RECOMMENDATION ITU-R S.1339-1*

SHARING BETWEEN SPACEBORNE PASSIVE SENSORS OF THE EARTH EXPLORATION-SATELLITE SERVICE AND INTER-SATELLITE LINKS OF GEOSTATIONARY-SATELLITE NETWORKS IN THE RANGE 54.25 TO 59.3 GHz

(Question ITU-R 246/4)

(1997-1999)

The ITU Radiocommunication Assembly,

considering

a)   that Resolution 643 (WRC-95) of the World Radiocommunication Conference (Geneva, 1995) (WRC-95) instructed the ITU-R to carry out the necessary studies to identify the bands most suitable for the inter-satellite service (ISS) in the frequency range from 50 to 70 GHz in order to enable the World Radiocommunication Conference (Geneva, 1997) (WRC-97) to make appropriate allocations to that service;

b)   that WRC-97 considered the allocation of frequency bands above 50 GHz to the Earth exploration-satellite service (EESS) (passive);

c)   that, as a result of WRC-97 decisions, the frequency bands 54.25-58.2 GHz and 59-59.3 GHz are currently shared on a co-primary basis by the EESS (passive), the space research service (SRS) (passive) and the ISS;

d)   that this unique band is important to passive measurements and sharing between the passive sensor space stations and space stations in the ISS should be considered;

e)   that planned use of the ISS in the frequency bands near 60 GHz has increased significantly;

f)   that the technical characteristics and operational requirements of the ISS in these bands are identified in Recommendation ITU-R S.1327;

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

h)   that studies have been conducted into the feasibility of sharing between spaceborne passive sensors and inter-satellite links (ISL) of geostationary-satellite networks, based on the protection criteria referred to above, as detailed in Annex 1;

j)   that studies have concluded that non-geostationary orbit (non-GSO) ISS systems are likely to cause harmful interference to the passive sensors and that, in general, sharing is not feasible;

k)   that effective sharing between passive sensors and GSO ISS systems will provide for maximum use of the spectrum,

recognizing

a)   that there is a need for continued operation of existing and planned ISS systems in the band 56.9-57.0 GHz, and that studies have shown these systems would not cause unacceptable interference into EESS (passive) sensors;

b)   that, based on the sharing studies contained in Annex 1, WRC-97 decided to adopt No. S5.556A of the Radio Regulations (RR),

recommends

1   that Annex 1 be used in the design of GSO ISS networks in order for them to comply with the power flux-density (pfd) limit given in RR No. S5.556A.

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*   This Recommendation should be brought to the attention of Radiocommunication Study Group 7.

ANNEX 1

1   Introduction

This Annex contains summaries of sharing studies, and methods for computing the sharing conditions between passive sensors of the EESS and geostationary systems of the ISS. The information was developed based on Recommendations ITU-R SA.1028 and ITU-R SA.1029. However, as these Recommendations are revised, this study should be reviewed for potential changes in the conclusions.

2   Assumptions

Planned passive sensors operate in sun-synchronous near polar orbits (inclination ~ 99°), at altitudes below 1 000 km.

2.1   Sensor assumptions

### 2.1.1   The advanced microwave sounder unit (AMSU) sensor

The AMSU sensor is planned for operation in the near future, with parameters as in Table 1. The AMSU sensor scans the surface of the Earth in sensing mode. The scanning is normal to the velocity vector, and through nadir (see Fig. 1). In calibration, the sensor takes a reading from space, away from the sun. The calibration angle can range between 65° and 85° away from nadir. The figure 83.3° is assumed in this example.

TABLE 1

Sensor assumptions

Item	AMSU Sensor	Pushbroom Sensor
Period (s)	6 304	6 304
Altitude (km)	833	833
Calibration antenna pattern	ex-CCIR Report 558	ex-CCIR Report 558
Calibration antenna back lobe (dBi)	–10	–10
Calibration antenna diameter (m)	0.15	0.133
Calibration antenna gain (dBi)	36	35
Frequency (GHz)	54.25	54.25
Inclination (degrees)	98.7	98.7
Calibration angle range (degrees)	65-85	To be determined
Planned calibration angle (degrees)	83.3	To be determined
Interference threshold (dBW in 100 MHz)	–161	–166
Time for interference (%)	< 0.01	< 0.01

FIGURE 1

Passive sensor scanning plane
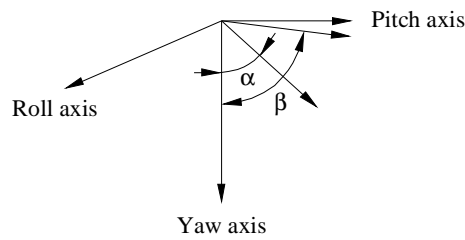
α: AMSU scanning angle (± 48°)

β: AMSU calibration angle (83.3°)

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The calibrations are all normal to the roll axis, and the locus of calibration vectors form a cone. The axis of the cone is tilted out of the equatorial plane by an amount Φ equal to $i - 90°$, where i is the inclination angle (degrees). The AMSU sensor antenna pattern is shown in Fig. 2. The pattern used in this analysis has been modified to provide for a –10 dBi back lobe, in accordance with the sensor design. This change makes no difference in the analysis, as back lobe coupling with GSO ISS has been shown not to cause interference.

