –38 dB(W/100 MHz). It should be noted that the densities of terminals that were considered in the compatibility analysis represent a worst-case approach and may be refined.

6.2 Conclusion

When FS systems follow the channel arrangements given in Annex 8 to Recommendation ITU-R F.746 and meet more stringent limits for unwanted emissions than the one given in Recommendation ITU-R SM.1541 and in RR Appendix 3, the level of unwanted emissions from FS systems deployed in the band 31-31.3 GHz may meet –38 dB(W/100 MHz), which would ensure compatibility between FS operating in the band 31-31.3 GHz and EESS operating in the band 31.3-31.5 GHz.

Annex 16

Compatibility analysis between EESS (passive) systems operating in the 31.5-31.8 GHz band and FS systems operating in the 31.8-33.4 GHz band

1 EESS (passive)

1.1 Allocated band

The 31.8-33.4 GHz band is allocated to FS and this band is adjacent to the 31.5-31.8 GHz band allocated to the EESS. This Annex provides calculations of levels of unwanted emissions from FS system operating above 31.8 GHz that may fall within the 31.5-31.8 GHz band.

The allocations adjacent to the 31.5-31.8 GHz passive bands are shown in Table 86.

TABLE 86

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
31.3-31.5 GHz	**31.5-31.8 GHz**	**31.8-32 GHz**
EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive)	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed (Regions 1 and 3) Mobile except aeronautical mobile (Regions 1 and 3)	FIXED RADIONAVIGATION SPACE RESEARCH (deep space) (space-to-Earth)

1.2 Application

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with the bands such as 23.8 GHz and 50.3 GHz for the characterization each layer of the Earth’s atmosphere.

In the band 31 GHz, a 416 MHz bandwidth is required to get 0.2 K of accuracy in the 31 GHz band. That means the passive microwave users community needs to protect both the 31.3-31.5 GHz band and the 31.5-31.8 GHz band.

This band will also be used in conjunction with the band 31.3-31.5 GHz as a “split window”. This will allow a comparison of the measurements conducted in the two sub-bands to check the quality of the data. This will then allow using the full band when the quality is expected good to increase the sensitivity of the sensor.

1.3 Required protection criteria

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

1.4 Operational characteristics

The following operational characteristics are considered for the EESS system:

– The EESS sensor is assumed to have a maximum gain on boresight of 45 dBi.

– The EESS sensor is pointing in the nadir direction.

– The pixel size for a sensor at an altitude of 850 km is 201 km^2 (16 km diameter).

2 FS

2.1 Allocated band

See Table 86.

2.2 Application

According to RR No. 5.547, the band 31.8-33.4 GHz is available for high-density applications in the FS.

This band may be used for both P-P FS systems and P-MP FS systems.

2.3 Levels based on existing ITU documents

The following ITU-R Recommendations provide information on unwanted emissions of FS systems:

Recommendation ITU-R F.1191 – Bandwidths and unwanted emissions of digital fixed service systems.

Recommendation ITU-R SM.329 – Unwanted emissions in the spurious domain.

Recommendation ITU-R SM.1541 – Unwanted emissions in the out-of-band domain.

2.4 Transmitter characteristics

The following characteristics (Tables 87 and 88) were considered for P-P and P-MP systems operating in the band 31.8-33.4 GHz.

TABLE 87

Characteristics of P-P systems
(Recommendation ITU-R F.758)

Channel spacing (MHz)	56	3,5
Antenna gain (maximum) (dBi)	46	46
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna type	Dish	Dish
Maximum Tx output power (dBW)	–3	–3
e.i.r.p. (maximum) (dBW)	43	43

TABLE 88

Characteristics of P-MP systems
(Recommendation ITU-R F.758)

Station type	CS	TS
Channel spacing (MHz)	28	28
Antenna gain (maximum) (dBi)	14	Dish 41 Planar 28
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna beamwidth (3 dB) azimuth/elevation (degrees)	> 15	1.2 × 1.2
Maximum Tx output power (dBW)	–5	–10
e.i.r.p. (maximum) (dBW)	9	31/18

2.5 Operational characteristics

Recommendation ITU-R F.1520 provides channel arrangement for systems using 3.5 MHz, 7 MHz, 14 MHz, 28 MHz and 56 MHz channel spacings to be deployed in the band 31.8-33.4 GHz.

2.5.1 P-P operational characteristics

It is proposed to use as a first step a density of terminals of one terminal per km^2[*].

2.5.2 P-MP operational characteristics

It is proposed to use as a first step a density of terminals of 0.3 terminal per km^2[*].

– *Frequency reuse*: a frequency reuse of 2 is commonly used and is considered as a typical scenario. A frequency reuse factor of 1 is to be considered as a worst-case situation, which occurs rarely.

– *Sector antenna*: the typical sector antenna width is 90°. In some cases, 45° sector antennas are foreseen where high amount of traffic capacities have to be transported from one station location.

[*] It should be noted that these numbers represent a worst-case approach and will be refined to obtain a realistic number of FS systems in each of the considered bands.

Based on these considerations, a hub of a P-MP cell may serve typically two co-channel subscribers within a given cell.

2.6 In band transmit power

See Tables 87 and 88.

3 Compatibility threshold

The passive sensor protection criterion is –163 dBW in a 100 MHz bandwidth (not to be exceeded for more than 0.01% of time as stipulated by Recommendation ITU-R SA.1029). Section 2.4 provides a set of characteristics for FS systems to be deployed in this band. Based on this information, it is possible to derive the allowed power from each FS system falling into the EESS band.

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service.

Further work is needed to address the impact of these multiple active services operating above and below the passive band.

4 Interference assessment

4.1 Methodology to assess the interference level

The first step of this approach is to calculate the acceptable power resulting from a deployment of FS systems that may fall within an EESS pixel:

Aggregate power at the Earth in 100 MHz = EESS protection criteria (dB(W/100 MHz)) –
EESS gain + free space loss

Then it is possible to derive the unwanted level of emissions per FS system falling into the EESS bandwidth:

Power/Tx (dB(W/100 MHz)) = Aggregate power at the Earth in 100 MHz –
N_b Tx (in EESS pixel) – FS gain in the EESS direction

4.2 Calculation

For P-P systems (see Table 89), Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. The density of terminals operating at the same frequency is assumed to be one terminal per km^2.

For P-MP terminal stations (see Table 90), Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. For P-MP central stations, Recommendation ITU-R F.1336 was used to derive the antenna gain in the zenith direction. The density of site of central station operating at the same frequency is assumed to be 0.3 terminal per km^2. On the same site, two central stations may use the same frequency assuming 90° sector antenna. Therefore, two terminal stations may use the same frequency within the same cell.

TABLE 89

Acceptable unwanted emissions level per P-P FS system falling into the EESS band

Frequency (GHz)	31.8	
Interference criteria (dB(W/100 MHz))	–163	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	181	
Aggregate at the Earth (dB(W/100 MHz))	–27	
Aggregate at the Earth (dB(W/MHz))	–47.0	
Station type	CS	TS
Channel spacing (MHz)	56.0	3.5
FS antenna gain	46	46
FS gain in the EESS direction	–12.6	–12.6
Aggregate power (dB(W/MHz))	–34.4	–34.4
Density of systems/km^2	1.0	1.0
Pixel size/km^2	201	201
N_b Tx	201	201
Power per Tx (dB(W/MHz))	–57.4	–57.4
Power per Tx (dB(W/100 MHz))	–37.4	–37.4

TABLE 90

Acceptable unwanted emissions level per P-MP FS system falling into the EESS band

Frequency (GHz)	31.8	
Interference criteria (dB(W/100 MHz))	–163	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	181	
Aggregate at the Earth (dB(W/100 MHz))	–27	
Aggregate at the Earth (dB(W/MHz))	–47.0	
Station type	CS	TS
Channel spacing (MHz)	28	28
FS antenna gain	14	41
FS gain in the EESS direction	–11.5	–11.3
Aggregate power (dB(W/MHz))	–35.4	–35.7
Density of systems/km^2	0.6	0.6
Pixel size/km^2	201	201
N_b Tx	121	121
Power per Tx (dB(W/MHz))	–56.2	–56.5
Power per Tx (dB(W/100 MHz))	–36.2	–36.5

4.3 Value achieved

4.3.1 Level of unwanted emissions based on ITU-R Recommendations

As a first step approach, only unwanted emissions falling into the spurious emissions are considered (if the guardband is larger than the OoB domain). Then, levels of attenuation provided in RR Appendix 3 and Recommendation ITU-R SM.329 are used to derive the levels of unwanted emissions from FS systems falling within the spurious emission domain (offset higher than 250% of the necessary bandwidth or channel separation compared to the centre frequency of the FS system signal). In the case of FS systems, the attenuation specified in RR Appendix 3 should be in dBc, the minimum of 70 dBc or (43 + 10 log (P)).

Based on the first step approach, for a system operating with an output power of 0 dBW and a channel spacing of 56 MHz (see Table 86). The spurious emission limits for this system is:

$$P \text{ (dBW)} - (43 + P) \qquad \text{dB in a 1 MHz reference bandwidth.}$$

Table 91 provides the level of unwanted emissions that may fall in a 100 MHz reference bandwidth.

TABLE 91

Calculation of the level of unwanted emissions that may fall within a 100 MHz bandwidth

FS system	Level of spurious emissions per MHz (dBW)	Level of spurious emissions per 100 MHz (dBW)
P-P 56 MHz (Table 87)	–43	–23
P-P 3.5 MHz (Table 87)	–43	–23
P-MP 28 MHz (CS Table 88)	–43	–23
P-MP 28 MHz (TS Table 88)	–43	–23

This first step approach leads to the conclusion that even if only unwanted emissions falling into the spurious domain are considered then the EESS protection criteria is not met.

4.3.2 Refinement of the calculations

FS systems deployed in this band may comply with limits given in ETSI Standard EN 300 197 and Category B given in Recommendation ITU-R SM.329 as those that will be deployed in the band 31-31.3 GHz (see Annex 15).

The acceptable powers per terminal that were calculated in Tables 89 and 90 are close to those that were considered in the Annex 15, dealing with compatibility between the EESS (passive) operating in the band 31.3-31.5 GHz and FS systems operating in the band 31.0-31.3 GHz. This means that the guardbands, which were derived in Annex 15, are sufficient to protect EESS operation. The corresponding guardband is provided in Table 92.

TABLE 92

Guardband depending on the channel spacing

Channel spacing (MHz)	Z_2S **(MHz)**	**Guardband (MHz)**
3.5	28.75	27
7	27.5	24
14	22	15
28	41	27
56	80	52

5 Mitigation techniques

5.1 EESS (passive) service

Recommendation ITU-R F.1520 provides channel arrangements for FS systems to be deployed in this band (see Fig. 60).

Table 93 provides the guardbands recommended in this channel arrangement and the difference with the required guardbands which were calculated in Annex 15, dealing with compatibility between the EESS (passive) systems operating in the band 31.3-31.5 GHz and FS systems operating in the band 31-31.3 GHz.

Then, for systems (which used more stringent mask for OoB emissions than those given in Recommendation ITU-R SM.1541 and meet limits given in Recommendation ITU-R SM.329 under Category B within the spurious domain), if a guardband of about 12 MHz is set up within the EESS allocated band, the protection of EESS systems will be ensured.

5.2 FS

The above calculations are based on the assumption that fixed service systems deployed in the band 31.8-33.4 GHz use more stringent mask for OoB emissions than those given in Recommendation ITU-R SM.1541 and limits for spurious emissions given in Recommendation ITU-R SM.329 (Category B).

Other mitigation techniques such as filtering may also be used to decrease the level of unwanted emissions from FS systems falling into the EESS band.

FIGURE 60

Occupied spectrum: 31.8 to 33.4 GHz band

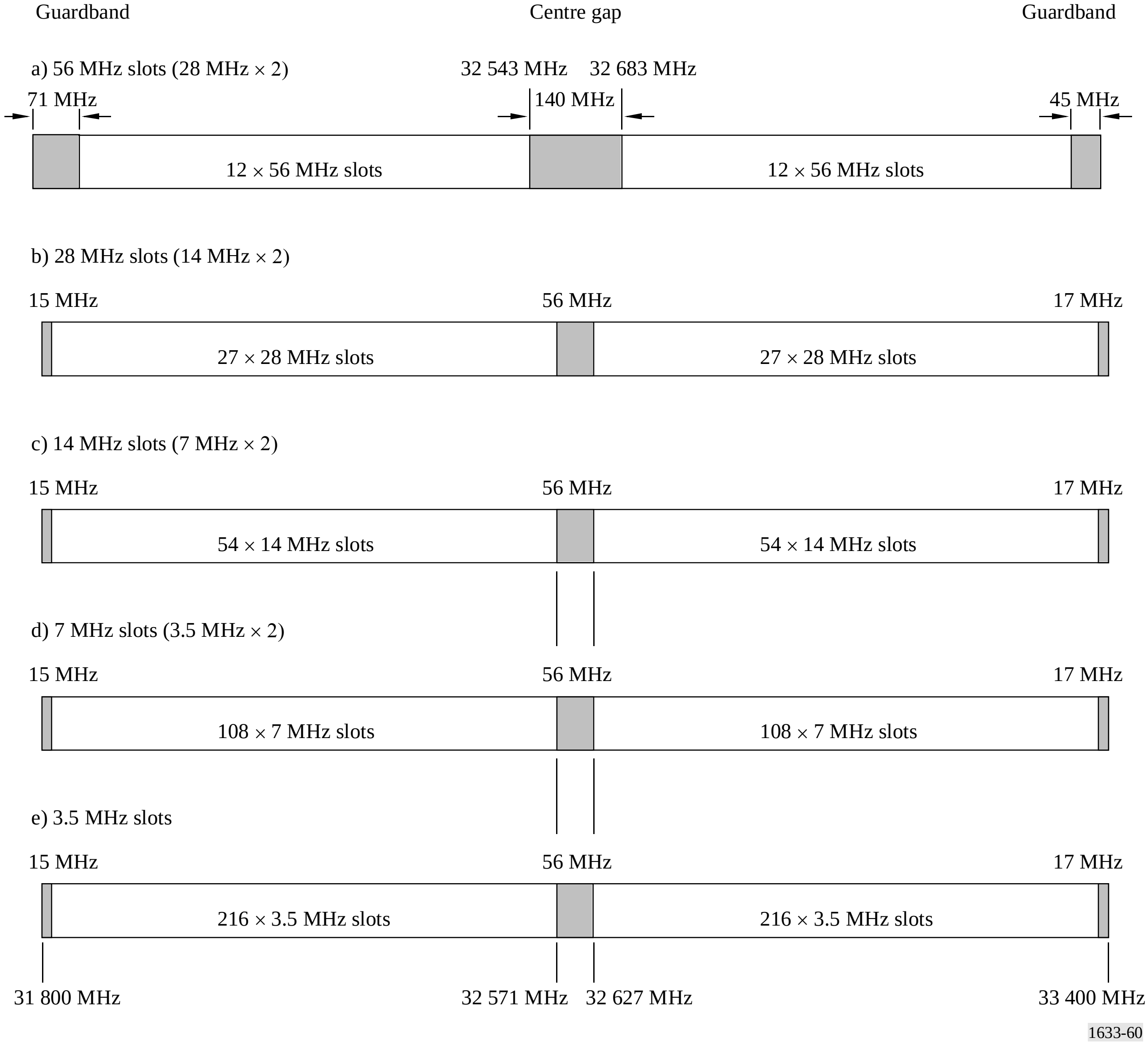


TABLE 93

Comparison of the guardbands

Channel spacing (MHz)	**Calculated guardband (MHz)**	**Guardband included in the plan (MHz)**	**Difference (MHz)**
3.5	27	15	12
7	24	15	9
14	15	15	0
28	27	15	12
56	52	71	–19

5.3 Impact of mitigation techniques

5.3.1 EESS

Since:

– to satisfy the requirements of EESS system in terms of checking the quality of the measurements conducted in the band 31.3-31.5 GHz (more than 200 MHz are available in the band 31.5-31.8 GHz);

– to obtain an accuracy better than 0.2 K, since more than 416 MHz are available for measurements,

the implementation of a 12 MHz in the upper part of the EESS band 31.5-31.8 GHz may have no impact of the operation of EESS sensors.

If FS systems do not implement mitigations techniques described in § 5.2, then the required guard-band will be larger and this may affect the operation of the EESS sensor.

5.3.2 FS

If the FS systems implement more stringent limits for unwanted emissions than those given in Recommendation ITU-R SM.1541 within OoB domain, as well as Category B limit given in Recommendation ITU-R SM.329, then the impact has yet to be determined for FS in countries that do not follow such limits. If the FS implements other techniques, then the impact of those techniques needs to be determined as well.

6 Results of studies

6.1 Summary

The analysis conducted in the previous sections shows that the guardband, which is currently included in the channels arrangements provided in Recommendation ITU-R F.1520 may not be sufficient to reduce the levels of unwanted emissions from FS systems in the band 31.8-33.4 GHz to the levels required to meet the EESS protection criteria.

The EESS designers may consider the possibility of including a guardband in the upper part of the EESS band 31.5-31.8 GHz when designing EESS systems so that the protection of EESS measurements may be ensured. The suitability and applicability of the mitigation techniques in this comprehensive study need to be further investigated.

6.2 Conclusion

Considering FS systems that comply with a more stringent mask for unwanted emissions than those laid out in Recommendation ITU-R SM.1541 and RR Appendix 3, and by taking into account the channel arrangements for fixed service systems in this band (Recommendation ITU-R F.1520), protection of the EESS (passive) may be assured when the EESS (passive) system would include a guardband of at least 12 MHz at the 31.8 GHz band edge. If FS systems cannot comply with the above conditions, much larger guardbands at the band edge would be required to ensure compatibility.

Annex 17

Compatibility between the EESS (passive) in the 31.5-31.8 GHz band and radionavigation systems operating in the 31.8-33.4 GHz band

1 EESS (passive)

1.1 Allocated band

The 31.8-33.4 GHz band is allocated to radionavigation service and this band is adjacent to the 31.5-31.8 GHz band allocated to the EESS (passive). This Annex provides calculations of levels of unwanted emissions from radionavigation system operating above 31.8 GHz that may fall within the 31.5-31.8 GHz band.

The allocations adjacent to the 31.5-31.8 GHz passive bands are shown in Table 94.

TABLE 94

Adjacent band allocations

Services in lower allocated band	**Passive band**	**Services in upper allocated band**
31.3-31.5 GHz	**31.5-31.8 GHz**	**31.8-32 GHz**
EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive)	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) Fixed (Regions 1 and 3) Mobile except aeronautical mobile (Regions 1 and 3)	FIXED RADIONAVIGATION SPACE RESEARCH (deep space) (space-to-Earth)

1.2 Application

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with bands such as 23.8 GHz and 50.3 GHz for the characterization of each layer of the Earth's atmosphere.

In the band 31 GHz, a 416 MHz bandwidth is required to get 0.2 K of accuracy in the 31 GHz band. That means the passive microwave users community needs to protect both the 31.3-31.5 GHz band and the 31.5-31.8 GHz band.

This band will also be used in conjunction with the band 31.3-31.5 GHz as a "split window". A comparison can be made of the measurements conducted in the two sub-bands to check the quality of the data. This will then allow using the full band when the quality is expected to be good to increase the sensitivity of the sensor.

1.3 Required protection criteria

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

1.4 Operational characteristics

The following operational characteristics are considered for the EESS system:

– The EESS sensor is assumed to have an antenna with a peak gain of 45 dBi.

– The EESS sensor is pointing in the nadir direction.

– The pixel size for a sensor at an altitude of 850 km is 201 km^2 (16 km diameter).

2 Radionavigation service

2.1 Allocated band

See Table 94.

2.2 Application

Radionavigation systems identified to operate in the band 31.8-33.4 GHz are onboard aircraft. The system operates worldwide mostly continuously during flight. This encompasses an altitude range of from just off the ground to approximately 30 000 ft (or 9 000 m). Flight times can be up to 6 h, and typically the majority of the time is spent en route, but some longer time at either the departure or destination points is expected. Information from one administration indicates that it operates a limited number of aircraft worldwide with radionavigation systems in this frequency band.

