SPACEX GEN2 NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A
TECHNICAL INFORMATION TO SUPPLEMENT SCHEDULE S

A.1 SCOPE AND PURPOSE

This attachment contains the information required under Part 25 of the Commission's rules that cannot be fully captured by the associated Schedule S.

A.2 OVERALL DESCRIPTION

Orbital Parameters

The SpaceX second-generation non-geostationary orbit ("NGSO") satellite system (the "Gen2 System") consists of 30,000 space stations as well as associated ground control facilities, gateway earth stations, and end user earth stations. The satellite constellation will be configured as shown in Table A.2-1 below:

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane
328	30	1	7,178
334	40	1	7,178
345	53	1	7,178
360	96.9	40	50
373	75	1	1,998
499	53	1	4,000
604	148	12	12
614	115.7	18	18

Table A.2-1: Gen2 Constellation Characteristics

As with its current constellation, apogee and perigee will be maintained to within 30 km, and inclination will be maintained to less than 0.5 degree of the respective target values. The right ascension of the ascending nodes ("RAANs") will precess and span the full range of 0-360 degrees.

SpaceX will generally observe a minimum elevation angle as low as 25 degrees, although certain shells may use lower elevations in certain circumstances as discussed more fully in Section A.3. below.

SpaceX also requests that the Commission grant authority in its license for communications during transition phases before and after reaching authorized positions. This would include authority to perform telemetry, tracking and command ("TT&C") functions during orbit-raising and de-orbit maneuvers, as is authorized by rule for GSO satellite systems.[1] This would also include authority for testing the communications payloads during the orbit-raising process, which would be conducted on a non-protected, non-harmful interference basis. Given that there are 30,000 satellites in the constellation with a design life of five years, it is likely that SpaceX will be engaged in launch and de-orbit activities on an ongoing basis. Granting the requested authority as part of the space station license would obviate the need for SpaceX to file—and the Commission to process—a never-ending stream of applications for special temporary authority to cover operations as satellites are raised into and de-orbited out of the constellation.[2]

Technology and Operations

The Gen2 System will make use of advanced phased array beam-forming and digital processing technologies onboard each satellite payload in order to make highly efficient use of spectrum resources and share spectrum flexibly with other space-based and terrestrial licensed users. User terminals will employ highly directive, steered antenna beams that track the system's satellites. Gateway earth stations will generate high-gain steered beams to communicate with

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1 *See* 47 C.F.R. §§ 25.282, 25.283.

2 Over the last eight months, SpaceX has been granted eleven space station STAs to cover orbit-raising and de-orbit activities for its first-generation constellation. It has received no reports of interference or other issue from any other licensed operator.

multiple satellites within the constellations from a single gateway site. SpaceX is in the process of developing optical inter-satellite links and anticipates that they will be deployed on the Gen2 System to provide seamless network management and continuity of service while minimizing the spectrum footprint of the system overall and facilitating spectrum sharing with other space-based and terrestrial systems. The broadband services will be available for residential, commercial, institutional, governmental, and professional users worldwide.

SpaceX has designed its Gen2 System to meet the dual requirements of the world's broadband demand—namely, high-speed, low-latency connectivity for rural, remote and hard-to-reach end-users, as well as efficient, high-capacity connectivity at all locations. Operation of the Gen2 constellations will improve upon the operations of SpaceX's original Ku/Ka-band system in several ways. First, the increase in capacity, frequency availability, and frequency reuse dramatically increases the number of customers who can be served. Second, the increase in bandwidth available per user improves the quality of service, bringing more high-speed, low-latency broadband to unserved areas and injecting additional competition in areas where terrestrial alternatives are available. Third, the operation of a large number of satellites with narrow, steerable spot beams in low altitude orbits creates opportunities to optimize spectrum use, which will enhance opportunities for coordination with other GSO and NGSO systems.

Spectrum

SpaceX's Gen2 System will use Ku-, Ka-, and E-band spectrum as summarized in Table A.2-2 below.[3] A representative illustration of the detailed channelized frequency plan is provided

[3] As mentioned above, SpaceX anticipates that the system will also employ optical inter-satellite links for communications directly between SpaceX satellites. As the Commission has previously found, "[b]ecause optical ISLs do not involve wire or radio frequency transmissions, the Commission does not have jurisdiction over the use of optical ISLs." *Teledesic LLC*, 14 FCC Rcd. 2261, ¶ 14 (Int'l Bur. 1999). Moreover, to the extent that the use of optical ISLs alleviates congestion in radio frequency bands, it is to be encouraged. *Id.*

in the associated Schedule S, and a more comprehensive specification is included in the Technical Database submitted herewith.

Type of Link and Transmission Direction	Frequency Ranges
User Downlink Satellite-to-User Terminal	10.7 – 12.75 GHz[4] 17.8 – 18.6 GHz 18.8 – 19.3 GHz 19.7 – 20.2 GHz
Gateway Downlink Satellite to Gateway	17.8 – 18.6 GHz 18.8 – 19.3 GHz 71.0 – 76.0 GHz
User Uplink User Terminal to Satellite	12.75 – 13.25 GHz[5] 14.0 – 14.5 GHz 28.35 – 29.1 GHz 29.5 – 30.0 GHz
Gateway Uplink Gateway to Satellite	27.5 – 29.1 GHz 29.5 – 30.0 GHz 81.0 – 86.0 GHz
TT&C Downlink	12.15 – 12.25 GHz 18.55 – 18.60 GHz
TT&C Uplink	13.85 – 14.00 GHz

Table A.2-2: Frequency Bands Used by the Gen2 System

SpaceX recognizes that, although the Gen2 System will use E-band spectrum in a manner consistent with its allocation, the Commission has not yet adopted service rules for satellite operations in the band. Pursuant to Section 25.289 of the Commission's rules, SpaceX will comply with the applicable default rules until such time as the Commission adopts service rules, at which

4 SpaceX does not seek authority to provide service in the United States using the 12.7-12.75 GHz band, but proposes to use that spectrum in other areas of the world where allowed.

5 At this time, SpaceX seeks authority to use this band in the United States only with individually licensed earth stations. No such limitations would apply outside the U.S. In the future, SpaceX may seek authority to operate blanket-licensed user terminals in the U.S. as well.

point SpaceX will come into compliance with such rules as appropriate.[6] SpaceX also recognizes that not all of the frequencies that it proposes to use are designated in the United States for use by NGSO FSS systems on a primary basis. As discussed below, SpaceX believes that its system can operate without causing harmful interference to or requiring protection from any other service duly licensed in these bands with higher priority.

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS

All satellites in the Gen2 System have been designed with transmit and receive antenna beams that fall within a defined range of minimum and maximum gain. SpaceX will use this flexibility to optimize broadband service to customers by accommodating different user densities (i.e., high-gain beams in highly populated areas with low-gain beams in rural areas) and service from various altitudes. The antenna gain contours for the transmit and receive beams for a representative space station operating at representative altitudes proposed herein are embedded in the associated Schedule S and the accompanying Technical Database.[7] Below we describe the methodology for their presentation.

All downlink spot beams on each SpaceX satellite are independently steerable over the full field of view of the Earth. Yet earth stations communicate only with satellites above a minimum elevation angle. Figure A.3-1 below illustrates the steerable service range of satellite beams using generalized parameters.

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6 *See* 47 C.F.R. § 25.217(b), (e).

7 As discussed in more detail below, SpaceX has generally provided the contours for satellites at the lowest and highest relevant operating altitudes with the lowest and highest antenna gains in order to illustrate the full range of values. SpaceX can supply the remaining contours to the Commission upon request.

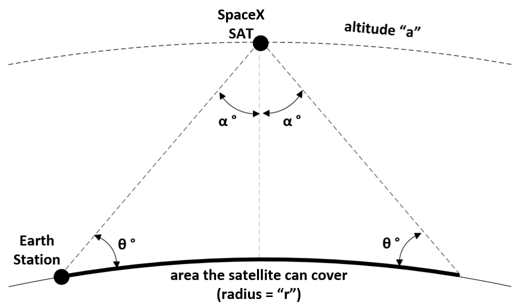

Figure A.3-1: Steerable Service Range of Satellite Beams

Tables A.3-1 and A.3-2 provide the specific values for the parameters in Figure A.3-1 for each of the new orbital altitudes proposed herein based on the minimum earth station elevation angle (θ) involved. Note that only the high inclination orbital shells will service Polar Regions where gateway earth stations operate at elevation angles as low as five degrees, while the higher altitude shells may communicate with Ku-band user terminals at elevation angles as low as five degrees as well.

Altitude "a" [km]	328	334	345	360	373	499	604	614
Max steering angle α [deg]	59.5	59.5	59.3	59.1	58.9	57.2	55.9	55.8
Coverage radius "r" [km]	607.8	617.5	635.2	659.0	679.5	868.5	1014.8	1028.2

Table A.3-1: Values for 25° Minimum Elevation Angle θ

Altitude "a" [km]	360	373	604	614
Max steering angle α [deg]	70.6	70.2	65.5	65.3
Coverage radius "r" [km]	1607.8	1642.4	2169.9	2189.8

Table A.3-2: Values for 5° Minimum Elevation Angle θ

Beams will be divided into small channels that, depending on utilization and other factors, may be bonded into channels as large 2,000 MHz in the downlink and 125 MHz in the uplink for user terminals and 5,000 MHz in each direction for gateways. Two beams can be transmitted at the same frequency (with right hand and left hand circular polarization ("RHCP and LHCP")), but SpaceX may use only one or the other polarization in specific circumstances. This provides operational flexibility to facilitate coordination and compliance with regional and country specific regulations.

A.3.1 Ku-Band Beams

Gen2 System satellites will transmit using Ku-band antennas with a minimum gain of 34 dBi and a maximum gain of 44 dBi at boresight. The minimum elevation angle at which user terminals communicate with SpaceX satellites may be as low as 25 degrees for the vast majority of satellites in the constellation, but may be as low as 5 degrees for satellites in the 604 km and 614 km altitude shells. Beams from antennas using phased arrays widen incrementally as they are steered away from boresight.[8] As a result, the shape of a phased array beam at boresight is circular but becomes increasingly elliptical when steered away from boresight. The antenna beam contours provided in Schedule S illustrate this dynamic by plotting antenna gain contours (for both uplink and downlink beams and for both the minimum and maximum gain) for operations at 328 km and 614 km at nadir and at 25°, 45°, and maximum slant away from nadir, which are representative of the contours for satellites throughout the proposed operating altitudes. As illustrated in Figures A.3.1-1 and A.3.1-2 below with respect to operations at these altitudes, as the transmitting beam is steered, the power is adjusted to maintain a constant maximum power flux-density ("PFD") at the surface of the Earth, compensating for variations in antenna gain and path loss associated with the steering angle.

8 For this purpose, we use "boresight" to refer to the direction normal to the phased array plane.

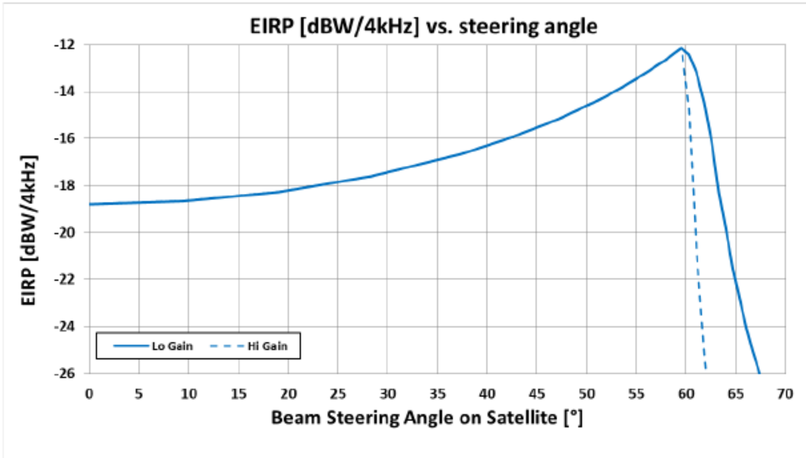

Figure A.3.1-1. EIRP Density Variation by Beam Steering Angle (328 km)

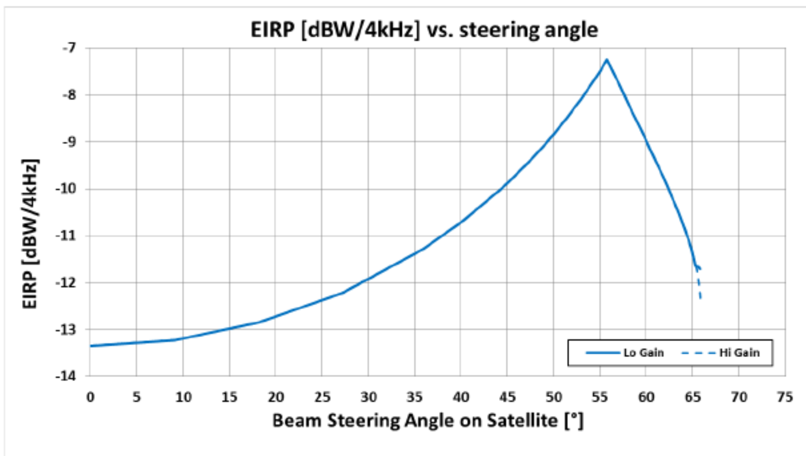

Figure A.3.1-2. EIRP Density Variation by Beam Steering Angle (614 km)

Table A.3.1-1 shows the maximum equivalent isotropically radiated power ("EIRP") density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/4kHz]
328	-12.2
334	-12.0
345	-11.8
360	-11.4
373	-11.1
499	-8.9
604	-7.4
614	-7.3

Table A.3.1-1: Maximum Ku-Band EIRP Density at Various Altitudes

For receiving beams, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (9.5-19.5 dB/K) at each altitude occurs at nadir, while the minimum G/T occurs at maximum slant (7.0-17.0 dB/K).[9]

The intended coverage area for each user beam is a cell inside the -3 dB contour, as illustrated in Figure A.3.1-2 below. At a given frequency, only a single beam (with either RHCP or LHCP) typically would cover a user cell on the ground from a given satellite. Alternatively, two beams (one with RHCP and one with LHCP) can cover a single user cell on the ground at a given frequency, but in this case their EIRP will be reduced by 3 dB to maintain the same PFD (see below).

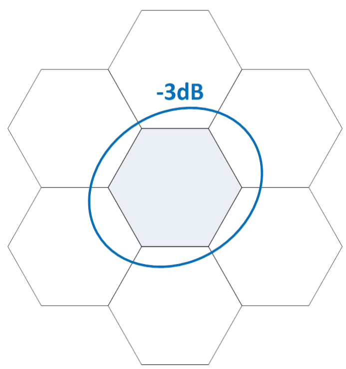

Figure A.3.1-2: Intended Beam Coverage Area

A.3.2 Ka-Band User and Gateway Beams

The Gen2 System will use Ka-band spectrum for communications with gateway earth stations as well as for supplemental capacity with user terminals. Satellites will use phased array antennas for communications with user terminals and parabolic antennas for communications with gateways. To the extent the Gen2 System uses this spectrum for both purposes, SpaceX will use angular separation to self-coordinate so that users located near a Ka-band gateway will use either

9 Section 25.114(c)(4)(v) requires both the minimum and maximum saturation flux density ("SFD") values for each space station receive antenna that is connected to transponders. The concept of SFD only applies to "bent pipe" satellite systems, and thus is not relevant to the constellation. However, because the Schedule S software requires a numerical entry for SFD (which must be different for maximum and minimum), SpaceX has entered values of "0" and "-0.1."

Ku-band spectrum or those Ka-band frequencies not in use by the gateway. Satellites will transmit using Ka-band antennas with a minimum gain of 34.5 dBi and a maximum gain of 44.5 dBi at boresight. The minimum elevation angle at which user terminals communicate with SpaceX satellites in Ka-band may be as low as 25 degrees. Gateways also communicate only with satellites above a specified minimum elevation angle. Generally speaking, this angle may be as low as 25 degrees. However, there will be exceptions in certain cases in order to achieve increased coverage. Specifically, satellites in the high inclination shells operating at altitudes of 360 km and 373 km will observe a minimum elevation angle of five degrees for gateways located inside the Polar Regions (i.e., above 62 degrees latitude).

As with Ku-band beams, the shape of the Ka-band beams becomes elliptical as it is steered away from the boresight. The antenna beam contours provided in Schedule S illustrate this dynamic by plotting antenna gain contours (for both uplink and downlink beams used with gateways (parabolic) and user terminals (phased array) at the highest and lowest gain) for operations at 328 km and 614 km at nadir and at 25°, 45°, and maximum slant away from nadir, and at 360 km at nadir and at 25°, 45°, and maximum slant away from nadir, which are representative of the contours for satellites throughout the proposed operating altitudes and elevation angles. While each Ka-band user beam is designed to cover a number of users within a cell, each Ka-band gateway beam is used to communicate with a single gateway at a time, and is optimized to be as close to beam-center-to-beam-center as possible with that link, using a beam as narrow as practical.

As illustrated in Figures A.3.2-1 through A.3.2-4 below with respect to operations at 328 km, 360 km, and 614 km altitude, as a satellite steers the transmitting beam, it adjusts the power to maintain a constant PFD at the surface of the Earth.

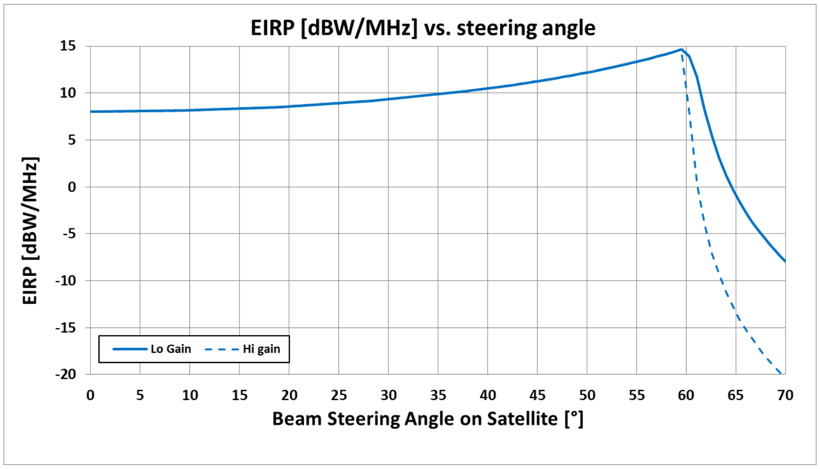

Figure A.3.2-1: EIRP Density Variation by Gateway Beam Steering Angle (328 km, 25° min)

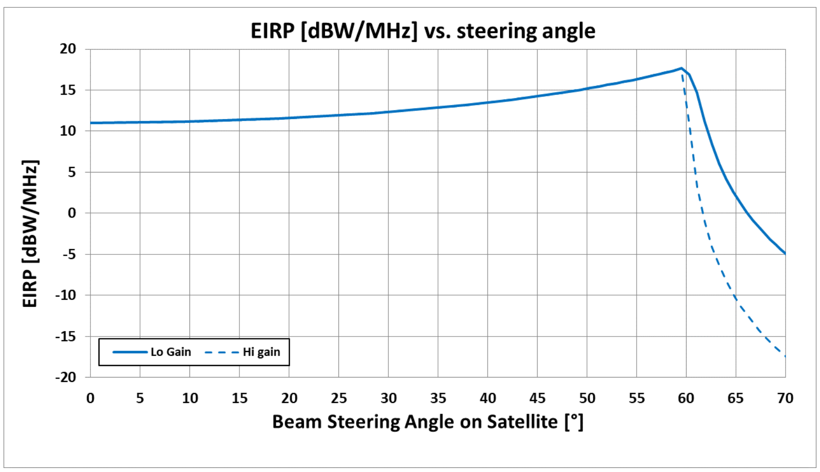

Figure A.3.2-2: EIRP Density Variation by User Beam Steering Angle (328 km, 25° min)

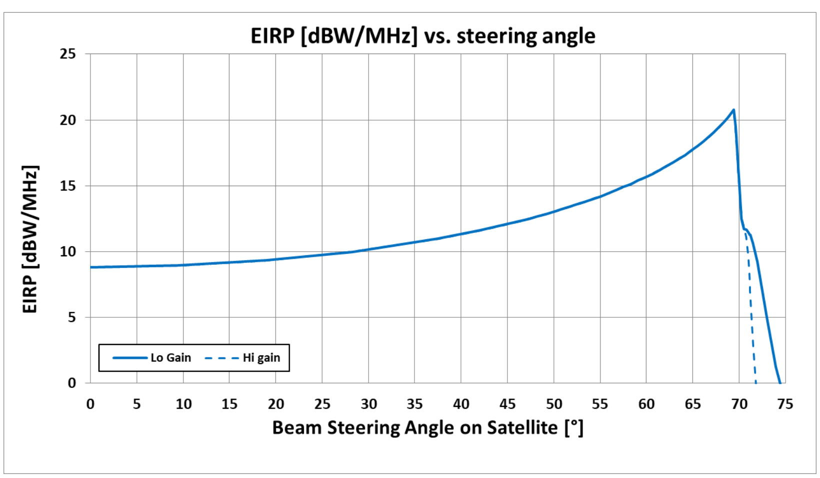

Figure A.3.2-3: EIRP Density Variation by Gateway Beam Steering Angle (360 km, 5° min)

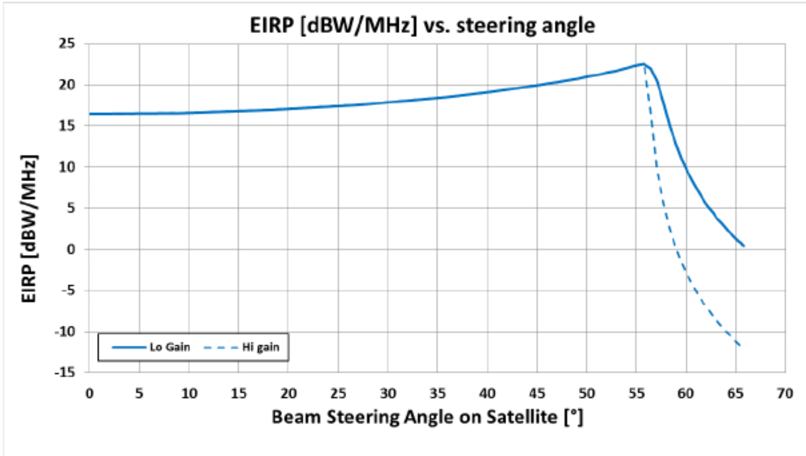

Figure A.3.2-4: EIRP Density Variation by User Beam Steering Angle (614 km, 25° min)

Table A.3.2-1 shows the maximum EIRP density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/MHz] (user beams)	Max EIRP [dBW/MHz] (gateway beams)
328	17.6	14.6
334	17.8	14.8
345	18.0	15.0
360	18.4	20.8
373	18.7	21.0
499	20.9	17.9
604	22.4	19.4
614	22.5	19.5

Table A.3.2-1: Maximum Ka-Band EIRP Density at Various Altitudes

Two Ka-band gateway beams are transmitted at the same frequency (RHCP and LHCP), while user beams can use one polarization (either RHCP or LHCP) or both at the same time. User beams from a given satellite will have only one co-frequency beam per spot, but there will be up to thirty-two satellites beaming transmissions to a gateway location, for a maximum of sixty-four co-frequency beams. SpaceX will adjust power in order to achieve the PFD levels indicated above

For gateway receiving beams, G/T will remain constant at 12.9 dB/K to 22.9 dB/K depending on antenna gain (but independent of altitude and steering angle). For user terminal receiving beams, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (12.9-22.9 dB/K) at each altitude occurs at nadir, while the minimum G/T occurs at maximum slant (10.4-20.4 dB/K).

A.3.3 E-Band Beams

The Gen2 System will use E-band spectrum for communications with gateway earth stations only. Satellites will transmit using E-band antennas with a minimum gain of 42 dBi and a maximum gain of 52 dBi As in the Ka-band, the minimum elevation angle at which gateways will communicate with SpaceX satellites may generally be as low as 25 degrees, but satellites in the high inclination shells operating at altitudes of 360 km and 373 km will observe a minimum elevation angle of five degrees for gateways located inside the Polar Regions (i.e., above 62 degrees latitude).

Here again, the shape of the beam becomes elliptical as it is steered away from boresight. The antenna beam contours provided in Schedule S illustrate this dynamic by plotting antenna gain contours (for both uplink and downlink beams with the highest and lowest gain) for operations at 328 km and 614 km at nadir and at 25°, 45°, and maximum slant away from nadir, and at 360 km at nadir and at 25°, 45°, and maximum slant away from nadir, which are representative of the contours for satellites throughout the proposed operating altitudes and elevation angles. Each E-band gateway beam is used to communicate with a single gateway at a time, and is optimized to be as close to beam-center-to-beam-center as possible with that link, using a beam as narrow as practical.

As illustrated in Figures A.3.3-1 and A.3.3-2 below with respect to operations at 328 km and 360 km altitude, respectively, as a satellite steers the transmitting beam, it adjusts the power (in both polarizations) to maintain a constant PFD at the surface of the Earth.

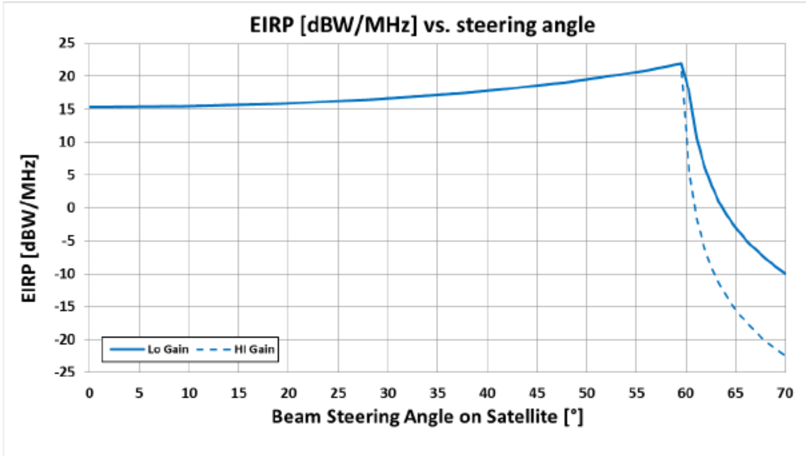

Figure A.3.3-1: EIRP Density Variation by Beam Steering Angle (328 km, 25° min)

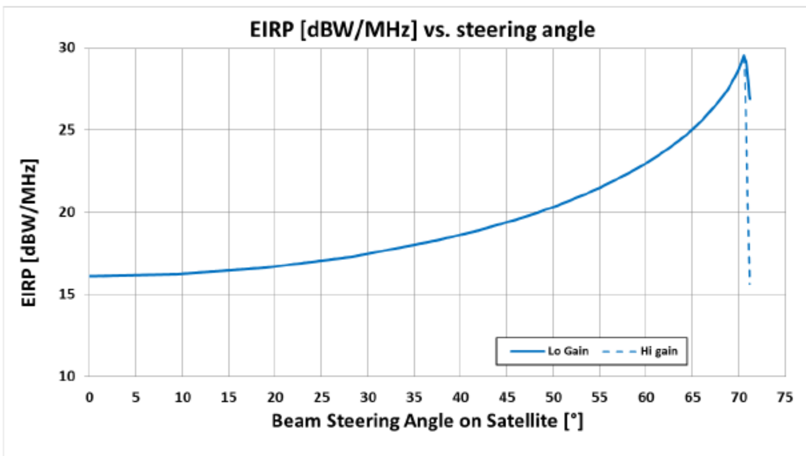

Figure A.3.3-2: EIRP Density Variation by Beam Steering Angle (360 km, 5° min)

Table A.3.3-1 shows the maximum EIRP density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/MHz]
328	21.9
334	22.1
345	22.3
360	29.5
373	29.7
499	25.2
604	26.7
614	26.8

Table A.3.3-1: Maximum E-Band EIRP Density at Various Altitudes

Two E-band beams are transmitted at the same frequency (RHCP and LHCP). Up to thirty-two satellites can beam transmissions to a gateway location, for a maximum of sixty-four co-frequency beams. SpaceX will adjust power in order to achieve the PFD levels indicated above. For receiving beams, G/T will remain constant at 17.7 dB/K to 27.7 dB/K depending on antenna gain (but independent of altitude and steering angle).

A.3.4 TT&C Beams

The Gen2 System conducts its dedicated TT&C functions using omni-directional antennas on each satellite that are designed to communicate with earth stations at virtually any attitude (95% lowest of the 4 pi steradian antenna-gain sphere). The maximum transmit EIRP density, maximum and minimum G/T for receiving beams, and diagrams of the antenna gain contours for the 328 km and 614 km altitudes are provided with the associated Schedule S.[10] Communication to and from the TT&C earth stations will be restricted to an elevation above the local horizon of at least five degrees.

SpaceX may also use Ka-band and E-band communications links to perform TT&C functions. As required by Section 25.202(g)(1), if these transmissions are not conducted at a band edge SpaceX will ensure that they cause no greater interference and require no greater protection from harmful interference than the communications traffic on the satellite network.[11]

A.4 TT&C CHARACTERISTICS

SpaceX's dedicated TT&C subsystem provides for communications with the spacecraft during pre-launch, transfer orbit, and on-station operations, as well as during spacecraft emergencies.[12] During all phases of the mission, this subsystem uses the following frequencies:

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[10] The one exception is the maximum transmit EIRP density for the Ku- and Ka-band TT&C downlink beams, which are -5.0 dBW and -3.0 dBW, respectively. Schedule S requires that the maximum transmit EIRP value for a beam be greater than 0 dBW. In order to accommodate this limitation, SpaceX has entered a value of "0" in Schedule S with respect to this parameter.

[11] *See* 47 C.F.R. § 25.202(g)(1).

[12] The information provided in this section complements that provided in the associated Schedule S submission.

- For space-to-Earth: 12.15-12.25 GHz and 18.55-18.6 GHz.[13]
- For Earth-to-space: 13.85-14.0 GHz.[14]

SpaceX will use primary and back-up TT&C ground station facilities at two locations within the United States – one on the East coast and one on the West coast – with additional TT&C ground station facilities at locations distributed internationally.

SpaceX may also use Ka-band and E-band communications links to perform TT&C functions. As required by Section 25.202(g)(1), if these transmissions are not conducted at a band edge SpaceX will ensure that they cause no greater interference and require no greater protection from harmful interference than the communications traffic on the satellite network.[15]

A.5 GEOGRAPHIC COVERAGE

The Gen2 System will meet the Commission's geographic coverage requirements set forth in Section 25.146(b) as it will be capable of providing FSS on a continuous basis throughout the fifty states, Puerto Rico, and the U.S. Virgin Islands.

A.6 CESSATION OF EMISSIONS

Each active satellite transmission chain (channel amplifiers and associated solid state power amplifier) can be individually turned on and off by ground telecommand, thereby causing cessation of emissions from the satellite, as required by Section 25.207 of the Commission's rules.

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[13] The 18.3-18.6 GHz band has been designated for use by NGSO systems on an unprotected, non-harmful interference basis with respect to GSO FSS systems.

[14] These frequencies are adjacent to the 14.0-14.5 GHz band used for uplinks from user terminals. To the extent necessary, SpaceX has requested a waiver for their use. In addition, SpaceX will not claim protection for its satellites from radiolocation transmitting stations operating in this band in accordance with the U.S. Table of Frequency Allocations. *See* 47 C.F.R. § 2.106, n.US356.

[15] *See* 47 C.F.R. § 25.202(g)(1).

A.7 Compliance With PFD Limits

SpaceX will operate the Gen2 System at low altitude, with a large majority of the satellites orbiting below 400 km (i.e., 328-373 km). To account for these low orbits, SpaceX also plans to operate those satellites at low EIRP, which will reduce the PFD created at the Earth's surface. To illustrate, the tables below show the PFD calculation for operations, both at maximum slant and at nadir, for Ku-band and Ka-band downlink beams from representative orbital altitudes. In each case, the table reflects operations at the lowest relevant altitude and lowest gain – and, for the Ka--band, accounting for both polarizations – which presents a worst case, maximum PFD scenario without considering any of the operational constraints discussed above.

