International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R RS.2260
(09/2012)

Sharing the 31.5-31.8 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive)

RS Series

Remote sensing systems

International Telecommunication Union

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

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REPORT ITU-R RS.2260

Sharing the 31.5-31.8 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive)*

(2012)

1 Introduction

The band 31.3 to 31.8 GHz is allocated on a primary basis to the Earth exploration-satellite service (passive). The intent of this allocation is to provide a 500 MHz band segment for sensing ice morphology to an accuracy of 1 K. To date, only the lower 200 MHz of this band has been extensively used by passive remote sensing systems. It remains to be determined if the upper 300 MHz band can be used on a shared basis with active services.

In Region 2, the band 31.5-31.8 GHz is exclusively allocated to passive services and all emissions are prohibited in the band by RR No. 5.340. However, in Regions 1 and 3, the band 31.5-31.8 GHz is allocated on a secondary basis to the fixed and mobile (except aeronautical mobile) services. Furthermore, RR No. 5.546 allocates the band 31.5-31.8 GHz to the fixed and mobile (except aeronautical mobile) services on a primary basis in 29 administrations in Region 1.

Although the primary terrestrial allocations apply only in Region 1, the passive sensor missions are worldwide so possible interference issues also concern Regions 2 and 3. The most likely location of fixed stations is indicted by RR No. 5.546 which lists administrations that have elevated the fixed service to a primary status. Most of these are in Europe, Western Asia and North Africa in the vicinity of the Mediterranean Sea. The single exception is South Africa, whose southern latitude is similar to the northern latitude of Egypt and the southern Mediterranean Sea. Therefore locations in Europe have been chosen for simulation studies because many of the administrations listed in RR No. 5.546 are in Europe and the latitude of almost all of the administrations in RR No. 5.546 are in the range of southern european latitudes.

Due to the limited primary allocation to the FS in this band (i.e. through a limited country footnote allocation), no specific ITU-R Report or Recommendation provided technical parameters for this band. Therefore, use and deployment practices for analysis were based upon systems that operate in nearby bands, as well as some general technical characteristics and deployment guidelines provided by an administration that does operate such systems. Scenarios and assumptions used to assess the interference potential to the EESS from the FS are varied in a series of simulations to determine the bounds of compatible deployments.

While the band is also similarly allocated to the mobile service, there is no indication that this band either being used or being planned for future use by mobile service operators.

* The Administration of the Islamic Republic of Iran stated that fixed service case studies referred to in the Report do not necessarily represent the operational characteristics of fixed service currently deployed nor it could represent those which would be deployed in the future. Consequently no general conclusion could be drawn with respect of compatibility between fixed service and EESS (passive).

2 Earth exploration-satellite service (passive)

2.1 Applications

The 31.3-31.5 GHz and 31.5-31.8 GHz bands are used to measure water vapour and cloud liquid water. They also examine Earth surface temperature, indicate sea ice, and they are also used in conjunction with 50 to 60 GHz bands for atmosphere temperature sounding. Sounding data is used in computer weather models and atmospheric research.

Sensors in these bands are flown on polar orbiting satellites. These missions offer frequent observations of the Earth, with each satellite providing global daily coverage.

2.2 Passive sensor parameters

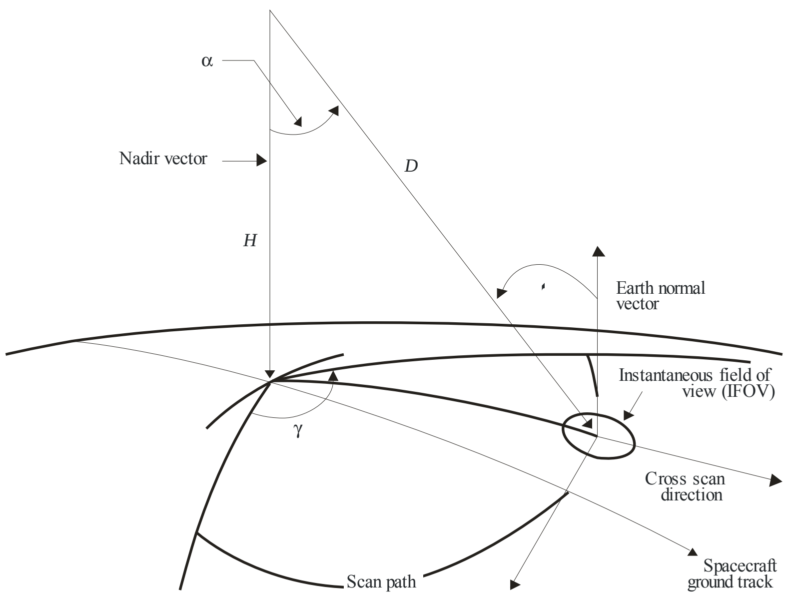
Only the MTVZA-OK sensor uses this band. The characteristics of two other sensors are proposed based upon instruments used in the 31.3 to 31.5 GHz band or the 36 to 37 GHz band, where they would be used as window channels being minimally affected by atmospheric gasses.

2.2.1 Technical characteristics used in the analyses in this Report

Figure 1 shows the geometric configuration of a scanning sensor. The terms in Table 1 are illustrated in this figure. The characteristics for Table 1 have been taken from Recommendation ITU-R RS.1861.

FIGURE 1

Scanning configuration



i = incidence angle at footprint centre
α = angle off nadir
γ = total scan angle
H = height above ground
D = distance from spacecraft to footprint field-of-view centre
R = radius of Earth (not shown in diagram)

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

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

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TABLE 1

EESS (passive) sensor characteristics in the 31.3-31.8 GHz band

	AMSU-A	**ATMS**	**MTVZA-OK**
Sensor type	Nadir scan	Nadir scan	Conical scan
Orbit parameters			
Altitude	833 km	824 km	835 km
Inclination	98.6°	98.7°	98.85°
Repeat period	9 days	9 days	
Sensor antenna parameters			
Number of beams	30 earth fields per 8 s scan period	96 earth fields per scan period	1continuous scan
Maximum beam gain	36 dBi	31.8 dBi	Estimated 39.9 dBi
Reflector diameter	0.30 m	0.203 m	0.6 m
Polarization	V	QV	H, V
–3 dB beamwidth	3.3°	5.2°	Estimated at 2.06°
Off-nadir pointing angle	±48.33° crosstrack	±52.725° crosstrack	55.4°
Beam dynamics	8 s scan period	8/3 s scan period cross track	2.88 s scan period
Incidence angle at Earth	Variable	Variable	65°
–3 dB beam dimensions (diameter)	49.1 km		
Instantaneous field of view	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km	Nadir FOV: 74.8 km Outer FOV: 323.1.1 × 141.8 km	30 km × 69 km
Approximate nadir pointing IFOV area (based upon altitude and antenna gain)	1 856 km^2	4 400 km^2	Estimated to be 1 657 km^2 at incident angle of 65^o
Main beam efficiency	95%	95%	> 95%
Sensor receiver parameters			
Sensor integration time	158 ms	18 ms	Continuous
Channel bandwidth	180 MHz centred at 31.4 GHz	180 MHz centred at 31.4 GHz	500 MHz centred at 31.55 GHz

2.2.2 Possible future characteristics derived from Recommendation ITU-R RS.1028-2[**]

Recommendation ITU-R RS.1028-2[**] specifies two values for radiometric resolution; $\Delta T_e = 0.2$ K for sharing conditions circa 2003 and $\Delta T_e = 0.05$ K for scientific requirements that are technically achievable by sensors in the next 5-10 years. Since it is now several years past 2003, the second radiometric resolution, $\Delta T_e = 0.05$ K, will be considered in this document.

The interference threshold in Recommendation ITU-R RS.1029-2[**] has already been updated to accommodate a new sensitivity level.

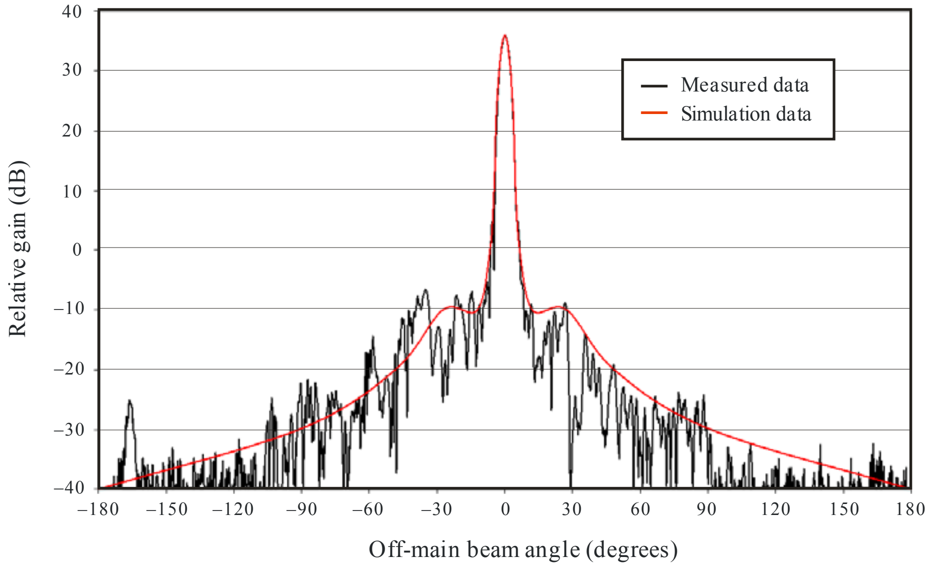
[**] Replaced by Recommendation ITU-R RS.2017.

2.2.3 Antenna characteristics

The antenna main beam gains are found in the Table 1. The antenna gain pattern used in AMSU simulations is given in Fig. 2. Figure 3 represents the gain pattern for ATMS, while Fig. 4 is for MTVZA-OK. Figure 4 was derived from Recommendation ITU-R RS.1813.

