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Study on compatibility between the mobile service (aeronautical) and the space research service (space-to-Earth) in the frequency band 37-38 GHz

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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 SA.2190

Study on compatibility between the mobile service (aeronautical) and the space research service (space-to-Earth) in the frequency band 37-38 GHz

(2010)

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1 Introduction

Earth stations for the space research service (SRS) have very sensitive receivers. To protect these (deep-space and near-Earth) SRS earth stations from interference, the ITU has published protection criteria in Recommendation ITU-R SA.1157 for the 2 GHz, 8 GHz, 13 GHz and 32 GHz bands.

For the 37-38 GHz band, Recommendation ITU-R SA.1396 gives the SRS earth station protection criterion as −217 dBW/Hz not to be exceeded more than 0.1% of the time for unmanned missions and 0.001% of the time for manned missions. This limit is applicable for both the deep-space and near-Earth SRS missions.

The analyses in § 2 show that since the range of an aircraft transmitter is much less than the range of SRS missions (see Table 1), interference from a transmitter in the aeronautical mobile service (AMS) to an SRS earth station receiver can significantly exceed the SRS earth station protection criteria.

TABLE 1

Typical slant ranges from an earth station

	Slant range (km)	**Relative inverse square loss (dB)**
Aircraft at 12 km altitude, 60° elevation	14	0
LEO at 300 km altitude, 15° elevation	1 400	40
GEO	33 000	67
Deep space mission at minimum distance	2 000 000	102

Recommendation ITU-R SA.1016 provided an example of a narrow-band aeronautical mobile transmitter interfering with a space research earth station (space-to-Earth) (deep space) at frequencies up to 32 GHz. Given an aircraft transmitter with maximum e.i.r.p. density of 10 W/4 kHz (equivalent to −26 dBW/Hz), antenna gain of 0 dBi, and altitude of 12 km, the results in Annex 1 (see Table 3) of this Recommendation showed that the minimum interference received by the SRS earth station would exceed the protection criteria. Therefore, the Tables of Frequency Allocations in the ITU Radio Regulations have excluded aeronautical mobile in the frequency bands 2.29-2.3 GHz, 8.4-8.5 GHz, 22.21-22.5 GHz and 31.5-31.8 GHz, where the mobile service is co-allocated with the space research service. This Recommendation did not, however, consider very low power AMS systems.

The following sections will present the results of compatibility studies for a single AMS transmitter or multiple AMS transmitters for sharing the 37-38 GHz band by SRS and AMS.

2 Single-entry analyses

The interference from a single aeronautical mobile transmitter to the space research earth stations is analyzed for a narrow-band (NB) mode and a wideband (WB) mode.

For the narrow-band mode, the aircraft e.i.r.p. density is assumed to be 10 W/4 kHz, which is equivalent to −26 dBW/Hz. For the wideband mode, the aircraft e.i.r.p. density is assumed to be 70 W/10 MHz, which is equivalent to −51.5 dBW/Hz. For both narrow and wideband modes, two cases are analyzed:

Case 1

The aircraft altitude is 12 km and it is at 0-degree elevation relative to the SRS earth station, with a transmit antenna gain of 0 dBi towards the SRS earth station. Furthermore, the SRS earth station antenna is assumed to have a −10 dB gain in the direction of the aircraft, corresponding to a boresight separation angle greater than 48° (using the antenna gain pattern given in Recommendation ITU-R SA.509). This case represents the minimum interference from AMS transmitter to the SRS earth station.

Case 2

The aircraft altitude is 12 km and it is at 60-degree elevation relative to the SRS earth station, with a transmit antenna gain of 0 dBi towards the SRS earth station. Furthermore, the SRS earth station antenna is assumed to have a 0 dB gain in the direction of the aircraft, corresponding to a boresight separation angle of 19° (using the antenna gain pattern given in Recommendation ITU-R SA.509). This case represents a more typical interference.

Note that in Recommendation ITU-R SA.1016, the interference analyses were done using Case 1 for the narrow-band mode only. Here we have extended the link analyses in Recommendation ITU-R SA.1016 given for the frequency bands below 32 GHz to the 37-38 GHz band. Table 2 gives the results for Cases 1 and 2 using the narrow- and wideband modes.

TABLE 2

Aeronautical mobile interference to space research service for narrow-band and wideband modes at 38 GHz

	Narrow-band (NB) mode		**Wideband (WB) mode**	
	Case 1	**Case 2**	**Case 1**	**Case 2**
Aeronautical mobile space station				
Transmitter power (W)	10		70	
Reference bandwidth (kHz)	4		10 000	
Aircraft antenna gain toward victim (dBi)	0		0	
Aircraft e.i.r.p. (dBW)	10		18.5	
e.i.r.p. density (dBW/Hz)	–26		–51.5	
Altitude (km)	12		12	
Elevation (degrees)	0	60	0	60
Slant range (km)	391	14	391	14
Space loss (dB)	176	147	176	147