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-54.8	-48.2
EIRP in 4kHz [dBW/4kHz]	-18.8	-12.2
EIRP in 1MHz [dBW/MHz]	5.2	11.8
Distance to Earth [km]	328.0	704.1
Spreading loss [dB]	121.3	127.9
PFD in 4 kHz [dB(W/m^2/4kHz)]	-140.1	-140.1
PFD in 1 MHz [dB(W/m^2/1MHz)]	-116.1	-116.1

Table A.7-1. PFD at the Surface of the Earth Produced by Ku-band Downlink Transmissions (328 km)

	Nadir	25° ES elev	5° ES elev
EIRP density [dBW/Hz]	-49.5	-43.4	-47.7
EIRP in 4kHz [dBW/4kHz]	-13.5	-7.4	-11.7
EIRP in 1MHz [dBW/MHz]	10.5	16.6	12.3
Distance to Earth [km]	604.0	1220.5	2338.7
Spreading loss [dB]	126.6	132.7	138.4
PFD in 4 kHz [dB(W/m^2/4kHz)]	-140.1	-140.1	-150.1
PFD in 1 MHz [dB(W/m^2/1MHz)]	-116.1	-116.1	-126.1

Table A.7-2. PFD at the Surface of the Earth Produced by Ku-band Downlink Transmissions (604 km)

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-52.0	-45.4
EIRP in 1MHz [dBW/MHz]	8.0	14.6
Distance to Earth [km]	328.0	704.1
Spreading loss [dB]	121.3	127.9
PFD in 1 MHz [dB(W/m^2/1MHz)]	-113.3	-113.3

Table A.7-3. PFD at the Surface of the Earth Produced by Ka-band Gateway Downlink Transmissions (328 km)

	Nadir	25° ES elev	5° ES elev
EIRP density [dBW/Hz]	-51.2	-44.6	-48.3
EIRP in 1MHz [dBW/MHz]	8.8	15.4	11.7
Distance to Earth [km]	360.0	766.8	1687.1
Spreading loss [dB]	122.1	128.7	135.5
PFD in 1 MHz [dB(W/m^2/1MHz)]	-113.3	-113.3	-123.8

Table A.7-4. PFD at the Surface of the Earth Produced by Ka-band Gateway Downlink Transmissions (360 km)

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-49.0	-42.4
EIRP in 1MHz [dBW/MHz]	11.0	17.6
Distance to Earth [km]	328.0	704.1
Spreading loss [dB]	121.3	127.9
PFD in 1 MHz [dB(W/m^2/1MHz)]	-110.3	-110.3

Table A.7-5. PFD at the Surface of the Earth Produced by Ka-band User Downlink Transmissions (328 km)

In addition, because the satellite downlink transmit power is adjustable on orbit, SpaceX has the ability to manage the satellites' PFD levels during all phases of the mission, as needed. Below, we plot these PFD values against the relevant PFD limits applicable in the various frequency bands used by the Gen2 System.[16]

A.7.1 PFD Limits in the Ku-Band

The PFD limits imposed by the Commission and the International Telecommunication Union ("ITU") in the Ku-band apply on a per-satellite basis. However, the Commission and ITU

[16] Neither the Commission nor the ITU has adopted PFD limits in the E-band.

have adopted different downlink PFD limits for different portions of the Ku-band spectrum used by the Gen2 System. For each of these limits, we demonstrate compliance by plotting the relevant limit and the worst-case PFD of a satellite operating in the proposed 328 km and 604 km shells with earth stations at a minimum elevation angle of 25 degrees and 5 degrees, respectively, for both the highest and lowest gain transmitting antennas. The first set of limits applies across the 10.7-11.7 GHz band.[17]

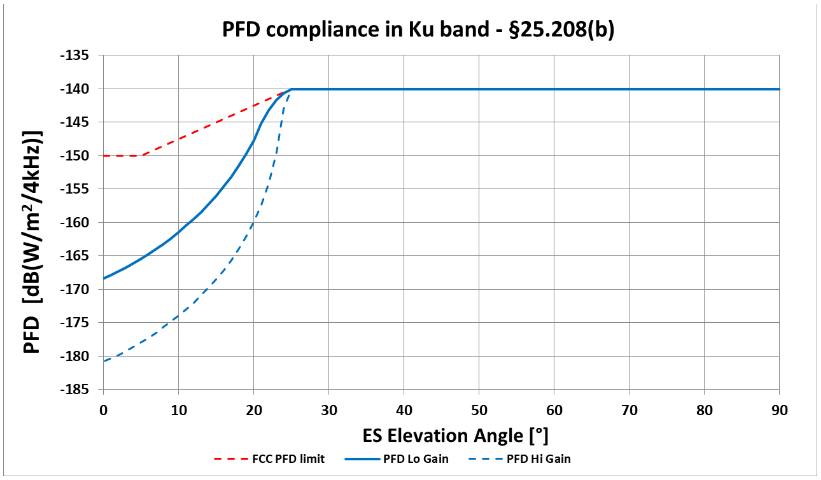

Figure A.7.1-1. Compliance with Downlink PFD Limits in the 10.7-11.7 GHz Band (328 km)

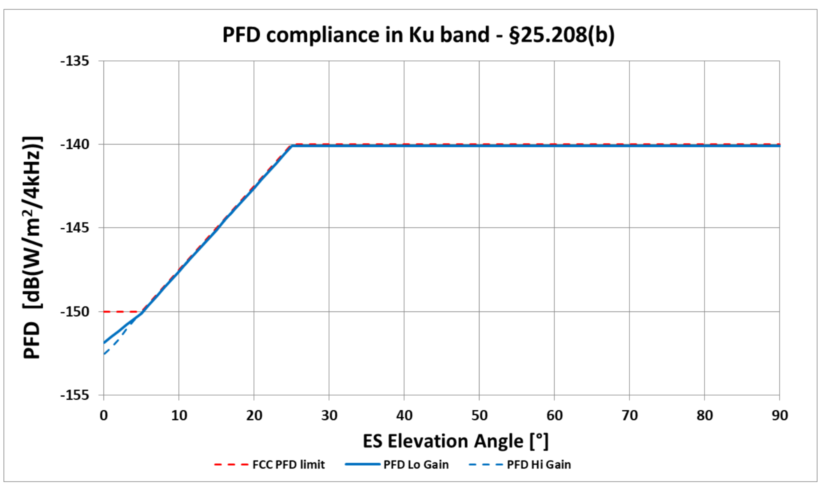

Figure A.7.1-2. Compliance with Downlink PFD Limits in the 10.7-11.7 GHz Band (604 km)

The ITU Radio Regulations include PFD limits across the 11.7-12.7 GHz band that are effectively

17 *See* 47 C.F.R. § 25.208(b); ITU Rad. Regs., Table 21-4.

2 dB higher than the PFD limits in the 10.7-11.7 GHz band plotted above.[18] Accordingly, given that the Gen2 System will comply with the lower limits applicable in the 10.7-11.7 GHz band, it will also comply with the limits applicable in the 11.7-12.7 GHz band.[19]

Section 25.208(o) of the Commission's rules specifies low elevation PFD limits that apply in the 12.2-12.7 GHz band to protect the Multichannel Video and Data Distribution Service ("MVDDS"). Figure A.7.1-2 below shows that satellites in the proposed 328 km shell will comply with these limits as well. As an added protection, SpaceX will not operate in this band below a 25 degree elevation angle, even for the 604 km and 614 km shells.

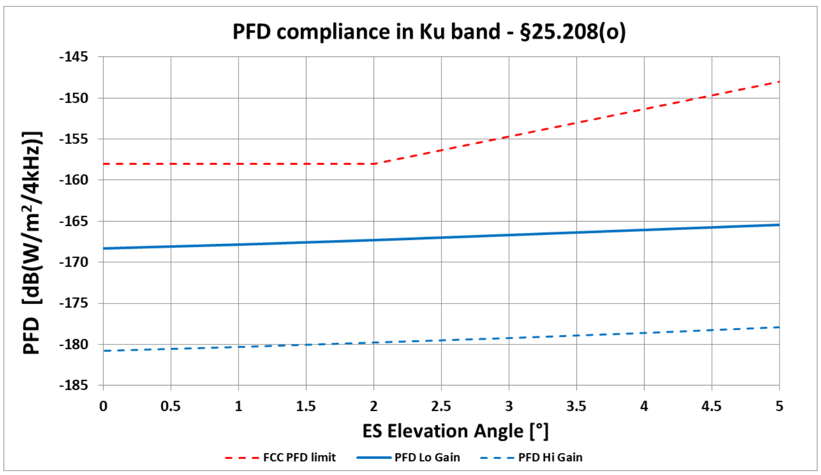

Figure A.7.1-2. Compliance with Downlink PFD Limits in the 12.2-12.7 GHz Band (328 km)

Operations at this lowest shell provide a worst-case PFD scenario, yet still remain compliant over the full range of antenna gains. Accordingly, all Ku-band downlink transmissions from SpaceX

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18 *See* ITU Radio Regs., Table 21-4.

19 In the Ku-band, SpaceX will operate TT&C downlinks in the 12.15-12.25 GHz band. The maximum EIRP for the TT&C links is always below the minimum EIRP radiated in any direction by the user links in this band. As a result, the PFD created when TT&C links in this band are active falls significantly below the PFD created due to operational links in all cases. Because, as demonstrated above, the Ku-band operational links comply with the applicable PFD limits, the TT&C downlinks necessarily will do so as well. Moreover, SpaceX plans to deploy only two TT&C earth stations in the U.S. – one on the East Coast and one on the West Coast. Areas outside the immediate vicinity of those facilities would be unaffected by their operations. Accordingly, SpaceX's TT&C operations in this band should prompt no concern.

satellites operating in the proposed constellation will comply with all applicable Commission and ITU PFD limits.

A.7.2 PFD Limits in the Ka-Band

The ITU has adopted a single set of PFD limits for NGSO systems across the entire 17.7-19.3 GHz band, which the Commission has incorporated by reference into its rules as well.[20] Unlike the limits applicable to the Ku-band, here the limits are expressed as a function of the number of satellites in the entire NGSO system, without any consideration to whether the satellites are in view of the terrestrial system or whether the satellites are turned on or off. These limits can be stated as follows:

- $-115-X$ $dB(W/m^2)$ in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- $-115-X+((10+X)/20)(\delta-5)$ $dB(W/m^2)$ in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and
- -105 $dB(W/m^2)$ in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

  Where X is defined as a function of the number of satellites in the NGSO FSS constellation, n, as follows:

  - $X = 0$ dB for $n \leq 50$
  - $X = (5/119)(n - 50)$ dB for $50 < n \leq 288$
  - $X = (1/69)(n + 402)$ dB for $n > 288$

For the Gen2 System, the value of "n" is 30,000, and therefore X is equal to 440.61 dB according to the above formulae. This results in the PFD masks for communications links (with the highest and lowest gain transmitting antennas) shown in Figures A.7.2-1 through A.7.2-3 below, and for TT&C operations in Figure A.7.2-4.

[20] *See* ITU Radio Regs., Table 21-4; 47 C.F.R. § 25.108(a)(2).

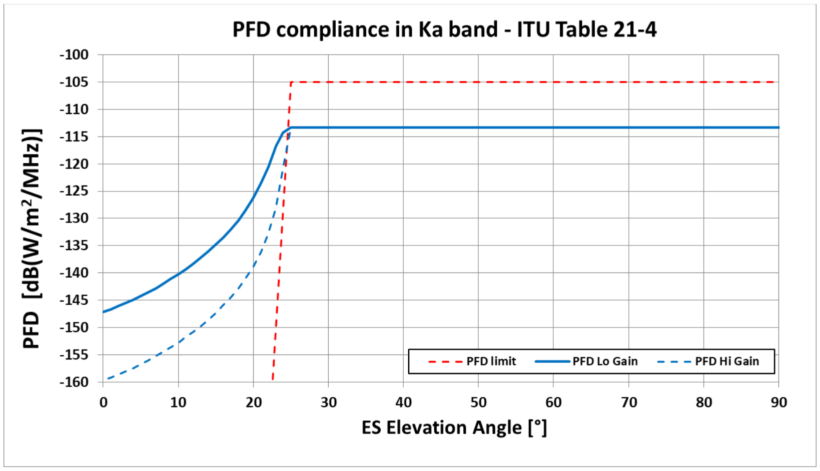

Figure A.7.2-1. SpaceX Gateway Link Compliance with Downlink PFD Limits in the 17.7-19.3 GHz Band (328 km, 25° min)

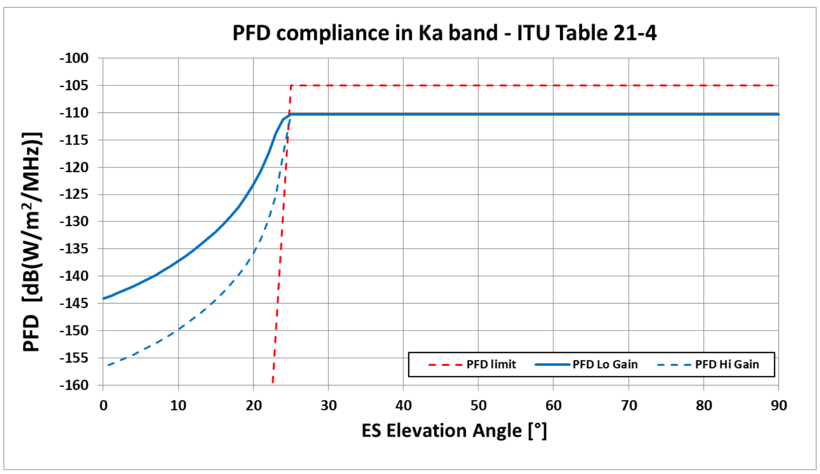

Figure A.7.2-2. SpaceX User Link Compliance with Downlink PFD Limits in the 17.7-19.3 GHz Band (328 km, 25° min)

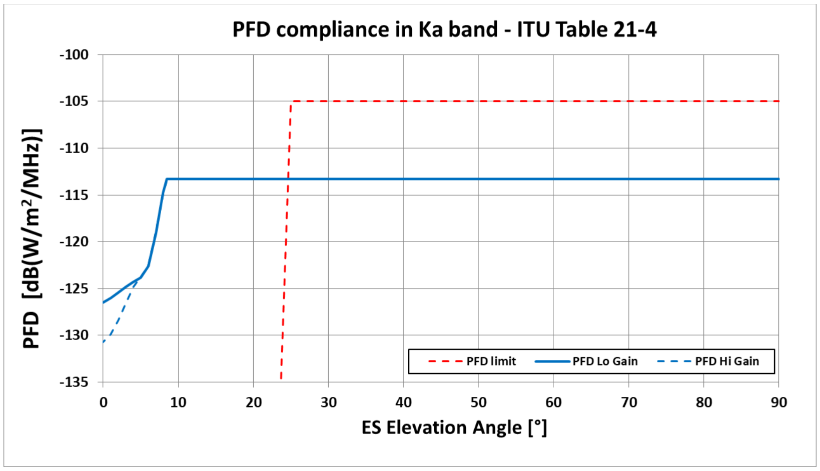

Figure A.7.2-3. SpaceX Gateway Link Compliance with Downlink PFD Limits in the 17.7-19.3 GHz Band (360 km, 5° min)

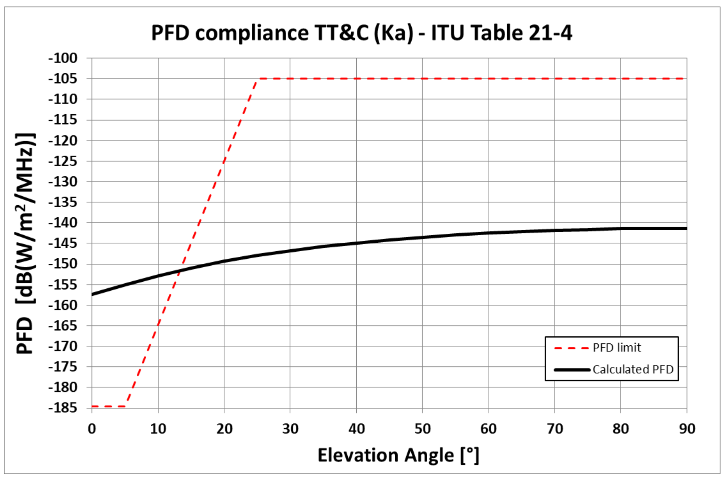

Figure A.7.2-4. SpaceX TT&C Compliance with Downlink PFD Limits in the 17.7-19.3 GHz Band

As shown in these figures, the Gen2 System complies with the PFD limits specified by the Commission and the ITU at most elevation angles, but below about twenty-five degrees for communications links and twelve degrees for TT&C the flawed calculation technique appears to yield a result that exceeds the limit.

In its previous applications, SpaceX has argued that the ITU methodology for establishing the Ka-band PFD limits was not developed with capability to scale up for application to dynamically controlled NGSO constellations with more than 840 satellites.[21] In granting the *Initial Authorization*, the Commission agreed with several points raised by SpaceX, "in particular that the ITU limits were derived for constellations up to 840 satellites and under worst case assumptions."[22] Rather than grant a waiver of these PFD limits, the Commission imposed a condition under which SpaceX must, before starting operation, provide a technical showing demonstrating that its operation will protect a fixed-service station with the characteristics described in Recommendation ITU-R SF.1483.[23] Accordingly, in this application, SpaceX requests as waiver of these PFD limits and also submits in Annex 1 to this Technical Attachment a showing with respect to the Gen2 System of the type previously required for SpaceX's first-generation system demonstrating the ability to protect Fixed Service ("FS") stations.

A.8 INTERFERENCE ANALYSES

As shown in Figure A.8-1 below, the frequency ranges SpaceX proposes to use are shared with other services in the U.S. Table of Frequency Allocations.

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[21] *See, e.g.,* Application, IBFS File No. SAT-LOA-20161115-00118, Attachment A at 29-32 (filed Nov. 15, 2016).

[22] *See Initial Authorization*, ¶ 35.

[23] *See id.*

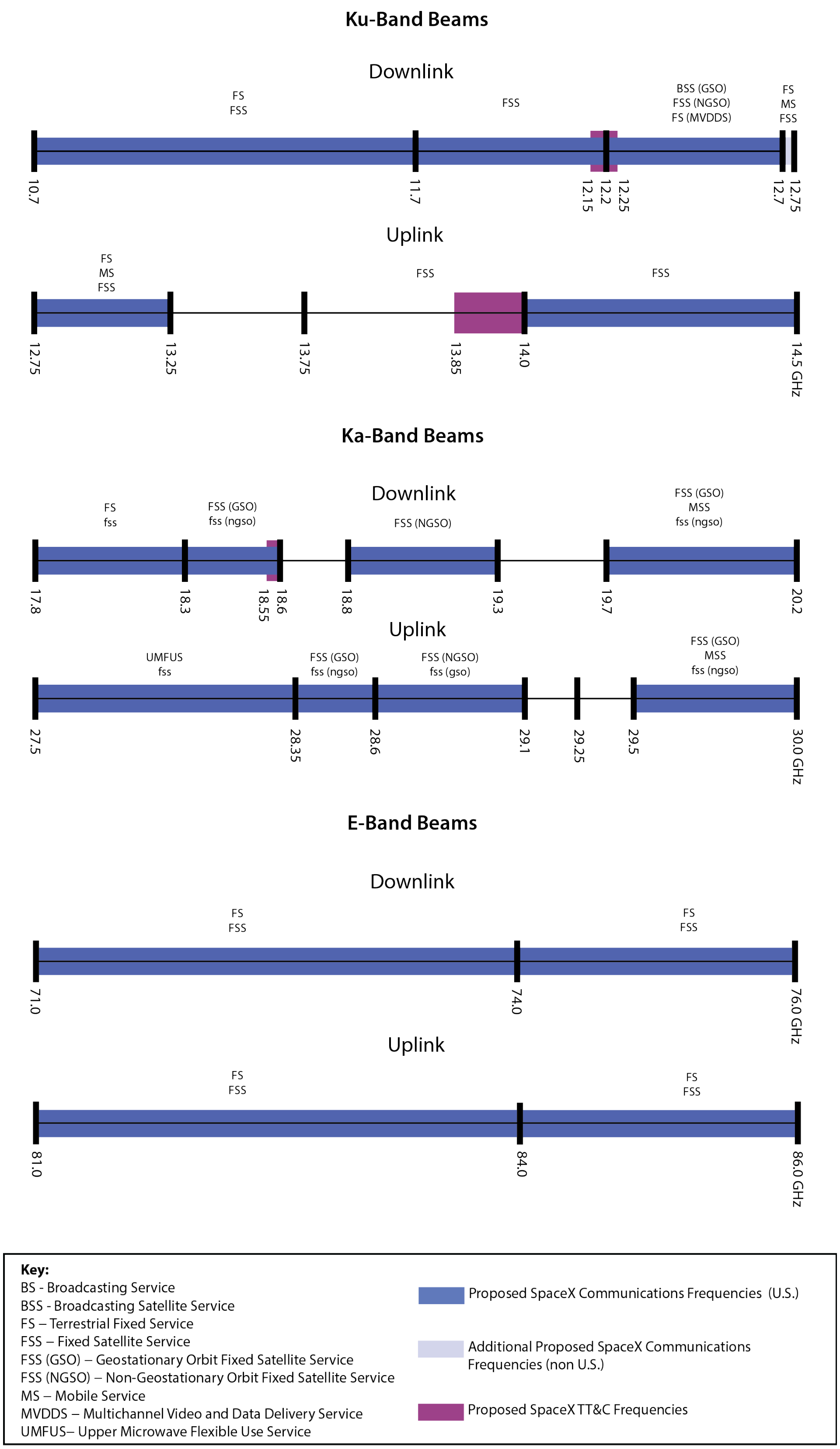

Figure A.8-1. Overview of Spectrum Allocations

The Gen2 System design has been engineered to achieve a high degree of flexibility in order to facilitate spectrum sharing and to protect other authorized satellite and terrestrial systems in compliance with U.S. and international regulations and under reasonable coordination arrangements. For example, the system has the following attributes:

- *Operation at high elevation angles.* The SpaceX System constellation is designed to provide service at minimum operational elevation angles of 25 degrees for most user terminals and gateway earth stations. Lower elevation angles will be used with gateways in Polar Regions where terrestrial systems are unlikely to operate. These factors will minimize the cases in which SpaceX transmissions would be expected to affect terrestrial systems.
- *Highly directional space station and earth station beams.* SpaceX satellites use narrow, steerable spot beams that can be directed away from potential areas of interference. Similarly, the earth stations used to communicate with the Gen2 System will operate with aperture sizes that enable narrow, highly-directional beams with strong sidelobe suppression. Combined with the fact that these beams will be steered to track NGSO satellites at elevation angles of at least 25 degrees in most cases, the system will provide significant off-axis isolation to other GSO and NGSO satellites. This will ensure that interference to other satellite systems could only occur in cases where there is an in-line event for satellites from each system.
- *Ability to select from multiple visible satellites for service.* The Gen2 System will provide multiple NGSO satellites in the field of view of any given earth station, providing the advantages of satellite diversity. The number of satellites in view will depend on the geographic location and the phase of deployment of the constellation. Where appropriate, the system will have the intelligence to select the specific satellite that would avoid a potential in-line interference event with other NGSO operations.

Applying these and other sharing mechanisms, SpaceX is confident that it can successfully coordinate its system with other authorized satellite and terrestrial networks. We discuss coordination considerations for various scenarios below.

A.8.1 Interference Protection for GSO Satellite Networks

Pursuant to Section 25.146 of the Commission's rules, SpaceX hereby certifies that its NGSO constellation will comply with the applicable equivalent power flux-density ("EPFD") limits set forth in Article 22 of the ITU Radio Regulations, which have been incorporated by reference into the Commission's rules.[24] As corroboration, SpaceX provides in Annex 2 to this Technical Attachment an analysis demonstrating that its Gen2 System will comply with applicable EPFD limits.[25]

In addition, Section 25.146(f) requires coordination between NGSO FSS systems and certain GSO FSS earth stations with very large antennas operating in the 10.7-12.75 GHz band. SpaceX is optimistic that such coordination can be completed in a mutually acceptable manner, and will inform the Commission once that has been accomplished.

A.8.2 Interference with Respect to Other NGSO Satellite Systems

The ITU has procedures for coordination amongst NGSO systems operating in all of the Ku-band and Ka-band frequency ranges to be used by the SpaceX system.[26] In addition, Section 25.261 of the Commission's rules anticipates that sharing between qualified NGSO applicants in the current processing round should be achievable, using whatever means can be coordinated between the operators to avoid in-line interference events, or by resorting to band segmentation in the absence of any such coordination agreement.[27] However, the Commission left open the relationship between participants in the current processing round and those NGSO systems licensed in prior rounds, finding that this "must necessarily be case-by-case based on the situation

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24 *See* 47 C.F.R. § 25.146(a)(2).

25 SpaceX will also operate its system in some portions of Ka-band spectrum (the 28.6-29.1 GHz uplink and 18.8-19.3 GHz downlink frequency bands, where NGSO satellite use is designated as primary) and E-band spectrum where no EPFD limits exist. According to ITU procedures applicable to these frequency ranges, coordination between NGSO and GSO networks is on a first-come, first-served basis. *See* ITU Radio Regs. No. 9.11A. SpaceX has engineered its system with the technical flexibility that will facilitate the necessary coordination and is confident that compatibility with all GSO satellite networks in these bands can be achieved. In addition, Resolution 76 of the ITU Radio Regulations includes limits on aggregate $EPFD_{down}$ produced by all co-frequency satellites of all NGSO FSS systems operating in certain Ku- and Ka-bands. SpaceX is prepared to work with other NGSO FSS operators to ensure compliance with the applicable limits.

26 *See id.* at No. 9.12.

27 *See* 47 C.F.R. § 25.261; *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 32 FCC Rcd. 7809, ¶ 48 (2017) ("*NGSO Update Order*").

at the time."[28]

SpaceX has engineered its system with the technical flexibility that will facilitate the necessary coordination with other NGSO satellite systems and is committed to achieving mutually satisfactory agreements. In addition, it has recently filed a petition for rulemaking proposing that the Commission revise Section 25.261 to provide more certainty to all NGSO operators by adopting protection criteria that later-round applicants can satisfy in order to be deemed coordinated with prior-round licensees.[29] SpaceX anticipates that other NGSO operators will engage with that proposal to help the Commission arrive at an appropriate sharing solution, and SpaceX will comply with the outcome of that proceeding.

A.8.3 Interference with Respect to Terrestrial Networks

Ku-Band

As demonstrated above, the Gen2 System will comply with all relevant PFD limitations in the Ku-band. SpaceX recognizes that user terminals operating in the 10.7-11.7 GHz band under a blanket earth station license must do so on an unprotected basis with respect to terrestrial FS networks.[30] There are also limitations in the 12.2-12.7 GHz band. Section 101.1409 of the Commission's rules provides that no new applications for point-to-point FS licenses in the band will be accepted, and that FS licensees in the band that were licensed prior to NGSO FSS satellite stations are not entitled to protection from harmful interference caused by later NGSO FSS entrants, except for legacy public safety stations which must be protected. According to the Commission's Universal Licensing System, there are currently 26 grandfathered public safety FS

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[28] *Id.* ¶ 61.

[29] *See* Petition for Rulemaking, RM No. 11855 (filed Apr. 30, 2020).

[30] *See* 47 C.F.R. § 25.115(f)(2).

licenses in the 12.2-12.7 GHz band that remain active,[31] and SpaceX will accept any interference caused by these links. In addition, SpaceX will observe a 25 degree minimum elevation angle for operations in this band, even from the 604 km and 614 km shells. As discussed in Section A.7 above, the SpaceX downlink transmissions in the 12.2-12.7 GHz band will comply with the applicable PFD limits, which are designed to protect FS operations in the band and so will ensure there is no downlink interference into these 26 legacy FS links.

The Commission has also authorized the Multichannel Video Distribution and Data Service ("MVDDS") in the 12.2-12.7 GHz band. Under the technical and service rules adopted for this service, MVDDS providers must share the 12 GHz band with new NGSO FSS operators on a co-primary basis.[32] To account for the particular interference mechanisms between MVDDS and NGSO systems, the Commission adopted the following operating requirements for the respective systems.

MVDDS Operating Requirements:

- To accommodate co-primary NGSO FSS earth stations in the band, the PFD of an MVDDS transmitting system must not exceed -135 dBW/m^2 in any 4 kHz band measured at a reference point at the surface of the Earth at a distance greater than 3 km from the MVDDS transmitting site.
- The maximum MVDDS EIRP shall not exceed 14 dBm per 24 MHz.
- The MVDDS transmitting antenna may not be installed within 10 km of any pre- existing NGSO FSS receiver unless the affected licensees agree to a closer separation.[33]

NGSO FSS Operating Requirements:

- Later-in-time NGSO FSS receivers must accept any interference resulting from pre-existing MVDDS transmitting antennas.

[31] *See Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, 17 FCC Rcd. 9614, App. I (2002) ("*NGSO-MVDDS Sharing Order*") (listing grandfathered call signs).

[32] *See id.* ¶ 26.

[33] *See* 47 C.F.R. §§ 101.105(a)(4)(i), 101.113 n.11, and 101.129(b).

- For angles of arrival between 0º to 2º above the horizontal plane, NGSO FSS downlinks in the 12.2-12.7 GHz band must meet a reduced PFD level of -158 dBW/m^2 in any 4kHz band, and for angles of arrival between from 2º to 5º above the horizontal plane, a reduced PFD level of -158 + 3.33 (δ-2) dBW/m^2 in any 4kHz band, where δ is the angle of arrival above the horizontal plane in degrees.[34]

In order to facilitate information sharing necessary to implement these requirements, both MVDDS and NGSO FSS operators must maintain and share databases of their respective transmitters and receivers.[35] SpaceX is committed to this sharing arrangement and will comply with the requirements of the Commission's rules, including the low-angle PFD limits (as demonstrated in Section A.7 above).

The 12.75-13.25 GHz uplink spectrum used by the Gen2 System for TT&C operations is shared with terrestrial FS in the U.S. on a co-primary basis.[36] By rule, only individually-licensed earth stations may operate with NGSO FSS systems in this band.[37] In addition, in order to protect Broadcast Auxiliary Service ("BAS") and Cable Television Relay Service ("CARS") operations in the 13.15-13.2125 GHz portion of the band, the Commission limited deployment of NGSO earth stations near major television markets and imposed a strict EIRP limit for uplink transmissions at low elevation angles.[38] Such limitations were designed to "ensure NGSO FSS operations could

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34 *See id.* at § 25.208(o); *NGSO-MVDDS Sharing Order*, ¶ 123.

35 *See* 47 C.F.R. §§ 101.103(f)(1), 25.139(a).

36 Specifically, in the band 13.15-13.25 GHz, the following provisions apply: (a) the sub-band 13.15-13.2 GHz is reserved for television pickup ("TVPU") and cable television relay service ("CARS") pickup stations inside a 50 km radius of the 100 television markets delineated in 47 C.F.R. § 76.51; and outside these areas, TVPU stations, CARS stations, and NGSO FSS gateway earth stations shall operate on a co-primary basis; (b) the sub-band 13.2-13.2125 GHz is reserved to TVPU stations on a primary basis and for CARS pickup stations on a secondary basis inside a 50 km radius of the 100 television markets delineated in 47 C.F.R. § 76.51; and outside these areas, TVPU stations and NGSO FSS gateway earth stations shall operate on a co-primary basis and CARS stations shall operate on a secondary basis. 47 C.F.R. § 2.106 n. NG53(a)-(b).

37 *See* 47 C.F.R. §§ 2.106 n.NG57, 25.115(f)(3).

38 *See Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-band Frequency Range*, 18 FCC Rcd. 2324, ¶¶ 11-14 (2003) ("*Ku-band Sharing Order*"); 47 C.F.R. § 2.106 n.NG53(d).

share spectrum with incumbent [FS] services without causing harmful interference or unduly constraining future growth of incumbent services, while allowing flexibility in implementing NGSO FSS systems."[39] SpaceX will not claim protection from licensed GSO FSS networks when operating on a primary basis, and will ensure compatibility with licensed FS users consistent with the limitations imposed on operations in this band under the Commission's rules.

Ka-Band

With respect to downlink spectrum, Annex 1 to this Technical Attachment presents an analysis demonstrating that SpaceX's operations will protect terrestrial FS networks operating in the Ka-band. Among the Ka-band spectrum to be used by the Gen2 System for its operations is the 17.8-18.3 GHz band, which is allocated to FS on a primary basis and FSS on a secondary basis in the U.S. In the unlikely event that a SpaceX gateway earth station experiences interference from an FS transmitter in this band, SpaceX will accept such interference and take the necessary measures to prevent it from affecting earth station operations. Such necessary technical measures may include adjusting the minimum operational elevation angles, frequency avoidance, earth station shielding, or some combination thereof.

Footnote NG62 to the U.S. Table of Allocations provides that NGSO FSS systems operating in the 28.5-29.1 GHz and shall not cause harmful interference to, nor claim protection from, 18 grandfathered FS stations.[40] SpaceX accepts these conditions.

The Gen2 System also uses the 27.5-28.35 GHz band for gateway links. Although FSS, FS, and Mobile services share this band on a co-primary basis, the Commission has designated this band for primary use in the U.S. by the FS (and specifically by the Upper Microwave Flexible

[39] *Ku-band Sharing Order* ¶ 5.

[40] *See* 47 C.F.R. § 2.106 n.NG62.

Use Service ("UMFUS")) and to the FSS on a secondary basis.[41] As a secondary service, FSS uplinks from gateway earth stations located in the United States must generally be operated so as not to cause harmful interference to any current or future licensed UMFUS station. However, the Commission has adopted a mechanism under which FSS earth stations will be able to deploy new gateways in limited circumstances without being required to take any additional actions to provide interference protection to UMFUS licensees.[42] The Commission concluded that "it should be possible for satellite and terrestrial services to share the 28 GHz band with *de minimis* impairment of each other's operations."[43] SpaceX will comply with the Commission's rules for deployment of gateway earth stations, and put in place procedures to protect UMFUS operations in the 27.5-28.35 GHz frequency band. These will involve careful site selection, shielding, and coordination with any UMFUS operators in the area where gateway earth stations are proposed. Any future SpaceX gateway earth station application that proposes operations in this band will demonstrate how potential interference to UMFUS systems has been addressed.

