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Potential Interference to the Deep Space Network Stations in Spain from NPOESS in the 25.5- to 27.0-GHz Band

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A new Instituto Nacional de Técnica Aeroespacial (INTA) station, located about 70 km east of the Deep Space Network (DSN) Madrid complex (Robledo), is planned to support National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellites. The 26.7-GHz NPOESS Ka-band downlink to this proposed station can potentially interfere with the DSN Madrid station that may support the future lunar and Sun–Earth Lagrange point missions operating in the 25.5- to 27.0-GHz band. A preliminary compatibility analysis has been conducted to assess the potential impact to the DSN Madrid complex from the NPOESS Ka-band downlink to the planned INTA station.

I. Introduction

A new Earth station for the National Polar-orbiting Operational Environmental Satellite System (NPOESS), located about 70 km east of the Deep Space Network (DSN) Madrid complex (Robledo), is planned by the Instituto Nacional de Técnica Aeroespacial (INTA) of Spain. The 26.7-GHz NPOESS Ka-band downlink to this station may interfere with NASA's antennas at the Madrid Deep Space Communications Complex (MDSCC). These antennas may be used to support the future lunar and Sun–Earth Lagrange point missions operating in the 25.5- to 27-GHz band. A compatibility analysis has been conducted to assess the potential impact to the MDSCC from NPOESS' 26.7-GHz Ka-band downlink to the planned INTA station.

Table 1 summarizes some key Ka-band link parameters for NPOESS.

Table 1. Ka-band link parameters for NPOESS.

Transmit signal power	7.78 dBW
Transmit antenna gain	38.2 dBi
Frequency	26700 MHz
Bandwidth	300 MHz
Orbit	Sun-synchronous, 833 km high, 98.75-deg inclination

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II. Current Use of the 25.5- to 27.0-GHz Band

Currently, the MDSCC does not support any downlink in the 25.5- to 27.0-GHz band. The James Webb Space Telescope (JWST) mission is the only NASA mission planned so far that requires support for its 25.9-GHz downlink at the MDSCC. JWST is an infrared observatory that will operate in a Halo orbit around the L2 Sun–Earth Lagrange point. The Lunar Reconnaissance Orbiter (LRO) and Solar Dynamics Observatory (SDO) missions also have downlinks in this band; however, they do not need support from the MDSCC at this time. Nevertheless, it is expected that more missions with high-rate downlinks will use the band in the future, and may require support from the MDSCC.

Table 2 summarizes some of the salient characteristics of the three missions that will operate in the 25.5- to 27.0-GHz band.

Table 2. Missions that will operate in the 25.5- to 27.0-GHz band.

Mission	JWST	LRO	SDO
Orbit	L2	Lunar	Geo-sync
Transmit signal power, dBW	13.12	11.42	–2.77
Frequency, MHz	25900	25650	26500
Bandwidth, MHz	56	229	300
Ground station(s)	DSN 34-m at all three complexes	White Sands, New Mexico	White Sands, New Mexico

Both JWST and LRO have a significant frequency separation from NPOESS. Their mainlobes do not overlap with NPOESS' mainlobe, although their sidelobes overlap with NPOESS' sidelobes. SDO, on the other hand, is closer to NPOESS in frequency and their mainlobes overlap.

This article examines the potential interference from the NPOESS' 26.7-GHz downlink to a nearby INTA station, to JWST and LRO when they are being tracked by the MDSCC. Since these two missions have a significant frequency separation from NPOESS, the interference results should be applicable to other low-power-flux-density missions (e.g., lunar and L1/L2 missions), which are recommended by the Space Frequency Coordination Group to use the lower 500 MHz of the 25.5 to 27.0 GHz allocation.

It is assumed that the LRO and JWST missions are representative of lunar and L1/L2 missions, respectively, in terms of their susceptibility to interference from NPOESS. Nevertheless, this article also examines potential interference from NPOESS to a hypothetical L1/L2 mission operating in a frequency closer to NPOESS. This hypothetical mission is discussed in Section IV.

