Recommendation SFCG 33-1R1

PROTECTION OF SPACE RESEARCH LINKS IN THE 8 400 – 8 450 MHZ AND 8 450 – 8 500 MHZ BANDS FROM UNWANTED EMISSION OF EESS (ACTIVE) SYSTEMS OPERATING AROUND 9.6 GHZ

The SFCG,

CONSIDERING

a. that the 9 300 – 9 800 MHz band is allocated to EESS (active) on primary basis;

b. that the 9 800 – 9 900 MHz band is allocated to EESS (active) on secondary basis;

c. that the 8 400 – 8 450 MHz band is allocated to Space Research Service (SRS) Category B (space-to-Earth) on primary basis, and the 8 450 – 8 500 MHz band is allocated to space research service (SRS) (space-to-Earth) on primary basis;

d. that SRS deep space critical events such as launch, orbit insertion, planetary fly-by, entry-descend-landing, often determine the success of the missions;

e. that the 8 400 – 8 450 MHz band is used by nearly all SRS Category B missions for the support of critical events and the 8 450 – 8 500 MHz band is used by nearly all SRS Lagrange and lunar missions;

f. that interference during the SRS Category B mission critical events can lead to the loss of spacecraft or loss of critical data and must be prevented;

g. that protection criteria of the SRS Category B missions in the 8 400 – 8 450 MHz band is given in Recommendation ITU-R SA.1157;

h. that the unwanted emission of EESS (active) in the 9 300 – 9 900 MHz band may exceed the SRS Category B protection criterion in the 8 400 – 8 450 MHz band;

i. that, during routine operations of the SRS Category B missions unwanted emission of EESS (active), exceeding the protection criterion of SRS Category B with a small probability, may be acceptable;

j. that critical events of SRS Category B systems must be protected 100% of the time;

k. that unwanted emission from EESS (active) may exceed the saturation levels and the damage levels of SRS earth station receivers used to support Category B and Lagrange and lunar missions, as shown in the Annex,

RECOMMENDS

1. that EESS (active) satellites use the methods described in the Annex to reduce their out of band emissions in the 8 400 – 8 500 MHz band in order to reduce the probability of saturating and to avoid damaging SRS earth station receivers used to support Category B and Lagrange and lunar missions, and causing interference to SRS Category B missions critical events;

2. that if the application of the methods described in the Annex is not adequate to eliminate damage, saturation and interference events as described in RECOMMENDS 1, operators of EESS (active) and SRS Category B and Lagrange and lunar missions use operational coordination to predict and mitigate any remaining events;

3. that in order to facilitate operational coordination, operators of EESS (active) and SRS Category B and Lagrange and lunar missions share the orbital and telecom characteristics of their respective operations, including the up–to-date trajectory of their missions, antenna pointing, and schedule of critical events.

Annex

This annex computes the unwanted emission of EESS (active) systems in the 9 300 – 9 900 MHz band using the parameters from Report ITU-R RS.2094. Several mitigation techniques to reduce the out-of-band (OOB) emission of EESS (active) system in the 8 400 – 8 500 MHz SRS bands are presented. The protection levels for damage and saturation of RF front-end components of SRS earth stations are also discussed.

1. Protection of deep-space SRS space-to-Earth links from harmful interference

Recommendation ITU-R SA.1157 gives the protection criterion of deep-space research earth stations as –221 dB(W/Hz) for the SRS frequency band 8 400 - 8 450 MHz The calculation of non-line-of-sight interference due to trans-horizon propagation should be based on weather statistics that apply for 0.001% of the time. Recommendation ITU-R SA.1157 provides the protection criterion for receiver systems in SRS deep-space spacecraft. Compliance to the protection criterion for these assets determines the mission success of SRS deep-space missions. Harmful interference during mission critical events, e.g. orbit insertions, planetary fly-bys, and entry-descent-and-landing (EDL) phases, can cause potential loss of a spacecraft or the loss of irreplaceable data. There are also critical events such as one-time scientific observations where a spacecraft penetrates the atmosphere of a planet or a moon, or it impacts a moon, a planet, an asteroid, or a comet. The spacecraft may be destroyed in the process, and therefore, the data transmitted during the approach or the moments before and during the impacts define the success of the missions. Therefore, the protection of SRS deep-space spacecraft and earth stations during mission critical events, to the extent demanded by Recommendation ITU-R, is crucial for the success of SRS deep-space missions. In addition, spacecraft emergencies for deep space systems should be considered as critical events.

