Techniques to Minimize Adjacent Band Emissions from Earth Exploration Satellites to Protect the Space Research (Category B) Earth Stations in the 8400-8450 MHz Band

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Abstract

The Earth Exploration Satellites operating in the 8025-8400 MHz band can have strong adjacent band emissions in the 8400-8450 MHz band which is allocated for Space Research (Category-B). The unwanted emission may exceed the protection criterion established by the ITU-R for the protection of the Space Research (Category B) earth stations, i.e., deep-space earth stations. An SFCG Action Item (SF 23/14) was created during the 23rd SFCG meeting to explore technical and operational techniques to reduce the adjacent band emissions. In response to this action item, a study was conducted and results are presented in this document.

1 Introduction

The 8400-8450 MHz band allocated for Space Research Service (SRS) (Category B) space-to-earth is often called the deep-space downlink X-band. This band is used extensively to support the vital communication and navigation links between a deep-space spacecraft and earth stations. Due to the extreme sensitivity of the deep-space earth stations and the importance of these links to the success of deep-space missions, the ITU-R established a protection criterion of –220 dB(W/Hz) to protect these earth stations from harmful interference (REC. ITU-R SA. 1157).This protection criterion corresponds to 1 dB increase in the noise floor of the deep-space ground receivers. While such degradation may be acceptable for some of the deep-space missions during some of the mission phases, it can still result in a loss of critical data for some missions. . The deep-space community at NASA has in practice adopted a more stringent criterion to protect deep-space missions from harmful interference, corresponding to 0.1 dB increase in the noise floor, or – 230 dB(W/Hz). For the purpose of this document, the less stringent ITU-R protection criterion will be used.

Adjacent to the deep-space downlink X-band, the 8025-8400 MHz Earth Exploration Satellite Service (EESS) band is allocated for the downlinks of earth exploration satellites. Because of the proximity of these two frequency bands, the adjacent band emission of EESS satellites can exceed the deep-space X-band protection criterion and interfere with the sensitive deep-space earth stations.

This document first estimates the level of adjacent band emissions that falls in the deep-space band for two hypothetical EESS satellites with downlink parameters that are similar to existing or proposed EESS missions. Then, various mitigation techniques will be presented. At the end, a few EESS satellite systems that have implemented some of these techniques will be discussed.

2 Adjacent Band Emission Levels from an EESS Satellite

EESS satellites using the 8025-8400 MHz band for downlink have very diverse communication needs. Some satellites require downlink data rates as high as 300 Mbps while some needs as little as 2 Mbps. For illustration purposes, the adjacent band emission of two hypothetical EESS satellite is calculated to demonstrate the severity of the potential interference to deep-space earth stations. The downlink parameters of these two satellites are similar to existing EESS satellites.

The first hypothetical EESS satellite system uses the EESS X-Band downlink frequency to broadcast low-rate data at 2 Msps using QPSK. The satellite is assumed to be in the 705 km sun-synchronous orbit with transmit power of 1 W and a nadir-pointing isoflux antenna with a gain of -4 dBi at boresight and peak gain of 8 dBi about 65-degrees off the boresight. The EESS earth station is assumed to have a G/T of 25 dB/K, the minimum G/T recommended by the SFCG (SFCG Rec.18-2). A sample link budget is shown in Table 1 blow.

Tx Power	1.00	W
Baud Rate	1000000.0	Hz
Peak Tx PSD	-60.0	dBW/Hz
Tx Ant Gain	-4.0	dBi
Range	705.0	km
space loss	-167.9	dB
G/T	25.0	dB/K
G/No	253.6	dBW/Hz
Eb/No	18.7	dB

Table 1. Sample Link Budget of a Hypothetical Low-Rate EESS Satellite

The center frequency of the EESS satellite downlink is near the center of the band at 8200 MHz. Due to spectral roll-off, the maximum EESS satellite adjacent band transmission in the 8400-8450 MHz is 56 dB below the peak power spectral density (PSD) at the center frequency. The adjacent band emission at a deep-space earth station is shown in Table 2. The deep-space earth station is assumed to have a receive antenna gain of 74.3 dBi. As can be seen, the interference level exceeds the protection criterion by 6.4 dB. The adjacent band emission needs to be reduced in order to avoid interference to the deep-space earth station.

Tx Power	1.00	W
Baud Rate	1000000.0	Hz
Peak Tx PSD	-60.0	dBW/Hz
Tx Ant Gain	-4.0	dBi
Range	705.0	km
space loss	-167.9	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-56.0	dB
Max Rx ESS PSD in Deep Space Band	-213.6	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	6.4	dB

Table 2. Adjacent Band Emission Calculation for a Hypothetical Low-Rate EESS Satellite without Interference Mitigation

The second hypothetical EESS satellite transmits at a high-rate of 300 Mbps using QPSK with 13 dBW of transmit power. The satellite is also in the same 705-km sun-synchronous orbit with the same isoflux antenna as the previous example. The transmit power, modulation, and data rate are in the same ranges as other high-rate EESS missions shown in Table 3.