FIGURE 2

AMSU-A Channel 2 (31.5 GHz)
Beam Position 15 – 1.65 degrees off nadir



Report RS.2260-02

FIGURE 3

ATMS Channel 2 (31.5 MHz)
Beam Position 48 – 1.11 degrees off nadir

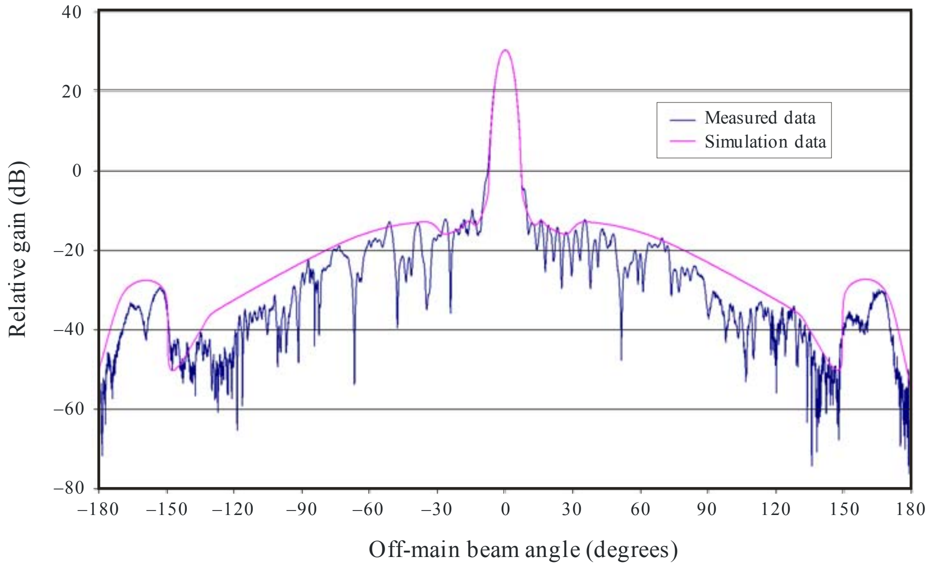


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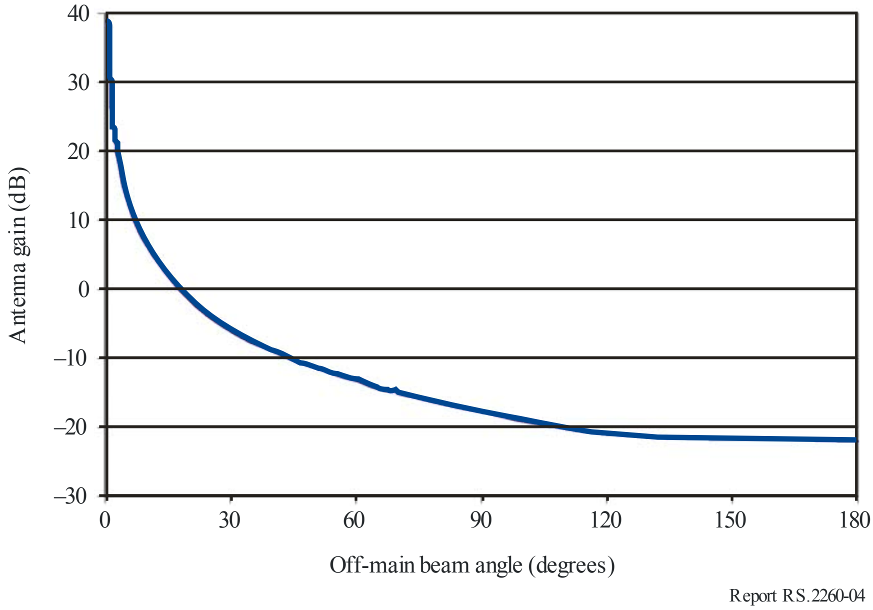
FIGURE 4

Antenna pattern from Recommendation ITU-R RS.1813 used for the MTVZA-OK



3 Active service parameters

3.1 Fixed service

In this study only a point-to-point type fixed service (FS) system was modelled, because only these systems were presented in the reference source.

These characteristics are used in the power density static analysis in § 6.

TABLE 2

P-P terrestrial FS station parameters for 31.5-31.8 GHz band

Parameter	FS
Maximum transmitter power	–20 to –10 dBW Typical: –18 dBW
Antenna gain	27 to 42 dBi Typical: 36 dBi
Antenna diameter	0.15 to 0.6 m Typical: 0.3 m
Antenna type	Parabolic and planar
Antenna pattern	Rec. ITU-R F.1245-1
Ratio of antenna diameter over the wavelength (calculated)	15.7 to 63 Typical 31.5
Respective antenna side-lobe gain from Rec. ITU-R F.1245-1 (calculated)	–9.0 dBi to –12.0 dBi Typical –10.5 dBi
e.i.r.p. (maximum)	7 to 32 dBW Typical: 15 dBW
Channel spacing	28 MHz

Although no definitive information is available on the fixed service deployment in the particular band, the technical parameters used are provided by an administration operating such systems in this band and consistent with systems in nearby bands in Recommendation ITU-R F.758-4, which specifically provides fixed service parameters to be used in developing sharing criteria. It is estimated that there are around 2 000 stations in Region 1 operating in the 31.5-31.8 GHz band, mainly spread around major cities. A number of different deployment densities are modelled. Six scenarios address widely spaced deployments in 2 000 000 km^2 areas and another scenario addresses dense deployment in urban areas.

3.2 Mobile (except aeronautical mobile)

No characteristics exist for systems operating in this service and no indication of its use was found in the 31.5-31.8 GHz band.

4 Interference criteria

4.1 Sensor interference threshold

Recommendation ITU-R RS.1029-2 provides permissible interference levels and reference bandwidths for use in any space borne passive sensor interference assessment or sharing studies. The permissible interference level for the 31.5-31.8 GHz band is –166 dBW in a reference bandwidth of 200 MHz as of 2003. When the permissible interference level is applied to a sensor with the allocated 300 MHz bandwidth, the interference level for passive sensors in operation is –164.24 dBW.

4.2 Sensor data availability criterion

Recommendation ITU-R RS.1029-2 also specifies that these interference levels should not be exceeded for more than 0.01% of sensor viewing area, described as a measurement area on the Earth of 2 000 000 km^2 for the 31.5-31.8 GHz band.

5 Simulation studies

Typically, passive sensors are flown on high inclination low Earth orbit (LEO) satellites, and these sensors have been shown to be sensitive to the cumulative effects of interference from other services. An effective method to study these effects is through a dynamic simulation of a sensor's operation and the interaction with realistic representations of other systems and comparing the results to the interference criteria as recommended in Recommendation ITU-R RS.1029.

Since high inclination satellites do not cover the same region on every orbit, it is necessary to simulate a sufficient amount of time to ensure the appropriate coverage of the region. Also, there are several different types of sensors and it is important to consider when the sensor footprint is within a specified area. In these cases, a satellite orbits the earth a sufficient number of days such that an area in question is adequately covered.

5.1 Simulation Study 1

5.1.1 Simulation Study 1 FS station distribution

This first simulation test area is a rectangular 2 000 000 km^2 area defined by 56.5° N latitude, 13° E longitude, 45° N latitude 35.23° E longitude. This area encompasses four nations where the 31.5-31.8 GHz band is allocated on a primary basis to the fixed service (FS) as identified in RR No. 5.546. The four nations selected in this region cover 647 155 km^2, or 32.3% of the test area. The FS station deployment strategy employed for this study is a simple 50 km grid for each country. The test area and FS deployment is shown in Fig. 5. While deploying FS stations evenly may not be an accurate representation of this particular region, it does provide a general sense of the interference impact of FS stations operating in this band.

5.1.2 Simulation Study 1 configuration

All of the stations employ the typical configuration described in Table 2 with horizontal pointing and 0° elevation.

The study is a dynamic simulation with a non-GSO passive sensing satellite, AMSU-A, as described in Table 2. The simulation time increment used is 1 s and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area.

Additional Simulation Study 1 assumptions:

– All FS stations are always transmitting;

– All FS stations are co-frequency;

– FS stations are pointed randomly.

FIGURE 5

Simulation Study area

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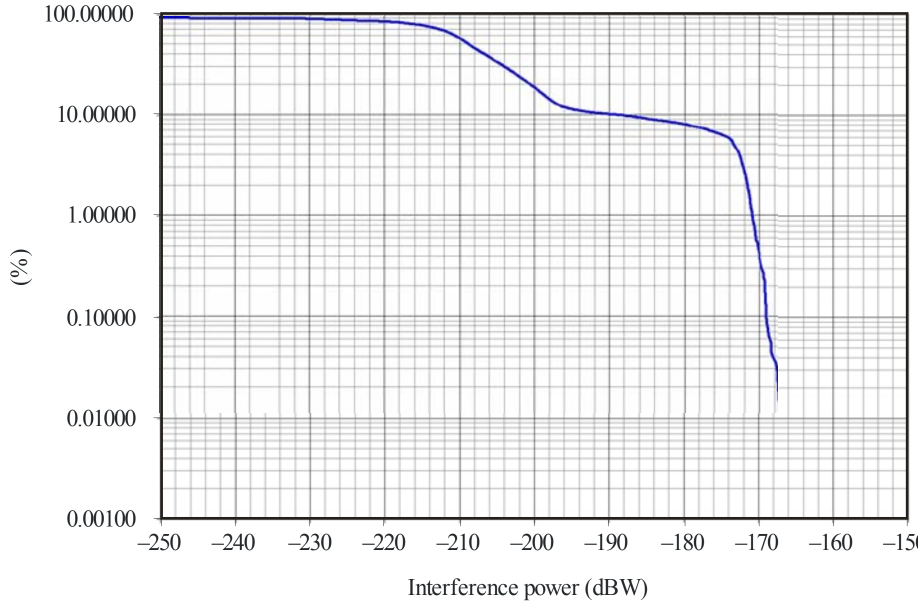
FIGURE 6

FS interference into AMSU-A



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5.1.3 Simulation Study 1 results

The simulation results in Fig. 6 show that the interference threshold for a future passive sensor sensor's interference threshold is –164.24 dBW is not exceeded when the sensor footprint is within the measurement area.

5.2 Simulation Study 2

5.2.1 Simulation Study 2 FS station distribution

Another approach is to deploy FS stations based on population. Using the same test area as Simulation Study 1, a rectangular 2 000 000 km^2 area defined by 56.5° N latitude, 13° E longitude, 45° N latitude 35.23° E longitude, cities with a population of at least 100 000 people in or near the test area were considered.

A selected city was assigned a random number of links from 1 to 20, where a link consists of two stations pointing at each other in order to emulate the two-way functionality of typical FS systems. These cities and locations are not limited to the nations used in Simulation Study 1. The first station in a link was randomly placed within 20 km of the city centre, and the second station in a link was randomly placed within 20 km of the first station.

This method led to the selection of 188 cities and the creation of 3 916 FS stations in and around the test area; these stations are shown in Fig. 7.

5.2.2 Simulation Study 2 configuration

The FS stations created are those described by the typical data shown in Table 2 and similar to those used in Simulation Study 1 with all of the stations employing a single transmit antenna with a 36 dBi gain and a maximum e.i.r.p. of –18 dBW.

Additional Simulation Study 2 assumptions:

– All FS stations are always transmitting;

– All FS stations are co-frequency.