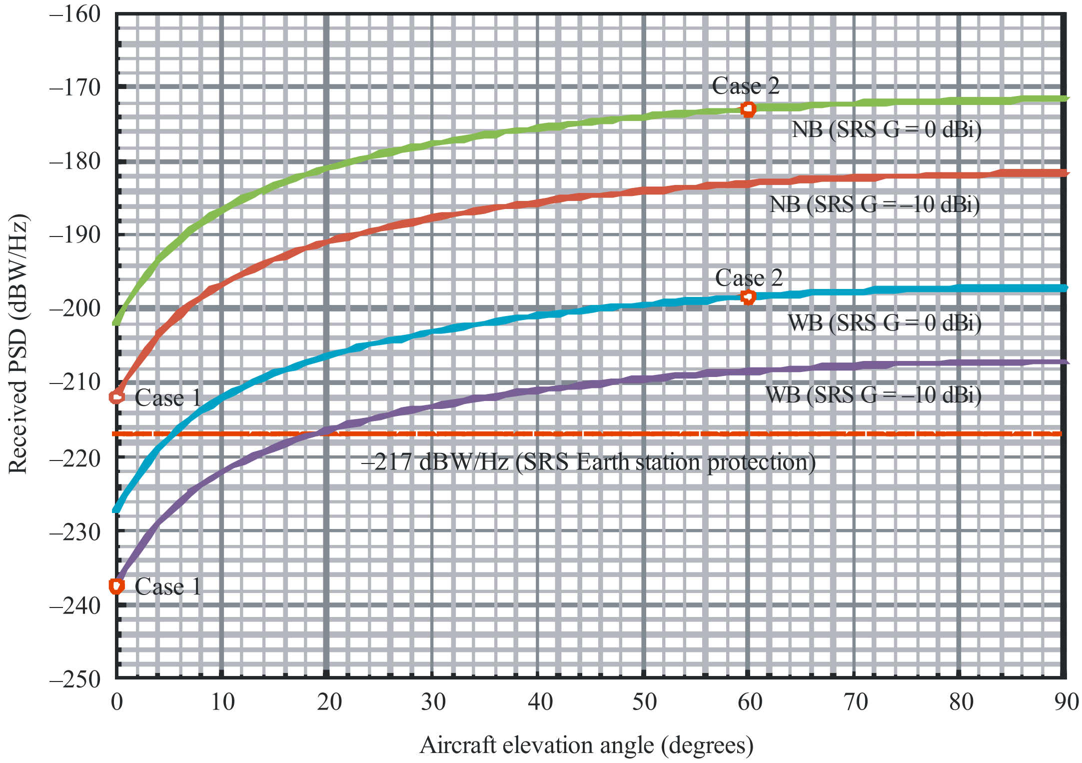
TABLE 2 (*end*)

	Narrow-band (NB) mode		**Wideband (WB) mode**	
	Case 1	**Case 2**	**Case 1**	**Case 2**
SRS earth station				
Victim antenna off-boresight angle (degrees)	≥ 48	19	≥ 48	19
Victim antenna gain toward interferer (Recommendation ITU-R SA.509) (dBi)	–10	0	–10	0
Maximum received PSD (dBW/Hz)	–212	–173	–237.5	–198.5
Protection criterion (deep-space and near-Earth) (Recommendation ITU-R SA.1396) (dBW/Hz)	–217			
Max received PSD exceedance above SRS protection criterion (deep-space and near-Earth) (dB)	5	44	–20.5	18.5

In Fig. 1, the received interference power spectral densities are plotted with respect to the aircraft elevation angle for narrow- and wideband modes. The figure also shows the Cases 1 and 2 points, which are analyzed in detail in Table 2.

FIGURE 1

Received power spectral density vs. aircraft elevation angle for the narrow-band and wideband modes



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In deriving the results shown in Fig. 1, we have used the parameters for the narrow- and wideband AMS transmitter modes with the receive antenna gains of –10 dBi and 0 dBi. The assumed aircraft altitude is 12 km. The figure also shows the deep-space earth station protection criterion for comparison.

2.1 Single-entry narrow-band transmitter mode

For the narrow-band mode, Table 2 above shows that in Case 1, the interferences will exceed the SRS protection criterion by 5 dB, whereas in Case 2, the interferences will exceed the SRS protection criterion by 44 dB. These interferences far exceed the protection criterion of space research earth stations for deep-space and near-Earth missions. Note that, for the narrow-band mode, the minimum expected interference is above the SRS earth station protection for all aircraft elevation angles (see Fig. 1).

2.2 Single-entry wideband transmitter mode

As shown in Table 2, for the wideband mode, we considered a possible aircraft transmission with 10 MHz bandwidth, at a carrier frequency less than 40 GHz, and with transmitter power of 70 W. The e.i.r.p. density for this wideband mode is calculated to be –51.5 dBW/Hz. This is 25.5 dB lower than the e.i.r.p. density of the narrow-band mode. As shown in Table 2, in Case 1, the interference levels will be below the protection criterion by 20.5 dB, but in Case 2, they will exceed the protection criterion by 18.5 dB. Note that, for the wideband mode, the minimum expected interference is above the SRS earth station protection when the aircraft elevation angle is greater than 19° (see Fig. 1)

2.3 Maximum AMS e.i.r.p. densities for single-entry case

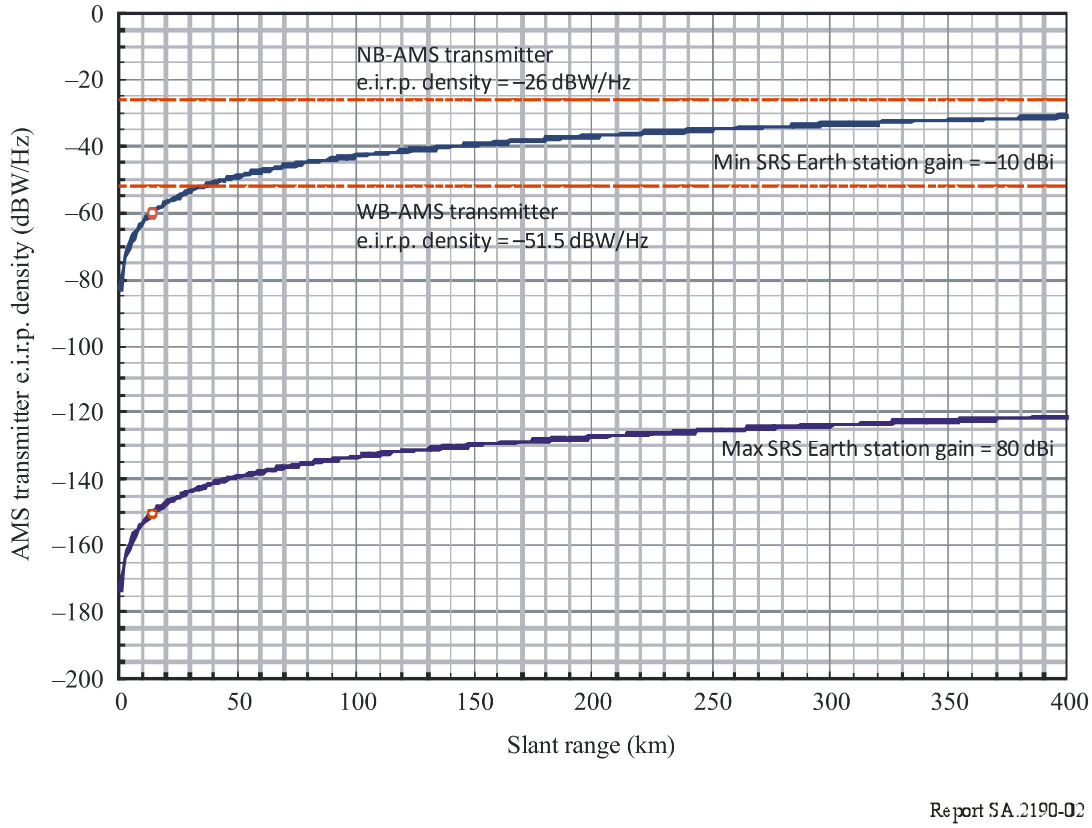
To bound the extent of the sharing situation, it is necessary to calculate the best and worst-case sharing scenarios. The interference power received at an SRS earth station is calculated by using the free space loss and the minimum gain of the SRS earth-station antenna, which results in a best case sharing scenario. By calculating this interference power received at different aircraft e.i.r.p. density levels as a function of slant range, it is possible to determine the maximum e.i.r.p. density allowed from the aircraft to satisfy the interference criteria. These results are in Fig. 2.

