RECOMMENDATION ITU-R RS.1279*, **

SPECTRUM SHARING BETWEEN SPACEBORNE PASSIVE SENSORS AND INTER-SATELLITE LINKS IN THE RANGE 50.2-59.3 GHz

(Question ITU-R 216/7)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that weather forecasting is an increasingly important tool which is essential to all human economic activities, and is also playing a predominant role in early identification and warnings of potentially dangerous phenomena;

b) that atmospheric temperature is essential data needed for weather forecasting on a global basis;

c) that the oxygen absorption band consisting of several absorption lines between 50 and 65 GHz represents a unique natural resource for remote temperature profile sensing in the atmosphere, not available in any other frequency band;

d) that all-weather atmospheric temperature profiles can only be obtained on a global basis with sufficient accuracy through three-dimensional microwave passive measurements from low-Earth orbiting (LEO) space platforms in the unique frequency band around 60 GHz where absorption by atmospheric oxygen is taking place;

e) that these passive measurements are extremely vulnerable to interference because the natural variability of the atmosphere makes it impossible to recognize and to filter out measurements contaminated by interference;

f) that contaminated passive sensor measurements can have a dramatic, adverse impact on climate studies and the quality of weather predictions;

g) that non-geostationary-satellite orbit (non-GSO) networks providing fixed-satellite services (FSS) and mobile-satellite services are being developed which plan to employ large numbers of inter-satellite links (ISL) near 60 GHz;

h) that geostationary-satellite orbit (GSO) networks providing FSS and mobile-satellite services are being developed which plan to employ ISLs near 60 GHz;

j) that the 54.25-58.2 GHz frequency band is shared on a co-primary basis by the Earth exploration-satellite service (passive) (EESS), the Space Research (passive) service, and the inter-satellite service (ISS);

k) that item 1.9.4.3 of Resolution 718 (WRC-95) (Agenda for the 1997 World Radiocommunication Conference) is to consider "the existing frequency allocations near 60 GHz and, if necessary, their re-allocation, with a view to protecting the Earth exploration-satellite (passive) service systems operating in the unique oxygen absorption frequency range from about 50 GHz to about 70 GHz";

l) that Recommendation ITU-R RS.1029 contains interference protection criteria for passive sensors in bands near 60 GHz;

m) that studies conducted in the band 54.25-58.2 GHz have shown that the ISLs in an non-GSO network can cause interference to the passive sensors well in excess of these protection criteria (see Annex 1);

n) that studies conducted in the band 54.25-58.2 GHz have shown that ISLs in GSO networks can share the band with passive sensors with suitable restrictions on the power flux density (pfd) produced by GSO satellites at the sensor orbital altitude (see Annex 2),

recognizing

a) the need to protect existing and planned ISS systems in the band 56.9-57 GHz,

* This Recommendation should be brought to the attention of Radiocommunication Study Group 4.

** Radiocommunication Study Group 7 made editorial amendments to this Recommendation.

recommends

1 that, in view of *considering* c) and m), passive sensors and ISLs of non-GSO networks should operate in separate bands in the range 50.2-59.3 GHz;

2 that, in view of *considering* n), passive sensors and ISLs of GSO networks can share bands in the range 50.2-59.3 GHz provided that the pfd at all altitudes from zero to 1 000 km above the Earth's surface produced by emissions from a space station in the ISS does not exceed –147 dB(W/(m^2 · 100 MHz)).

ANNEX 1

Results of the non-GSO interference study

1 Introduction

The EESS includes spaceborne passive sensors which measure temperatures of various atmospheric layers in several frequency bands within the oxygen absorption bands near 60 GHz. Depending on the frequency, measurements in the 60 GHz band can be substantially protected from interference from terrestrial emissions. Frequency bands near 60 GHz are also attractive for ISL of a non-GSO communications system. Unfortunately these ISLs introduce potential interference to spaceborne passive sensor measurements, which are not attenuated by oxygen absorption. Table 1 describes the non-GSO and sensor satellite orbits, and Table 2 describes the non-GSO transmission and sensor satellite reception characteristics used in the study. All antennas were modelled using Recommendation ITU-R S.672, with –10 dBi minimum gain.