FIGURE 7

Simulation Study 2 test area

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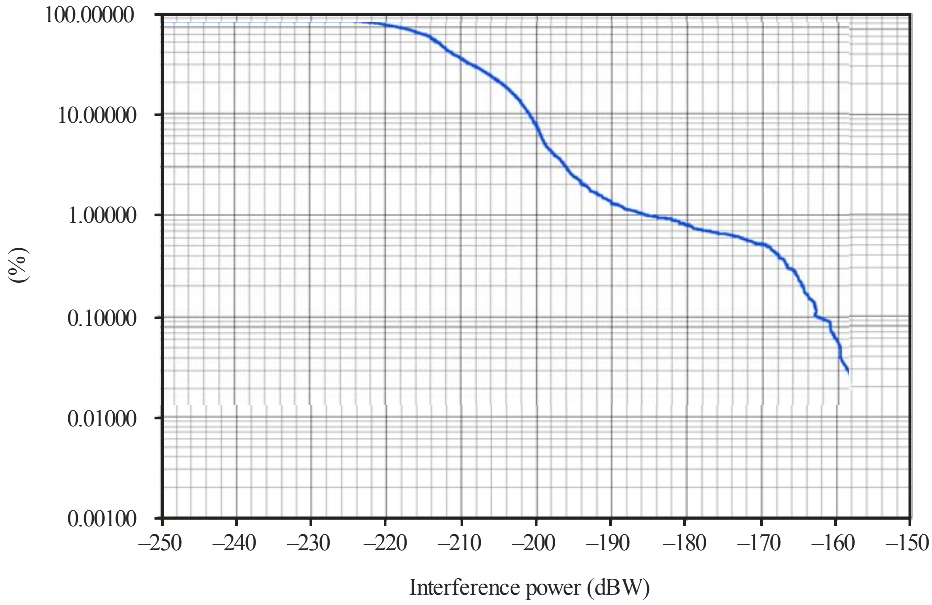
The study is a dynamic simulation with a non-GSO passive sensing satellite as described in Table 1. The simulation time increment used is 1 s, and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area.

FIGURE 8

Interference from random city based FS deployment to AMSU-A



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5.2.3 Simulation Study 2 results

The results of Simulation Study 2, shown in Fig. 8, show that the current sensor interference criteria of –164.24 dBW is exceeded 0.167% of the time studied, which exceeds the interference criteria given in Recommendation ITU-R RS.1029.

5.3 Simulation Study 3

5.3.1 Simulation Study 3 FS station distribution

Simulation Study 3 uses the same FS station distribution as Simulation Study 2, and is described in § 6.2.1.

5.3.2 Simulation Study 3 configuration

The FS stations use the parameters in Table 2.

Channel spacing and bandwidth are randomly assigned for each fixed service station, histograms of the channel spacing and bandwidths are in Fig. 9. This simulation is run five times, FS stations transmitting at –20 dBW, –30 dBW, –40 dBW and –50 dBW.

Simulation Study 3 assumptions:

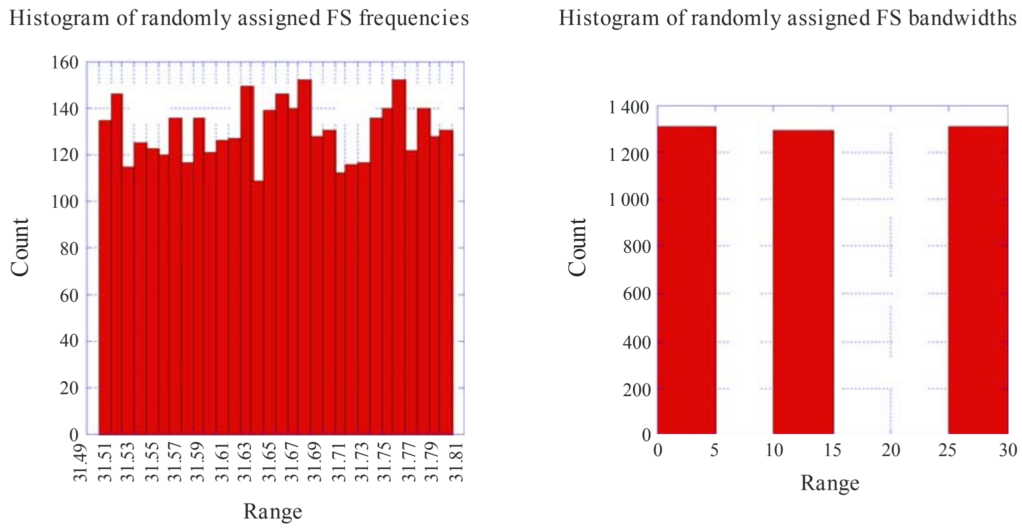
– All FS stations are always transmitting;

– All FS stations are transmitting at the same power;

– All FS stations are assigned frequencies within the 31.5-31.8 GHz band.

FIGURE 9

FS station frequencies and bandwidths used in the simulation



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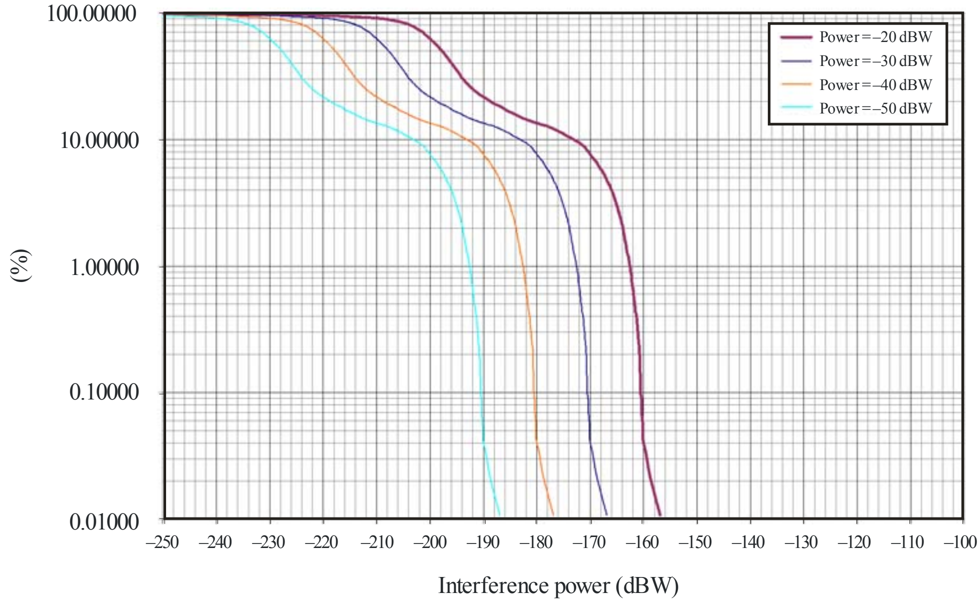
The study is a dynamic simulation with a non-GSO passive sensing satellite as described in Table 1. The simulation time increment used is 1 s, and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area.

FIGURE 10

Interference from random city based FS deployment to AMSU-A



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5.3.3 Simulation Study 3 results

The results of the simulation are shown in Table 10. The simulation with FS stations transmitting at a power of –20 dBW exceeds the sensor interference criteria of –164.24 dBW approximately 2.3% of the time studied. These numbers improve as the FS transmit power was reduced, FS stations transmitting at a power of –30 dBW meet the current sensor interference criteria of –164.24 dBW for over 0.01% of the time.

5.4 Simulation Study 4

5.4.1 Simulation Study 4 FS station distribution

Another alternate population based FS deployment approach is used in Simulation Study 4. Using the same test area as Simulation Study 1, a rectangular 2 000 000 km^2 area defined by 56.5° N latitude, 13° E longitude, 45° N latitude 35.23° E longitude, cities with a population of at least 100 000 people in or near the test area were considered.

A selected city was assigned a random number of links from 1-20, where a link consists of two stations pointing at each other in order to emulate the two-way functionality of typical FS systems. These cities and number of links per city are identical to those used in Simulation Study 3. The first station in a link was randomly placed within 10 km of the city centre, and the second station in a link was randomly placed within 10 km of the first station, in both instances the 10 km is a maximum limitation, and a majority of stations were selected within 2 km of the city centre or first station in a link pair. The range distribution of these stations is shown in the histogram of Fig. 11.

This method led to the selection of 188 cities and the creation of 3 916 FS stations in and around the test area; these stations are shown in Fig. 12, based on the cities selected and the FS link distribution, there is an average population of 65 794.48 per FS link.

FIGURE 11

Simulation Study 4 FS link ranges

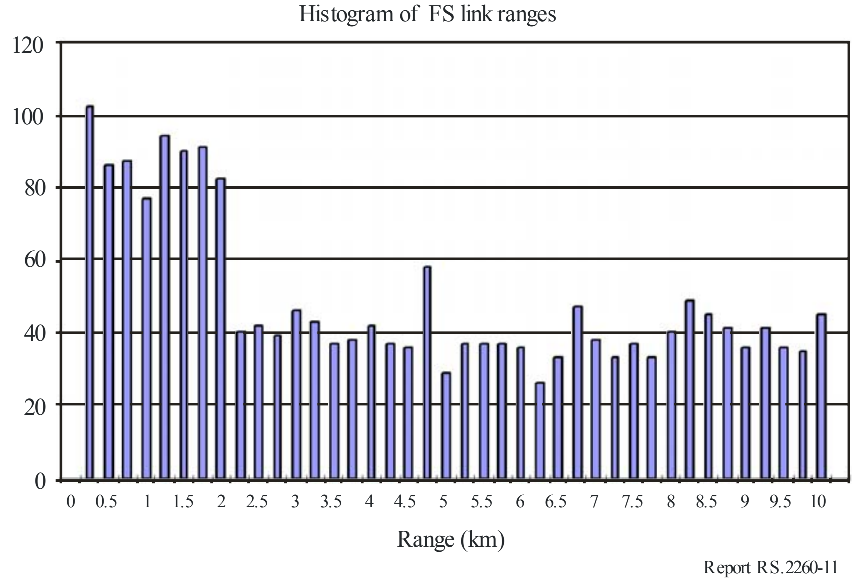
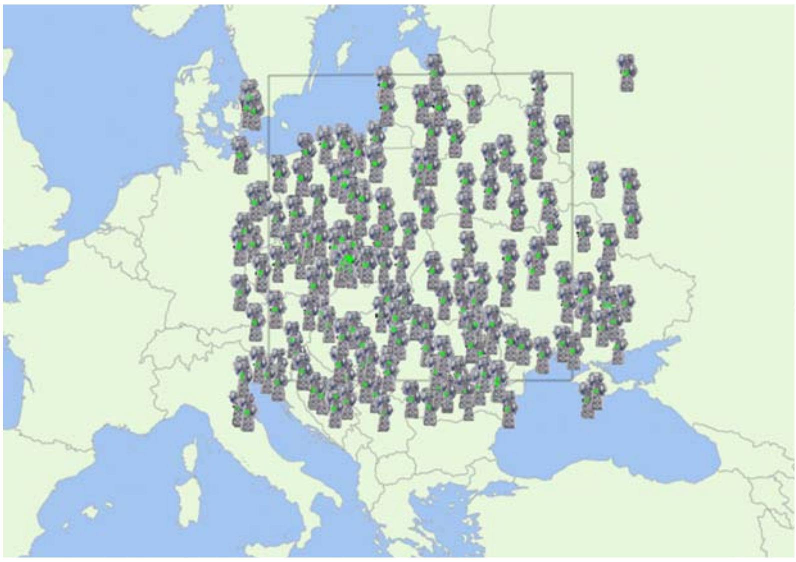


FIGURE 12

Simulation Study 4 FS station locations



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5.4.2 Simulation Study 4 configuration

The FS stations use the parameters in Table 2. Channel spacing and bandwidth are randomly assigned for each fixed service station, histograms of the channel spacing and bandwidths are in Fig. 13.