2. Characteristics of EESS (active) systems in the 9.6 GHz band

The 9 300 – 9 900 MHz band, typically identified by as the 9.6 GHz EESS (active) band, is used by synthetic aperture radar (SAR) systems. Report ITU-R RS.2094 provides the characteristics of three SAR systems operating in band.

Table 1
Characteristics of SAR 1, SAR 2 and SAR 3 systems

Parameter	SAR1	SAR2	SAR3
Orbital altitude (km)	400	619	506
Orbital inclination (degrees)	57	98	98
RF centre frequency (GHz)	9.6	9.6	9.6
Peak radiated power (W)	1 500	5 000	25 000
Pulse modulation	Linear FM chirp	Linear FM chirp	Linear FM chirp
Chirp bandwidth (MHz)	10	400	450
Pulse duration (μs)	33.8	10-80	1-10
Pulse repetition rate (pps)	1 736	2 000-4 500	410-515
Duty cycle (%)	5.9	2.0-28.0	0.04-0.5
Range compression ratio	338	< 12 000	450-4 500

Parameter	SAR1	SAR2	SAR3
Antenna type	Slotted waveguide	Planar array	Planar phased array
Antenna peak gain (dBi)	44.0	44.0-46.0	39.5-42.5
e.i.r.p. (dBW)	75.8	83.0	83.5-88.5
Antenna orientation from Nadir	20˚ to 55˚	34˚	20˚ to 44˚
Antenna beamwidth	5.5˚ (El) 0.14˚ (Az)	1.6-2.3˚ (El) 0.3˚ (Az)	1.1-2.3˚ (El) 1.15˚ (Az)
Antenna polarization	Linear vertical	Linear HH or VV	Linear horizontal/ vertical
System noise temperature (K)	551	500	600

3. Unwanted emission of EESS (active) systems in the 8 400 – 8 500 MHz band

The unwanted emission levels of the three SAR systems described in Table 1 in the 8 400 – 8 450 MHz band are shown in Table 2. The LFM (linear FM) SAR systems are assumed to have 10 ns rise-time and fall-time with trapezoidal waveforms. The pulse durations for SAR2 and SAR3 systems are 10 μs and 1 μs, respectively. The SRS deep space earth station antenna gain is 74 dBi.

Table 2

Unwanted emission from SAR1, SAR2, and SAR3 in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-109	-86	-78
Rx interference PSD (dB(W/*Hz)*)	-196	-185	-174
Deep-space protection criterion (dB(W/*Hz)*)	-221	-221	-221
Exceedance of protection criterion (dB)	25	36	47

Table 2 shows that the unwanted emission of SAR1, SAR2, and SAR3 systems exceeds the deep space protection criterion by 25-47 dB. The unwanted emission from the SAR systems is computed based on theoretical roll-off. Higher unwanted emission is possible if EESS (active) systems include components that increase the out-of-band (OOB) emission such as high-efficiency power amplifiers operating in saturation. Further analysis of the effects of EESS (active) power amplifiers in saturation mode on EESS (active) OOB emission is needed.

Computation of unwanted emission of the SAR systems using Annex 8 of Rec. ITU-R SM.1541 results in higher wanted emission, and hence, higher interference to the deep space space-to-Earth links in the 8 400 – 8 450 MHz band.

The level of unwanted emissions falling in the band 8 450 – 8 500 MHz would even be higher due to the reduced frequency separation. Although studies show that there would not be any harmful interference issue for this band, there may be a risk of saturation and damage of the Earth station receivers in case of direct illumination, which requires specific mitigation techniques to also apply in this band. See also section 5.

4. Mitigation techniques

Several interference mitigating techniques are described in this section. Potential interference from the unwanted emissions of MHz EESS (active) systems can be reduced using one or a combination of some of the techniques described. Generally, the first three techniques, pulse shaping, antenna pointing, and filtering, can significantly reduce the unwanted emission of EESS (active) systems.

4.1. Pulse shaping

Pulse shaping changes the envelope of the LFM chirp pulses to reduce the out-of-band emission of the radar. Compared to a LFM system with 10 ns rise-time and 10 ns fall-time, pulse shaping with trapezoid waveforms and raised-cosine waveforms with 100 ns rise time and 100 ns fall-time can theoretically reduce the unwanted emission of LFM radars by about 20 dB and 60 dB, respectively. Table 3 shows that the 100-ns rise-time and 100 ns fall-time trapezoid waveform can reduce the unwanted emission of SAR1 system to be below the protection level of SRS deep space, although the unwanted emissions of SAR2 and SAR3 still exceed the protection level. With the raised-cosine pulse shaping, the unwanted emissions of all three SAR systems are below the protection criterion. It should be noted that imperfections and nonlinearities of various components in the EESS (active) transmit chain will likely increase the out-of-band emission. More analysis is needed to understand the effectiveness of this technique.