The term "radionavigation" throughout the text refers to an airborne radar system operating in the 31.8-33.4 GHz band. One administration has reported worldwide use of this band for the radionavigation service in terms of a limited number of airborne radar systems. The actual radar system is used for ground mapping, weather avoidance and navigation, but not primarily for functions such as airport approaching and landing. Future replacement of some of the fixed frequency systems with the frequency agile system is envisaged.

2.3 Levels based on RR provisions and ITU-R Recommendations

2.3.1 RR No. 1.153

The RR defines *occupied bandwidth* as follows:

"**1.153** *occupied bandwidth:* The width of a frequency band such that, below the lower and above the upper frequency limits, the *mean powers* emitted are each equal to a specified percentage β/2 of the total *mean power* of a given *emission*.

Unless otherwise specified in an ITU-R Recommendation for the appropriate *class of emission*, the value of β/2 should be taken as 0.5%."

If the upper edge of the occupied bandwidth were at or below the upper limit of the radiolocation allocation, the total power of unwanted emissions at frequencies above the allocated bandwidth would be no greater than 0.5% of *P*, where *P* is the in-band power. Therefore, the total power of unwanted emission at frequencies in the EESS band and above is no greater than *P* − 23 dB.

2.3.2 Recommendation ITU-R SM.1541

Recommendation ITU-R SM.1541, Annex 8 specifies a generic mask for OoB emissions for primary radars. This is repeated below as a segmented relationship. The dependent variable *F* is the frequency offset from band centre as a per cent of the –40 dB bandwidth of the radar, as illustrated in Fig. 61, where:

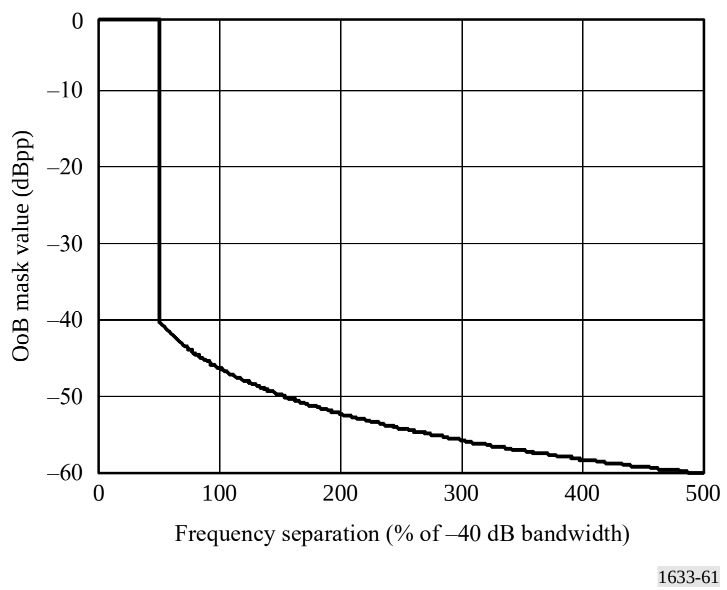
F: frequency offset from band centre as a per cent of the –40 dB bandwidth of the radar, and

dBpp: expressed in decibels relative to the maximum value of the peak power, measured with the reference bandwidth within the occupied bandwidth.

It provides the minimum attenuation for OoB emission power, within a reference bandwidth, relative to the in-band peak power.

FIGURE 61

OoB mask for primary radars



2.4 Transmitter characteristics

Two radar systems are implemented: one system using fixed frequency (of 80% of aircraft stations) and one system (of 20% of aircraft stations) with the option to use frequency agility (nine channels in the band 32.2-33 GHz). The technical characteristics of systems operating in the radionavigation service can be found in Recommendation ITU-R F.1571 and are given here in Table 95.

TABLE 95

Emissions bandwidth of systems in the radionavigation service operating in the 31.8-33.4 GHz band

Parameter	System 1	System 2
Tuning type	Fixed frequency; tunes continuously across 31.8-33.4 GHz	Fixed frequency or frequency hopping; operates in either mode on one of nine discrete channels spaced 100 MHz apart (32.2-33 GHz)
Emission type (MHz)	Unmodulated pulses	Unmodulated pulses
RF emission bandwidth (MHz)	37	17 (instantaneous) 117 (hopping)
Pulse width (μs)	0.2	0.2
Pulse repetition frequency (pps)	2 000	1 600
Peak transmitter power (kW)	60	39
Antenna type	Parabolic reflector	Parabolic reflector
Antenna main beam gain (dBi)	44	41.1
Antenna scan	Elevation: –30° to +10°, manual Azimuth: 360° at 7, 12 or 21 r.p.m.	Elevation: –30° to +10°, manual Azimuth: 360° at 12 or 45 r.p.m.

From Table 95, it can be concluded that the concept of pulse compression technique using coded pulses (with error detection capability) is not implemented in the considered radar systems.

It should be noted that the antenna rotation is mechanically, i.e. the antenna beam is not electronically controlled.

2.5 Operational characteristics

Up to 18 aircraft operating these radionavigation systems can be active in a small geographic area (i.e. separated by less than a kilometre from each other), though most often only 1-3 aircraft will be operating simultaneously together.

2.6 In band transmit power

See Table 95.

3 Compatibility threshold

The passive sensor protection criterion is –163 dBW in a 100 MHz bandwidth (not to be exceeded for more than 0.01% of time as stipulated by Recommendation ITU-R SA.1029). Section 2.4 provides a set of characteristics for radionavigation systems to be deployed in this band. Based on this information, it is possible to derive the allowed power from each radionavigation system falling into the EESS band.

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service.

Further work is needed to address the impact of these multiple active services operating above and below the passive band.

4 Interference assessment

4.1 Methodology to assess the interference level

The first step is to analyse the required attenuation to satisfy the EESS (passive) protection criteria. The second step is to calculate the attenuation when the EESS (passive) band is falling just outside the –40 dB bandwidth of the radar.

4.2 Calculation of interference level

4.2.1 Required attenuation in passive band

The required attenuation for the four radiolocation systems is given in Table 96, for which the EESS (passive) instrument’s antenna main-lobe “sees” the radar antenna side-lobe of the radionavigation system.

TABLE 96

Compatibility analysis with radar

	System 1	**System 2**
Frequency (GHz)	31.8	31.8
Radionavigation power (dBW)	47.8	45.9
Radionavigation antenna gain	–10	–10
Altitude (km)	850	850
Free space loss	181	181
Gain EESS	45	45
Power in a 100 MHz reference bandwidth	–98.2	–100
Interference criteria (dB(W/100 MHz))	–163	–163
Required attenuation	–64.8	–63

4.2.2 Calculation of unwanted emissions from radar Systems 1 and 2

An assumption used in this analysis is that the –40 dB bandwidth of the radar is located within the radionavigation band and that the EESS band is located from the 50% value of the –40 dB bandwidth as depicted in Fig. 61.

For Systems 1 and 2 the attenuation levels have been calculated. This has been done using the mask and equations in Annex 8 of Recommendation ITU-R SM.1541. For the calculations of both the necessary bandwidth and the –40 dB bandwidth the pulse rise-time is needed. This parameter has been estimated at 50 ns for both Systems 1 and 2. For Systems 1 and 2 this resulted in a B_N of 17.9 MHz and a B_{-40} of 76 MHz. Here it has to be noted that considering the characteristics of System 2 as given in Table 95, the closest radar channel is located around 32.2 GHz, thus giving a large (already implemented) guardband. For System 1, the EESS (passive) reference bandwidth of 100 MHz (31.7-31.8 GHz) runs from 50% to 181.6% in Fig. 61. The unwanted emission power falling into the reference bandwidth of 100 MHz is –45.7 dBpp for System 1.

4.3 Values achieved

The resulting margins assuming a radar antenna gain –10 dBi (in the direction of the sensor) are 19.1 dB for System 1. It is very likely that System 2, due to its large frequency separation, will be compatible with EESS (passive) systems operation in the adjacent band.

5 Mitigation techniques

5.1 EESS (passive)

From the description in § 1.2, it may be possible for the band 31.5-31.8 GHz to implement a guardband at the end of the passive service allocation at the band edge of 31.8 GHz.

5.2 Radionavigation service

Mitigation techniques for systems that are currently in use may be used from a practical point of view. Most of the radars used in the range 31.8-33.4 GHz are frequency agile and have relatively small RF emission bandwidths compared to allocated band. A possibility to avoid emissions in the lower part of the spectrum adjacent to the existing passive band edge at 31.8 GHz needs to be investigated and could resolve the discrepancy. For example, it is likely that the compatibility analysis would result in a positive scenario when the closest radar channel with respect to the existing edge of the passive band has a frequency separation of approximately 2 to 2.5 times the –40 dB bandwidth of the radionavigation system.

5.3 Potential impact

5.3.1 EESS (passive)

By implementing a suitable guardband to prevent potential interference from adjacent band interferers, the EESS (passive) may have a better environment for conducting its measurements. The applicability and suitability of such a guardband would need further investigation.

5.3.2 Radionavigation service

The feasibility to keep the complete –40 dB radar bandwidth within the radionavigation band combined with either an additional frequency separation or a lower peak power limit (i.e. future radars for the band 31.8-33.4 GHz may have different parameters) would need further investigation.

6 Results of studies

6.1 Summary

This compatibility analysis has calculated the potential interference from radionavigation systems in the upper adjacent band in the band 31.5-31.8 GHz allocated to the EESS (passive).

6.2 Conclusion

This compatibility analysis resulted in a discrepancy of 19.1 dB for a single system of System 1 (Table 95), assuming an antenna gain of –10 dBi in the direction of the sensor. Mitigation techniques for both services have been identified and would need further investigation to assess their applicability and suitability. An implementation of a guardband in the radionavigation or the EESS (passive) band would result in a positive scenario. Also, by taking into account the usage of this system by aircraft, the interference may be below the availability criterion of the passive sensor.

Radionavigation systems of System 2 in Table 95 will be compatible due to its large frequency separation (around 400 MHz) with respect to the band edge with the passive band 31.5-31.8 GHz.

Annex 18

Compatibility analysis between RAS systems operating in the 42.5-43.5 GHz band and FSS and BSS (space-to-Earth) systems operating in the 41.5-42.5 GHz band

1 RAS

1.1 Allocated band

The RAS shares the 42.5-43.5 GHz band with the FS, FSS (Earth-to-space) and mobile (except aeronautical mobile) service on a primary basis.

1.2 Type of observations

The 42.5-43.5 GHz band is used by the RAS for both continuum and spectral line observations. The band is very important for radio astronomy, because at approximately twice the frequency of the 23.6-24 GHz continuum band, it provides an effective point for the sampling of continuum emission at octave intervals, essential for the determination of the spectral index of radio sources.

Observations of the continuum emission provide critical information on the physical state of the interstellar medium associated with star-forming regions. The 43 GHz band is also used extensively for studies of the cosmic microwave background (CMB). The band also includes the spectral lines associated with the silicon monoxide (SiO) molecule at rest frequencies of 42.519, 42.821, 43.122 and 43.424 GHz that are among the astrophysically most important lines, but which are not all listed in Recommendation ITU-R RA.314.

These are lines essential for studies of cosmic phenomena, such as the birth and death of stars.

1.3 Required protection criteria

Recommendation ITU-R RA.769 specifies the protection criteria for radio astronomical observations and gives threshold levels of detrimental interference for primary radio astronomy bands. In the 42.5-43.5 GHz band, for single dish spectral line observations made using a channel bandwidth (one of the spectrometer channels) of 500 kHz, the threshold pfd for detrimental interference is -153 dB(W/m^2). For making single-dish continuum observations using the entire 1 GHz bandwidth, the threshold pfd limit is -137 dB(W/m^2).

VLBI observations, where signals from widely separated antennas are recorded and correlated after the observations, are much less susceptible to interference. This is reflected in the threshold pfd level for VLBI observations in this band, -116 dB(W/m^2), for a bandwidth of 500 kHz.

For detrimental interference from non-GSO systems, the protection criteria and the relevant methodologies are described in Recommendations ITU-R RA.769 and ITU-R RA.1513, as well as in Recommendation ITU-R S.1586 for FSS systems. The thresholds of detrimental interference levels to the RAS as defined and calculated in the Recommendation ITU-R RA.769 are protection criteria above which radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded then it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the level of interference, under the assumptions of Recommendation ITU-R RA.769 (e.g. antenna performance, etc.), becomes 10 dB or more above the Recommendation ITU-R RA.769 definition, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

The following ITU-R Recommendations deal directly with, or may be relevant to, the protection of radio astronomy stations observing in the 42.5-43.5 GHz band:

Recommendation ITU-R RA.314 – Preferred frequency bands for radio astronomical measurements.

Recommendation ITU-R RA.517 – Protection of the radio astronomy services from transmitters operating in adjacent bands.

Recommendation ITU-R RA.611 – Protection of the radio astronomy service from spurious emissions.

Recommendation ITU-R RA.769 – Protection criteria used for radio astronomical measurements.

Recommendation ITU-R RA.1237 – Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation.

Recommendation ITU-R RA.1513 – Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation from interference for frequency bands allocated to the radio astronomy on a primary basis.

Recommendation ITU-R S.1586 – Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service satellite system at radio astronomy sites.

RR Nos. 5.149, 5.547, 5.551AA and 5.551G apply to this band.

1.4 Operational characteristics

Radio astronomy observations in the 42.5-43.5 GHz band are carried out in all ITU Regions. Table 97 shows a list of radio astronomical observatories, which operate or are planned to operate in the 42.5-43.5 GHz band. Planned facilities are those under construction in Mexico (The Large Millimeter Telescope, a joint U.S.-Mexico project), Chile (The Atacama Large Millimeter Array) and Italy (Sardinia Telescope) or the implementation of this frequency band at the UK MERLIN interferometer array.

Scientific interest in the 43 GHz band is extremely high. Most interest comes from observations of very weak radio sources that push the technological limits, corresponding to antenna noise temperatures of the order of 2-20 μK involving integrations of the order of 2 000-4 000 s. Long integration times are essential to observe the faint sources that scientists are interested in. Correlation and differencing observing modes have been developed and are used successfully to counter atmospheric fluctuations to enable such long integration times.

The very large array (VLA) of the U.S. National Radio Astronomy Observatory (NRAO), possibly the most heavily used radio telescope in the world, spent nearly 20% of its total observing time in this band in the last few years. Similar statistics hold for NRAO’s very long baseline array (VLBA). The VLA and VLBA receive two to three times as many requests for observing time than they can accommodate.

The percentage of time that each station spends at 42 GHz varies from station to station and from year to year. Many radio telescopes now have frequency flexibility, enabling them to switch operations from one frequency band to another on a timescale of one minute or less. This enables flexible scheduling, to take best advantage of the observing conditions (weather, etc.). From the point of view of inter-service compatibility studies therefore, it is safest to assume that any radio astronomy station in the Tables might observe at 43 GHz at any time.

TABLE 97

Radio astronomy stations operating in the 42.5-43.5 GHz band

Country	Site	Longitude	Latitude	Altitude (m)	Diameter (m)	Remarks
Region 1						
Finland	Metsähovi	24° 23' 17"	60° 13' 04"	61	13.7	S
France	Bordeaux Plateau de Bure	–00° 31' 37" 5° 54' 26"	44° 50' 10" 44° 38' 01"	73 2 552	2.5 6 × 15	S S
Germany	Effelsberg	06° 53' 00"	50° 31' 32"	369	100	S
Italy	Medicina Noto Cagliari	11° 38' 43" 15° 03' 00" 09° 14' 40"	44° 31' 14" 36° 31' 48" 39° 29' 50"	44 85 570	32 32 64	S S S
Russian Federation	Dmitrov	37° 27' 00"	56° 26' 00"	200	32	S
Spain	Pico Veleta Yebes	–03° 23' 34" –03° 06' 00"	37° 03' 58" 40° 31' 30"	2 870 931	30 40	S S
Sweden	Onsala	11° 55' 35"	57° 23' 45"	10	20	S
United Kingdom (planned)	Cambridge Darnhall Jodrell Bank Knockin Pickmere	00° 02' 20" –02° 32' 03" –02° 18' 26" –02° 59' 45" –02° 26' 38"	52° 09' 59" 53° 09' 21" 53° 14' 10" 52° 47' 24" 53° 17' 18"	24 47 78 66 35	32 47 76 25 25	S S S S S
Region 2						
Brazil	Atibaia, SP	–46° 33' 28"	–23° 11' 05"	805	13.7	S
Chile	San Pedro de Atacama	–67° 44' 00"	–23° 02' 00"	5 000	64 × 12	S
Mexico	Sierra Negra	–97° 18' 00"	18° 59' 00"	4 500	50	S
United States of America	Goldstone, CA Green Bank, WV Socorro, NM St. Croix, VI Hancock, NH North Liberty, IA Ft. Davis, TX Los Alamos, NM Pie Town, NM Kitt Peak, AZ Owens Valley, CA Brewster, WA Mauna Kea, HI Kitt Peak, AZ Mauna Kea, HI Westford, MA	–116° 47' 40" –79° 50' 24" –107° 37' 06" –64° 35' 01" –71° 59' 12" –91° 34' 27" –103° 56' 41" –106° 14' 44" –108° 07' 09" –111° 36' 45" –118° 16' 37" –119° 41' 00" –155° 27' 19" –111° 36' 50" –155° 28' 20" –71° 29' 19"	35° 14' 50" 38° 25' 59" 34° 04' 44" 17° 45' 24" 42° 56' 01" 41° 46' 17" 30° 38' 06" 35° 46' 31" 34° 18' 04" 31° 57' 23" 37° 13' 54" 48° 07' 52" 19° 48' 05" 31° 57' 10" 19° 49' 33" 42° 37' 23"	[] 1 071 946 16 309 241 1 615 1 967 2 371 1 916 1 207 255 3 720 1 916 3 720 [122]	34 100 27 × 25 25 25 25 25 25 25 25 25 25 25 12 10.4 36	S S S VLBI VLBI VLBI VLBI VLBI VLBI VLBI VLBI VLBI VLBI S S S

TABLE 97 (*end*)

Region 3						
Country	**Site**	**Longitude**	**Latitude**	**Altitude (m)**	**Diameter (m)**	**Remarks**
Australia	Parkes Mopra Narrabri, NSW Tidbinbilla	148° 15' 44" 149° 05' 58" 149° 32' 56" 148° 58' 59"	–33° 00' 00" –31° 16' 04" –30° 59' 52" –35° 24' 18"	415 866 237 677	64 22 6 × 22 34	S S S S
Japan	Nobeyama Kashima Mizusa Ogasawara Ishigakijima	138° 28' 32" 140° 39' 46" 141° 07' 57" 130° 26' 25" 142° 13' 00" 124° 10' 06"	35° 56' 29" 35° 57' 15" 39° 08' 01" 31° 44' 53" 27° 05' 30" 24° 24' 38"	1 350 50 117 569 273 60	45 34 20 20 20 20	S S S S S S
Korea (Republic of)	Taejon Yonsei U. Ulsan U. Tamna U.	127° 22' 18" 126° 56' 35" 129° 15' 04" 126° 27' 43"	36° 23' 54" 37° 33' 44" 35° 32' 33" 33° 17' 18"	120 260 120 100	13.7 20 20 20	S S S S
Other						
United States of America funded	Antarctica	N/A	–90° 00' 00"	3 000	Various	S

NOTE 1 – S refers to stations were single-dish operations are made, and VLBI refers to stations used exclusively for VLBI.

2 FSS and BSS

2.1 Allocated transmit band

The active service band considered is the band 41.5-42.5 GHz.

2.2 Application

Based on ITU filings, more than 250 FSS and BSS systems are planned for operation within the 40 GHz band and the corresponding 47 GHz uplink band. The typical parameters of FSS systems planned to operate in the 50/40 GHz bands are shown in Table 98.

2.3 Levels based on existing ITU documents

Relevant ITU-R Recommendations are as follows:

Recommendation ITU-R S.1557 – Operational requirements and characteristics of fixed-satellite service systems operating in the 50/40 GHz bands for use in sharing studies between the fixed-satellite service and the fixed service.

Recommendation ITU-R SF.1484 – Maximum allowable values of power flux-density at the surface of the Earth produced by non-geostationary satellites in the fixed-satellite service operating in the 37.5-42.5 GHz band to protect the fixed service.

Recommendation ITU-R SF.1573 – Maximum allowable values of power flux-density at the surface of the Earth by geostationary satellites in the fixed-satellite service operating in the 37.5-42.5 GHz band to protect the fixed service.