TABLE 1

non-GSO and sensor satellite orbit characteristics

Orbital parameter	non-GSO satellite	Sensor
Altitude (km)	700	833
Inclination (degrees)	98.16	98.7
Period (min.)	98.8	101.5
Eccentricity	0.0	0.0
Number of orbital planes	21	2
Number of satellites per plane	40	1
Ascending nodes	Spaced 9.5° starting at 0°	N.A.

TABLE 2

non-GSO and sensor satellite characteristics

Parameter	non-GSO satellite	Advanced microwave sounding unit (AMSU) sensor	Pushbroom sensor
Carrier frequencies (GHz)	56 and 59	56	56
Bandwidth per channel (MHz)	1 000	400	100
Power in each band (dBW)	7.4	N.A.	N.A.
Peak antenna gain (dBi)	48	36	45

2 Interference from non-GSO satellites

To determine whether interference from even a single non-GSO satellite can exceed the interference threshold of the sensor, three fixed geometries are considered. Figure 1 illustrates the geometries considered.

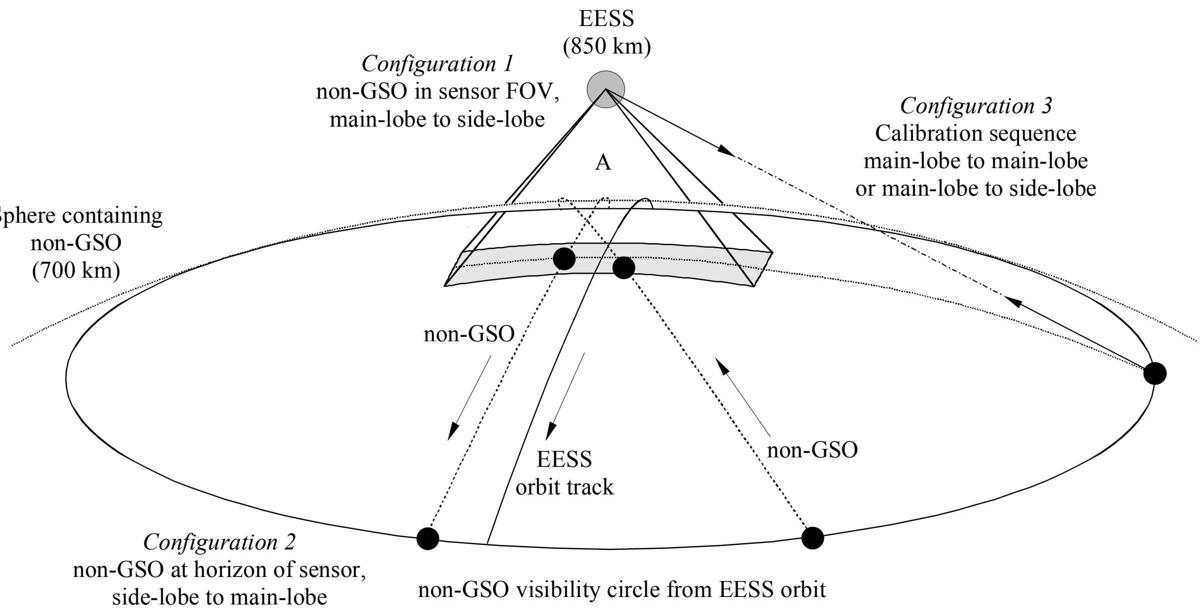
Configuration 1: The potential interference path may be through the antenna main lobes of the sensor and the antenna side lobes of one (or several) inter-satellite transmitter.

Configuration 2: The interference path may be through the antenna side lobes of the sensor and the antenna main lobe of one (or several) inter-satellite transmitter.

Configuration 3: During "cold space calibration", main lobe-to-far lobe and main lobe-to-main lobe interferences paths are possible, as well as various intermediate combinations.

