SPACEX 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

Apart from the additional frequencies, the Original Application's general description of the overall system facilities, operations and services for the SpaceX non-geostationary orbit ("NGSO") satellite system (the "SpaceX System") remains unchanged. For the Commission's convenience, SpaceX has included in the accompanying Schedule S the information filed as part of the Original Application with revisions associated with adding the supplemental frequency bands sought in this application. The accompanying Schedule S therefore reflects the system as it will operate over all frequencies, including the supplemental spectrum sought in this application. However, unless otherwise specified, the material contained below in this technical narrative is applicable only to the portion of the SpaceX System relevant to the supplemental spectrum. The portion already being considered in the November processing round remains unchanged from the Original Application.

The frequency ranges used by the SpaceX System are summarized in Table A.2-1 below, with the supplemental frequency bands sought in this amendment highlighted in bold. Figure A.2-1 depicts the spectrum used by the system for gateway and user beams and for telemetry, tracking, and control ("TT&C") operations, with the supplemental frequency bands sought in this amendment highlighted in green, along with an indication of the U.S. frequency allocations and designations that exist in these bands. The detailed channelized frequency plan is provided in the associated Schedule S.

Type of Link and Transmission Direction	**Frequency Ranges**
User Downlink Satellite-to-User Terminal	10.7 – 12.7 GHz
Gateway Downlink Satellite to Gateway	17.8 – 18.6 GHz 18.8 – 19.3 GHz **19.7 – 20.2 GHz**
User Uplink User Terminal to Satellite	**12.75 – 13.25 GHz**[1] 14.0 – 14.5 GHz
Gateway Uplink Gateway to Satellite	27.5 – 29.1 GHz **29.3 – 29.5 GHz** 29.5 – 30.0 GHz
TT&C Downlink	12.15 – 12.25 GHz 18.55 – 18.60 GHz
TT&C Uplink	13.85 – 14.00 GHz

Table A.2-1: Frequency Bands Used by the SpaceX System

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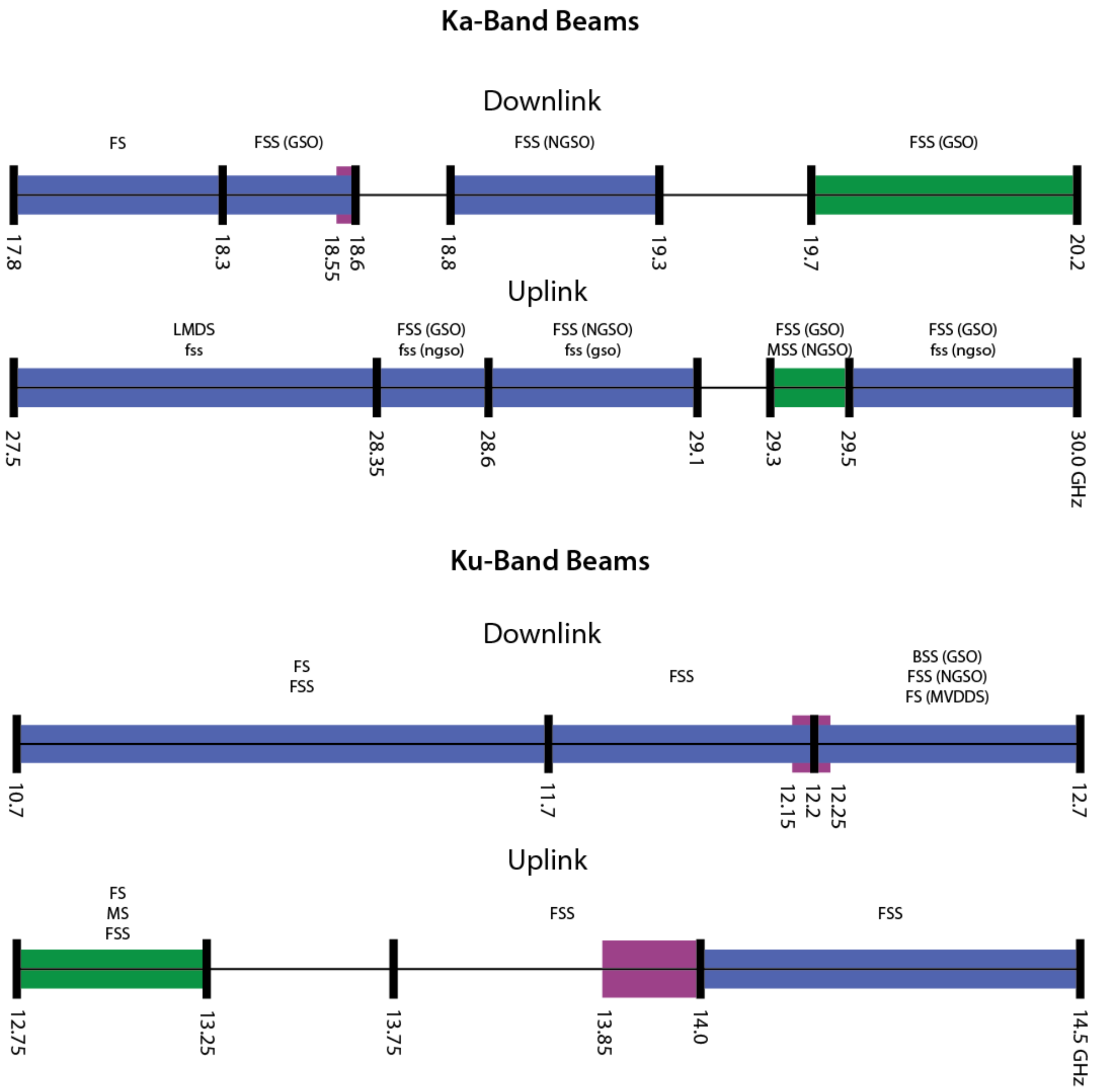
[1] At this time, SpaceX seeks authority to use this band in the United States only with individually-licensed earth stations. No such limitations would apply outside the U.S. In the future, SpaceX may seek authority to operate blanket-licensed user terminals in the U.S. as well.

Figure A.2-1—Frequency Plans and FCC Spectrum Allocations



Key:
FS – Terrestrial Fixed Service
FSS – Fixed Satellite Service
FSS (GSO) – Geostationary Orbit Fixed Satellite Service
FSS (NGSO) – Non-Geostationary Orbit Fixed Satellite Service
LMDS – Local Multipoint Distribution Service
MS – Mobile Service
MVDDS – Multichannel Video and Data Delivery Service

🟦 Original SpaceX Communications Frequencies
🟪 SpaceX TT&C Frequencies
🟩 Supplemental SpaceX Frequencies

SpaceX recognizes that not all of the supplemental frequencies 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 its system can operate without causing harmful interference to or requiring protection from any other service duly licensed in these bands with higher priority.[2]

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS

All satellites in the SpaceX System have been designed with the same transmit and receive antenna beams. The antenna gain contours for the transmit and receive beams for a representative space station are embedded in the associated Schedule S, as required by Section 25.114(c)(4)(vi)(B). The contours for all transmit and receive beams are essentially the same for satellites operating in all planes and altitudes. Below we describe the methodology for their presentation in the associated Schedule S.

A.3.1 Ku-Band User Beams

The SpaceX system will use the 12.75-13.25 GHz band for uplink transmissions from user terminals.[3] These terminals communicate only with satellites at an elevation angle of at least 40 degrees. Consequently, as shown in Figure A.3.1-1 below, each satellite operating at an altitude of 1,150 km will provide service only up to 40.46 degrees away from boresight (nadir), covering an area of about 3.5 million square kilometers (1,060 km radius).[4]

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[2] Where appropriate, SpaceX has requested a waiver for non-conforming use of spectrum.

[3] In the U.S., such user terminals would be limited to individually-licensed earth stations, such as those used by enterprise customers. In the future, SpaceX may seek authority to operate blanked-licensed user terminals in the U.S. as well.

[4] While the 40 degree minimum elevation angle remains the same from the earth station point of view, the maximum angle from boresight at which service can be provided from the satellite changes slightly depending upon altitude. Thus, satellites operating at 1,110 km, 1,130 km, 1,275 km, and 1,325 km altitude can provide service up to 40.72, 40.59, 39.67, and 39.36 degrees away from boresight, respectively.

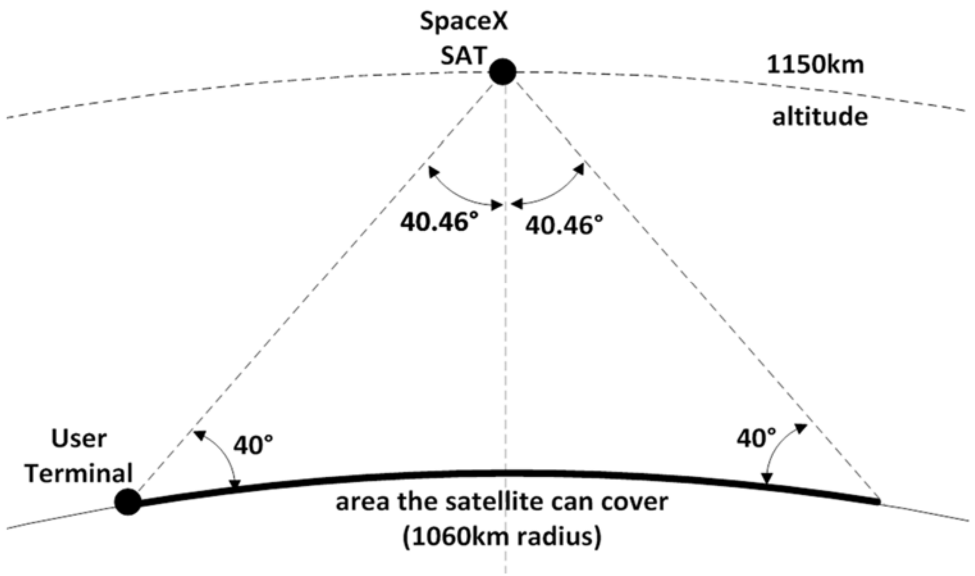

Figure A.3.1-1: Steerable Service Range of Ku-band Beams (1,150 km)

Generally, beams from antennas using phased arrays widen incrementally as they are steered away from boresight.[5] However, this widening occurs only in the plane formed by boresight and the center of the beam ("elevation"), and not in the plane normal to that plane formed by boresight and the center of the beam ("azimuth"). As a result, the shape of a phased array beam at boresight is circular but becomes increasingly elliptical when steered away from boresight.

This beam widening behavior with phased array antennas creates several effects that must be offset in order to achieve efficient use of spectrum through frequency re-use. As the beam widens, the size of the spot on the ground increases due to the increased distance to the Earth's surface, and the curvature of the Earth enhances this effect. For receiving antennas, this results in reception of radiofrequency energy from a wider area, which increases both the susceptibility to interference from other systems and the potential for self-interference from user terminal uplink transmissions.

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

The SpaceX System offsets these beamwidth variations by switching antenna elements in the phased array on and off at certain steering angles. By ensuring that radio energy is received from the desired direction, this switching helps to mitigate interference with other systems. Specifically, as shown in Figure A.3.1-2 below, additional elements are turned on when the angle reaches 23 degrees, and then again when it reaches 32 degrees. (Note this applies for both transmit and receive antennas on each satellite.)

Figure A.3.1-2: Beamwidth Variation at Various Steering Angles

The following figures illustrate this dynamic by plotting antenna gain contours (for both uplink and downlink beams) at key steering angles, in each case at a roll off of -2 dB, -4 dB, -6 dB, -8 dB, -10 dB, -15 dB, and -20 dB.

Figure A.3.1-3 shows the antenna gain contour with the beam pointed to nadir (boresight, or zero steering angle).

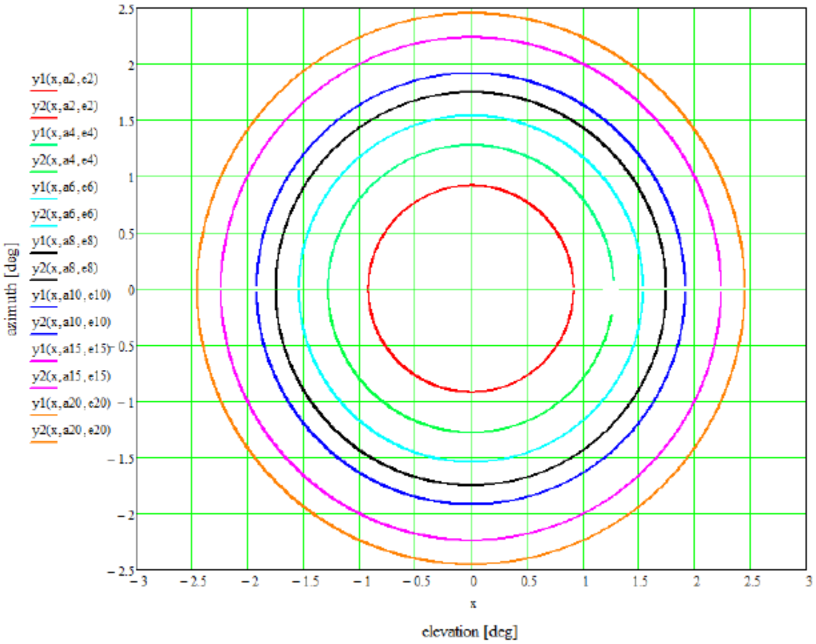

Figure A.3.1-3: Beam Contour at Nadir

Figure A.3.1-4 shows a plot for the same beam when it is steered to 23 degrees away from nadir, just before additional elements are engaged.

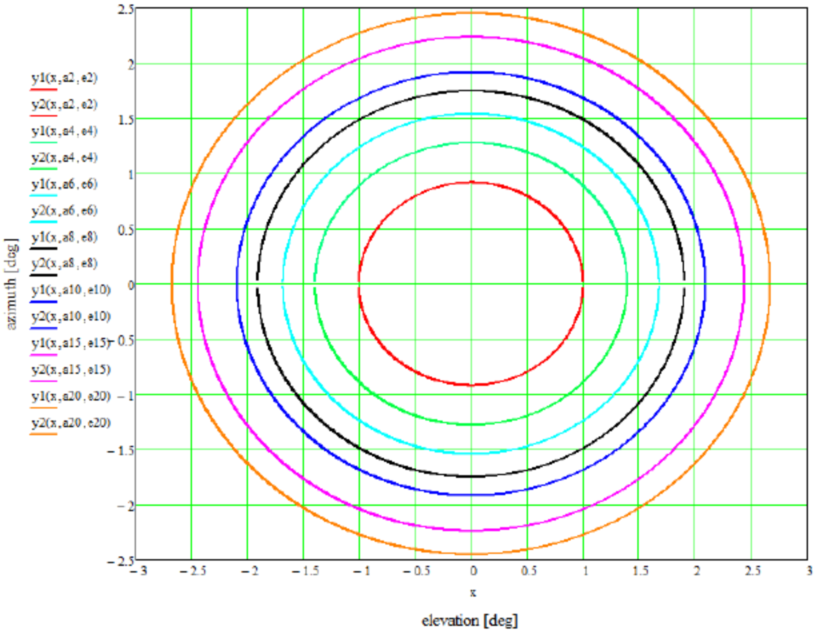

Figure A.3.1-4: Beam Contour at 23 Degrees Elevation Before Additional Elements Turned ON

Figure A.3.1-5 shows the same plot, but after additional elements of the phased array antenna have been turned on to reduce beamwidth.