As a secondary user, SpaceX must also accept incoming interference from UMFUS operations. Although transmitting UMFUS stations are not likely to cause harmful interference into the transmitting FSS earth stations in this band, the aggregation of transmissions from UMFUS stations could be sufficient to interfere with the receiving spot beam of SpaceX's satellites. SpaceX will accept this risk and will not seek protection from such interference in the event it occurs, subject to further Commission consideration of this issue.[44]

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41 *See Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, 31 FCC Rcd. 8014 (2016) ("*Spectrum Frontiers R&O*").

42 *See* 47 C.F.R. § 25.136(a)(4).

43 *Spectrum Frontiers R&O*, ¶ 52.

44 *See id.* ¶ 69 (directing the International Bureau, the Office of Engineering and Technology, and the Wireless Telecommunications Bureau "to jointly establish a separate docket that parties can use to file the relevant data and analyses, and we reserve the right to revisit this [aggregate interference] issue should additional information

E-Band

Consistent with the U.S. Table of Frequency Allocations, the Gen2 System will use the 71-76 GHz band for gateway downlink transmissions and will receive gateway uplink transmissions in the 81-86 GHz band. Based upon information available from the third-party database managers responsible for registering links in those bands, as of March 2020, there were 18,770 registered fixed links in the 70 GHz and 80 GHz bands.[45] As shown in Figure A.8.4-1 below, the great majority of these links were concentrated in just 16 counties, leading the Commission to conclude that, "[g]iven the narrow beamwidths and limited path lengths involved, it would be reasonable to treat the remaining 3,125 counties and county equivalents as the functional equivalent of a green field, provided that adequate measures are taken to protect the few incumbents in them."[46]

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or other circumstances warrant further Commission review or action").

45 *See Modernizing and Expanding Access to the 70/80/90 GHz Bands*, Draft Notice of Proposed Rulemaking and Order, FCC CIRC-2006-02, ¶ 5 (rel. May 19, 2020). A link in this context is defined as a communication path between one location and another in a single direction. Multiple channels registered between the same transmit and receive location are considered separate links. Bi-directional communications are also counted as separate links.

46 *See Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al.*, 31 FCC Rcd. 8014, ¶ 432 (2016) (showing data as of June 2016) ("*Spectrum Frontiers R&O*").

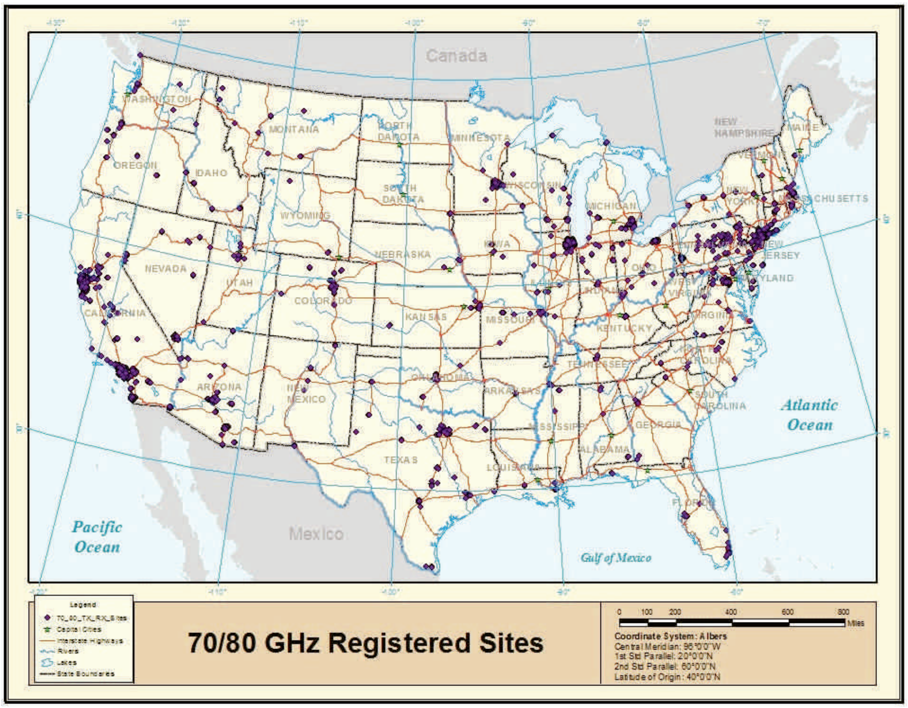

Figure A.8.4-1. Registered FS Links in the 71-76/81-86 GHz Bands

To date, SpaceX has deployed its gateway earth stations in fairly rural areas that are likely to be far from any of these registered links. Moreover, such gateways are individually licensed so both SpaceX and any terrestrial operator in the band will have an opportunity to explore the potential for coordination in those rare instances where operations in nearby areas occur.

A.8.4 Interference with Respect to the Radio Astronomy Service

Several footnotes to the U.S. Table of Frequency Allocations address the need for satellite downlink transmissions in a limited number of bands used by the Gen2 System to adequately protect the Radio Astronomy Service ("RAS") at specific sites in the U.S. SpaceX will ensure that such systems are protected from any in-band and out-of-band interference from its NGSO system's operations. To this end, the Gen2 System will comply with the protections described under the relevant ITU footnotes, resolutions, and recommendations for the protection of RAS. It will similarly comply with all applicable procedures for coordination with RAS users. SpaceX has already begun discussions with RAS stakeholders to address any interference concerns.

A.9 COORDINATION WITH U.S. GOVERNMENT NETWORKS

Footnote US334 of the U.S. Table of Frequency Allocations requires SpaceX to coordinate its NGSO system with U.S. government satellite networks, both GSO and NGSO, in portions of the Ka-band spectrum. SpaceX has reached agreement with various U.S. government agencies for the operation of its first-generation system, and is committed to successful coordination of the Gen2 System with all government satellite networks operating in these bands to protect critical national security and government systems. For the reasons discussed above, SpaceX is confident that the characteristics of its proposed system will facilitate an operational approach that will allow equitable sharing of this spectrum with government systems. SpaceX will inform the Commission when such coordination has been completed.

A.10 ITU FILINGS FOR SPACEX

SpaceX has not yet submitted system information for ITU publication. SpaceX will submit this information at the appropriate time and will unconditionally accept all consequent ITU cost-recovery responsibility for the filing.

A.11 ORBITAL DEBRIS MITIGATION

SpaceX's launch and space experience provide the knowledge base for implementing an aggressive and effective space-debris mitigation plan. The company's current and planned space-based activities underscore its unparalleled commitment to safe space. SpaceX has had extensive experience in safe-flight design and operation through many missions of both the Falcon 9 launch vehicle and the Dragon spacecraft carrying out missions to the International Space Station ("ISS"), including the upcoming Crew Dragon flight that will mark the first manned mission from U.S. soil since 2011. The company is highly experienced with cutting-edge debris mitigation practices and has deep ties with the domestic and international institutions tasked with ensuring the continued safety of space operations. SpaceX has a long-standing collaborative working relationship with the 18th Space Control Squadron, a multinational focal point for management of space traffic, debris, and other space coordination functions associated with the U.S. Department of Defense. It also has existing relationships with NASA in the support of its space-based activities, and will continue to utilize these experiences and relationships as resources while developing its NGSO system and spacecraft.

Maintaining a clean orbital environment is a fundamental consideration for SpaceX, which is planning to launch its Falcon 9 vehicles into orbital altitudes dozens of times this year alone for its commercial and government customers, as well as undertaking Dragon cargo missions to the ISS for NASA and Crew Dragon missions that will carry astronauts to the ISS. SpaceX is implementing an aggressive and effective space-debris mitigation plan, leveraging both its nearly two decades of technical and operational experience in cost-effectively deploying large, complex space systems to support other operators and its more recent experience with its first-generation NGSO constellation.

SpaceX has incorporated the material objectives set forth in this application into the technical specifications established for design and operation of the proposed Gen2 System. SpaceX will internally review orbit debris mitigation as part of the preliminary design review and critical design review for the spacecraft, and incorporate these objectives, as appropriate, into its operational plans. SpaceX will continue to stay current with the Space Situational Awareness community and technology to continue its leadership in this area.

Spacecraft Hardware Design

SpaceX has assessed and limited the amount of debris released in a planned manner during normal operations and does not intend to release debris during the planned course of operations of the satellite constellation. In deploying multiple satellites with each launch, SpaceX uses four separate rod assemblies, each consisting of two rods, to hold the stacked satellites in place within the fairing. To deploy the stack of satellites from the launch vehicle, the rods release the satellites to separate them prior to further orbit raising activities. Thereafter, the rods – which are made of lightweight aluminum and are only 1.5 inches in diameter and about six meters long – naturally re-enter the Earth's atmosphere. Leveraging impact predictions from NASA's Debris Assessment Software ("DAS"), SpaceX used internal software developed to provide higher fidelity analysis[47] to determine that these rods have an expected orbital lifetime of at most 36 days (assuming the highest deployment altitude SpaceX expects to use) and will completely demise in the atmosphere. Given the small size and brief orbital existence of these rods, the analysis yields a collision risk of approximately 0.00000000653. In addition, because the satellites separate naturally and predictably after the rods are released, they are at most susceptible to very low velocity recontact with each other but do not present a risk of generating debris during this process. To date, SpaceX has used rod assemblies for deployment of 420 satellites over seven launches without incident, confirming the conclusion of the analysis.

SpaceX is also aware of the possibility that its system could become a source of debris in the unlikely case of a collision with small debris or meteoroids that could either create jetsam or cause loss of control of the spacecraft and prevent post-mission disposal. SpaceX is undertaking steps to address this possibility by incorporating redundancy, shielding, separation of components, and other physical characteristics into the satellites' design. For example, tanks are protected by a 1 mm aluminum shield, and even in the unlikely event of an impact reaching the tank, the tank

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47 In particular, while DAS can provide decay times and collision probabilities at different altitudes, it does not actually propagate a decay trajectory through the different debris flux levels at different altitudes. SpaceX's proprietary model uses the impact flux information that DAS uses to compute impact rate as a function of altitude.

is designed to suffer impact penetration without explosive consequences, while batteries are shielded and have isolation features to prevent cascading failure from impacted battery cells to other battery cells. In addition, many on-board command receivers, telemetry transmitters, and the bus control electronics will be redundant and appropriately shielded to minimize the probability of the spacecraft becoming flotsam due to a collision. As a result, an analysis using SpaceX's proprietary software yields an overall probability of collision with small debris (down to one millimeter in diameter) sufficient to prevent compliance with post-mission disposal maneuvers of approximately 0.000776 for an individual space station during its mission lifetime. Moreover, as discussed below, atmospheric drag at the low operating altitude of these satellites ensures that even if they fail upon deployment or at their operational altitudes, most will de-orbit in less than three months and all will de-orbit in less than ten years – which the Commission considers successful disposal.[48]

SpaceX will continue to review these aspects of on-orbit operations throughout the spacecraft manufacturing and deployment processes and will make such adjustments and improvements as appropriate to assure that its spacecraft will not become a source of debris during operations or become derelict in space due to a collision.

Minimizing Accidental Explosions

SpaceX has designed its spacecraft in a manner that limits the probability of accidental explosion. The key areas reviewed for this purpose include rupture of propellant tanks and batteries. The basic propulsion design, propulsion subsystem component construction, preflight verification through both proof testing and analysis, and quality standards have been designed to ensure a very low risk of tank failure. During the mission, batteries and various critical areas of

[48] *See Orbital Debris Mitigation Update Order*, ¶ 96.

the propulsion subsystem will be instrumented with fault detection, isolation, and recovery (similar or in many cases identical to flight-proven methods utilized onboard the SpaceX Dragon capsule for its missions to ISS) to continually monitor and preclude conditions that could result in the remote possibility of energetic discharge and subsequent generation of debris.

SpaceX will not, however, remove all stored energy at the spacecraft's end of life. In adopting this strategy, SpaceX recognized that its satellites rely on fuel to continue maneuvering during the de-orbit process right to the point at which the satellite is re-entering the Earth's atmosphere. At that point, the satellite is already in the process of breaking up, virtually nullifying the danger from an orbital debris strike. By contrast, adding a valve or other mechanism to enable passivation would simultaneously increase the risk of accidentally venting the propellant tank and thereby leaving the satellite stranded in orbit. Accordingly, SpaceX concluded that that the risk of an inoperable satellite in orbit far outweighed the risk of having a satellite with a very small inert krypton gas reserve in its tank during the days-long period over which it enters the atmosphere and demises. Through this process, SpaceX has assessed and limited the possibility of accidental explosions during mission operations.

Safe Flight Profiles

As a leader in space safety, SpaceX is planning to fly the vast majority of the Gen2 satellites at altitudes in the 300-399 km range. While flying at this altitude comes at a cost because it increases the number of satellites required for coverage, it dramatically decreases the demise time of the satellites at end of life or in failure cases to a matter of months instead of years. Because of the higher drag at these low altitudes, these orbits are significantly less crowded and the collision risk is reduced. A satellite flying at 350 km is 21,000 times less likely to have a collision with a piece of space debris than one flying at 800 km.

SpaceX takes seriously the responsibility of deploying large numbers of satellites into space and intends to exceed industry best practices to ensure the safety of space. Through detailed and conscientious mission planning, SpaceX has carefully assessed and limited the probability of its system becoming a source of debris by collisions with large debris or other operational space stations. It will maintain the accuracy of its orbital parameters at a level that will allow operations with sufficient spacing to minimize the risk of conjunction with adjacent satellites in the constellation and other constellations. SpaceX has and will continue to work closely with the 18th Space Control Squadron and other relevant agencies to ensure the service provided for conjunction assessment to SpaceX and all operators is robust, reliable, and secure. Significant coordination must be performed with other satellite operators in nearby orbits to ensure any altitude perturbations do not result in unnecessarily close approaches. The propulsion system onboard can respond quickly and at high cadence, allowing SpaceX to coordinate in advance and respond to conjunction risks, whether with debris or other active spacecraft. SpaceX is willing to engage with any operators of nearby constellations to ensure safe and coordinated space operations.

Maneuverability

All SpaceX spacecraft will leverage on-board propulsion. These efficient propulsion systems are ideal for orbit raising, station-keeping maneuvers including the ability to avoid other satellites and debris, and initiating the de-orbit process by lowering the satellites' perigee to approximately 300 km. In fact, the efficiency of these ion thrusters improves the overall safety of the system by enabling the vehicles to perform a vastly greater number of maneuvers for the same amount of fuel compared to alternative systems. In just ten minutes, the thruster can adjust a satellite's orbit sufficiently to avoid an object half an orbit away.

SpaceX confirms that it intends to perform collision avoidance procedures, including conjunction assessment, execution of avoidance maneuvers, trajectory planning and conjunction assessment for any planned alteration of satellite trajectory, and notification to other potentially affected operators of any planned alteration of a satellite's trajectory. SpaceX will perform conjunction screening and avoidance maneuvers for all phases of operations, including any planned alteration of satellite trajectory, prior to passive disposal. For this purpose, SpaceX will observe a risk threshold of 0.001% as the trigger for a collision avoidance maneuver, which is significantly stricter than industry standards. All satellites will have sufficient propellant and capability to perform any avoidance maneuvers required for all phases of the satellites' mission.[49]

SpaceX certifies that upon receipt of a space situational awareness conjunction warning, it will review and take all possible steps to assess the collision risk, and will mitigate the collision risk if necessary. As appropriate, steps to assess and mitigate the collision risk may include, but are not limited to: contacting the operator of any active spacecraft involved in such a warning; sharing ephemeris data and other appropriate operational information with any such operator; and modifying space station attitude and/or operations.

Satellite Tracking

Prior to deployment, SpaceX will register its satellites with the 18th Space Control Squadron (or a successor entity). Following deployment, SpaceX will identify its satellites using a network of ground stations located around the world that will establish contact with the satellites. SpaceX certifies that each of its space stations will have a unique telemetry marker allowing it to be distinguished from other satellites or space objects. Because SpaceX satellites will be larger

[49] The 300 km target does not account for a fuel margin stack-up reserved for other uses. In the vast majority of cases, any remaining margin would allow satellites to expedite demise. SpaceX will reserve at least 70 m/s of delta-V – a measure of the impulse required for a given maneuver or, here, the capability to perform those maneuvers if necessary – to deliver the described de-orbit functionality.

than 10 cm in their smallest dimension, they are presumed to be trackable.[50] Nonetheless, SpaceX satellites autonomously estimate their own position using GPS and other sensors and regularly report that information to enhance active tracking. SpaceX plans to share information regarding initial deployment, ephemeris, and planned maneuvers with the 18th Space Control Squadron (or a successor entity) and other entities that engage in space situational awareness or space traffic management functions. SpaceX will also share ephemeris data with other NGSO system operators through spacetrack.org. SpaceX is the first operator to optimize the usefulness of this data by supplementing it with co-variance data, which allows other operators to better assess the collision risk between their own vehicles and SpaceX satellites.

Collision Risk

SpaceX has made clear that it intends to conduct active maneuvers to avoid collisions with both debris and other spacecraft throughout the life of its satellites, even through the de-orbit phase until the spacecraft enters the atmosphere. As the Commission has recognized, because SpaceX has invested in advanced propulsion capabilities for its satellites, collision risk with large objects is considered to be zero while the spacecraft are capable of maneuvering.[51] While SpaceX expects its satellites to perform nominally and deorbit actively as described below, in the unlikely event a vehicle is unable to finish its planned disposal maneuver, the denser atmospheric conditions at the low altitudes used by the Gen2 System provide fully passive redundancy to SpaceX's active disposal procedures.

The natural orbital decay of a satellite at these altitudes will take less than ten years – and in a large majority of satellites, less than three months – even considering worst-case assumptions.

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50 *See Orbital Debris Mitigation Update Order*, ¶ 58.

51 *See, e.g.*, *id.*, ¶ 35; *First Modification*, ¶ 22.

Due to the very lightweight design of the new spacecraft, SpaceX achieves a very high area-to-mass ratio on its vehicles. Combined with the natural atmospheric drag environment at lower altitude, this high ratio ensures rapid decay even in the absence of the nominally planned disposal sequence. Thus, even assuming an extreme worst-case scenario – i.e., the spacecraft fails while in the operational orbit, has no attitude control, and solar activity is at a minimum – the longest decay time is still only approximately ten years. The time to satellite demise from various altitudes is illustrated in Figure A.11-1 below.[52]

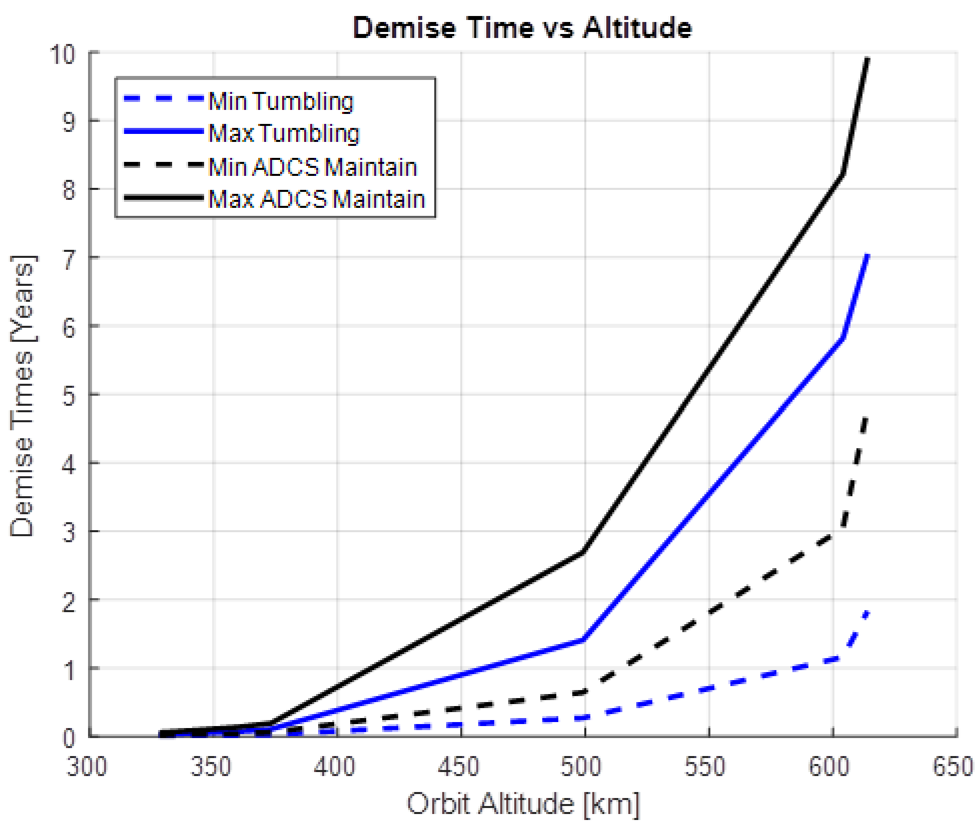

Figure A.11-1. Demise Time at All Proposed Altitudes

[52] These figures show demise time as a function of altitude, using ballistic coefficients corresponding to the SpaceX spacecraft. Dashed curves show conditions around solar minimum, characteristic of the current atmosphere, and solid curves show conditions around solar maximum, characteristic of the atmosphere in the early/mid 2020s. The blue curves assume that propulsion has failed, but the vehicle can still orient itself into a high-drag attitude. The black curves assume that the Attitude Determination & Control System ("ADCS") has also failed, and the vehicle is unable to hold a specific attitude.

Because approximately 85% of the constellation will operate at the lower altitudes (from 328-373 km) where demise times are very short, Figure A.11-2 below shows those demise times in greater detail. As this figure illustrates, the longest decay time for the vast majority of the constellation is less than three months even assuming an extreme worst-case scenario.

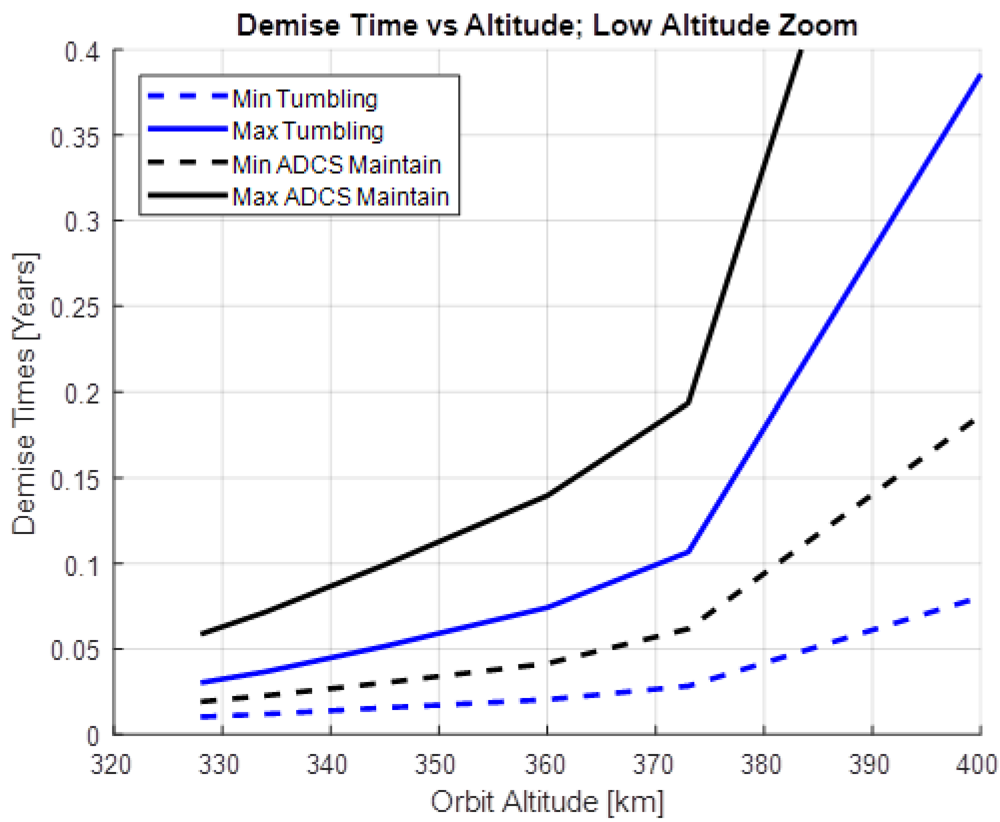

Figure A.11-2. Demise Time at Lower Proposed Altitudes

In reality, this confluence of worst-case assumptions is unlikely to be realized for a number of reasons, not the least of which is that overall solar activity is ramping up into the next decade, meaning a more realistic worst-case decay time of approximately seven years (and less than 50 days for most satellites). But even assuming the unlikely ten-year decay period, SpaceX satellites will reach demise well within the prevailing 25-year deorbit standard. In fact, SpaceX will exceed the aspirational goal recently set by the Commission for safe operation of large constellations[53] by

53 *See Orbital Debris Mitigation Update Order*, ¶ 94 (establishing a "goal of 0.99 or better for large systems").

achieving a 100% success rate of post-mission disposal within about ten years even assuming worst-case conditions. Nonetheless, SpaceX's nominal disposal plan that it anticipates for nearly every spacecraft will result in a lifetime of less than 70 days after SpaceX initiates disposal, an advantage of operating at the low altitudes proposed in this application.

These short demise times significantly limit the risk of collision in the event that a satellite loses maneuverability while in operational orbit. Table A.11-1 below shows the probability of collision between a space object larger than 10 cm in diameter and a Gen2 System satellite at each of the various operating altitudes proposed herein, assuming that the satellite has lost all maneuver capability, and assuming alternative cases of a satellite for which attitude is maintained and one that is tumbling. In addition, the table provides the analysis for satellites designed with and without sun shade panels.

Altitude (km)	Standard Satellite		Satellite with Sun Shade Panels	
	Maintained	Tumbling	Maintained	Tumbling
328	0.000000059	0.000000058	0.000000062	0.000000061
334	0.000000075	0.000000075	0.000000079	0.000000078
345	0.00000013	0.00000013	0.00000013	0.00000013
360	0.00000036	0.00000036	0.00000038	0.00000036
373	0.00000041	0.00000040	0.00000046	0.00000041
499	0.0000128	0.0000125	0.0000135	0.0000132
604	0.0001773	0.0001558	0.0001902	0.0001605
614	0.0002702	0.0002322	0.0002867	0.0002373

Table A.11-1. Collision Risk Assuming No Maneuver Capability

As this table demonstrates, the collision risk of a Gen2 System satellite in all cases falls well below the 0.001 benchmark recently adopted by the Commission,[54] and in most cases does so by orders of magnitude.

Moreover, due to SpaceX's decision to minimize risk by using a low injection altitude,[55]

[54] *See id.* ¶¶ 33-34.

[55] SpaceX intends to inject satellites into an elliptical orbit of approximately 210 km by 370 km. Though it is

in the unlikely event any satellites after the initial launch experience immediate failure upon deployment, they would decay to the point of demise very quickly – as little as one day to at most 25 days under worst-case conditions. Table A.11-2 below shows the probability of collision between a space object larger than 10 cm in diameter and a SpaceX satellite if rendered totally incapacitated immediately following orbital injection.

	Solar Minimum	**Solar Maximum**
Stowed Configuration	0.0000000298	0.0000000144
Deployed Configuration	0.0000000301	0.0000000148

Table A.11-2: Collision Risk of Incapacitated Satellite at Injection

Here again, SpaceX satellites satisfy the Commission's safety standard by several orders of magnitude under all scenarios even assuming failure upon deployment.

SpaceX will continue to take a number of steps to ensure that its constellation does not unduly affect other constellations. First, SpaceX has implemented autonomous conjunction avoidance technology on its spacecraft and expects to continue to upgrade that capability as it gains operational experience. Second, as stated above, SpaceX will perform nominal conjunction avoidance at all stages of flight. To aid with its other conjunction avoidance efforts, SpaceX has worked closely with the 18th Space Control Squadron and will provide it or other relevant regulatory agencies with forecasts of vehicle positions, during both ballistic and propulsive phases of flight. SpaceX will also provide such forecasts through secure interfaces to other operators, if communication is necessary beyond the 18th Space Control Squadron.

In order to determine whether the normal operation of any other planned or operational

possible that injection parameters may vary slightly in a small number of cases, the maximum altitude is not planned to be more than 370 km.

space stations pose a risk of collision with the Gen2 System, SpaceX undertook a review of the list of licensed systems and systems that are under consideration by the Commission for the orbital altitudes it has requested. The Commission has authorized a number of operators to deploy cubesats at altitudes from 400 km to 650 km with orbits that will naturally decay to lower altitudes due to lack of propulsion, including Astro Digital US, Inc., Spire Global, Inc., Swarm Technologies, Inc., and Kepler Communications, Inc.[56] There are also two market access applications under consideration for non-U.S. licensed cubesat systems that will launch to an altitude of 600 km and naturally decay, filed by Hiber Inc. and Myriota Pty. Ltd.[57] Kuiper Systems LLC has also filed an application for an NGSO constellation operating at 590 km, 610 km, and 630 km.[58]

In addition, in order to address non-U.S. licensed systems, SpaceX has reviewed the list of NGSO satellite networks filed with the ITU by other administrations that have a perigee within the range of altitudes used by the Gen2 System for which a request for coordination has been published by the ITU. The results, summarized in Annex 3 hereto, show that there are 54 non-U.S filings, of which 59% propose five or fewer satellites at the relevant orbital altitudes and 74% propose twenty or fewer.

From this good faith review, SpaceX concludes that physical coordination should be practicable, facilitated by the maneuverability of its system and its willingness to share information

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56 *See, e.g.*, Grant Stamp, IBFS File No. SAT-LOA-20170508-00071 (granted Aug. 1, 2018) (deployment altitude from 475-625 km); Letter from George John to Marlene H. Dortch, IBFS File No. SAT-LOA-20151123-00078 (June 26, 2019) (Annual Report for IBFS Call Sign S2946 showing deployments from 400-650 km); *Swarm Technologies, Inc.*, 34 FCC Rcd. 9469 (IB 2019) (deployment altitude from 400-550 km); *Kepler Communications Inc.*, 33 FCC Rcd. 11453 (2018) (operational altitude from 500-600 km). SpaceX will provide launch services for many of these operators, which should facilitate coordination for the injection and orbit raising processes.

57 *See* IBFS File Nos. SAT-PDR-2018910-00069 and SAT-PDR-20190328-00020.

58 *See* Application, IBFS File No. SAT-LOA-20190704-00057 (filed July 4, 2019).

on the operations of its system. SpaceX has already begun discussions with some of the existing licensees identified above and will engage these and any other systems seeking to operate at the same nominal orbital ranges sought by SpaceX to carefully coordinate physical operations to ensure that their respective constellations can coexist safely.

Post-Mission Disposal

Each satellite in the Gen2 System is designed for a useful lifetime of five to seven years. SpaceX intends to dispose of satellites through uncontrolled atmospheric re-entry at end of life. As discussed above, SpaceX anticipates that its satellites will reenter the Earth's atmosphere within approximately 70 days after completion of their mission under normal circumstances, and even in a worst case would de-orbit within no more than ten years – much sooner than the international standard of 25 years. Accordingly, the probability of successful disposal of each SpaceX satellite as defined by the Commission is deemed to be 100% – surpassing the goal set by the Commission for large NGSO systems.[59]

SpaceX intends to perform an active disposal of all of its satellites at the end of their life, in which the satellites first drop to a perigee of approximately 300 km over the course of at most a few weeks, after which several weeks of "passive" disposal follow, with the exact time depending on solar activity. Even this phase is not fully passive – to minimize the risk of debris even further, SpaceX satellites will continue to perform conjunction avoidance until the high atmospheric torques from low altitudes cause the vehicle to be uncontrollable. At all times during this descent, including the period during which they could potentially traverse the orbital altitude of inhabitable spacecraft, SpaceX satellites will retain sufficient fuel to perform maneuvers and thus will not impose any undue operational constraints to such inhabitable spacecraft. After all propellant is

[59] *See Orbital Debris Mitigation Update Order*, ¶ 96.

consumed, the spacecraft will be reoriented to maximize the vehicle's total cross-sectional area. Finally, the spacecraft will begin to passivate and power down.

Casualty Risk Assessment

The spacecraft's small mass and predominantly aluminum construction maximize the likelihood of atmospheric demise on re-entry. To verify this, SpaceX used internal software leveraging NASA's DAS to provide higher fidelity re-entry survivability analysis. This analysis confirmed that all Gen2 satellites are fully demisable upon atmospheric re-entry, and no components would be expected to survive to reach the Earth's surface with a kinetic energy in excess of 15 joules. Accordingly, the calculated risk of human casualty is zero.

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge and belief.

/s/ *Mihai Albulet*

Mihai Albulet, PhD
Principal RF Engineer
SPACE EXPLORATION TECHNOLOGIES CORP.