The maximum altitude of a typical aircraft is 12 km. If an aircraft is flying at an altitude of 12 km, the minimum slant range would be 12 km. From Fig. 2 we see that for this range, the maximum allowed aircraft e.i.r.p. density would be –60 dBW/Hz emanating from the aircraft. However, this best-case sharing scenario does not take into account the aircraft interfering with the earth station's main beam. In practice, SRS earth stations may track satellites in near-Earth orbit, lunar orbit, or deep-space missions, resulting in a wide variety of antenna pointing angles, and aircraft may fly in any number of directions, altitudes and speeds. Under these circumstances, it is reasonable to assume that the aircraft may be within the main beam of the SRS earth station antenna. Assuming a boresight antenna gain of 80 dB, the previous static link analysis is repeated. Results of this analysis are also shown in Fig. 2.

While an e.i.r.p. density of –60 dBW/Hz emanating from an aircraft is acceptable for the back lobe, the power level received in the main lobe will exceed the interference criteria by 90 dB. Purely on a static basis, in order to completely satisfy the interference power requirement for the SRS earth station's main lobe, an aircraft e.i.r.p. density of –150 dBW/Hz must not be exceeded, at an aircraft's maximum altitude of 12 km. Aircraft operating lower than a 12 km altitude will need lower e.i.r.p. emissions to meet the interference criteria in both the SRS earth station's main and back lobes. Since aircraft position and SRS earth station antenna pointing direction are both changing dynamically, the limit of aircraft's e.i.r.p. should be determined statistically, using a dynamic simulation.

FIGURE 2

Max AMS e.i.r.p. densities for mininimum (–10 dBi) and maximum (80 dBi) SRS antenna gains to meet the SRS earth station protection



2.4 Interference time duration

2.4.1 Static link considerations

In the narrow-band mode, as discussed in § 2.1, interference from a single aeronautical mobile station is above the space research earth station protection criteria for all elevation angles of the aircraft and for all pointing directions of the earth station antenna (see Figs 1 and 2). Therefore, the interference is expected to exceed the SRS earth station protection criteria 100% of the time.

In the wideband mode, as discussed in § 2.2, the interference under the same geometry will be 25.5 dB weaker than the corresponding narrow-band mode. Therefore, for low elevation angles (less than 19°) when the slant range is large the received interference PSD would be less than the SRS earth station protection (see Figs 1 and 2). However, if the aircraft elevation is greater than 19° the interference PSD would exceed the protection for all pointing direction of the SRS earth station antenna. Using these facts, it is estimated that the interference levels would exceed the protection criterion for about 70% of the time.

2.4.2 Dynamic simulation

The SRS earth station can track different types of missions, such as polar orbiting spacecraft, manned spaceflight in Earth orbit, lunar missions, and deep-space missions. Each of these applications requires different earth station requirements, and will involve different antenna elevation, azimuth, and speed characteristics.

Two simulation scenarios investigating the interaction between an aircraft and either a polar orbiting lunar satellite or a polar orbiting satellite were used in order to calculate the interference power received at the SRS earth station. The simulations consist of an earth station, the particular SRS mission, and a single aircraft transmitter. Simulation configuration details are summarized in Table 3.