Recommendation ITU-R SM.1540 – Unwanted emissions in the out-of-band domain falling into adjacent allocated bands.

Recommendation ITU-R SM.1541 – Unwanted emissions in the out-of-band domain.

2.4 Transmitter characteristics

Most FSS systems being proposed for operation in the 50/40 GHz bands plan to provide high data rates ranging from video conferencing quality through very high transmission rates of STM-1 (155 Mbit/s) to 10 × STM-4 (6.22 Gbit/s). Since propagation impairments in this frequency range are severe, special design considerations apply to this frequency band, which do not necessarily apply at lower frequencies. In order to achieve link availability and the high data rate in the 40 GHz band, most proposed FSS systems will operate with high gain satellite antennas. The 3 dB beam-width of the transmit and receive antennas are in a range from 0.3° to 0.65°. Also, due to satellite weight and power constraints, the number of active beams at any instant in the satellite field-of-view of all proposed FSS systems planned to operate in these bands will be very small, typically less than 5%. In the relevant study (Recommendation ITU-R S.1557), the FSS and the BSS systems planned to operate in the 40 GHz band are assumed to have similar system parameters.

Table 98 indicates that most proposed FSS systems plan to use at least 2 GHz of spectrum in the space-to-Earth direction, and most systems will use a 4-times frequency reuse scheme. This means that 500 MHz will be allocated to each beam. However, some proposed systems plan to use 2 GHz of spectrum for each beam. The actual bandwidth for each beam will depend on the applications and the separation between beams.

TABLE 98

Typical downlink system characteristics of GSO and non-GSO FSS systems planned to operate in the 37.5-42.5 GHz band (Recommendation ITU-R S.1557)

Parameters	GSO FSS	Non-GSO FSS (MEO)
Satellite antenna beam size (degrees)	0.3 to 0.6	0.6 to 1.8 depending on the satellite altitude
Typical space station DC power (kW)	10 to 15	3 to 5
Typical satellite transmit RF power into the antenna	2.5 kW to 3.5 kW	700 W to 1.1 kW
Number of beams	30 to 60	10 to 20
Bandwidth (GHz)	2.0 to 5.0 Including HDFSS and gateway/hub	

TABLE 98 (*end*)

Parameters	GSO FSS	Non-GSO FSS (MEO)
Frequency reuse scheme	4 or 7 times (most systems use 4-times frequency reuse scheme)	
Link availability: – Gateway/hub (%) – HDFSS (VSAT) (%)	 – > 99.9 – 99.5 to 99.7	
Payload	Transparent transponder or processing payload	
Minimum operation elevation angle (degrees)	> 15	> 20
Modulation	QPSK / 8-PSK / 16-QAM	
BER	1×10^{-8} to 1×10^{-10}	
Coding	Concatenated code	
Required E_b/N_0 (dB)	6 to 12.5 depending on modulation and coding	
Interference degradation (dB)	2 to 4	
System margin (dB)	1 to 3	
Earth terminal antenna size: – Gateway/hub (m) – HDFSS (VSAT) (m)	 – 1.8 to 2.7 – 0.3 to 0.6	 – 1.5 to 2.7 – 0.3 to 0.6
Earth terminal system noise temperature (K)	600 to 800	

HDFSS: high density fixed-satellite service.

VSAT: very small aperture terminal.

2.5 Operational characteristics

See Recommendation ITU-R S.1557 and § 2.4.

2.6 In-band transmit level

The FSS and BSS systems planning to operate in the 40 GHz band will only be able to transmit at the pfd limits in RR Table 21-4 for a very small percentage of time. The actual downlink pfd levels during clear-sky conditions will depend on each satellite system design such as, transparent transponder, on board processing payload, modulation, coding, etc. In the study it was assumed that FSS systems will typically operate at the pfd level of –117 dB(W/m^2) for elevation angles from 25° to 90° in clear-sky conditions.

The value of –117 dB(W/(m^2 · MHz)) represents a clear sky level that is 12 dB below the peak pfd level listed in RR Table 21-4. Due to the power limitations of the space station, the full power is only reached for very short periods of time on beams where propagation effects must be overcome.

Furthermore, the clear-sky level provides protection to certain sensitive FS systems deployed in the band. Additional details are available in Recommendations ITU-R S.1557 and ITU-R SF.1572.

3 Compatibility threshold

See § 1.3.

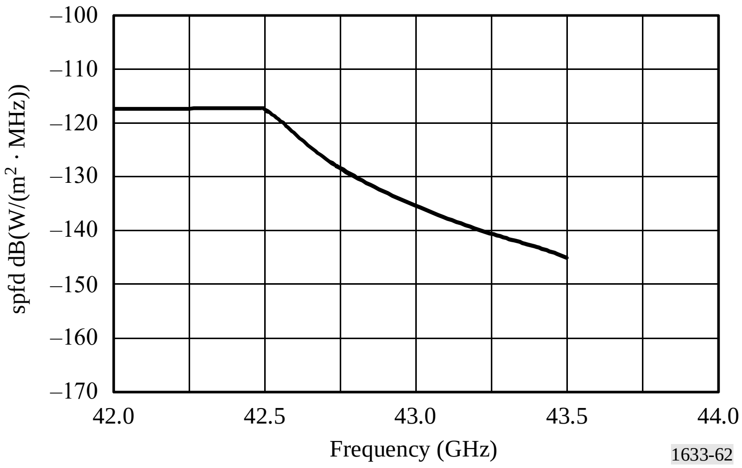
4 Interference assessment

4.1 Methodology used to assess the interference level

The example presented in Fig. 62 is a worst-case example based on a necessary bandwidth of 500 MHz and a spectral roll-off at the maximum level identified in Recommendation ITU-R SM.1541. As, well this example assumes that the necessary bandwidth extends to the edge of the FSS allocation.

FIGURE 62

Spectral performance



4.2 Calculation of interference level

The spectral performance curve in Fig. 62 was numerically integrated in order to derive the aggregate unwanted emission power in order to assess the impact in the continuum band of 1 GHz.

Values were taken directly from the curve (with 3 dB removed in order to reflect the change in bandwidth from 1 MHz to 500 kHz) so as to verify compliance with the single-dish spectral line threshold and with the VLBI level.

The calculation assumes a beam at the sub-satellite point. As a result, the actual pfd values would be lower for radio telescopes where the elevation angle to the satellite is less than 90°.

The calculation does not take into account the impact of atmospheric attenuation[4].

[4] See Recommendation ITU-R P.676. The value will vary from 1 to 2 dB at sea level.

4.3 Values achieved

Based on this curve, the following worst-case levels are achieved in the band 42.5 to 43.5 GHz:

– –97 dB(W/(m^2 · GHz)), which is 37 dB above the continuum threshold for the band 42.5-43.5 GHz.

– –120 dB(W/(m^2 · 500 kHz)) at 42.5 GHz, which is 36 dB above the spectral line threshold.

As a result, compliance to the radio astronomy criteria would require the application of one or more mitigation methods.

5 Mitigation techniques

5.1 RAS

The possible mitigation methods for the RAS are either:

– a guardband; or

– other mitigation methods as listed in Recommendation ITU-R SM.1542.

5.2 FSS and BSS

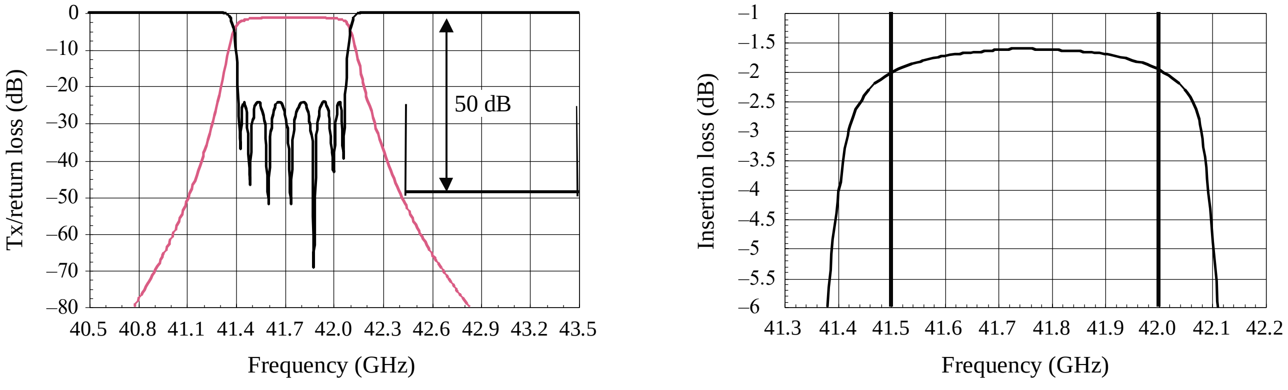
5.2.1 Satellite filtering

Case 1: Multibeam space station

For wideband carriers, the curve in Fig. 63 shows as an example, the performance of a typical filter design in this band with a 7-pole filter.

FIGURE 63

Tx/return loss/insertion loss



N = 7 TE101 filter

Size (W × H × L): 1.125" × 1.125" × 3.80"/Weight: 0.24 lb (copper)

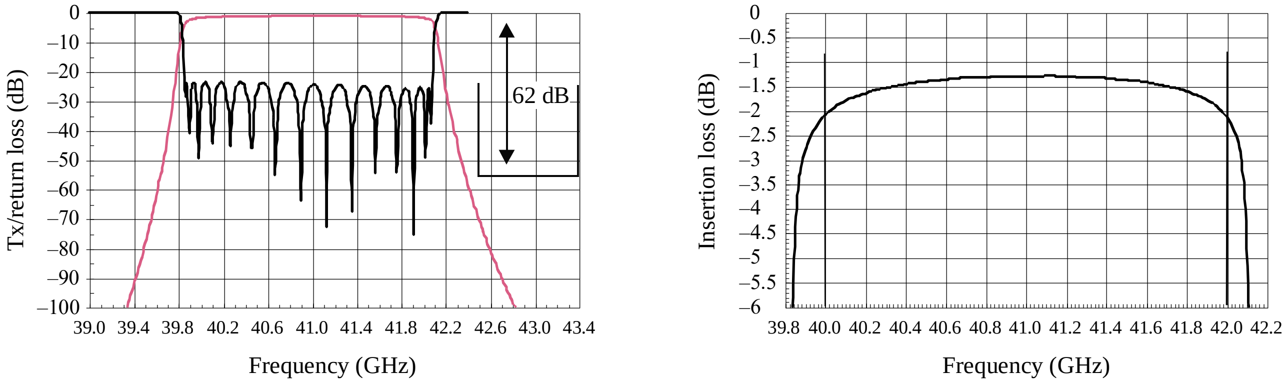
1633-63

Case 2: Phased array space station

For wideband carriers on a phased array, the performance of a typical filter design in this band with a 15-pole filter is shown in Fig. 64.

FIGURE 64

Tx/return loss/insertion loss



N = 15, TE101 band-pass filter (BPF) cascade with WR22 lowpass filter/WR22 waveguide filters

Size (W × H × L): 1.125" × 1.125" × 5.50"/Weight: 0.33 lb (for copper)

1633-64

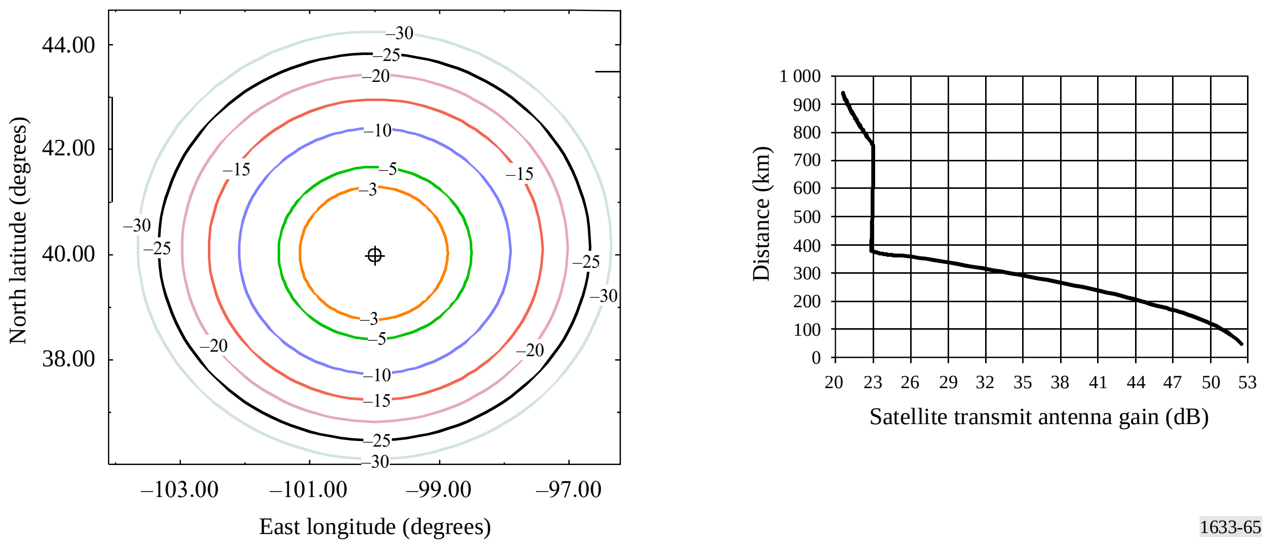
5.2.2 Geographic isolation

If FSS and BSS systems operating in the 40.5-42.5 GHz band are not able to implement the additional transmit filters needed to meet the detrimental interference criteria of RAS stations operating in the 42.5-43.5 GHz band, geographical isolation should be considered as an interference mitigation technique.

Based on Table 99, the satellite transmit antenna beam size is in a range from 0.3° to 0.6°. The left-hand portion of Fig. 65 shows the gain contours for a GSO space station antenna having a peak gain of 53 dBi and a 3-dB beamwidth of 0.4°. The geographical isolation advantage relative to the peak gain can be found for any distance by using the right-hand curve in Fig. 65.

FIGURE 65

Satellite antenna contours and distance between beam centre and edge of coverage vs. satellite transmit antenna gain



1633-65

5.2.3 Spectral shape of FSS/BSS signal

The waveform used by the FSS/BSS for the transmission of information could be selected that minimizes spectral roll-off, thus limiting the amount of unwanted emissions transmitted. As well it may be possible to design or operate the high power amplifier in such a way as to further minimize the unwanted emission level from the FSS/BSS signal.

5.2.4 Guardband

A guardband between the two services would allow for roll-off of the signal and filter.

5.2.5 Additional mitigation methods

Additional mitigation methods are listed in Recommendation ITU-R SM.1542.

5.3 Potential impact

5.3.1 RAS

Guardband at edge of RAS band – In the case of broadband continuum measurements, the use of a guardband within the radio astronomy band would effectively lead to a loss of data, since the integration time would need to be increased to compensate for the loss of bandwidth. This method has limited practicability as described in § 1.3.

The band also includes the spectral lines associated with the silicon monoxide (SiO) molecule at rest frequencies of 42.519, 42.821, 43.122 and 43.424 GHz that are among the astrophysically most important lines, but which are not all listed in Recommendation ITU-R RA.314. Thus there is limited scope for a guardband within the radio astronomy band, without impacting the capability to observe one or more of the SiO spectral lines.

5.3.2 FSS and BSS

5.3.2.1 Satellite filtering

In the multibeam example above, based on a 7-pole transmit filter, the insertion loss is 2.0 dB, which corresponds to a 37% degradation in system capacity. Such filtering would increase the weight of the space station by 120 g or more per beam, depending on the transmitter power.

In the phased array example above, based on a 15-pole transmit filter, the insertion loss is 2.0 dB, which corresponds to a 37% degradation in system capacity. Such filtering would increase the mass of the space station by 160 g or more per element, depending on the transmitter power. For a space station with a 2 818-element phased array antenna, an additional 450 kg would be added to the payload mass, with consequential cost and performance penalties.

In addition, most systems operating with phased array antennas prefer to use solid state power amplifiers (SSPAs). If additional transmit filters are required, and depending on the actual transmit power, due to an additional loss, travelling-wave tube amplifiers (TWTAs) may be required. It is difficult to implement phased array antennas with TWTAs.

5.3.2.2 Geographic isolation

This mitigation method is only useable if the number of radio telescopes in the service area of the satellite is small and if their locations are taken into account while the space station antenna sub-system is being designed. Also this mitigation method limits the ability of the space station to be re-located or for the beam to be re-oriented to other portions of the satellite field of view.

5.3.2.3 Spectral shape of FSS/BSS signal

The high power amplifier (HPA) linearity and the point in the dynamic range at which the HPA is operated determine the spectral shape of the space station emission. Improving the unwanted emissions from the HPA can be achieved through operation at a lower input power or improving the amplifier linearity. However, maintaining the operation of the amplifier in the linear range reduces unwanted emissions at the cost of decreased HPA efficiency. Both methods have an impact on the throughput of the space station as well as its cost and weight.

5.3.2.4 Guardband

The usage of any guardband imposes a reduction of capacity on the FSS/BSS if the guardband is implemented within its allocation.

6 Results of studies

6.1 Summary

The majority of the RAS sites around the world utilize this band for single-dish measurements. A combination of appropriate mitigation techniques would be required to meet the levels of protection for single-dish measurements.

One study considered frequency separation without the use of any other mitigation method. This study assumed FSS and BSS systems operating up to 42 GHz and unwanted emission levels from Recommendation ITU-R SM.1541. The study shows that the detrimental level of interference for VLBI given in Recommendation ITU-R RA.769 is met. However, the threshold pfd limits for single-dish line or continuum observations are not met, and interference would be sufficiently severe as to effectively prevent any useful astronomical measurements unless additional mitigation methods are used.

The worst-case scenario presented in § 4.1, using no mitigation methods, is based on a necessary bandwidth of 500 MHz and a spectral roll-off at the rate identified in Recommendation ITU-R SM.1541. In addition, this example assumes that the necessary bandwidth extends to the edge of the FSS allocation at 42.5 GHz.

The unwanted emissions resulting from the worst-case example considered exceed the limits in RR No. 5.551G as well as the single-dish spectral line and continuum criteria from Recommendation ITU-R RA.769. However, the VLBI criterion is met across the entire band 42.5 to 43.5 GHz. The shortfall may be addressable through the use of mitigation methods. A diverse range of mitigation methods can be considered for application in practical systems; a combination of such methods is likely to be required.

If, for some systems, the provisional FSS spectral representation as described in the technical Appendix to Annex 1 is considered instead of Recommendation ITU-R SM.1541, the shortfall with the continuum criteria is reduced. This does not necessarily alleviate the shortfall on band-edge unless additional mitigation methods are considered. It was however indicated that this spectral representation is based on experience at lower frequency bands.

It is expected that, using one or more of the mitigation methods identified in this Annex, FSS/BSS systems may be able to meet the Recommendation ITU-R RA.769 protection criterion for continuum measurements. In addition, it may be difficult for FSS systems to meet the spectral line criterion in some parts of the 42.5-43.5 GHz band. It is doubtful whether FSS systems that are required to meet the RR No. 5.551G criteria would be practical, since these requirements would impose severe operational constraints and significantly increasing satellite system costs.

As a result, it is unlikely that the complete needs of both services can be met. Further work may be needed to refine the study.

6.2 Conclusions

In this band, the threshold level for detrimental interference to radio astronomical observations as given in Recommendation ITU-R RA.769 can be met by the FSS and BSS for the VLBI case. For the continuum case, it may be possible for FSS/BSS systems to meet the threshold with the use of mitigation methods. Meeting the spectral line threshold across part of the band may be possible. It is uncertain if mitigation methods will be sufficient to meet the spectral line criteria at the lower edge of the RAS allocation.

As nearly two-thirds of the RAS sites around the world (see Table 97) utilize this band for single-dish measurements, it is therefore important that a combination of appropriate mitigation techniques is applied to meet these levels of protection for single-dish measurements.

Annex 19

Compatibility analysis between EESS (passive) systems operating in the 50.2-50.4 GHz band and FSS (Earth-to-space) systems operating in the 47.2-50.2 GHz band

1 EESS (passive)

1.1 Allocated band

The allocations adjacent to the 50.2-50.4 GHz EESS passive bands are shown in Table 99. It should be noted that the band 50.2-50.4 GHz is covered by RR No. 5.340, and RR No. 5.340.1 is also applicable.