Simulation Study 4 assumptions:

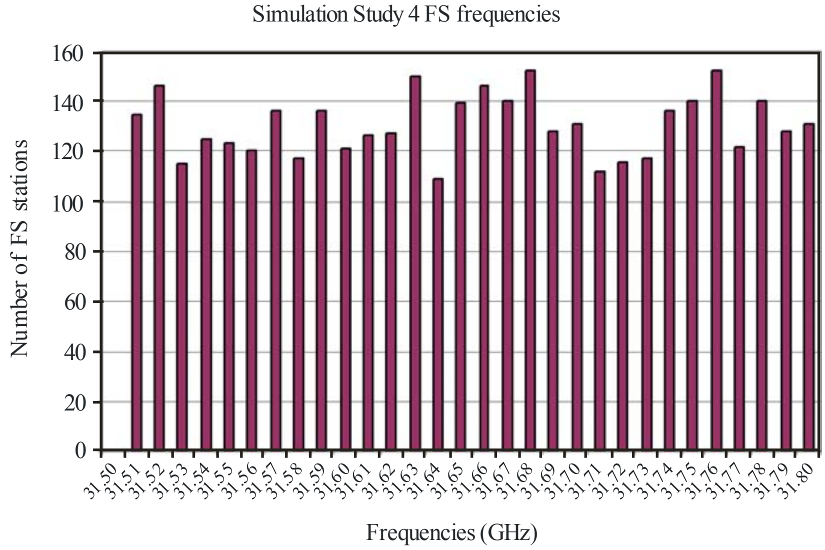
– All FS stations are always transmitting;

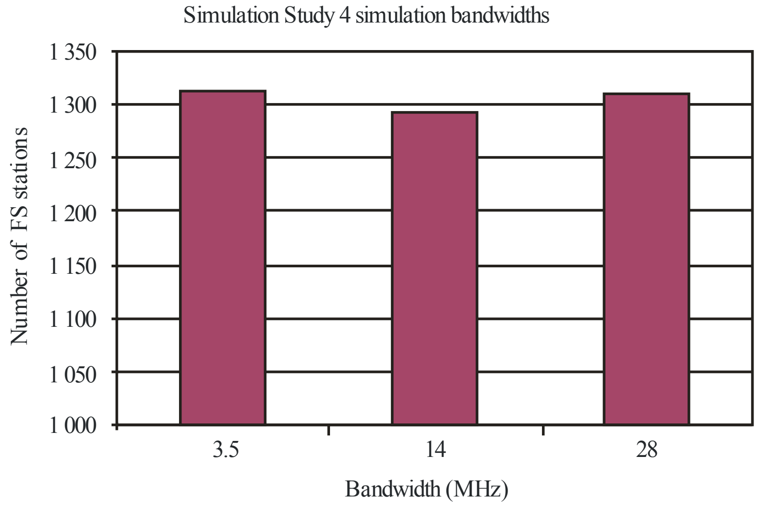
– All FS stations are assigned frequencies within the 31.5-31.8 GHz band;

– Terrain and buildings are not taken into account.

FIGURE 13

Station frequencies and bandwidths used in Simulation Study 4





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The study is a dynamic simulation with a non-GSO passive sensing satellite as described in Table 1. The simulation time increment used is 1 s, and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area.

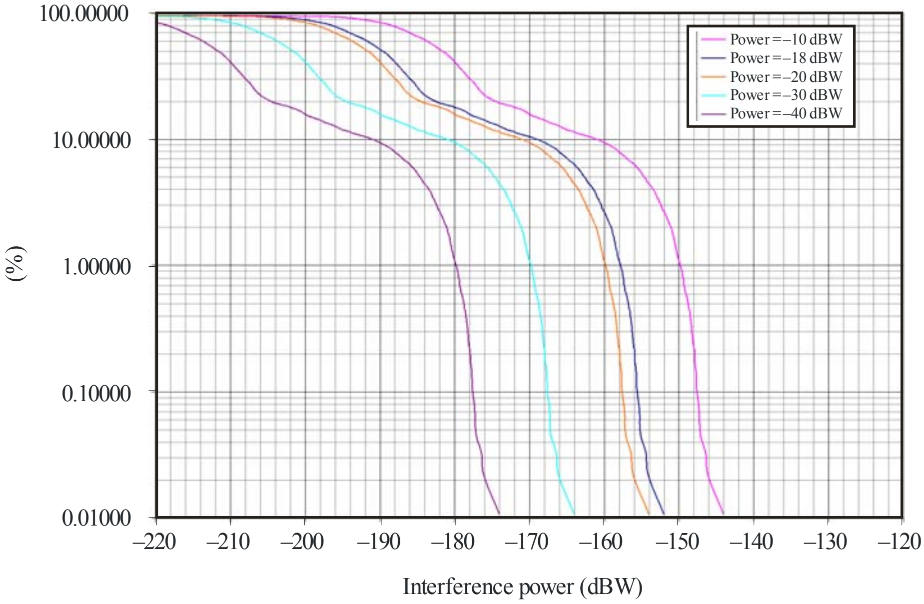
The simulation is repeated with the same FS stations configurations but with the links transmitting at different power levels, –10 dBW, –18 dBW, –20 dBW, –30 dBW and –40 dBW.

5.4.3 Simulation Study 4 results

The results of the simulation are shown in Fig. 14. For the simulations FS stations transmitting at –20 dBW the current sensor interference criteria of –164.24 dBW is experienced approximately 4.6% of the time studied. The trend of these results is that the sharing situation improves as the FS transmit power is reduced, the simulation with FS stations transmitting at a power of –30 dBW experience interference 0.025% of the time studied, whereas the simulation with FS stations transmitting at a power of –40 dBW meets the interference criteria.

FIGURE 14

Simulation Study 4 interference results



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5.5 Simulation Study 5

5.5.1 Simulation Study 5 FS station distribution

As the FS deployment density is an important factor in determining interference into an EESS (passive) sensor, Simulation Study 5 introduces another population based FS deployment scenario. Using the same test area as Simulation Study 1, a rectangular 2 000 000 km^2 area defined by 56.5° N latitude, 13° E longitude, 45° N latitude 35.23° E longitude, cities with a population of at least 100 000 people in or near the test area were considered.

A selected city was assigned a random number of links from 1-10, where a link consists of two stations pointing at each other in order to emulate the two-way functionality of typical FS systems. These cities and number of links per city are identical to those used in Simulation Study 3. The first station in a link was randomly placed within 10 km of the city centre, and the second station in a link was randomly placed within 10 km of the first station, in both instances the 10 km is a maximum limitation, and a majority of stations were selected within 2 km of the city centre or first station in a link pair. The range distribution of these stations is shown in the histogram of Fig. 15. This method led to the selection of 188 cities and the creation of 1 910 FS stations in and around the test area; these stations are shown in Fig. 16, based on the cities selected and the FS link distribution, there is an average population of 134 896 per FS link.

FIGURE 15

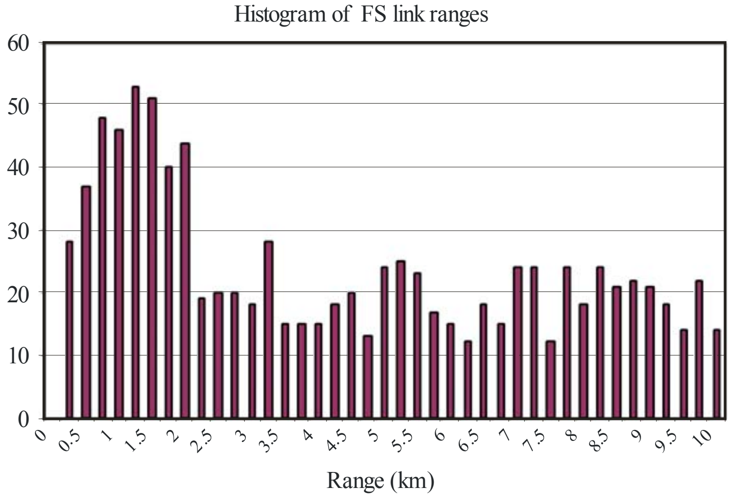

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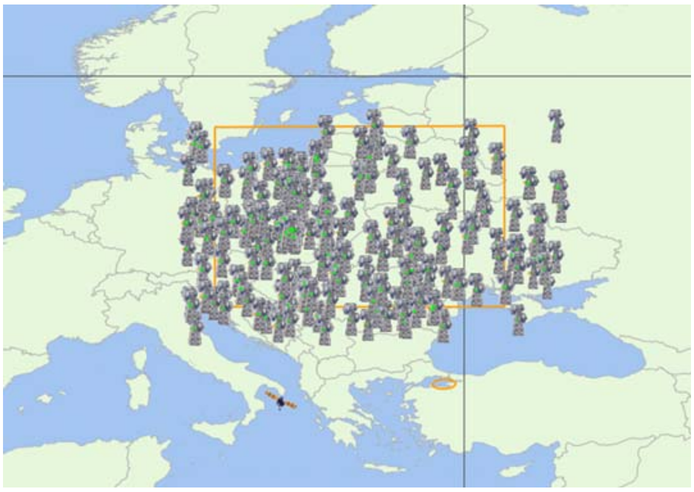
FIGURE 16



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5.5.2 Simulation Study 5 configuration

The FS stations use the parameters in Table 2. Channel spacing and bandwidth are randomly assigned for each fixed service station, histograms of the channel spacing and bandwidths are in Fig. 17.