III. Protection Criterion

The protection criterion for Space Research Service (SRS) in the 25.5- to 27.0-GHz band can be derived from the International Telecommunication Union Radiocommunication Sector (ITU-R) *Space Applications and Meteorology: Protection Criteria for Radiocommunication Links for Manned and Unmanned Near-Earth Research Satellites,* SA.609-2. The recommendation, among other things, gives the following:

(a) the allowable interference power is –156 dBW/MHz for SRS in the 20- to 30-GHz band, and

(b) calculation of interference that may result from atmospheric and precipitation effects should be based on weather statistics for 0.001 percent of the time for manned missions and 0.1 percent of the time for unmanned missions.

The protection criterion for unmanned missions is applicable to the missions of interest in this study. This article calculates the received interference power in a 1-MHz reference bandwidth centered at the carrier of the mission being tracked, computes the statistics, and compares the interference statistics against the protection criterion: the received interference power should not exceed the –156 dBW threshold for more than 0.1 percent of the time.

In addition to the maximum allowable interference power, this article also uses the interference-to-system-noise spectral density ratio (I_0/N_0) of –6 dB as a protection criterion. In other words, the maximum allowable interference spectral density over the receiver's bandwidth should be 6 dB below the noise floor of the receiving system. This threshold may be exceeded for no more than 0.1 percent of the time. The DSN antenna supporting the 25.5- to 27.0-GHz band has a receiver noise temperature of 36 K in addition to the atmospheric noise temperature, which is a function of the elevation angle. Figure 1 shows the atmospheric noise temperature as a function of frequency and elevation angle for the MDSCC antennas. For simplicity, we will first use a fixed system noise temperature in our simulation and calculate the I_0/N_0 statistics. We will then calculate the statistics for selected system noise temperatures corresponding to different elevation angles.

It should be noted that the I_0/N_0 ratio will be computed using the bandwidth of the receiver, which is matched to the data rate of the mission being tracked. It is believed that this will give a more accurate assessment of the severity of interference than using a fixed reference bandwidth of 1 MHz. The I_0/N_0 ratio in a fixed bandwidth of 1 MHz around the carrier can readily be obtained from the received interference power statistics.

IV. Interference Analysis

The analysis for this study is focused on (i) the interference-to-system-noise spectral density ratio, derived as the ratio between the averaged interference power over the receiver's bandwidth (i.e., I_0) and the spectral density of the receiver's system noise, and (ii) the amount of received interference power from NPOESS in a 1-MHz reference bandwidth centered at the carrier frequency of the mission being tracked by the MDSCC. The protection criteria, as