May 26, 2020
Date

ANNEX 1

POTENTIAL INTERFERENCE TO KA-BAND FIXED SERVICE SYSTEMS

In the *Initial Authorization*, the Commission imposed a condition under which SpaceX must submit a technical showing demonstrating that the operation of its first-generation NGSO system would protect a fixed-service ("FS") station with the characteristics described in Recommendation ITU-R SF.1483.[1] SpaceX made such a showing in connection with its recent modification, which the Commission found to satisfy the condition.[2] In support of its application for the Gen2 System, SpaceX provides that showing below for the second-generation constellation proposed herein. For purposes of this analysis, SpaceX used the following assumptions:

1. FS link characteristics per Recommendation ITU-R SF.1483

Parameters	Specifications
Elevation Angles	0° and 2.2°
FS Antenna Height (m)	0
FS Antenna Gain (dBi)	32, 38, and 48
FS Antenna Pattern	Per Rec. ITU-R F.1245
Latitude (degrees)	24° N, 45° N, 60° N
Atmospheric Attenuation	Not considered (conservative)
Feeder Loss (dB)	3
Polarization Loss	0, per Rec. ITU-R F.1245 (Note 7)
Rx Thermal Noise (dBW/MHz))	-139

1 *See Initial Authorization*, ¶ 35.

2 *See First Modification*, ¶ 29.

In addition to the test latitudes suggested by ITU-R SF.1483, SpaceX has performed the analysis with an FS station at 75°N latitude in light of the polar orbits used by some of its satellites.

Protection criteria used in this analysis per Rec. ITU-R F.1495:

a. Long-term: I/N should not exceed –10 dB for more than 20% of the time in any year.
b. Short-term: I/N should not exceed +14 dB for more than 0.01% of the time in any month, and I/N should not exceed +18 dB for more than 0.0003% of the time in any month.

For a given FS victim antenna gain, latitude, and elevation, the analysis considers the worst-case antenna pointing. The analysis considers one user beam per spot (worst case) or 32 gateway beams per spot (the closest beams to the boresight of the terrestrial antenna), and also includes the contribution of the sidelobes from all other SpaceX satellites in view. Note that this is a conservative analysis, as it does not account for the mitigating effect of atmospheric attenuation.

The results are shown for both user beams and gateway beams in Figures A1-1 to A1-16 below. In each case, the results are shown for the full proposed Gen2 System with minimum elevation angles discussed in the Technical Attachment. Note that in all cases, the aggregate I/N are lower than ITU-R F.1495 long-term and short-term limits.