Satellites	Data Rates [Mbps]	Modulation	Tx Power [dBW]	Max Antenna Gain [dBi]	Antenna Type
Aura	150	QPSK	12.5	8	Isoflux
TerraSAR-X	300	QPSK	15.8	7.5	Isoflux
OCO	150	QPSK	7.8	20.5	Patch Array

Table 3. Link Parameters for Selected High-rate EESS Satellites

With the high data rate, a large aperture EESS earth station with G/T of 34.5 dBi (11-m) is selected for this example. The center frequency is near the center of the EESS band at 8200 MHz, same as the previous example. A sample link budget is shown in Table 4 blow.

Tx Power	20.00	W
Baud Rate	150000000.0	Hz
Peak Tx PSD	-68.8	dBW/Hz
Tx Ant Gain	-4.0	dBi
Range	705.0	km
space loss	-167.9	dB
G/T	34.5	dB/K
G/No	263.1	dBW/Hz
Eb/No	19.5	dB

Table 4. Sample Link Budget of a Hypothetical High-Rate EESS Satellite

If the satellite transmits when it is directly above a deep space earth station, the interference generated in the 8400-8450 MHz band exceeds the protection criterion by 40.4 dB, as shown in Table 5. The deep-space earth station is again assumed to have receive antenna gain of 74.3 dBi. The interference from this EESS satellite can severely affect the deep-space earth station.

Tx Power	20.00	W
Baud Rate	150000000.0	Hz
Peak Tx PSD	-68.8	dBW/Hz
Tx Ant Gain	-4.0	dBi
Range	705.0	km
space loss	-167.9	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-13.3	dB
Max Rx ESS PSD in Deep Space Band	-179.6	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	40.4	dB

Table 5. Adjacent Band Emission Calculation for a Hypothetical High-Rate EESS Satellite without Interference Mitigation

Although not all EESS satellites have the same transmit power, antenna patterns, earth stations, and data rates, the two hypothetical examples show that adjacent band emission of an EESS satellite, whether low-rate or high-rate, can exceed the deep-space protection threshold and can severely degrade the receiver of a deep-space earth station when the EESS satellite flies near the boresight of a deep-space earth station antenna. Interference mitigation techniques, whether through technical or operational means, are therefore necessary in order to avoid causing harmful interference to a deep-space earth station.

3 Interference Mitigation Techniques for Minimizing EESS Satellite Adjacent Band Emission

There are a number of technical and operational techniques that can reduce the adjacent band emissions in the 8400-8450 MHz band to enable an EESS satellite to comply with the deep-space protection threshold. An EESS satellite can choose one or more of the techniques described in this section as appropriate, although not all of the techniques are applicable to all EESS users. Many of the techniques described in this section are also recommended by SFCG Rec. 14-3R5 for EESS users to avoid mutual interference among themselves.

3.1 Use On-Board Filtering

On-board filtering aims to reduce the adjacent band emission level as measured at the output of the power-amplifier. On-board filtering may result in some link degradation depending on the design of the filter. The advantage of on-board filtering is that there is no impact on the ground receivers. On-board filtering has been used in various degrees by many EESS satellites. For example, NASA's Aqua and Aura satellites have an X-band filter that is designed to provide a minimum of 78 dB attenuation in the 8400-8450 MHz band, as shown in Figure 3. Similarly, TerraSAR-X has an on-board filter that would lower its adjacent band emission in the 8400-8450 MHz band to 72.5 dB below the peak spectral density.