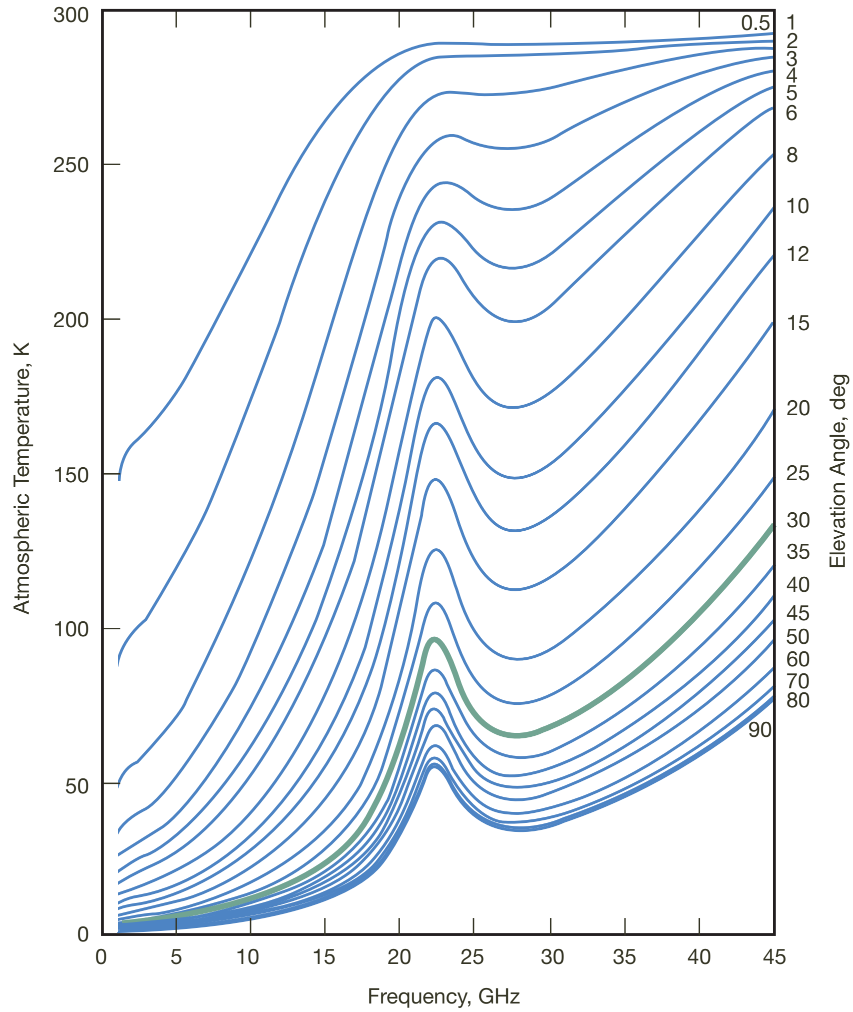

Figure 1. Atmospheric noise temperature as a function of frequency and elevation angle for MDSCC.

mentioned in Section III, require the received interference spectral density to be 6 dB below the receiver's noise floor and the interference power received in the 1-MHz reference bandwidth below –156 dBW. Neither of the above may be exceeded for more than 0.1 percent of the time.

The interference scenario considers the following elements: two satellites, NPOESS and a NASA lunar or Sun–Earth Lagrange point mission, and two ground stations, the planned INTA station and a 34-m DSN station at the MDSCC. The trajectories of satellites were either computed from known orbit parameters or borrowed from other similar satellites. The current trajectory of the Microwave Anisotropy Probe (MAP) orbiting around the L2 Sun–Earth Lagrange point is used for JWST, and the trajectory of the Moon is used for LRO. In addition, the current trajectory of the Solar and Heliospheric Observatory (SOHO), a satellite orbiting around the L1 Sun–Earth Lagrange point, is used for simulation of a hypothetical L1 mission.

The antenna gain pattern used in this study for the transmit antenna onboard NPOESS is computed from a built-in model in our simulation program. The parameters for the modeled gain pattern are adjusted until the model matches the actual pattern as closely as possible. Figure 2 shows the actual antenna gain pattern provided by the NPOESS project and this modeled pattern. As shown, there is a reasonably good agreement in the main beam (within 5 deg of the boresight), except in the region between 2 to 2.9 deg off the axis where the modeled gain pattern has a higher gain than the actual. This deviation means that we will overestimate the amount of interference in our simulation. On the other hand, the deviation in the sidelobe region is not important. Based on the orbit altitude of NPOESS and the distance between the INTA and MDSCC stations, the maximum angular separation between the ground stations as seen from NPOESS is about 5 deg and, therefore, both stations will be in the main beam of NPOESS when NPOESS is pointing to the planned INTA station.

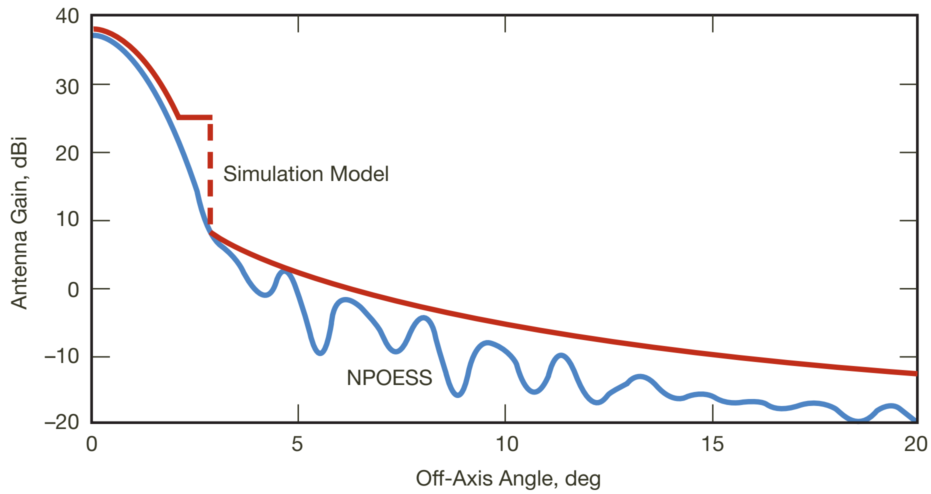

Figure 2. Comparison of antenna gain patterns: NPOESS vs. the one used in our simulation.