FIGURE 2

Sensor calibration antenna patterns

——— AMSU sensor
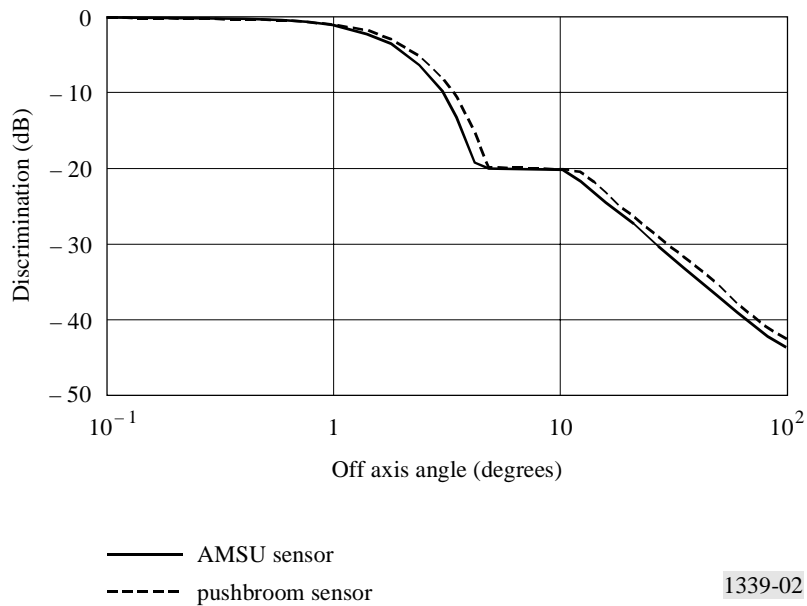
- - - - pushbroom sensor

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2.1.2   The pushbroom sensor

Recommendation ITU-R SA.1029 contains the value of –166 dBW per 100 MHz as the permissible interference level for pushbroom sensors. As is the case for a scanning sensor, the most severe interference configuration that must be examined is for the calibration mode when the sensor is directed at cold space and interference can be coupled into the main beam of the sensor antenna.

The AMSU scanning sensor uses a common mechanically rotating antenna for both sensing of the atmosphere and for calibration. Thus, the main beam gain of this high-gain (36 dBi) antenna must be considered in an analysis of interference levels. In contrast to the scanning sensor, the advantage of the pushbroom sensor is that its antenna need not be mechanically scanned. Its orientation toward the Earth is fixed.

Pushbroom sensors are not expected to come into use before about 2005, and their design has not been finalized. However, it is clear that it will be undesirable to use the same antenna for calibration as for atmospheric sensing. A likely configuration would be a separate calibration antenna fixed to the side of the spacecraft that faces away from the Earth. There is no need for a high-gain calibration antenna, and in fact a physically small antenna with moderate gain would have advantages from a mechanical design perspective.

In this analysis it is assumed that the pushbroom calibration antenna would have a sensor with similar gain to the AMSU, but with higher main lobe efficiency, effectively widening the main lobe of the antenna. Additionally, it must be noted that yaw steering of the satellite is implemented routinely when the satellite is carrying also an active sensor such as a wind scatterometer, i.e. ERS-1 and METOP. The purpose of yaw steering is to compensate for the Earth's rotation, rendering the zero Doppler line normal to the plane which contains the yaw and roll axis of the satellite. For a 850 km altitude sun synchronous orbit, the maximum value of yaw steering at the equator crossing is about $\pm 4°$.

As the interference limit of the pushbroom sensor is lower than that of the AMSU, it can be concluded that the pfd limit adopted to adequately protect the pushbroom sensor from interference will also provide adequate protection from interference for AMSU sensors.

2.2   ISS GSO assumptions

The ISS GSO assumptions in Table 2 were taken from Recommendation ITU-R S.1327. The maximum theoretical orbital separation (line 7) is determined by the minimum C/N for the link, which is assumed to be 12 dB. This calculated value does not consider atmospheric attenuation. Line 8 is the antenna discrimination of the GSO to the 1 000 km altitude point. Line 9 is the corresponding pfd at 1 000 km point. Note that only three systems (W1, W2A and W4) can close their links at the full 162.6 km separation. Note also that an e.i.r.p. of 65 dBW or greater is required to close the link at orbital separations of 120°. The antenna pattern assumed is ex-CCIR Report 558, modified for a back lobe level of –10 dBi.

Some ISS systems are designed for a separation angle of around 160°. Other systems are designed for lower orbital separations. The pfd at 1 000 km will vary with the orbital separation of the GSO ISS. For example, a system such as W2A, the pfd at 1 000 km is depicted in Fig. 3. As illustrated in Fig. 3, if a pfd of –155 dB(W/m^2) in 100 MHz were required, W2A systems would be limited to a maximum of 140° of separation.

FIGURE 3

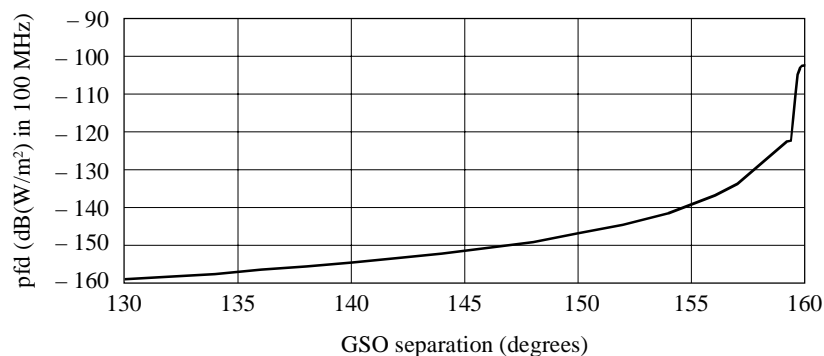**GSO separation allowed for varying pfd thresholds**