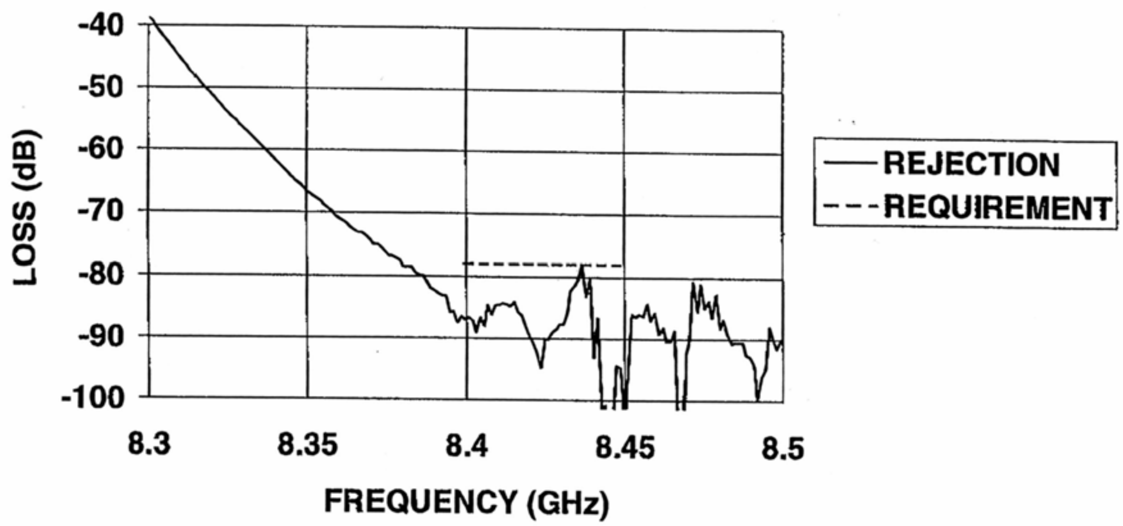

Figure 3. Frequency Response of Transmit Filter of NASA's Aqua and Aura Satellites*
(*NASA GSFC/ITT Presentation on January 6, 2003, titled "Assessment of Aura Adjacent Band Emission Compliance with the DSN S- and X-band Protection Criteria (including X-band Broadcast Mode)")

3.2 Use a Bandwidth Efficient Modulation

Like on-board filtering, bandwidth efficient modulation techniques can significantly lower sideband levels and reduce adjacent band emission in the deep-space downlink X-band. They also can alleviate the congestion problem in the 8025-8400 MHz band by reducing mutual interference among EESS users. Recognizing the benefits of and the need for using the allocation efficiently, a spectral mask is recommended by the SFCG (SFCG Rec. 21-2R2) for space science services (including EESS satellites) operating in the 8025-8400 MHz and having a symbol rate of 2 Msps or more. (The definition of symbol rate is given in SFCG Rec. 21-2R2.) This mask requires that the sideband levels of PSD be reduced to at least 60 dB below the peak starting at frequencies equal to three times the symbol rate from the carrier. In response to the SFCG recommendation, the CCSDS has recommended a bandwidth efficient modulation, SQRC filtered 4D-8PSK TCM, for EESS satellites to meet the spectral mask (CCSDS Rec 2.4.18). The power spectrum of SQRC filtered 4D-8PSK TCM is shown in Figure 1 along with the SFCG spectral mask. Compared to a QPSK PSD where the maximum PSD for frequencies more than one symbol rate away from the center frequency is only about 17.8 dB from the peak, the maximum PSD of SQRC filtered 4D-8PSK TCM is about 40 dB from the peak in the same frequency range.

There are other bandwidth efficient modulations, such as GMSK and filtered OQPSK, which can also lower the adjacent band emissions significantly. GMSK, in fact, is one of the bandwidth efficient modulations recommended by the CCSDS for space research services (category A) in the 2200-2290 MHz and 8450-8500 MHz bands (CCSDS Rec. 2.4.17A) and space research services (category B) in the 2290-2300 MHz and 8400-8450 MHz bands (CCSDS Rec. 2.4.17B),. This modulation can achieve very low sideband level as shown in Figure 2.