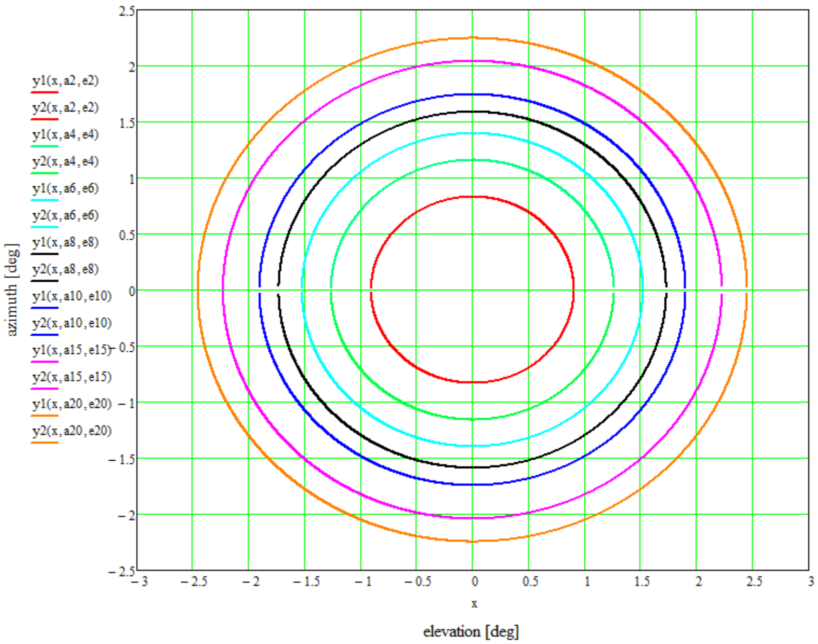

Figure A.3.1-5: Beam Contour at 23 Degrees Elevation After Additional Elements Turned ON

Similarly, Figures A.3.1-6 and A.3.1-7 below show the same beam when it has been steered to 32 degrees, first without the additional elements turned on and then with them turned on to reduce beamwidth.

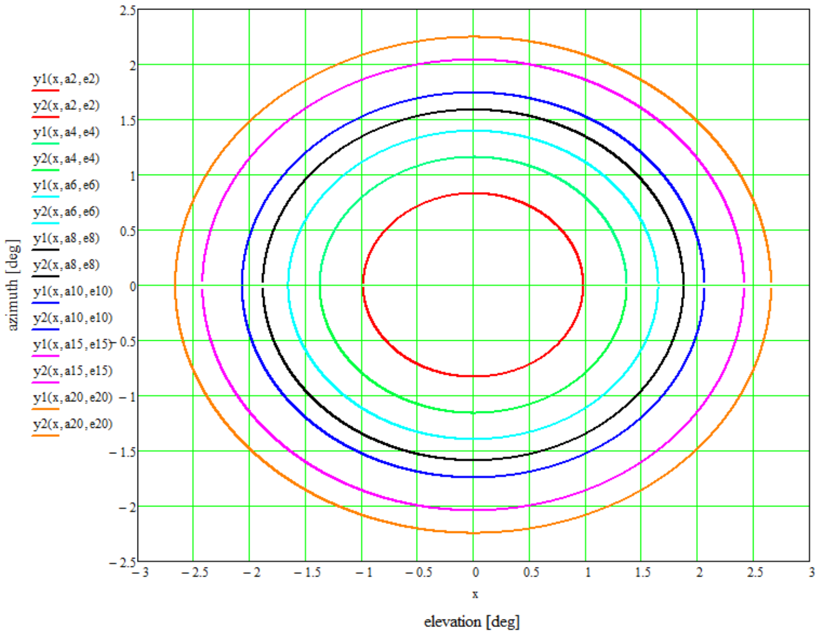

Figure A.3.1-6: Beam Contour at 32 Degrees Elevation Before Additional Elements Turned ON

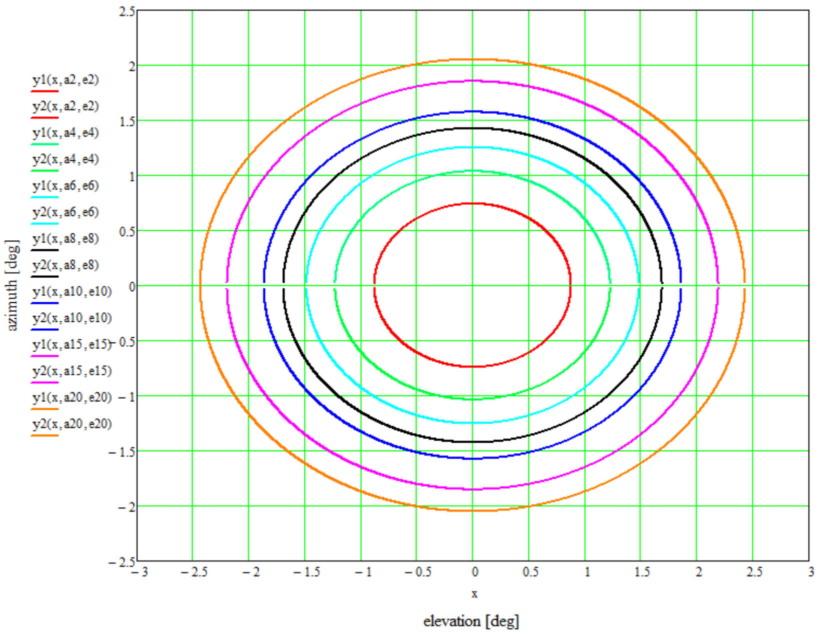

Figure A.3.1-7: Beam Contour at 32 Degrees Elevation After Additional Elements Turned ON

Finally, Figure A.3.1.8 below shows the antenna gain contour when the beam is steered to its maximum angle of 40.46 degrees, where it has the greatest beamwidth.

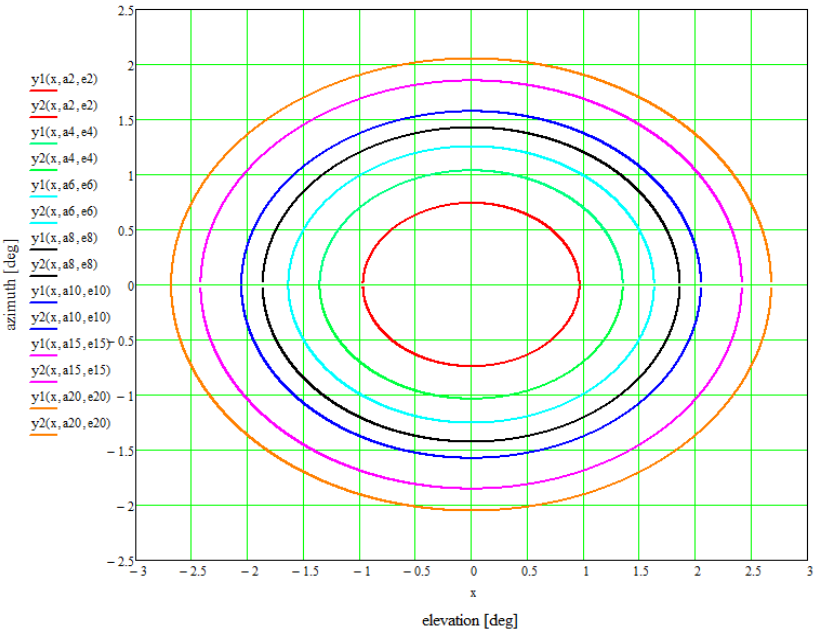

Figure A.3.1-8: Beam Contour at 40.46 Degrees Elevation

The intended coverage area for each beam is a cell inside the -3 dB contour, as illustrated in figure A.3.1-9 below. At a given frequency, only a single beam (with left hand circular polarization ("LHCP") on the uplink) would cover a single cell on the ground.

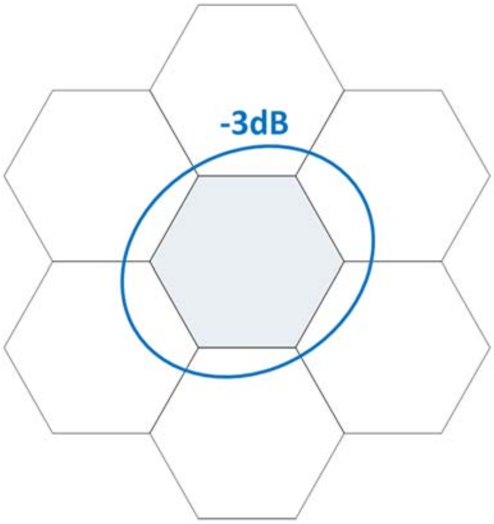

Figure A.3.1-9: Intended Beam Coverage Area

For receiving beams, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (9.8 dB/K) occurs at nadir, while the minimum G/T (8.7 dB/K) occurs at maximum slant.[6] In addition, as required under the Commission's rules, SpaceX earth stations will transmit in the 13.15-13.2125 GHz sub-band at EIRP of no more than 3.2 dBW towards the radio horizon.[7]

A.3.2 Ka-Band Gateway Beams

As with the Ku-band beams discussed above, all Ka-band gateway downlink spot beams on SpaceX satellites are independently steerable over the full field of view of the Earth. As with user terminals, gateways communicate only with satellites at an elevation angle of at least 40 degrees. Consequently, as discussed above, each satellite can be supported by gateways located

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[6] 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 SpaceX System. 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."

[7] *See* 47 C.F.R. § 2.106, n. NG53.

only up to a certain limit away from boresight (nadir), which varies slightly by operating altitude. Each satellite transmits two beams at the same frequency (with right hand and left hand circular polarization ("RHCP and LHCP")). Up to four satellites can beam transmissions to the gateway location, for a maximum of eight co-frequency beams.

As with Ku-band user beams, the shape of the Ka-band gateway beam becomes elliptical as it is steered away from the boresight as a consequence of the phased array technology employed. It widens in the elevation plane, but not the azimuth plane. However, unlike the Ku-band user beams, SpaceX does not adjust the elements of the Ka-band phased array gateway antenna in order to limit beamwidth variation. While each Ku-band user beam is designed to cover a number of users within a cell, each Ka-band 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.

Figure A.3.2-1 shows the antenna gain contour (for both uplink and downlink gateway beams) with the beam pointed to nadir (boresight, or zero steering angle).

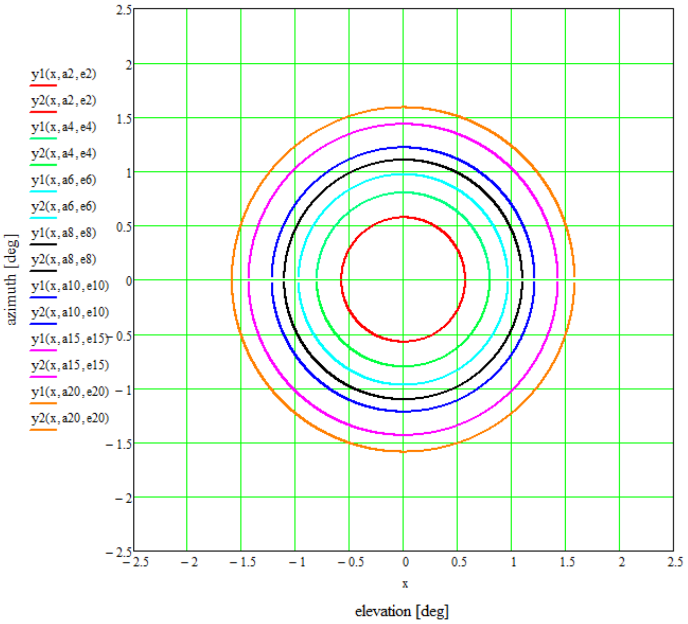

Figure A.3.2-1: Beam Contour at Nadir

Figures A.3.2-2 through A.3.2-5 likewise show plots for the same gateway beam when it is steered to 10, 20, 30, and 40.46 degrees away from nadir. As these figures show, the beam becomes increasingly elliptical as the angle increases.