TABLE 99

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
47.2-50.2 GHz	**50.2-50.4 GHz**	**50.4-51.4 GHz**
FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.149 5.340 5.552 5.552A 5.555	EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive) 5.340 5.555A	FIXED FIXED SATELLITE (Earth-to-space) MOBILE Mobile-satellite (Earth-to-space)

1.2 Application

This frequency band is one of several bands between 50 GHz and 60 GHz that are used collectively to provide three-dimensional temperature profiles of the atmosphere.

These measurements feed the numerical weather prediction models. The model needs data every 6 h and is used for fine mesh weather predictions (10 km or less) on a short time basis (6 to 48 h.)

1.3 Required protection criteria

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

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

The first criterion is the acceptable 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. For nadir sounders used for three-dimensional measurements of atmospheric temperature or gas concentration, the proportion of measurement cells lost due to interference must not exceed 0.01%. This frequency of occurrence limit is valid for mechanically scanned and push-broom nadir sounders.

1.4 Operational characteristics

Three types of sensor designs have been considered for measurements in this frequency range. The cross track scanner which scans through nadir, the conical scanner which scans in an arc in front of the space station across its track, and the push-broom which uses multiple fixed beams across its track. The push-broom sensor will be analysed because it represents the future in microwave sounding. It has the specific advantage of permitting a longer integration time. Table 100 provides the operating characteristics of the sensor under study.

TABLE 100

Parameters of push-broom sensor

Parameter	Value
Altitude (km)	850
Orbit	Sun-synchronous polar
Mainlobe antenna gain (dBi)	45
Antenna 3 dB beamwidth (degrees)	1.1
Antenna pattern	Recommendation ITU-R F.1245
FOV (re. sensor) (degrees)	± 50 cross track re. nadir direction
FOV (re. Earth's centre) (degrees)	± 10.25 geocentric
Pixel diameter at nadir (km)	16
Pixels per swath	90
Swath width (km)	2 300

2 FSS (Earth-to-space)

2.1 Transmit band

Refer to Table 99.

2.2 Application

The active services under consideration for this Annex are the FSS (Earth-to-space) in the 47.2-50.2 GHz band.

2.3 Levels based on spectral representation

This Annex uses the raised cosine spectral representation, which is described in Annex 1 of this Recommendation.

This spectral representation is intended for band-by-band studies and is provisional, pending further review within the ITU-R. It represents in a very general way the typical mean power distribution through the OoB and spurious domains in an adjacent or nearby allocation.

2.4 Transmitter characteristics

The characteristics for the FSS and MSS are derived from Recommendation ITU-R S.1328-3 – Satellite system characteristics to be considered in frequency sharing analyses between geostationary-satellite orbit (GSO) and non-GSO satellite systems in the fixed-satellite service (FSS) including feeder links for the mobile-satellite service (MSS), and listed in Tables 101 and 102.

2.5 Operational characteristics

TABLE 101

Characteristics of non-GSO uplink earth stations

System	**MEOSAT-X**	**LEO V1**	**LEO V2**
Orbit	Circular	Circular	Circular
Altitude (km)	10 352	1 350	10 355
Inclination (degrees)	50	47	50
Satellites in plane	8	6	5
Planes	4	12	3
Polarization	LHCP/RHCP	LHCP/RHCP	LHCP/RHCP
Modulation	O-QPSK	QPSK	O-QPSK
Bandwidth (MHz)	500	90	300
Passive allocation (% B_N)	40	222	67
e.i.r.p. (dBW)	88	60.2	69.7
Antenna gain (dBi)	66.08	54.4	57.8
Transmitter power (dBW)	21.92	5.8	11.9

TABLE 102

Characteristics of GSO uplink earth stations

System	**GSO-VX**	**GEO-SV**	**GEOSAT**		**GSOV-B1**	**GSOV-B2**
			Gateway	**User**		
Polarization	LHCP/RHCP	LHCP/RHCP	LHCP/RHCP	RHCP/LHCP	Linear	
Modulation	D-QPSK	D-QPSK	QPSK	QPSK	QPSK	QPSK
Bandwidth (MHz)	300	200	125	11	105.6	150
Passive allocation (% of B_N)						
e.i.r.p. (dBW)	73.8	75.5	83.9	69.2	31.5	84.7
Antenna gain (dBi)	59.5	59.5	64.8	59.3	45.2	65.4
Transmitter power (dBW)	14.3	16	19.1	9.8	–13.7	19.3

3 Compatibility threshold

There are two criteria for this band. First there is a power threshold of –166 dBW in 100 MHz. This is a maximum interference level from all sources. Secondly the availability criterion is 99.99% of all measurement cells or 0.01% loss of measurement pixels.

Interference is potentially received from several sources arising from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service. Therefore further work is needed to address the impact of multiple active services above and below the passive band.

4 Interference assessment

The interference margins for interference from the earth station main lobe are from 95 to 40 dB when in the sensor's main lobe and 55 dB or less when the sensor side lobe is coupled to the earth stations main lobe. Calculations of the probability of this interference occurrence per earth station show that it is low. The interference impact of these systems may depend upon the earth station population density.

4.1 Methodology used to assess interference levels

In a first step, interference levels are computed in a co-frequency case, where the FSS earth stations are assumed to transmit within the EESS (passive) band. In cases where the earth station necessary bandwidth is greater than the EESS (passive) band, the power falling within the EESS band is reduced proportionally, assuming that the power density is constant in the necessary bandwidth.

In a second step, the OoB mask for the active service is taken into account, and the guardband is defined, which may be necessary to protect the passive service.

4.1.1 GSO FSS earth stations

The following basic hypothesis are adopted for the analysis:

– Interference occurs via direct coupling between the passive sensor and the FSS earth station antennas.

– Both antennas are modelled using Recommendation ITU-R F.1245.

– In an attempt to identify possibly worst-case configurations, it is assumed that the pointing direction of the FSS earth station (aiming at the GSO orbit in case of GSO FSS) is contained in the orbit plane of the Earth exploration-satellite. This configuration renders possible sensor side-lobe to earth station main-lobe and sensor main-lobe to earth station side-lobe interfering paths. Main-lobe to main-lobe interfering paths may also occur but, because the earth stations are aiming at the GSO orbit, this is only possible with those located near the equator; Their probability of occurrence should be studied further in a dynamic analysis which is not implemented in this study.

– The FSS earth station is assumed to be located at a latitude of 35°. This value was selected as a fair compromise to represent a worst-case sensor side-lobe to earth station main-lobe scenario, because it may represent the lower latitude above which earth stations are the most densely distributed and where, due to the relatively high incidence angle of the interfering path (about 49°), the natural protection due to the path-loss plus atmospheric absorption losses is the lowest.

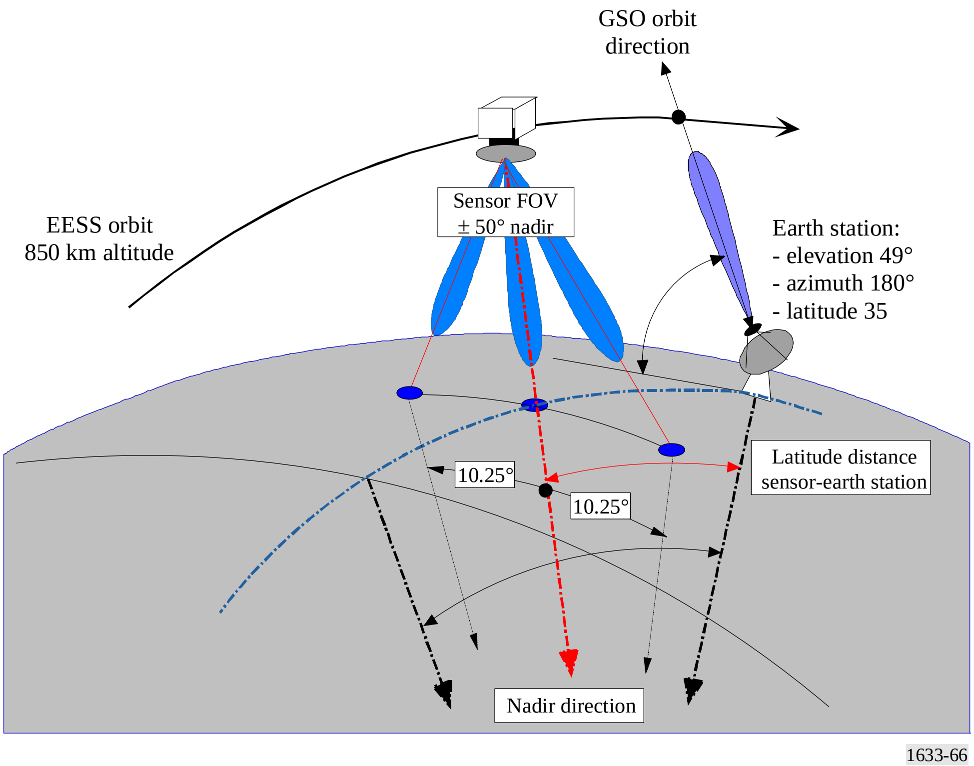
– The dynamic analysis in § 4.4 will consider latitudes between 0° and 50° N in order to get an extended range of results.

This configuration is described on the Fig. 66, where the major geometric parameters of the analysis are indicated.

FIGURE 66

Configuration of GSO FSS/MSS earth station to passive sensor interferences

(Configuration of FSS/MSS earth station interference to a nadir sensor)



4.1.2 Non-GSO FSS earth stations

The problem is more complex, because in this case the pointing direction of the earth station is a varying parameter: a specific earth station may be pointing at any elevation angle and at any azimuth.

For convenience, the present study is limited to a configuration similar to that adopted for the GSO FSS case (see Fig. 66), where main-lobe to main-lobe scenarios are not considered. It is clear however that this will result in a very optimistic evaluation of the real situation.

4.2 Calculation of interference in the co-frequency hypothesis

Noting that the most critical scenarios are those involving simultaneously a high e.i.r.p. and a wide necessary bandwidth, one non-GSO and two GSO systems are selected on these criteria for detailed analysis; these are the MEOSAT-X (see Table 101), the GEO-SV and the GSOV-B2 (see Table 102) respectively.

Assuming that the pointing direction of the FSS earth station antenna (aiming at the GSO orbit in case of GSO systems) is contained in the orbital plane of the Earth exploration-satellite, and considering only the nadir beam of the pushbroom passive sensor, the following parameters are computed, depending on the latitudinal distance between the passive sensor and the FSS earth station:

– line-of-sight distance between the sensor and the earth station (km);
– off-set angles between the line-of-sight sensor/earth station and the antennas main axis;
– mutual gains in direction of each other, of the sensor and earth station antennas;
– space loss;
– atmospheric absorption depending on the elevation angle of the path (Recommendation ITU-R P.676);
– power received by the passive sensor;
– margin referred to the interference threshold in the EESS (passive) allocated band;
– the size of the area around the earth station position, where the sounding data are contaminated by interference.

4.3 Result of the analysis and discussion

The results are plotted in Figs. 67 and 68 for a non-GSO FSS earth station and in Figs. 69 and 70 for a GSO FSS earth station. While the Earth exploration-satellite is moving in the direction of the earth station, a first event appears when the sensor is crossing the earth station's main-lobe, and a second event occurs when the sensor is at the zenith of the earth station.

FIGURE 67

Power received by the passive sensor from a non-GSO-MEOSAT-X earth station

(Co-frequency case, earth station at 35° latitude)

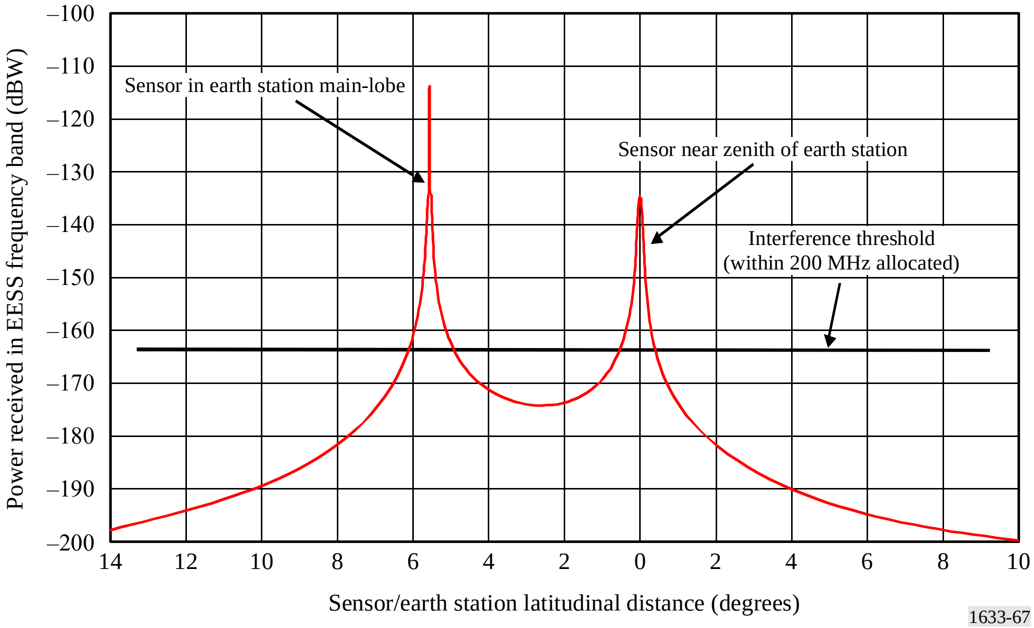
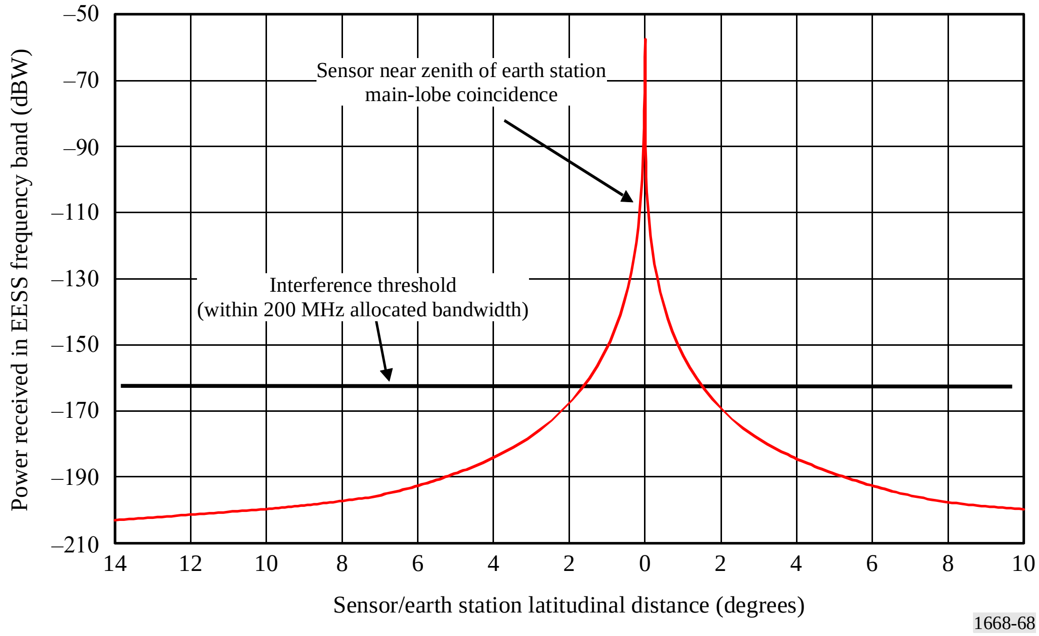


FIGURE 68

Power received by the passive sensor from a non-GSO-MEOSAT-X earth station (main-lobe to main-lobe configuration)



It should be noted that in case of non-GSO FSS systems, main-to main-lobe interfering paths are possible at all latitudes when the passive sensor is passing near the zenith of earth stations. In that case, the excess of power over the interference threshold is augmented by the earth station antenna main-lobe to far-lobe discrimination (about 80 dB).

FIGURE 69

Power received by the passive sensor from a GSOV-B2 earth station

(Co-frequency case, earth station at 35° latitude)

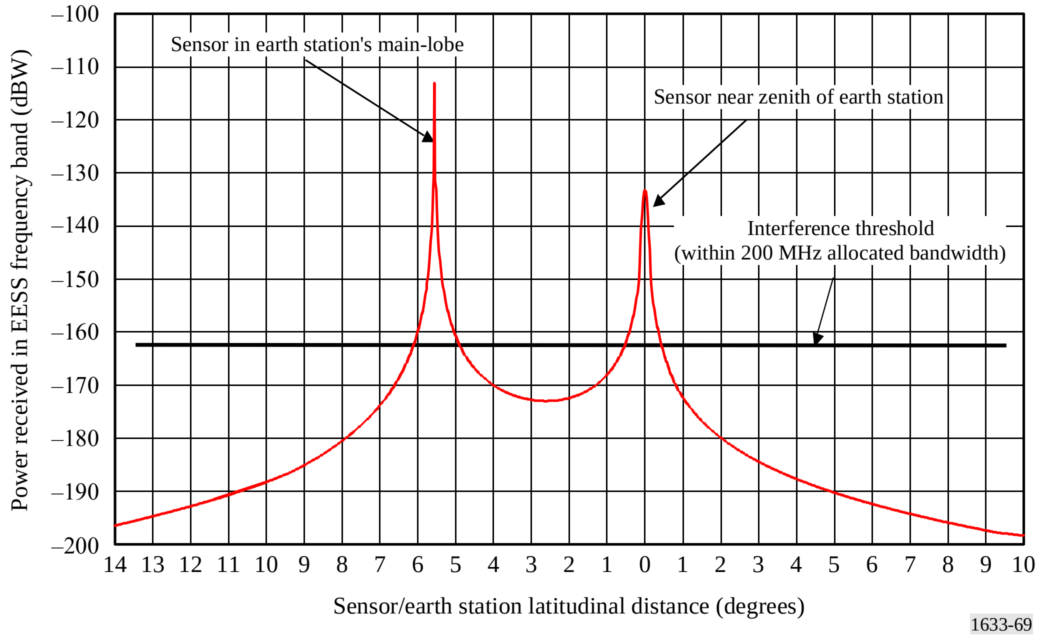
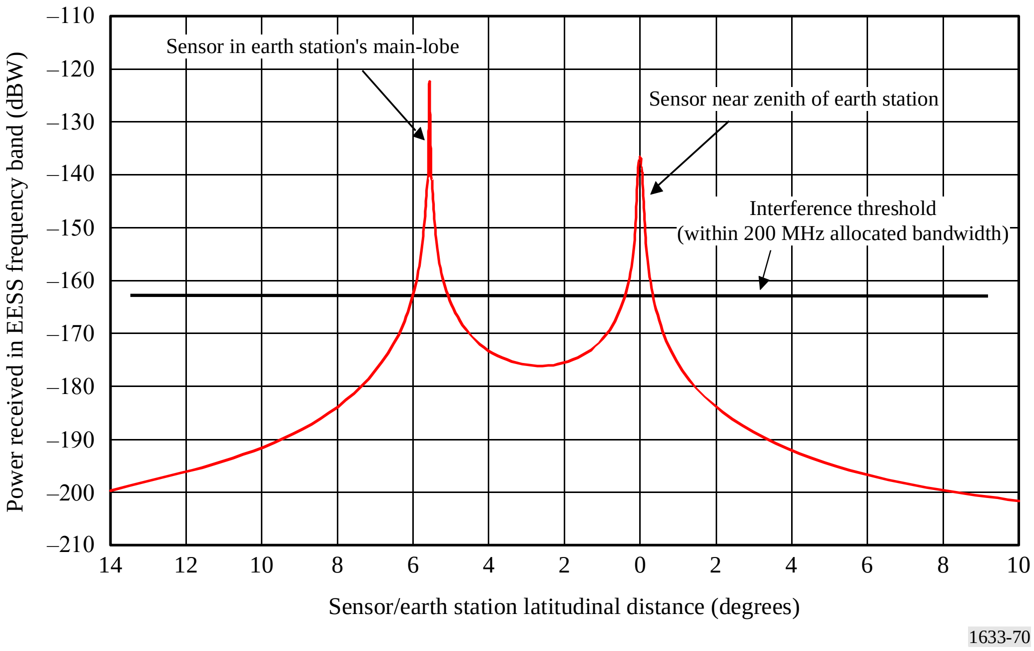


FIGURE 70

Power received by the passive sensor from a GEO-SV earth station

(Co-frequency case, earth station at 35° latitude)



4.3.1 Interference events occurring via passive sensor antenna far-lobe and FSS earth station antenna main-lobe

They are almost 50 dB above the interference threshold of the passive sensor (non-GSO MEOSAT-X and GSOV-B2). They last up to 21 s, which is to be compared to the passive sensor orbital period of 100 min. Since all antenna beams of the sensor are permanently activated, several complete scan-lines (90 pixels each) may be lost at each event. This leads to about 810 pixels being lost per event in case of the GSOV-B2 network. Since the Earth exploration-satellite is in an almost polar orbit, the condition required for interference is a coincidence within ±0.6° around the longitude of the earth station. The probability of occurrence of such events should be further studied, considering in particular the passive sensor drifting-orbit parameters, the density and latitude of earth stations and the availability criteria of passive sensors. Owing to the magnitude of the events, it is doubtful however, that their probability of occurrence may be neglected.