Table 3

Unwanted emission of EESS (active) with 100-ns rise-time and fall-time trapezoid waveform in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-135	-106	-95
Rx interference PSD (dB(W/*Hz))*	-222	-205	-191
Deep-space protection criterion (dB(W/*Hz))*	-221	-221	-221
Exceedance of protection criterion (dB)	-1	16	30

Table 4

Unwanted emission of EESS (active) with 100-ns rise-time and fall-time raised-cosine waveform in the 8 400 – 8 450 MHz band

Parameter	SAR1	SAR2	SAR3
e.i.r.p. (dBW)	76	83	86
Bandwidth (MHz)	10	400	450
Minimum slant range (km)	424	654	536
Space loss (dB)	-164	-167	-166
Rx antenna peak gain (dBi)	74	74	74
Polarization loss (dB)	-3	-3	-3
Spectral roll-off (dB)	-168	-147	-137
Rx interference PSD (dB(W/*Hz))*	-255	-246	-233
Deep-space protection criterion (dB(W/*Hz))*	-221	-221	-221
Exceedance of protection criterion (dB)	-34	-25	-12

Discussions with radar design experts indicate that the benefits of a specific pulse shaping at signal generation stage of the SAR can be lost in the high saturation mode of the power amplifier chain used to minimize power dissipation (heat).

4.2. Antenna pointing

All three SAR systems in Report ITU-R RS.2094 have highly directional antennas. For example, the antenna peak gain of SAR2 system is between 43 and 46 dBi. The antenna pattern rolls-off quickly in horizontal (or azimuth) direction to –3 dBi. If SAR2 can point the antenna away from the SRS earth stations such that the antenna gain is –3 dBi towards the SRS earth stations, the unwanted emission of SAR2 system can be reduced by 46 to 49 dB. Similar technique will also work for SAR1 and SAR3 systems.

4.3. Filtering

Depending on the implementations of EESS (active) systems, transmit filters and waveguides with steep cut-off below the EESS (active) band can be implemented to limit the unwanted emission of the systems. Filtering techniques have been successfully implemented by EESS space-to-Earth links in the 8 025-8 400 MHz band to reduce the unwanted emission of EESS downlinks by 40 dB and more in the 8 400-8 450 MHz band.

SAR systems may use phased array antennas which are composed of several hundreds of transmission and receive (TR) modules including high-power amplifiers. Any output filtering would have to be applied to the high power stages of these modules and, thus, increases the system complexity, costs, and performance losses of the radar.

4.4. Selection of sweep range and pulse width

The unwanted emission of LFM radars is a function of both the frequency sweep range and pulse width of the LFM chirp signal. The unwanted emission increases as the chirp sweep range increases, and also as the pulse width of the chirp signal decreases. It may be possible for an EESS (active) operator to vary the radar sweep range and pulse duration to reduce the unwanted emission, especially when the EESS (active) antenna is pointing near an SRS earth station. The effectiveness of these techniques is limited. They may reduce the unwanted emission of an EESS (active) system by just a few decibels.

4.5. Geographic separation

It is also possible to reduce the interference from EESS (active) systems through geographic separation. EESS (active) systems may keep a minimum slant range from an SRS earth station to maintain a minimum free space loss resulting in an exclusion zone. Taken to extreme, EESS (active) systems may refrain from transmission whenever there is line-of-sight between the EESS (active) systems and an SRS earth station.

5. Damage and saturation to front end of the SRS earth station receivers

NASA and ESA have provided characteristics of potential damage levels to their SRS earth station receivers if their earth stations are exposed to the EESS (active) radiation under very unfavorable geometry, i.e. near-boresight coupling of antennas. These levels are –107 dBW in the band 8 400-8 500 MHz for the ESA earth stations and –105 dBW in the band 8 200-8 700 MHz for the NASA earth stations as measured directly at the input terminal of the receiver front-ends (LNA). These damage levels should not be exceeded for any amount of time. The potential saturation level for the NASA earth station is –115 dBW. The unwanted emission from the EESS (active) should be below this level especially during the critical events of SRS missions.