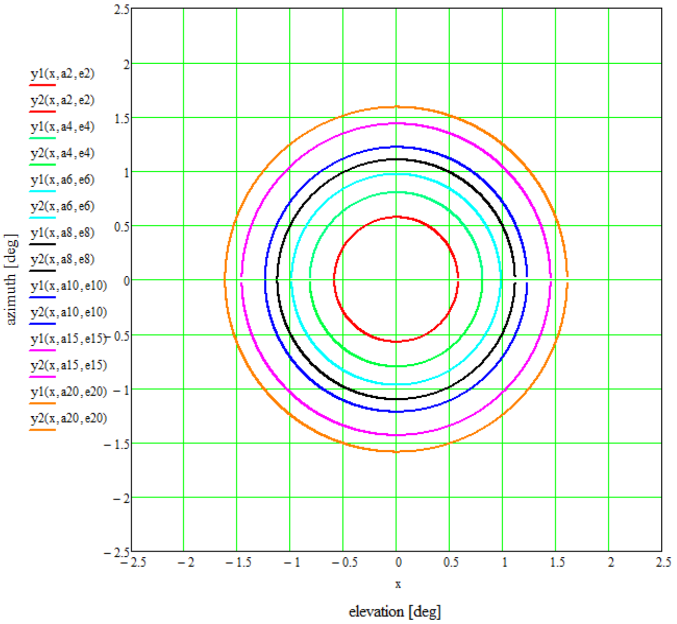

Figure A.3.2-2: Beam Contour at 10 Degrees Elevation

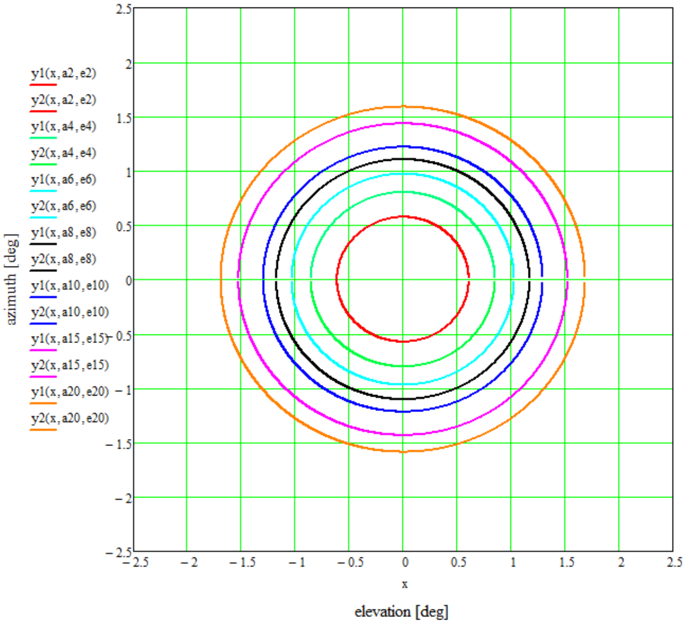

Figure A.3.2-3: Beam Contour at 20 Degrees Elevation

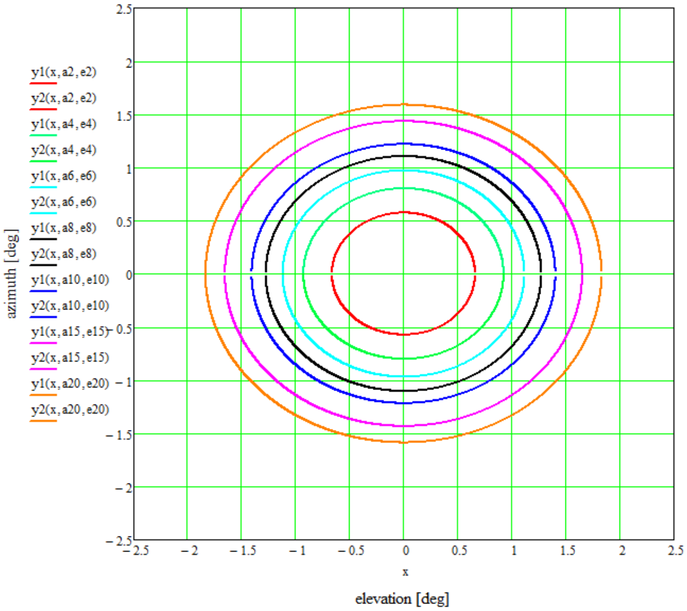

Figure A.3.2-4: Beam Contour at 30 Degrees Elevation

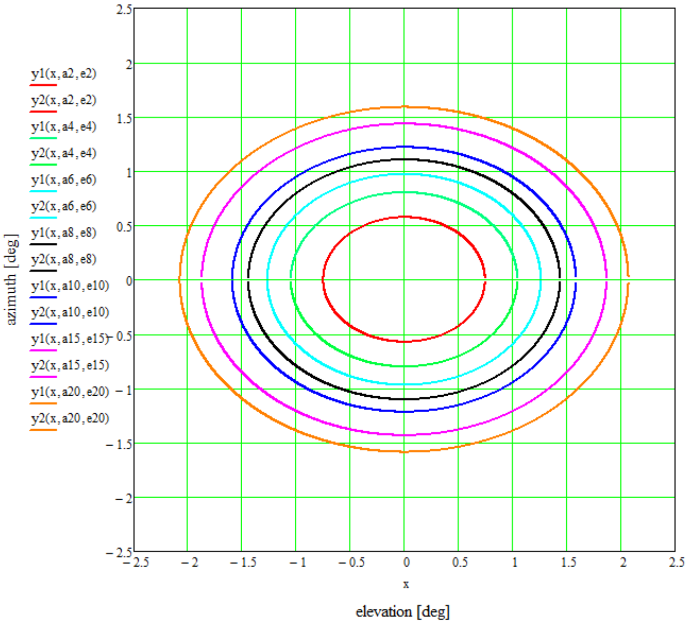

Figure A.3.2-5: Beam Contour at 40.46 Degrees Elevation

As the transmitting beam is steered, the power (in both polarizations) is adjusted to maintain a constant PFD at the surface of the Earth, compensating for variations in antenna gain and path loss associated with the steering angle. As illustrated in Figure A.3.2-6 below, the highest EIRP density (10.14 dBW/1MHz) in the 19.7-20.2 GHz band occurs at maximum slant.

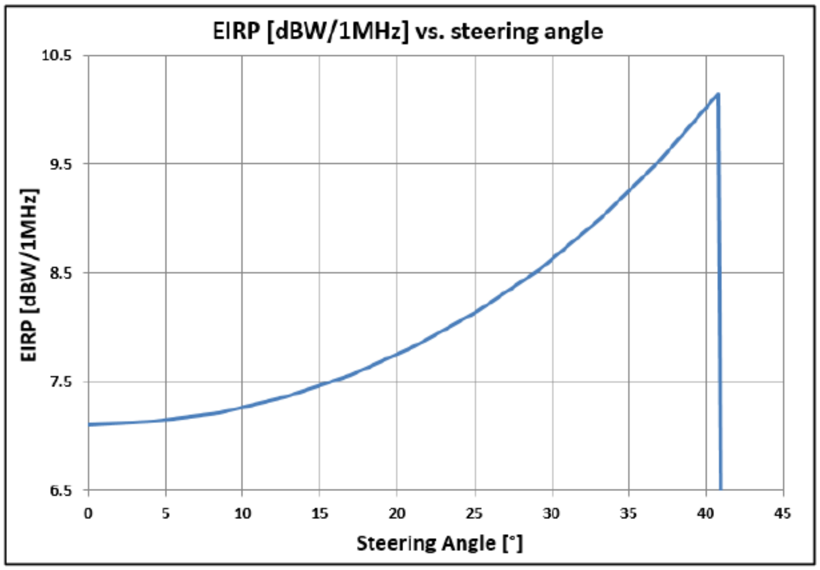

Figure A.3.2-6: EIRP Density Variation by Beam Steering Angle

For receiving beams in the 29.3-29.5 GHz band, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (13.7 dB/K) occurs at nadir, while the minimum G/T (11.4 dB/K) occurs at maximum slant.

A.4 GEOGRAPHIC COVERAGE

At Final Deployment, the SpaceX System will meet the Commission's geographic coverage requirements set forth in Section 25.145(c) for Ka-band and Section 25.146(i) for Ku-band operations.[8] They are essentially the same for both frequency bands, and require the applicant to demonstrate that:

(1) the proposed system is capable of providing Fixed-Satellite Service on a continuous basis throughout the fifty states, Puerto Rico and the U.S. Virgin Islands; and

(2) the proposed system is capable of providing Fixed-Satellite Services to all locations as far north as 70° North Latitude and as far south as 55° South Latitude for at least 75 percent of every 24-hour period.

Because the Ku-band user links and Ka-band gateway links are conceptually distinct for

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[8] To the extent necessary, SpaceX has requested a waiver of these requirements with respect to the Initial Deployment.

purposes of this analysis, we discuss them separately below.

Ku-Band Geographic Coverage

As discussed above, SpaceX intends to begin providing commercial broadband service in the U.S. and internationally after launching 800 satellites of the Initial Deployment. With those satellites, SpaceX could provide service in the areas between approximately 60º North Latitude and 15º North Latitude and between 15º South Latitude and 60º South Latitude. This would be sufficient to cover the contiguous United States ("CONUS"), Hawaii, Puerto Rico, and the U.S. Virgin Islands, but would not cover the region near the equator or areas at more extreme latitudes (including portions of Alaska). Once the Initial Deployment has been completed, the system will provide continuous FSS service from approximately 60º North Latitude to 60º South Latitude. This is sufficient to cover CONUS, Hawaii, Puerto Rico, and the U.S. Virgin Islands, as well as the southernmost areas required by the rule. However, the system will not yet provide continuous coverage to the northernmost areas required by the rule (including portions of Alaska) until service from one of the more inclined orbital constellations is launched.

Once fully deployed, the SpaceX System will pass over virtually all parts of the Earth's surface and therefore, in principle, have the ability to provide ubiquitous global service. Because of the combination of orbital planes used in the SpaceX System, including the use of near-polar orbits, every point on the Earth's surface will see, at all times, a SpaceX satellite at an elevation no less than 40 degrees, with increasing minimum elevation angles at lower latitude. This will satisfy the Commission's geographic coverage requirements.

Ka-Band Geographic Coverage

The gateway earth stations of the SpaceX System provide the necessary communications links back from the SpaceX satellites to the global Internet. SpaceX intends to install sufficient gateway sites in the U.S. and around the world to ensure the SpaceX satellites have a visible gateway earth station with which they can communicate from all parts of their orbits. The actual number of gateways will scale with user demand and system deployment. For example, SpaceX estimates that it will deploy approximately 200 gateways in the United States to support the Initial Deployment. At Final Deployment, the SpaceX Ka-band gateway links will be sufficient to serve SpaceX satellites at all latitudes, which meets the requirements of Section 25.145(c)(1) and (2) as far as these rules can be applied to such types of links.

A.5 TT&C CHARACTERISTICS

A complete description of the SpaceX TT&C subsystem, including the maximum transmit EIRP density, maximum and minimum G/T for receiving beams, and diagrams of the antenna gain contours, is provided with the Original Application and its associated Schedule S, and those materials are incorporated herein by reference.[9]

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.

A.7 INTERFERENCE ANALYSES

As shown in Figure A.2-1 above, the frequency ranges SpaceX proposes to use in Ku-band and Ka-band are shared with other services in the U.S. table of frequency allocations. The SpaceX system design has been engineered to achieve a high degree of flexibility in order to

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[9] *See, e.g.,* Original Application, Sections A3.3, A.5, and Schedule S.

protect other authorized satellite and terrestrial systems under reasonable coordination arrangements and facilitate spectrum sharing. 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 40 degrees for all gateway and user earth stations.
- *Highly directional earth station beams.* The earth stations used to communicate with the SpaceX 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 40 degrees, 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.* With over 4,400 satellites, the SpaceX System will provide multiple NGSO satellites in the field of view of any given earth station. Where appropriate, the system will have the intelligence to select the specific satellite that would avoid a potential in-line interference event with GSO and 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. Below we discuss the SpaceX System's compliance with international operating parameters designed to prevent harmful interference to other systems operating in Ku-band and Ka-band spectrum.

A.7.1 Interference Protection for GSO Satellite Networks

The SpaceX System has been designed to provide all necessary interference protection to GSO satellite networks in both the Ku-band and Ka-band as required under Article 22 of the ITU Radio Regulations. In addition, in the Ku-band, the SpaceX System will fully comply with the similar requirements in Sections 25.146 and 25.208 of the Commission's rules. In the following sections, we will demonstrate compliance with the Equivalent Power Flux-Density ("EPFD") limits set forth in Article 22 of the ITU Radio Regulations and in Section 25.146 (for the Ku-band).

Specifically, No. 22.5C and 22.5I of the Radio Regulations define EPFD limits for the downlink transmissions from an NGSO satellite system in certain Ku- and Ka-band downlink frequency ranges that must be followed in order to avoid causing unacceptable interference to GSO satellite networks.[10] Similarly, No. 22.5D of the Radio Regulations defines corresponding EPFD limits applicable to the uplinks from an NGSO satellite system in certain Ku- and Ka-band uplink frequency ranges.[11] Although the Commission's rules do not include the ITU Ka-band $EPFD_{down}$ limits, the ITU Ku-band $EPFD_{up}$ limits are reflected in Sections 25.146 and 25.208(k).

SpaceX will meet all EPFD limits that apply within the supplemental frequency ranges requested herein, and all other obligations of the ITU Radio Regulations and the Commission's Part 25 rules in this regard within the frequency ranges where such limits apply. Below, we provide an explanation of the techniques SpaceX will use to comply with the EPFD limits separately for Ku-band and Ka-band operations. Note that these techniques are used to protect GSO satellite networks from interference from the SpaceX System but also have the effect of

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[10] These limits are referred to in the Commission's rules as "$EPFD_{down}$" limits, and in the ITU Radio Regulations as "EPFD↓".

[11] These limits are referred to in the Commission's rules as "$EPFD_{up}$" limits, and in the Radio Regulations as "EPFD↑".

protecting the SpaceX System from GSO interference, as they are based on the principle of avoiding inline and near-inline events. In addition, SpaceX has begun to provide initial briefings on the operational parameters of its system to GSO satellite operators whose systems use the same Ku- and Ka-band frequency ranges as the SpaceX System, and is confident that compatibility with all GSO satellite networks in these bands can be achieved.

Finally, Resolution 76 of the ITU Radio Regulations include limits on aggregate $\text{EPFD}_{\text{down}}$ produced by all co-frequency satellites of all NGSO FSS systems operating in certain Ku- and Ka-bands, including the 19.7-20.2 GHz band.[12] SpaceX is prepared to work with other NGSO FSS operators in order to ensure compliance with the applicable limits.

A.7.1.1 EPFD Compliance in Ku-Band

Annex 1 provides a detailed analysis of the EPFD levels produced by the SpaceX System in the 12.75-13.25 GHz uplink band, and how they comply with the single-entry EPFD validation limits referenced in Section 25.146(a)(1) and (2). Annex 1 also addresses other related aspects of Section 25.146. Below we explain the principles by which the SpaceX system protects GSO satellite networks from interference in Ku-band.

In order for an NGSO satellite system to comply with the EPFD limits for the protection of GSO satellite networks, it must ensure that there is sufficient angular separation between the transmissions from the NGSO satellites (in the downlink bands) and user earth stations (in the uplink bands) relative to the potential victim GSO earth stations (in the downlink bands) and satellites (in the uplink bands), respectively. A key factor to achieving this goal is the number of SpaceX satellites in the NGSO constellation relative to the service areas being covered. The SpaceX constellation has sufficient satellites to ensure that there are always multiple SpaceX

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[12] *See* ITU Rad. Regs., Res. 76.

satellites visible from any point in the service area at a high elevation angle – always greater than 40 degrees. In concert with the ability to turn specific antenna elements off and manage traffic across multiple satellites utilizing inter-satellite links, SpaceX can serve a user by selecting a satellite that offers sufficient angular separation from the GSO arc to avoid the line of sight between GSO earth stations and their corresponding GSO satellites without interrupting service.

At higher latitudes, this is less of an issue as there is an inherent interference isolation due to the angular separation from the GSO arc for all SpaceX satellites. In these situations, GSO earth stations would only potentially receive low-power signals from the far-out sidelobes of the SpaceX satellites that are in the main beam of the GSO earth station, and maximum power signals only from the SpaceX satellites that appear in the far-out sidelobes of the GSO earth station. Similarly, because the transmitting SpaceX earth stations point well away from the GSO arc when communicating with SpaceX satellites at higher latitudes, receiving GSO satellites benefit from uplink isolation as well. Using its advanced phased array antennas, the SpaceX System further minimizes any potential interference through precision beamforming and by using sidelobe nulling to suppress unwanted signals from both satellites and user terminals in the direction of the GSO arc.

As the SpaceX satellites approach lower latitudes, they move closer to the line of sight between GSO earth stations and their corresponding GSO satellites. Accordingly, in addition to the sidelobe nulling discussed above, the SpaceX System will implement GSO arc avoidance to protect against interference into GSO systems. Specifically, SpaceX will turn off the transmit beam on the user terminal whenever the angle between the boresight of a GSO earth station (assumed to be collocated with the SpaceX user) and the direction of the SpaceX satellite transmit beam is 22 degrees or less. Because of the number and configuration of satellites in the

SpaceX System, there will be ample alternate satellites in view to provide uninterrupted service to a user from satellites operating outside of the exclusion zone around the GSO arc.