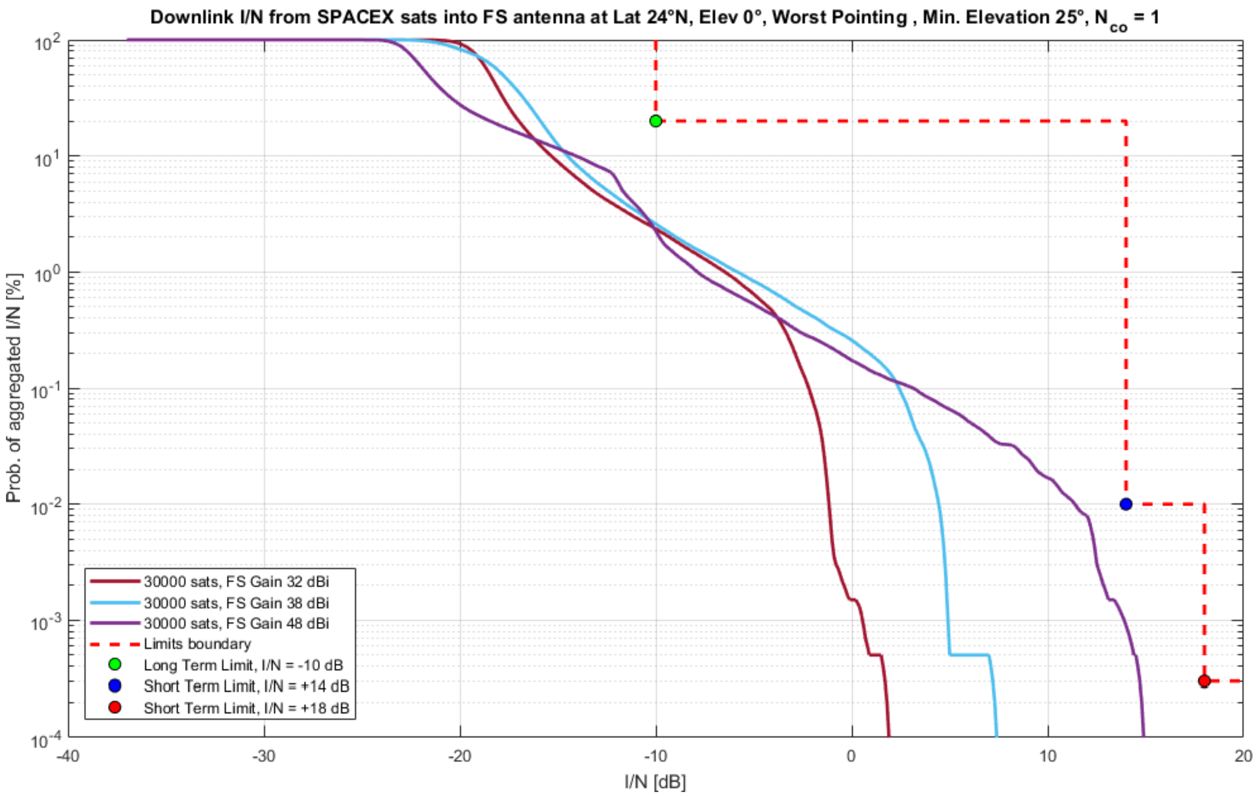


Figure A1-1. FS Station: Lat. 24°, Elevation 0° - SpaceX User Beams

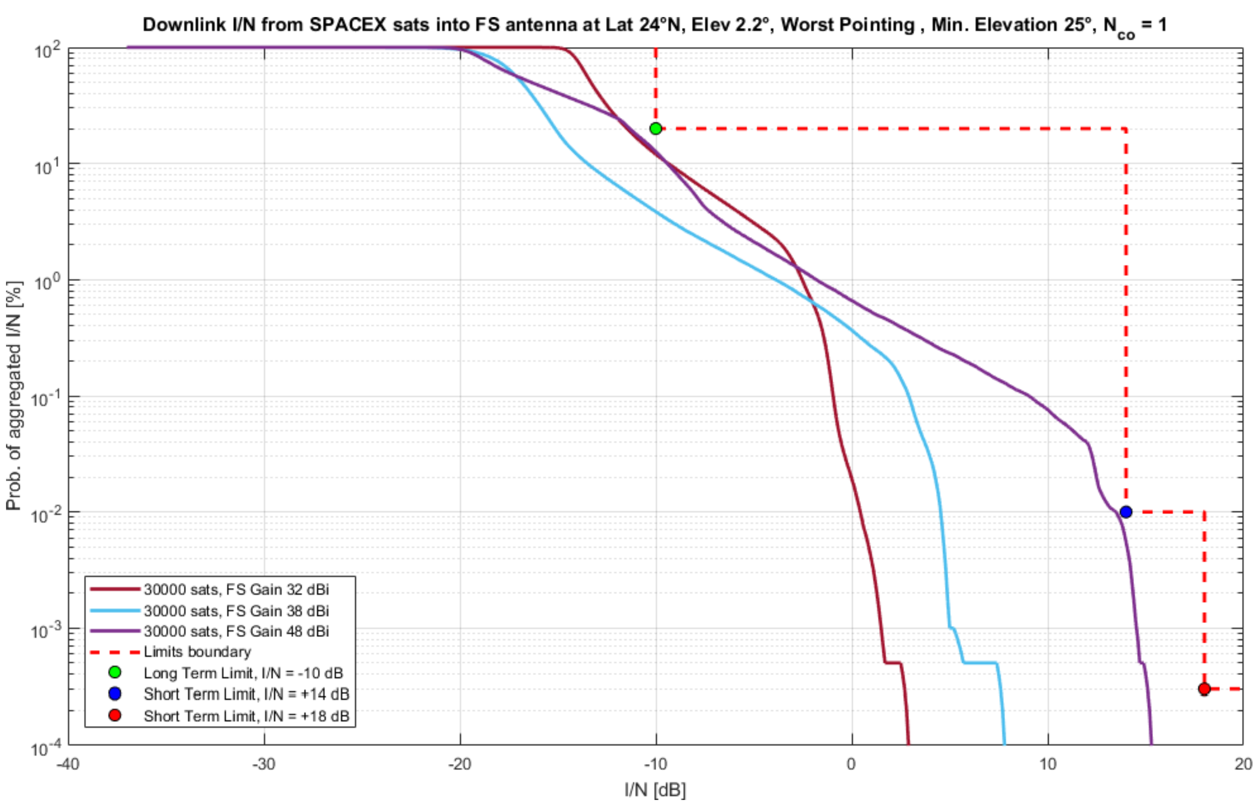


Figure A1-2. FS Station: Lat. 24°, Elevation 2.2° - SpaceX User Beams

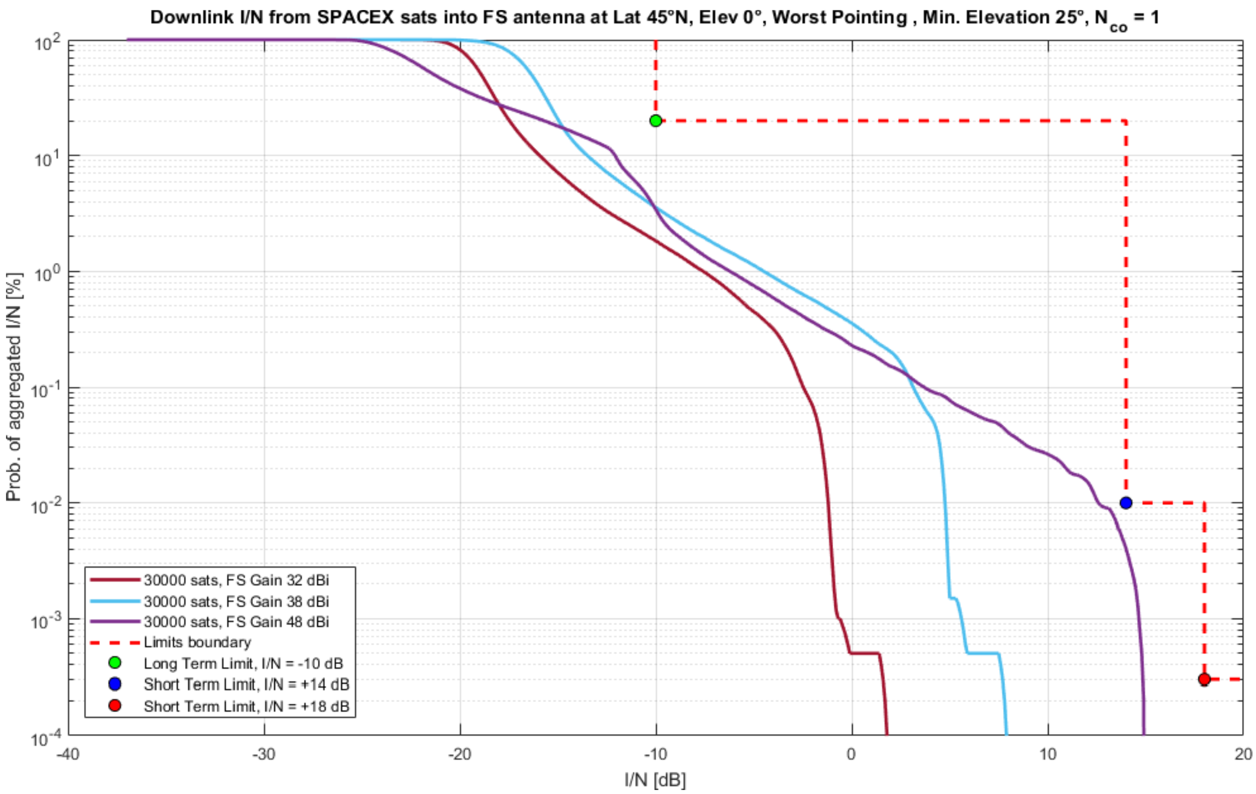


Figure A1-3. FS Station: Lat. 45°, Elevation 0° - SpaceX User Beams

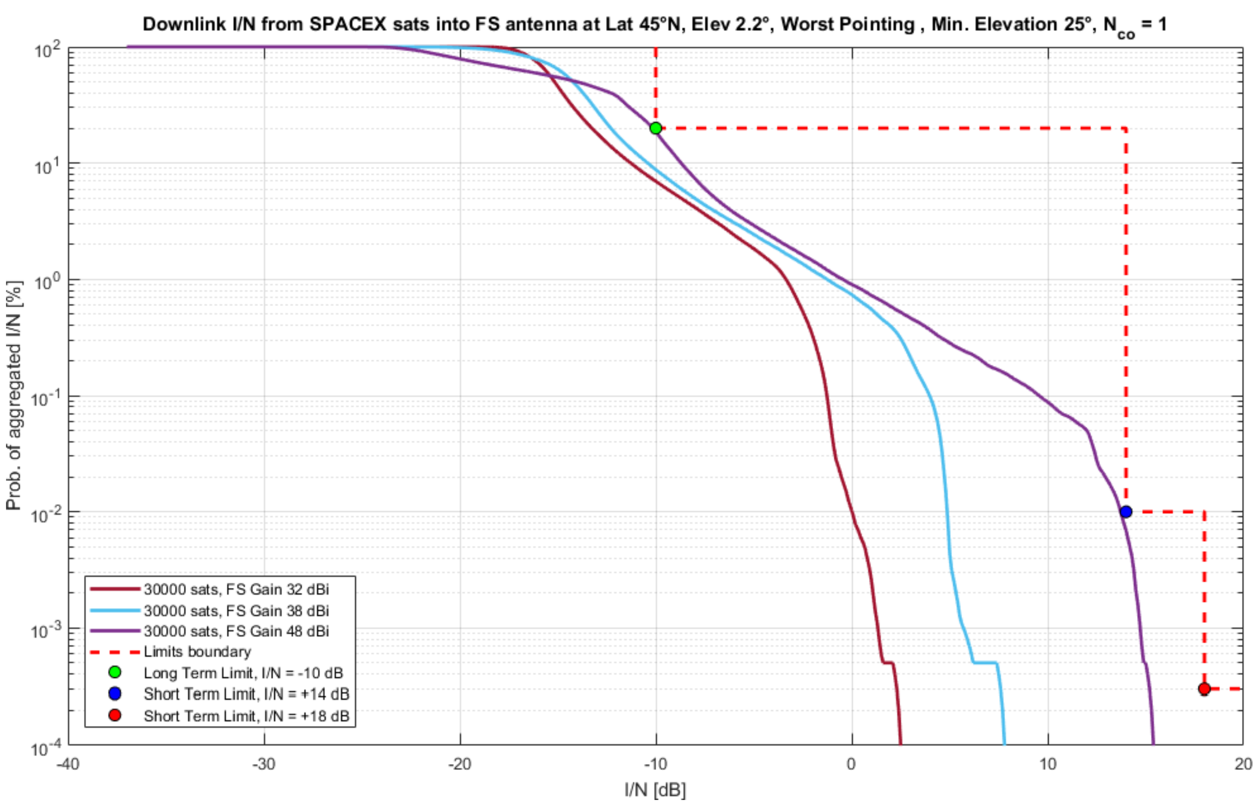


Figure A1-4. FS Station: Lat. 45°, Elevation 2.2° - SpaceX User Beams

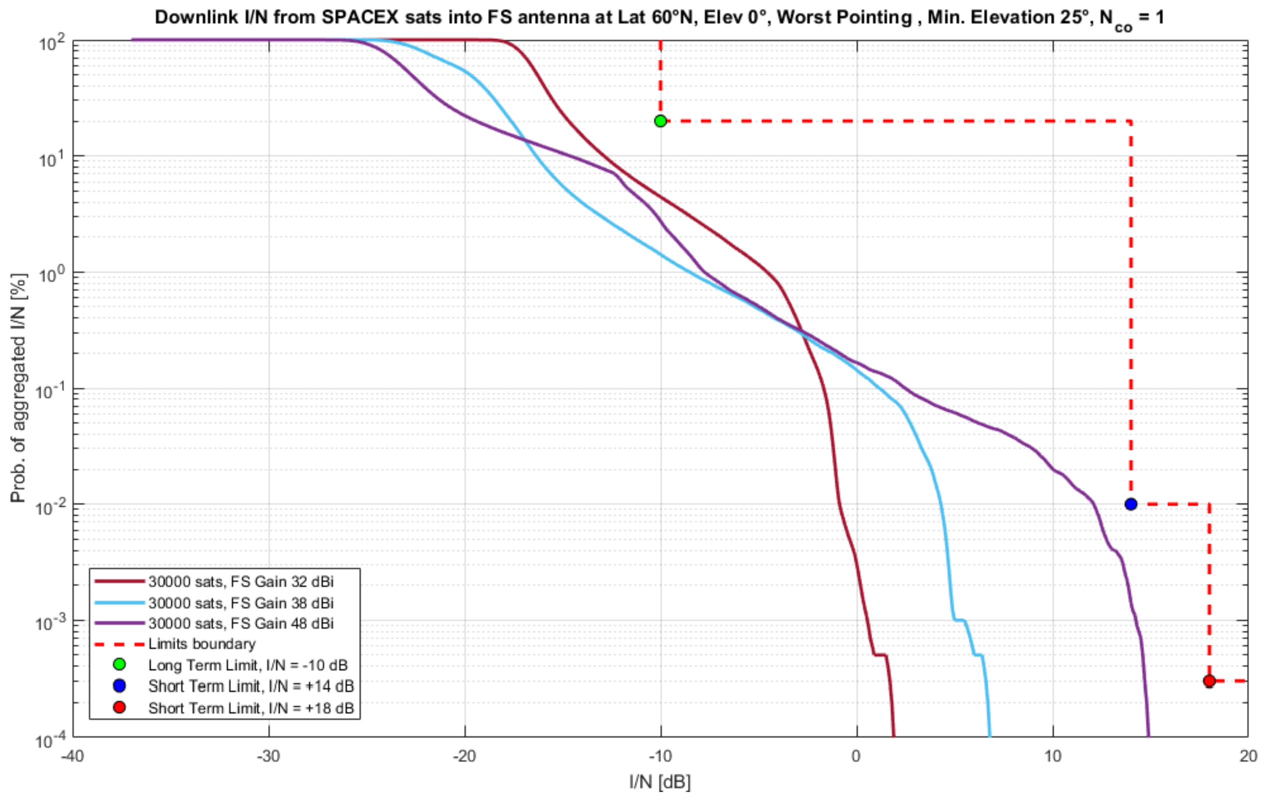


Figure A1-5. FS Station: Lat. 60°, Elevation 0° - SpaceX User Beams

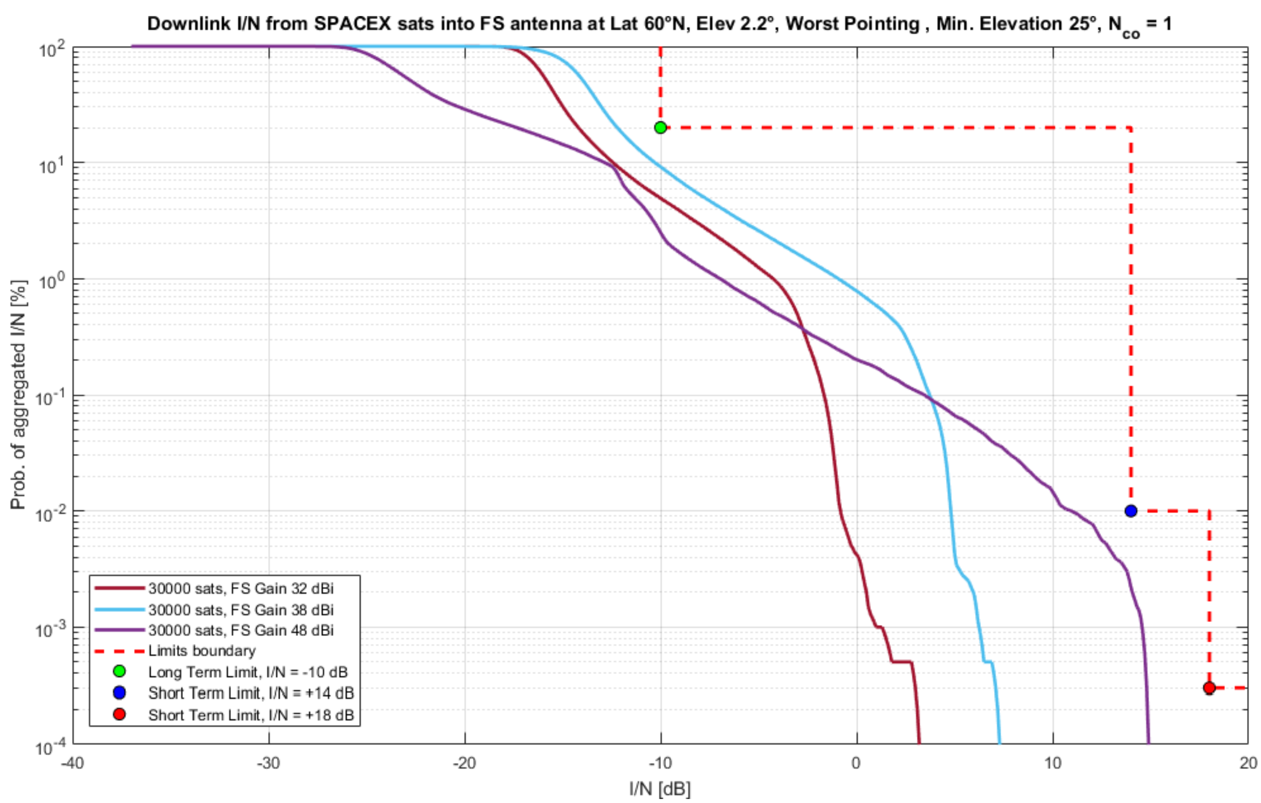


Figure A1-6. FS Station: Lat. 60°, Elevation 2.2° - SpaceX User Beams

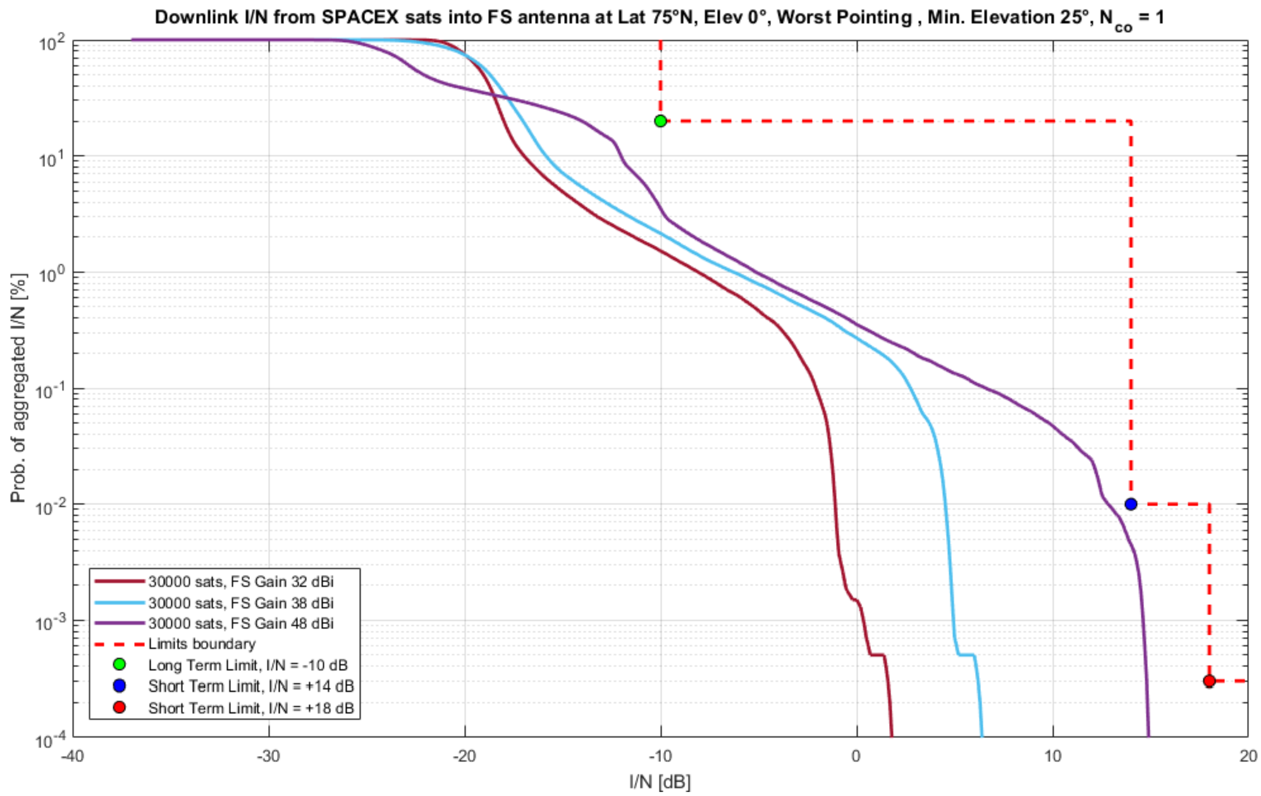


Figure A1-7. FS Station: Lat. 75°, Elevation 0° - SpaceX User Beams

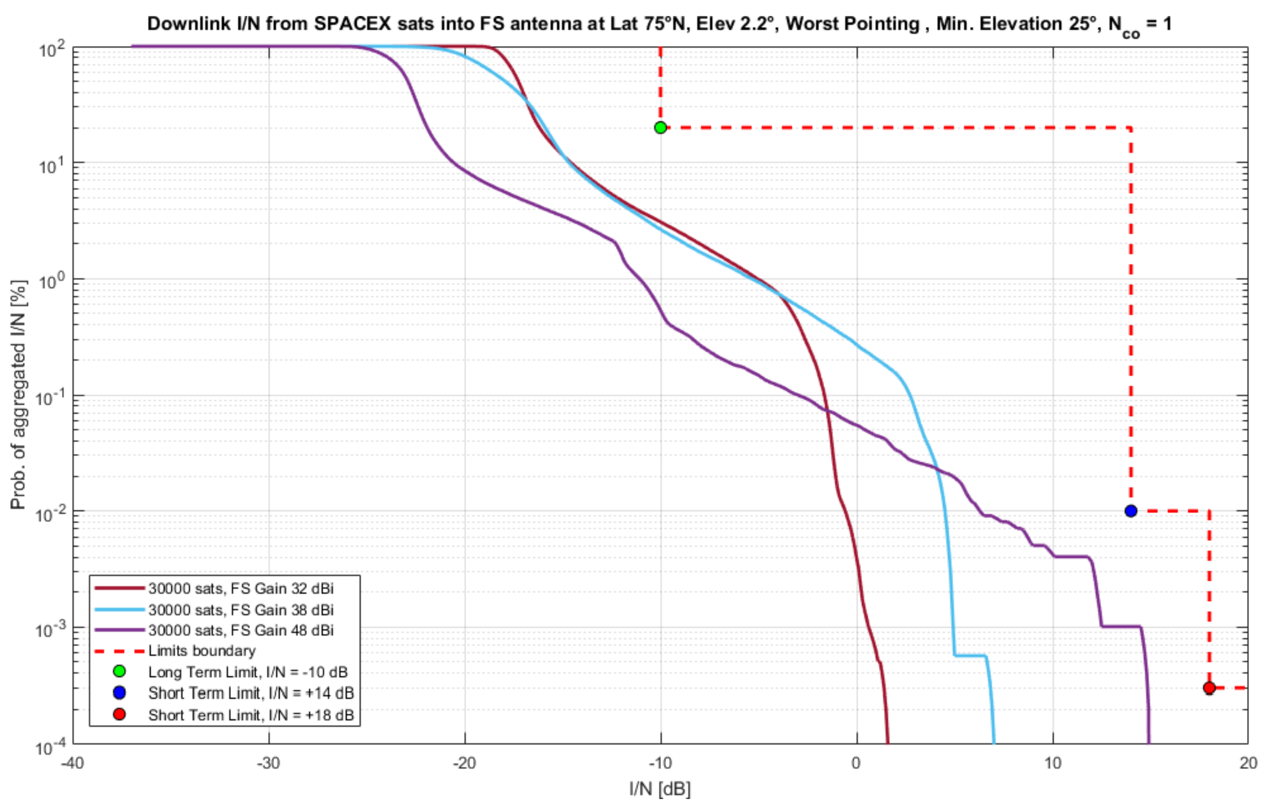


Figure A1-8. FS Station: Lat. 75°, Elevation 2.2° - SpaceX User Beams

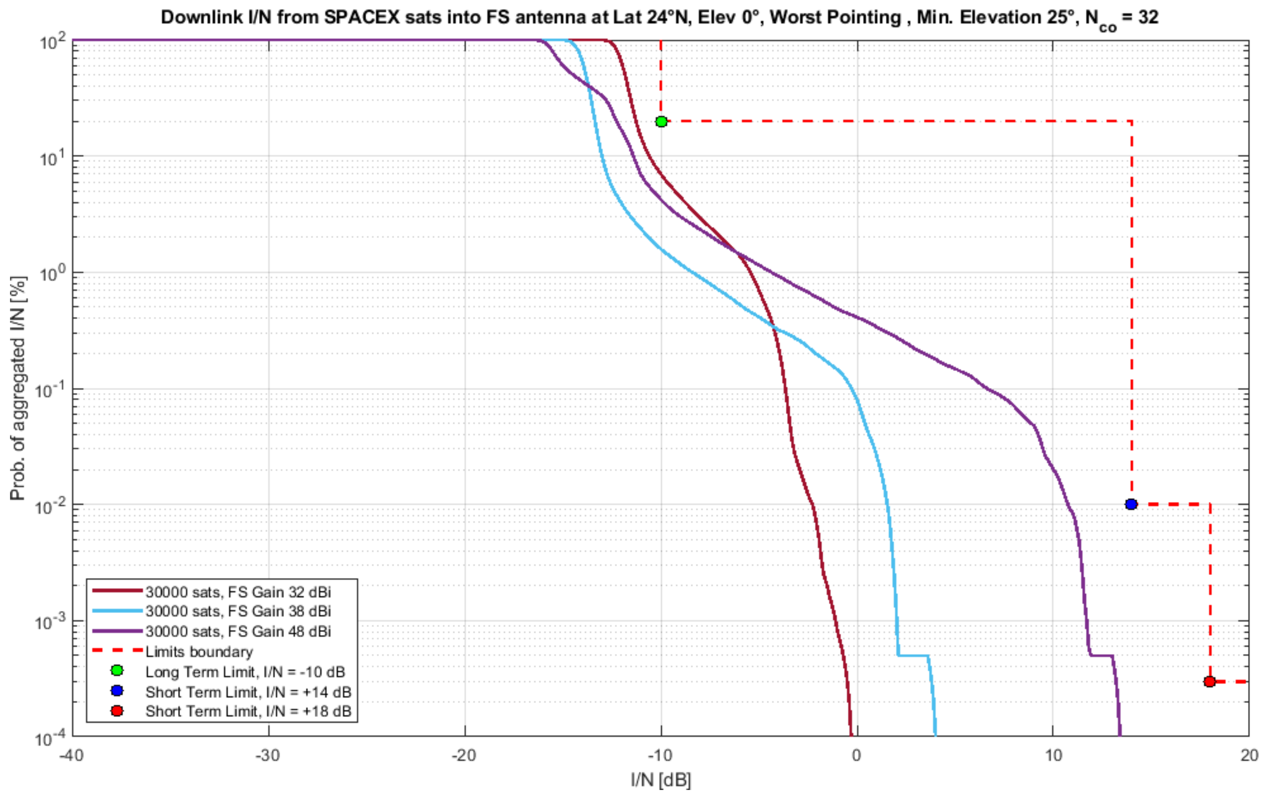


Figure A1-9. FS Station: Lat. 24°, Elevation 0° - SpaceX Gateway Beams

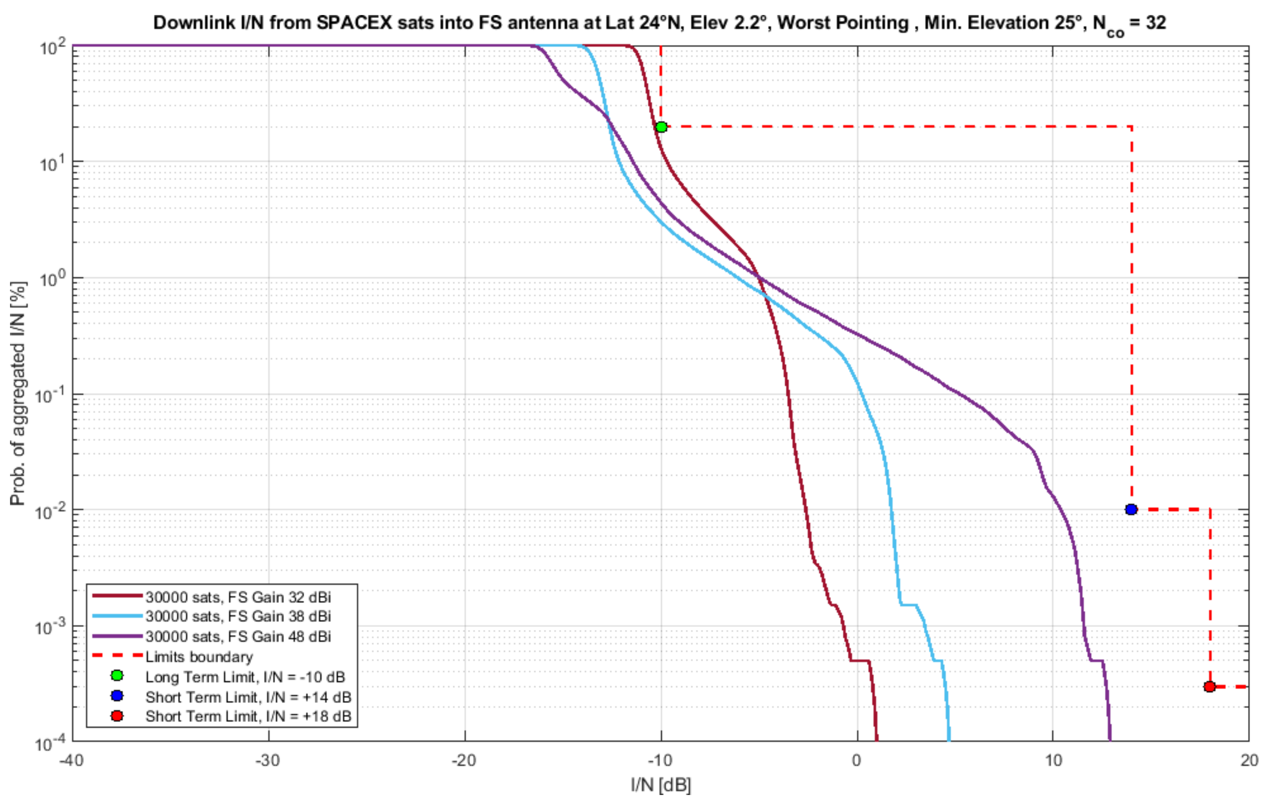


Figure A1-10. FS Station: Lat. 24°, Elevation 2.2° - SpaceX Gateway Beams

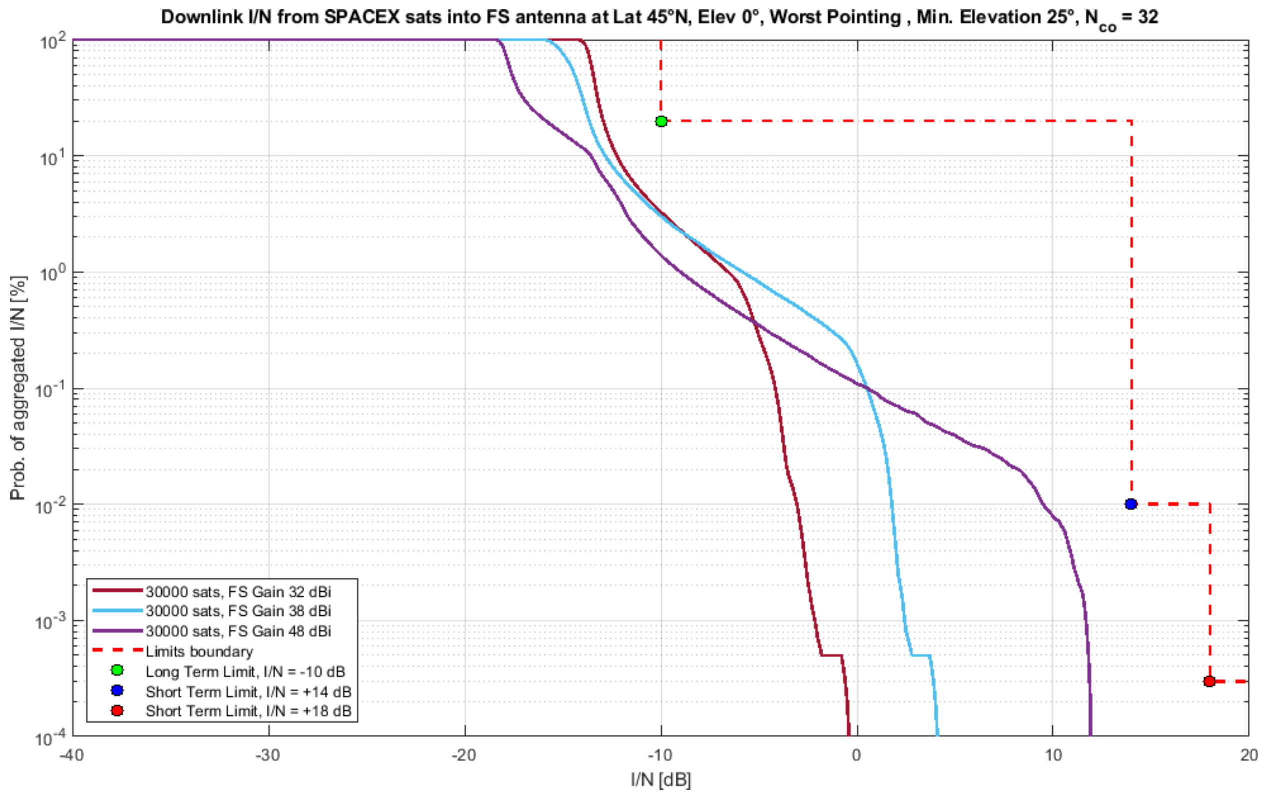


Figure A1-11. FS Station: Lat. 45°, Elevation 0° - SpaceX Gateway Beams

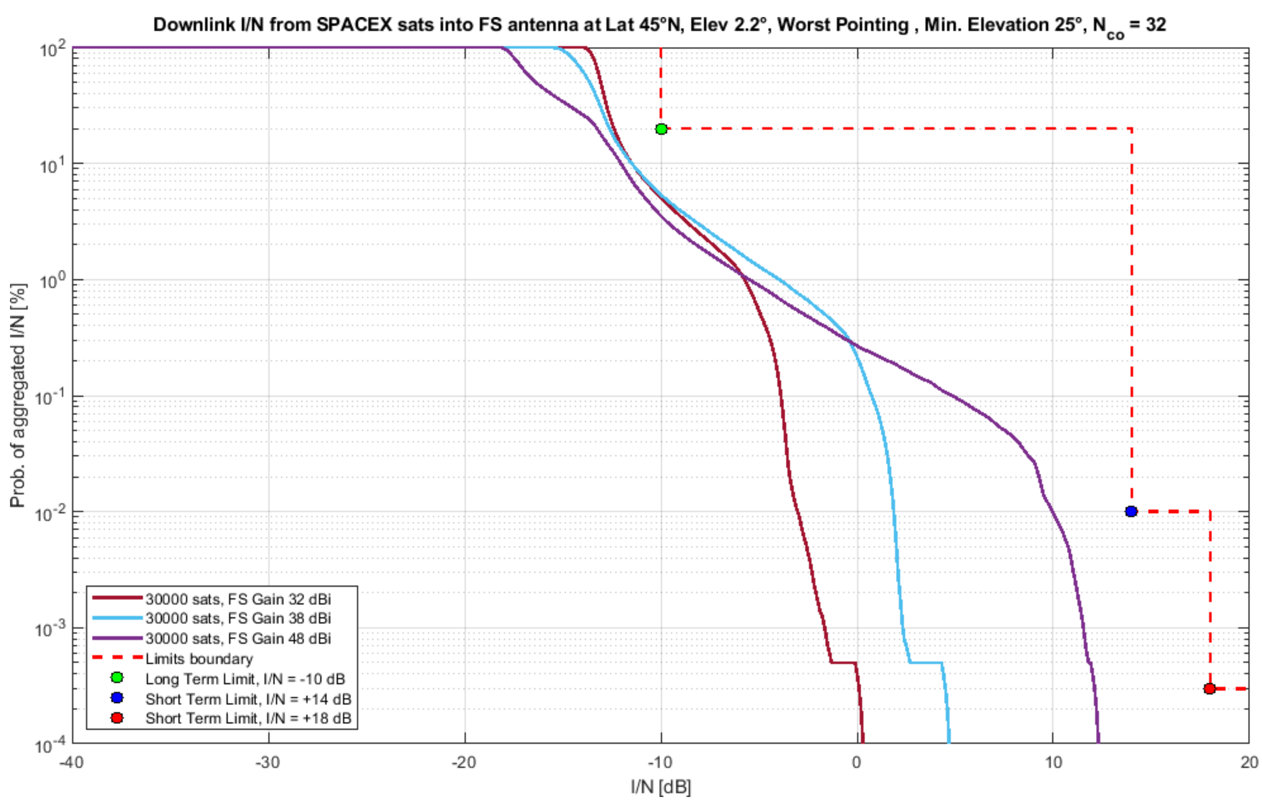


Figure A1-12. FS Station: Lat. 45°, Elevation 2.2° - SpaceX Gateway Beams

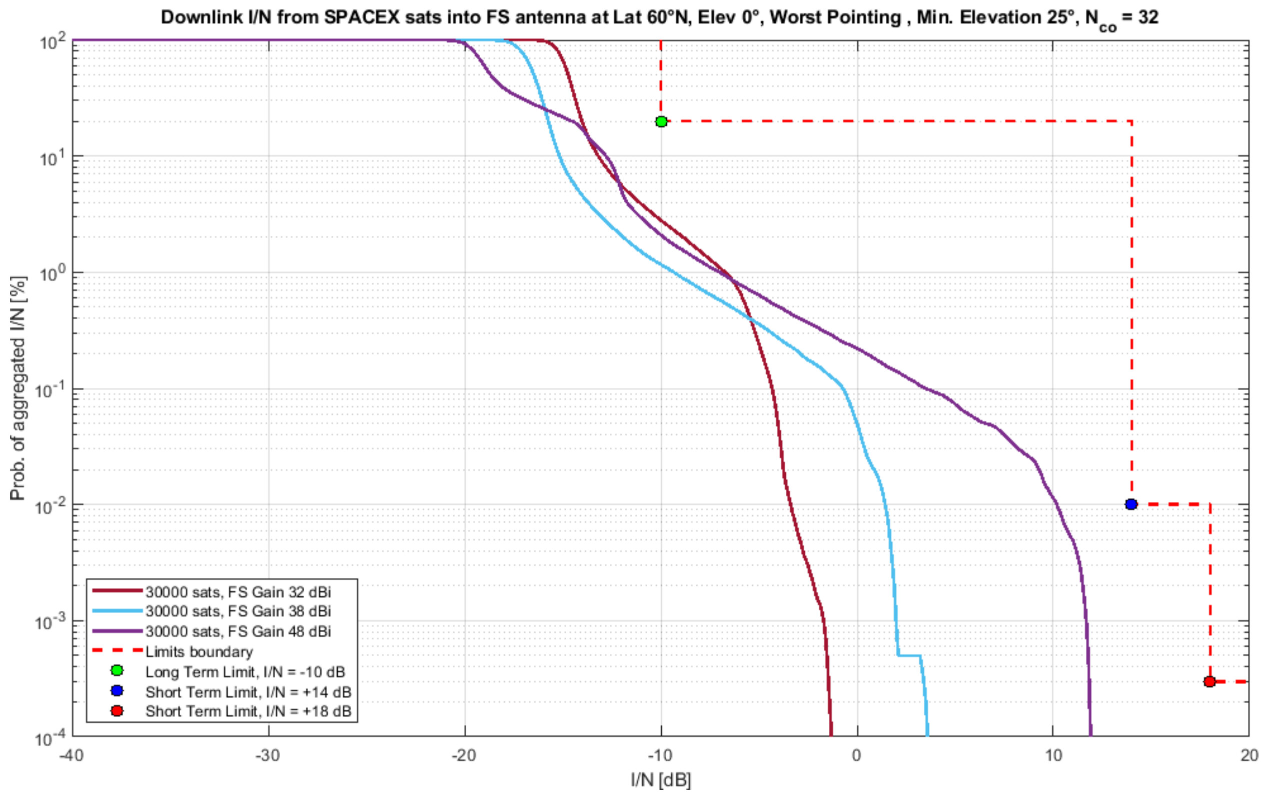


Figure A1-13. FS Station: Lat. 60°, Elevation 0° - SpaceX Gateway Beams

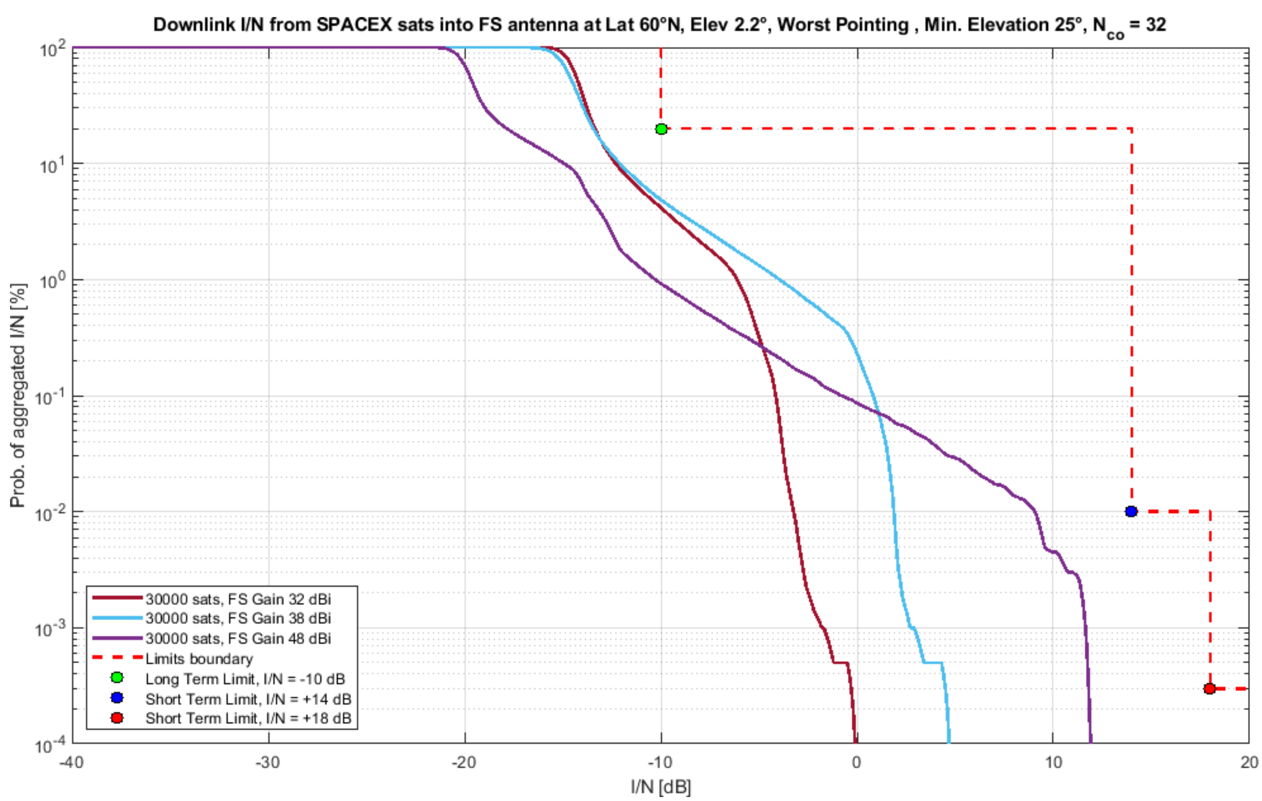


Figure A1-14. FS Station: Lat. 60°, Elevation 2.2° - SpaceX Gateway Beams

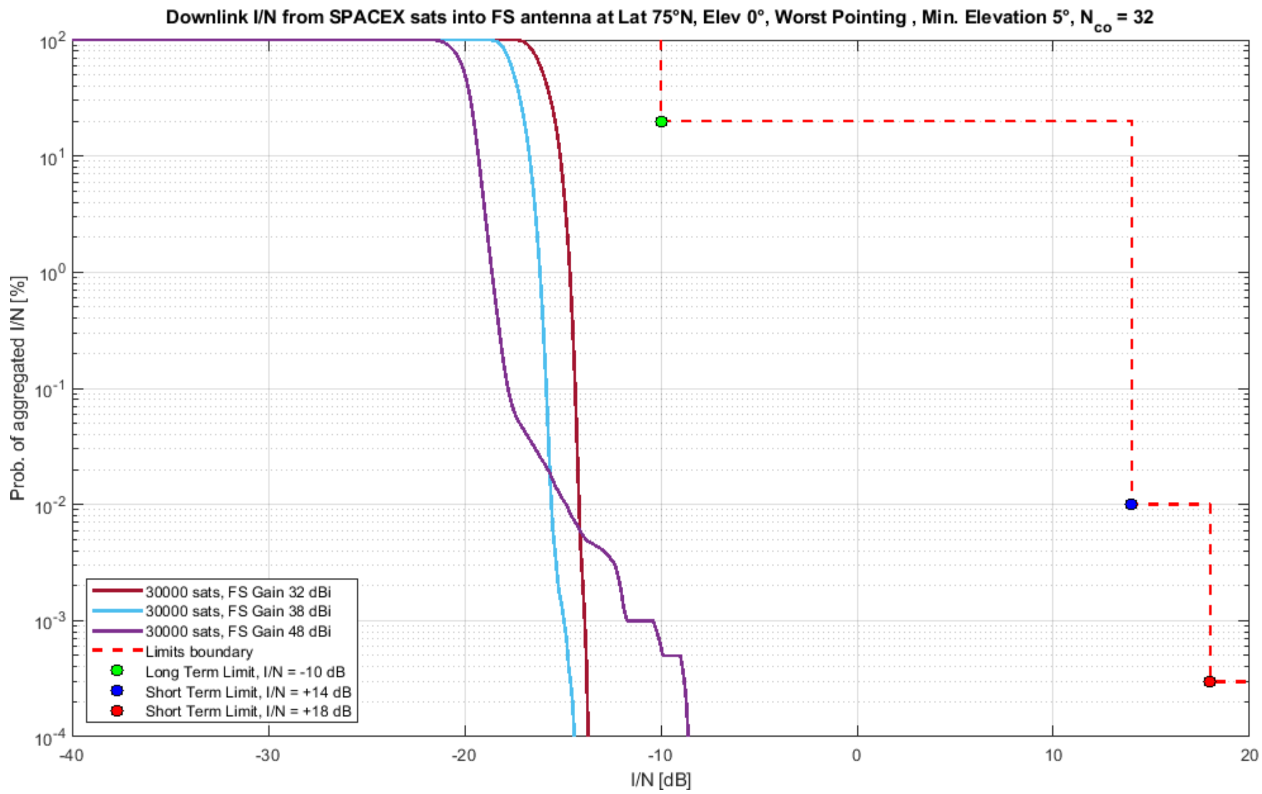


Figure A1-15. FS Station: Lat. 75°, Elevation 0° - SpaceX Gateway Beams

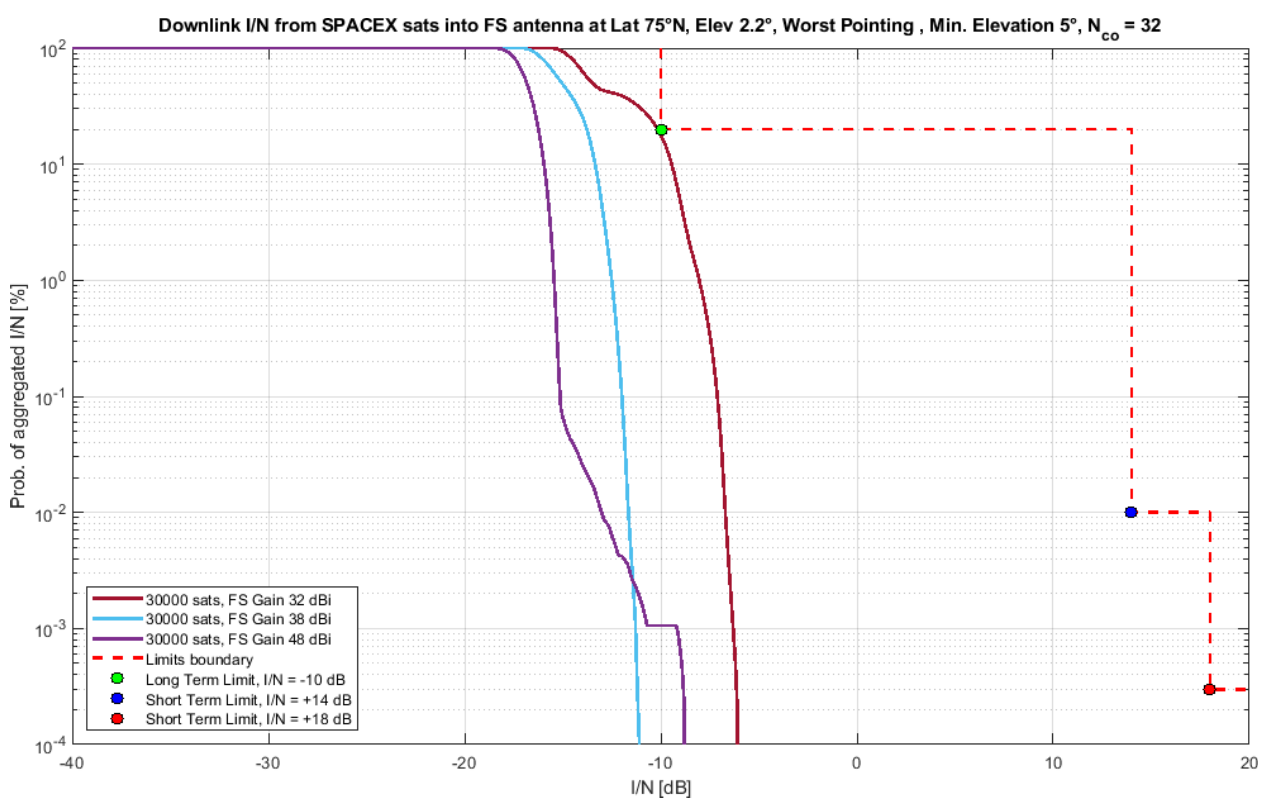


Figure A1-16. FS Station: Lat. 75°, Elevation 2.2° - SpaceX Gateway Beams

ANNEX 2

POTENTIAL INTERFERENCE TO GSO SATELLITE SYSTEMS

A. Demonstration of EPFD Compliance for Ku-Band Operations

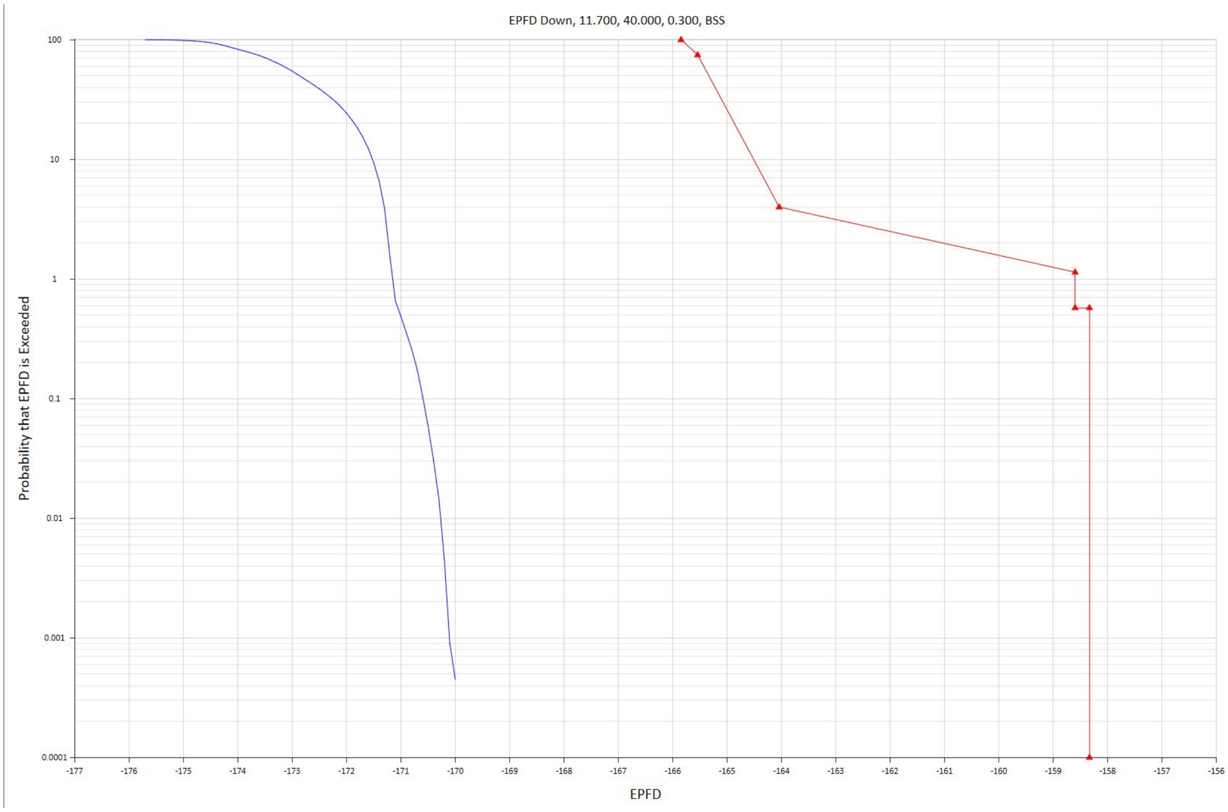
The following analysis demonstrates that the Ku-band operations of the SpaceX NGSO satellite system will comply with the applicable equivalent power flux-density ("EPFD") limits set forth in Article 22 of the ITU Radio Regulations, which have been incorporated by reference into the Commission's rules.[1] For this purpose, SpaceX has used the latest version of the ITU-approved computer program developed by Transfinite Systems ("Transfinite") for determining compliance with the EPFD single-entry validation limits.

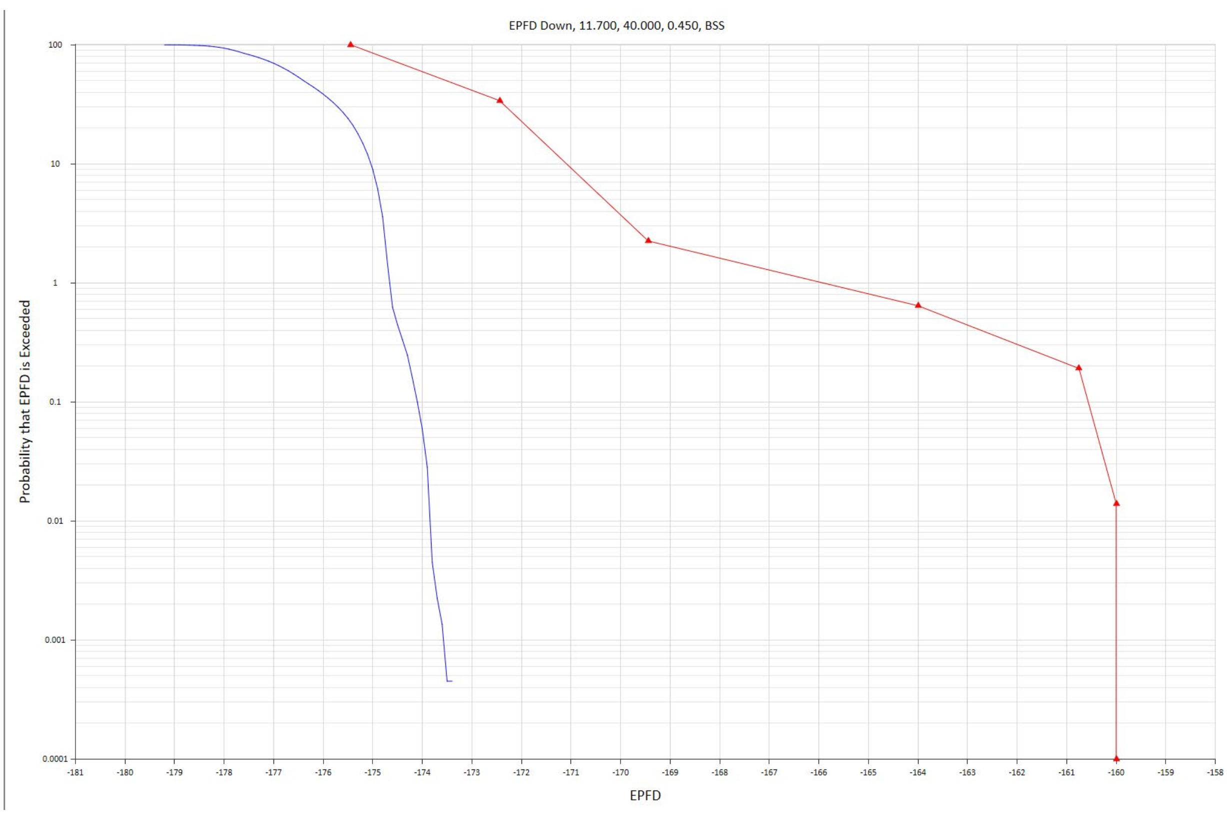
The figures below present the results of the Transfinite analysis with respect to the space-to-Earth direction ($EPFD_{down}$), the Earth-to-space direction ($EPFD_{up}$), and for transmissions between satellites in orbit where spectrum is allocated bi-directionally ($EPFD_{is}$). The satellite system consists of a deployment of 30,000 satellites operating at a range of altitudes between 328 and 614 km with minimum earth station elevation angles as discussed in the Techincal Attachment. The labeling of each diagram provides the relevant details for each analysis generated by the software. On each diagram, the resulting EPFD level is shown by the blue curve and the EPFD mask that applies is shown by the red line.

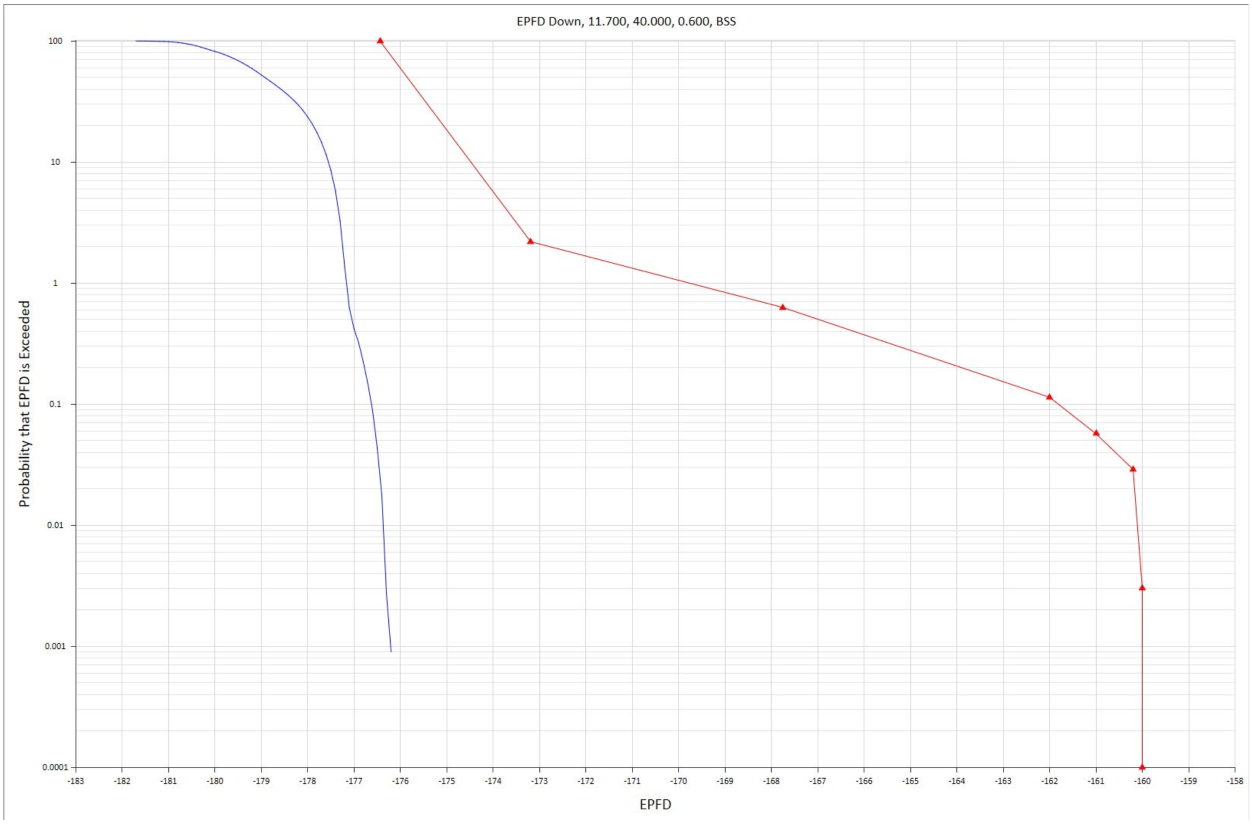
As these diagrams demonstrate, SpaceX's NGSO system complies with all EPFD limits applicable to its Ku-band operations. SpaceX will make the data files underlying this analysis available to interested parties upon request.