TABLE 3

Dynamic simulation parameters

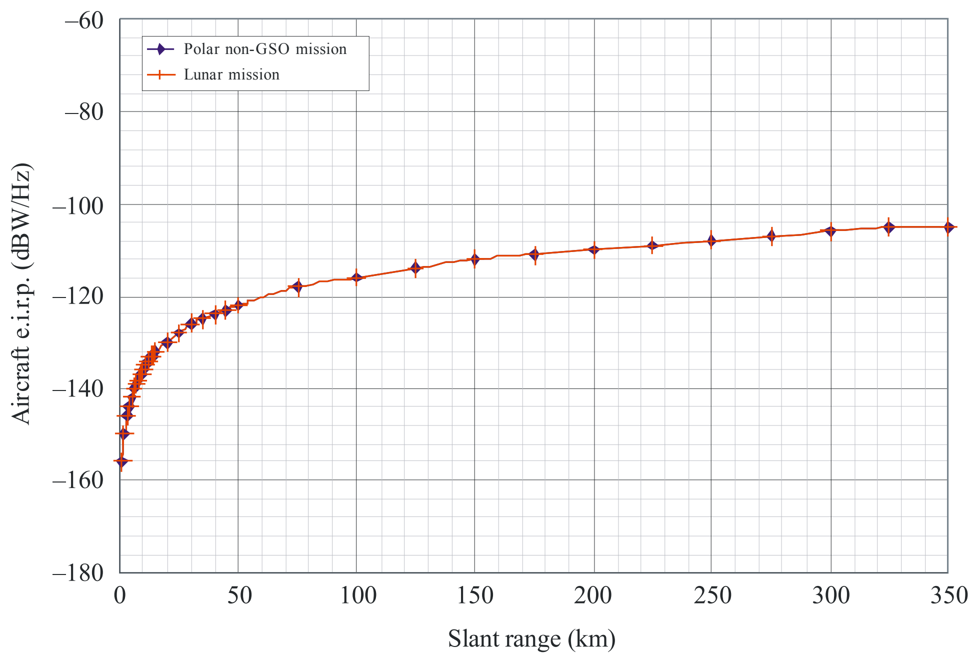
SRS earth station parameters	
Latitude	40.4° N
Longitude	4.3° W
Antenna pattern	Recommendation ITU-R S.465-5
Antenna gain	80 dB
Antenna diameter	34 m
Antenna efficiency	55%
Lunar satellite parameters (referenced to the Moon)	
Altitude	50 km
Orbital period	2 h
Inclination	90°
Non-GEO satellite parameters	
Altitude	703 km
Orbital period	98.8 min
Inclination	98.2°
Aircraft parameters	
Altitude	0-12.2 km
Slant ranges from SRS earth station	1-350 km
Elevation at SRS earth station	0°-90° (provided aircraft altitude is less than 12.2 km)
Aircraft elevation increment	1° (Slant range ≤ 100 km) 2° (Slant range > 100 km)

Data is collected in order to get a view of the interference caused by the aircraft transmitter. The aircraft is initially placed at 90° elevation and a heading of 0° with respect to the earth station for a particular slant range. Using data from § 2.3, an initial aircraft transmission e.i.r.p. density of –60 dBW/Hz was chosen, and then the simulation is run over one year, the aircraft's power is then reduced and the simulation is re-run at the new power level, until the aircraft system meets the SRS earth station protection criterion. Then the aircraft elevation is decreased, at the same slant range. Only values with an aircraft altitude of 12.2 km or less are considered in this analysis. The process is repeated for subsequent azimuth angles at 10° increments until a full circle has been completed, for a particular slant range.

Results of this simulation provide information based on a static aircraft and a dynamic SRS earth station antenna. For each slant range the case that causes the most interference is selected. Figure 3 plots the relationship of aircraft e.i.r.p. density and slant ranges from 1 km to 350 km while meeting the SRS earth station protection criterion for the manned spaceflight. The aircraft e.i.r.p. density that conforms to the criteria at all slant ranges studied is –156 dBW/Hz. Figure 3 shows that, in general, the maximum allowed e.i.r.p. density decreases as the slant range decreases.

FIGURE 3

Maximum aircraft e.i.r.p. density vs. slant range while meeting SRS earth station protection



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The PFD spectral density received at the earth station is also calculated for the points selected in Fig. 3. Due to the selection process to ensure that an aircraft's transmission would not exceed the SRS earth station protection criterion, the resulting PFD spectral density data is fairly similar along all elevation angles, and vary slightly with range. The PFD spectral density received at an earth station during the lunar orbiting mission simulation has a maximum value of –226.2 (dBW/Hz)/m^2, and a minimum value of –227.0 (dBW/Hz)/m^2.

Similarly, the PFD spectral density received at the earth station during the polar orbiting mission simulation has a maximum value of –226.2 (dBW/Hz)/m^2, and a minimum value of –227.1 (dBW/Hz)/m^2.

2.5 Interference to the planned SRS mission ASTRO-G

A Space-VLBI satellite, named ASTRO-G, enables high-resolution celestial observations through its onboard radio telescope. It is planned to be launched in 2012.

ASTRO-G conducts studies of regions where extreme physical conditions are encountered, and its instruments are consequently designed to realize the following science goals:

i) the structures and magnetic field configurations of accretion disks in nearby active galactic nuclei (AGNs);

ii) the mechanism of jet acceleration and collimation;

iii) the motion of masers in galactic star forming regions;

iv) the study of proto-stellar magnetospheres;

v) the structures and magnetic fields of accretion disks in active galactic nuclei.

To achieve an order of magnitude higher sensitivity for continuum sources, VLBI data needs to be down-linked in real-time at 1 Gbit/s using the 37-38 GHz band. ASTRO-G follows Recommendation ITU-R SA.1344 – Preferred frequency bands and bandwidths for the transmission of space VLBI data.

Table 4 summarizes link performance when the ASTRO-G downlink has AMS transmitter interference. As shown in the table, when ASTRO-G is at its apogee orbital position and the SRS earth station tracks ASTRO-G in the zenith direction, link margin of 6.0 dB is secured.

However, as also shown in the table, when the AMS transmitter signal comes in the same direction as ASTRO-G, the link margin degrades to –92.85 dB.

Link margin can be secured when the AMS transmitter signal is received with SRS antenna boresight separation angle of 86°, which corresponds to a distance of about 172 km from the SRS station. In this case, the time period when ASTRO-G is being interfered with is about 23 min for flight speed of Boeing 747 (time calculation for distance of 170 km × 2).

The above analysis result is for the AMS transmitter narrow-band mode. For the wideband mode, link margin can be secured until the boresight separation angle becomes more than 31°, where distance from the SRS station is about 7.2 km with an interference time of about 1 min.

As the on-board data production rate of ASTRO-G is 1 Gbit/s, which is too large to store the data on the on-board recorder, several SRS stations around the world are necessary for downlinking the SVLBI data in real time. The SRS stations currently planed are Usuda in Japan, Yebes in Spain, and one or two more sites in southern hemisphere, such as Australia and/or South Africa. Interference with any of these stations jeopardizes the observations.