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TABLE 2

GSO ISS assumptions

Line	Reference	W1	W2A	W2B	W3A	W3B	W4	W5	W6	W7	W8
1	Power (dBW)	13	16	–1	8.5	8.5	8	11.76	13	13	13
2	e.i.r.p. (dBW)	71.5	75	57	54.5	64	68.3	64.76	63.3	62.1	68.7
3	Bandwidth (GHz)	1.00	3.2	0.04	1.00	1.00	1.00	1.00	0.12	0.12	1.00
4	e.i.r.p.(dB(W/) m^2 in 100 MHz)	61.3	61	57	47.5	56.5	58.3	54.8	62.5	61.3	58.7
5	System noise (K)	468	800	2 034	300	300	630	300	290	290	330
6	Diameter (m)	1.8	2.0	2.0	0.4	1.2	1.8	0.77	0.75	0.75	1.0
7	Maximum theoretical orbital separation (degrees)	162.6	162.6	78.6	10.1	67.3	162.6	53.9	111.1	77.4	136.4
8	GSO discrimination to 1 000 km (dB)	0.0	0.0	65.7	54.8	61.4	0.0	58.1	49.6	55.0	44.8
9	pfd at 1 000 km (dB(W/m^2) in 100 MHz)	–102.2	–102.5	–172.2	–170.8	–168.4	–105.2	–166.8	–150.6	–157.2	–149.6

3 Development of a pfd threshold for GSO ISS to protect EESS (passive)

For planned sensors, previous studies on this subject showed that the worst case occurred when a passive sensor is in cold calibration mode, when looking at space, as opposed to sensor mode, when looking at the Earth. It is assumed that there are two potential worst-case situations:

Case 1:   When the sensor is in the main beam of the GSO ISS station

Case 2:   When the GSO ISS station is in the main beam of the sensor.

In this section we will examine these two cases to determine the pfd level.

3.1 Case 1 – The sensor is in the main beam of the GSO ISS station

The sensor can be in the main beam of a GSO ISS station, only if the separation angle between the GSO ISS stations is close to 160°.

In case 1, illustrated by Fig. 4, the main beam of the GSO ISS station is directed at the passive sensor. At the equator, the passive sensor will be calibrating at an angle Φ, to the GSO ISS station, equal to the inclination minus 90°. Therefore, the main beam of the passive sensor is not directed toward the GSO ISS station.

The sensor inclination, i, minus 90° is the angle, Φ, the effective off-bore sight angle, at the passive sensor, toward the GSO arc. This angle is about 9°, from which we subtract the yaw steering angle of 4°. From Fig. 2 it can be seen that for an angle of 5°, amount of sensor antenna discrimination is 20 dB. A factor of 3 dB is included to account for multiple GSO systems. Therefore the required pfd threshold, to protect passive sensors (in this case) is –126.9 dB, per Table 3.

If the orbit of GSO ISS satellite is inclined, the required pfd to protect the sensor should be given by the values in Table 4. Thus, the worst case is –147 dB(W/m^2) in 100 MHz.

FIGURE 4

Passive sensor at equatorial plane
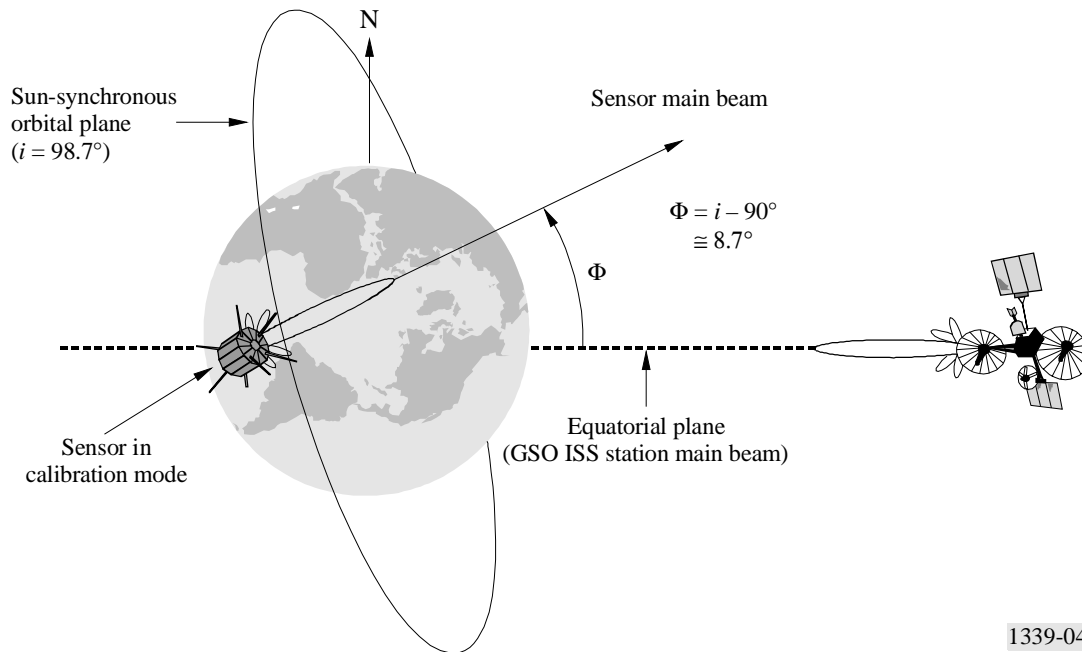
TABLE 3

pfd threshold to protect passive sensors

| Item	With discrimination
Sensor threshold (dBW in 100 MHz)	−166.0
Antenna gain (towards GSO arc) (dBi)	15
Effective aperture (dB(m^2))	−42.1
Factor for multiple GSO systems (dB)	3.0
Resultant pfd threshold (dB(W/m^2) in 100 MHz)	−126.9

TABLE 4

pfd value for inclined GSO

GSO Inclination (degrees)	pfd value (dB(W/m^2) in 100 MHz)
0	−127
From 0 to 5	$−147 + 0.78(5 − i^2)$
Greater than 5	−147

3.2   Case 2 – The GSO ISS station is in the main beam of the sensor

In this case, illustrated by Fig. 5, the passive sensor takes a calibration reading toward the GSO arc. Geometric analysis shows that the sensor can only see the GSO arc for angles below 71.9° or above 88.9°. The range of calibration angles

for the AMSU is 65°-85°. If the sensor is calibrating at angles below 71.9°, a GSO ISS station could be in the main beam of the sensor. One clear solution would be for sensors to calibrate between 75°-85°. Then, the passive sensor will never take a calibration reading toward the GSO arc.