The simulations were carried out for a period of one full year with a 10-s time resolution. Interference data were collected only when the MDSCC was tracking its targeted satellite. At the end of each simulation, two complementary cumulative distribution functions (CCDF), one for I_0/N_0 and the other for the received interference power, were compiled from the simulation data. The plot of a CCDF function shows the probability of a given threshold being violated versus the associated threshold level. In our case, this probability, when represented as a percentage, is actually the percentage of time that the associated protection criterion is exceeded when the targeted mission is being tracked by the MDSCC station.

A. JWST Simulations

Simulations for JWST assume a Ka-band system noise temperature of 99 K, which corresponds to a 34-deg elevation angle and 95 percent weather condition. The 34-deg elevation represents the median value of the elevation angle of a JWST-tracking antenna at the MDSCC. Figure 3 shows that the percentage of time I_0/N_0 exceeds the –6 dB threshold is about 0.00007 percent. Figure 4 shows the percentage of time that the received interference power in the 1-MHz reference bandwidth exceeds the –156 dBW threshold is also about 0.00007 percent.

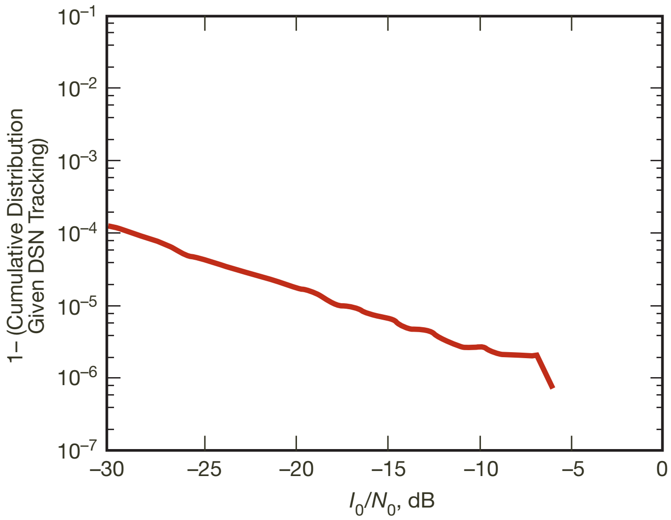

Figure 3. CCDF plot of the interference-to-noise ratio: NPOESS interference to the MDSCC when it tracks JWST.

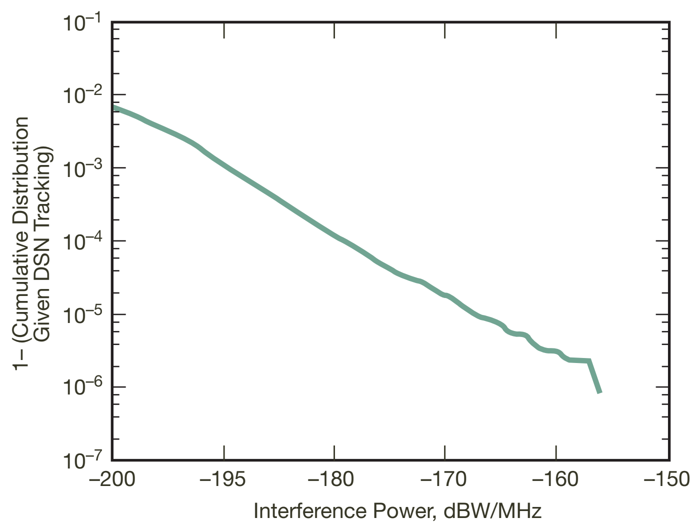

Figure 4. CCDF plot of the interference power: NPOESS interference to the MDSCC when it tracks JWST.