A.7.1.2 EPFD Compliance in Ka-Band

Annex 2 provides a detailed analysis of the EPFD levels produced by the SpaceX System in 19.7-20.2 GHz downlink band, and how they comply with the single-entry EPFD validation limits in Article 22 of the ITU Radio Regulations. Below we explain the principles by which the SpaceX system protects GSO satellite networks from interference in Ka-band.[13]

As explained above in relation to Ku-band, in order for an NGSO satellite system to comply with the Ka-band EPFD limits for the protection of GSO satellite networks (for both uplink and downlink), it must ensure that there is sufficient angular separation between the NGSO and GSO system assets. SpaceX uses a straightforward GSO arc avoidance strategy, combined with sophisticated sidelobe nulling, to protect GSO satellite networks from interference in the Ka-band. This approach depends upon careful choice of the SpaceX gateway sites and placing modest constraints on the positions of SpaceX satellites with which each gateway site is allowed to communicate. Because of the characteristics of the system, including suppression of potentially interfering satellite and earth station transmissions through the application of sidelobe nulling, the necessary GSO arc avoidance angle is 22 degrees. This angle is used as the basis of the EPFD compliance analysis provided in Annex 2.

A.7.1.3 Ka-Band Frequency Range Where No EPFD Limits Exist

Neither the Commission's rules nor the ITU Radio Regulations include EPFD limits for the 29.3-29.5 GHz downlink frequency band. According to ITU procedures applicable to this

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[13] SpaceX recognizes that its use of the 19.7-20.2 GHz and 29.3-29.5 GHz bands will be on a non-conforming basis with respect to GSO FSS systems, and has requested a related waiver. Accordingly, it will neither cause harmful interference to, nor be protected against harmful interference from, authorized GSO FSS operations in these bands.

frequency range, coordination between NGSO and GSO networks is on a first-come, first-served basis, depending on the ITU date priority of the relevant ITU filings.[14] SpaceX has provided initial briefings to various GSO satellite operators that use this frequency range, and is confident that compatibility with all GSO satellite networks in this band can be achieved using the GSO arc avoidance strategies discussed above.

A.7.2 Interference with Respect to Other NGSO Satellite Systems

Currently, there are no other NGSO satellite systems licensed by the Commission, or granted access to the U.S. market, that operate within the frequency ranges subject to this application, although applications for such authorizations are currently pending.[15] The ITU has procedures for coordination amongst NGSO systems operating in all of the Ku-band and Ka-band frequency ranges at issue here.[16] In addition, the Commission has adopted an avoidance of in-line interference events regime for the 12.75-13.25 GHz band,[17] and has proposed to extend that regime to the 19.7-20.2 GHz and 29.3-29.5 GHz bands as well,[18] such that spectrum sharing between NGSO satellite systems should be achievable using whatever means can be coordinated between the operators to avoid such in-line interference events, or by resorting to band splitting in the absence of any such coordination agreement.

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[14] *See* ITU Radio Regs. No. 9.11A.

[15] As set out in the public notice that initiated this series of processing rounds, one or more NGSO system application has previously been filed for each frequency band sought herein. *See* Public Notice, 32 FCC Rcd. 4180, 4183 n.3 (IB 2017). Although not licensed by the Commission, there is a U.S. government NGSO satellite system with which coordination is required under footnote US334 of the domestic table of allocations. This is addressed in Section A.9 below.

[16] *See* ITU Rad. Regs. No. 9.12.

[17] *See Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ku-band*, 17 FCC Rcd 7841, ¶ 27 (2002).

[18] *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 31 FCC Rcd. 13651, ¶ 23 (2016).

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.

A.7.3 Coordination With Respect to Terrestrial Networks in the 12.75-13.25 GHz Band

The 12.75-13.25 GHz uplink spectrum used by the SpaceX System is shared with terrestrial Fixed Service ("FS") in the U.S. on a co-primary basis.[19] By rule, only individually-licensed earth stations may operate with NGSO FSS systems in this band.[20] 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.[21] Such limitations were designed to "ensure NGSO FSS operations could 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."[22]

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

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[19] 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).

[20] *See* 47 C.F.R. § 25.202(a) n.6.

[21] *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).

[22] *Ku-band Sharing Order* ¶ 5.

limitations imposed on operations in this band under the Commission's rules.

A.8 COORDINATION WITH U.S. GOVERNMENT OPERATIONS

Under the U.S. Table of Frequency Allocations, federal usage of the 19.7-20.2 GHz band is allocated solely for FSS downlink operations. Footnote G117 limits these operations to military systems, while footnote US334 limits federal operations to specific areas of the orbital arc and of the country.[23] Footnote US334 also requires SpaceX to coordinate its NGSO system with U.S. government satellite networks, both GSO and NGSO, in the 19.7-20.2 GHz band. SpaceX has provided various U.S. government agencies initial information on the operational parameters of its system, and is committed to successful coordination with all government satellite networks operating in these bands to protect critical national security and government systems. SpaceX will inform the Commission when coordination has been completed.

There is no federal allocation in the 12.75-13.25 GHz band. Footnote US251 notes that this band is also allocated to the Space Research Service on a primary basis for reception only at Goldstone, CA. In addition, the National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.[24] SpaceX will coordinate with the relevant facilities to achieve mutually acceptable agreements regarding the protection of these important sites and their contributions to the space and Earth sciences.

A.9 ITU FILINGS FOR SPACEX

The SpaceX System will operate under network filings made on its behalf with the ITU by the administrations of the U.S. (under the satellite network name USASAT NGSO-3) and

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[23] *See* 47 C.F.R. § 2.106 nn. G117, US334.

[24] *See* NTIA Office of Spectrum Management, *Federal Spectrum Use Summary, 30 MHz – 3000 GHz*, at 61 (2010), *available at* https://www.ntia.doc.gov/files/ntia/Spectrum_Use_Summary_Master-06212010.pdf.

Norway (under the satellite network name STEAM). Taken together, these U.S. and Norway network filings encompass all the frequencies SpaceX proposes to use in this application.

A.10 ORBITAL DEBRIS MITIGATION

SpaceX's launch and space experience provides 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"). 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 Joint Space Operations Center ("JSpOC"), 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 both NASA and the Air Force Center for Space Situational Awareness in the support of its space-based activities, and will continue to utilize these experiences and relationships as resources while developing the SpaceX System and spacecraft.

SpaceX will largely be using recommendations set forth in both NASA Technical Standard 8719.14A and AIR FORCE INSTRUCTION 91-217, typically choosing the more restrictive of the two and, where deemed applicable, choosing a more restrictive value than either reference due to the scope of the project. SpaceX intends to incorporate the material objectives set forth in this application into the technical specifications established for design and operation of the SpaceX 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. Because this mitigation statement is necessarily forward looking, the process of designing, building, and testing may result in minor changes to the parameters discussed herein. In addition, SpaceX will continue to stay current with the Space Situational Awareness community and technology and, if appropriate, SpaceX will modify this mitigation statement 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.

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. Tanks are 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.

SpaceX will continue to review these aspects of on-orbit operations throughout the spacecraft manufacturing process 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 is designing its spacecraft in a manner that limits the probability of accidental explosion. The key areas reviewed for this purpose will include rupture of propellant tanks and batteries. The basic propulsion design (including a dual wall shielding effect from the bus walls), propulsion subsystem component construction, preflight verification through both proof testing and analysis, and quality standards will be designed to ensure a very low risk of tank failure. A burst disk ensures that sudden failure of propulsion containment cannot overpressure and fragment the spacecraft. During the mission, batteries and various critical areas of 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. Through this process, SpaceX will assess and limit the possibility of accidental explosions during mission operations and assure that all stored energy at the end of the satellite's operation will be removed.

Safe Flight Profiles

SpaceX takes seriously the responsibility of deploying large numbers of satellites into space, and intends to exceed 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 JSpOC 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 safely ascend and descend through constellations and 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.

SpaceX has determined that no other system is currently licensed by the Commission for, is currently operating in, or has submitted a request for coordination to the ITU with respect to the same nominal orbital planes sought by SpaceX. SpaceX determined this after review of the list of licensed systems and systems that are under consideration by the Commission for the orbital planes it has requested. In addition, in order to address non-U.S. licensed systems, SpaceX has reviewed the list of NGSO satellite networks for which a request for coordination has been published by the ITU.

Post-Mission Disposal

Each satellite in the SpaceX System is designed for a useful lifetime of five to seven years. SpaceX intends to dispose of satellites through atmospheric re-entry at end of life. As suggested by the Commission,[25] SpaceX intends to comply with Section 4.6 and 4.7 of NASA Technical Standard 8719.14A with respect to this re-entry process. In particular, SpaceX anticipates that its satellites will reenter the Earth's atmosphere within approximately one year after completion of their mission – much sooner than the international standard of 25 years. After the mission is complete, the spacecraft (regardless of operational altitude) will be moved to a 1,075 km circular orbit in its operational inclination, then gradually lower perigee until the propellant is exhausted, achieving a perigee of at most 300 km. After all propellant is

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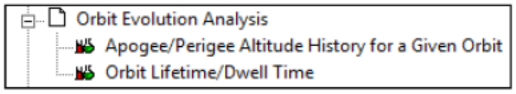
[25] *Mitigation of Orbital Debris*, 19 FCC Rcd. 11567, ¶ 88 (2004).

consumed, the spacecraft will be reoriented to maximize the vehicle's total cross-sectional area, a configuration also stable in the direction of aerodynamic drag. Finally, the spacecraft will begin to passivate itself by de-spinning reaction wheels and drawing batteries down to a safe level and powering down. Over the following months, the denser atmosphere will gradually lower the satellite's perigee until its eventual atmospheric demise.

SpaceX has conducted an assessment using NASA's Debris Assessment Software ("DAS"). That analysis indicates a total spacecraft Risk of Human Casualty rate of between 1:18,200 and 1:31,200 depending upon operational altitude – satisfying the requirement of 1:10,000 established by NASA. This analysis will be conducted regularly throughout the spacecraft design life cycle to ensure continued compliance. The results of the analysis done to date are included on the following pages.

Re-Entry Timeline Estimates / Orbit Dwell Time

NASA's DAS provides tools to estimate spacecraft post-mission dwell time prior to atmospheric re-entry:



The solar cycle has a dynamic influence on the duration to demise of a spacecraft due to atmospheric reentry. During solar-max, the atmosphere swells up, making re-entry occur much more rapidly than during periods of solar-min. Figure A.10-1 shows a nominal re-entry time estimate using DAS across the foreseeable future. Periods of solar-min become evident at 2019/2029, while a favorable period of solar-max is anticipated around 2022-24.

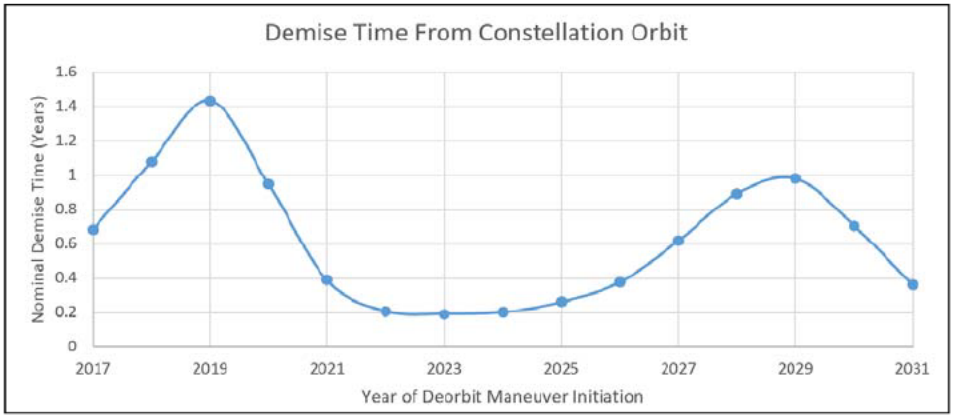
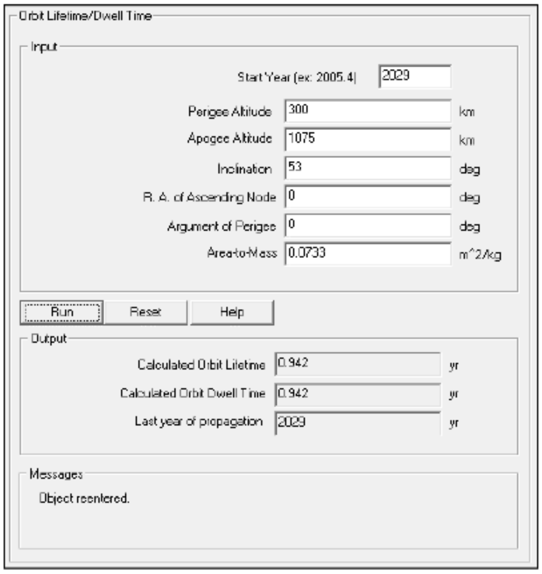


Figure A.10-1. Demise Time from Constellation Orbit

SpaceX satellites have a designed expected lifespan of between 5 and 7 years. Those satellites launched in 2019 that reach the end of life in 2024 will have a favorable de-orbit duration due to coincidence with solar-max. However, in the interest of margin, the de-orbit estimates provided below are calculated for 2029, corresponding to a local maximum for the following solar-min period. Because satellites are anticipated to reach end-of-life prior to 2029, satellite de-orbit performance is anticipated to exceed these reported values. Throughout the deorbit phase, the satellite area to mass ratio is 0.0733 m^2/kg and is used in the following DAS input.