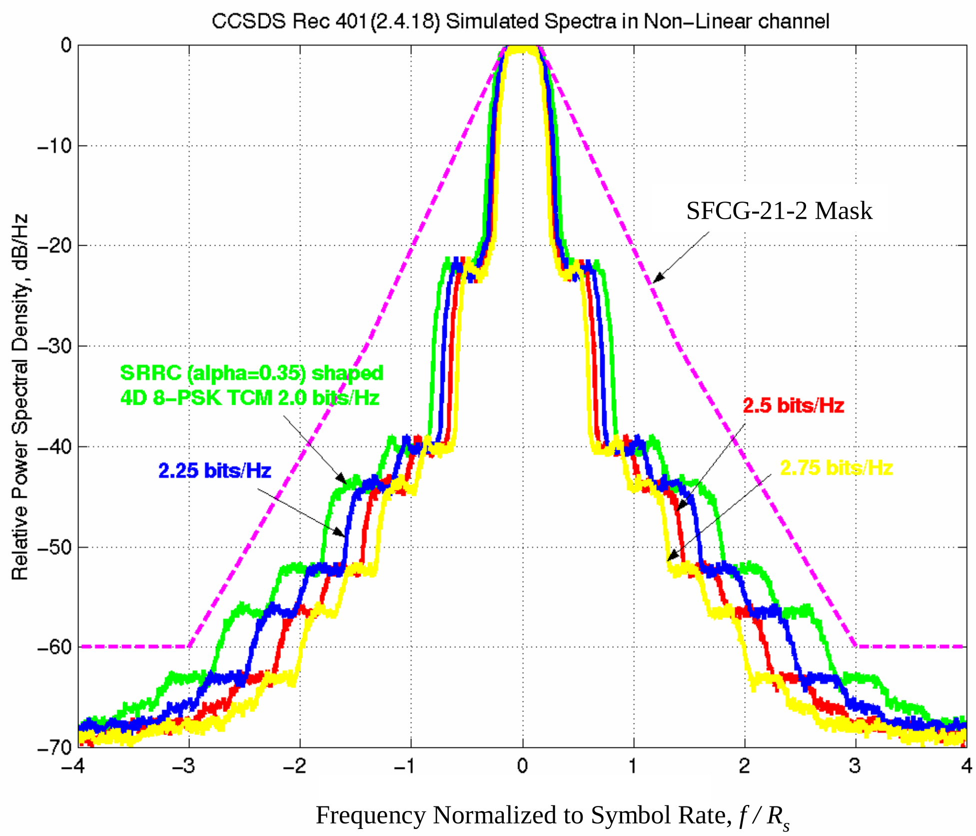

Figure 1. PSD of CCSDS Recommended 4D 8PSK TCM

One issue with using bandwidth efficient modulation is that it may require modifications on both the satellite transmitter and the ground receiver. The use of bandwidth efficient modulation, therefore, must be planned ahead in order to reap the benefits. At least one space agency is planning to use GMSK on some future SRS missions.

If the hypothetical low-rate system described in the previous section uses GMSK, it can surely meet the deep-space X-band protection threshold. Unfortunately, this is not true for the high-rate case. If the hypothetical high-rate (300 Mbps) example uses GMSK with $BT_b = 0.25$, the spectral roll-off at the 8400 MHz is about 30 dB from the peak, compared to 13.3 dB using QPSK. The additional spectral roll-off of 16 dB for GMSK by itself does not bring the adjacent band emission level to be below the deep-space protection threshold. In such cases, additional interference mitigating techniques are needed. .

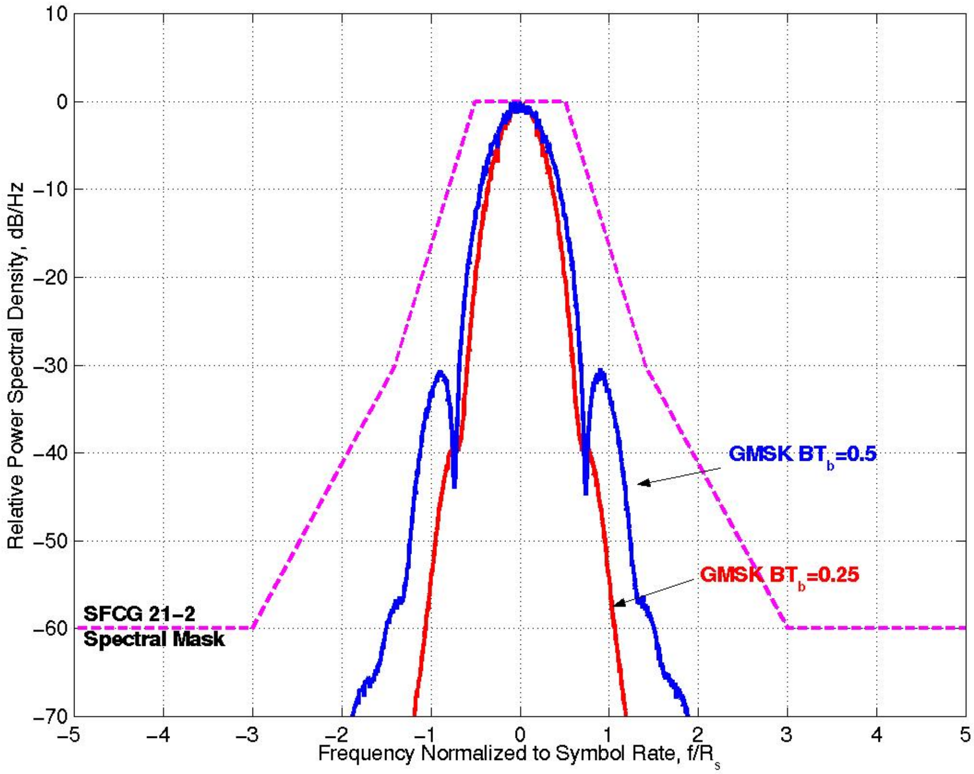

Figure 2. PSD of GMSK with BT_b of 0.5 and 0.25

3.3 Use a Narrowbeam High-Gain/Directional Satellite Antenna

Many EESS satellites use a nadir-pointing isoflux antenna, which in theory provides an equal-power flux density on the surface of the Earth. The gain of this type of antenna is higher towards the horizon (away from the antenna boresight) and lower near nadir (towards the antenna boresight). While this type of antenna has the advantage of offering operational simplicity, it has two drawbacks – the antenna does not provide antenna discrimination and the peak gain is limited. Using a narrowbeam (directional) antenna can provide a higher peak gain, hence lowering the required transmitter power and consequently the adjacent band emission level. In addition, the antenna spatial discrimination, due to the narrow antenna beamwidth, can further reduce the interference level to the deep-space earth stations when they are geographically separated from the EESS earth station.