4.3.2 Interference occurring when the passive sensor is close to the zenith of the FSS earth station

They are almost 30 dB above the sensor's interference threshold in case of GSO networks, but can reach more than 105 dB above the sensor's interference threshold in case of non-GSO networks (main-lobe to main-lobe configuration). They are also a most serious matter of concern, because the 100° FOV of the push-broom sensor (cross-track) is composed of about 90, permanently activated, adjacent antenna beams, creating a ±10.25° longitudinal zone around the earth station position, where the sensor can receive harmful interference in any of its antenna beams.

Therefore, interference will occur whenever the two following geometric conditions are met:

– the sensor is crossing the latitude of the earth station;

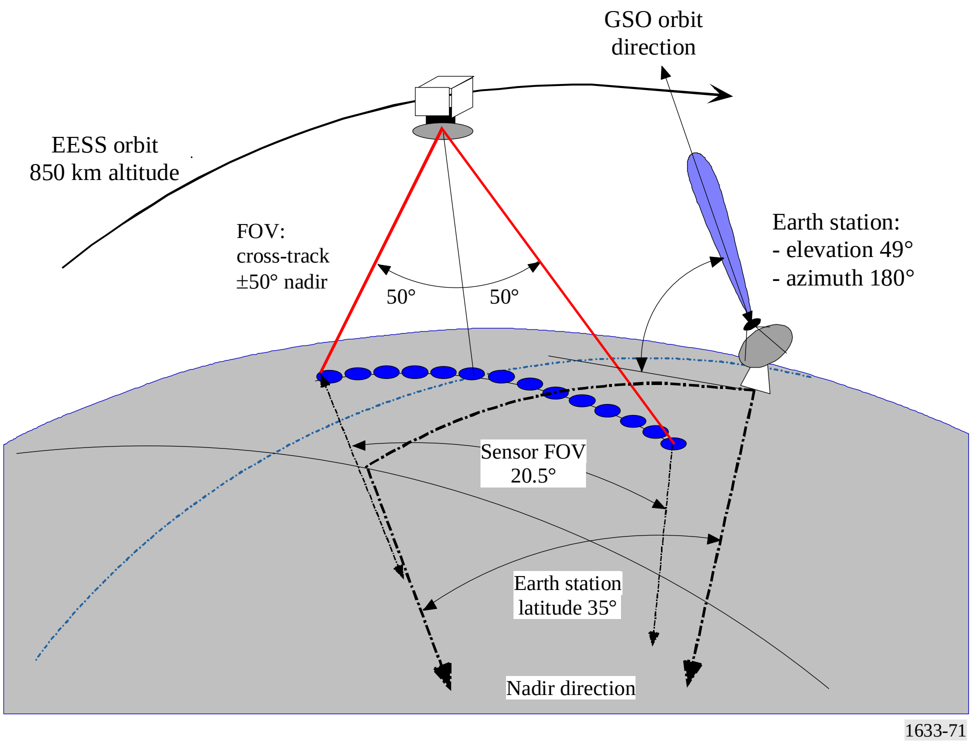
– the sensor is at a longitudinal distance within ±10.25° from the earth station.

This configuration is illustrated in Fig. 71.

FIGURE 71

Specific case of the push-broom sensor

(Configuration of FSS/MSS earth station interference to push-broom sensor)



Considering that the longitudinal distance between two successive orbits is about 25° at the equator, the consequence is that passive sensor operation will be hampered by one interference event about twice a day from a unique earth station, considering both ascending and descending orbital paths. The number of events increases with the latitude of the earth station, as the distance between successive orbits decreases with the cosine of the latitude. It is directly proportional to the number of earth stations.

The main characteristics of each interference event are the following, in the case of a GSOV-B2 FSS earth station:

– the duration is about 16 s;

– a circular area on the Earth's surface of about 110 km in diameter around each earth station position, is contaminated by harmful interference;

– this 9500 km^2 zone, corresponding to 47 pixels is to be compared to the 2000000 km^2 reference sensor's service area which is stipulated in the Recommendations ITU-R SA.1028 and ITU-R SA.1029;

– the non-availability criterion of 0.01% is by far exceeded in the vicinity of earth stations.

The most significant numerical results are summarized in the Tables 103 and 104.

TABLE 103

Power excess over interference threshold, non-GSO network (co-frequency assumption)

Sensor far-lobes to earth station main-lobe	**MEOSAT-X**	**LEO V1**	**LEO V2**
Power excess in sensor's antenna beams (dB)	49.2	21.4	30.9
Geographic zone concerned (approximately) (km)	125 × 110	–	–
Number of contaminated pixels (approximately)	8 scan-lines	–	–
Duration of one event (approximately) (s)	18	–	–
Sensor close to zenith of earth station	**MEOSAT-X**	**LEO V1**	**LEO V2**
Sensor main-lobes to earth station far-lobe interference			
Power excess in nadir beam (dB)	28.3	4.5	12
Power excess in ±50° off-nadir beams (dB)	22.1	None	6
Zone around earth station (approximately) (km)	Diameter 98	–	–
Number of contaminated pixels/event	38 pixels	–	–
Duration of one event (s)	15	–	–
Sensor close to zenith of earth station	**MEOSAT-X**	**LEO V1**	**LEO V2**
Sensor main-lobes to earth station main-lobe interference			
Maximum power excess in sensor's beams (dB)	105.6	70	81
Zone around earth station (approximately) (km)	Diameter 325	–	–
Number of contaminated pixels (approximately)	20 scanlines	–	–
Average duration of event (approximately) (s)	46	–	–

NOTE 1 – The duration of events is evaluated under the hypothesis that the pointing direction of the earth station antenna is steady (i.e. only the EESS satellite is moving). It is clear that this duration can be shorter or longer depending on the relative velocity of the EESS and the FSS non-GSO satellites.

TABLE 104

Power excess over interference threshold, GSO networks (co-frequency assumption)

Sensor in earth station main-lobe	V-B2 FSS earth station	SV FSS earth station
Power excess (dB)	49.9	40.5
Zone concerned (approximately) (km)	150 × 130	102 × 88
Number of contaminated pixels/event	9 scan-lines	6.4 scan-lines
Duration of one event (approximately) (s)	21	15
Sensor close to zenith of earth station	**V-B2 FSS earth station**	**SV FSS earth station**
Nadir beam (dB)	29.7	26.4
± 50° off-nadir beams (dB)	23.5	20.2
Zone around earth station (approximately) (km)	Diameter 110	Diameter 82
Number of contaminated pixels/event	47	27
Duration of one event (approximately) (s)	16	12

Note that main-lobe to main-lobe configurations are becoming possible with GSO FSS earth stations located near the equator. In that case the power excess indicated in the second part of Table 104 are augmented by the earth station antenna discrimination (up to 80 dB). The probability of occurrence of such configurations must be studied further.

4.4 Dynamic interference analysis

In addition to the above static and semi-static cases, a dynamic analysis is necessary in order to take into consideration the percentage of time when the interference occurs. As indicated above, the threshold of –166 dBW must not be exceeded no more than 0.01% of time in a bandwidth of 100 MHz.

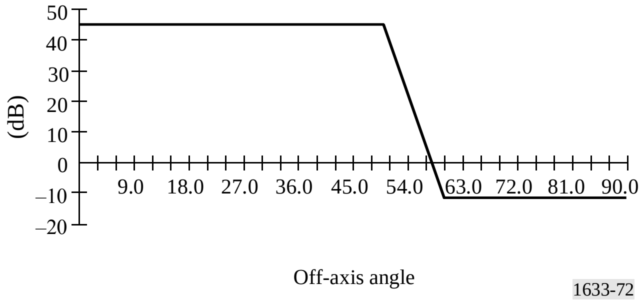
Simulations were conducted to determine the probability of interference using a time increment (sampling) of 5 s in order to get accurate results. The simulations stopped when the cumulative distribution function becomes stable. Furthermore, it has to be noted that all these simulations presented hereunder only deal with the nadir sounder push-broom satellite, because the above static and semi-static cases have shown that it is the worst case.

4.4.1 Modelling of the push-broom antenna

As explained above, the push-broom antenna is able to see a whole line of pixels located around the nadir at ±50° for the azimuth, and in ±0.55° for the elevation. The maximum antenna gain is 45 dBi, and as usual for radiometer antennas, there is a steep decrease to the side lobe level of −12 dBi. Figure 72 shows the antenna pattern according to the azimuth off-axis angle.

FIGURE 72

Push-broom composite antenna pattern



4.4.2 Dynamic calculations with GSO systems

TABLE 105

Dynamic analysis between GSO system GSOV-B2 and EESS with only one earth station operating at the location N0, E0

Cumulative distribution (%)	3	1	0.1	0.06	0.01	0.001	0.0002
Push-broom: corresponding interference power received by EESS (dBW) (150 MHz bandwidth)	–220	–200	–186	–166	–138	–115	–58

Table 105 shows that it is possible to find a 108 dB difference between the threshold of −166 dBW and the maximum power received by the radiometer of –58 dBW. Such a level has a potential to cause damage to the sensor.

TABLE 106

Dynamic analysis between GSO system GSOV-B2 and EESS with only one earth station operating at the location N50, E0

Cumulative distribution (%)	5.3	1	0.1	0.08	0.01	0.008
Push-broom: corresponding interference power received by EESS (dBW) (150 MHz bandwidth)	–220	–194	–170	–166	–138	–134

According to Tables 105 and 106, there is a risk that the EESS satellite experiences interference when only one earth station is in operation (or the percentage of data interfered is above the acceptable one). Taking into account the relative bandwidth, the required spectral attenuation is 26.3 dB for GSOV-B2. It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Tables 105 and 106. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criterion is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.4.3 Dynamic calculations with non-GSO systems

TABLE 107

Dynamic analysis between non-GSO system MEOSAT-X and EESS with six earth stations evenly operating along the equator

Cumulative distribution (%)	23	1	0.3	0.1	0.01	0.009
Push-broom: corresponding interference power received by EESS (dBW) (500 MHz bandwidth)	–250	–175	–166	–134	–120	–119

TABLE 108

Dynamic analysis between non-GSO system MEOSAT-X and EESS with six earth stations operating at (N35,E0), (N35,E60), (N35,E120), (N0,W60), (N35,W110), (N35,W80)

Cumulative distribution (%)	25	1	0.4	0.1	0.01	0.004
Push-broom: corresponding interference power received by EESS (dBW) (500 MHz bandwidth)	–250	–175	–166	–131	–123	–122

According to the Tables 107 and 108, there is a risk that the EESS satellite experiences interference when six earth stations are in operation (or the percentage of data interfered is above the acceptable one). In that case, the required spectral attenuation is 39 dB for MEOSAT-X in the worst case. It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Tables 107 and 108. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criterion is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.5 Application of OoB spectral representation to the FSS earth station transmission

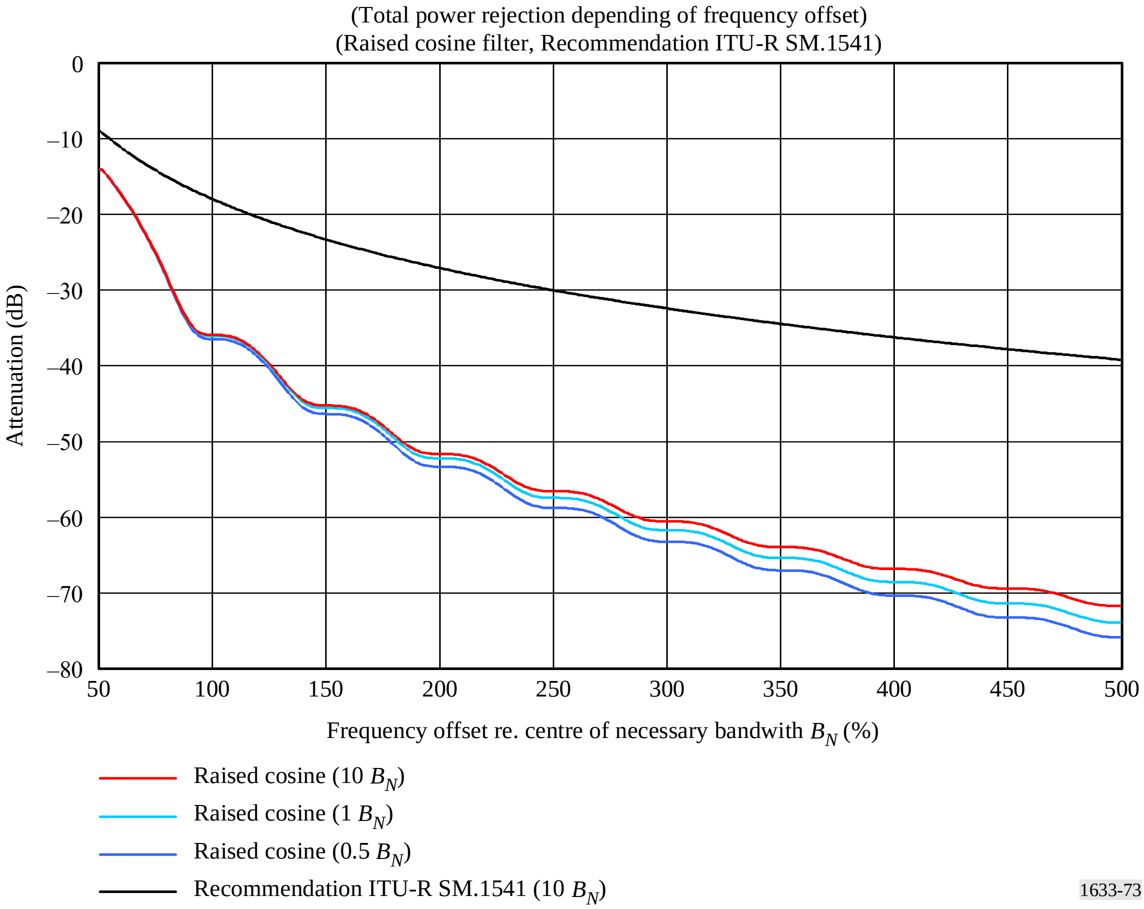
Considering now that the FSS earth stations are transmitting in their own frequency band, the rejection of their transmitter power within the adjacent EESS (passive) allocated band is ranging between 26.4 dB and 49.9 dB for the configurations involving the GSO systems V-B2 and SV. Peak values in case of scenarios involving the other GSO systems listed in the Table 102 are also computed.

Figure 73 represents the power falling within the EESS allocation, depending on guardband. To cover the varying characteristics of the FSS emissions, the sliding integration is performed for three values of the passive band, expressed in terms of percentage of the FSS necessary bandwidth (1 000%, 100% and 50%). There is only a minor difference between the three curves.

Note that on Fig. 73, the frequency off-set is taken from the centre of the necessary bandwidth. This will be used to determine the minimum separation between the centre of the necessary bandwidth and the upper limit of the FSS allocated band, which is required to protect the adjacent EESS allocated band from unwanted FSS emissions.

FIGURE 73

Attenuation of OoB power contained within the EESS bandwidth



Using this spectral representation, the following conditions can be derived, which are summarized in Tables 109 and 110 for non-GSO FSS systems, in Tables 111 and 112 for GSO FSS systems. The last line in these Tables indicate the additional guardband which would be necessary between the upper limit of B_N and the lower limit of the EESS allocated band, to protect the passive sensors from unwanted emissions in the adjacent band. This additional guardband is expressed by Off-set from centre $B_N - B_N/2$.

TABLE 109

Summary of necessary guardbands to protect passive sensors from non-GSO FSS earth stations (sensor far-lobe to earth station main-lobe)

FSS system	**MEOSAT-X**
Required power rejection (dB)	49.2
Necessary bandwidth (MHz)	500
Passive allocation (% B_N)	40
Offset from centre of B_N (% B_N)	180
Offset from centre of B_N (MHz)	**900**
Required additional guardband (MHz)	**650**

TABLE 110

Summary of necessary guardbands to protect passive sensors from non-GSO FSS earth stations (sensor close to zenith of the earth station)

FSS system	**MEOSAT-X**
Required power rejection (dB)	105.6
Necessary bandwidth (MHz)	500
Passive allocation (% B_N)	40
Offset from centre of B_N (% B_N)	> 500
Offset from centre of B_N (MHz)	**> 2 500**
Required additional guardband (MHz)	**Out of range**

The dynamic analysis provides a required attenuation of 39 dB, which corresponds to a required guardband of 375 MHz.

TABLE 111

Summary of necessary guardbands to protect passive sensors from GSO FSS earth stations (sensor in the earth station main-lobe)

FSS system	**GSOV-B1**	**GSOV-B2**	**GSO-VX**	**GSO-SV**	**GEOSAT**	
					Gateway	**User**
Required power rejection (dB)	None	49.9	37.2	40.5	49.1	34.4
Necessary bandwidth (MHz)	105.6	150	300	200	125	11
Passive band (% B_N)	190	133	67	100		
Offset from centre B_N (% B_N)	None	184	116	128	181	91
Offset from centre B_N (MHz)	**None**	**276**	**250**	**256**	**226**	**10**
Required additional guardband (MHz)	**0**	**201**	**100**	**156**	**164**	**0**

TABLE 112

Summary of necessary guardbands to protect passive sensors from GSO FSS earth stations (sensor close to zenith of the earth station)

FSS system	**GSOV-B1**	**GSOV-B2**	**GSO-VX**	**GSO-SV**	**GEOSAT**	
					Gateway	**User**
Required power rejection (dB)	None	29.7	17	26.4	28.9	14.2
Necessary bandwidth (MHz)	105.6	150	300	200	125	11
Passive band (% B_N)	190	133	67	100	160	1 818
Offset from centre B_N (% B_N)	None	82	60	77	81	53
Offset from centre B_N (MHz)	**None**	**123**	**180**	**154**	**101**	**6**
Required additional guardband (MHz)	**0**	**48**	**30**	**54**	**39**	**0**

The dynamic analysis provides a required attenuation of 26.3 dB for GSOV-B2 which implies a guardband of 30 MHz.

5 Mitigation techniques

5.1 EESS (passive)

This subject needs further investigation.

5.2 FSS

5.2.1 Offset of the active channel from band edge

The results of the analysis (see Tables 111 and 112) indicate that, in most cases, considerable frequency off-sets between the centre of the necessary bandwidths and the upper limit of the FSS allocated band would be required to protect the passive sensors from unwanted emissions. The most critical situations are obtained with transmissions involving simultaneously high e.i.r.p. and wide necessary bandwidth. Because the likelihood of main-lobe to main-lobe coincidences may be high in case of non-GSO FSS systems and in case of GSO FSS earth stations close to the equator, in most cases, there are difficulties to achieve acceptable frequency offset to protect the adjacent passive allocation.

5.2.2 Power and necessary bandwidth

The reduction of power and necessary bandwidth could reduce the size of the required frequency offset.

5.2.3 Inversion of the directions of transmission

According to the characteristics of some GSO FSS Earth-to-space links, guardbands of about 30 MHz (following dynamic analysis) would be needed to fully protect the EESS (passive) band 50.2-50.4 GHz.

The characteristics of some non-GSO FSS Earth-to-space links make them clearly incompatible with satisfactory operations of passive sensors in the adjacent frequency band, because the frequency offset that would be required to ensure sufficient rejection of the unwanted power is generally too large (required guardband of about 375 MHz). In Table 113, the power excess over the interference threshold is computed (co-frequency), under the assumption that the space-to-Earth links are implemented in the 47.2-50.2 GHz frequency band, instead of in the 37.5-42.5 GHz frequency band. The results show that the situation would be more favourable and that no, or minor frequency offsets would be required to protect the allocated passive band.