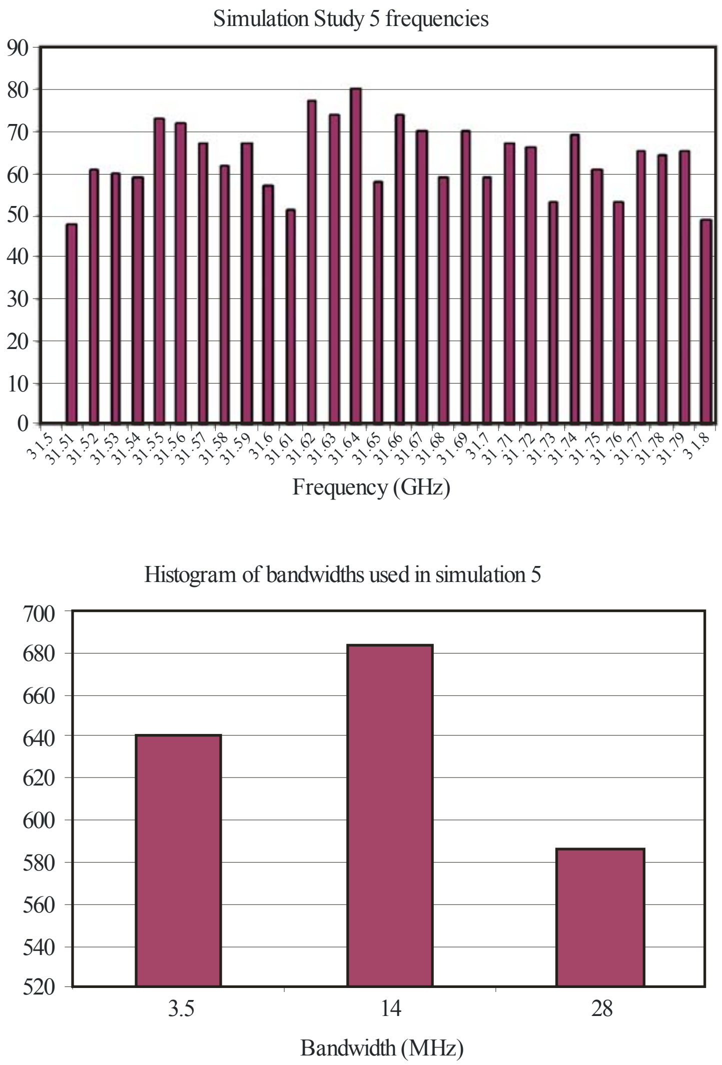
Simulation Study 4 assumptions:

– All FS stations are always transmitting;

– All FS stations are assigned frequencies within the 31.5-31.8 GHz band;

– Terrain and buildings are not taken into account.

FIGURE 17



Report RS.2260-17

The study is a dynamic simulation with a non-GSO passive sensing satellite as described in Table 1. The simulation time increment used is 1 s, and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area. The simulation is repeated for different FS power levels, 15 dBW, 10 dBW, 5 dBW, 0 dBW, –5 dBW,–25 dBW, –30 dBW, and –35 dBW.

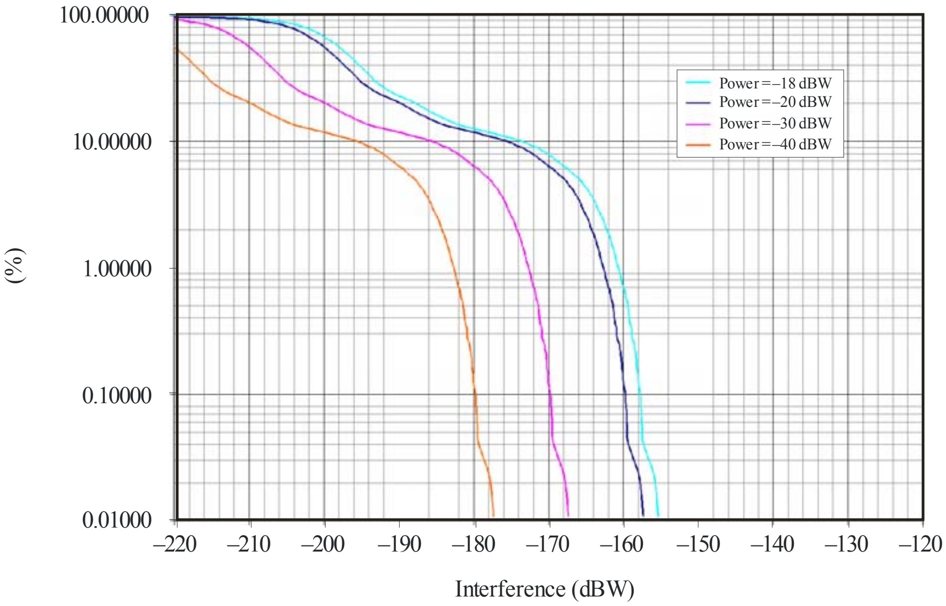
5.5.3 Simulation Study 5 results

The results of the simulation are shown in Fig. 18. The simulations with FS stations transmitting at a power of –20 dBW meets the sensor interference criteria of –164.24 dBW approximately 1.7% of the time studied. The trend of these results is that the sharing situation improves as the FS transmit power is reduced, with FS stations transmitting at a power of –30 dBW meeting the interference criteria.

FIGURE 18

Interference from random city based FS deployments to AMSU-A

(FS limit = 10 stations per city)



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5.6 Simulation Study 6

5.6.1 Simulation Study 6 FS station distribution

As the FS deployment density is an important factor in determining interference into an EESS (passive) sensor, Simulation Study 6 introduces another population based FS deployment scenario. Using the same test area as Simulation Study 1, a rectangular 2 000 000 km^2 area defined by 56.5° N latitude, 13° E longitude, 45° N latitude 35.23° E longitude, the FS stations are all configured as in Table 2 each simulation has decreasing numbers of stations deployed in order to determine the sensitivity to the FS deployment density.

FS station deployment was based upon city population size, but the number of FS links and maximum number of links per city were varied for each simulation in order to vary the total number of FS stations in an individual simulation. Simulations with 868, 344, 112, 48, and 8 FS stations were run.

5.6.2 Simulation Study 6 configuration

Simulation Study 6 assumptions:

– All FS stations are always transmitting;

– All FS stations are assigned frequencies within the 31.5-31.8 GHz band;

– Terrain and buildings are not taken into account.

The study is a dynamic simulation with a non-GSO passive sensing satellite as described in Table 1 and FS stations described in Table 2. The simulation time increment used is 1 s, and the simulation is for duration of 7 days. Output data is taken from the simulation and is further processed, by calculating spacecraft heading and sensor angle, to eliminate any data point where the sensor footprint does not fall within the simulation test area. Each FS station deployment simulation is run independently.

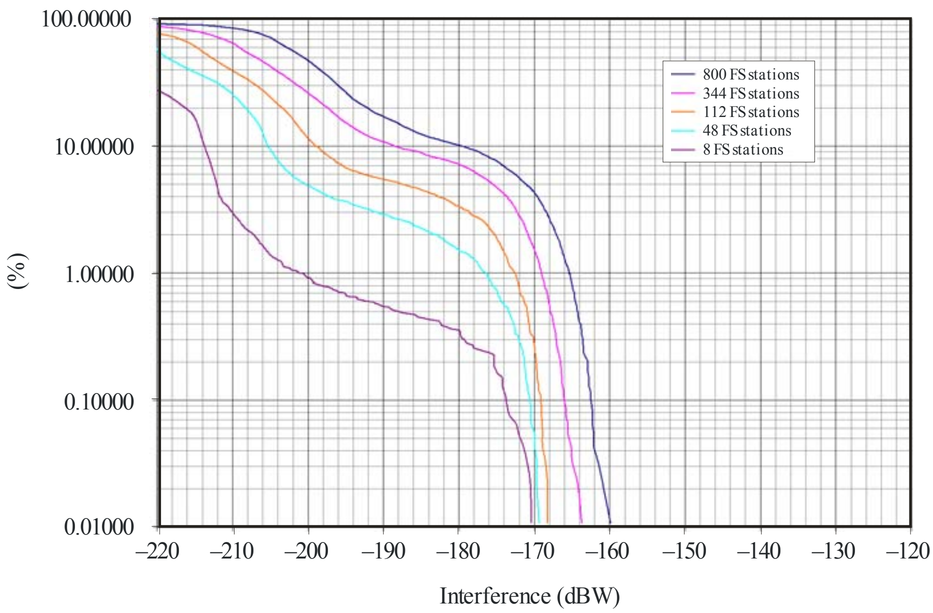
5.6.3 Simulation Study 6 results

The results of Simulation Study 6 are shown in Fig. 19. The interference received by AMSU-A in the simulation with 800 FS stations exceeds the –164.24 dBW criteria 0.4% of the time studied and the simulation with 344 FS stations exceeds the –164.24 dBW interference criteria approximately 0.005% of the time studied. Of the FS deployment densities selected for this study, the 112, 48 and 8 station scenarios meet the criteria.

FIGURE 19

Interference from random city FS deployment to AMSU-A

(Varying FS deployment densities)



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5.7 Summary of Simulations 1 to 6

The preliminary results from Simulation Study 1 and Simulation Study 2 show that the cumulative interference from the fixed service exceeds the interference criteria as given in Recommendation ITU-R RS.1029-2. While Simulation Study 2 exhibits sensitivity to the increased number of fixed service stations over Simulation Study 1, there is likely an overestimation of interference since both studies were conducted with co-frequency transmitters. Results from Simulation Study 3 demonstrate that the combined effects of the FS stations offer more interference to the passive sensor when the FS station transmissions are concentrated into smaller bandwidths than in the Studies 1 and 2. Decreasing the power of the stations reduces this effect, and a sufficient reduction in transmitter power would result in the FS stations meeting the interference criteria.

Simulation Study 4 and Simulation Study 5 show a reduction of interference from Simulation Study 3 based on shorter range FS deployments, and in the case of Simulation Study 5, fewer FS stations. With sufficiently low amounts of power emitted from the FS stations, the interference criteria can be met in both studies. Simulation Study 6 further investigates the sensitivity of FS station deployment using FS station characteristics in Table 2. This study uses fewer FS stations within the test area selected, but shows that the interference criteria can be met with higher power FS stations than in Simulation Studies 3, 4 and 5, but with much fewer stations.

TABLE 3

Summary of analysis results

Scenario	Type of investigation	Power toward sensor including –10 dBi side-lobe antenna gain	Number of stations	Power density dB(W/km^2)	Power in IFOV	Interference probability
1	Baseline even distribution within 4 countries with stations in 50 km grid	–28 dBW	337	–62 dB(W/km^2)	–28 dBW	0.0%
2	Increased number of fixed stations	–28 dBW	3 916	–54 dB(W/km^2)	–20 dBW	0.167%
3	Stations concentrated into smaller bandwidths and power reduced	–20 dBW –30 dBW –40 dBW –50 dBW	3 916		–15 dBW –25 dBW –35 dBW –45 dBW	2.3% < 0.01% < 0.01% < 0.01%
4	Shorter range deployments and power reduction	–10 dBW –18 dBW –20 dBW –30 dBW –40 dBW	3 916	–29.7 dB(W/km^2) –37.7 dB(W/km^2) –39.7 dB(W/km^2) –49.7 dB(W/km^2) –59.7 dB(W/km^2)	–4.3 dBW –12.4 dBW –14.4 dBW –24.4 dBW –34.4 dBW	12% 7% 4.6% 0.025% < 0.01%
5	Shorter range deployments, fewer stations and power reduction	–18 dBW –20 dBW –30 dBW –40 dBW	1 910		–8 dBW –10 dBW –20 dBW –30 dBW	5% 1.7% < 0.01% < 0.01%
6	Reduction in number of stations		800 344 112 48 8		–21.3 dBW –23.3 dBW –28 dBW – –	0.4% 0.005% < 0.01% < 0.01% < 0.01%

From the summary given in Table 3, the interference probability criterion is met (< 0.01%) when the power in an IFOV is equal to or below –25 dBW and the power per individual transmitter is below –30 dBW (Scenario 3). Also the criterion is met when the number of transmitters is below 344 (Scenario 6). This leads to a consideration of power density.