Antenna spatial discrimination is also useful in mitigating mutual interference among EESS satellites. SFCG Rec. 14-3R5 recommends the use of high gain satellite antennas (with typical values above 20 dBi) for EESS satellites, whenever practicable.

3.4 Increase Frequency Separation

For low- to medium- rate EESS satellites having the flexibility of using a carrier frequency farther away from the deep-space frequency, maximizing the frequency separation will alleviate the interference problem somewhat. Unfortunately, increasing frequency separation may not completely eliminate the adjacent band emission problem. Table 6 uses the hypothetical low-rate satellite example from the previous section to demonstrate spectral roll-off as a function of the frequency separation between the carrier (center) frequency of the satellite and the deep-space downlink X-band. As shown, the adjacent band emission violates the deep-space protection criterion by over 30 dB when the EESS satellite center frequency is close to the 8400-8450 MHz band, requiring over 30 dB of attenuation. On the other hand, if the center frequency of the EESS downlink is near the lower band edge of the EESS band, only a modest amount of on-board filtering, 1 dB, will ensure that the interference is at an acceptable level.

Center Frequency [MHz]	Spectral Roll-Off [dB]	Exceed Protection Criterion [dB]
8026	61.4	1.0
8200	56.0	6.4
8390	30.4	32.0

Table 6. Spectral Roll-off of an EESS Satellite Downlink using 2 Mbps QPSK as a Function of the Center Frequency

The option of maximizing frequency separation may not be available for very high-rate (300 Msps) EESS satellites. However, very high-rate EESS satellites can use the 25.5-27 GHz band as an alternative once the ground infrastructure is developed. This band is allocated to EESS on a primary basis. NASA is planning to implement the 25.5-27 GHz reception capability on the ground, and at least one NOAA/NASA EEES mission is planning to use this band for high rate downlinks. Additionally, two NASA SRS missions are planning to use this band.

3.5 Reduce Transmit Power

Any reduction in the transmit power without increasing the signal bandwidth, directly leads to the reduction of adjacent band emissions. The reduction of the transmit power can be achieved by selecting an EESS earth station with a larger G/T, using a more directional satellite antenna, etc.

Using a ground station with larger G/T can also alleviate mutual interference and enhance spectrum sharing among EESS satellites. It is consistent with SFCG Rec. 14-3R5, which recommends that due consideration be given (by EESS satellites), among others, to use large earth station antennas with low sidblobes.

3.6 Maximize Geographical Separations

Maximizing the geographical separation between the ground station used by an EESS satellite and the deep-space ground stations will reduce or eliminate the amount of interference to the deep-space earth stations. If the separation is sufficiently large to eliminate any mutual visibility of an EESS satellite to its own earth station and any deep-space earth station, interference to the deep-space earth stations can be completely avoided. If this is not possible, a large geographical separation can at least reduce the interference level due to antenna spatial discrimination and increased space loss. A large geographic separation is beneficial even for satellites using isoflux antennas, because interference would be coupled through large off-boresight angles (towards the horizon of the satellite). In theory, an isoflux antenna would provide a constant flux density on the surface of the Earth and hence a constant level of adjacent band interference independent of the off-boresight angle that a deep-space earth station is at. However, the pattern of a practical isoflux antenna deviates from that of an ideal one. An isoflux antenna may have just enough gain towards the horizon to close the link while a 5-10 dB excessive gain near nadir. Adjacent band interference to a deep-space earth station is thus much stronger when the victim station is at or near the satellite antenna boresight, and weaker when it is near the horizon.

4 Examples of EESS Systems with Low Adjacent Band Interference

4.1 Aura/Aqua Low-Rate Mode

NASA’s Aura was launched in July 2004. It is on a 705-km sun-synchronous orbit. Aura’s X-band downlink is centered at 8160 MHz with a transmit power of 12.5 dBW. It has two X-band transmit modes. The high-rate playback mode transmits at 150 Mbps using QPSK to earth stations in Svalbard, Norway and Poker Flat, Alaska, US. The low-rate broadcast mode transmit at 15 Mbps using QPSK . The low-rate mode broadcasts data continuously except when the satellite is transmitting in the high-rate play-back mode. Both the high-rate and the low-rate mode have the same transmit power and use the same isoflux antenna.