Start Year (ex: 2005.4) 2029

Perigee Altitude 300 km

Apogee Altitude 1075 km

Inclination 53 deg

R. A. of Ascending Node 0 deg

Argument of Perigee 0 deg

Area-to-Mass 0.0733 m^2/kg

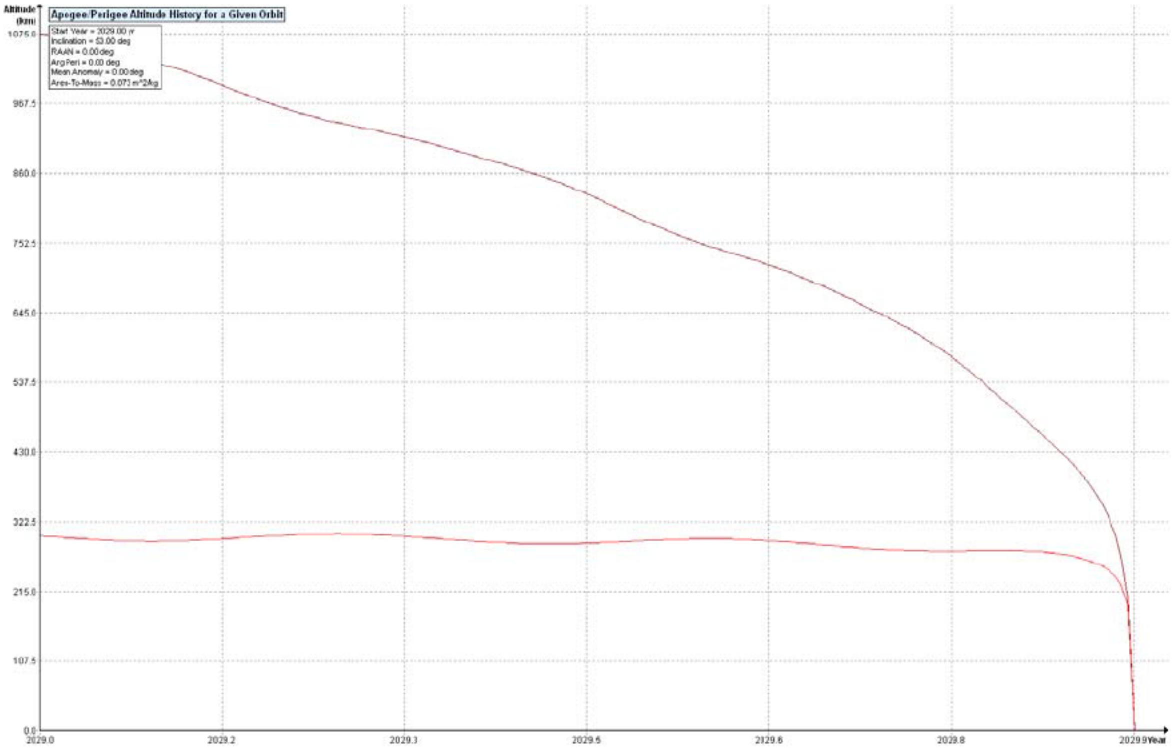
Calculated Orbit Lifetime 0.942 yr

Calculated Orbit Dwell Time 0.942 yr

Last year of propagation 2029 yr

Object reentered.

53 Degree Inclination DAS Input



Start Year = 2029.00 yr
Inclination = 53.00 deg
RAAN = 0.00 deg
Arg Peri = 0.00 deg
Mean Anomaly = 0.00 deg
Area-To-Mass = 0.073 m^2/kg

53 Degree Inclination DAS Output

Start Year (ex: 2005.4) 2029

Perigee Altitude 300 km

Apogee Altitude 1075 km

Inclination 53.78 deg

R. A. of Ascending Node 0 deg

Argument of Perigee 0 deg

Area-to-Mass 0.0733 m^2/kg

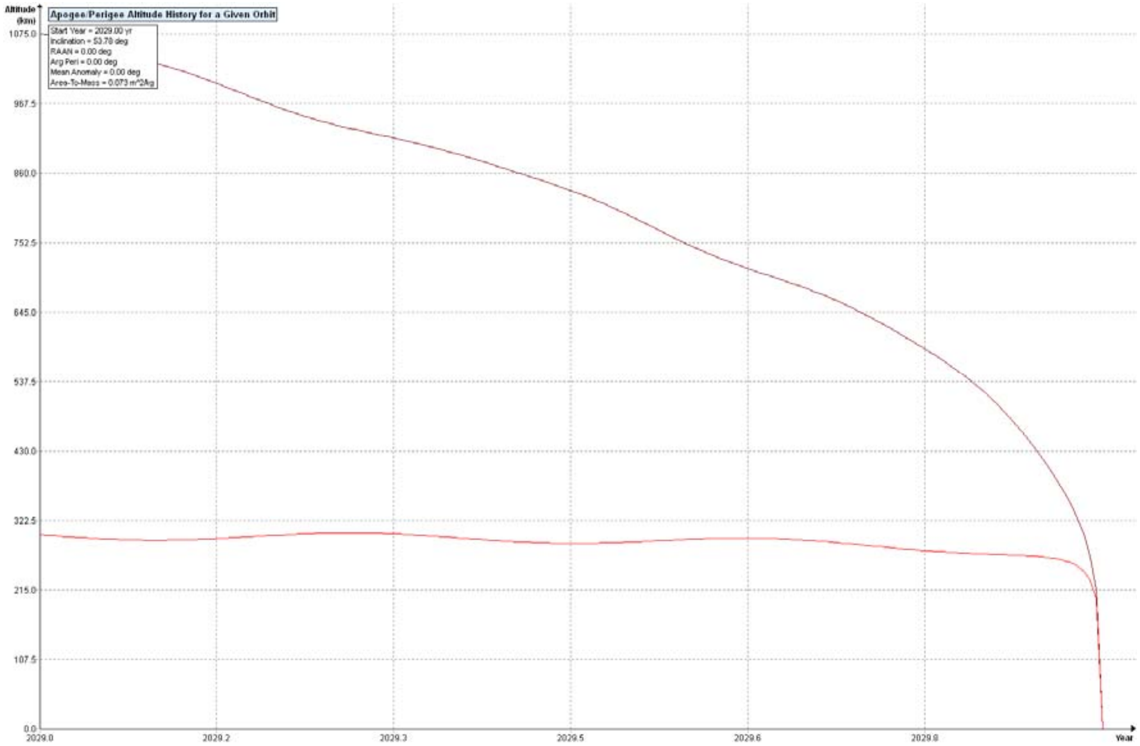
Calculated Orbit Lifetime 0.936 yr

Calculated Orbit Dwell Time 0.936 yr

Last year of propagation 2029 yr

Object reentered.

53.8 Degree Inclination DAS Input



53.8 Degree Inclination DAS Output

Start Year (ex: 2005.4) 2029

Perigee Altitude 300 km

Apogee Altitude 1075 km

Inclination 70 deg

R. A. of Ascending Node 0 deg

Argument of Perigee 0 deg

Area-to-Mass 0.0733 m^2/kg

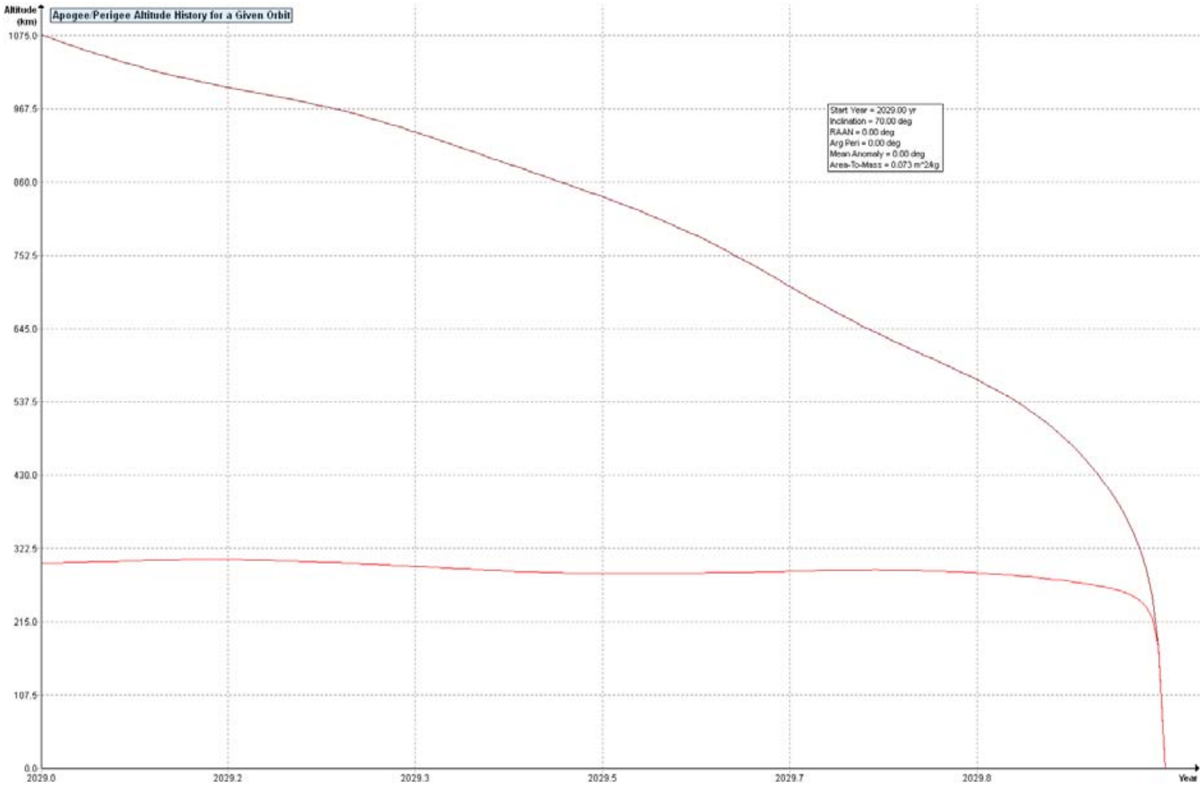
Calculated Orbit Lifetime 0.991 yr

Calculated Orbit Dwell Time 0.991 yr

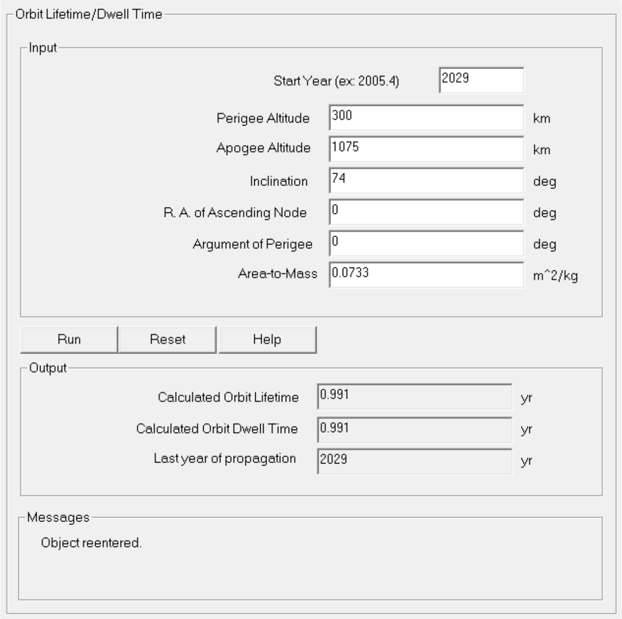
Last year of propagation 2029 yr

Object reentered.

70 Degree Inclination DAS Input



70 Degree Inclination DAS Output



Start Year (ex: 2005.4) 2029

Perigee Altitude 300 km

Apogee Altitude 1075 km

Inclination 74 deg

R. A. of Ascending Node 0 deg

Argument of Perigee 0 deg

Area-to-Mass 0.0733 m^2/kg

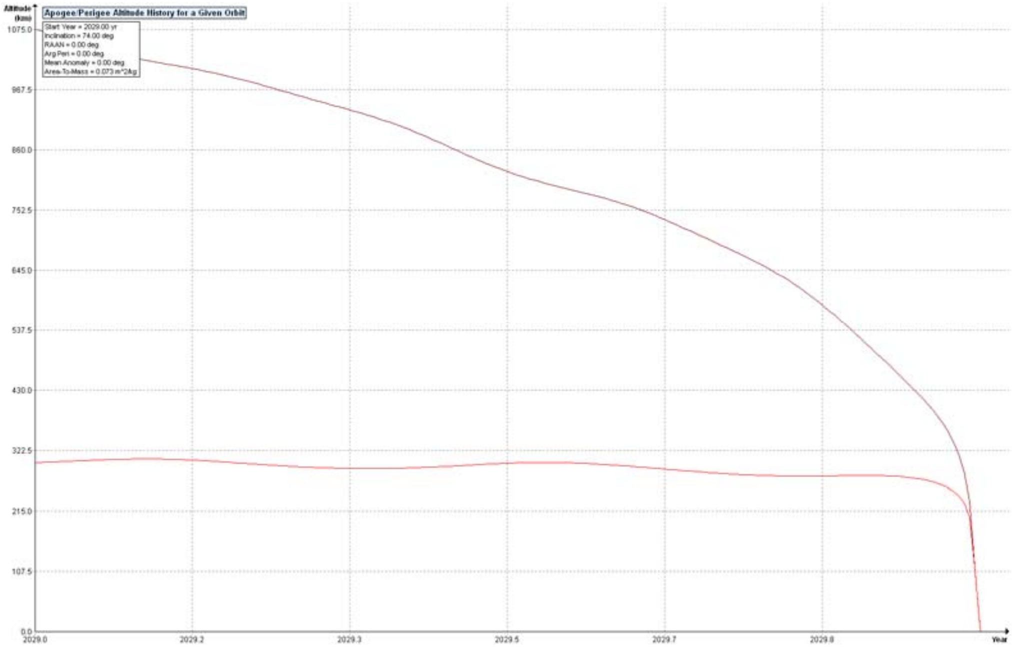
Calculated Orbit Lifetime 0.991 yr

Calculated Orbit Dwell Time 0.991 yr

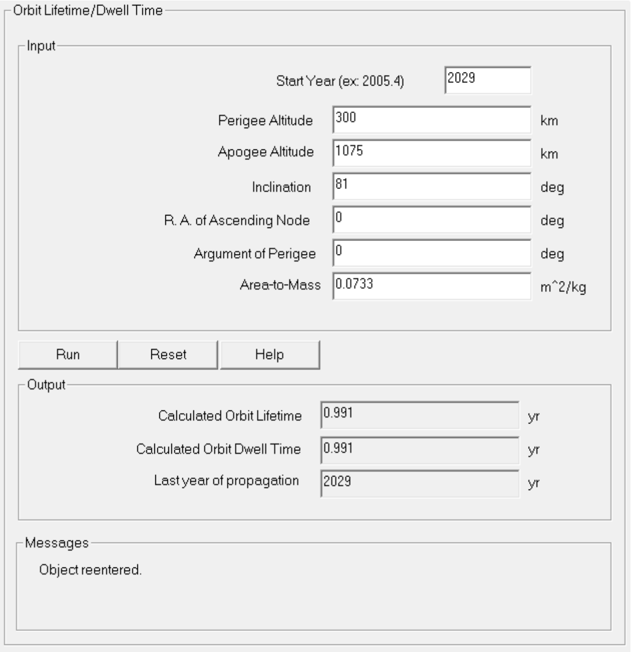
Last year of propagation 2029 yr

Object reentered.