TABLE 113

Co-frequency interference with FSS downlinks

FSS system	MEOSAT-X	LEO V1	LEO V2	GSO-VX	GSO-SV	GSOV-B2
Frequency (GHz)	37.5-42.5					
Orbit shape	Circular			GSO		
Orbit altitude (km)	10 352	1 350	10 355	35 900		
e.i.r.p. (dBW)	60	46.9	49.5	56	62	63.8
Bandwidth (MHz)	500	90	300	300	200	150
Minimum distance to sensor (km)	9 502	500	9 505	35 050	–850	–850
Minimum path-loss (dB)	–206.03	–180.45	–206.03	–217.37	–217.37	–217.37
Co-frequency received power (dBW)	–162.34	–145.88	–170.62	–175.46	–167.70	–165.90
Excess over interference threshold (dB)	**0.66**	**17.12**	**–7.62**	**–12.46**	**–4.70**	**–2.90**

NOTE 1 – The above characteristics may need further refinement.

5.2.4 Baseband filtering

The levels of unwanted emissions from the active service systems can be reduced through the use of efficient modulation techniques and filtering.

5.3 Potential impact

5.3.1 EESS (passive)

The potential impact on the EESS (passive) cannot be assessed until the mitigation techniques (§ 5.1) are finalized.

5.3.2 FSS

The impact of the mitigation techniques needs to be evaluated.

6 Results of studies

This analysis shows that, in general, a push-broom sensor will receive considerable unwanted power, exceeding the interference threshold both in magnitude and in duration, twice per orbit through one of its antenna beams when crossing the latitude of any earth station.

Worst-case configurations involving interference paths through the earth station main-lobe are more detrimental because they lead to the loss of a number of successive complete scan-lines of the passive sensor. Furthermore, the magnitude of the power excess over the interference threshold, which can be as high as 108 dB, might have a destructive effect on the passive sensor's receivers.

Annex 20

Compatibility analysis between EESS (passive) systems operating in the 50.2-50.4 GHz band and the FSS (Earth-to-space) and MSS (Earth-to-space) service systems operating in the 50.4-51.4 GHz band

1 EESS (passive)

1.1 Allocated band

The allocations adjacent to the 50.2-50.4 GHz EESS passive band are shown in Table 114. It should be noted that the band 50.2-50.4 GHz is covered by RR No. 5.340 and RR No. 5.340.1 is also applicable.

TABLE 114

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
47.2-50.2 GHz	**50.2-50.4 GHz**	**50.4-51.4 GHz**
FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.149 5.340 5.552 5.552A 5.555	EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive) 5.340 5.555A	FIXED FIXED SATELLITE (Earth-to-space) MOBILE Mobile-satellite (Earth-to-space)

1.2 Application

This frequency band is one of several bands between 50 GHz and 60 GHz that are used collectively to provide three-dimensional temperature profiles of the atmosphere.

These measurements feed the numerical weather prediction models. The model needs data every 6 h and is used for fine mesh weather predictions (10 km or less) on a short time basis (6 to 48 h.)

1.3 Required protection criteria

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

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

The first criterion is the acceptable 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. For nadir sounders used for three-dimensional measurements of atmospheric temperature or gas concentration, the proportion of measurement cells lost due to interference must not exceed 0.01%. This frequency of occurrence limit is valid for mechanically scanned and push-broom nadir sounders.

1.4 Operational characteristics

Three types of sensor designs have been considered for measurements in this frequency range. The cross track scanner which scans through nadir, the conical scanner which scans in an arc in front of the space station across its track, and the push-broom which uses multiple fixed beams across its track. The push-broom instrument is a nadir-looking instrument configured to measure in a plane normal to the satellite velocity vector. The push-broom scanner will be analysed because it represents the future in microwave sounding. It has the specific advantage of permitting a longer integration time. Table 115 provides the operating characteristics of the sensor under study.

TABLE 115

Parameters of the push-broom sensor

Parameter	Value
Altitude (km)	850
Orbit	Sun-synchronous polar
Main lobe antenna gain (dBi)	45
Antenna 3 dB beamwidth (degrees)	1.1
Antenna pattern	Recommendation ITU-R F.1245
FOV (re. sensor) (degrees)	± 50 cross track re. nadir direction
FOV (re. Earth’s centre) (degrees)	± 10.25 geocentric
Pixel diameter at nadir (km)	16
Pixels per swath	90
Swath width (km)	2 300

2 FSS and MSS

2.1 Allocated transmit band

Refer to Table 114.

2.2 Application

The active service under consideration for this Annex is the FSS (Earth-to-space) and MSS (Earth-to-space) in the 47.2-50.2 GHz band.

2.3 Levels based on spectral representation

This Annex uses the raised cosine spectral representation which is described in Annex 1.

This spectral representation is intended for band-by-band studies and is provisional, pending further review within the ITU-R. It represents in a very general way the typical mean power distribution through the OoB and spurious domains in an adjacent or nearby allocation.

2.4 Transmitter characteristics

The characteristics for the FSS and MSS are derived from Recommendation ITU-R S.1328-3 – Satellite system characteristics to be considered in frequency sharing analyses between geostationary-satellite orbit (GSO) and non-GSO satellite systems in the fixed-satellite service (FSS) including feeder links for the mobile-satellite service (MSS). MSS terminals are modelled as similarly to the fixed-satellite terminals except for narrower bandwidths and smaller antennas. It is assumed that they are mounted on a vehicle and used while at rest.

TABLE 116

Characteristics of GSO uplink earth stations

	System	
	Fixed-satellite	**Mobile-satellite**
Polarization	LHCP/RHCP	RHCP/LHCP
Modulation	QPSK	QPSK
Bandwidth (MHz)	125	11
e.i.r.p. (dBW)	83.9	69.2
Antenna gain (dBi)	64.8	59.3
Transmitter power (dBW)	19.1	9.9

3 Compatibility threshold

Interference is potentially received from several sources arising from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service. Therefore further work is needed to address the impact of multiple active services above and below the passive band.

4 Interference assessment

4.1 Methodology used to assess interference level

In a first step, interference levels are computed in a co-frequency case, where the FSS/MSS earth stations are assumed to transmit within the EESS (passive) band. In cases where the earth station necessary bandwidth is greater than the EESS (passive) band, the emitted power is adjusted, assuming that the power density is constant in the necessary bandwidth.

In a second step, the OoB mask for the active service is taken into account, and the guardband, which may be necessary to protect the passive service, is defined.

The following basic hypothesis are adopted for the analysis:

– the interference occurs via direct coupling between the passive sensor and the FSS/MSS earth station antennas;

– both antennas are modelled using Recommendation ITU-R F.1245;

– as a worst-case configuration, it is assumed that the pointing direction of the FSS/MSS earth station (aiming at the geostationary orbit) is contained in the orbit plane of the Earth exploration-satellite. This configuration renders possible sensor side-lobe to earth station main-lobe and sensor main-lobe to earth station side-lobe interfering paths. Main-lobe to main-lobe interfering paths are also possible, but only if the earth stations is located near the equator, a case which is not further considered in this Annex;

– the FSS/MSS earth station is assumed to be located at a latitude of 35°. This value was selected as a fair compromise to represent a worst-case sensor side-lobe to earth station main-lobe scenario, because it may represent the lower latitude above which earth stations are the most densely distributed and where, due to the relatively high incidence angle of the interfering path (about 49°), the natural protection due to the path plus atmospheric absorption losses is the lowest;

– the dynamic analysis in § 4.4 will consider latitudes between 0° and 50° N in order to get an extended range of results.

This configuration is described on the Fig. 74, where the major geometric parameters of the analysis are indicated.

4.2 Calculation of interference in the co-frequency hypothesis

Assuming that the pointing direction of the FSS/MSS earth station antenna (aiming at the geostationary orbit) is contained in the orbital plane of the Earth exploration-satellite, and considering only the nadir beam of the push-broom passive sensor, the following parameters are computed, depending on the latitudinal distance between the passive sensor and the FSS/MSS earth station:

– the linear distance between the sensor and the earth station (km);

– the offset angles between the line-of-sight sensor/earth station and the antennas main axis;

– the mutual gains in direction of each other, of the sensor and earth station antennas;

– the space loss;

– the atmospheric absorption depending on the elevation angle of the path (Recommendation ITU-R P.676);

– the power received by the passive sensor in the 200 MHz allocated bandwidth;

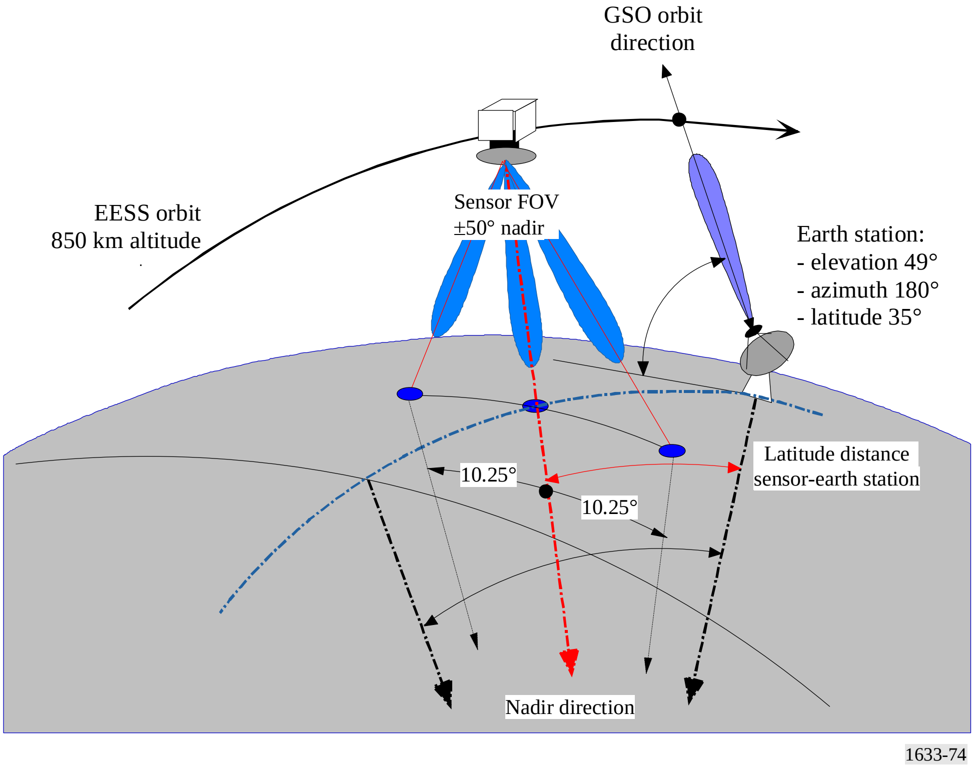
– the margin referred to the interference threshold, in the FSS and the MSS cases;

– the size of the area around the earth station position, where sounding data are contaminated by interference.

FIGURE 74

Configuration of FSS/MSS earth stations to passive sensor interferences

(Configuration of FSS/MSS earth station interference to a nadir sensor)



A sampling of numerical calculation is shown in the Table 118. Note that the resolution (in latitude) of the real spreadsheet is ten times better, in order to accurately identify the interference peaks and the size of the zones contaminated.

4.3 Result of the analysis and discussion

The results are plotted in Figs. 75 and 76, for FSS and MSS earth stations respectively. While the Earth exploration-satellite is moving in direction of the earth station, a first event appears when the sensor is crossing the earth station's main-lobe and the second event occurs when the sensor is at the zenith of the earth station.

FIGURE 75

Power received by the passive sensor from an FSS earth station

(Co-frequency case, earth-station at 35° latitude)

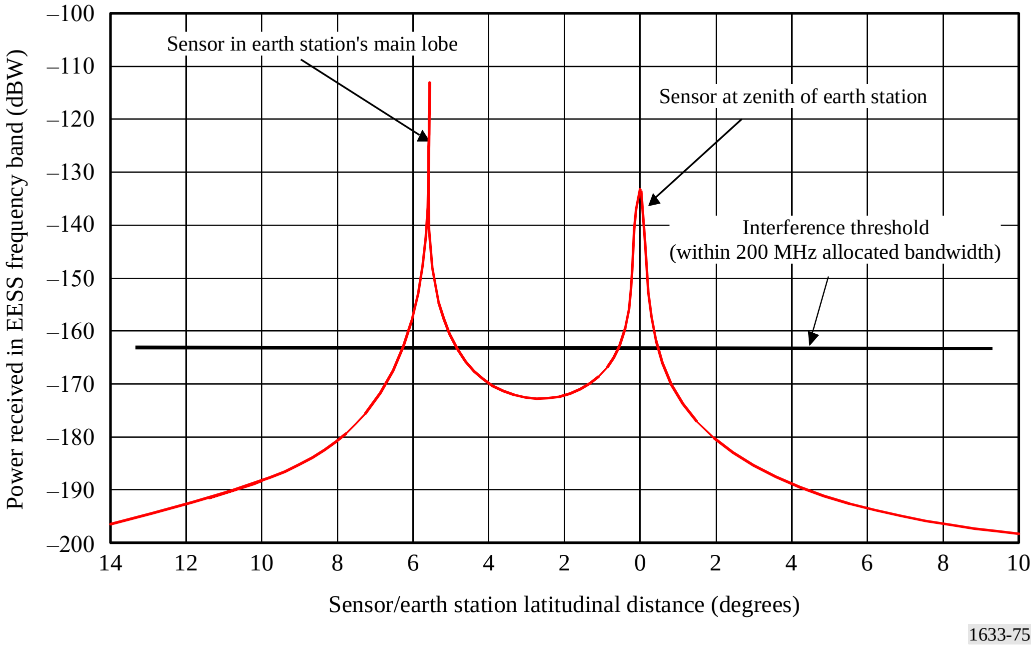
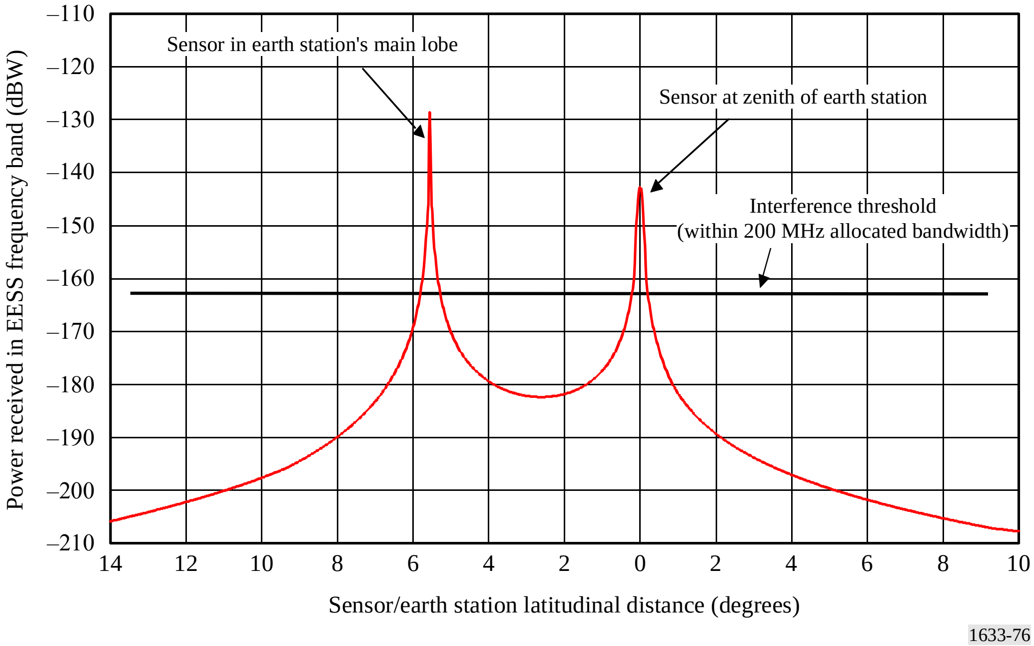


FIGURE 76

Power received by the passive sensor from a MSS earth station

(Co-frequency case, earth station at 35° latitude)



4.3.1 Interference events which occur when the passive sensor is in the main lobe of the FSS earth station

They are 49 dB above the interference threshold of the passive sensor. They last up to 21 s, which is to be compared to the passive sensor orbital period of 100 min. Since all antenna beams of the sensor are permanently activated, several complete scan-lines (90 pixels each) are contaminated at each event; this leads to about 810 pixels being lost at each event in case of the GSO FSS earth station. Since the Earth exploration-satellite is in an almost polar orbit, the condition required for interference is a coincidence within ±0.6° around the longitude of the earth station. The probability of occurrence of such events should be further studied, considering in particular the passive sensor drifting orbit parameters, the density and latitude of earth stations and the availability criteria of passive sensors. Owing to the size of the events, it is doubtful however, that their probability of occurrence may be neglected.

4.3.2 Interference which occurs when the passive sensor is close to the zenith of the FSS earth station

They are 29.5 dB above the sensor’s interference threshold. They appear the most serious matter of concern, because the 100° FOV of the push-broom sensor (cross-track) is composed of about 90, permanently activated, adjacent antenna beams, creating a ±10.25° longitudinal zone around the earth station position, where the sensor can receive harmful interference in any of it antenna beams.

Therefore interference will certainly occur whenever the two following geometric conditions are met:

– the sensor is crossing the latitude of the earth station;

– the sensor is at a longitudinal distance within ±10.25° from the earth station.

Considering that the longitudinal distance between two successive orbits is about 25° at the equator, the consequence is that passive sensor operation will be hampered by one interference event about twice a day from a unique earth station, considering both ascending and descending orbital paths. The number of events increases with the latitude of the earth station, as the distance between successive orbits decreases with the cosine of the latitude. It is directly proportional to the number of earth stations.

The main characteristics of each interference event are the following, in the case of a FSS earth station:

– the duration is about 16 s;

– a circular area on the Earth’s surface of about 110 km in diameter around each earth station position, is contaminated by harmful interference;

– this 9 500 km^2 zone, corresponding to 47 pixels is to be compared to the 2 000 000 km^2 reference sensor’s service area which is stipulated in the Recommendations ITU-R SA.1028 and ITU-R SA.1029;

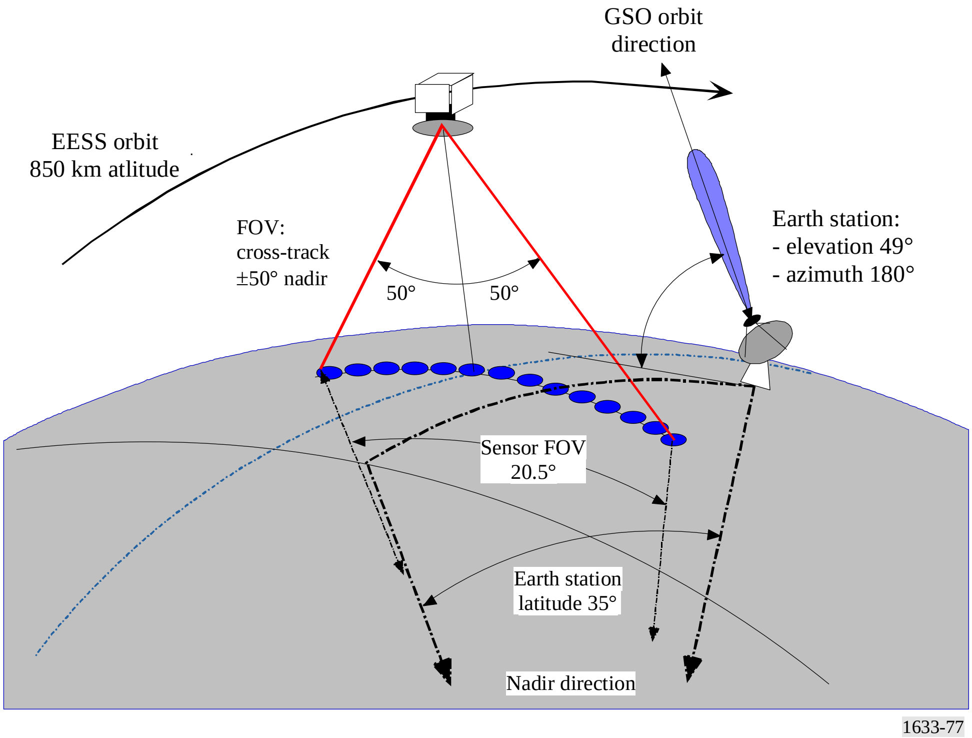
– the non-availability criteria of 0.01% is by far exceeded in the vicinity of earth stations.