For Aura’s low-rate broadcasting mode, the peak adjacent band emission when it is directly above a deep-space earth station is computed in Table 7 below assuming Aura does not have the transmit filter. Even at the moderate rate of 15 Mbps, the peak of Aura’s PSD in the 8400-8450 MHz band is 26 dB above the deep-space protection criterion. To mitigate this interference problem, Aura’s downlink includes a 9-pole Chebychev filter whose frequency response is shown in Figure 3. The filter has a minimum of 78 dB attenuation across the 8400-8450 MHz band and suppresses the adjacent band emission to below the protection threshold.

NASA’s Aqua satellite is a sister mission of Aura. Aqua was launched in May 2002 with a similar 705-km sun-synchronous orbit. Both satellites carry very similar X-band downlink equipment with the same high-rate and low-rate data rates. The missions share the same transmit filter and center frequency and have very similar antenna patterns and transmit power. Interference analysis of Aqua’s low-rate mode is very similar to that of Aura. Just as Aura is able to reduce the adjacent band emission in the 8400-8450 MHz to below the protection criterion, Aqua’s adjacent band interference at a deep-space earth station is also below the protection threshold through the use of the filter.

Tx Power	17.78	W
Baud Rate	7500000.0	Hz
Peak Tx PSD	-56.3	dBW/Hz
Tx Ant Gain	-4.0	dBi
Range	705.0	km
space loss	-167.9	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-40.2	dB
Max Rx ESS PSD in Deep Space Band	-194.0	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	26.0	dB

Table 7. Adjacent Band Emission Calculation for Aura's Low-Rate Mode without Filtering

4.2 Aura/Aqua High-Rate Mode

For Aura's high-rate mode, it is possible that Aura can have line-of-sight (LOS) with its ground station in Poker Flat, Alaska and the deep-space earth stations in Goldstone, California at the same time, as shown in Figure 4. The two circles in Figure 4 are the projection of coverage area of the two earth station sites for Aura's altitude. The overlapped area is where the satellite has line-of-sight with both sites simultaneously. It is also possible for Aura to have line-of-sight with its ground station in Svalbard and the deep-space earth stations in Madrid, Spain at the same time. Table 8 shows the calculation of Aura adjacent band emission at the Goldstone stations when Aura is as close to the Goldstone station as possible while still in view of the Poker Flat Earth station. It should be noted that since Aura carries an isoflux antenna, the adjacent band emission calculation when the satellite has mutual visibility between its earth station and a deep-space earth station should be similar to the calculation shown in Table 8 regardless of the angle off the Aura antenna boresight to the deep space station. Table 8 shows that Aura's interference to the deep-space earth station is approximately 38 dB above the protection criterion, if the mission did not implement any interference mitigating technique. Like in the low-rate mode, Aura's high-rate transmission is also filtered through the same 78 dB suppression filter resulting in Aura's adjacent band emission in the 8400-8450 MHz band to be below the deep-space protection criterion.

Like Aura, Aqua, whose high-rate earth station is located at Wallops Island, VA, USA, can have mutual visibility with both its earth station and the Goldstone stations at the same time. The transmit equipment of Aqua is very similar to that of Aura, including the transmit filter. Interference analysis shows that through the use of the transmit filter, Aqua is able to suppress its adjacent band emission at a deep-space earth station to be below the deep-space protection threshold.

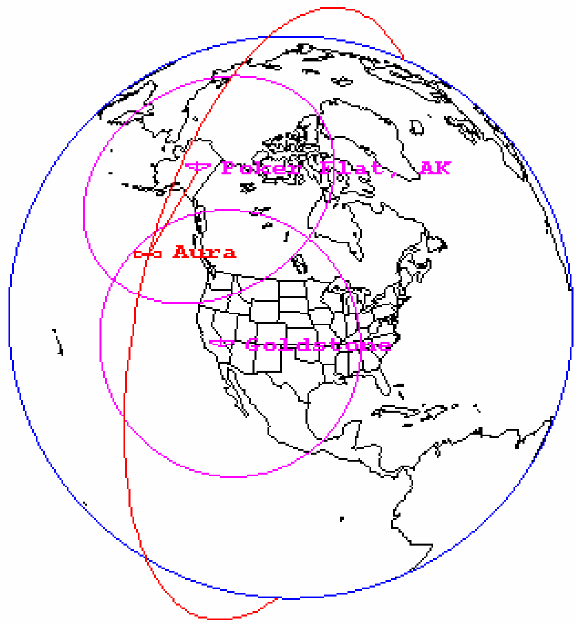

Figure 4. A Capture of When Aura Has Mutual Visibility with the Alaska and the Goldstone Earth Stations.