ASTRO-G will be placed in an elliptical orbit with an apogee height of 25 000 km above the Earth's surface and a perigee height of 1 000 km. The orbit period is about 7.5 h. Since ASTRO-G will conduct VLBI observation over an orbital location of more than 5 000 km height above the Earth's surface when the SRS antenna motion is slow, ASTRO-G is vulnerable to the AMS transmitter during this observation period in terms of both the time duration interfered and strength of interference signal. When the SRS antenna tracks ASTRO-G at a lower elevation angle, the duration of interference becomes longer and rain attenuation becomes larger, resulting in larger data loss.

Also noted is that ASTRO-G establishes a continuous two-way phase link, measuring round trip phase difference from the prediction. In this measurement, as the SVLBI system estimates the onboard clock time by integrating two-way phase variation data, any break of the phase link results in the necessity of resetting the timing system at the SRS station. Therefore, frequent short link breaks may cause all the measurement data useless.

TABLE 4

Interference from AMS transmitter into ASTRO-G downlink at 37-38 GHz

ASTRO-G to SRS station			
Frequency (MHz)	37 536		
ASTRO-G transmitter power (dBW)	12.0		
ASTRO-G antenna gain (dBi)	38.6		Includes feeder loss and pointing loss
ASTRO-G e.i.r.p. (dBW)	50.6		
Distance (km)	25 000		ASTRO-G at apogee and tracking at EL = 90°
Space loss (dB)	211.9		
Polarization loss (dB)	0.4		
Atmospheric loss (dB)	1.2		Includes rain loss
SRS earth station antenna gain (dBi)	62.0		Includes feeder loss
Pointing loss (dB)	0.4		
Received signal level "C" (dBW)	–101.3		
SRS receiver system noise temperature (K)	104.0		
N_0 (dBW/Hz)	–208.4		
Received C/N_0 (dBW/Hz)	107.1		
Required C/N_0 (dBW/Hz)	101.1		QPSK
Margin without interference (dB)	**6.0**		
Interference to SRS station (Aircraft in the same direction of ASTRO-G (worst case))			
	Narrow-band	Wideband	
Aircraft transmitter power (dBW)	10.0	18.5	
Aircraft antenna gain (dBi)	0.0		
Slant range (km)	12.0		
Space loss (dB)	145.5		
SRS earth station antenna gain (dBi)	62.0		Aircraft received from same direction of ASTRO-G
Interference level (dBW)	–73.5	–65.1	
Bandwidth (kHz)	4	10 000	
Interference PSD "I_0" (dBW/Hz)	–109.5	–135.1	Average power per 1 Hz
Received $C/(N_0 + I_0)$ (dBW/Hz)	8.2	33.8	
Required C/N_0 (dBW/Hz)	101.1	101.1	QPSK
Margin (dB)	–92.9	–67.3	Worst case

TABLE 4 (*end*)

ASTRO-G to SRS station			
Aircraft interference from boresight separation angle			
Boresight separation angle from zenith direction (degrees)	86	31	Angle when link becomes marginal
SRS earth station antenna gain (dB)	–10.0	–5.3	Gain corresponding to boresight separation angle
Aircraft range to SRS station (km)	172	14	
Time period of interference	23 min	1 min	

3 Multiple-entry analysis

3.1 Methodology summary

The methodology used for multiple-entry study is basically a Monte-Carlo simulation. The interference power produced at the SRS earth station input by all aircraft is calculated and compared to the SRS protection criterion. Several experiments are done, with varying the aircraft position, as well as varying the SRS earth station pointing direction. The percentage of time when the criterion is exceeded is then calculated.

In order to have a uniform distribution of the pointing directions of the SRS station over the hemisphere, the sky is divided in cells of equal solid angles, as depicted in the epfd methodology widely used for radio astronomy in Recommendation ITU-R M.1583-1.

The aircraft are deployed on actual air-routes. Their position on these routes is chosen randomly.

3.2 SRS station parameters

In order to reuse simulation modules already developed and validated for the sharing studies between AMSS and FS or RAS systems prior to 2003, an SRS station location in France was chosen. The coordinates are:

Latitude: 48.5° Longitude: 2°

It is recognized that France does not have any SRS deep-space station. However, the methodology may be transposed to for example Spain, with the same results.

The antenna gain pattern shown in Fig. 4 is based on the Recommendation ITU-R SA.1811 (Ja gain model), with an antenna diameter of 34 m, an efficiency of 0.7, and a surface tolerance value of $h_{RMS} = 0.35$ mm.

3.3 Air-traffic model parameters

The air-traffic assumptions are the same as in the sharing study between AMSS and FS and between AMSS and RAS performed before 2003. Figure 5 shows the air-routes simulated.

FIGURE 4

SRS earth station antenna pattern (d = 34 m, eff. = 0.7, h_{RMS} = 0.35 mm)