This configuration is described in Fig. 77.

FIGURE 77

Specific case of the push-broom sensor

(Configuration of FSS/MSS earth station interference to push-broom sensor)



The most significant numerical results are summarized in the Table 117.

TABLE 117

Power excess over interference threshold (co-frequency assumption)

Sensor in earth station main lobe	**FSS earth station**	**MSS earth station**
Power excess (dB)	49.1	34.4
Zone around earth station (approximately) (km)	150 × 130	60 × 51
Number of contaminated pixels/event	9 scan-lines	4 scan-lines
Duration of one event (approximately) (s)	21	8.3
Sensor close to zenith of earth station	**FSS earth station**	**MSS earth station**
Nadir beam (dB)	29.5	20.3
±50° off-nadir beams (dB)	23.3	14.2
Zone around earth station (approximately) (km)	Diameter 110	Diameter 41
Number of contaminated pixels/event	47	7
Duration of one event (approximately) (s)	16	6

Note that main-lobe to main-lobe configurations are becoming possible for FSS/MSS earth stations located near the equator. In that case the power excess indicated in the second part of Table 117 are augmented by the earth station antenna discrimination (up to 80 dB). The probability of occurrence of such configurations must be studied further.

4.4 Dynamic interference analysis

In addition to the above static and semi-static cases, a dynamic analysis is necessary in order to take into consideration the percentage of time when the interference occurs. As indicated above, the threshold of –166 dBW must not be exceeded by no more than 0.01% of time in a bandwidth of 100 MHz.

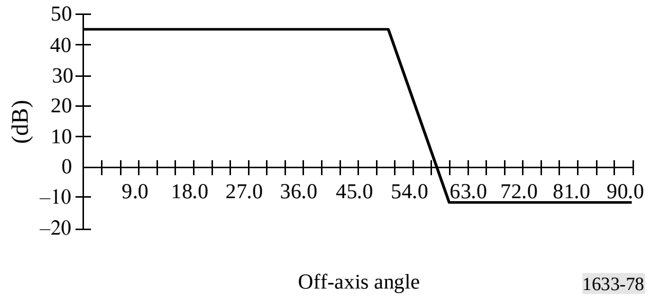
Simulations were conducted to determine the probability of interference using a time increment (sampling) of 5 s in order to get accurate results. Simulations stopped when the cumulative distribution function becomes stable. Furthermore, it has to be noted that all these simulations presented hereunder only deal with the nadir sounder push-broom satellite, because the above static and semi-static cases have shown that it is the worst case.

4.4.1 Modelling of the push-broom antenna

As explained above, the push-broom antenna is able to see a whole line of pixels located around the nadir at ±50° for the azimuth, and in ±0.55° for the elevation. The maximum antenna gain is 45 dBi, and as usual for radiometer antennas, there is a steep decrease to the side-lobe level of –12 dBi. Figure 78 shows the antenna pattern according to the azimuth off-axis angle.

FIGURE 78

Push-broom composite antenna pattern



4.4.2 Dynamic calculations with GSO FSS systems

TABLE 118

Dynamic analysis between GSO FSS system and EESS with only one earth station operating at the location N0, E0

Cumulative distribution (%)	4.1	1	0.07	0.01	0.002
Push-broom: corresponding interference power received by EESS (dBW) (125 MHz bandwidth)	–212	–190	–166	–131	–53

Table 118 shows that it is possible to find a 113 dB difference between the threshold of –166 dBW and the maximum power received by the radiometer of –53 dBW. Such a level has a potential to cause damage to the sensor.

TABLE 119

Dynamic analysis between GSO FSS system and EESS with only one earth station operating at the location N50, E0

Cumulative distribution (%)	7.2	1	0.15	0.01	0.004
Push-broom: corresponding interference power received by EESS (dBW) (125 MHz bandwidth)	–212	–186	–166	–131	–126

According to Table 119, there is a risk that the EESS satellite experiences interference when only one earth station is in operation (or the percentage of data interfered is above the acceptable one). Taking into account the relative bandwidth, the required spectral attenuation is 34 dB for GSO FSS. It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Tables 118 and 119. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criterion is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.4.3 Dynamic calculations with GSO MSS systems

TABLE 120

Dynamic analysis between GSO MSS system and EESS with only one earth station operating at the location N0, E0

Cumulative distribution (%)	3.9	1	0.1	0.05	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (11 MHz bandwidth)	–220	–200	–186	–166	–141	–67

TABLE 121

Dynamic analysis between GSO MSS system and EESS with only one earth station operating at the location N50, E0

Cumulative distribution (%)	7.2	1	0.1	0.06	0.01	0.003
Push-broom: corresponding interference power received by EESS (dBW) (11 MHz bandwidth)	–220	–194	–172	–166	–141	–136

According to Table 121, there is a risk that the EESS satellite experiences interference when one earth stations is in operation (or the percentage of data interfered is above the acceptable one). In that case, the required spectral attenuation is 25 dB for GSO MSS. It is expected that significantly more earth stations would be operational in the satellite systems for which the results of dynamic simulations are reported in Tables 120 and 121. Increasing the number of earth stations included in the dynamic simulations is likely to increase the percentage of time that the EESS criteria is exceeded. In this event, the conclusions drawn in § 4.5 with respect to the amount of required guardbands would have to be re-evaluated.

4.5 Application of OoB masks to the FSS/MSS earth station transmission

Assuming now that the FSS/MSS earth stations are transmitting in their own frequency band, the rejection of this power within the adjacent EESS (passive) allocated band must be:

– up to 49 dB to cover the case where the passive sensor is crossing the main-lobe of the FSS earth station antenna;

– up to 29.5 dB to cover the case where the passive sensor is close to the zenith of the FSS earth station antenna;

– up to 34 dB according to the dynamic analysis (see Tables 119 and 120).

Clearly the OoB mask described in the Recommendation ITU-R SM.1541 does not provide an appropriate protection. The raised cosine mask proposed by the Radiocommunication Working Party 4A is much more realistic. Figure 79 represents the power falling within the EESS allocation, depending on guardband. To cover the varying characteristics of the FSS emissions, the sliding integration is performed for three values of the passive band, expressed in terms of percentage of the FSS necessary bandwidth (1 000%, 100% and 50%). There is only a minor difference between the three curves.

It should be noted that in Fig. 79, the frequency offset is taken from the centre of the necessary bandwidth. This will be used to determine the minimum distance between the centre of the necessary bandwidth and the upper limit of the FSS/MSS allocated band, which is required to protect the adjacent EESS allocated band from unwanted FSS/MSS emissions.

Assuming that this mask will be adopted and is representing reliably the real spectral characteristics of the FSS transmitters, the following conditions can be derived, which are summarized in the Table 122 for GSO FSS and GSO MSS systems. The last line in this Table indicate the additional guardband above the lower limit of the FSS allocated band which would need to be applied to protect the passive sensors from unwanted emissions in the adjacent band.

The dynamic analysis provides a 34 dB rejection for FSS, and a 25 dB rejection for MSS. Therefore, the corresponding required additional guardbands are 50 MHz and 2.3 MHz.

FIGURE 79

Attenuation of OoB power contained within the EESS bandwidth

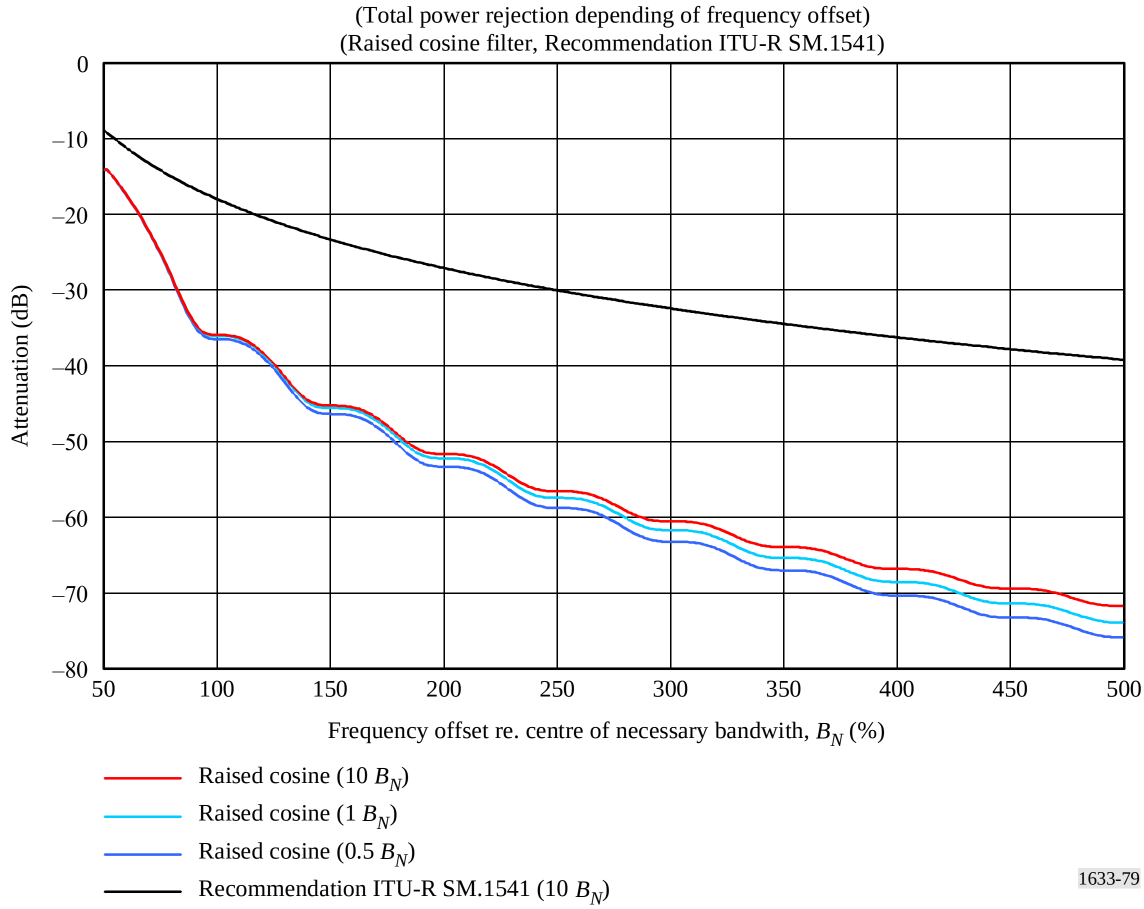


TABLE 122

Summary of necessary guardbands to protect passive sensors from GSO FSS/MSS earth stations

	GSO FSS		**GSO MSS**	
	Sensor in station main-lobe	**Sensor near zenith of station**	**Sensor in station main-lobe**	**Sensor near zenith of station**
Power rejection (dB)	49	29.5	34.4	20.3
Necessary bandwidth (MHz)	125		11	
Passive band (% B_N)	160		1 818	
Offset (% B_N)	181	82	91	67
Offset (MHz)	226	103	10	7.4
Required additional guardband (MHz)	164	41	4	1.4

5 Mitigation techniques

5.1 EESS (passive)

This subject needs further investigation.

5.2 SFS and MSS

5.2.1 Implementation of guardbands

The results of the analysis (see Table 122) indicate that guardbands would be required to protect the passive sensors from unwanted emissions. The most critical situations are obtained with transmissions involving simultaneously high e.i.r.p. and wide necessary bandwidth. Because the likelihood of main-lobe to main-lobe alignment may be high in case of GSO FSS/MSS earth stations located near the equator, no practicable size of frequency offset seems to be possible with such systems, to protect the adjacent passive allocation.

5.2.2 Power and necessary bandwidth

The reduction of power and necessary bandwidth could reduce the size of the required frequency offset.

5.2.3 Baseband filtering

The level of unwanted emissions from the active service systems can be reduced through the use of efficient modulation techniques and filtering.

5.3 Potential impact

5.3.1 EESS (passive)

The potential impact on the EESS (passive) cannot be assessed until the mitigation techniques (§ 5.1) are finalized.

5.3.2 FSS and MSS

The impact of the mitigation techniques needs to be evaluated and reviewed within the ITU-R.

6 Results of studies

This analysis shows that, in general, a push-broom sensor will receive considerable unwanted power, exceeding the interference threshold both in magnitude and in duration, twice per orbit through one of its antenna beams when crossing the latitude of any earth station.

Worst-case configurations involving interference paths through the earth station main lobe are more detrimental because they lead to the loss of a number of successive complete scan-lines of the passive sensor. Furthermore, the magnitude of the power excess over the interference threshold, which can be as high as 113 dB, raises concerns about the possibility of damages on the passive sensor's receivers.

Annex 21

Compatibility analysis between EESS (passive) systems operating in the 52.6-52.8 GHz band and FS systems operating in the 51.4-52.6 GHz band

1 EESS (passive)

1.1 Allocated band

The 51.4-52.6 GHz band is allocated to FS and this band is adjacent to the 52.6-52.8 GHz band allocated to the EESS. Therefore there is a need to evaluate the effect of unwanted emissions from FS systems falling in the EESS 52.6-52.8 GHz band. This Annex provides for FS system operating above 31.8 GHz calculation of levels of unwanted emissions falling in the 51.4-52.6 GHz band.

It should be noted that according to RR No. 5.340, all emissions are prohibited in the band 52.6-54.25 GHz.

The allocations adjacent to the 52.6-52.8 GHz passive bands are shown in Table 123.

TABLE 123

Adjacent band allocations

Services in lower allocated band	Passive band	Services in upper allocated band
51.4-52.6 GHz	**52.6-54.25 GHz**	**54.25-55.78 GHz**
FIXED MOBILE	EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive)	EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.556A GSO only with pfd limit SPACE RESEARCH (passive)

1.2 Application

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with the bands at 23.8 GHz, 31.5 GHz, 50.3 GHz to characterize each layer of the atmosphere.

1.3 Required protection criteria

These following three Recommendations establish the interference criteria for passive sensors:

Recommendation ITU-R SA.515 – Frequency bands and bandwidths used for satellite passive sensing.

Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.

Recommendation ITU-R SA.1029 – Interference criteria for satellite passive remote sensing.

1.4 Operational characteristics

The following operational characteristics are considered for the EESS system:

– The EESS sensor is assumed to have an antenna with a gain of 45 dBi.

– The EESS sensor is pointing in the nadir direction.

– The pixel size for a sensor at an altitude of 850 km is 201 km^2 (16 km diameter).

2 FS

2.1 Allocated band

See Table 123.

2.2 Application

According to RR No. 5.547, the band 51.4-52.6 GHz is available for high-density applications in the FS.

This band may be used for both P-P FS systems and P-MP FS systems.

2.3 Levels based on existing ITU documents

The following ITU-R Recommendations provide information on unwanted emissions of FS systems:

Recommendation ITU-R F.1191 – Bandwidths and unwanted emissions of digital fixed service systems.

Recommendation ITU-R SM.329 – Unwanted emissions in the spurious domain.

Recommendation ITU-R SM.1541 – Unwanted emissions in the out-of-band domain.

2.4 Transmitter characteristics

The following characteristics contained in Tables 124 and 125 have been used.

TABLE 124

Characteristics of P-P systems
(Recommendation ITU-R F.758)

Channel spacing (MHz)	56	3,5
Antenna gain (maximum) (dBi)	50	50
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna type	Dish/horn	Dish/horn
Maximum Tx output power (dBW)	–20	–20
e.i.r.p. (maximum) (dBW)	30	30

TABLE 125

Characteristics of P-MP systems
(Recommendation ITU-R F.758)

Station type	CS	TS
Channel spacing (MHz)	28	28
Antenna gain (maximum) (dBi)	14	Dish 41 Planar 28
Feeder/multiplexer loss (minimum) (dB)	0	0
Antenna beamwidth (3 dB) azimuth/elevation (degrees)	>15	1.2 × 1.2
Maximum Tx output power (dBW)	–10	–15
e.i.r.p. (maximum) (dBW)	4	26/13

2.5 Operational characteristics

Recommendation ITU-R F.1496 provides channel arrangements for systems using 3.5 MHz, 7 MHz, 14 MHz, 28 MHz and 56 MHz channel spacing to be deployed in this band.

2.5.1 P-P operational characteristics

It is proposed to use as a first step a density of terminals of one terminal per km^2*.

2.5.2 P-MP operational characteristics

It is proposed to use as a first step a density of terminals of 0.3 terminal per km^2*.

Frequency reuse: A frequency reuse of two is commonly used and is considered as a typical scenario. A frequency reuse factor of one is to be considered as a worst-case situation, which occurs rarely.

Sector antenna: The typical sector antenna width is 90°. In some cases, 45° sector antennas are foreseen where high amount of traffic capacities have to be transported from one station location.

Based on these considerations, a hub of a P-MP cell may serve typically two co-channel subscribers within a given cell.

2.6 In-band transmit power

See Tables 124 and 125.

3 Compatibility threshold

The passive sensor protection criterion is –166 dBW in a 100 MHz bandwidth (not to be exceeded for more than 0.01% of time as stipulated by Recommendation ITU-R SA.1029). Section 2.4 provides a set of characteristics for FS systems to be deployed in this band. Based on this information, it is possible to derive the allowed power from each FS system falling into the EESS band.

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* It should be noted that these numbers represent a worst-case approach and will be refined to obtain a realistic number of FS systems in each of the considered bands.

Interference is potentially received from several sources from multiple services simultaneously. The value listed in Recommendation ITU-R SA.1029 (for a specific band) is the maximum allowable interference level for the passive sensor.

This Annex provides an analysis of the interference generated by a single active service.

Further work is needed to address the impact of these multiple active services operating above and below the passive band.

4 Interference assessment

4.1 Methodology to assess the interference level

The first step of this approach is to calculate the acceptable power resulting from a deployment of FS systems that may fall within an EESS pixel:

Aggregate power at the earth in 100 MHz = EESS protection criteria (dB(W/100 MHz)) – EESS gain + free space loss.

Then it is possible to derive the unwanted level of emissions per FS system falling into the EESS 100 MHz reference bandwidth:

Power/Tx (dB(W/100 MHz)) = aggregate power at the Earth in 100 MHz – N_b Tx (in EESS pixel) – FS gain in the EESS direction

4.2 Calculation

For P-P systems (see Table 126), Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. The density of terminals operating at the same frequency is assumed to be one terminal per km^2.

TABLE 126

Acceptable unwanted emissions level per P-P FS system falling into the EESS band

Frequency (GHz)	52.6	
Interference criteria (dB(W/100 MHz))	–166	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	185.5	
Gaseous absorption (dB)	3	
Aggregate at the Earth (dB(W/100 MHz))	**–22.5**	
Aggregate at the Earth (dB(W/MHz))	–42.5	
Station type	CS	TS
Channel spacing (MHz)	**56**	**3.5**
FS antenna gain	50	50
FS gain in the EESS direction	–13	–13
Aggregate power (dB(W/MHz))	–29.5	–29.5
Density of systems/km^2	1	1
Pixel size/km^2	201	201
N_b Tx	201	201
Power/Tx (dB(W/MHz))	–52.5	–52.5
Power/Tx (dB(W/100 MHz))	**–32.5**	**–32.5**

For P-MP terminal stations (see Table 127), Recommendation ITU-R F.1245 was used to derive the antenna gain in the zenith direction. For P-MP central stations, Recommendation ITU-R F.1336 was used to derive the antenna gain in the zenith direction. The density of site of a central station operating at the same frequency is assumed to be 0.3 terminal per km^2. On the same site, two central stations may use the same frequency assuming 90° sector antenna. Therefore, two terminal stations may use the same frequency within the same cell.