74 Degree Inclination DAS Input



74 Degree Inclination DAS Output



Orbit Lifetime/Dwell Time

Input

Start Year (ex: 2005.4) 2029

Perigee Altitude 300 km

Apogee Altitude 1075 km

Inclination 81 deg

R. A. of Ascending Node 0 deg

Argument of Perigee 0 deg

Area-to-Mass 0.0733 m^2/kg

Output

Calculated Orbit Lifetime 0.991 yr

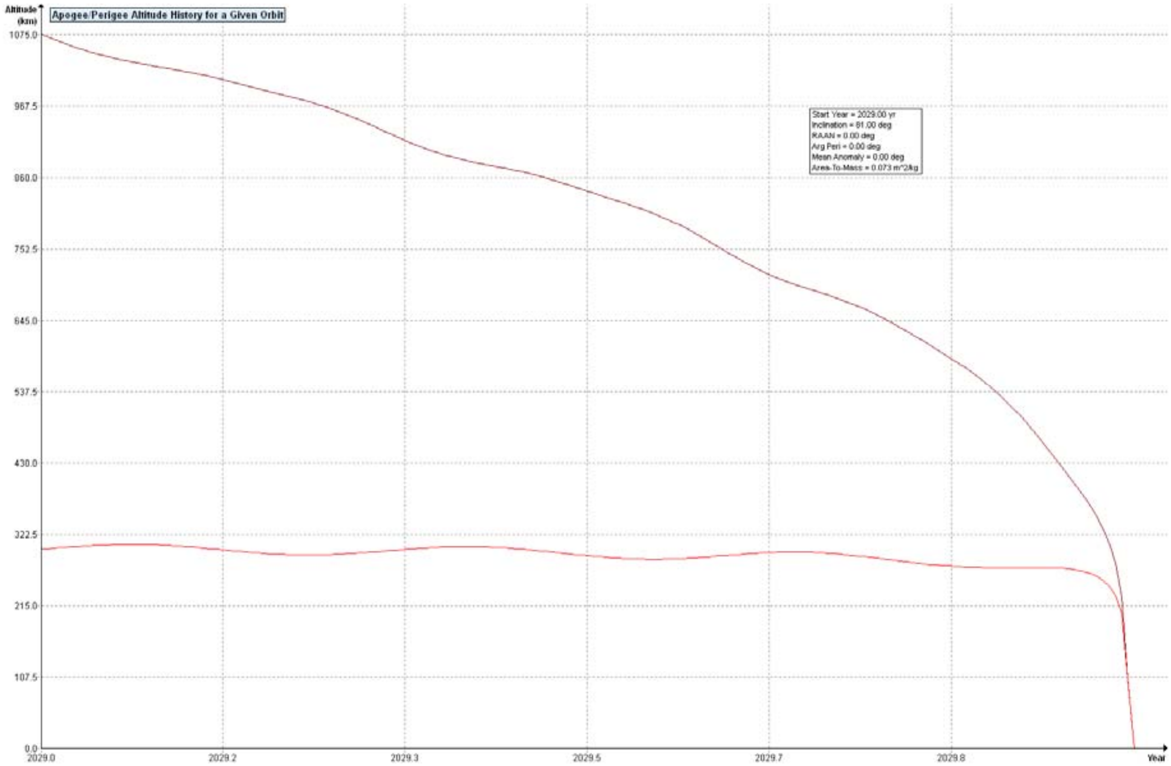
Calculated Orbit Dwell Time 0.991 yr

Last year of propagation 2029 yr

Messages

Object reentered.

81 Degree Inclination DAS Input



81 Degree Inclination DAS Output

Re-entry timelines are also provided for several disposal perigees in proximity of the target. 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 push their perigee even lower than 300 km. Nonetheless, satellites would hold some fuel in reserve for conjunction avoidance during the active de-orbit phase.[26] Re-entry estimates for the year 2029 are set forth in the tables below.

53 Degree Inclination

Disposal Perigee	Time to Re-entry
200 km	22 days
250 km	100 days
> 300 km <	344 days
350 km	2.0 years
400 km	2.9 years

53.8 Degree Inclination

Disposal Perigee	Time to Re-entry
200 km	22 days
250 km	98 days
> 300 km <	342 days
350 km	2.0 years
400 km	2.9 years

70 Degree Inclination

Disposal Perigee	Time to Re-entry
200 km	24 days
250 km	118 days
> 300 km <	1.0 year
350 km	2.1 years
400 km	2.9 years

74 Degree Inclination

Disposal Perigee	Time to Re-entry
200 km	26 days
250 km	112 days
> 300 km <	1.0 year
350 km	2.1 years
400 km	2.9 years

81 Degree Inclination

Disposal Perigee	Time to Re-entry
200 km	28 days
250 km	110 days
> 300 km <	1.0 year
350 km	2.1 years
400 km	2.9 years

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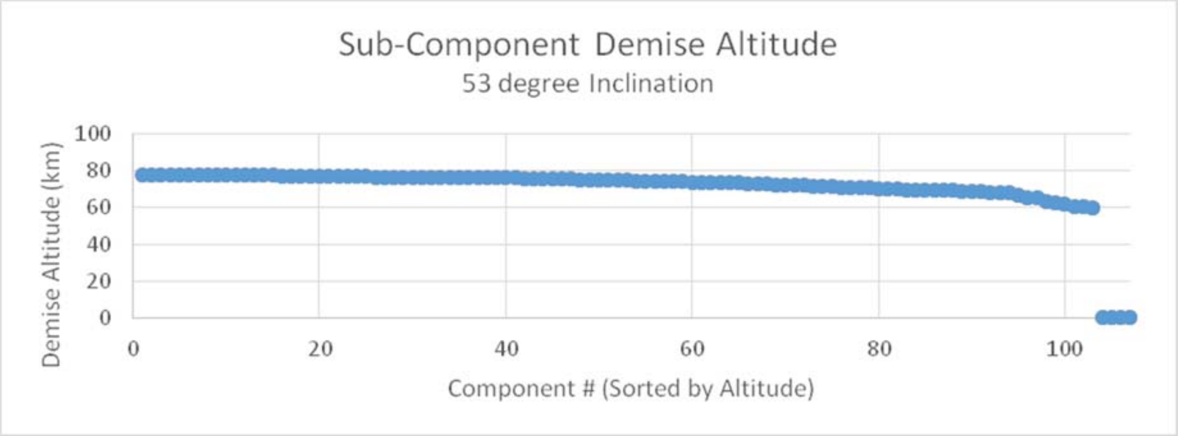
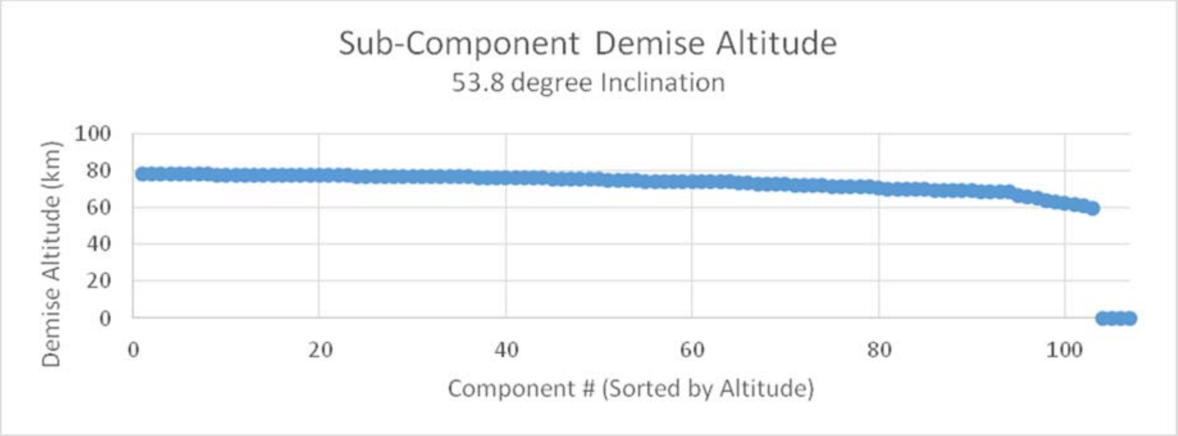
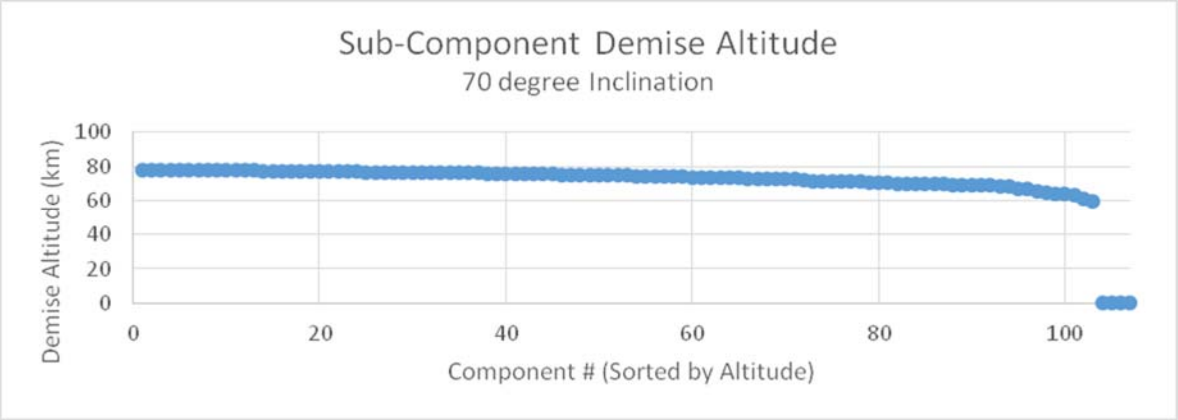
[26] SpaceX will reserve approximately 245 m/s of delta-V – a measure of the impulse required for a given maneuver or, here, the capability to perform those maneuvers if necessary – to deliver the described de-orbit functionality. A spacecraft's ability to perform a given maneuver is determined not just by the mass or volume of propellant available, but also factors specific to the propellant tank and propellant lines (such as propellant leakage), the exact efficiency of the propulsion system, and even the mass of the spacecraft itself, all of which the delta-V measurement takes into account. These additional factors also remain subject to additional testing and design improvements meaning that, while SpaceX's reserved delta-V value will remain constant, mass of available propellant reserves may vary as the spacecraft design is finalized.

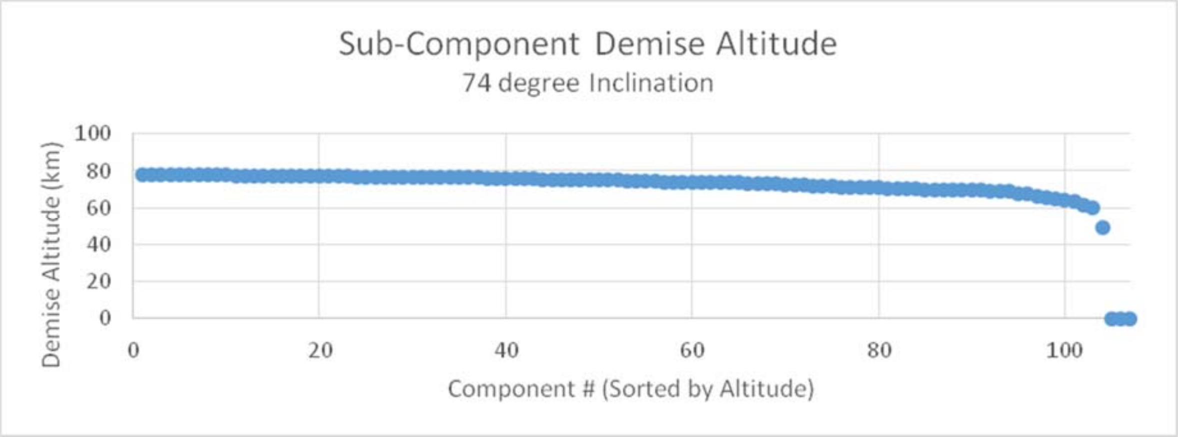
Atmospheric Demise

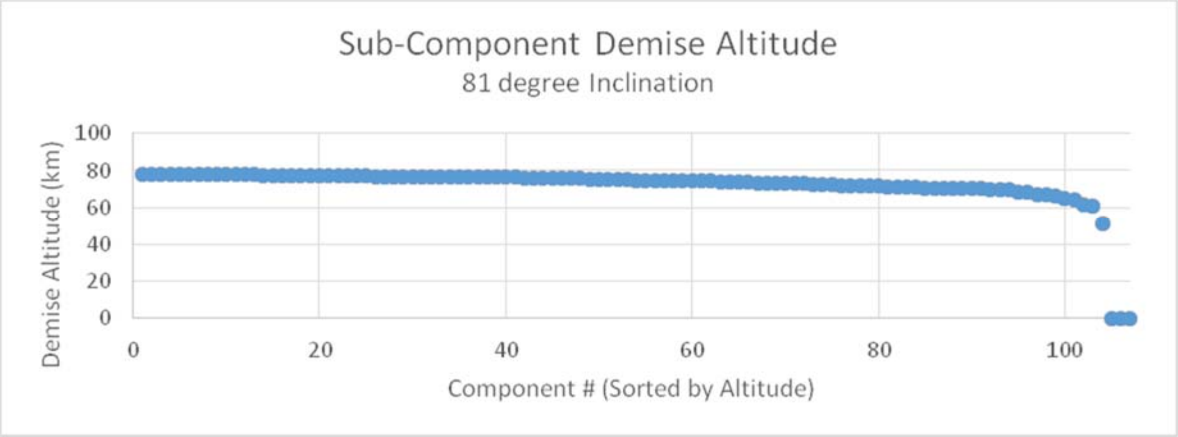
The spacecraft's small mass and predominantly aluminum construction make atmospheric demise a likely scenario upon re-entry. To verify this, SpaceX also utilized NASA's DAS. The satellite was broken down into approximately 100 major components, each defined with its own shape, material, mass and dimensions. Components were modeled in a nested fashion; a child component would not be exposed to the environment until its parent burned up. This enabled conservative re-entry survivability analysis of common problematic components, such as spherical fuel tanks contained within an enclosed spacecraft bus. DAS models the release of all root components 79 km above the surface; the demise altitudes of all modeled components at all inclinations is shown in the following figures:











Several objects were identified as components of interest. This reflected objects that had a distinct mass, quantity, or shape factor that made them of particular concern during re-entry analysis. Those components and their corresponding demise altitudes are provided in the tables below:

53 Degree Inclination

Component	Demise (km)
First Bus Panel	76.6
Reaction Wheels	74.4
Batteries	70.9
Propellant Tank	70.9
Last Bus Panel	70.3

53.8 Degree Inclination

Component	Demise (km)
First Bus Panel	76.6
Reaction Wheels	74.4
Batteries	71.0
Propellant Tank	70.9
Last Bus Panel	70.3

70 Degree Inclination

Component	Demise (km)
First Bus Panel	76.4
Reaction Wheels	74.2
Batteries	71.3
Propellant Tank	70.8
Last Bus Panel	70.3

74 Degree Inclination

Component	Demise (km)
First Bus Panel	76.4
Reaction Wheels	74.2
Batteries	71.6
Propellant Tank	71.0
Last Bus Panel	70.7

81 Degree Inclination

Component	Demise (km)
First Bus Panel	76.7
Reaction Wheels	74.6
Batteries	72.1
Propellant Tank	71.7
Last Bus Panel	71.3

Although a major effort was made to avoid the use of components resistant to disintegration, some scenarios were unavoidable. DAS analysis indicates that four components may have a chance of reaching the Earth's surface; these components are listed in the tables below. Of the four, only two contribute substantially to the total Debris Casualty Area ("DCA") calculation.[27]

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[27] The debris casualty area is a function of the dimensions of an average person and of the specific debris fragment. The model does not consider more complicated aspects, such as sheltering within structures. The total casualty area is the sum of the casualty areas of all surviving debris fragments that reach the ground with kinetic energy greater than 15 joules.