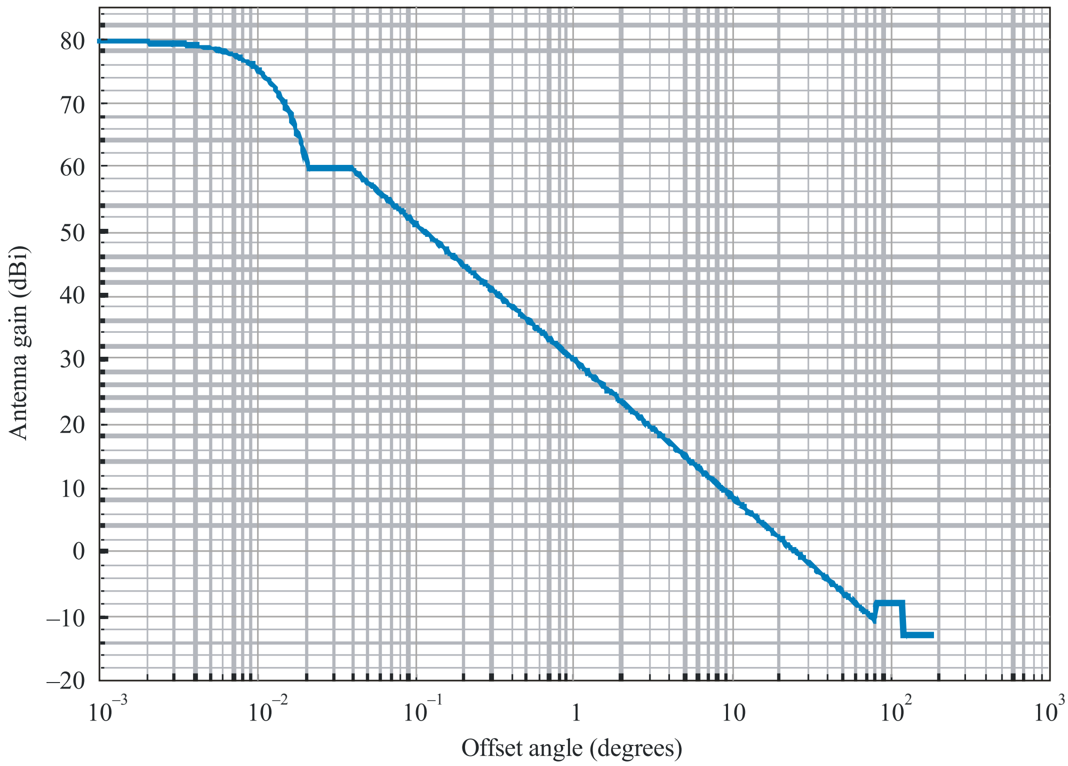

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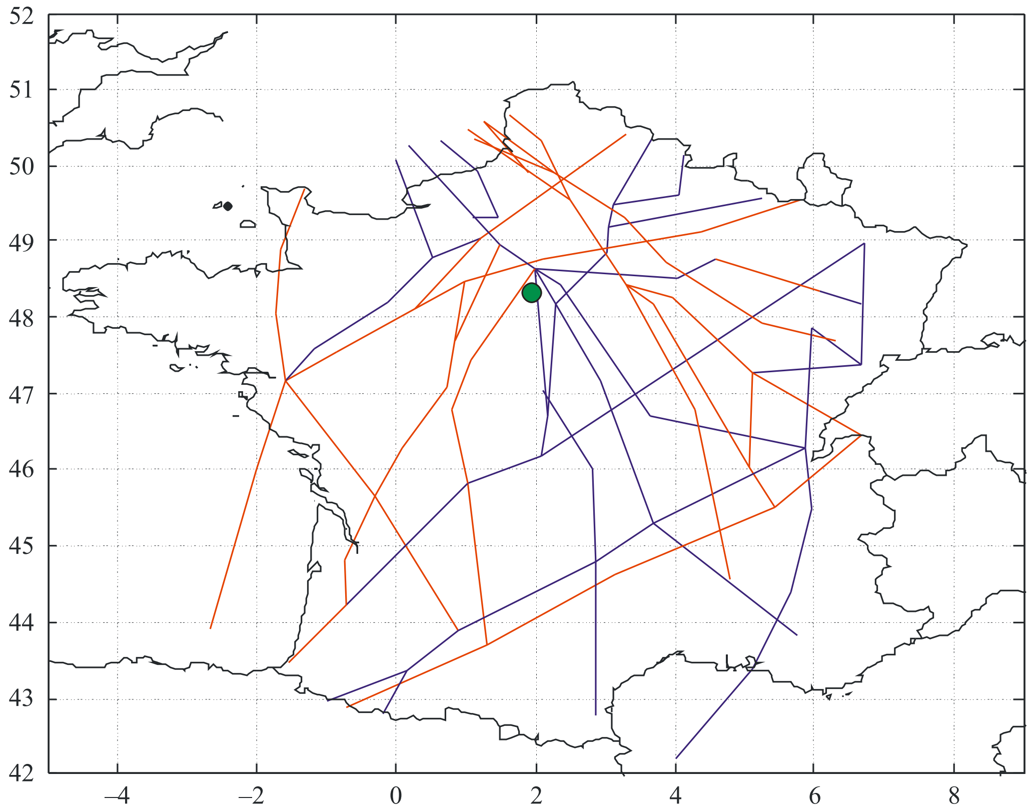
FIGURE 5

Air-routes considered for simulation



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The total number of aircraft deployed is set at 50. Their altitude is randomly chosen up to 10 000 m.

3.4 Simulation description and results

The simulation developed consists of the following steps:

1. Place a specific number of aircraft over a country on the selected air routes. The interference study used 50 aircraft.
2. Divide the sky into cells of approximately equal solid angles. The interference study used 2 334 cells.
3. Choose a random SRS antenna pointing direction for each cell.
4. Taking into account the AMS and SRS characteristics, compute the aggregate interference power into the SRS station, using:

$$I = 10\log\left(\sum_{i=1}^{Nplanes} \frac{pfd(i)G_{SRS}(i)\lambda^2}{4\pi L_{gas}(i)}\right)$$

where:

$pfd(i)$: PFD spectral density generated at the SRS earth station location by aircraft i assuming free space loss only ((W/Hz)/m^2)

$G_{SRS}(i)$: SRS earth station antenna gain in the direction of aircraft i (as a ratio)

$L_{gas}(i)$: atmospheric attenuation for aircraft i (as a ratio)

λ: wavelength (m).

The PFD spectral density generated by each aircraft at the SRS earth station is calculated from the aircraft elevation angle as seen from the SRS earth station and its altitude.

5. Compare the interference power calculated in Step 4 with the SRS earth station protection criterion (§ 3.2).
6. Repeat Steps 1 to 5 to get a given number of experiments (at least 100 times in order to get representative time statistics for unmanned missions, 2 000 times for manned missions).
7. Determine for each cell the percentage of experiments where the SRS earth station protection criterion has been exceeded and average it over all cells.
8. Compare this number with the SRS percentage of time criterion.