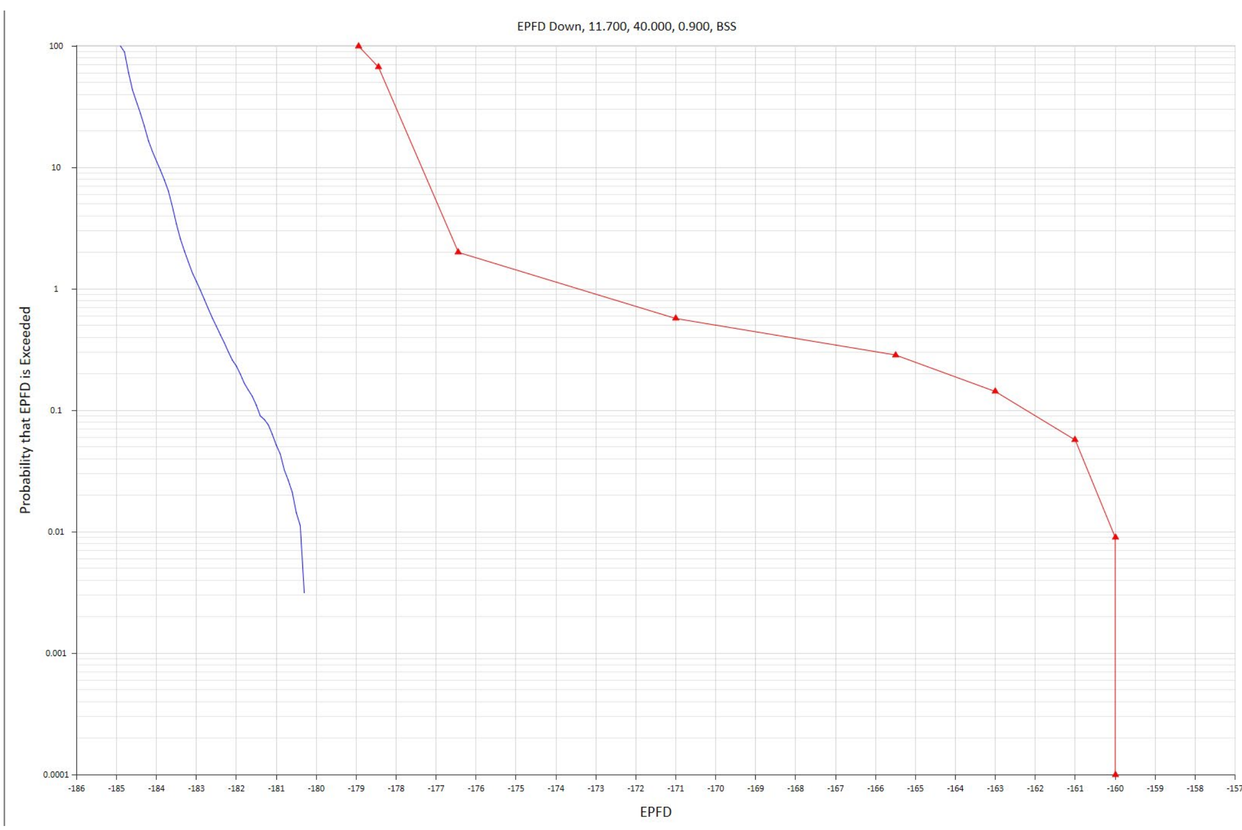
1 *See* 47 C.F.R. § 25.146(a)(2).

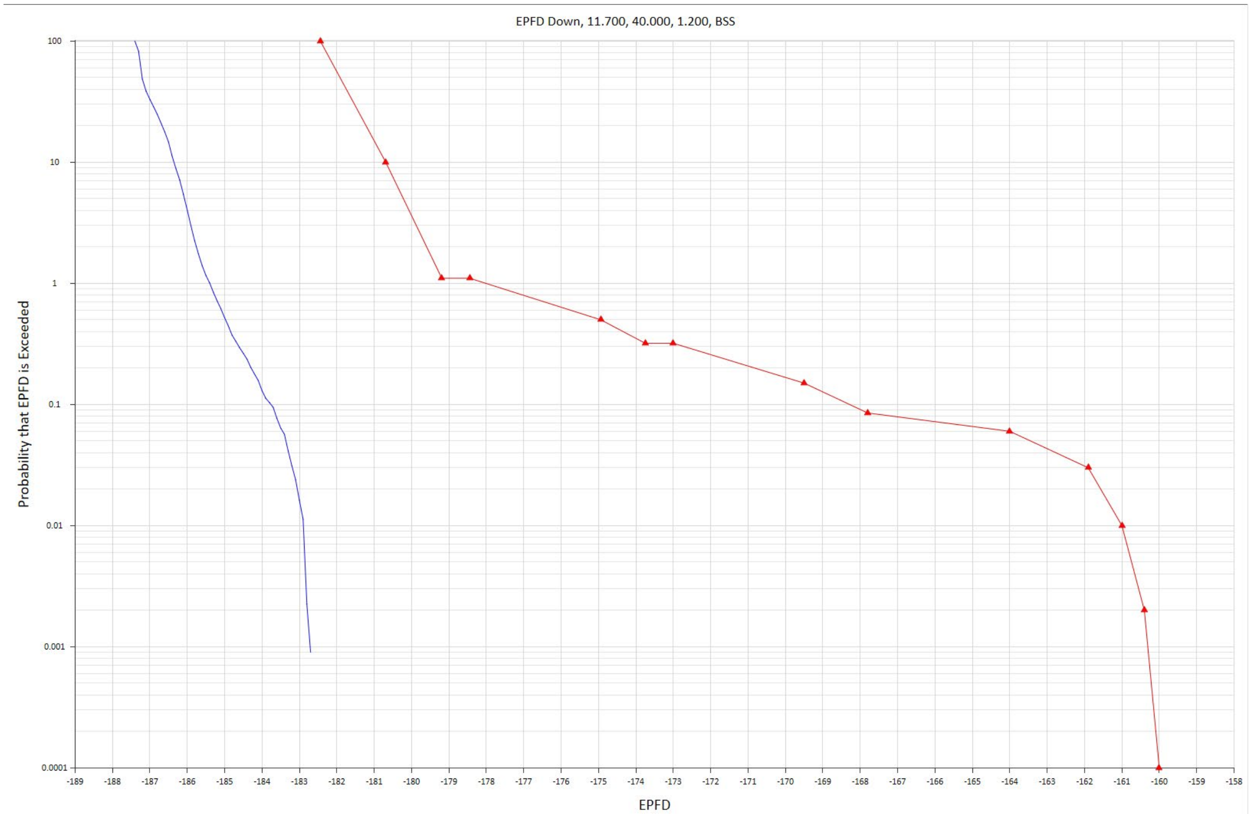
OUTPUTS FOR EPFD$_{DOWN}$ ASSESSMENT OF BSS LIMITS

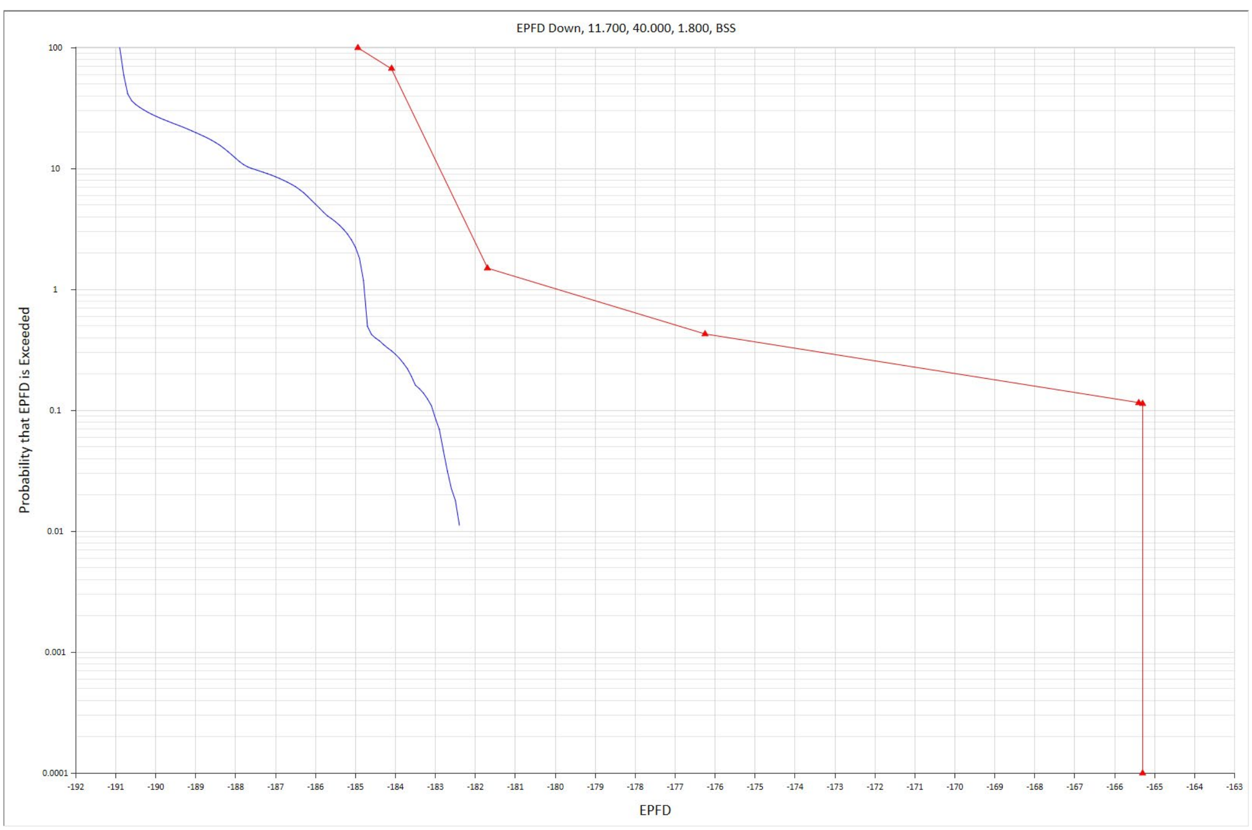


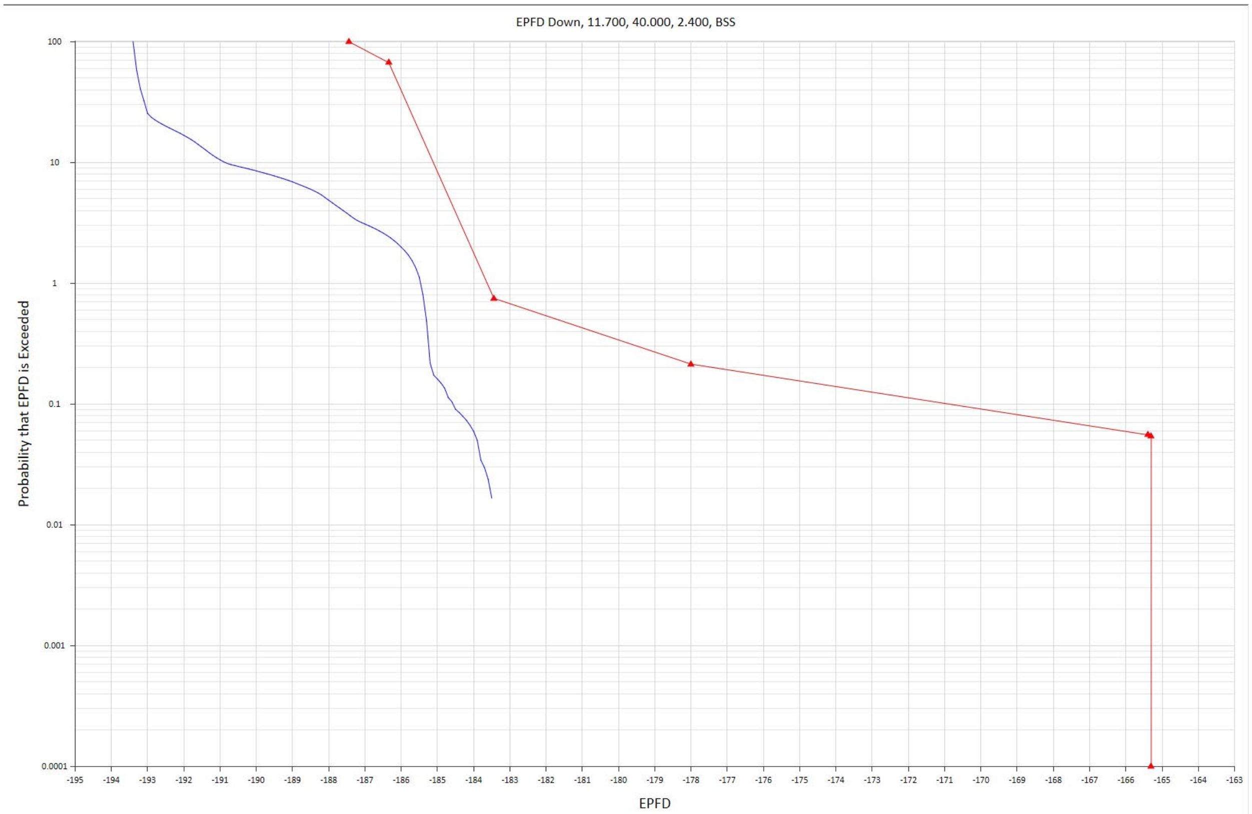


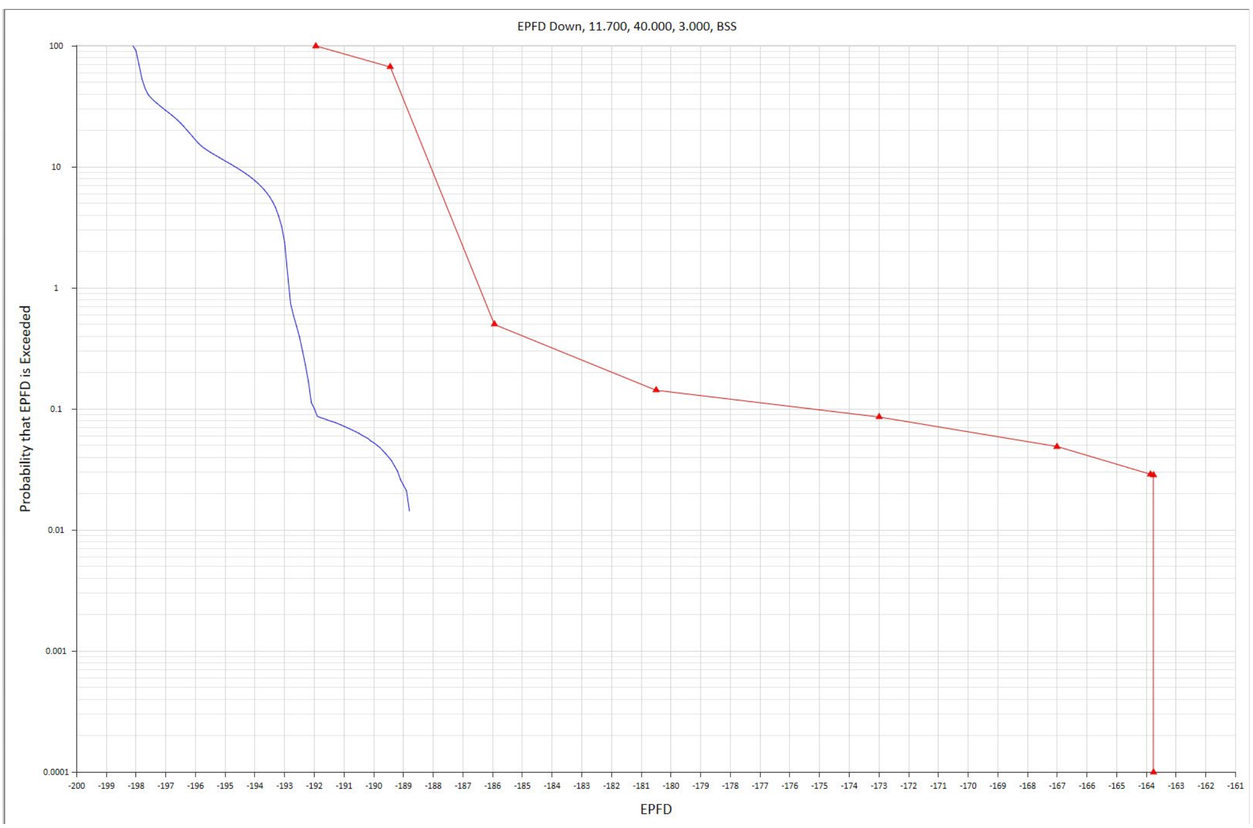

EPFD Down, 11.700, 40.000, 0.600, BSS
Probability that EPFD is Exceeded
EPFD


EPFD Down, 11.700, 40.000, 0.900, BSS
Probability that EPFD is Exceeded
EPFD

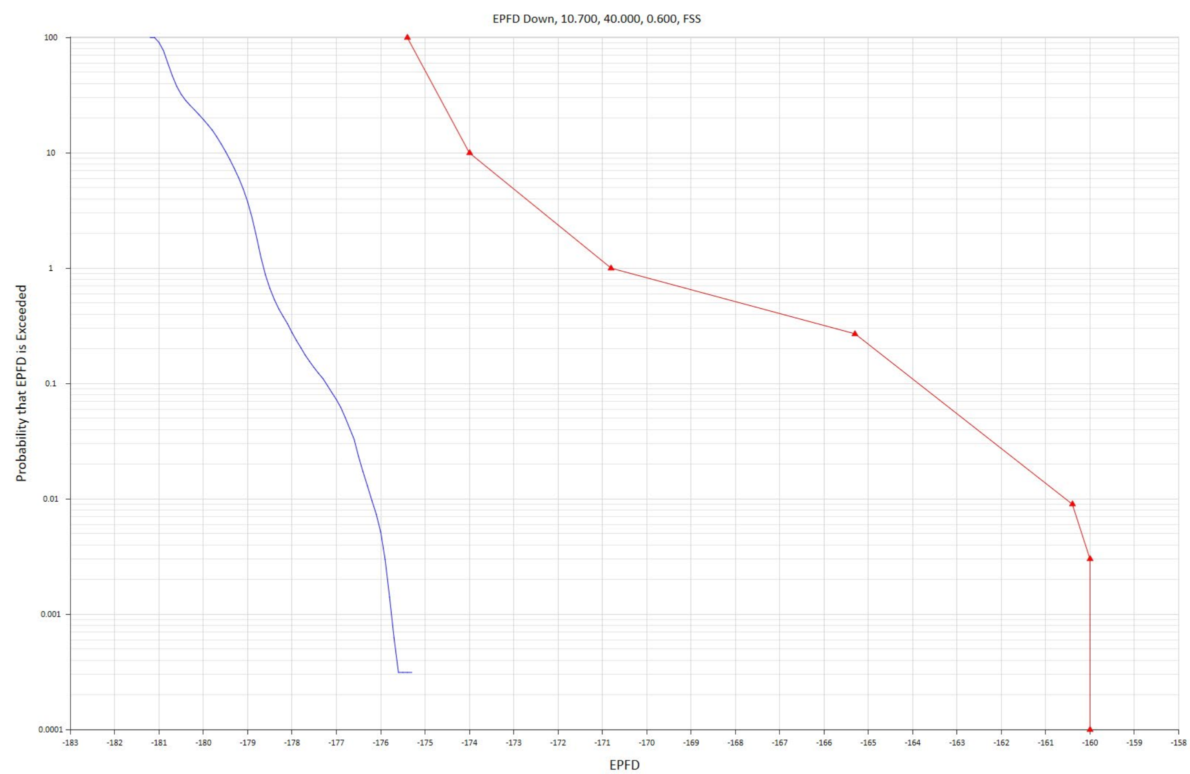

EPFD Down, 11.700, 40.000, 1.200, BSS
Probability that EPFD is Exceeded
EPFD

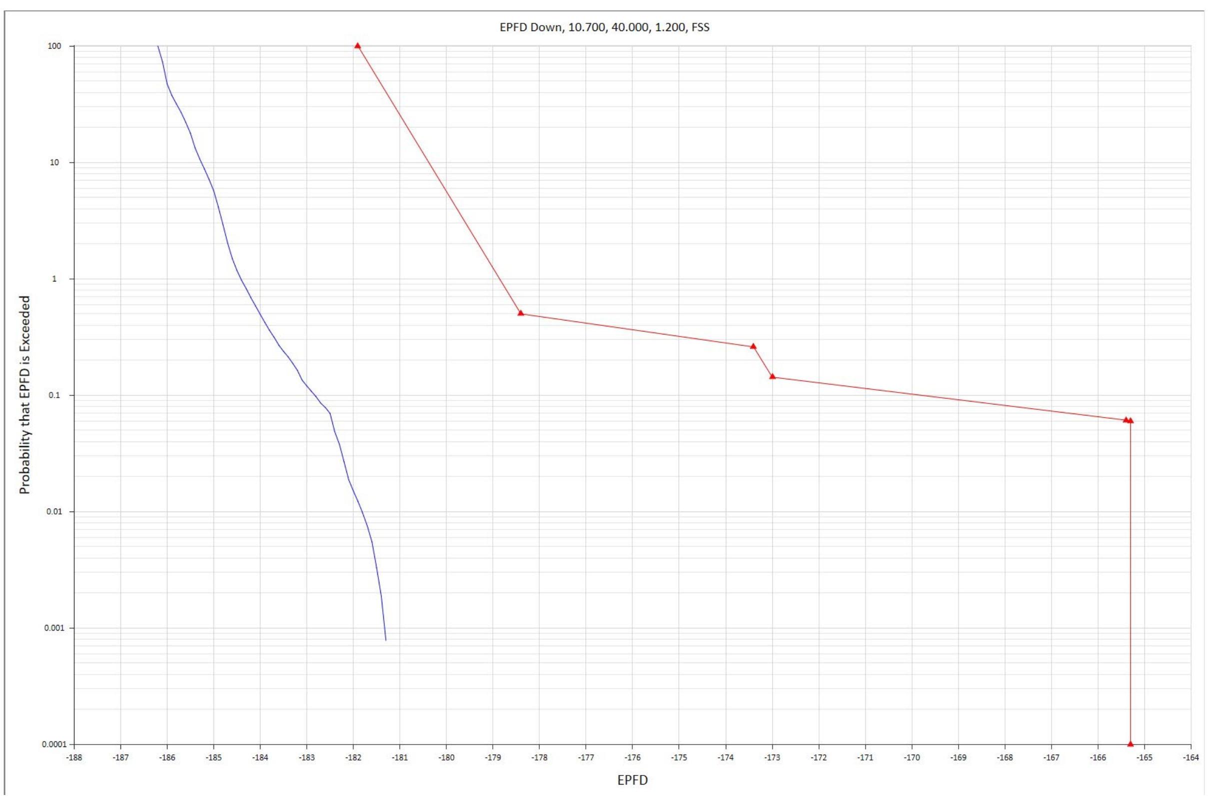

EPFD Down, 11.700, 40.000, 1.800, BSS
Probability that EPFD is Exceeded
EPFD

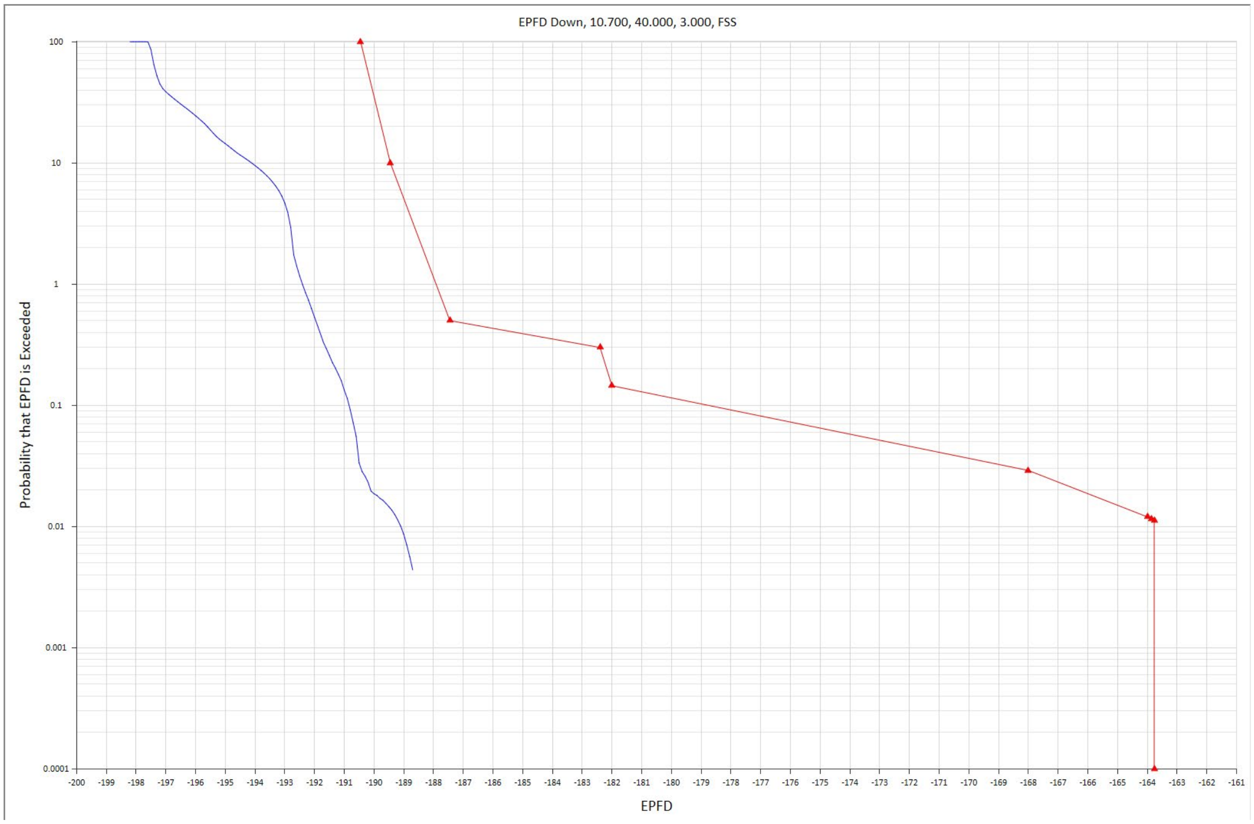

EPFD Down, 11.700, 40.000, 2.400, BSS
Probability that EPFD is Exceeded
EPFD

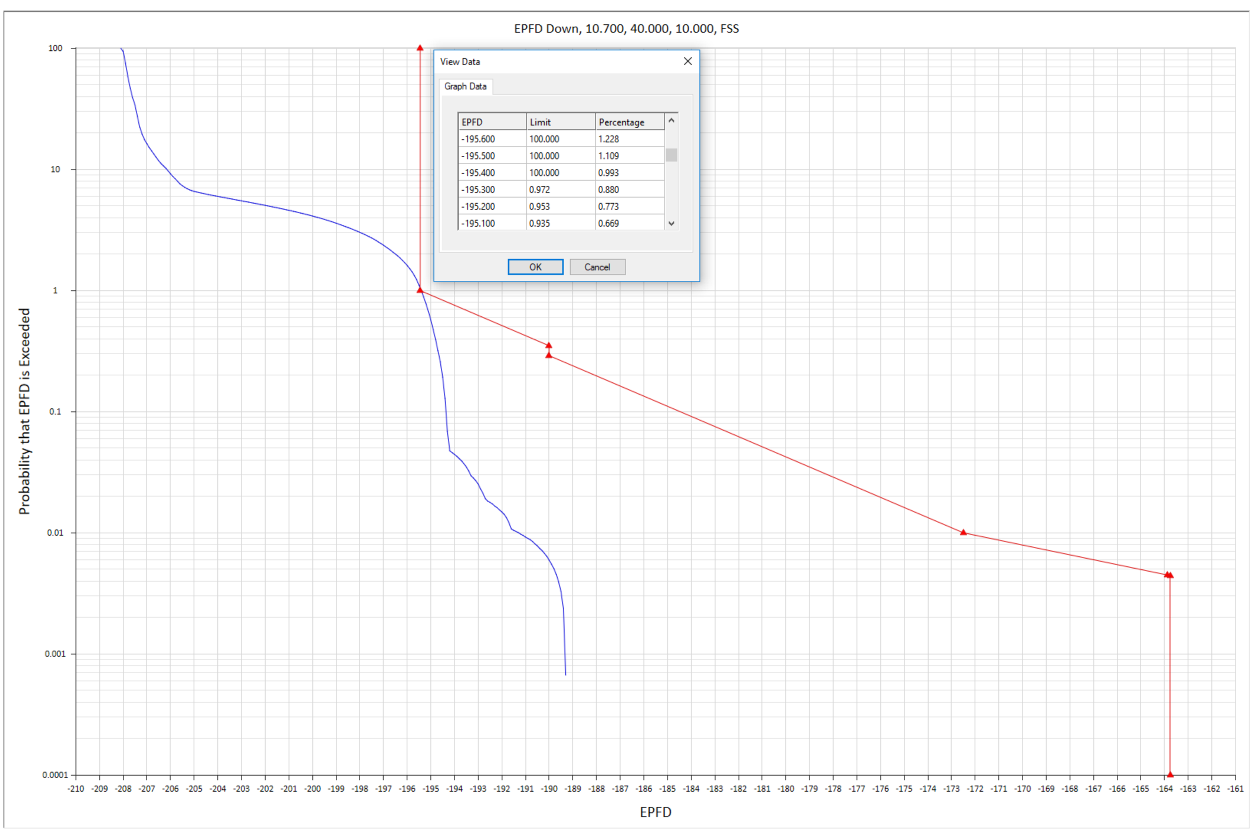

EPFD Down, 11.700, 40.000, 3.000, BSS
Probability that EPFD is Exceeded
EPFD

OUTPUTS FOR EPFD$_{DOWN}$ ASSESSMENT OF FSS LIMITS

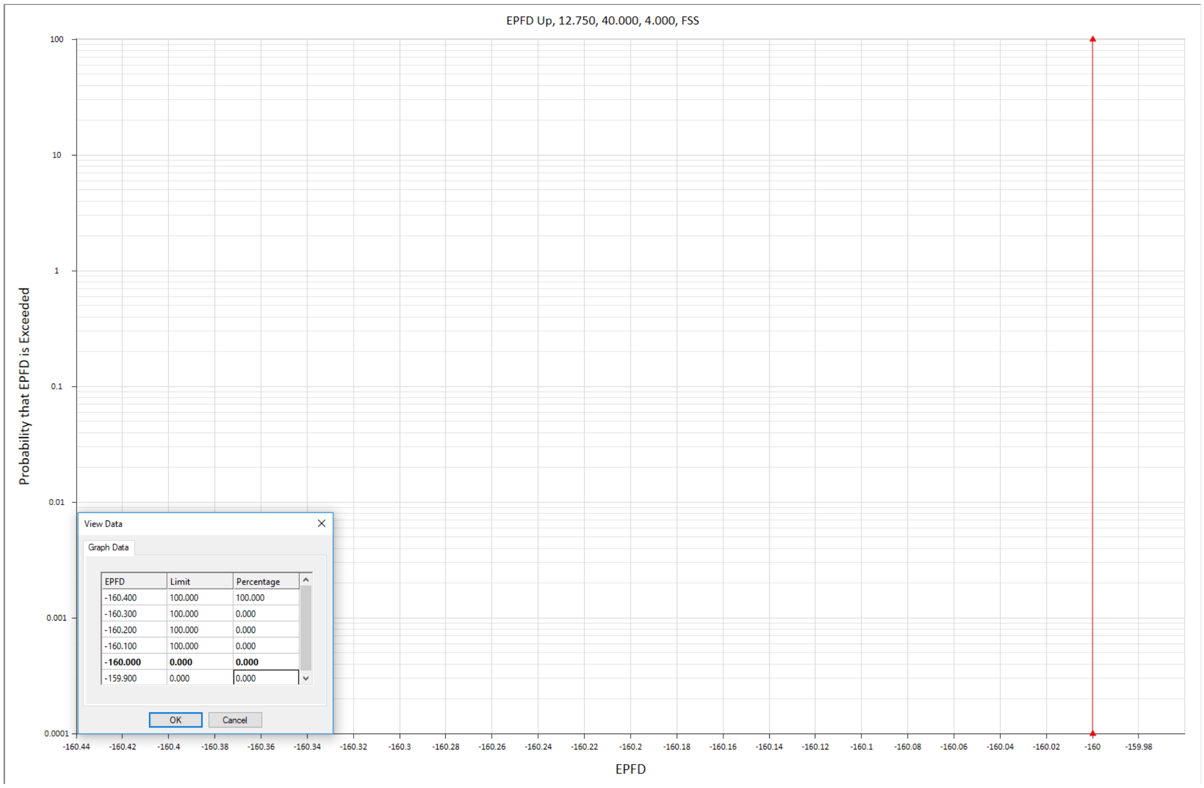




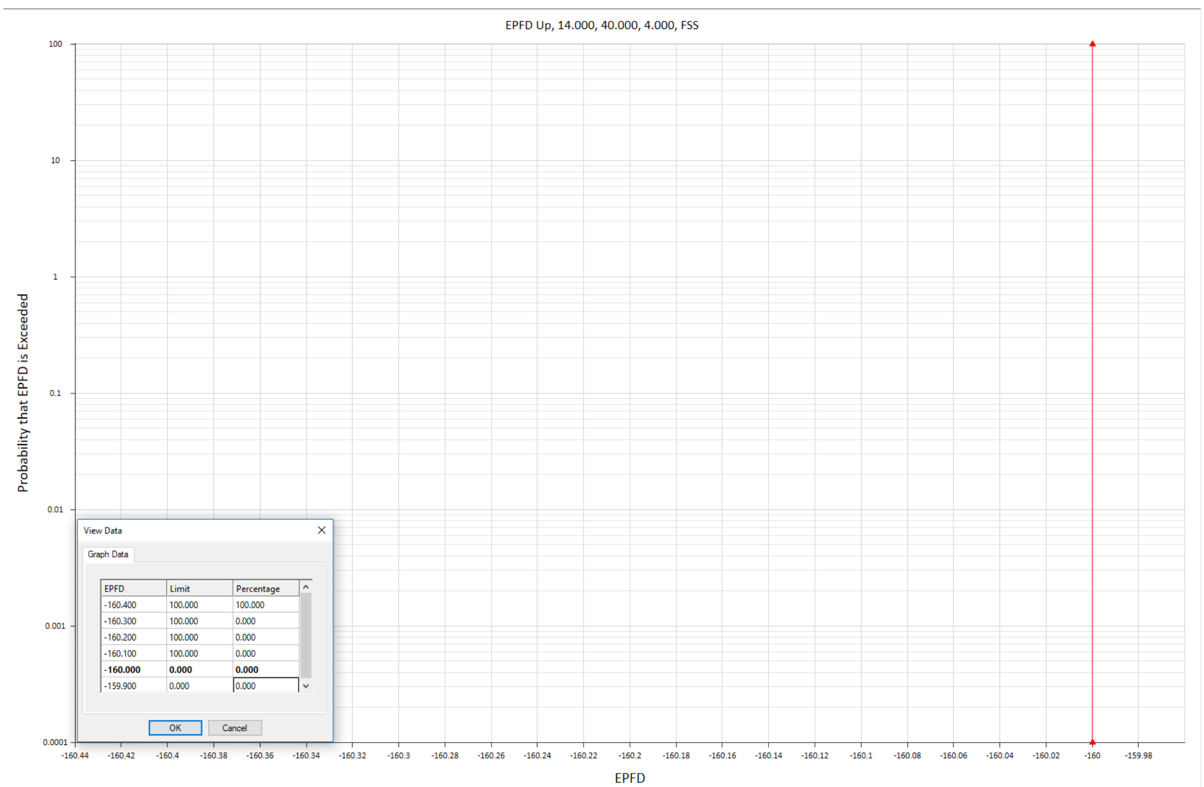

EPFD Down, 10.700, 40.000, 3.000, FSS
Probability that EPFD is Exceeded
EPFD


EPFD Down, 10.700, 40.000, 10.000, FSS
View Data
Graph Data
EPFD Limit Percentage
-195.600 100.000 1.228
-195.500 100.000 1.109
-195.400 100.000 0.993
-195.300 0.972 0.880
-195.200 0.953 0.773
-195.100 0.935 0.669
OK
Cancel
Probability that EPFD is Exceeded
EPFD