53 Degree Inclination

Component	Qty.	Material	Mass (kg)	Total DCA (m^2)	Energy (J)
Thruster Internals	1	Iron	1.66	0.47	2733
Comms. Component	5	Silicon Carbide	1.50	2.79	961
Rotor Bearing	5	Stainless Steel	0.07	2.45	8
Strut Fitting	12	Titanium	0.03	4.92	6

53.8 Degree Inclination

Component	Qty.	Material	Mass (kg)	Total DCA (m^2)	Energy (J)
Thruster Internals	1	Iron	1.66	0.47	2733
Comms. Component	5	Silicon Carbide	1.50	2.79	961
Rotor Bearing	5	Stainless Steel	0.07	2.45	8
Strut Fitting	12	Titanium	0.03	4.92	6

70 Degree Inclination

Component	Qty.	Material	Mass (kg)	Total DCA (m^2)	Energy (J)
Thruster Internals	1	Iron	1.66	0.47	2733
Comms. Component	5	Silicon Carbide	1.50	2.79	961
Rotor Bearing	5	Stainless Steel	0.07	2.45	8
Strut Fitting	12	Titanium	0.03	4.92	6

74 Degree Inclination

Component	Qty.	Material	Mass (kg)	Total DCA (m^2)	Energy (J)
Comms. Component	5	Silicon Carbide	1.50	2.79	961
Rotor Bearing	5	Stainless Steel	0.07	2.45	8
Strut Fitting	12	Titanium	0.03	4.92	6

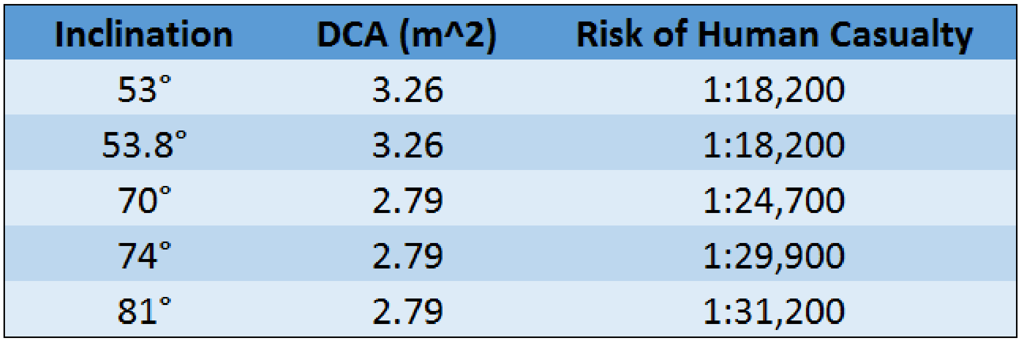
81 Degree Inclination

Component	Qty.	Material	Mass (kg)	Total DCA (m^2)	Energy (J)
Comms. Component	5	Silicon Carbide	1.50	2.79	961
Rotor Bearing	5	Stainless Steel	0.07	2.45	8
Strut Fitting	12	Titanium	0.03	4.92	6

The DCA model does not consider components characterized by a ground impact energy of less than 15 joules. The two components in the simulation that fall into this category are rotor bearings and strut fittings. The former may survive re-entry due to being nested in a larger sub-assembly, while the latter may survive because they are made of titanium. These components are 70 and 30 grams respectively, causing their impact at terminal velocity to remain benign.

Two other components with a chance of re-entry survivability are iron thruster internals and a set of silicon carbide communications components. While the majority of the thruster is expected to burn up in the atmosphere, the nested nature of the assembly leaves a chance of survivability for internal components. Fortunately, the DCA of these components is relatively small at 0.47 m^2. At higher inclinations, DAS indicates the thruster internals are no longer a risk, which is reflected by the disappearance of that row from the tables of 74 and 81 degrees of inclination. The high survivability of the silicon carbide communications components stems from the material properties, primarily its very high melting point of 2,730 °C.

The four components discussed above are the main contributors to the satellite's total DCA, set forth in Table A.10-1 below.



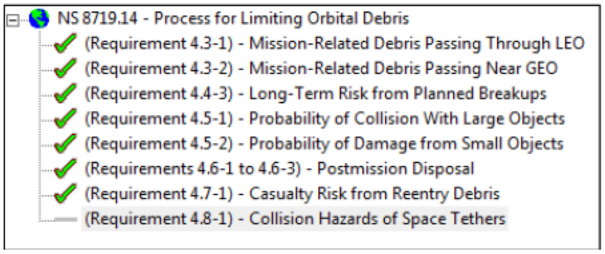
Inclination	DCA (m^2)	Risk of Human Casualty
53°	3.26	1:18,200
53.8°	3.26	1:18,200
70°	2.79	1:24,700
74°	2.79	1:29,900
81°	2.79	1:31,200

Table A.10-1. Summary of Human Casualty Risk Assessment

Yet even with these components, the total spacecraft Risk of Human Casualty is no more than 1:18,200, satisfying the requirement of 1:10,000 established by NASA.

DAS Accordance

As shown in the screen shot below, the DAS assessment concludes that SpaceX's anticipated de-orbit plan satisfies all applicable requirements under NASA-STD-8719.14 for each inclination.[28]



NS 8719.14 - Process for Limiting Orbital Debris
- ✓ (Requirement 4.3-1) - Mission-Related Debris Passing Through LEO
- ✓ (Requirement 4.3-2) - Mission-Related Debris Passing Near GEO
- ✓ (Requirement 4.4-3) - Long-Term Risk from Planned Breakups
- ✓ (Requirement 4.5-1) - Probability of Collision With Large Objects
- ✓ (Requirement 4.5-2) - Probability of Damage from Small Objects
- ✓ (Requirements 4.6-1 to 4.6-3) - Postmission Disposal
- ✓ (Requirement 4.7-1) - Casualty Risk from Reentry Debris
- — (Requirement 4.8-1) - Collision Hazards of Space Tethers

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[28] Requirement 4.8-1, related to Collision Hazards of Space Tethers, does not apply to SpaceX's satellites.

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.

July 26, 2017
Date

ANNEX l

Demonstration of EPFD Compliance for Ku-Band Operations

This annex provides a detailed explanation of the equivalent power flux-density ("EPFD") levels produced by the SpaceX System in the 12.75-13.25 GHz band, and how they comply with the single-entry EPFD validation limits defined in Section 25.146(a)(l) and (2). This comprehensive technical showing demonstrates that the SpaceX system will not exceed the validation EPFD limits in this band as specified in Section 25.208(k) for the Earth-to-space direction (EPFD_{up}).[1]

In order for a non-geostationary orbit ("NGSO") satellite system to comply with the EPFD limits for the protection of geostationary orbit ("GSO") satellite networks, it must ensure that there is sufficient angular separation between the transmissions to and from the NGSO satellites relative to the potential victim GSO earth stations and satellites. Accordingly, SpaceX will turn off the user downlink beam on the satellite and uplink beam on the user terminal whenever the angle between the boresight of a GSO earth station (assumed to be collocated with the SpaceX user) and the direction of the SpaceX satellite transmit beam is 22 degrees or less. Because of the number and configuration of satellites in the SpaceX System, there will always be a satellite available to provide service to a user from outside the exclusion zone around the GSO arc with a minimum elevation angle of 40 degrees, and the use of inter-satellite links will ensure continuity of service throughout any interference mitigation activities.

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[1] The EPFD limits for the transmissions to an NGSO satellite system defined in the Commission's rules reflect the limits set forth in No. 22.5D of the ITU Radio Regulations.

In addition, SpaceX will use its advanced phased array antennas to further minimize any potential interference through precision beamforming and by using sidelobe nulling to suppress unwanted signals from both satellites and user terminals in the direction of the GSO arc. The sidelobe nulling will reduce the sidelobe level by an additional 10 dB in a ±2 degree zone around the GSO arc. SpaceX will also carefully coordinate its broadband transmissions in the band to limit overall energy of the system and remain within EPFD restrictions. The combination of these strategies ensures that EPFD levels produced by the SpaceX System comply with the prescribed limits as demonstrated below.

$\mathbf{EPFD_{up}}$ Compliance

This section demonstrates SpaceX's compliance with the single-entry EPFD limits with respect to Ku-band uplinks. For this purpose, SpaceX has used the latest version of the computer program developed by Transfinite Systems ("Transfinite") for determining compliance with the EPFD validation limits. With its application, SpaceX is submitting the input files that will allow the Commission to confirm that the SpaceX System complies with the single-entry validation EPFD limits in the Earth-to-space direction in the 12.75-13.25 GHz band.

The first set of files contains the Ku-band earth station maximum off-axis EIRP masks for the user earth stations anticipated for use in the SpaceX System. These masks have been generated in accordance with the specification stipulated in Recommendation S.1503-2. The EIRP masks define the off-axis EIRP density of the Ku-band transmitting user earth stations as a function of off-axis angle. They were derived using a composite antenna pattern taking into account, for each angle off-boresight, the highest off-axis gain in all directions around that boresight. The masks then assume the off-axis gain is rotationally symmetric around the boresight of the antenna, and therefore represent a worst-case situation. According to Recommendation S.1503-2, they may be constant or variable as a function of the earth station latitude, but the simulations assume the same EIRP mask at all latitudes. A single EIRP mask is created that represents the highest on-axis and off-axis EIRP density levels (per 40 kHz) for any of the Ku-band transmitting user terminal earth stations, which does not depend upon earth station latitude, but is inclusive of all conditions of modulation and traffic patterns.

As discussed above, SpaceX will use advanced beam forming antenna technology to suppress sidelobe energy in the direction of the GSO arc. The nulling zone moves around as needed when the user earth station antenna is steered. This achieves an additional 10 dB sidelobe rejection for an area approximately ±2 degrees around the GSO arc. Unfortunately, the software program used for this EPFD analysis does not capture this sidelobe nulling by earth stations used in the SpaceX System. However, as the earth station EIRP mask is only used to calculate the earth station emissions toward the GSO arc, SpaceX has been able to model EIRP beyond the 22 degree GSO arc avoidance angle based on the sidelobe level in the nulling zone.

In addition, SpaceX is submitting a file that contains the orbital parameters and other data concerning the SpaceX System necessary to run the EPFD validation software. The data contained in this file is as follows:

1. The orbital parameters of the SpaceX constellation, consistent with the associated Schedule S submission.

2. The parameter entitled “nbr_sat_td” in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.a). This is defined as the “[m]aximum number of co-frequency tracked non-geostationary satellites receiving simultaneously.” The SpaceX System is designed such that only one satellite provides service to a given location. Accordingly, this parameter is set to 1 for purposes of the EPFD validation analysis.

3. The parameter entitled “density” in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.b). This is defined as the “[a]verage number of associated earth stations transmitting with overlapping frequencies per km^2 in a cell.” The value of this parameter is related directly to the size of the aggregate beam coverage area from each SpaceX satellite, which is a hexagonal cell with a diameter of 45 km, and the maximum number of times an uplink frequency can be spatially re-used within this area. It is conservatively assumed that any uplink frequency will be re-used every other cell. Therefore, the average density will be $1/((45)^2*3*\sqrt{(3)}/4)=0.000380$ earth stations per square kilometer.

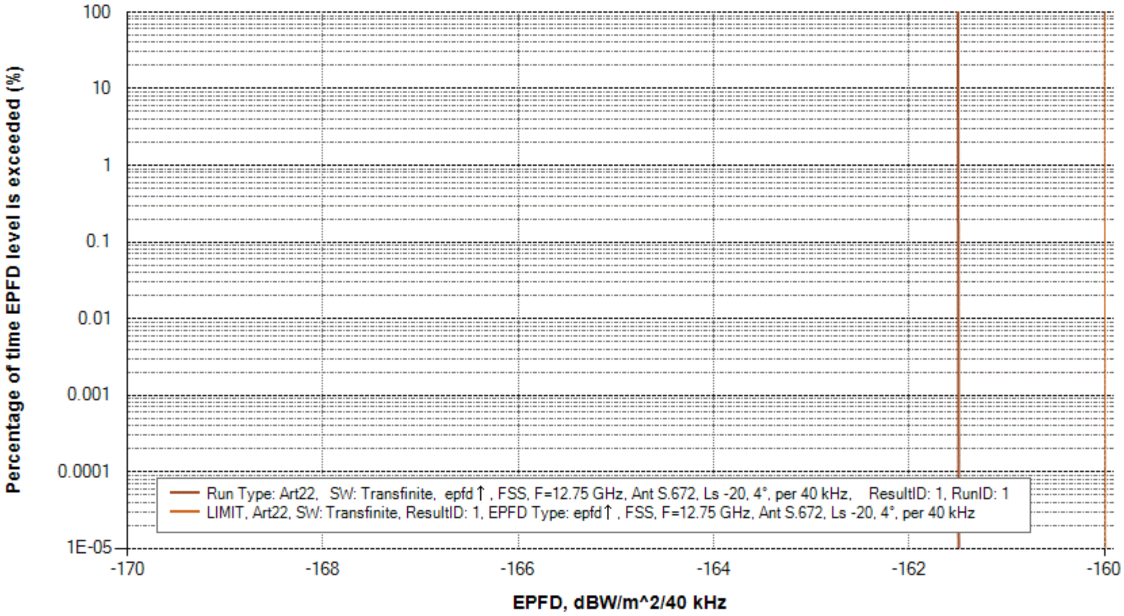
4. The parameter entitled “avg_dist” in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.c). This is defined as the “[a]verage distance between co-frequency cells in kilometres.” The value of this parameter is directly related to the “density” value described above, and is in fact the square root of the inverse of the density value. This gives a value of 51.3 km as the average distance between co-frequency transmitting earth stations.

5. The parameter entitled “elev_min” in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as the “[m]inimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite.” For the SpaceX Ku-band user terminals, this parameter is set to 40°.

6. The parameter entitled “x_zone” in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.d.2). This is defined as the “[w]idth of the exclusion zone in degrees,” and is meant to reflect the minimum GSO avoidance angle measured at the surface of the Earth. For the SpaceX Ku-band user terminals, this parameter is set to 22°.

The Ku-band $EPFD_{up}$ results from Transfinite’s EPFD validation computer program using the input data discussed above are shown below. The labeling of the diagram provides the relevant details for the analysis generated by the software. The resulting

EPFD level is shown by the red curve and the EPFD mask is shown by the orange line.



Other Rules Related to EPFD:

SpaceX will comply at the appropriate time with the requirements of Section 25.146(b) of the Commission’s rules for additional submissions prior to the initiation of service to the public.

SpaceX confirms, consistent with Section 25.146(e), that it is not claiming interference protection from GSO FSS networks operating in accordance with the Commission’s Part 25 rules and the ITU Radio Regulations.