6 Power density considerations

The analysis that follows will address interference concentrated in cities rather than distributed over an area as large as 2 000 000 km^2. This shift in the focus of the investigation is guided by the fact that the deployment of fixed terrestrial stations will be around urban areas. The analysis will consider all three sensors given in Table 1 and determine which is most sensitive to interference.

6.1 Interference probability criterion

The approach to investigating the interference probability in the previous scenarios was to run long simulations, plot probability density functions, and compare the probability and power interference threshold to the plot in the distribution. The following analyses will determine the probability from geometry. This is possible because the analyses will investigate concentrations of emitters in the relatively small urban areas (2 000 km^2 compared to 2 000 000 km^2).

Simulations run over long time periods may incorrectly estimate interference. The polar orbiting sensor has coverage gaps near the equator. If a source of interference is in the gap, no data is taken and no interference occurs. Similarly the swathes from the sensor overlap at the higher latitudes so a single location for interference could cause interference in adjacent swaths. However the sensor also receives data twice so no additional data is affected yet the simulation may count the interference twice.

6.1.1 IFOV size relative to criterion

A simple model is composed of evenly spaced elements, each element representing an instrument field of view (IFOV) of the sensor. If the area is 2 000 000 km^2, then 0.01% of the area is 200 km^2. That is, there are 10 000 segments each 200 km^2 and the interference criterion is exceeded if more than one of these segments contains interference power above the threshold of the sensor.

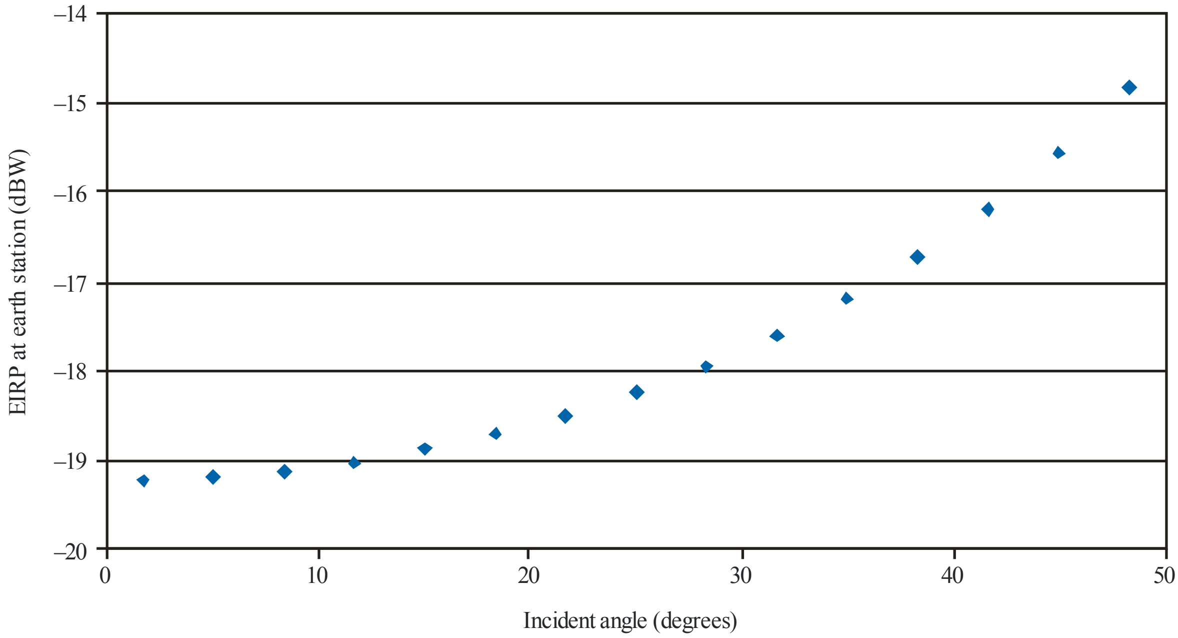
The area of a single IFOV from Table 1 is 1 856 km^2 for the AMSU, 4 393 km^2 for the ATMS and 1 625 km^2 for the MTVZA-OK. All these areas are larger than 200 km^2 so the interference probability criterion would be violated for any of these instruments if any of the IFOVs receives interference power over the threshold. However, as will be shown, the IFOVs of the sensor have different sensitivity levels. If only 1 in 10 of the IFOVs is sensitive to an interference level, then interference to a 2 000 km^2 IFOV just meets the interference criterion.

6.1.2 Relative sensitivity of IFOV

Different IFOVs have different interference sensitivities because it takes more power at greater distance to produce the same power level in the receiver. Using a simulation for the AMSU, the terrestrial powers at each off-nadir angle that just caused receive power in the sensor at the threshold are shown in Fig. 20.

FIGURE 20

E.i.r.p. at terrestrial station just equal to interference threshold



In Fig. 20, each dot represents a position of the sensor antenna for each IFOV. For the IFOV position with the lowest incident angle (and thus the lowest off-nadir antenna pointing angle) an e.i.r.p. of –19.23 dBW will just cause a received interference power of –164.24 dBW in the sensor. For the furthest out IFOV it would take a power of –14.73 dBW to achieve the interference threshold at the sensor. For the second least incident angle it would take an e.i.r.p. of –19.19 dBW. Therefore an interference signal less than –19.19 dBW but over –19.23 dBW would exceed the interference threshold at only one IFOV incident angle.

If interference can occur at any IFOV incident angle of the AMSU, it equates to a probability of (1 856 km^2/2 000 000 km^2)*100% = 0.0928%. However if it only occurs in the 2 most nadir IFOVs of 30 sensor IFOVs the probability of interference is reduced to 0.0928 %*(2/30) = 0.006187%. This would meet the criterion.

6.1.3 Criterion applied to power density

Unlike the wide distribution of emitters already investigated, interference from cities will consist of many emitters in or near the IFOV. Interference in this case is a function of power density.

Interference power density can be determined with the following equation:

$$\alpha \frac{N}{A} p_t = \frac{p_r l_2 \cos\theta_i}{\lambda^2}\left(\frac{64}{\pi}\right) \tag{1}$$

where:

p_r: is the maximum interference level of (–164.24 dBW in 300 MHz)

λ: is the wavelength

p_t: is the power of one transmitter at the antenna port

N: is the number of transmitters in area A on the Earth's surface

α: is the portion of the transmitter power radiated toward the sensor which includes side-lobe gain, power reflected off of objects and polarization mismatch

θ: is the incident angle at the Earth's surface measured from the local vertical, and

l_2: the atmospheric attenuation over slant paths:

$$l_2 = l_z^{\frac{1}{\cos\theta}} \tag{2}$$

where:

l_z: is the atmospheric gaseous attenuation at zenith which at 31.5 GHz = 0.25 dB or a ratio of 1.059.

The density value $\left(\alpha \frac{N}{A} p_t\right)$ is in units of Watts/unit area.

What is notable about this expression is that the received power density is not dependent upon the antenna gain or the altitude of the sensor. However it is dependent upon the cosine of the incident angle. Thus as the incident angle approaches zero, the interference power density approaches a minimum. Therefore the sensor IFOV closest to nadir is the most sensitive to interference.

Applying this to the ATMS sensor with an IFOV of 4 393 km^2, the entire group of IFOV would have an interference probability of (4 394 km^2/2 000 000 km^2)*100% = 0.2197%. To achieve the threshold of 0.01% (0.01/0.2197)*96 ≈ 4 IFOVs of the 96 IFOVs can receive interference.

6.1.4 Exclusion for MTVZA-OK

This approach cannot be applied to the MTVZA-OK because all the IFOVs have the same incident angle. The probability of interference is thus (1 625 km^2/2 000 000 km^2)*100% = 0.08125% if the threshold is exceeded.

6.1.5 Number of IFOVs to meet the criterion

The number of IFOV positions per instrument that can receive interference before the 0.01% criterion is exceeded is shown in Table 4.

TABLE 4

Number of IFOVs that can have interference power exceeding the interference threshold and still meet the probability criterion

Sensor	Number of IFOVs that can exceed the threshold for 0.01% probability of interference	Number of IFOVs on each side of nadir that can exceed the threshold for 0.01% probability of interference
AMSU-A	2	1
ATMS	4	2
MTVZA-OK	None	None

6.2 Simulation Study 7 for cities

City sizes will be simulated with different size rectangular clusters of emitters. First it is necessary to determine the range of sizes that will be simulated and the density of emitters that may be in the city.

6.2.1 City sizes where terrestrial fixed service systems might be deployed

Information in the ITU-R indicated a total of 2 000 transmitters presently in Region 1. The interference potential will depend upon the size of deployment areas relative to the size of the IFOVs. The cities that are of most concern are the largest. Table 5 contains the 13 most populated cities in countries that are included in the RR No. 5.546. They are ordered in size by population. The urban area in km^2 is included which corresponds to the population data. The list was compiled from data provided by the European Union with the addition of other administrations listed in the footnote.

TABLE 5

Metropolitan areas in Region 1

City	Population	Area (km^2)
Istanbul	12 697 164	1 832
Moscow	10 524 400	1 081
Greater London	7 556 900	1 572
St Petersburg	4 601 219	1 439
Ankara	3 763 465	2 516
Izmir	3 739 353	855
Madrid	3 213 271	698
Kiev	2 819 566	839
Bucharest	1 944 367	280
Budapest	1 712 210	525
Warsaw	1 706 724	517
Barcelona	1 615 908	636
Birmingham	1 016 800	268

The city areas range from 268 km^2 to 2 516 km^2. The simulated cities will range from 256 km^2 to 3 136 km^2.

6.2.2 Maximum possible deployment density of terrestrial systems

The maximum potential deployment for fixed systems can be derived from Table 2. The following tables investigate the characteristics of the longest and shortest terrestrial system links. Table 6 looks at the achieved performance level in terms of C/N and C/N_0 for the longest and shortest links.

TABLE 6

Investigation of fixed service links

Parameter	Longest distance	Shortest distance
Transmitter power	–10 dBW	–20 dBW
Transmitter antenna gain	42 dBi	27 dBi
Transmitter main beam e.i.r.p.	32 dBW	7 dBW
Bandwidth	28 MHz	28 MHz
Transmitter power density	17.5 dBW/MHz	–7.87 dBW/ MHz
Range	10 000 m	100 m
Propagation loss	–142.4 dB	–102.4 dB
Receiver antenna gain	42 dBi	27 dBi
Received power	–68.4 dBW	–68.4 dBW
Assumed noise temperature	290 K	290 K
Noise power	–129.5 dBW	–129.5 dBW
C/N	61.1 dB	61.1 dB
C/N_0	135.6 dBW/Hz	135.6 dBW/Hz

Table 6 indicates that the received signal level is the same for the longest and shortest paths. From this, the path length of a typical link with the same received signal strength will be calculated.