FIGURE 1

Geometry of EESS-non-GSO satellite mutual visibilities



A: FOV (± 50° re nadir)

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Table 3 gives the results of the static evaluation for the three configurations assuming a pushbroom sensor. The importance of the relative positions of the EESS orbit and of the interfering non-GSO ascending nodes is illustrated by the considerable variation in the duration of interference and of the intervals between interference events. The shortest durations and intervals apply to the case where ascending nodes of the two systems are about 180° apart. Recommendation ITU-R RS.1029 cites an interference threshold of –166 dB(W/100 MHz) for a pushbroom sensor. This is the interference threshold used in Table 3.

3 Interference statistics

A computer simulation was used to model the dynamic interaction of the non-GSO constellation and the spaceborne sensor in order to determine how often, and by how much, the sensor interference threshold is exceeded. The simulation considers interference to an advanced microwave sounding unit (AMSU) sensor rather than a pushbroom sensor because spectrum sharing is less likely to be feasible when a pushbroom sensor is used than when an AMSU sensor is used.

All of the non-GSO ISLs are assumed to be transmitting continuously, and the sensor is assumed to be making measurements continuously. The results of the dynamic analysis are summarized in Fig. 2.

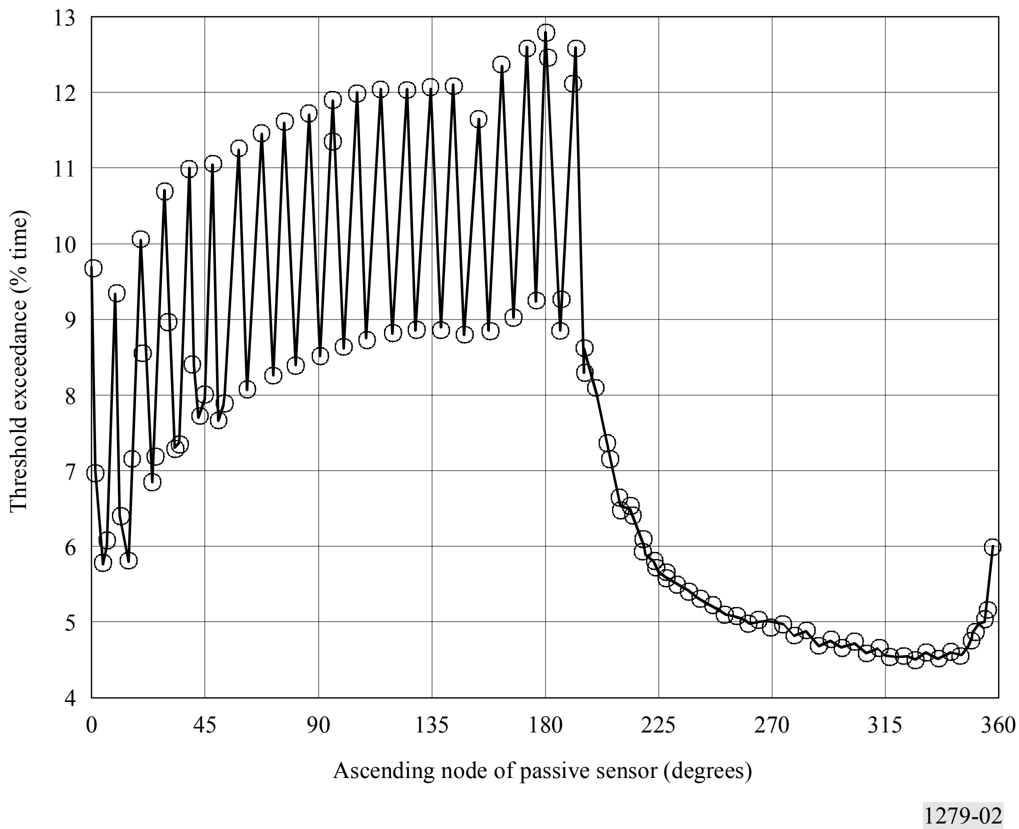
TABLE 3

Interference levels and durations

	Level above interf. threshold (dB)	Duration of a single interference event (s)	Interval between successive events (min)
Configuration 1	18.5-31	1-75	1-81
Configuration 2	7-10	10-665	1-81
Configuration 3	7-65	2-138	1-81