ANNEX 2

Demonstration of EPFD Compliance for Ka-Band Operations

This annex provides a detailed explanation of the equivalent power flux-density ("EPFD") levels produced by the SpaceX System in the 19.7-20.2 GHz and how they comply with applicable single-entry EPFD validation limits. This comprehensive technical showing demonstrates that the SpaceX System will not exceed the single-entry validation EPFD limits in this band as specified in No. 22.5C of the ITU Radio Regulations[1] for the space-to-Earth direction ($EPFD_{down}$). As discussed in Annex 1, SpaceX employs several strategies to reduce EPFD levels of its system. These include a GSO arc avoidance area of ±22 degrees, as well as sophisticated beam forming and sidelobe nulling by the phased array antennas used by the system that achieve an additional 10 dB sidelobe rejection in the area closest to the GSO arc.

$\mathbf{EPFD_{down}}$ Compliance

This section demonstrates SpaceX's compliance with the single-entry EPFD limits with respect to its Ka-band downlinks. As discussed in Annex 1, SpaceX has used the latest version of the Transfinite software to determine compliance with the single-entry EPFD validation limits. With its application, SpaceX is submitting input files that will allow the Commission to confirm that the SpaceX System complies with these limits in the space-to-Earth direction in the 19.7-20.2 GHz band.

The first set of computer files contains the sets of Ka-band power flux-density ("PFD") masks for each space station in the SpaceX System. These masks define the

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[1] There are no EPFD limits for Ka-band in the Commission's Part 25 rules.

maximum satellite downlink PFD in the Ka-band over the surface of the Earth that is visible to the satellite and capture contributions from transmissions using both polarizations (RHCP and LHCP) used for Ka-band gateway links. The PFD masks are expressed as a function of the azimuth ("Az") and elevation ("El") angles as viewed from the satellite towards the Earth relative to nadir.[2]

The PFD masks submitted with this application have been generated in accordance with the specification stipulated in Recommendation S.1503-2, using the following methodology and assumptions related to the actual design and real-world operation of the SpaceX System:

1. We start with the two dimensional (as a function of Az/El) EIRP density mask for a single SpaceX Ka-band satellite gateway transmit beam at the maximum operational transmit EIRP level (for all conditions of modulation and traffic patterns). This will vary for each of the beams on the satellite because of their slightly different pointing directions.

2. The different spatial frequency re-use patterns used within each SpaceX satellite are then taken into account to derive a set of different aggregate EIRP density masks, one for each combination of co-frequency beams that is used. These satellite-aggregate EIRP masks will be different for each re-use pattern because of the relative pointing directions of the different beams.

3. As discussed above, gateway beams are turned off when the separation angle to the GSO arc is 22 degrees or less. In addition, the satellites radiate lower sidelobes toward the GSO arc, within a ±2 degree zone around the GSO arc. These measures are reflected in the EIRP masks.

4. The different EIRP masks are then converted to PFD masks (also as a function of Az/El) by taking account of the spreading loss from the satellite to the surface of the Earth. The resulting PFD masks for each set of satellites are therefore a function of Az/El and sub-satellite latitude.

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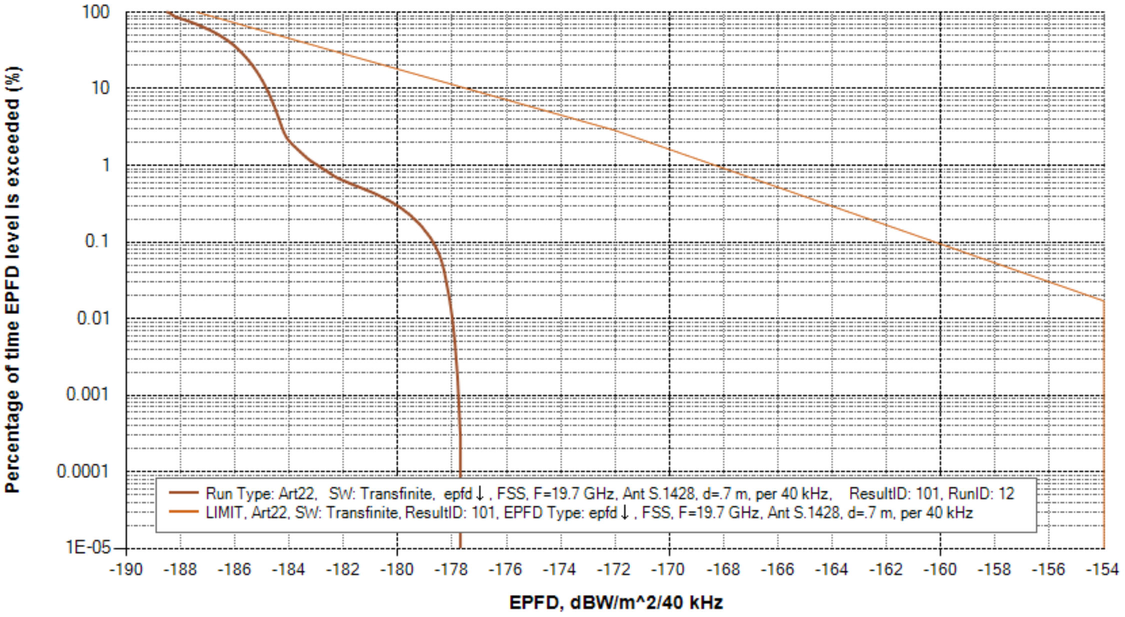
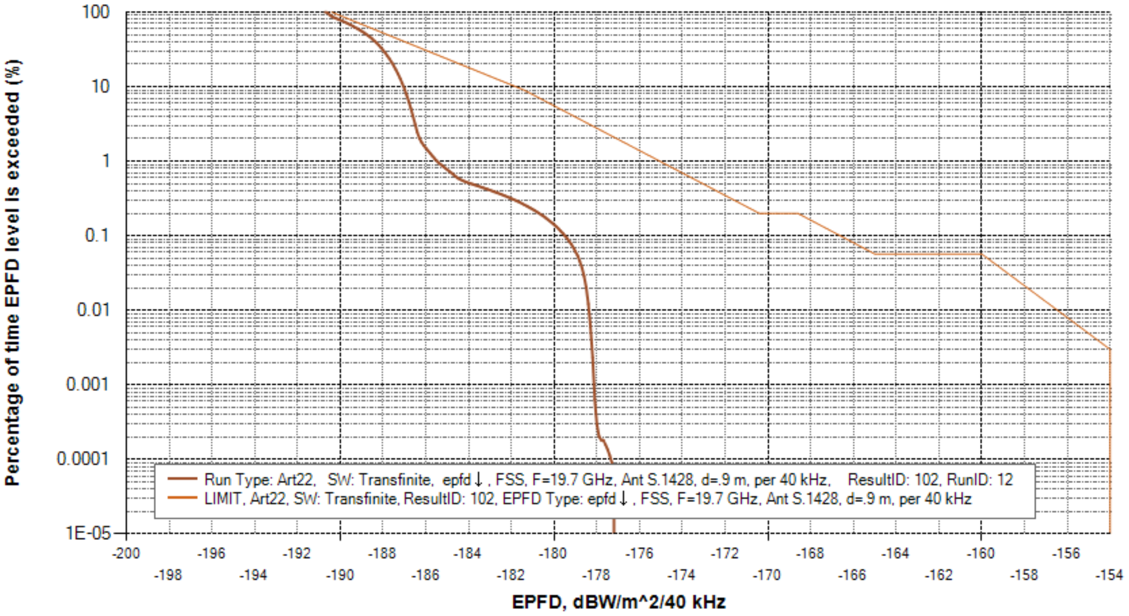
[2] Azimuth is in the East-West direction and elevation is in the North-South direction, as seen at the sub-satellite point.

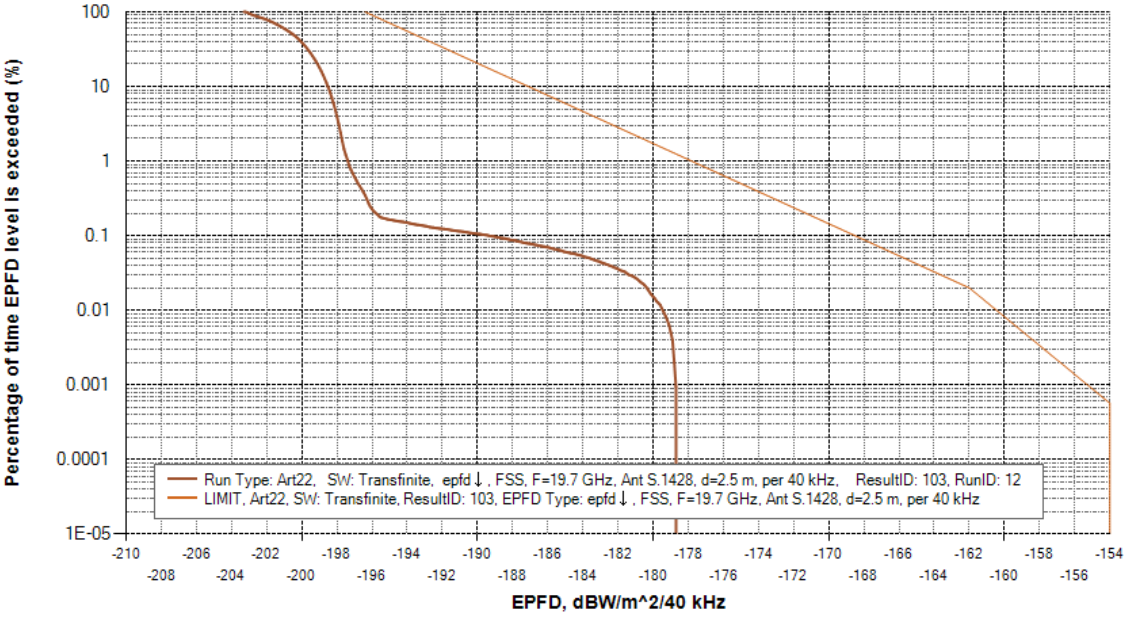
SpaceX is also submitting the input data file needed to run the EPFD analysis to validate the $\text{EPFD}_{\text{down}}$ levels. This file contains the orbital parameters and other data concerning the SpaceX System necessary to run the EPFD validation software. The data contained in this file is as follows:

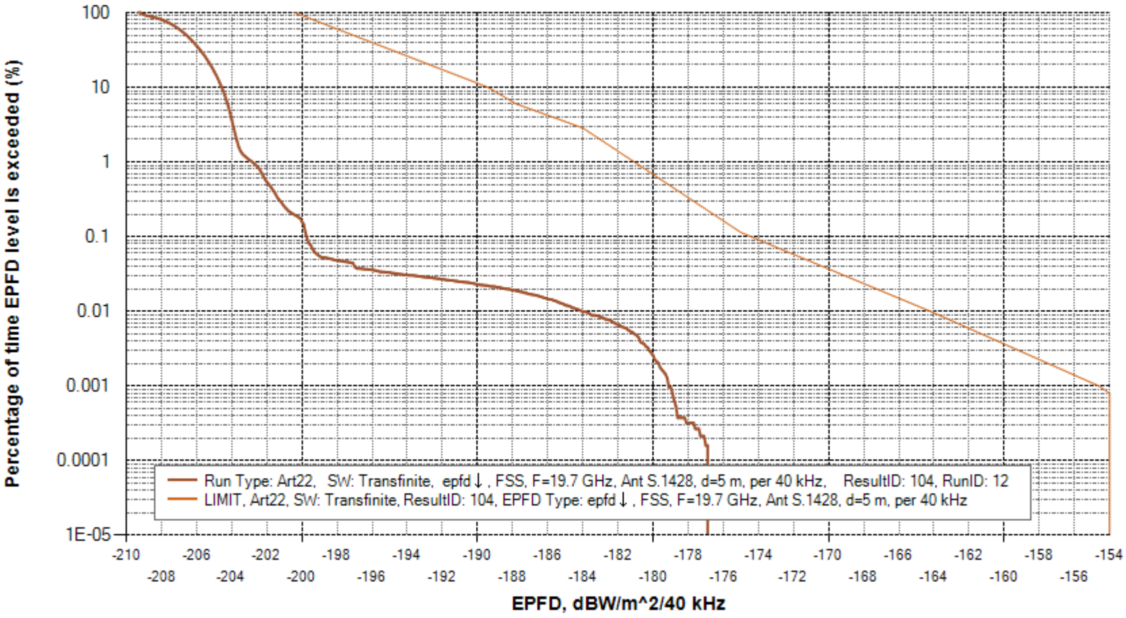
1. The orbital parameters of the SpaceX System, consistent with the associated Schedule S.
2. The parameter entitled "nbr_op_sat" in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.6.a). This is defined as the "[m]aximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location within the latitude range." In this band, SpaceX will ensure that no more than one satellite is supported by a given gateway location at one time. Accordingly, this parameter is set to 1 for purposes of the EPFD validation analysis.
3. The parameter entitled "elev_min" in Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as the "[m]inimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite." This parameter is set to a value of 40° for both uplink and downlink gateway transmissions.

The Ka-band $\text{EPFD}_{\text{down}}$ results from the EPFD validation computer program using the input data described above are shown below. Each plot corresponds to one of the GSO reference earth station antenna sizes from the EPFD limits. The labeling of each diagram provides the relevant details for each analysis generated by the software. The resulting EPFD level is shown by the red curve and the EPFD mask that applies is shown by the orange line.


Percentage of time EPFD level is exceeded (%)
100
10
1
0.1
0.01
0.001
0.0001
1E-05
-190
-188
-186
-184
-182
-180
-178
-176
-174
-172
-170
-168
-166
-164
-162
-160
-158
-156
-154
EPFD, dBW/m^2/40 kHz
Run Type: Art22, SW: Transfinite, epfd↓ , FSS, F=19.7 GHz, Ant S.1428, d=.7 m, per 40 kHz, ResultID: 101, RunID: 12
LIMIT, Art22, SW: Transfinite, ResultID: 101, EPFD Type: epfd↓ , FSS, F=19.7 GHz, Ant S.1428, d=.7 m, per 40 kHz


Percentage of time EPFD level is exceeded (%)
100
10
1
0.1
0.01
0.001
0.0001
1E-05
-200
-198
-196
-194
-192
-190
-188
-186
-184
-182
-180
-178
-176
-174
-172
-170
-168
-166
-164
-162
-160
-158
-156
-154
EPFD, dBW/m^2/40 kHz
Run Type: Art22, SW: Transfinite, epfd↓ , FSS, F=19.7 GHz, Ant S.1428, d=.9 m, per 40 kHz, ResultID: 102, RunID: 12
LIMIT, Art22, SW: Transfinite, ResultID: 102, EPFD Type: epfd↓ , FSS, F=19.7 GHz, Ant S.1428, d=.9 m, per 40 kHz





Other Rules Related to EPFD:

SpaceX confirms that it is not claiming interference protection from GSO FSS networks operating in accordance with the Commission's Part 25 rules and the ITU Radio Regulations.