OUTPUTS FOR EPFD_{UP} ASSESSMENT

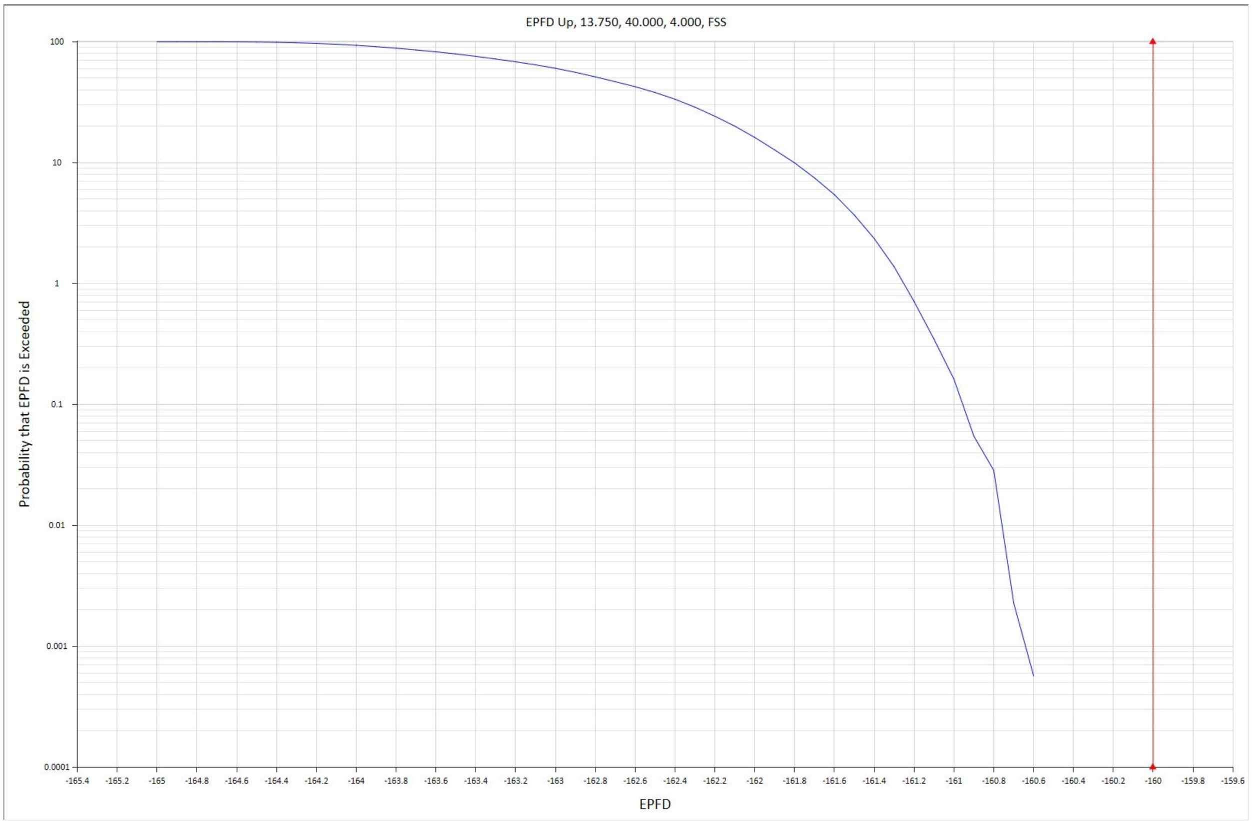


EPFD	Limit	Percentage
-160.400	100.000	100.000
-160.300	100.000	0.000
-160.200	100.000	0.000
-160.100	100.000	0.000
-160.000	**0.000**	**0.000**
-159.900	0.000	0.000

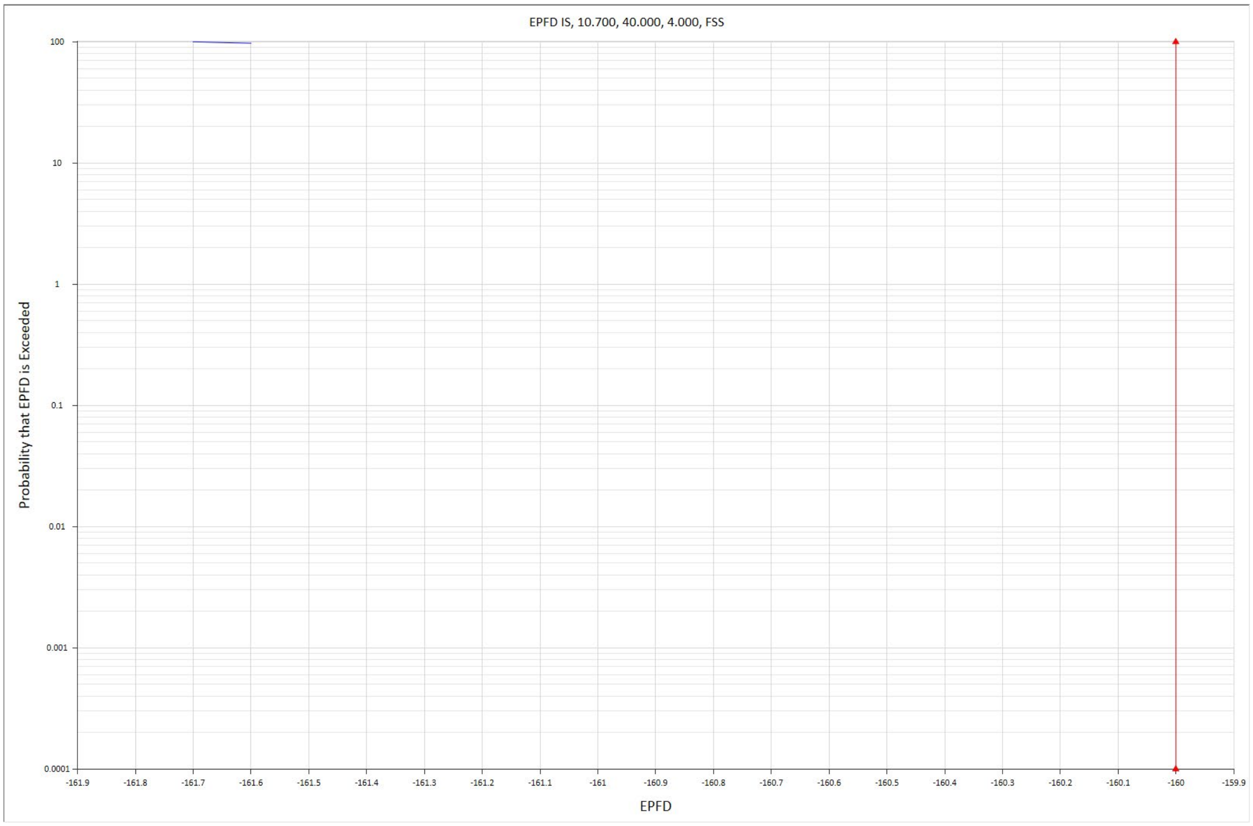


EPFD	Limit	Percentage
-160.400	100.000	100.000
-160.300	100.000	0.000
-160.200	100.000	0.000
-160.100	100.000	0.000
-160.000	**0.000**	**0.000**
-159.900	0.000	0.000

OUTPUTS FOR EPFD$_{UP}$ ASSESSMENT (TT&C beams)



OUTPUT FOR EPFD$_{IS}$ ASSESSMENT



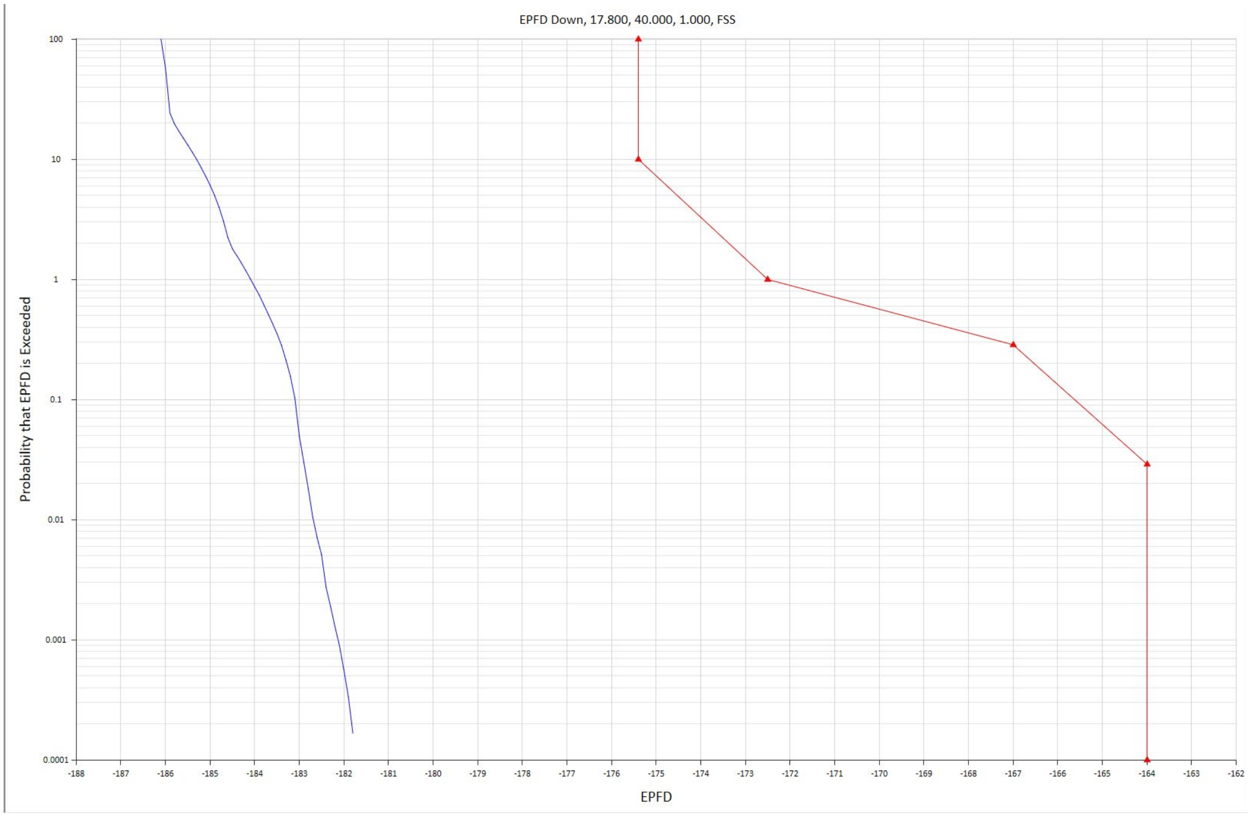
B. Demonstration of EPFD Compliance for Ka-Band Operations

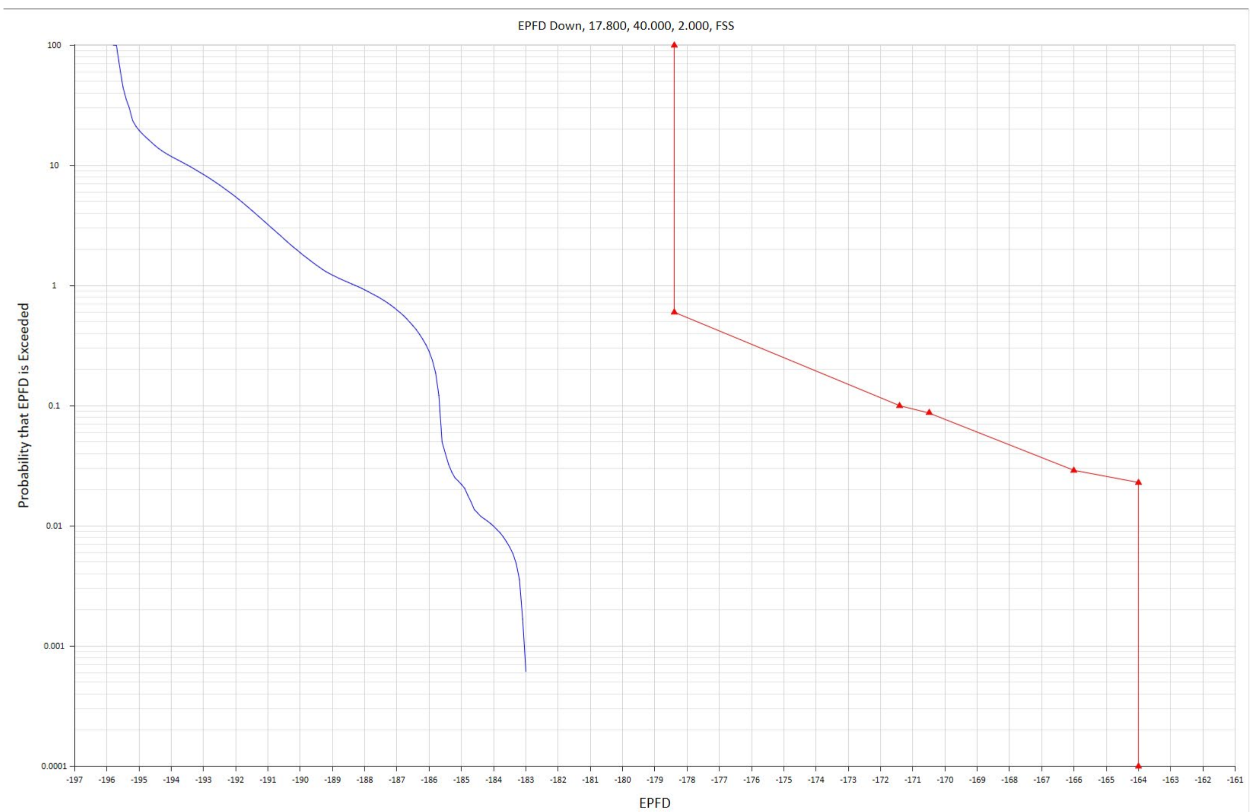
This annex demonstrates that the Ka-band operations of the SpaceX NGSO satellite system will comply with the applicable EPFD limits. For this purpose, SpaceX has used the latest version of the ITU-approved computer program developed by Transfinite for determining compliance with the EPFD single-entry validation limits.

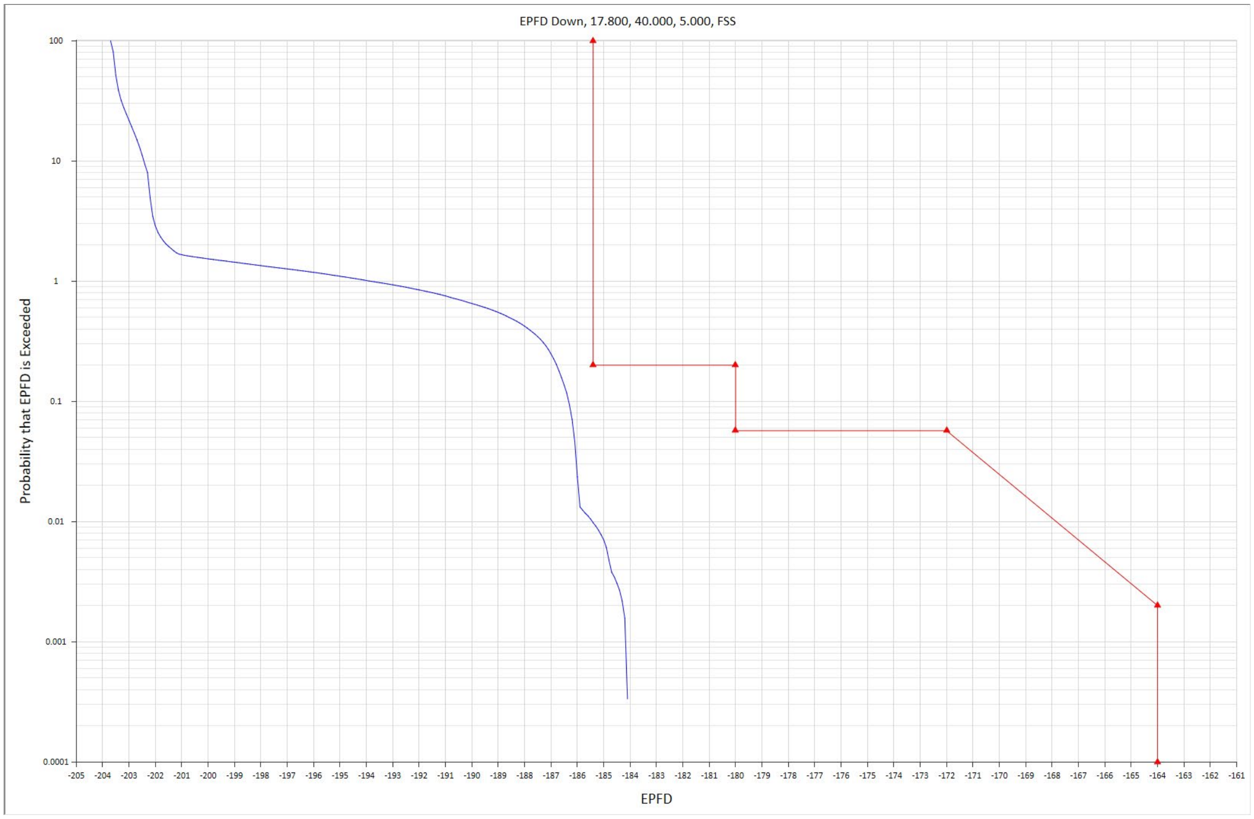
The figures below present the results of the Transfinite analysis with respect to the space-to-Earth direction ($EPFD_{down}$), the Earth-to-space direction ($EPFD_{up}$), and for transmissions between satellites in orbit where spectrum is allocated bi-directionally ($EPFD_{is}$). There are two variants of beams and earth stations (users and gateways); there will be a separate analysis for each of them, where applicable. The satellite system consists of a deployment of 30,000 satellites operating at an altitude between 328 and 614 km with minimum earth station elevation angles as discussed in the Techincal Attachment. The labeling of each diagram provides the relevant details for each analysis generated by the software. On each diagram, the resulting EPFD level is shown by the blue curve and the EPFD mask that applies is shown by the red line.

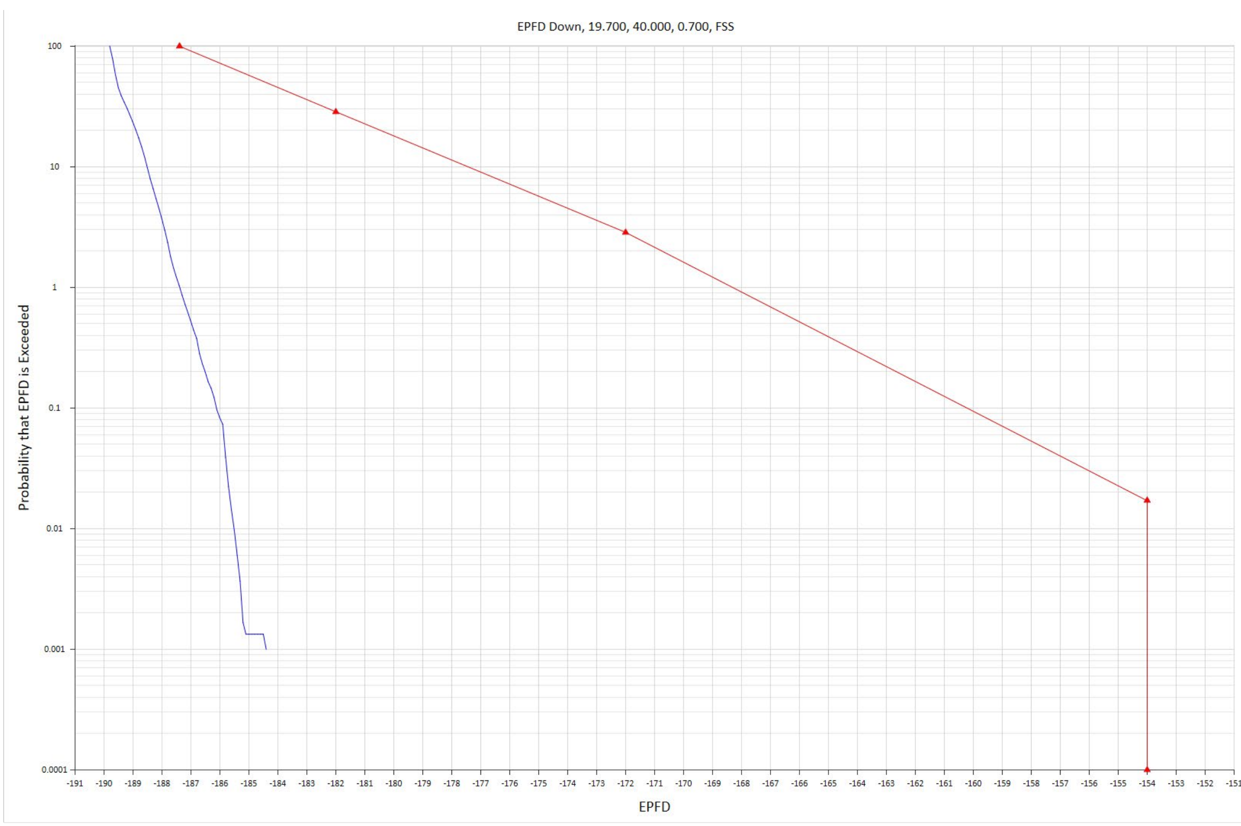
As these diagrams demonstrate, SpaceX's NGSO system complies with all EPFD limits applicable to its Ka-band operations. SpaceX will make the data files underlying this analysis available to interested parties upon request.

OUTPUTS FOR EPFD$_{DOWN}$ ASSESSMENT (User beams)