FIGURE 5

Case 2 geometry

View of equatorial plane
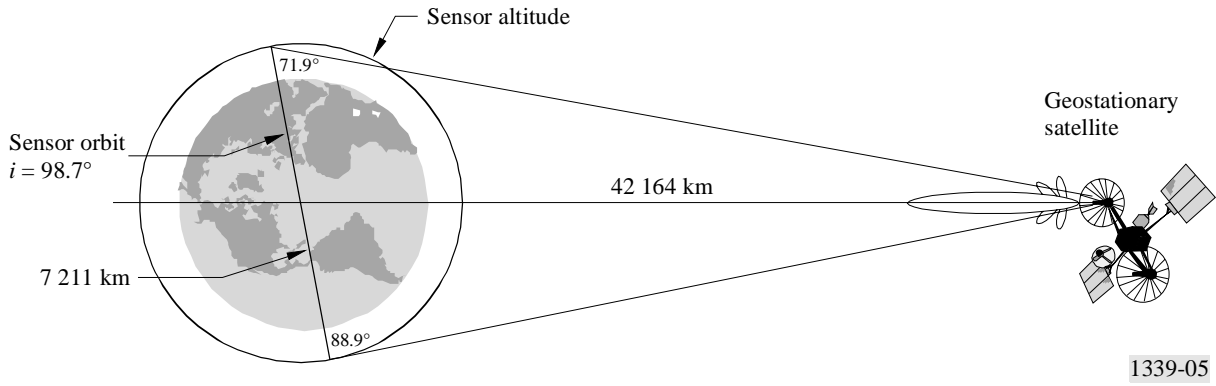
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Although the AMSU design allows for the use of the desirable range 75°-85° it may be premature to assume that sensor design will always use the calibration angles near 80°. If a sensor is calibrating toward the GSO arc, it is necessary to calculate the discrimination angle from the GSO. The following paragraphs provide the methods for computing the pfd at the sensor.

The angle from the GSO to the sensor is illustrated in Fig. 6. In this view from the GSO, the GSO ISS station is pointing at another GSO ISS station at point A. The angle from point A (GSO ISS station) to point B (sensor) is the angle of interest. The angle is a function of the GSO separation, as well as the sensor mean anomaly.

FIGURE 6

Off-bore sight angle from GSO to passive sensor

View from GSO
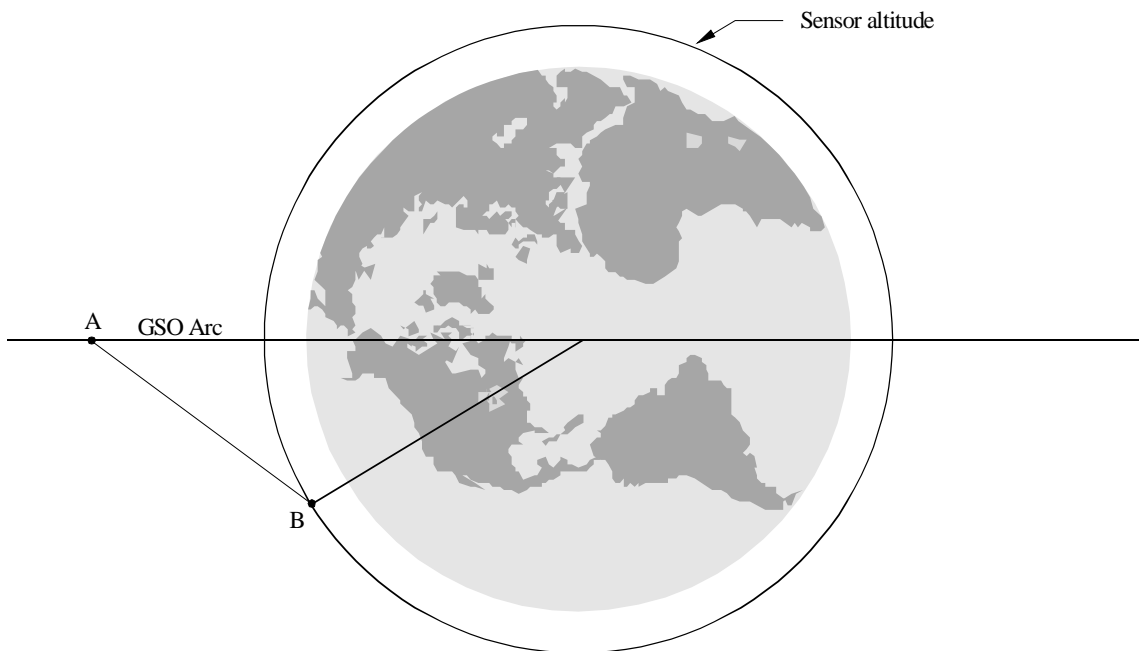
A: GSO ISS station aiming point

B: passive sensor is at this point

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3.3   Method for calculation of pfd from a GSO ISL measured at a latitude on the sensor orbital sphere

To calculate the pfd from a GSO ISL measured at a given latitude on the sensor orbital sphere, the terminology is found in Table 5.