FIGURE 2

Dependence of threshold exceedance on sensor ascending node



Each point in Fig. 2 represents the result of a simulation performed for a given ascending node of the AMSU sensor spacecraft orbit. The per cent of time that the interference level exceeds the sensor interference threshold is plotted as a function of the given AMSU ascending node. In general, for the runs represented by the points along the "top" of the curve envelope, the AMSU node was coincident with an ascending node of an non-GSO plane (e.g. 0°, 66.5°, ... 180.5°, and 190°). The runs represented by the data points defining the "bottom" of the envelope correspond to AMSU orbit nodes placed in between the non-GSO planes. It should be noted that the AMSU ascending nodes between 0° and 50° were selected in arbitrary steps rather than exactly coincident with non-GSO nodes. In contrast, above 50°, the AMSU orbit ascending nodes were selected to be either coincident with or half-way in between two non-GSO nodes. There are more co-channel, cross-plane, ISL pointed in the direction of the AMSU sensor at 180.5° than at 0°, resulting in a higher percentage of interference if the AMSU node is at 180.5°.

The AMSU interference threshold is –157 dB(W/400 MHz). This is the threshold assumed in Fig. 2. The calibration mode was not modelled in the simulation. Had it been modelled, Fig. 2 would have exhibited more severe interference. Interference is considered to be excessive whenever the sensor threshold is exceeded more than 0.01% of the time.

Assuming that a threshold exceedance of *x*% of the time corresponds to a contamination of *x*% of the measurement cells scanned by the sensor, Fig. 2 shows that the spatial interference criteria of Recommendation ITU-R RS.1029 are violated at all of the ascending nodes that were examined.

4 Conclusion

The results in Fig. 2 demonstrate that the interference levels introduced by the ISLs of the non-GSO constellation assumed here exceed the sensor interference threshold at least 4% of the time and as much as 13% of the time. The amount of threshold exceedance depends on the ascending node of the sensor satellite relative to those of the non-GSO constellation.

ANNEX 2

Results of the GSO interference study

1 Introduction

When the difference in longitude between two GSO satellites communicating on an ISL is sufficiently small, there will be no interference to the sensor satellites because the link does not penetrate the orbit spheres of the sensor satellites. A parametric analysis was done to determine the maximum pfd produced by an ISL at the altitude of a sensor satellite that would not cause the sensor interference threshold to be exceeded for either the scan or the calibration mode. For both modes the maximum pfds were obtained analytically. For the calibration mode simulations were performed to determine the interference statistics. These statistics depend on the GSO satellite longitude separation. The separation was reduced from its maximum value of 162.6° (the separation at which the GSO-GSO link grazes the Earth) until the interference level dropped below the sensor interference threshold.

Potential GSO systems have transmit and receive antenna gains ranging from 45 to 60 dBi, bandwidths ranging from 90 MHz to 1 GHz, and receive system noise temperatures of approximately 650 K. The simulations that were carried out consider antenna gains of 45, 50, 55 and 60 dBi, and a bandwidth of 1 GHz. Antenna patterns from Recommendation ITU-R S.672 are assumed for the ISL antennas. The GSO satellite transmit power was adjusted throughout the simulations to achieve an ISL E_b/N_0 of 12 dB. Table 4 summarizes the assumed microwave sensor characteristics.

TABLE 4

Microwave pushbroom sensor characteristics

Sensor interference threshold	–166 dB(W/100 MHz)
Maximum antenna gain	45 dBi –14 dBi back lobes
Calibration antenna gain	35 dBi
Field of view	+48.5° from nadir
Altitude	≤ 1 000 km
Inclination	Sun synchronous (100.1° for 1 000 km altitude)
Centre frequency	56 GHz

2 Results of the study

In its Earth-viewing mode the sensor (assumed to be a pushbroom sensor) receives interference through its antenna side lobes, which are assumed to have a gain of –14 dBi. To avoid exceeding the interference threshold while the sensor is in the Earth-viewing mode, the pfd produced at altitudes of 1 000 km or less above the Earth's surface from a single ISL transmission should not exceed –97 dB(W/(m^2 · 100 MHz)). A one dB allowance for interference from multiple ISLs reduces the allowable pfd to –98 dB(W/(m^2 · 100 MHz)).