Using these steps, it is determined that the PFD spectral density limit given below just meets the –217 dBW/Hz interference PSD with 0.001% exceedence probability:

$-174 - 10.6 \cdot \theta$	(dBW/Hz)/m^2	for	$\theta \leq 5°$
-227	(dBW/Hz)/m^2	for	$5° < \theta \leq 90°$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal). It is plotted in Fig. 6.This limit relates to the PFD spectral density that would be obtained assuming free-space loss and aircraft fuselage loss for the AMS transmitters that are inside the aircraft.

For the PFD spectral density limit given in Figs 6 and 7 shows an example distribution of the interference power density over the sky divided into 2 334 cells of equal solid angle for one single experiment.

FIGURE 6

PFD spectral density limit to be met by each AMS transmitter at each SRS earth station

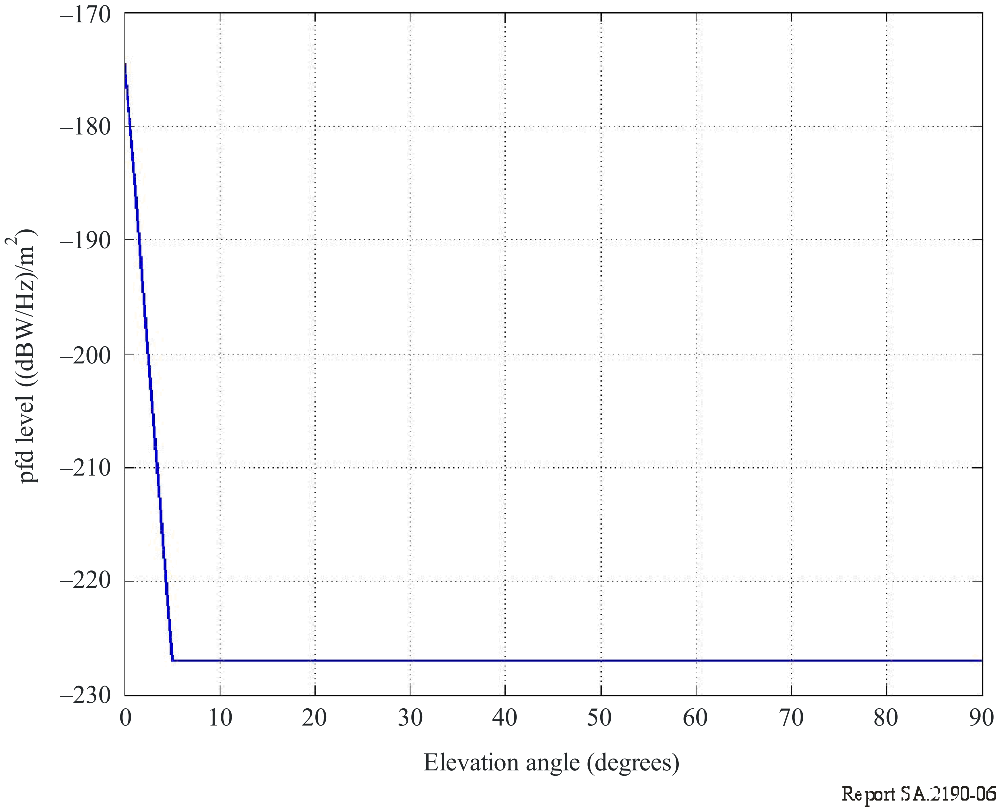
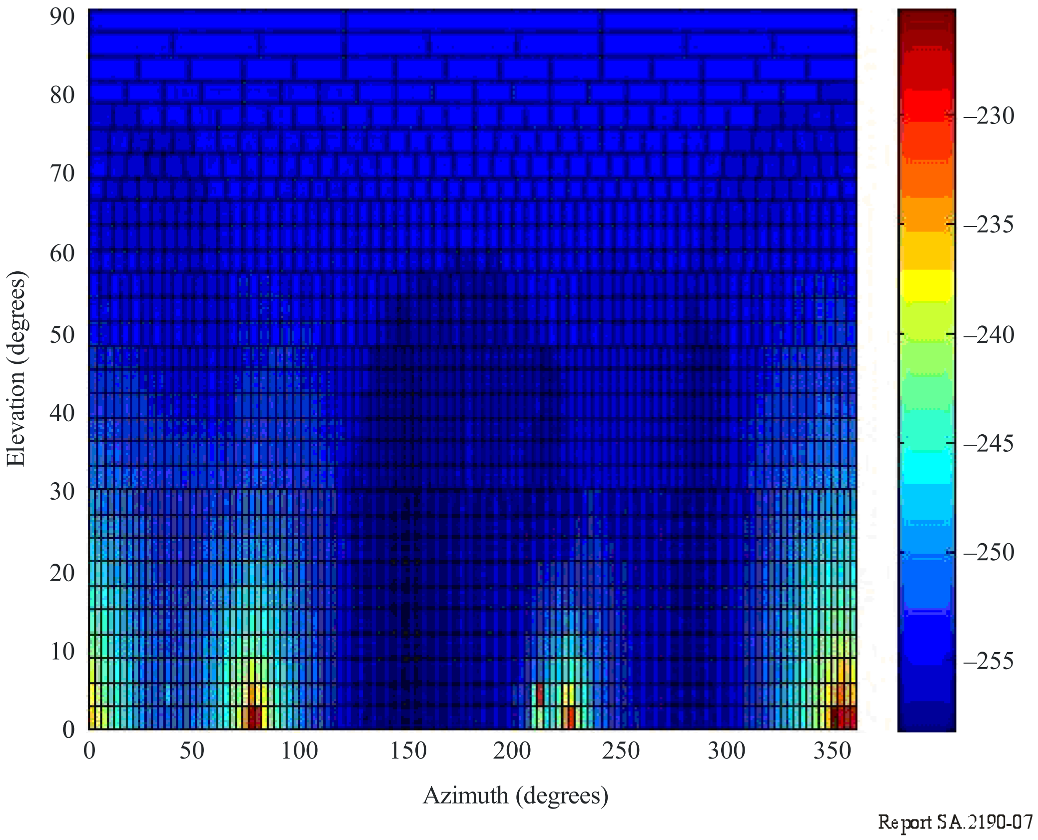


FIGURE 7

Interference power (dBW/Hz) for one single experiment



In practice, for a complete interference analysis 2 000 experiments are performed, which gives an overall number of 4 668 000 samples for the Monte-Carlo simulation.