TABLE 5

pfd methodology terminology

Symbol	Definition
Inputs	
$\Delta\Omega$	Orbital separation between two GSO satellites (degrees)
λ	Sub-satellite latitude, assuming spherical Earth (absolute value) (degrees)
r_{GSO}	Radius of GSO (km)
$r_{sens.}$	Radius of sensor orbit (km)
i_{GSO}	Inclination of GSO plane (absolute value) (degrees)
P	Transmit power of GSO ISL in a 100 MHz reference bandwidth (dBW in 100 MHz)
$G(\theta)$	Off-axis antenna gain of GSO ISL transmitter (dB)
Intermediate values	
λ'	Effective sub-satellite latitude, compensating for GSO inclination (degrees)
b	1/2 distance between two GSO satellites (km)
z	Distance from midpoint of GSO ISL to nearest point on sensor orbital sphere at latitude λ' (km)
h	Vertical distance from sensor at latitude λ' to GSO plane (km)
a_2	Horizontal distance from sensor at latitude λ' to Earth's rotational axis (km)
a_1	Horizontal distance from sensor at latitude λ' to midpoint of GSO ISL (km)
Outputs	
R	Distance from GSO ISL transmitter to link's closest approach point on sensor orbital sphere at latitude λ' (km)
θ	Off-axis angle from GSO ISL transmitter to tangent point on sensor orbital sphere at latitude λ' (degrees)
pfd	pfd from GSO ISL measured at tangent point on sensor orbital sphere at latitude λ' (dB(W/m^2) in 100 MHz)

The pfd from an ISL between GSO satellites to a latitude on the sensor's orbital sphere is measured at the link's closest approach to the sensor's orbital sphere, as shown in Fig. 7.
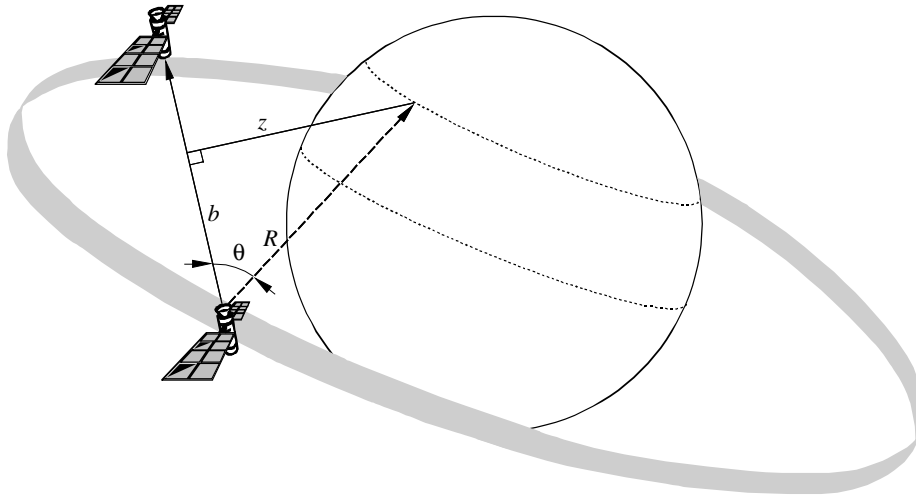
As shown in Fig. 8, b is half of the distance between the transmitting GSO satellite and the receiving GSO satellite, given by:

$$b = {}_{GSO} \sin(\Delta\Omega/2) \qquad \text{km}$$

The effective subsatellite latitude λ' is computed, to compensate for the inclination of the GSO plane:
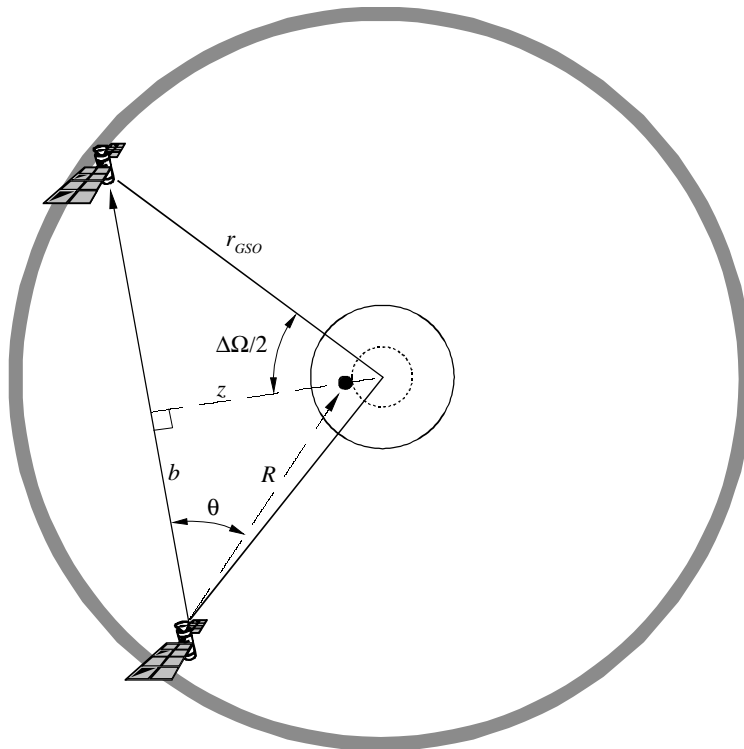
$$\lambda' = \begin{cases} \lambda - i_{GSO} & \text{if } \lambda \geq i_{GSO} \\ i_{GSO} & \text{otherwise} \end{cases}$$

FIGURE 7

GSO ISL closest approach

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FIGURE 8

Polar view for distance *b*

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The length of a_1, shown in Fig. 9, is:

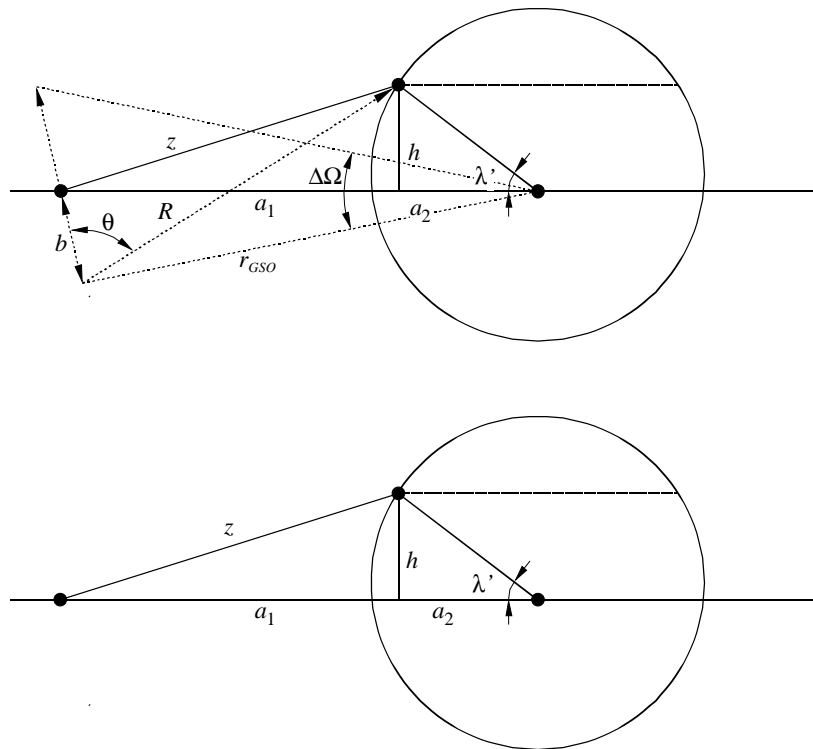$$a_1 = \sqrt{r_{GSO}^2 - b^2} - a_2 \qquad \text{km}$$

where:

$$a_2 = r_{sens.} \cos \lambda' \qquad \text{km}$$

By substitution:

$$a_1 = \sqrt{r_{GSO}^2 - b^2} - r_{sens.} \cos \lambda' \qquad \text{km}$$

FIGURE 9

View along GSO plane for distance a_1

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The distance h of the sensor from the GSO plane is:

$$h = r_{sens.} \sin \lambda' \qquad \text{km}$$

so the shortest distance z from the ISL to the sensor's orbital sphere at latitude λ' is:

$$z = \sqrt{a_1^2 + h^2} \qquad \text{km}$$

The distance R from the GSO ISL transmitter to the point on the sensor sphere closest to the ISL is:

$$R = \sqrt{z^2 + b^2} \qquad \text{km}$$

and the off-axis angle from the GSO ISL transmitter is:

$$\theta = \text{tg}^{-1} (z/b) \qquad \text{degrees}$$

The pfd calculated at the sensor sphere at latitude λ is therefore given by:

$$pfd = \begin{cases} P + G(\theta) - 10 \log\left(4\pi(R \times 1000)^2\right) \\ P + G(\theta) - (20 \log R + 20 \log 1000 + 10 \log 4\pi) \\ P + G(\theta) - 20 \log R - 71 \qquad \text{dB (W/m}^2\text{) in 100 MHz} \end{cases}$$

where $G(\theta)$ is the off-axis gain of the GSO ISL transmitter antenna. Table 6 shows the results of a sample calculation.

TABLE 6

pfd calculation

Inputs	
$\Delta\Omega$ (degrees)	150
λ (degrees)	49.0
r_{GSO} (km)	42 164
$r_{sens.}$ (km)	7 378
i_{GSO} (degrees)	2
P (dBW in 100 MHz)	2.8
Maximum gain (dBi)	58.5
G(θ) (dB)	See G (ψ) in Rec. ITU-R S.672, Annex 1
Outputs	
R (km)	41 502
θ (degrees)	11.1
$G(\theta)$ (dB)	8.2
pfd (dB(W/m^2) in 100 MHz)	–152.3

3.4 Methodology to compute the latitude of sensor when pointing at the GSO arc

One of the inputs to the previous methodology on pfd calculation is λ, the latitude of the spacecraft when pointing at the GSO arc. This methodology provides the necessary angle λ.

A passive sensor in low-Earth orbit needs to perform a cold space calibration. It accomplishes this task by pointing its antenna away from the Earth and sun, at an angle α with respect to the plane of its orbit. The problem occurs when the combination of calibration angle α and position in the sensor orbit causes the calibration path to intersect the GSO arc. The goal of this test is to find, for a given geometry, the locations in the sensor orbit where this can occur.

Given:

    $r_{sens.}$:   the radius of the sensor orbit

    $i_{sens.}$:   the inclination of the sensor orbit

    i_{GSO} :   the inclination of the GSO plane

    φ :   the sensor calibration angle

    r_{GSO} :   the radius of the geostationary orbit

find λ, the latitude of the sensor when calibration can intersect the GSO arc.

The calibration is always directed at a point C as indicated in Fig. 10.

FIGURE 10

Geometry for calculating sensor latitude

Sensor orbital plane

GSO plane
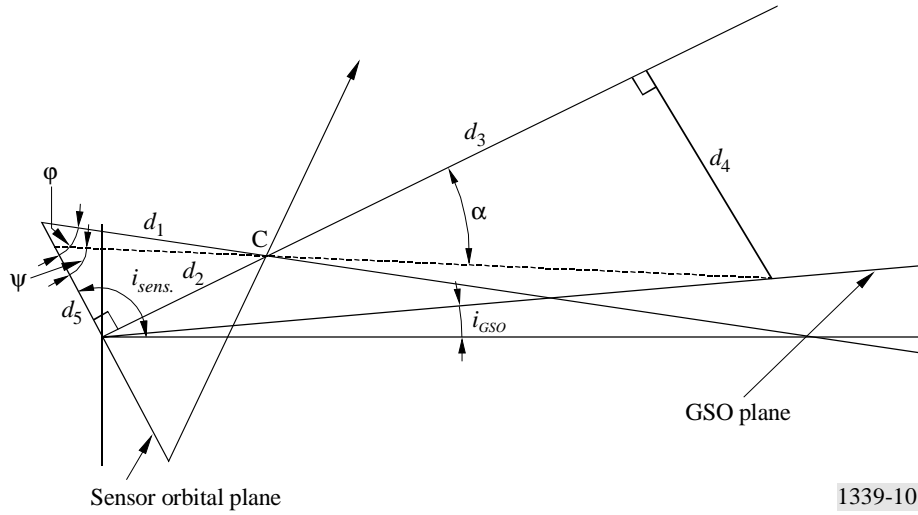
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The distances and angles are found by the method below.