B. LRO Simulations

Simulations for LRO use a system noise temperature of 353 K, which includes additional thermal noise from the Moon. At this high noise-floor level, our simulation results, as shown in Figure 5, indicate that the percentage of time that the interference-to-noise ratio exceeds the –6 dB threshold is about 0.00007 percent during an MDSCC track. Moreover, as indicated in Figure 6, the received interference power in the 1-MHz reference bandwidth does not reach the –156 dBW threshold at all.

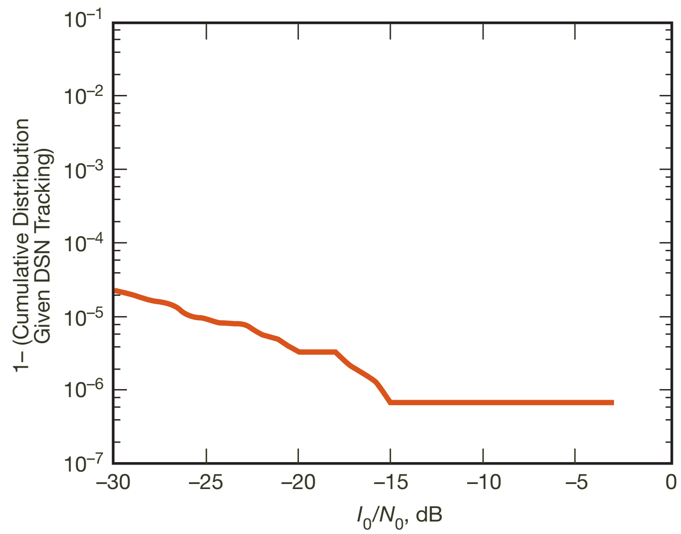

Figure 5. CCDF plot of the interference-to-noise ratio: NPOESS interference to the MDSCC when it tracks LRO.

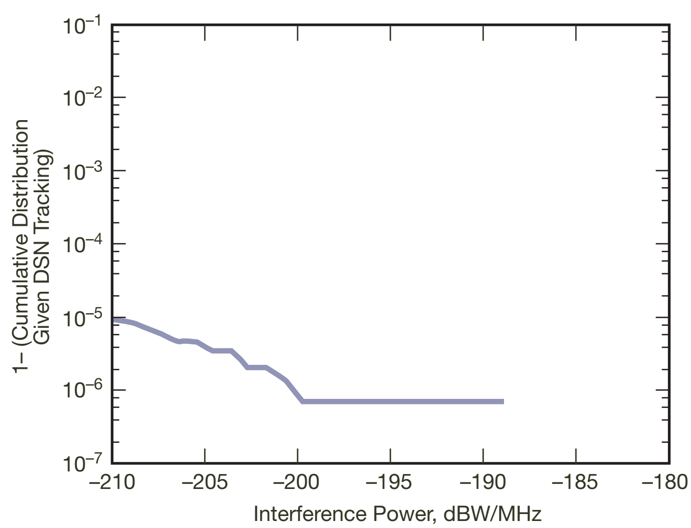

Figure 6. CCDF plot of the interference power: NPOESS interference to the MDSCC when it tracks LRO.

C. Simulations of Hypothetical L1 and L2 Missions

In addition to JWST, which is an L2 mission, more simulations were performed to assess the potential impact on the MDSCC of the NPOESS Ka-band downlink to the planned INTA station. Two hypothetical mission scenarios were created by using SDO's Ka-band parameters, i.e., a 26.5-GHz carrier and a 300-MHz bandwidth: one for a satellite orbiting the L1 Sun–Earth Lagrange point and the other for a satellite orbiting the L2 Sun–Earth Lagrange point. The current trajectories of SOHO and MAP were used for these simulations, respectively.

Because of the much greater spectral overlap between NPOESS and these missions, the percentage of time for the interference-to-noise ratio exceeding the –6 dB threshold became much larger. Figure 7 shows the CCDF plots of the interference-to-noise ratios for these hypothetical L1 and L2 missions, respectively, with the system noise temperature fixed at 72 K (90-deg elevation angle). The percentage of time for the RFI events at different Ka-band system noise temperatures can be read from these plots with respect to different threshold levels.