4 Compatibility of low power AMS systems with the PFD spectral density mask

Although high power aircraft transmitters of the AMS system will cause excessive interference to the SRS and FSS earth stations, it is necessary to assess whether very low power AMS transmitters within an aircraft could meet the protection criteria of SRS, FSS and FS.

For example, the aviation industry is anticipating a growing demand for wireless avionics intra-communications (WAIC) systems to be installed on-board aircraft. These systems are envisioned to be very low power, and are intended to support data, voice, and video communications between various systems in an aircraft. They are not intended to provide air-to-ground, air-to-satellite, or air-to-air communication. They will include wireless sensors located at various points throughout the aircraft that monitor the health of the aircraft structure and many of its critical systems, and communicate this information within the aircraft.

There are basically four types of WAIC applications.

– High data rate for indoor applications (HI)

– High data rate for outdoor applications (HO)

– Low data rate for indoor applications (LI)

– Low data rate for outdoor applications (LO).

Since the low data rate applications are limited to frequencies up to 10 GHz, Only the high data rate applications are considered here. At 37 GHz the total power for HI WAIC applications would range from 25 to 39 dBm, and the power spectral density from –8 dBm/MHz to 16 dBm/ MHz. Similarly, the power spectral density for HO WAIC applications would range from –16 dBm/ MHz to 8 dBm/MHz.

Tables 5 and 6 give the e.i.r.p. density limits for an aircraft at 10 000 m altitude, derived from the PFD spectral density mask defined in § 2, assuming respectively an indoor WAIC application (HI) with a 20 dB fuselage attenuation, and an outdoor WAIC application (HO). Tables 7 and 8 give the same for an aircraft at 6 000 m altitude.

Assuming a 0 dBi antenna gain for the WAIC transmitter, it appears that high data rate applications would not be able to meet the PFD spectral density mask for elevation angles higher than 3 to 5° depending on the cases.

As WAIC are supposed to be transmitting from take off to landing, it is clear that they will not meet the PFD spectral density mask defined for the protection of FS, SRS and FSS.

TABLE 5

e.i.r.p. density limit for HI WAIC at 10 000 m

Elevation (degrees)	PFD spectral density (dBW/Hz)/m^2	Range (km)	e.i.r.p. density (dBm/ MHz)
0	–180	357	52.1
2	–198.8	198	28.1
4	–217.6	126	5.4
5	–227	105	–5.6
10	–227	56	–11.0
20	–227	29	–16.7
30	–227	20	–20.0
40	–227	16	–22.2
50	–227	13	–23.7
60	–227	12	–24.8
70	–227	11	–25.5
80	–227	10	–25.9
90	–227	10	–26.0

TABLE 6

e.i.r.p. density limit for HO WAIC at 10 000 m

Elevation (degrees)	PFD spectral density (dBW/Hz)/m^2	Range (km)	e.i.r.p. density (dBm/ MHz)
0	–180	357	32.1
2	–198.8	198	8.1
4	–217.6	126	–14.6
5	–227	105	–25.6
10	–227	56	–31.0
20	–227	29	–36.7
30	–227	20	–40.0
40	–227	16	–42.2
50	–227	13	–43.7
60	–227	12	–44.8
70	–227	11	–45.5
80	–227	10	–45.9
90	–227	10	–46.0

TABLE 7

e.i.r.p. density limit for HI WAIC at 6 000 m

Elevation (degrees)	PFD spectral density $(dBW/Hz)/m^2$	Range (km)	e.i.r.p. density (dBm/ MHz)
0	–180	277	49.8
2	–198.8	133	24.6
4	–217.6	79	1.3
5	–227	65	–9.7
10	–227	34	–15.4
20	–227	17	–21.2
30	–227	12	–24.4
40	–227	9	–26.6
50	–227	8	–28.1
60	–227	7	–29.2
70	–227	6	–29.9
80	–227	6	–30.3
90	–227	6	–30.4

TABLE 8

e.i.r.p. density limit for HO WAIC at 6 000 m

Elevation (degrees)	PFD spectral density $(dBW/Hz)/m^2$	Range (km)	e.i.r.p. density (dBm/ MHz)
0	–180	277	29.8
2	–198.8	133	4.6
4	–217.6	79	–18.7
5	–227	65	–29.7
10	–227	34	–35.4
20	–227	17	–41.2
30	–227	12	–44.4
40	–227	9	–46.6
50	–227	8	–48.1
60	–227	7	–49.2
70	–227	6	–49.9
80	–227	6	–50.3
90	–227	6	–50.4

5 Conclusions

Emissions in the 37-38 GHz band from a single aeronautical mobile transmitter, operating with narrow-band or wideband modulation under the assumptions contained in this Report, may severely interfere with the space research earth stations (deep-space and near-Earth) used for space-to-Earth communications. The studies related to ASTRO-G, lunar missions, as well as the multiple-entry study also indicate that the aeronautical mobile transmitters may severely interfere with the space research earth stations.

To satisfy the protection criteria, aeronautical mobile stations would need to avoid transmitting in the 37-38 GHz band when they are in view of the space research earth stations. If such transmission cannot be avoided, the PFD spectral density produced at the space research earth station by any aircraft station would need to satisfy the PFD spectral density limit given in Fig. 6.

It should be noted that the PFD spectral density limit of –227 (dBW/Hz)/m² for high elevation angles corresponds to an e.i.r.p. density level of –136 dBW/Hz at an altitude of 10 km, considering free space loss only. If a typical WiFi transmitter radiating 100 mW in 20 MHz (equivalent to –83 dBW/Hz) is deployed in the aircraft in this frequency range, then the aircraft fuselage attenuation required for the protection of the SRS earth stations would be around 53 dB.

Low power aircraft transmitters such as WAIC will not be able to use the band without causing harmful interference to the SRS earth stations.