In its calibration mode the sensor can receive interference through its antenna main beam. Potential interference is therefore much more severe in the calibration mode. The level and duration of interference events are variable, requiring dynamic simulation. Simulation with AMSU sensors reveals that for 45 dBi GSO satellite antennas, the sensor interference threshold is exceeded approximately 5% of the time at large separations of the GSO satellites (near 160°). Interference is negligible for separations less than 70°. The duration of interference events varies from 0.2 to 21.5 min. On the other hand, for 60 dBi GSO satellite antennas, the sensor interference threshold is exceeded only 0.14% of the time for longitudinal separations more than 160°, with negligible interference for separations less than 160°. The duration of interference events varies from 0.1 to 4.1 min. Simulation with pushbroom sensors would have revealed even more interference.

Pushbroom sensors have fixed antennas for sensing toward the Earth. The cold calibration antenna will be a separate antenna aimed toward the cold sky. The dynamic analysis performed for the AMSU sensor would provide similar results for the pushbroom antenna because of the similar orientations. The durations of the interference periods would be a function of the gain of the calibration antenna.

Pfd limits for GSO inter-satellite systems must be sufficient to protect both present and future systems. The present AMSU sensor has an antenna gain of 36 dBi, an effective aperture of –21 dB/m^2 at 58 GHz, and a sensitivity of –161 dBW. Allowing 3 dB for multiple interferers, it needs a pfd limit of –143 dB(W/(m$^2 \cdot$ 100 MHz)) to prevent interference to the sensor if it points towards the GSO. Planned scanning antenna systems will have a 3 dB higher antenna gain and therefore need a pfd limit of –146 dB(W/(m$^2 \cdot$ 100 MHz)).

The pushbroom sensor has a sensitivity of –166 dB(W/100 MHz). As shown in Table 5, it can be protected from interference with a –147 dB(W/(m$^2 \cdot$ 100 MHz)) limit when pointing at the GSO if its calibrating antenna gain does not exceed 35 dBi.

TABLE 5

Sensor protection limit based on the calibration mode

Parameter	AMSU Sensor	Pushbroom	AMSR
Sensor interference threshold (dB(W/100 MHz))	–161	–166	–161
Calibration antenna gain (dBi)	36	35	39
Effective aperture at 58 GHz (dB/m^2)	–21	–22	–18
Two simultaneous interferers (dB)	3	3	3
pfd maximum at 1 000 km to protect the sensor (dB(W/(m$^2 \cdot$ 100 MHz)))	–143	–147	–146

A pfd limit of –147 dB(W/(m$^2 \cdot$ 100 MHz)) is sufficient to protect passive sensors from interference during the calibration mode and it places only a minor constraint on ISLs in the GSO. A further reduction of pfd below –147 dB(W/(m$^2 \cdot$ 100 MHz)) would severely impact the ISS.

The pfd limit of –147 dB(W/(m$^2 \cdot$ 100 MHz)) will protect the sensor when its antenna points directly at the GSO. Interference to passive sensors from GSO ISS links could also be avoided by choosing calibration directions that avoid aiming the antenna directly at the GSO. The factors that influence the aiming of the antenna are the inclination of both the sensor and the GSO inter-satellite orbits, calibration off-nadir angle, and yaw. Control of all these factors may not be practical. Further, control of these factors would require detailed coordination between the sensors and the ISS networks which would impede further development of the passive sensors.

3 Conclusion

Sharing between microwave sensors and GSO ISLs is feasible with the adoption of a single-entry pfd limit of –147 dB(W/(m$^2 \cdot$ 100 MHz)) for emissions produced by an ISS (GSO) network at all altitudes 0 to 1 000 km above the surface of the Earth.