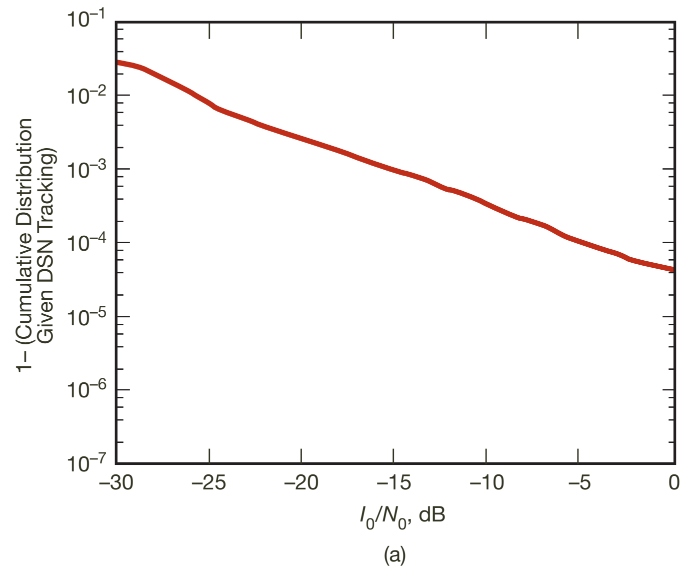

Figure 7. CCDF plots of the interference-to-noise ratio: NPOESS interference to (a) an L1 mission or (b) an L2 mission being tracked by the MDSCC. System noise temperature of 72 K was assumed.

Table 3 summarizes the percentage of time for the interference-to-noise ratio exceeding the –6 dB threshold at system noise temperature of 72 K, 91 K (40-deg elevation angle), 114 K (25-deg elevation angle), and 226 K (7-deg elevation angle). The system noise temperatures (SNT) for these elevation angles are for the 26-GHz band with 95 percent weather.

Table 3. Percentage of time the interference-to-noise ratio exceeded the –6dB threshold.

Mission	SNT = 72 K	SNT = 91 K	SNT = 114 K	SNT = 226 K
L1	0.01239%	0.00969%	0.00791%	0.00455%
L2	0.01617%	0.01283%	0.01054%	0.00530%

Figure 8 shows the CCDF plots of the received interference power for the hypothetical L1 and L2 missions, respectively. The percentage of time that the –156 dBW/MHz threshold is violated during MDSCC tracks is 0.00079% for the L1 case and 0.00105% for the L2 case.