Tx Power	17.78	W
Baud Rate	75000000.0	Hz
Peak Tx PSD	-66.3	dBW/Hz
Tx Ant Gain	3.5	dBi
Range	1217.0	km
space loss	-172.6	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-20.8	dB
Max Rx ESS PSD in Deep Space Band	-181.9	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	38.1	dB

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Table 8. Adjacent Band Emission Calculation for Aura's High-Rate Mode without Filtering

4.3 Orbiting Carbon Observatory (OCO)

NASA's OCO mission is planned to be launched in 2007-2008. It will be in a similar 705-km sun-synchronous orbit as its sister mission Aura. OCO's X-band downlink data rate is 150 Mbps using QPSK with a center frequency of approximately 8115 MHz. The ground station will be in or near Poker Flat, Alaska. The satellite will only transmit when there is line-of-sight with the earth station. As in the case of Aura, OCO will have line-of-sight with its earth station and the Goldstone earth station at the same time.

The adjacent band emission of OCO as received at Goldstone is shown in Table 9. OCO's transmit power is 6 W. It will carry a high-gain directional antenna with a peak antenna gain of 20.5 dBi. The worst case interference will occur when OCO is as far away from its earth station as possible while being as close to the Goldstone station as possible. This will occur when OCO is at 1217 km from Goldstone at an elevation angle of 31 degrees. Since the antenna will be pointing towards the Poker Flat station, the transmit antenna gain towards Goldstone station is -5 dB. Instead of having to attenuate its adjacent band emission in 8400-8450 MHz by 38.1 dB as in the case of Aura, it will only need to attenuate its signal by 19.1 dB in the same band. The difference is accounted for by the difference in the transmit power due to OCO's higher peak antenna gain and the narrower beamwidth of the antenna which offers antenna discrimination to an unintended receiver.

In addition to using a high-gain antenna, OCO will employ on-board filtering to insure compliance with the deep-space X-band protection threshold.

Tx Power	6.00	W
Baud Rate	75000000.0	Hz
Peak Tx PSD	-71.0	dBW/Hz
Tx Ant Gain	-5.0	dBi
Tx Circuit Loss	-3.6	dBi
Range	1217.0	km
space loss	-172.6	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-23.0	dB
Max Rx ESS PSD in Deep Space Band	-200.9	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	19.1	dB

Table 9. Adjacent Band Emission Calculation for OCO without Filtering

4.4 TerraSAR-X

DLR's TerraSAR-X satellite is scheduled to be launched in 2005-2006. The satellite will be in a circular orbit with an altitude of 514.8 km and an inclination angle of eighty-five degrees. The X-band transmit data rate will be 300 Mbps using QPSK and the X-band earth station is located in Neustrelitz, Germany which is close to NASA's DSN Madrid site. TerraSAR-X will carry a nadir-pointing isoflux antenna with a peak gain of 7.5 dB at boresight. Figure 5 shows the locations of the two earth stations with the satellite maintaining LOS with both of the earth stations. The two circles represent the area that the two earth stations would each have LOS with the satellite. There is a significant overlap of the two circles which covers most of the Central and Western Europe, including the two earth stations. In other words, when the satellite is directly above the DSN Madrid site, it can still downlink data to the Neustrelitz station.

