SPACEX ORBITAL DATA CENTER SYSTEM

ATTACHMENT A
Technical Information to Supplement Schedule S

A. 1 Scope and Purpose

This attachment contains information describing SpaceX's proposed non-geostationary orbit ("NGSO") satellite system (the "SpaceX Orbital Data Center system") and its limited use of spectrum, as required under Part 25 of the Commission's rules.[1] Because portions of the technical information included below cannot be fully captured by the Schedule S software, SpaceX provides this attachment as a supplement.

A. 2 Overall Description

Orbital Parameters

SpaceX's Orbital Data Center system is an NGSO system that will consist of up to one million satellites. To maximize the time during which these satellites can generate solar power and to meet the rapidly evolving global AI compute needs, SpaceX requests authority to distribute these satellites in near-circular shells at altitudes between 500 km and 2,000 km and at 30 degree and sun-synchronous inclinations. SpaceX plans to deploy its satellites at discrete altitudes within narrow orbital shells spanning up to 50 km. SpaceX plans to design and operate different versions of satellite hardware to optimize operations across orbital shells.

Spectrum

SpaceX's system will employ Ka-band spectrum in the 18.8-19.3 GHz (space-to-Earth) and 28.6-29.1 (Earth-to-space) bands, which the Commission designates for NGSO Fixed-Satellite

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[1] 47 C.F.R. § 25.117.

Service ("FSS") operations on a primary basis.[2] SpaceX includes representative radiofrequency parameters in the Schedule S, including a representative 5 MHz transmit channel. The transmission in downlink (space-to-Earth) and reception in uplink (Earth-to-space) will be composed of between 1 and 100 channels.

SpaceX requests that the Commission grant authority for radiofrequency communications from satellites in their authorized shells and during transition phases before and after reaching authorized shells. Specifically, SpaceX seeks authority to conduct backup communications including for conducting telemetry, tracking, and command ("TT&C") in its proposed shells, as well as during orbit-raising and de-orbit maneuvers, as is authorized by rule for geostationary orbit satellite systems[3] and the Commission found in the public interest for SpaceX's Gen1 and Gen2 systems.[4] All operations will be conducted on a non-protected, non-harmful interference basis with respect to co-primary non-federal NGSO FSS spectrum users and with respect to Federal operations subject to footnote US334 of the U.S. Table of Frequency Allocations.

A. 3 Predicted Space Station Antenna Gain Contours

SpaceX proposes to operate Ka-band transmit antennas with minimum gain of 40 dBi and maximum gain of 42.6 dBi at boresight. SpaceX seeks 25-degree minimum elevation for its parabolic Ka-band antennas.

The antenna beam contours provided in the Schedule S include both uplink and downlink

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2 *See id.* § 2.106 n.NG165.

3 *See id.* §§ 25.282, 25.283.

4 *See Space Exploration Holdings, LLC*, Order and Authorization, 37 FCC Rcd. 14882, 14927 ¶ 91 (2022) (Gen2); *Space Exploration Holdings, LLC*, Order and Authorization and Order on Reconsideration, 36 FCC Rcd. 7995, 8034 ¶ 70 (2021) (Gen1).

beams used with parabolic antennas at the highest and lowest gain for operations at 500 km, 1000 km, and 2000 km at 0°, 25°, and maximum slant away from nadir, which are representative of the contours for satellites throughout the proposed operating altitudes and elevation angles. The satellite steers the transmitting beam and adjusts the power to maintain a constant power flux-density ("PFD") at the surface of the Earth (to the extent allowed by applicable PFD limits). Table A.3.1-1 shows the maximum effective isotropic radiated power ("EIRP") density at each representative operating altitude over CONUS.

Altitude [km]	Max EIRP [dBW/Hz] (Transmit beams)	Beams
500	-57.7	Tx1, Tx2, Tx7, Tx8
1000	-51.5	Tx3, Tx4, Tx9, Tx10
2000	-46.7	Tx5, Tx6, Tx11, Tx12

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

A. 4 Compliance with PFD Limits

SpaceX will comply with ITU-R Article 21-4 PFD limits for Ka-band downlink beams in this frequency band, which the Commission has incorporated by reference in Section 25.146(a)(1). Because SpaceX's downlink transmit power remains adjustable on orbit, SpaceX has the ability to manage the PFD levels of the space station during all phases of the mission, as needed.

A. 5 Interference Analysis

SpaceX's system will primarily rely upon optical inter-satellite links, which may connect among or between those satellites and satellites in SpaceX's Gen1 or Gen2 system. To provide additional redundancy, SpaceX's system will include backup Ka-band antennas with the capability to communicate directly with SpaceX's authorized Gen1 and Gen2 Ka-band earth stations.

SpaceX seeks limited authority to conduct these backup operations using Ka-band spectrum the Commission designated for NGSO FSS operations on a primary basis and for which Article 22 equivalent power flux-density ("EPFD") limits do not apply. SpaceX will conduct its limited backup communications and TT&C operations on a non-interference, non-protected basis with respect to co-primary, non-federal NGSO FSS operations. SpaceX will coordinate with NTIA and federal users prior to operations as required by footnote US334 of the U.S. Table of Frequency Allocations.

A. 6 ITU Filings

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

A. 7 Orbital Debris Mitigation

SpaceX provides below its orbital debris mitigation plan for the system in the Commission's recommended format.