TABLE 127

Acceptable unwanted emissions level per P-MP FS system falling into the EESS band

Frequency (GHz)	52.6	
Interference criteria (dB(W/100 MHz))	–166	
Altitude (km)	850	
Reference bandwidth (MHz)	100	
Gain EESS	45	
Free space loss	185.5	
Gaseous absorption	3	
Aggregate at the Earth (dB(W/100 MHz))	–22.5	
Aggregate at the Earth (dB(W/MHz))	–42.5	
Station type	CS	TS
Channel spacing (MHz)	28	28
FS antenna gain	14	41
FS Gain in the EESS direction	–10.3	–11.3
Aggregate power (dB(W/MHz))	–32.2	–31.2
Density of systems/km^2	0.6	0.6
Pixel size/km^2	201	201
N_b Tx	121	121
Power/Tx (dB(W/MHz))	–53	–52
Power/Tx (dB(W/100 MHz))	–33	–32

4.3 Value achieved

4.3.1 Level of unwanted emissions based on ITU-R Recommendations

As a first step approach, only unwanted emissions falling into spurious emissions are considered (if the guardband is larger than the OoB domain). Then, levels of attenuation provided in RR Appendix 3 of the RR and Recommendation ITU-R SM.329 are used to derive the levels of unwanted emissions from FS falling within the spurious emission domain (offset higher than 250% of the necessary bandwidth or channel separation compared to the centre frequency of the FS signal). In the case of FS systems, the attenuation specified in RR Appendix 3 should be in dBc, the minimum of 70 dBc or (43 + 10 log (P)).

Based on the first step approach, for a system operating with an output power of –6 dBW and a channel spacing of 56 MHz (see Table 124). The spurious emission limits for this system is:

$$P \text{ (dBW)} - (43 + P) \qquad \text{dB in a 1 MHz reference bandwidth}$$

Table 128 provides the level of unwanted emissions that may fall in a 100 MHz reference bandwidth.

TABLE 128

Calculation of the level of unwanted emissions that may fall within a 100 MHz bandwidth

FS system	Level of spurious emissions per MHz	Level of spurious emissions per 100 MHz
P-P 56 MHz (Table 124)	–43 dBW	–23 dBW
P-P 3.5 MHz (Table 124)	–43 dBW	–23 dBW
P-MP 50 MHz (Table 125)	–43 dBW	–23 dBW
P-MP 2.5 MHz (Table 125)	–43 dBW	–23 dBW

This first step approach leads to the conclusion that even if only unwanted emissions falling into the spurious domain are considered then the EESS protection criteria is not met.

4.3.2 Refinement of the calculations

4.3.2.1 Refinement of calculations using the methodology described in Appendix 1 to Annex 1

Recommendation ITU-R SM.1541 provides mask for OoB emissions in case of FS systems. The integrated power within the EESS band may be calculated by assuming (see Appendix 1 to Annex 1) that the spurious emission level does not exceed the limit at the edge of the OoB domain

4.3.2.1.1 Case of 3.5, 7 and 14 MHz channel spacing, C_s

It should be noted that Recommendation ITU-R F.1496 provides channel arrangements for systems using 3.5 MHz, 7 MHz, 14 MHz, 28 MHz and 56 MHz C_s to be deployed in this band. These channel arrangements include a guardband of 40 MHz in the lower part of the FS band.

This means that for C_s of 3.5, 7 and 14 MHz, the OoB domain (which extend from 50% of the C_s to 250% of the channel spacing compared to the centre frequency of the FS signal) will be included in the guardband. Then, for systems using 3.5, 7 and 14 MHz C_s only unwanted emissions falling into the spurious domain need to be considered.

Recommendation ITU-R SM.1541 provides mask for OoB emissions in case of FS systems. At this edge of the OoB domain, the attenuation is equal to 40 dBsd. If we assume that the spurious emission level does not exceed the limit at the edge of the OoB domain, the integrated power within the EESS band will be:

For 3.5 MHz C_S:

–10 dBW –10 log (3.5) –40 + 10 log (100) = –35 dB(W/100 MHz)

For 7 MHz C_S:

–10 dBW –10 log (7) –40 + 10 log (100) = –38 dB(W/100 MHz)

For 14 MHz C_S:

–10 dBW –10 log (14) –40 + 10 log (100) = –41 dB(W/100 MHz)

The EESS protection criterion is met in all these cases.

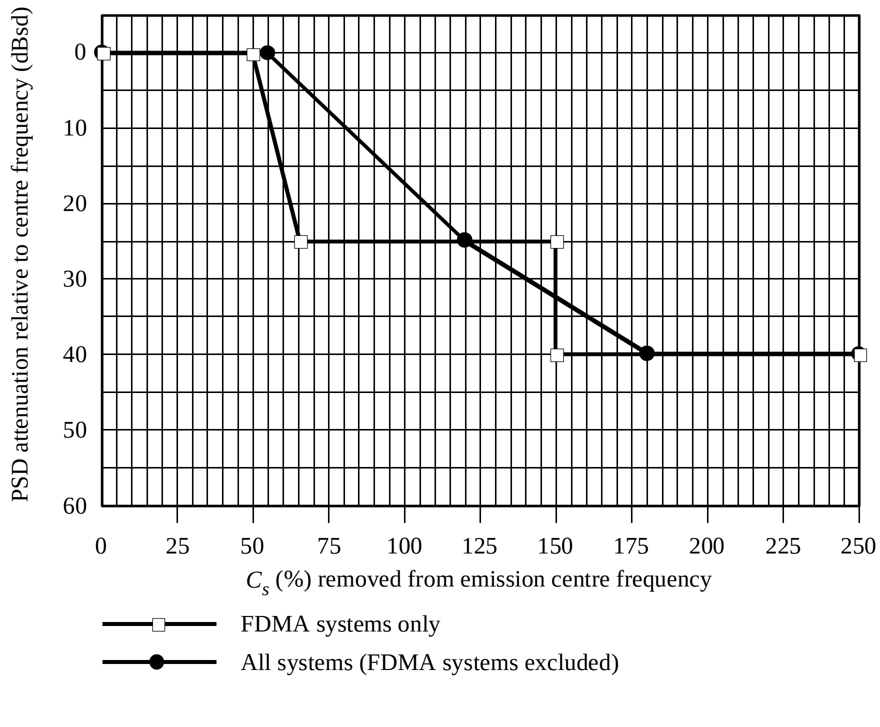
4.3.2.1.2 Case of 28 and 56 MHz, C_s

For unwanted emissions falling into the OoB domain, the OoB masks given in Recommendation ITU-R SM.1541 are considered.

FIGURE 80

Generic spectrum masks for digital FS operating above 30 MHz

(see Table 129)



Note – The masks specified are expressed as function of C_S percentage, however, for systems operating in frequency bands where no radio-frequency channel arrangement is established, the C_S percentage should be substituted by necessary bandwidth percentage or, if applicable by the lower threshold of necessary bandwidth as defined by Recommendation ITU-R SM.329. When not elsewhere specified in ITU-R Recommendations, the necessary bandwidth should be derived from Recommendation ITU-R F.1191.

1633-80

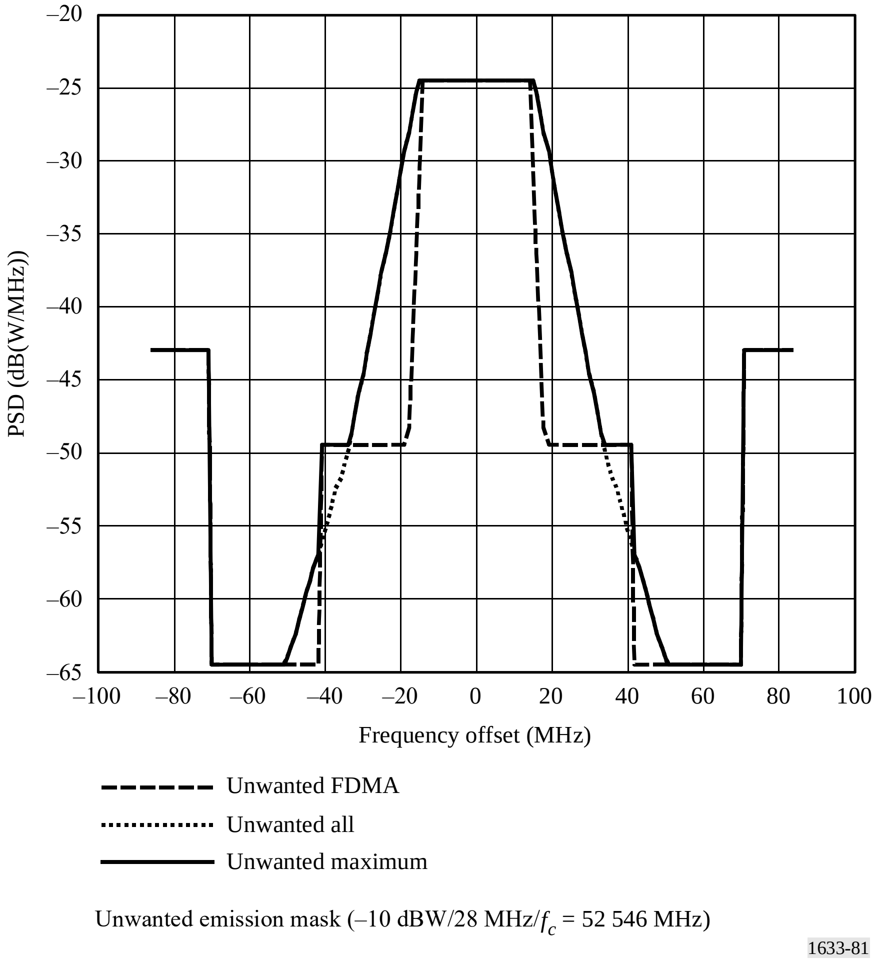
TABLE 129

Digital FS operating above 30 MHz (Reference to Fig. 81)			
All systems (FDMA excluded)		**FDMA systems only**	
Frequency offset (C_s %)	**Attenuation (dBsd)**	**Frequency offset (C_s %)**	**Attenuation (dBsd)**
0	0	0	0
55	0	50	0
120	25	65	25
180	40	150	25
250	40	150	40
		250	40

The corresponding OoB emissions masks are provided in Fig. 81.

FIGURE 81

OoB emission mask for 28 MHz C_s system



In the following analysis, we consider the envelop of the two masks (very worst-case assumption).

Again the power falling into the EESS band may be calculated by assuming that the spurious emission level does not exceed the limit at the edge of the OoB domain. This gives:

For 28 MHz C_s: –44.5 dB(W/100 MHz).

For 56 MHz C_s: –39.5 dB(W/100 MHz).

The EESS protection criterion is met in all these cases.

4.3.2.2 Refinement of the calculation using Recommendation ITU-R SM.1541 and Category B limits (see Recommendation ITU-R SM.329)

4.3.2.2.1 Case of 3.5 and 7 MHz C_s

It should be noted that Recommendation ITU-R F.1496 provides channel arrangements for systems using 3.5 MHz, 7 MHz, 14 MHz, 28 MHz and 56 MHz C_s to be deployed in this band. These channel arrangements include a guardband of 40 MHz within the FS band.

This means that for C_s of 3.5 and 7 MHz, the OoB domain (which extends from 50% of the C_s to 250% of the C_s compared to the centre frequency of the FS signal) will be included in the guardband. Then, for systems using 3.5 and 7 MHz C_s only unwanted emissions falling into the spurious domain need to be considered.

Recommendation ITU-R SM.329 gives information on the levels of unwanted emissions falling into the spurious domain, in particular, this analysis considers levels adopted in Europe and used by some other countries (Category B levels).

In case of FS systems operating with a C_s lower than 10 MHz, there is a step before reaching this –60 dB(W/MHz) value. From an offset of 2.5 × C_s compared to the centre frequency to an offset of 70 MHz, the limit is equal to –50 dB(W/MHz) (or –60 dBW in a 100 kHz reference bandwidth).

In case of FS systems operating with a C_s lower than 10 MHz, to obtain more realistic results we made the assumption that there is a linear decreasing between the –50 dB(W/MHz) point on the mask and the point corresponding to the level of –60 dB(W/MHz).

Figure 82 provides an example of unwanted emissions mask for system using a 3.5 MHz C_s.

Then the power at the edge of the EESS band is calculated (52.6 GHz). This gives:

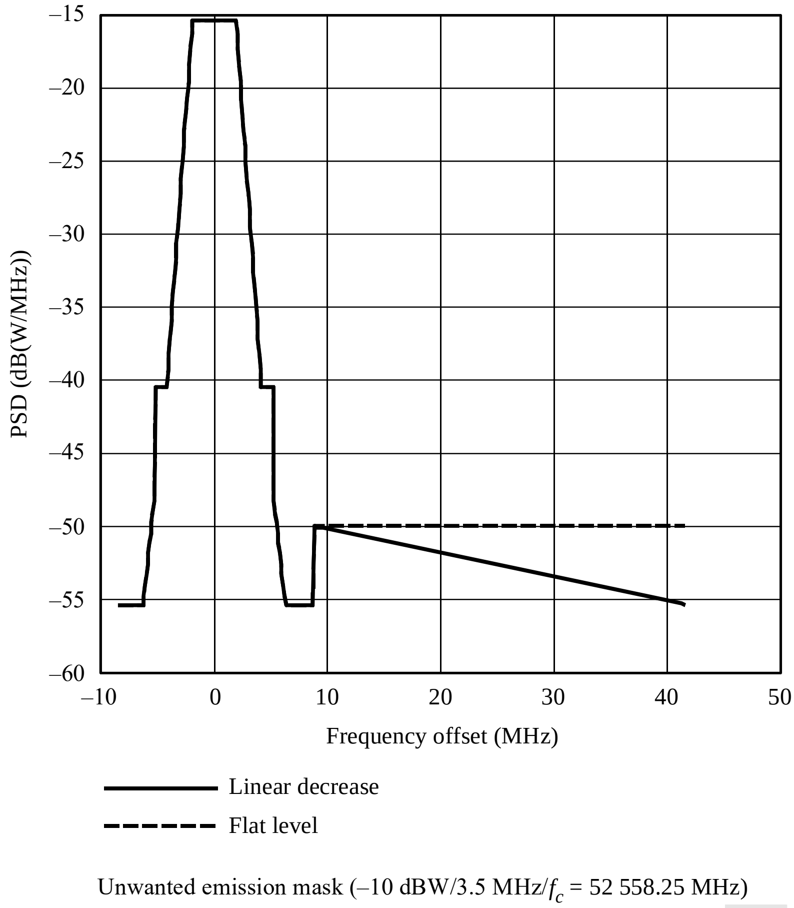
For 3.5 MHz C_s: –55.5 dB(W/MHz).

For 7 MHz C_s: –54.5 dB(W/MHz).

These values are below the minimum one (–53 dB(W/MHz)) given in Tables 126 and 127; this means that the EESS interference criteria will be met. Indeed, since the interfering power should be integrated over a 100 MHz reference bandwidth, the margin is much larger.

FIGURE 82

Level of unwanted emissions for a system using a 3.5 MHz C_s



1633-82

4.3.2.2.2 Case of 14 MHz C_s

It should be noted that Recommendation ITU-R F.1496 provides channel arrangements for systems using 3.5 MHz, 7 MHz, 14 MHz, 28 MHz and 56 MHz C_s to be deployed in this band. These channel arrangements include a guardband of 40 MHz within the FS band.

This means that for C_s of 14 MHz, the OoB domain (which extend from 50% of the C_s to 250% of the C_s compared to the centre frequency of the FS signal) will be included in the guardband. Then, for systems using 3.5 and 7 MHz C_s only unwanted emissions falling into the spurious domain need to be considered.

Recommendation ITU-R SM.329 gives information on the levels of spurious emissions, in particular, this analysis considers levels adopted in Europe and used by some other countries (Category B levels).

For system operating with a C_s higher than 10 MHz, the spurious emission limit is –60 dB(W/MHz).

The level of unwanted emissions falling into a 100 MHz reference bandwidth may directly be calculated:

$$P = -60 \text{ dB(W/MHz)} + 10 \times \log (100 \text{ MHz})$$

$$P = -40 \text{ dB(W/100 MHz)}$$

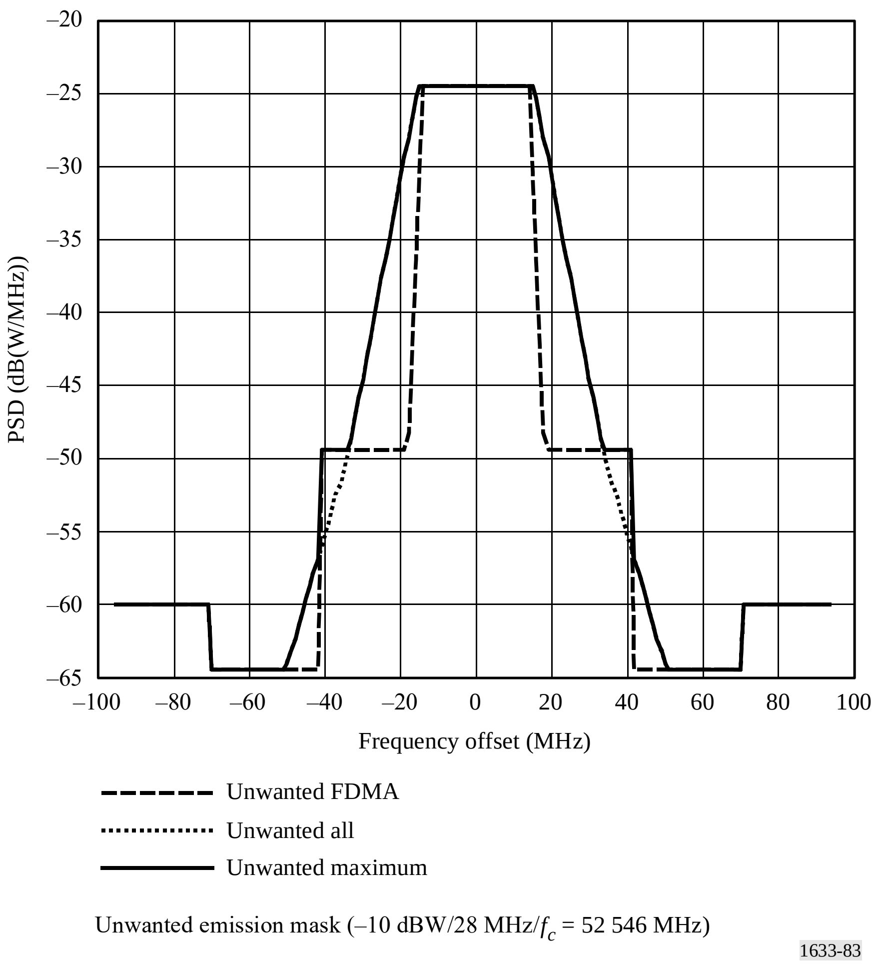
Again the EESS interference criteria are met (–33 dB(W/100 MHz)).

4.3.2.2.3 Case of 28 MHz C_s

For unwanted emissions falling into the OoB domain, the OoB masks given in Recommendation ITU-R SM.1541 was considered (see Fig. 80). OoB emissions masks derived from Recommendation ITU-R SM.1541 are provided in Fig. 83.

FIGURE 83

OoB emission mask for 28 MHz C_s system



In the following analysis, we consider the envelop of the two masks (very worst-case assumption).

Recommendation ITU-R SM.329 gives information on the levels of spurious emissions, in particular, this analysis considers Category B levels. For system operating with a C_s higher than 10 MHz, the spurious emission limit is –60 dB(W/MHz).

Using the OoB mask and the spurious emission level given in Recommendation ITU-R SM.329 (Category B) it is possible to derive the level of unwanted emission that may fall in the band 52.6-52.7 GHz. This gives for a 28 MHz channel spacing operating at −10 dBW (maximum value given in Recommendation ITU-R F.758) −40.5 dBW in a 100 MHz reference bandwidth. The EESS protection is met.

4.3.2.2.4 Case of 56 MHz C_s

The same approach as the previous one is used. This gives for a 56 MHz C_s operating at −10 dBW, −38.7 dBW in a 100 MHz reference bandwidth. The EESS protection is met.

5 Mitigation techniques

5.1 EESS (passive)

No mitigation techniques are needed.

5.2 FS

No additional mitigation techniques need to be considered in the design of FS systems.

5.3 Potential impact

5.3.1 EESS

No impact.

5.3.2 FSS

No impact.

6 Results of the studies

6.1 Summary

In this Annex, it was shown that the level of unwanted emissions of FS systems operating in the band 51.4-52.6 GHz would meet the protection criteria of the EESS service.

6.2 Conclusion

The level of unwanted emissions from FS systems in the band 51.4-52.6 GHz may meet −33 dB(W/100 MHz), which would ensure compatibility between EESS and FS systems at 52.6 GHz.