FIGURE 11

Sensor latitude angle

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$$d_1 = \frac{r_{sens.}}{\cos \varphi}$$

$$d_2 = d_1 \sin \varphi$$

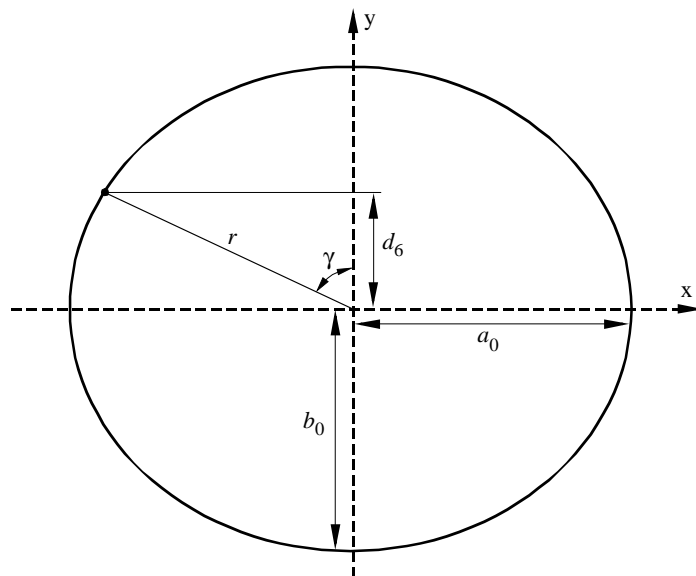$$d_3 = r_{GSO} \cos\left(i_{sens.} - 90° - i_{GSO}\right)$$

$$d_4 = r_{GSO} \sin\left(i_{sens.} - 90° - i_{GSO}\right)$$

$$\alpha = tg^{-1}\left(\frac{d_4}{d_3 - d_2}\right)$$

$$\psi = 180° - (90° + \alpha)$$

$$d_5 = d_2\left(\sin \alpha / \sin \psi\right)$$

$$d_6 = d_5 \cos\left(i_{sens.} - 90°\right)$$

Now solving for the angle γ, as in Fig. 11

$$x = r \sin \gamma$$
$$y = d_6$$

$$\frac{r^2 \sin^2 \gamma}{a_0^2} + \frac{d_6^2}{b_0^2} = 1$$

where:

$$a_0 = r_{sens.}$$
$$b_0 = r_{sens.} \cos \left(i_{sens.} - 90° \right)$$

and r is as shown in Fig. 11.

By substitution:

$$\frac{r^2 \sin^2 \gamma}{r_{sens.}^2} = 1 - \frac{d_6^2}{\left[r_{sens.} \cos \left(i_{sens.} - 90° \right) \right]^2}$$

Since:

$$r^2 = d_6^2 + x^2 = d_6^2 + r^2 \sin^2 \gamma$$
$$r^2 = \frac{d_6^2}{\left(1 - \sin^2 \gamma \right)}$$

Therefore:

$$\frac{\sin^2 \gamma}{r_{sens.}^2 \left(1 - \sin^2 \gamma \right)} = \frac{1}{d_6^2} - \frac{1}{\left[r_{sens.} \cos \left(i_{sens.} - 90° \right) \right]^2}$$

$$\frac{\sin^2 \gamma}{1 - \sin^2 \gamma} = \frac{r_{sens.}^2}{d_6^2} - \frac{1}{\cos^2 \left(i_{sens.} - 90° \right)}$$

$$\operatorname{tg}^2 \gamma = \frac{r_{sens.}^2}{d_6^2} - \frac{1}{\cos^2 \left(i_{sens.} - 90° \right)}$$

$$\gamma = \operatorname{tg}^{-1} \sqrt{\frac{r_{sens.}^2}{d_6^2} - \frac{1}{\cos^2 \left(i_{sens.} - 90° \right)}}$$

$$\lambda = 90° - \gamma$$

Table 7 shows the results of a sample calculation.

TABLE 7

Sample latitude calculation

Inputs	
Sensor inclination (degrees)	100.1
Sensor altitude (km)	1 000
Calibration angle (degrees)	70.0
GSO inclination (degrees)	2.0
Output	
Latitude where sensor's main beam intersects the GSO arc (degrees)	49.0

3.5 pfd at altitudes less than 1 000 km

The discrimination from a typical ISS GSO system (pointed at the 1 000 km altitude) is illustrated in Fig. 12. If a sensor is in orbit lower than 1 000 km, a complementary relaxation of the pfd may be made.
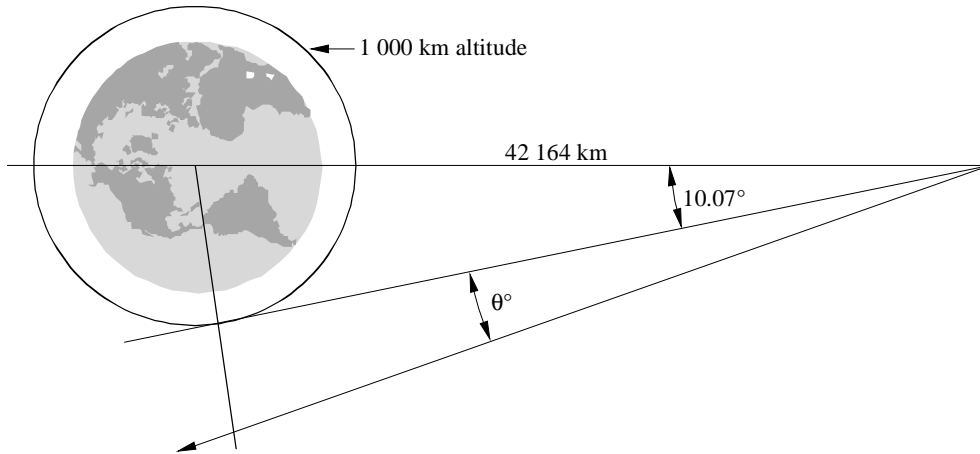
FIGURE 12