TABLE 7

Investigation of typical fixed service link range

Parameter	Value for typical path length
Transmitter power	–18 dBW
e.i.r.p.	15 dBW
Antenna gain derived from e.i.r.p. power	33 dBi
Matching receiver antenna gain	33 dBi
Received signal power	–68.4 dBW
Calculated propagation loss	–116.4 dB
Propagation loss as ratio	$(0.000001514)^2$
Wavelength	0.00952
Range	500 m

Table 7 indicates that the typical/mean distance is 500 m which is less than 2 000 m as indicated in Table 2, so for density calculations 500 m will be used. Simulations with this density will be useful for simulating any other lesser density.

6.3 Simulations using clusters of emitters

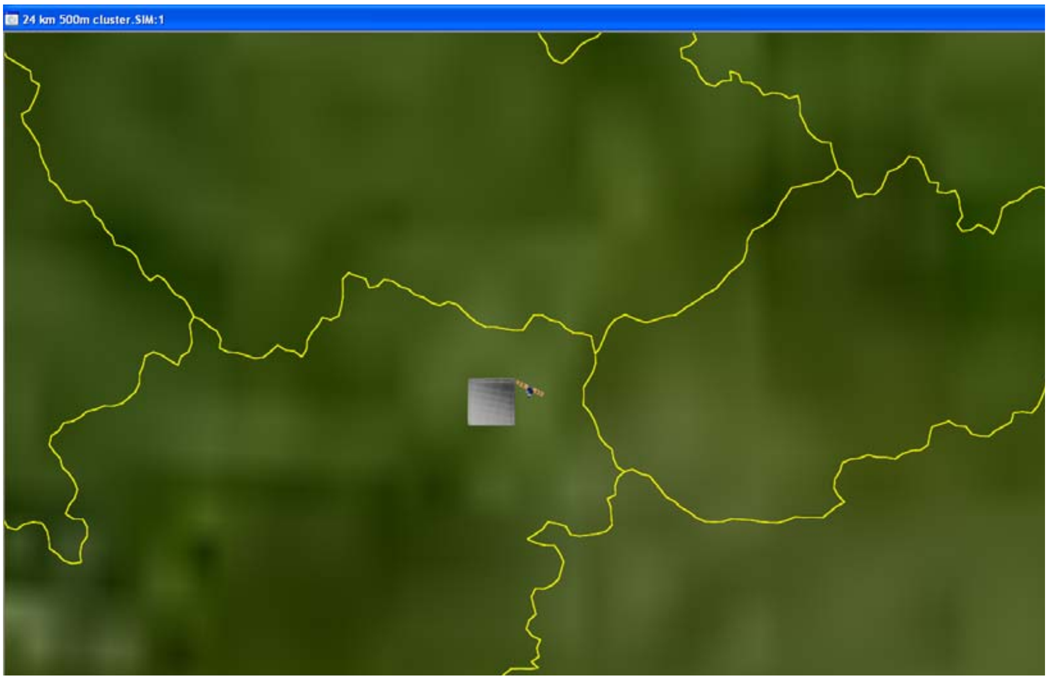
The objective of this investigation is to see how the interference in the sensor changes with the size of an area from which it receives interference. The purpose of this investigation is to provide information of interference area sizes that can be compared to city sizes.

The rectangular areas were created ranging in size so that they are both smaller and larger than cities being analysed. Transmitters are placed every 500 m within the rectangles providing a consistent power for each area size.

Figure 21 shows the cluster of emitters in the simulation at a location in Europe. To create this representation the simulation was stopped in a position when the sensor was at its most nadir IFOV. A terrestrial location was found that was centre in the IFOV and this location was used for the centre of all clusters representing city sizes.

FIGURE 21

Rectangular cluster as appears in the simulation



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The software simulated the scan of the sensor while the track of the sensor progressed. The e.i.r.p. applied to each transmitter was adjusted iteratively to the point where the maximum interference value recorded was exactly the same as the interference threshold of the sensor. This value was recorded for six clusters representing six different city sizes. This value was subsequently converted to a total power in the area and to a power density in the area.

The results for each sensor are presented in the three following tables.

TABLE 8

Results of simulation of area size investigation for AMSU-A

Cell width	Cell area	Number of transmitters in cell	Power determined from the simulation for each transmitter dBW	Total power in the cell dBW = power per transmitter number of transmitters	Power density = total power divided by cell area dB(W/km^2)
16 km	256 km^2	1 089	–49.34 dBW	–18.98 dBW	–43.06 dB(W/km^2)
24 km	576 km^2	2 401	–52.57 dBW	–18.77 dBW	–46.37 dB(W/km^2)
32 km	1 024 km^2	4 225	–54.74 dBW	–18.48 dBW	–48.58 dB(W/km^2)
40 km	1 600 km^2	6 561	–56.26 dBW	–18.09 dBW	–50.13 dB(W/km^2)
48 km	2 304 km^2	9 409	–57.38 dBW	–17.64 dBW	–51.27 dB(W/km^2)
56 km	3 136 km^2	12 781	–57.77 dBW	–16.70 dBW	–51.67 dB(W/km^2)

TABLE 9

Results of simulation of area size investigation for ATMS

Cell width	Cell area	Number of transmitters in cell	Power determined from the simulation for each transmitter dBW	Total power in the cell dBW = power per transmitter number of transmitters	Power density = total power divided by cell area dB(W/km^2)
16 km	256 km^2	1 089	–45.50 dBW	–15.13 dBW	–39.21 dB(W/km^2)
24 km	576 km^2	2 401	–48.91 dBW	–15.11 dBW	–42.71 dB(W/km^2)
32 km	1 024 km^2	4 225	–51.12 dBW	–14.95 dBW	–45.06 dB(W/km^2)
40 km	1 600 km^2	6 561	–52.97 dBW	–14.80 dBW	–46.84 dB(W/km^2)
48 km	2 304 km^2	9 409	–53.35 dBW	–13.61 dBW	–47.24 dB(W/km^2)
56 km	3 136 km^2	12 781	–55.46 dBW	–14.391 dBW	–49.35 dB(W/km^2)

TABLE 10

Results of simulation of area size investigation for MTVZA-OK

Cell width	Cell area	Number of transmitters in cell	Power determined from the simulation for each transmitter dBW	Total power in the cell dBW = power per transmitter number of transmitters	Power density = total power divided by cell area dB(W/km^2)
16 km	256 km^2	1 089	–51.25 dBW	–20.88 dBW	–44.96 dB(W/km^2)
24 km	576 km^2	2 401	–54.34 dBW	–20.53 dBW	–48.14 dB(W/km^2)
32 km	1 024 km^2	4 225	–55.84 dBW	–19.58 dBW	–49.69 dB(W/km^2)

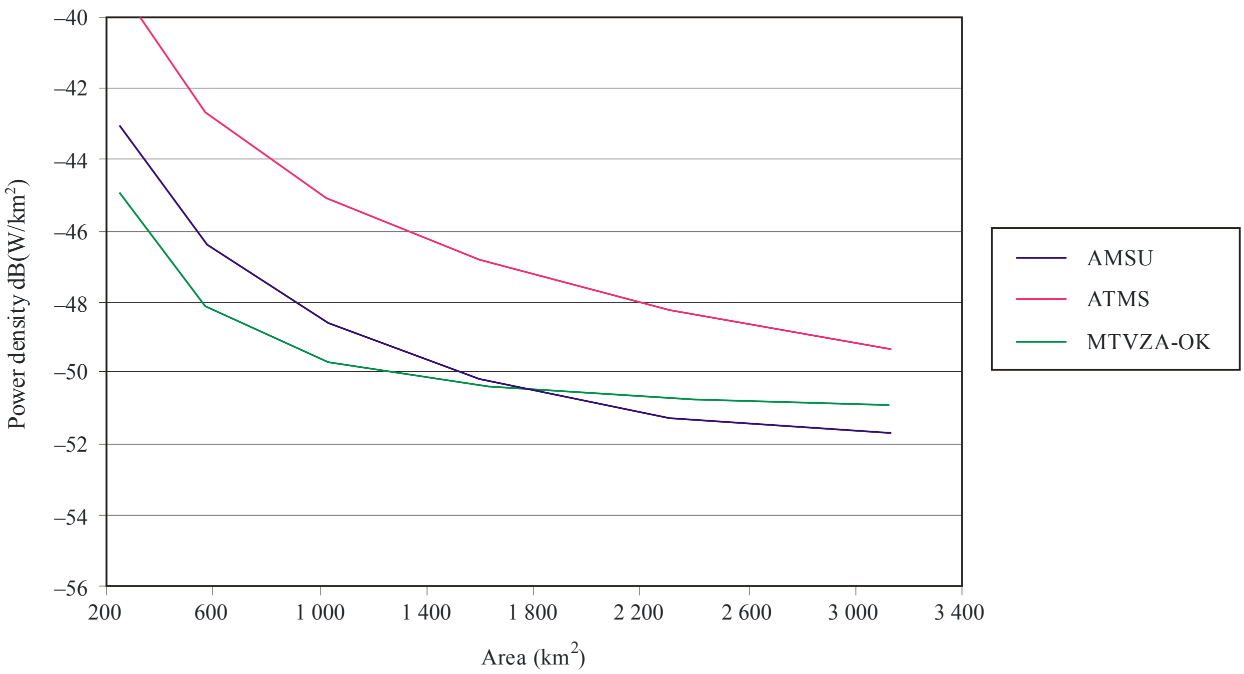
TABLE 10 (*end*)

Cell width	Cell area	Number of transmitters in cell	Power determined from the simulation for each transmitter dBW	Total power in the cell dBW = power per transmitter number of transmitters	Power density = total power divided by cell area dB(W/km^2)
40 km	1 600 km^2	6 561	–56.48 dBW	–18.31 dBW	–50.35 dB(W/km^2)
48 km	2 304 km^2	9 409	–56.80 dBW	–17.17 dBW	–50.69 dB(W/km^2)
56 km	3 136 km^2	12 781	–57.04 dBW	–15.98 dBW	–50.94 dB(W/km^2)

Figure 22 provides a comparison of the density values between the three sensors in the report.

FIGURE 22

Comparison of IFOV size to power density for the three sensors



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The lower the curve in Fig. 22 is, the more sensitive the sensor is. The AMSU-A and MTVZA-OK are more sensitive than the ATMS. The MTVZA-OK curve levels off at larger city areas because the areas are greater than the IFOV. Since the antenna gain roll off and side-lobe gain is reflected in these results there is some continued drop in the sensitivity curve beyond the specified IFOV size. The worst case sensitivity is for the AMSU at large city sizes. This can be observed in the figure and from the tables above the power density level is –51.97 dB(W/km^2) in 300 MHz.