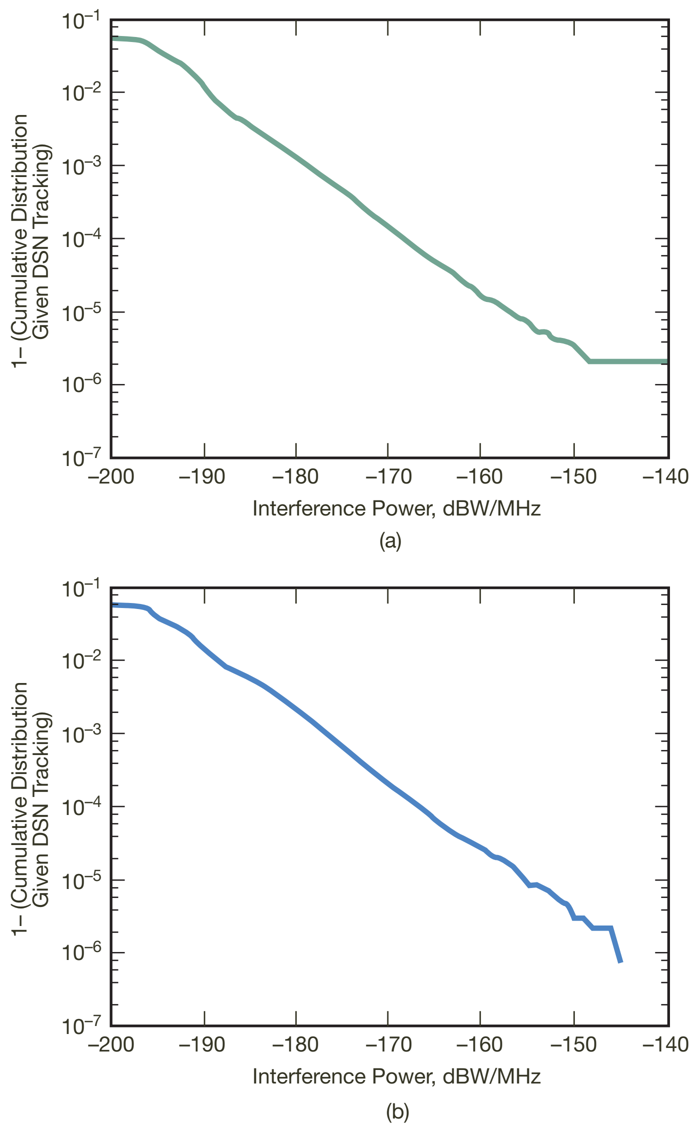

Figure 8. CCDF plots of the received interference power: NPOESS interference to (a) an L1 mission or (b) an L2 mission being tracked by the MDSCC.

V. A Static Link Analysis

In addition to the analysis on the interference-to-noise ratio and the received interference power level presented above, a separate link analysis is given in Table 4 for a scenario when the angular separation between the two Earth stations (i.e., the INTA and MDSCC stations) viewed from the NPOESS satellite is minimized, i.e., the MDSCC station is closest to the boresight of the NPOESS' transmitting antenna. In this analysis, it is assumed that the INTA station starts tracking at an elevation angle of 5.0 deg. The analysis indicates that

Table 4. Link analysis for scenario when angular separation between INTA and MDSCC stations viewed from NPOESS is minimized.

Transmit carrier frequency	26700 MHz
Transmit signal bandwidth	300 MHz
Transmit signal power	7.8 dBW
Transmit-to-MDSCC off-axis angle	0.13 deg
Transmit antenna gain, off-axis	37.2 dBi
Transmit effective isotropic radiated power, off-axis	44.9 dBW
MDSCC-to-NPOESS elevation angle	5.7 deg
MDSCC-to-NPOESS slant range	2787 km
Path loss	189.9 dB
Receive carrier frequency	26500 MHz
Receive signal bandwidth	300 MHz
Attenuation — 1-MHz ref BW rejection	35.5 dB
Receive-to-NPOESS off-axis angle	2.0 deg
Receive antenna gain, off-axis	24.4 dBi
Receive interference power	–156.0 dBW

the minimum separation is 0.13 deg. When this happens, the INTA station just starts tracking the NPOESS satellite and the MDSCC-to-NPOESS elevation angle is about 5.7 deg. The interference power is calculated for the hypothetical L1/L2 mission with a carrier frequency of 26.5 GHz, 200 MHz away from NPOESS' carrier frequency but inside the second sideband of NPOESS' spectrum. Using a reference receiver bandwidth of 1 MHz, the receiver rejection is 35.5 dB, including the effects of frequency offset and bandwidth mismatch. With these assumptions, the pointing of the MDSCC antenna needs to be about 2.0 deg away from NPOESS in order to keep the received interference power in the 1-MHz reference bandwidth below –156 dBW.

VI. Conclusions

This compatibility analysis addresses the potential interference to the MDSCC from NPOESS downlinks to a planned INTA station, located about 70 km east of the MDSCC. The 26.7-GHz NPOESS Ka-band downlink to the INTA station may cause interference to NASA's

MDSCC antennas supporting future lunar and Sun–Earth Lagrange point missions operating in the 25.5- to 27.0-GHz band.

Preliminary computer simulations provided interference results for JWST, LRO, and a hypothetical L1/L2 mission. These simulations indicate that the protection criteria given in Section III (interference power at –156 dBW/MHz I_0/N_0 = –6 dB) are met for all the SRS missions examined. It should be noted that currently only JWST is planning to use the MDSCC. There is no requirement for the MDSCC to track LRO at this time.

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