Discrimination of typical GSO ISS system from 1 000 km

(maximum pfd at 1 000 km)
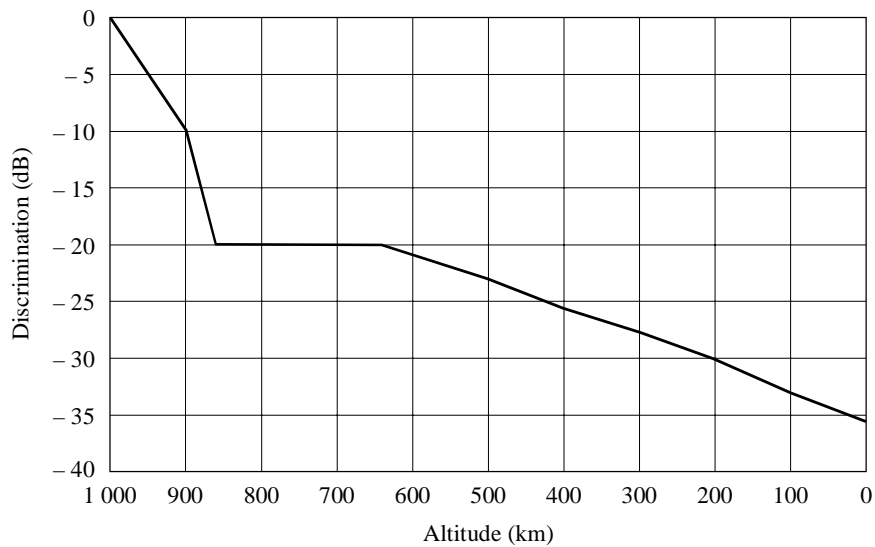
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3.6 pfd impact on GSO ISS systems

A pfd threshold would limit the separation angle for some GSO ISS systems, as illustrated in Fig. 13.

FIGURE 13

View from the North Pole, angle to 1 000 km

θ°: Angle required to meet pfd at 1 000 km altitude

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Table 8 lists the maximum allowed orbital separation, as a function of theoretical design (line 1). Also computed is the operational limitation (line 5) from a pfd of -128 and -147 dB(W/m^2) in 100 MHz, for the three systems which the theoretical design exceeds the pfd limit. This completes the analysis for case 1.

TABLE 8

Maximum separation angle for GSO ISS systems

Line	System	W1	W2A	W2B	W3A	W3B	W4	W5	W6	W7	W8
1	Theoretical orbital separation (degrees)	162.6	162.6	78.6	10.1	67.3	162.6	53.9	111.1	77.4	136.4
2	pfd at 1 000 km (dB(W/m^2) in 100 MHz)	−102.2	−102.5	−172.2	−170.8	−168.4	−105.2	−166.8	−150.6	−157.2	−149.6
3	Sensor margin (dB)	−21.8	−21.5	48.2	46.8	44.8	−18.8	42.8	24.4	33.2	25.6
4	Separation limitation (degrees) to meet pfd limit of −128 dB(W/m^2) in 100 MHz	158.3	158.5	–	–	–	159.3	–	–	–	–
5	Separation limitation (degrees) to meet pfd limit of −147 dB(W/m^2) in 100 MHz	146.5	148.2	–	–	–	149.1	–	–	–	–

Some GSO ISS system may desire to operate with longitudinal separations of up to 162.6°. However, when pfds of -128 to -147 dB(W/m^2) in 100 MHz are required, typical GSO ISS systems may be required to operate at smaller separations.

3.7   Conclusions with regard to analytic development of a pfd for GSO ISS

It was shown that a single entry pfd value of -147 dB(W/m^2) in 100 MHz will protect spaceborne passive sensors for all configurations of sensors and GSO ISS systems. A relaxation of this value (on the order of 10-20 dB) may be achieved, depending on the characteristics of the specific systems studied.

4   Conclusions

In this Annex, methods were presented for calculating the interference into a low-Earth orbiting sensor satellite. These methods can be used to calculate the required criteria to meet the interference levels contained in Recommendation ITU-R SA.1029. A minimum pfd level was developed that would protect all sensors from interference in all configurations. A pfd limit of -147 dB(W/m^2) in 100 MHz is sufficient to protect passive sensors from interference in all configurations of passive sensors and GSO ISS systems. For specific configurations of GSO ISS systems and passive sensors, this value may be relaxed 10 to 20 dB.

It was also shown that sensors with calibration angles of between 75° and 85° from nadir will never take a calibration reading toward the GSO arc. Thus, a design objective of these sensors to utilize an 80° calibration angle (as in the AMSU sensor) will enhance sharing with the GSO ISS.

Analysis was presented on the interference of existing systems into proposed passive sensors. The analysis considered sensors operating in the EESS (passive), in an orbit with altitude less than 1 000 km, and sun synchronous orbit inclination (close to 98.7°). In the Earth sensing mode, sensors are protected from emissions of GSO transmitters, via the sensor antenna back lobe. However, these sensors must take a "cold calibration reading" toward deep space, and in this mode there is a possibility of interference from GSO transmitters.