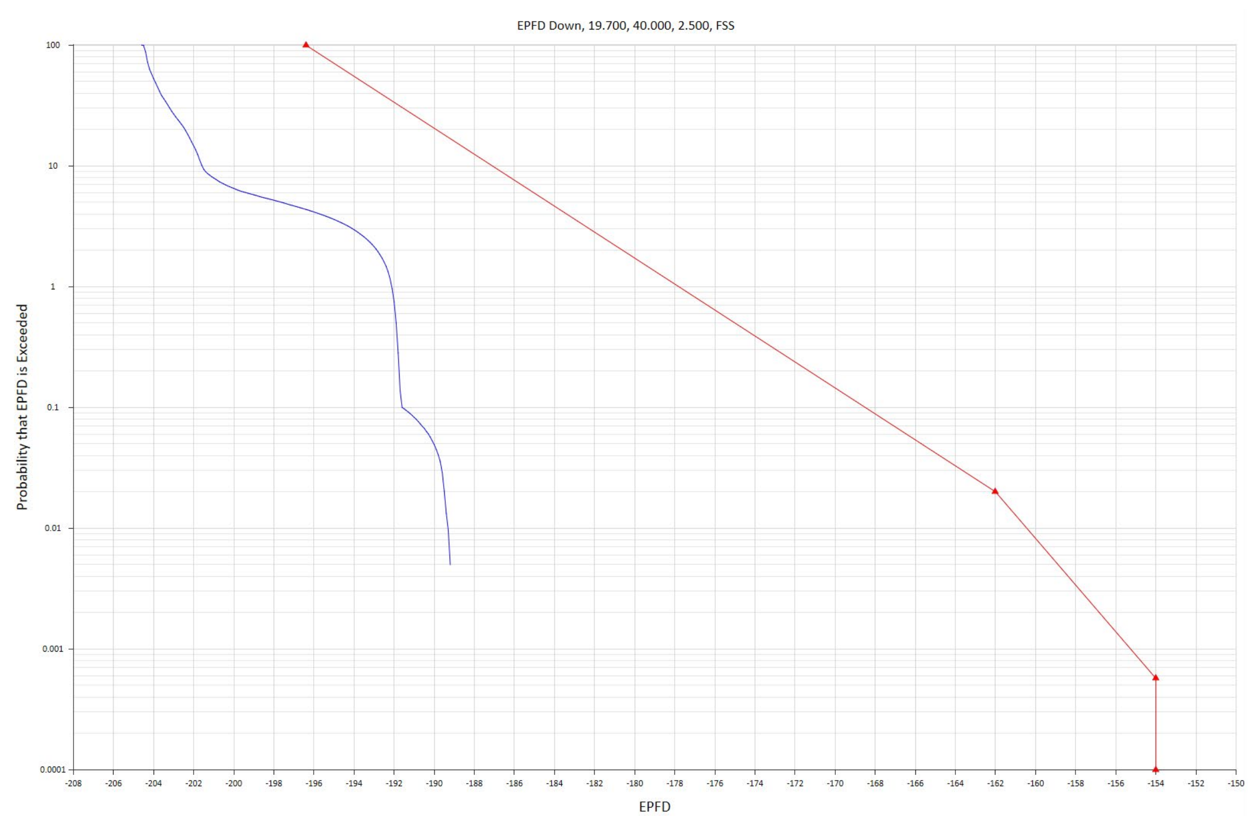


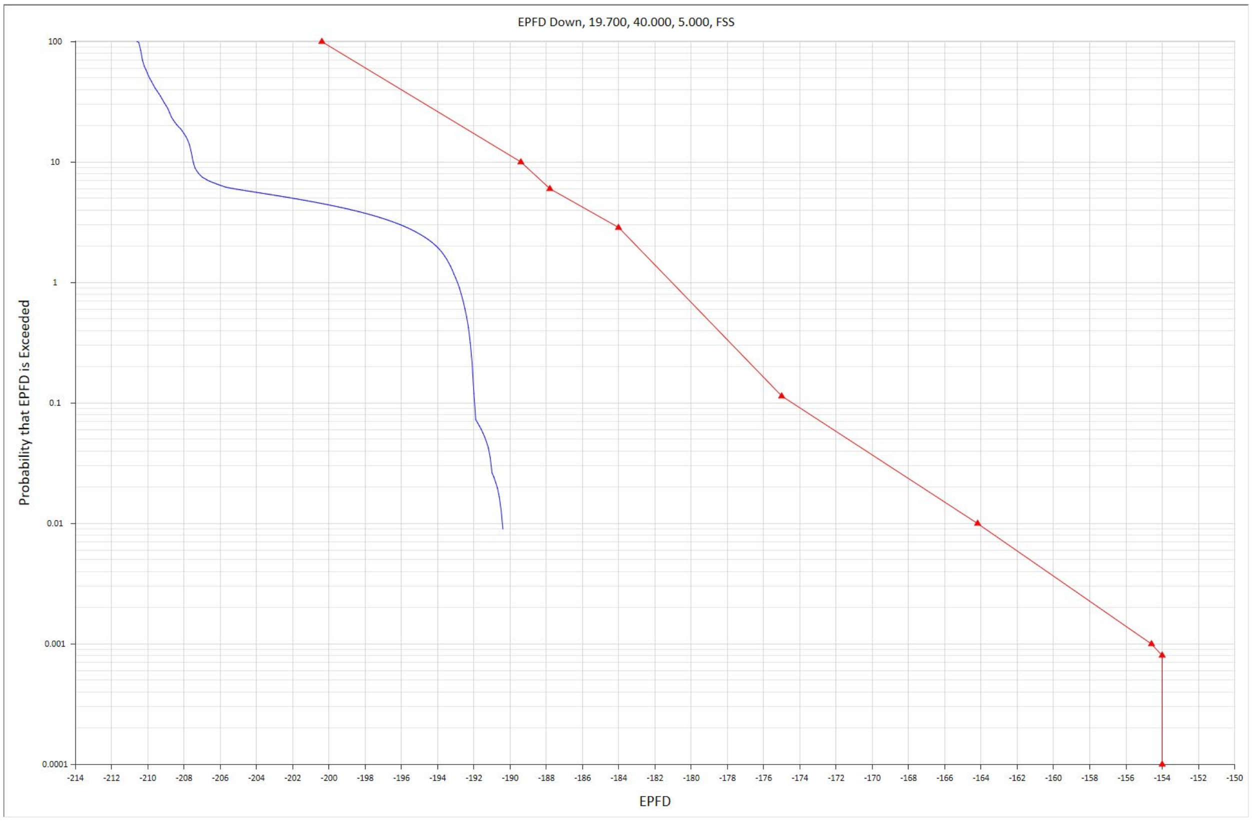



EPFD Down, 17.800, 40.000, 5.000, FSS
Probability that EPFD is Exceeded
EPFD

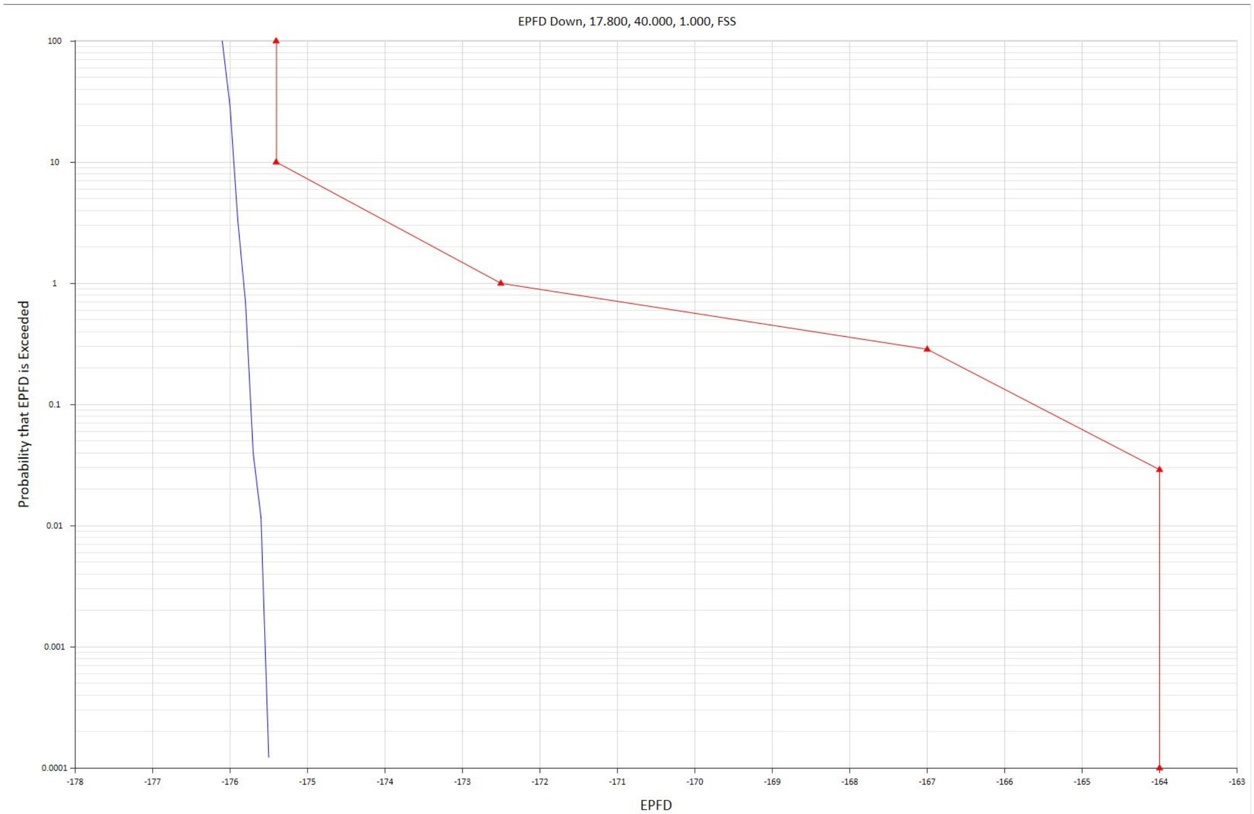

EPFD Down, 19.700, 40.000, 0.700, FSS
Probability that EPFD is Exceeded
EPFD

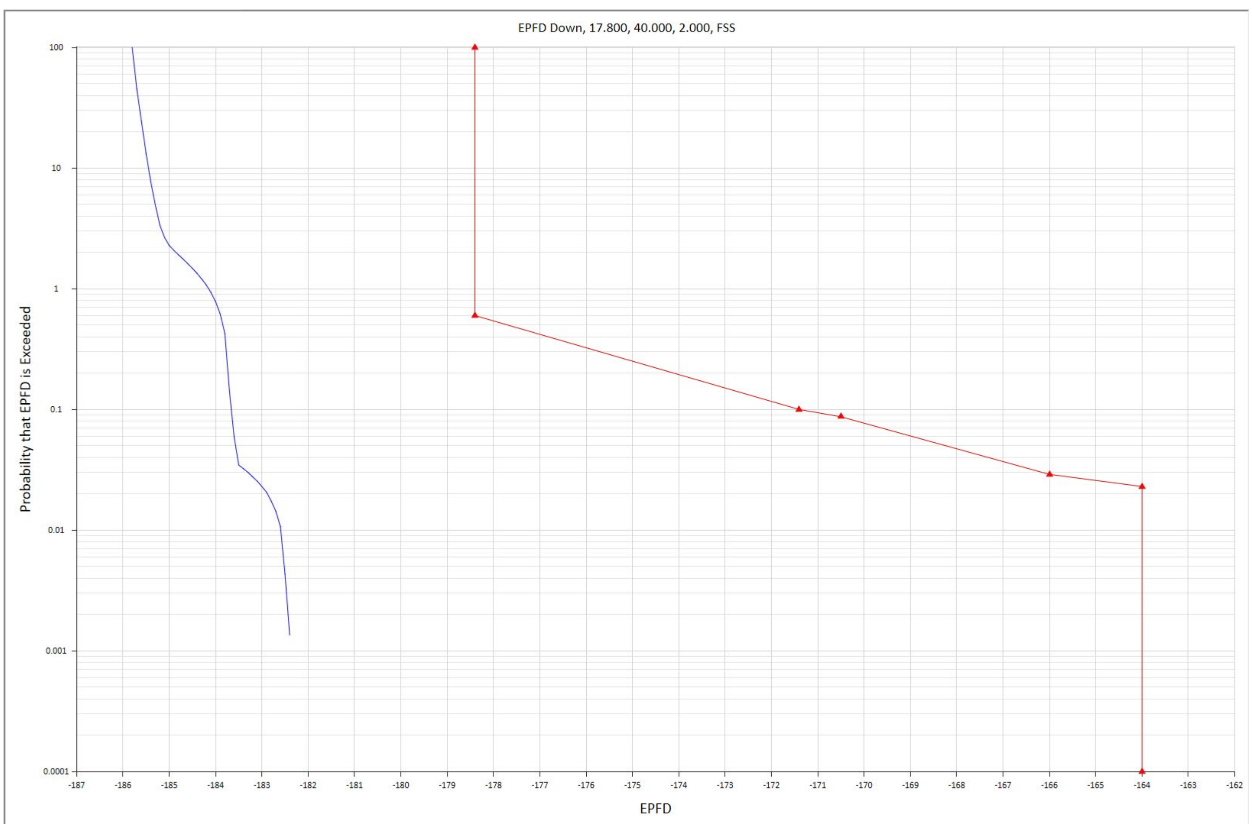

EPFD Down, 19.700, 40.000, 0.900, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-194 -193 -192 -191 -190 -189 -188 -187 -186 -185 -184 -183 -182 -181 -180 -179 -178 -177 -176 -175 -174 -173 -172 -171 -170 -169 -168 -167 -166 -165 -164 -163 -162 -161 -160 -159 -158 -157 -156 -155 -154 -153 -152
EPFD

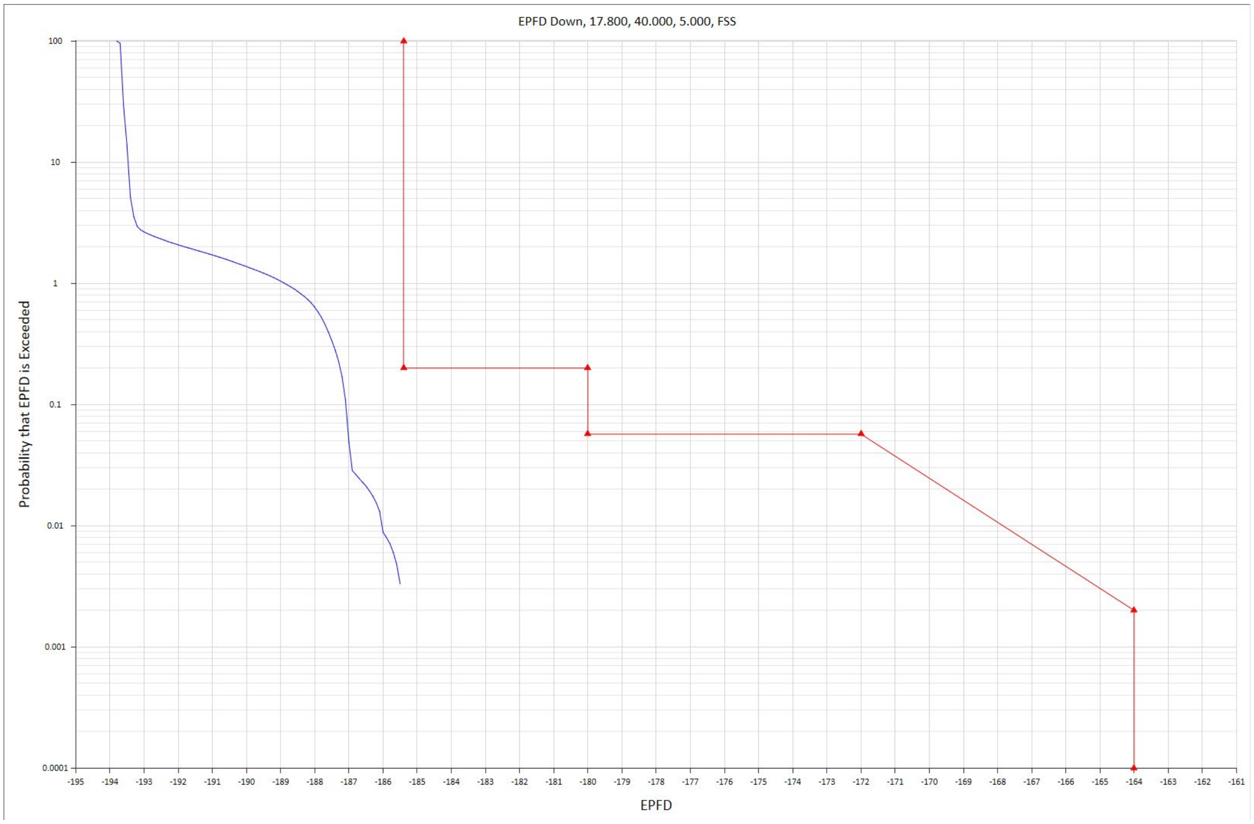

EPFD Down, 19.700, 40.000, 2.500, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-208 -206 -204 -202 -200 -198 -196 -194 -192 -190 -188 -186 -184 -182 -180 -178 -176 -174 -172 -170 -168 -166 -164 -162 -160 -158 -156 -154 -152 -150
EPFD


EPFD Down, 19.700, 40.000, 5.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-214
-212
-210
-208
-206
-204
-202
-200
-198
-196
-194
-192
-190
-188
-186
-184
-182
-180
-178
-176
-174
-172
-170
-168
-166
-164
-162
-160
-158
-156
-154
-152
-150
EPFD

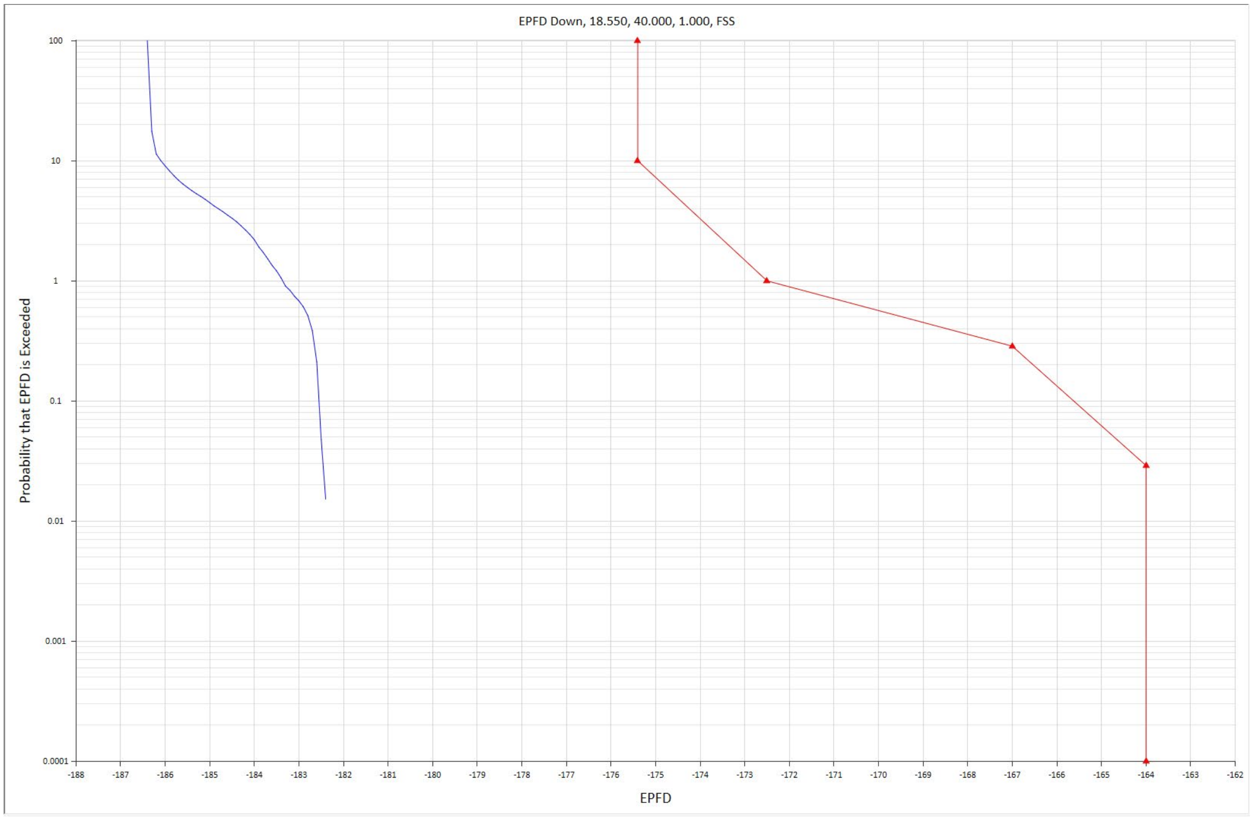
OUTPUTS FOR EPFD$_{DOWN}$ ASSESSMENT (Gateway beams)

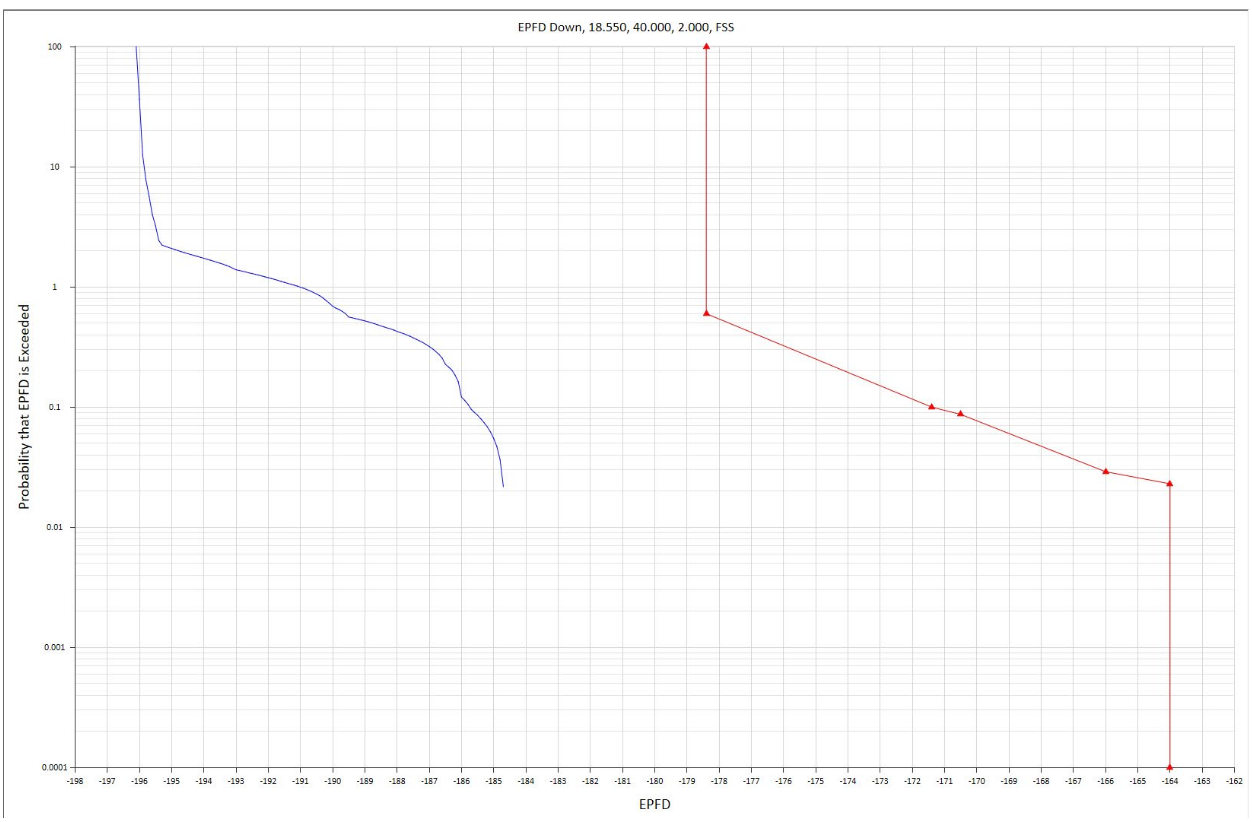


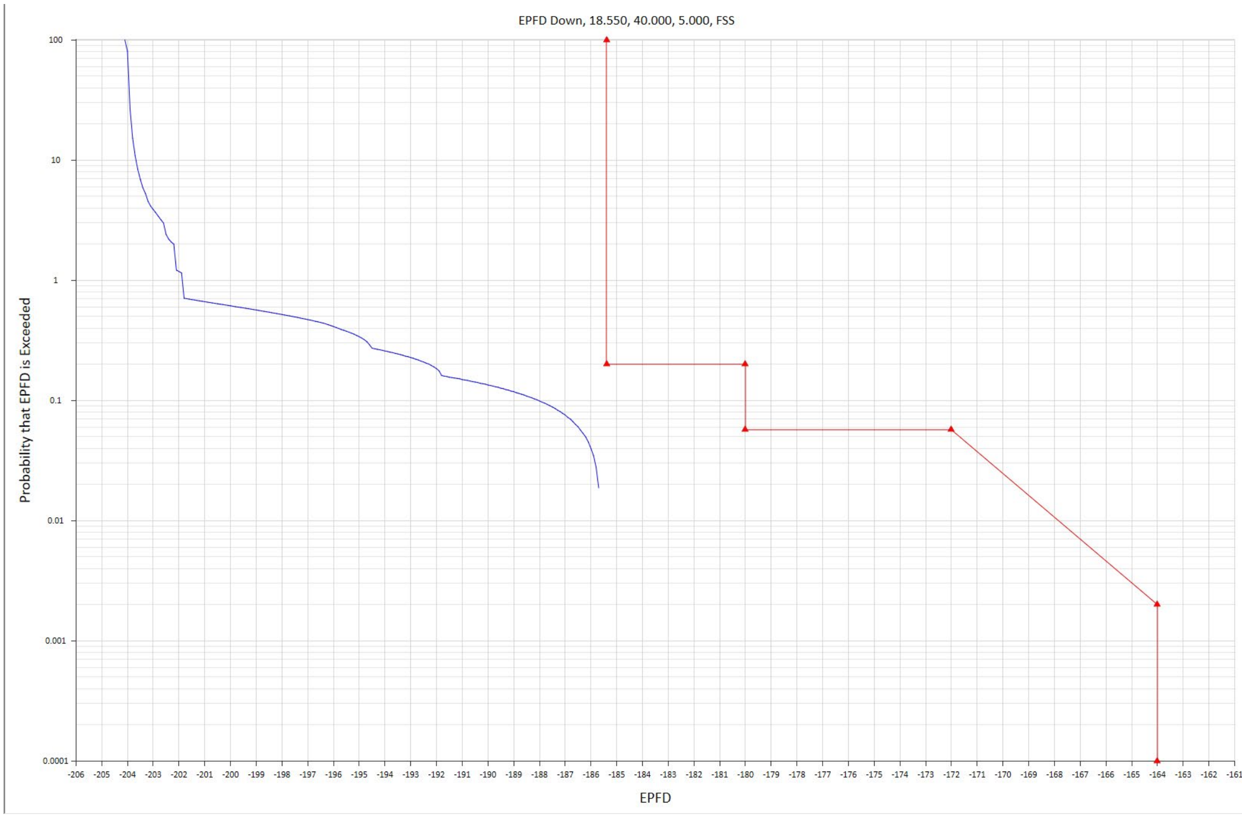



EPFD Down, 17.800, 40.000, 5.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-195 -194 -193 -192 -191 -190 -189 -188 -187 -186 -185 -184 -183 -182 -181 -180 -179 -178 -177 -176 -175 -174 -173 -172 -171 -170 -169 -168 -167 -166 -165 -164 -163 -162 -161
EPFD

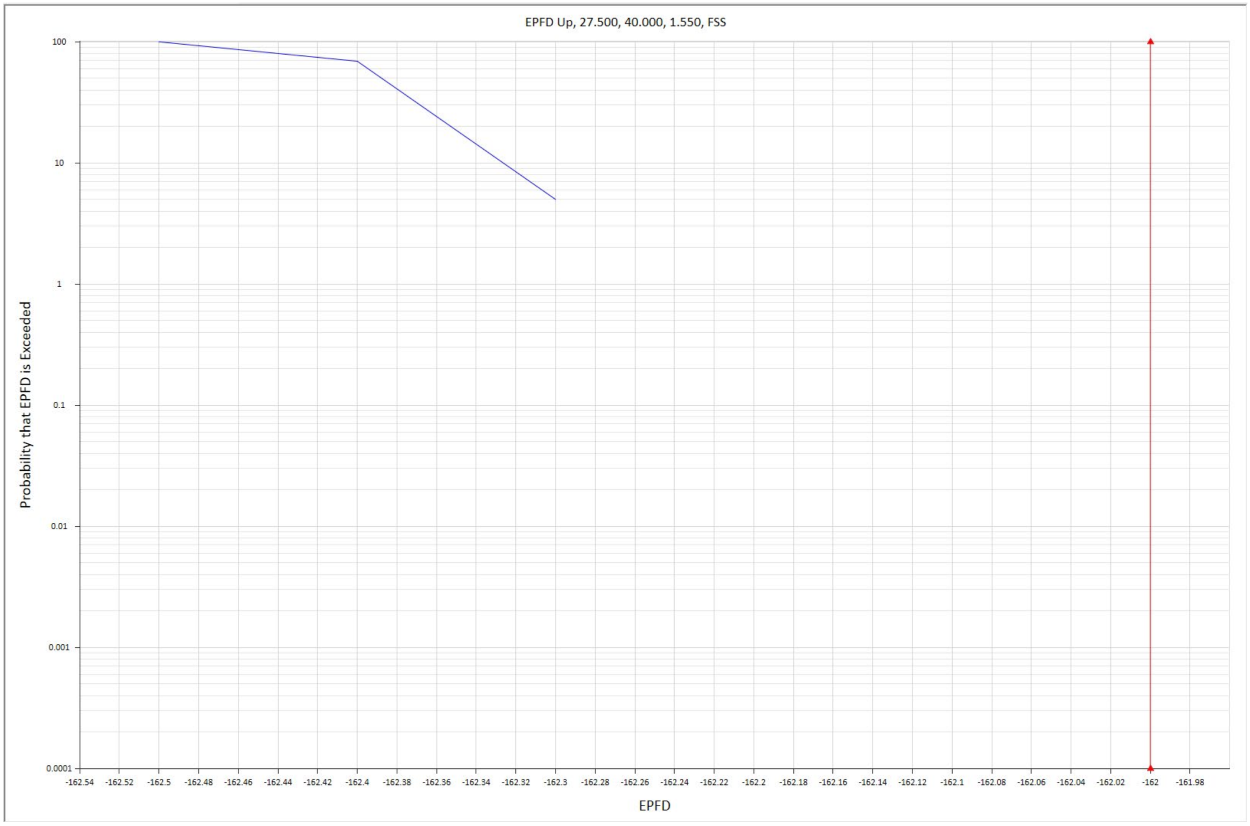
OUTPUTS FOR EPFD$_{DOWN}$ ASSESSMENT (TT&C beams)



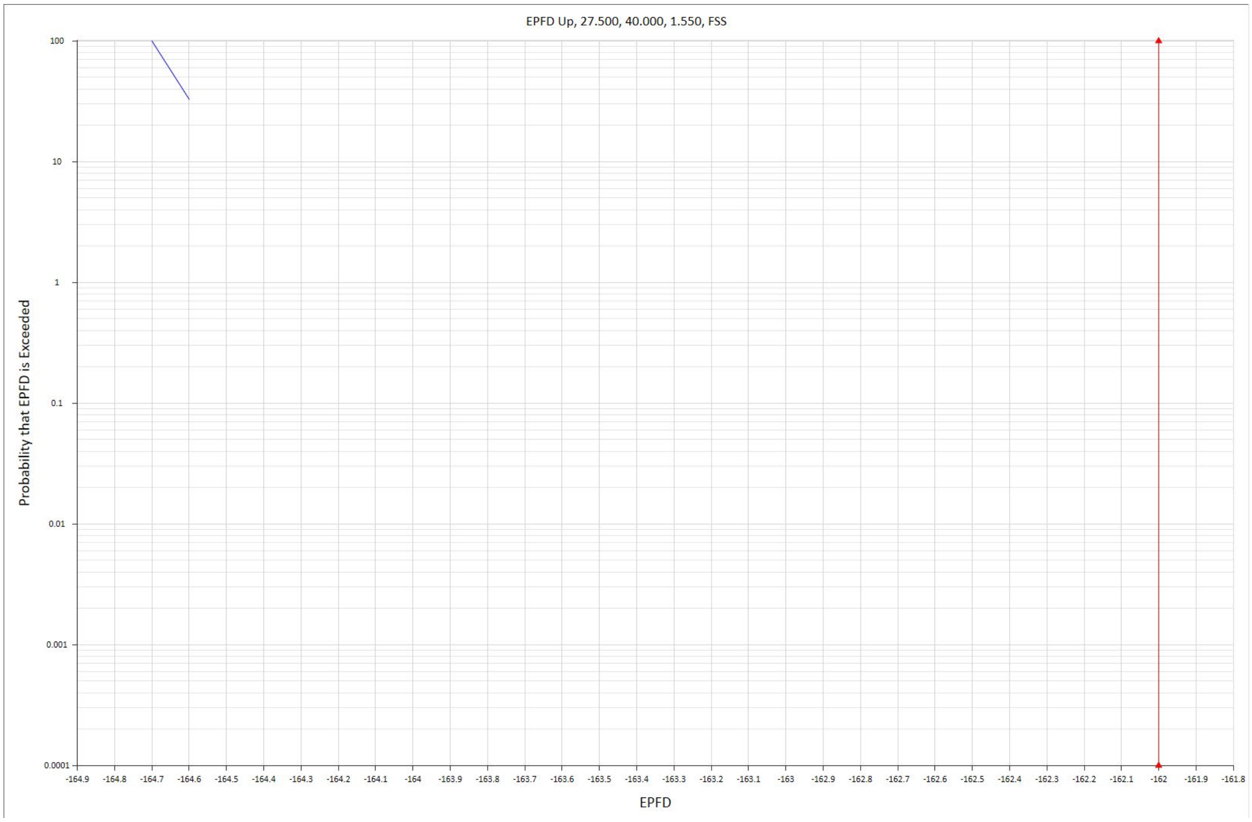



EPFD Down, 18.550, 40.000, 5.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-206 -205 -204 -203 -202 -201 -200 -199 -198 -197 -196 -195 -194 -193 -192 -191 -190 -189 -188 -187 -186 -185 -184 -183 -182 -181 -180 -179 -178 -177 -176 -175 -174 -173 -172 -171 -170 -169 -168 -167 -166 -165 -164 -163 -162 -161
EPFD

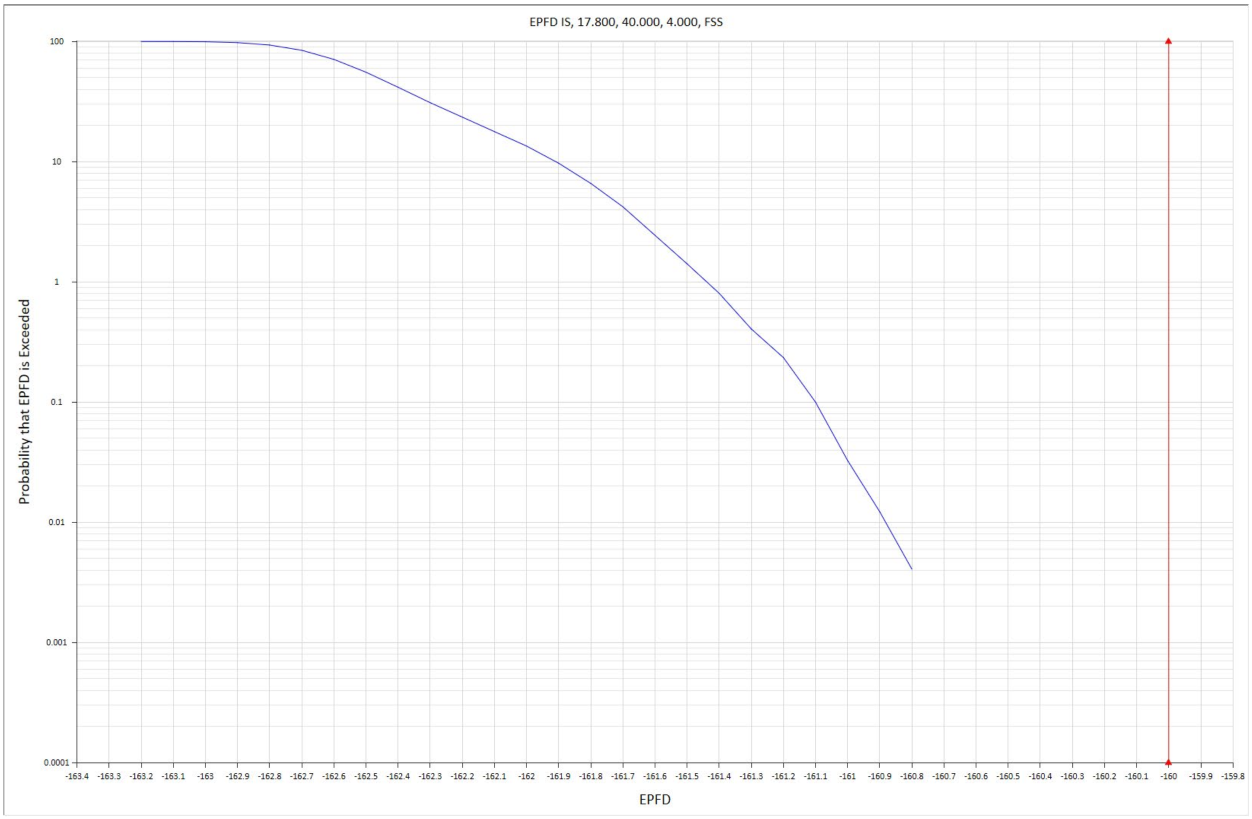
OUTPUT FOR EPFD$_{UP}$ ASSESSMENT (User beams)



OUTPUT FOR EPFD$_{UP}$ ASSESSMENT (Gateway beams)



OUTPUTS FOR EPFD$_{IS}$ ASSESSMENT



ANNEX 3

POTENTIALLY RELEVANT NON-U.S. NGSO SYSTEMS

The table below lists the NGSO satellite networks filed with the ITU by administrations other than the United States that have a perigee within the range of altitudes that could be used by the Gen2 System for which a request for coordination has been published. For each such network, the table lists the filing administration, the proposed altitude(s) at which normal operations could pose a collision risk for the Gen2 System, and the number of satellites proposed for operation at those altitudes.

NGSO Network	Administration	Relevant Altitude(s) (km)	Number of Satellites
ALOS-2	J	628	1
ALOS-4	J	628	1
ARE-2	NOR	640	1
ARE-3	NOR	640	1
CASCADE-CX	CAN	300	1
DK-1	CHN	605.8	1
EVIO	CAN	516	1
GTS	RUS	350	1
IPS	HOL	400	1
MSTD	J	480	1
PAZ	E	510	1
RTAFSAT	THA	500	1
S4P	SUI	400	1
SAUDISAT-5	ARS	600	1
SAUDISAT-6	ARS	600	1
SIMBA	BEL	500	1
TFSTAR	CHN	500	1
TY3-04	CHN	500	1
COSMOSKYMED-2	I	623.9	2
GC-8	CHN	599.3	2
JARVIS	LUX	500, 600	2
KS-2	CHN	500	2
MCSCS	CHN	643	2
SAMSON-2	ISR	500, 525	2
WL-1	CHN	400	2
QZSS-1	J	316	3
SSG-CSL	G	500	3
CATAPULT-IOD-UP	G	400	4
LXS-AIS	LUX	600	4
SMARTSAT-1	CHN	500	4
TY1-06	CHN	500	4
TY2D	CHN	500	5
NSL-1	ISR	600, 620, 640	9

SPATIUM	J	400	10
ZG6U-1	CHN	500	10
PROGNOZ-N	RUS	500	12
JUKEBOX	G	500	13
MULTUS	CAN	500	15
A4MSSNG	F	600	20
THUMBSAT-1	MEX	500	20
GRID	CHN	500	24
KELYPSIS	CAN	500	25
OKSAT	CHN	600	64
ARNG-C	F	600	66
HOL-MG-A006	HOL	600	70
FALAK-1	UAE	600	82
EB-SAT-LEO-1	F	600	90
F-SAT-NG-10	F	500, 600	100
F-SAT-NG-9	F	500, 600	100
SI-SAT-KURUKURU	SLM	500, 505, 525, 577	103
M5L2SAT	PNG	630	144
SI-SAT-BILIKIKI	SLM	300, 500	164
HISPASAT-LEO-NB	E	600	400
EN-C	G	525, 575	539