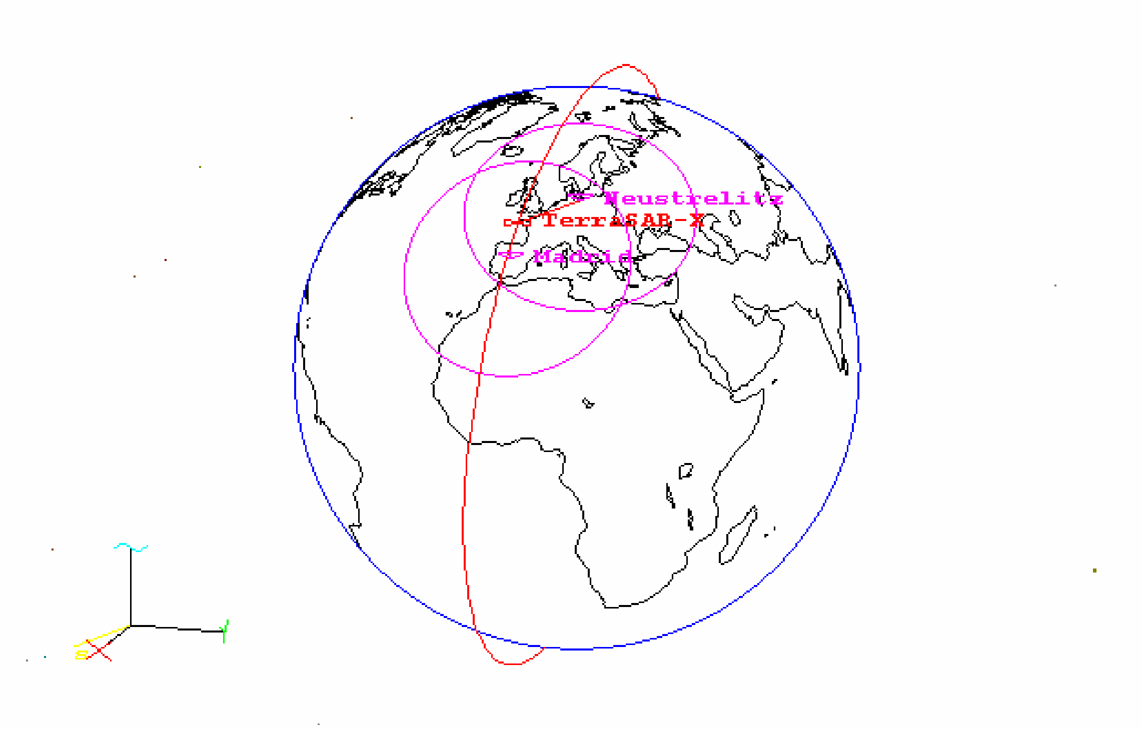

Figure 5. A Capture of When TerraSAR-X Has Mutual Visibility with the Neustrelitz and the Madrid Earth Stations.

The transmit power of TerraSAR-X is 37.1 W and the center frequency is 8150 MHz. Table 10 shows the maximum interference PSD received by the Madrid earth station in the deep-space X-band is -165 dBW/Hz. In order to meet the deep-space protection threshold, the adjacent band emission needs to be attenuated by at least 55 dB in the 8400-8450 MHz band. TerraSAR-X has designed a transmitter filter that will attenuate the transmit PSD in the deep-space band by 57 dB. The resulting PSD in the deep-space X-band is 2 dB below the ITU-R protection criterion of -220 dB(W/Hz).

Tx Power	37.70	W
Baud Rate	150000000.0	Hz
Peak Tx PSD	-66.0	dBW/Hz
Tx Ant Gain	7.5	dBi
Range	514.8	km
space loss	-165.2	dB
Deep Space Rx Ant Gain	74.3	dBi
Frequency Roll-Off	-15.6	dB
Max Rx ESS PSD in Deep Space Band	-165.0	dBW/Hz
Protection Criterion	-220.0	dBW/Hz
Exceed Protection	55.0	dB

Table 10. Adjacent Band Emission Calculation for TerraSAR-X without Filtering

5 Conclusion

The 8400-8450 MHz deep-space band is critical to the success of deep-space missions and must be protected against harmful adjacent band interference from EESS satellites operating in the adjacent 8025-8400 MHz band. As discussed in this paper, there are several techniques for EESS satellites to reduce their adjacent band emissions and hence their interference to deep-space earth stations. Some of the techniques only require changes in the satellite transmitter hardware while others require changes to earth station receivers. The real EESS satellites shown in this document have all successfully implemented one or more of these techniques to meet the ITU-R protection criterion. In fact three of these systems (Aqua, Aura, and OCO) also satisfy the more stringent criterion adopted by the NASA deep-space community. As the 8025-8400 MHz becomes increasingly congested due to increasing number of missions and demand for large data volume, and the ground infrastructure becomes available to support operation in the 25.5-27 GHz band, the high-rate EESS users should consider using the 25.5-27 GHz band where more bandwidth is available.

While the interference mitigation techniques described in this paper are for the purpose of reducing interference to the deep space earth stations, many of the techniques, such as the use of high gain/directional antenna and the use of bandwidth efficient modulation are also recommended by SFCG (SFCG Rec. 14-3R5) for the benefit of the EESS community. These techniques can also be used to reduce mutual interference among EESS users and alleviate the congestion problem in the 8025-8400 MHz band.
Based on results of simple link analyses and real EESS systems presented, it is recommended the provisional SFCG Recommendation 14-3R5 be appropriately modified to protect the deep-space X-band earth stations. Specifically, it is recommended:

(1) that all future EESS satellites comply with the protection criterion for deep-space Earth stations in the 8400-8450 MHz band (ITU-R Rec SA. 1157), using applicable technical and operational means including;

a. that non-broadcasting EESS satellites transmit only when in view of their ground stations;
b. that broadcasting EESS satellites operate near the lower edge of the 8025-8400 MHz band and employ spectrum containment techniques;
c. that high rate EESS satellites use Earth stations with a large geographical separation from the deep-space earth stations and maximize their frequency separation from the 8400-8450 MHz deep-space allocation;
d. that high rate EESS satellites employ spectrum containment techniques including bandwidth efficient modulation and transmitter filters;
e. that high rate EESS satellites use narrow-beam satellite antennas and high gain earth station antennas;
f. that very high rate EESS satellites use the 25.5-27 GHz band once the necessary ground infrastructure is available to support these missions;

(2) that operational coordination be used only as a last resort to mitigate interference from EESS missions to deep space Earth stations, when methods such as those in (1) are not adequate.

The above proposed recommendations have been incorporated in the provisional SFCG Recommendation 14-3R5, as shown in annex.