7 Propagation adjustments

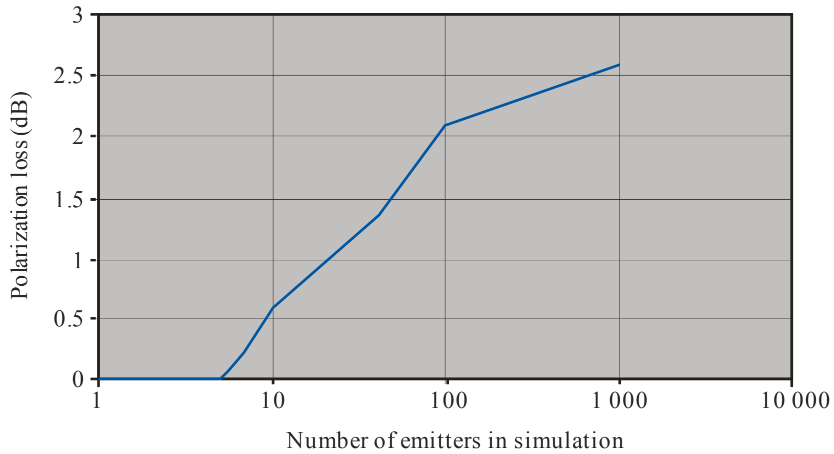
The values obtained in the section above have been determined with the free space propagation model. There are other factors that will add additional attenuation to the signal path between the terrestrial stations and the sensor space station. These factors will allow the terrestrial systems to have a higher transmitter power without exceeding the interference threshold at the sensor.

7.1 Polarization loss

The polarization loss, on the average, is 3 dB between the linearly-polarized, sensor antenna and the randomly-polarized, terrestrial antennas. However, this loss is a statistical average, and what is needed in these calculations is the loss exceeded 0.01 per cent of the time, which is the data availability requirement. Assuming random linear polarizations for the emitters, relative to the sensor antenna polarization, Fig. 23 shows the cumulative polarization loss exceeded 99.99% of the time, as a function of the number of emitters in the sensor's antenna IFOV. The figure was developed using a Monte-Carlo simulation technique. A maximum polarization loss would be 3 dB where the number of emitters is high (> 1 000). For the deployment ranges considered in this analysis, 100 emitters would have a polarization loss of 2 dB while 10 emitters would have a polarization loss of 0.5 dB.

FIGURE 23

Propagation loss relative to the number of emitters exceeded 0.01% of the time



7.2 Atmospheric attenuation

Atmospheric attenuation over slant paths is calculated with equation (2). It is an exponential function of the incident angle unlike the propagation loss which is directly proportional to the incident angle.

For the AMSU and ATMS the attenuation for the most sensitive sensor beam position at about 1° from nadir is approximately 0.249 dB. For the MTVZA-OK at an inclination angle of 65° the attenuation value would be 0.254 dB.

7.3 Antenna side-lobe gain

The maximum transmitter power that will still not exceed the sensor interference threshold is determined from the e.i.r.p. toward the sensor for the terrestrial station. Table 2 shows the characteristics of the terrestrial stations and there is a relationship between the station power, antenna main beam gain and the antenna side-lobe gain.

Table 11 shows in its rows the related values taken from Table 2.

TABLE 11

Relationship between power and side-lobe gain

Station type	Power	Main lobe gain	Computed side lobe gain from Recommendation ITU-R F.1245-1
Minimum	–20 dBW	27 dBi	–9.0 dBi
Maximum	–10 dBW	42 dBi	–12.0 dBi
Typical	–18 dBW	36 dBi	–10.5 dBi

7.4 Application of additional losses

The result derived from Fig. 22 was that the power density should not exceed –51.97 dB(W/km^2). However this value must be adjusted to determine a value of power from the transmitters in the city. The adjustment values have ranges, so assumptions must be made to choose single values. It will be assumed that each city has about 10 transmitters with a typical antenna. Thus the power density will be adjusted by 0.6 dB for polarization loss, 0.249 dB for gaseous attenuation and –10.5 dB for the antenna side-lobe gain. This increases our interference power threshold value to –40.62 dB(W/km^2) of transmitter power.

7.5 Evaluation of results

The next step is to convert these results into deployment results. In terms of transmitters per city, at –40.62 dB(W/km^2) with a typical transmitter having –18 dBW power the transmitter density would be 0.0055 transmitters per km^2. A large city to which this would be applied with an area of 3 139 km^2 there could be about 17 transmitters. If the assumed total number of 2 000 transmitters from ITU-R data is contained in 13 cities in Table 5, there would be on the average 154 transmitters per city. The average city size from Table 5 is about 1 000 km^2. This is a deployment density of 0.154 transmitters per km^2 in an average city. To meet the interference threshold each transmitter could have only –32.5 dBW per transmitter. The lowest power given for these transmitters is –20 dBW.

It appears that the deployment density given in ITU-R data would not be compatible with the sensor. Compatible configurations would have an average of 17 or fewer transmitters per city at typical power levels.

Using the calculations demonstrated in Table 7, a circuit with the largest antennas could have a link of 750 m. The smallest link would be 24 m and a link with a typical antenna would be about 100 m. These distances are in the lower ranges specified in Table 2.

If terrestrial fixed service systems are spread throughout a large area of about 2 000 000 km^2, compatibility could be achieved if the power in any IFOV is below –25 dBW or the individual power per transmitter is below –30 dBW.

If terrestrial fixed service systems are concentrated in urban areas compatibility can be achieved if the power density of these systems is –40.62 dB(W/km^2) or less. This density would support up to 17 transmitters per city with links of 750 m or less. Also the power per transmitter in heavily concentrated areas should not exceed –32.5 dBW.

A deployment scenario was provided by one administration. Table 12 below shows the specifics of this system.

TABLE 12

Deployment scenario parameters

Estimated maximum total number of FS stations in a worst case 2 000 000 km^2 area[(1)]	**About 700 of which 350 are within a city with an area of about 1 600 km^2**
FS station e.i.r.p. in direction of satellite (FS stations e.i.r.p. randomly distributed across the area)	3% at –19 dBW 22% at –24 dBW 35% at –28 dBW 40% at –32 dBW
Bandwidth	One 28 MHz channel per FS station
Polarization	Equal numbers of vertical and horizontal
Frequency distribution	Equally spread across the band 31.5 to 31.8 GHz

(1) In other 2 000 000 km^2 areas the expected number of FS stations is likely to be much lower.

The values in § 7.1 deal with random polarizations which have been accounted for in the resulting values. It will be assumed that all transmitter emissions fall within sensor bandwidth. Six 28 MHz channels can be within the bandwidth of the AMSU and ATMS and 18 28 MHz channels within the bandwidth of the MTVZA-OK sensor as indicated in Table 1.

The distribution of e.i.r.p.s as indicated in Table 12 average to –26.86 dBW per transmitter. If the 700 transmitters are evenly disbursed over 2 000 000 km^2 at –26.86 dBW each the power density would be –61.42 dBW/km^2. The total power in the AMSU sensor using the IFOV sizes from Table 1 is –28.73 dBW. Likewise the total power for the ATMS is –24.98 dBW and for the MTVZA-OK it would be –29.21 dBW. The value derived from the analysis was –25 dBW in the IFOV. Although the ATMS is close, this scenario with evenly distributed transmitters appears compatible.

However, a realistic distribution is not uniform. If the scenario changed so there are 350 transmitters in a city area of about 1 600 km^2 (as per Table 12), then the total power would be –1.42 dBW. Because the IFOV sizes of all three sensors studied are larger than the 1 600 km^2-city the total power is the same. This far exceeds the interference threshold value of –25 dBW total.

Since the total power is transmitter power times the number of transmitters the transmitter population could vary. From the distribution in Table 12, the –18 dBW and –24 dBW transmitters would exceed the criterion of –25 dBW with only one transmitter. It would take two transmitters to equal the threshold at –28 dBW and 5 transmitters at –32 dBW.

This analysis looks at two densities; one which meets the criterion and one that fails the criterion. The actual assessment of compatibility would require a statistical function to represent the distribution of transmitters within a certain size area. The system would be considered compatible if the probability of the power in an area the size of an IFOV were exceeded for less than 0.01% of the areas over a total area of 2 000 000 km^2.

8 Conclusions

The only current sensor known to operate in the 31.5 to 31.8 GHz segment of the 31.3 to 31.8 GHz band is the MTVZA-OK. The AMSU-A and ATMS operate in a lower portion from 31.3 to 31.5 GHz only, which avoids potential interference at the expense of instrument sensitivity. Future systems may use this band to increase their sensitivity because of the bandwidth increase from 200 MHz to 500 MHz. Of the three sensor systems examined, the AMSU is the most sensitive to interference.

From the range of technical parameters used in this study, and supported in Recommendation ITU-R F.758-4, results indicate that compatibility between terrestrial systems and EESS (passive) systems is dependent on the power level and deployment density of the FS systems. The investigation has identified compatible deployments, noting that they do not account for particular FS applications for which shielding exists in the direction of the satellite (such as transmissions from surveillance cameras located underground or in shielded environment).

As described in § 7.5 of this Report compatible deployment from the investigation of large deployment areas in § 5 is bounded by a transmitter power of –30 dBW per transmitter or –25 dBW aggregate power in the IFOV of the sensor. A compatible deployment scenario based on an investigation of concentrated average urban deployment areas is –32.5 dBW per transmitter. Current terrestrial systems may be compatible with passive sensors if deployments do not exceed –40.62 dB(W/km^2).

9 Supporting documents

[1] Recommendation ITU-R RS.1029-2 – Interference criteria for satellite passive remote sensing (Replaced by Recommendation ITU-R RS.2017).

[2] Report ITU-R RS.2095 – Sharing of the 36-37 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive).

[3] Report ITU-R RS.2096 – Sharing of the 10.6-10.68 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive).

[4] Recommendation ITU-R RS.1861 – Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz (2010).

[5] Recommendation ITU-R F.758-4 – Considerations in the development of criteria for sharing between the fixed service and other services.

[6] Recommendation ITU-R RS.1813 (2009) – Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz.

[7] Question ITU-R 232-1/7 – Frequency sharing between space borne passive sensors and other services in the bands 10.60-10.68 GHz, 31.5-31.8 GHz and 36-37 GHz (2000-2002).

[8] Technical and operational characteristics of the microwave radiometer MTVZA-OK, Russian Federation, Document 7C/165, 25 October 2005.

[9] Working Party 5C, Liaison statement to Working Party 7C, Information regarding studies under Question ITU-R 232-1/7, Document 7C/106, 5 June 2009.

[10] Working Party 5C, Reply Liaison statement to Working Party 7C, Information regarding studies under Question ITU-R 232-1/7, Document 7C/151, 23 December 2009.