Mission Overview and Spacecraft Information	
A statement describing the extent of satellite maneuverability, including whether or not the space station design includes a propulsion system. *§25.114(d)(14)(iv)(A)(4).* Indicate the components required for the propulsion system to operate reliably, including communications with the satellite.	Each satellite will have a robust and redundant propulsion system with enough delta-v to orbit raise to the operational altitude, station-keep, perform collision avoidance maneuvers with conservative thresholds, and complete disposal (either via atmospheric reentry or to Earth or heliocentric disposal orbits). All propulsion components will rely on Starlink heritage for high operational reliability and high reliability in maintaining communications. Furthermore, satellites will be designed with redundant propulsion systems to

	minimize the risk of stranding satellites in operational orbits.
A statement describing the accuracy, if any, with which orbital parameters will be maintained, including apogee, perigee, inclination, and the right ascension of the ascending node(s). If a system is not able to maintain orbital tolerances, *e.g.,* its propulsion system will not be used for orbital maintenance, that fact must be included in the debris mitigation disclosure. Such systems must also indicate the anticipated evolution over time of the orbit of the proposed satellite or satellites. *§ 25.114(d)(14)(iv)(A)(4)*	SpaceX's satellites are capable of maneuvering to ensure appropriate shell spacing and operate in accordance with authorized altitudes and inclinations, as well as orbital tolerances.
A statement addressing the trackability of the space station(s), including whether the smallest dimension of the spacecraft is 10 cm or Space station(s) operating in LEO will be presumed trackable if each individual space station is 10 cm or larger in its smallest dimension, excluding deployable components. *§ 25.114(d)(14)(v)*	SpaceX's satellites will be larger than 10 cm in their smallest dimension and are therefore presumed to be trackable. SpaceX's satellites autonomously estimate their own position using GNSS and other sensors and regularly report that information to accelerate cataloging and enhance active tracking.
A statement describing how the operator plans to identify the space station(s) following deployment and whether space station tracking will be active or passive. Active tracking involves the use of instruments or devices that emit signals or radiation which are detected by sensors on the space station or other tracking systems. Passive tracking relies on detecting naturally occurring emissions or reflections off the surface of the space station or radio signals emitted by the station itself. Operators should also indicate if they plan to use enhanced tracking services and whether the information gathered by such services will be available to other operators. *§ 25.114(d)(14)(v)(A)*	Following deployment, SpaceX identifies its satellites using a network of ground stations. SpaceX certifies that each of its space stations have a unique telemetry marker allowing it to be distinguished from other satellites or space objects. Furthermore, prior to launch, SpaceX assigns each satellite a temporary nine-digit number that is coordinated with USSPACECOM (18 Space Defense Squadron - SDS) and published on Space-Track.org. Within several hours of deployment, SpaceX uploads propagated ephemerides (position and velocity predictions) and covariance (prediction uncertainty) to Space-Track.org for use by USSPACECOM for conjunction

	assessment screening and for identification. Once the satellites are cataloged by USSPACECOM, they transition to using their assigned NORAD catalog identification number.
A statement indicating whether, prior to deployment, the space station(s) will be registered with the 18th Space Control Squadron (http://www.space-track.org/) or successor entity. *§ 25.114(d)(14)(v)(B)*	Prior to deployment, SpaceX registers its satellites with the 18th Space Defense Squadron (or a successor entity).
A statement describing the extent to which the space station operator plans to share information regarding initial deployment, ephemeris, and/or planned maneuvers with the 18th Space Control Squadron or successor entity, other entities that engage in space situational awareness or space traffic management functions, and/or other operators. *§ 25.114(d)(14)(v)(C)*	SpaceX shares contact information with all registered satellite owner/operators on Space-Track.org both for routine and urgent 24/7/365.25 coordination. Furthermore, SpaceX shares propagated ephemerides and covariance, that include planned maneuvers, with 18SDS, other entities and satellite owner/operators on Space-Track.org. SpaceX also shares these ephemerides on Space-Track.org and makes them available publicly via a company website.
Satellite Operations and Collision Risk	
For non-geostationary satellites, a statement identifying the characteristics of the space station(s)' orbits that may present a collision risk, including any planned and/or operational space stations in those orbits. This statement must indicate what steps, if any, have been taken to coordinate with the other spacecraft or system, or what other measures the operator plans to use to avoid collision. *§ 25.114(d)(14)(iv)(A)(2)*. If the space station operator is relying on coordination with another system, the statement must indicate what steps have been taken to contact and ascertain the likelihood of successful coordination of physical operations with the other system. *§ 25.114(d)(14)(iii)*	SpaceX regularly conducts physical coordination with other satellite owner/operators that operate in or near its operational shells and those that also regularly transit through its shells and whose shells SpaceX satellites transits through. In addition, SpaceX works with other launch providers to coordinate when satellites are deployed in or near its operational shells. Where coordination is not possible, SpaceX satellites will take maneuver responsibility to mitigate the risk of conjunctions with probability above its conservative threshold.

For geostationary satellites, assess whether there are any known satellites located at, or reasonably expected to be located at, the requested orbital location, or assigned in the vicinity of that location, such that the station keeping volumes of the respective satellites might overlap or touch. *§ 25.114(d)(14)(iii)*. If relevant, the statement must include the identities of those parties and the measures that will be taken to prevent collisions. *§ 25.114(d)(14)(iv)(B)*	N/A
A certification that upon receipt of a space situational awareness conjunction warning, the operator 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 should 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. *§ 25.114(d)(14)(iv)(A)(5)*	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. SpaceX assesses collision risk and takes appropriate action to mitigate conjunction risks for all conjunctions that meet conservative collision probability and miss distance thresholds. Furthermore, in the rare case that a SpaceX satellite is not able mitigate the risk of a conjunction, SpaceX makes every effort to coordinate with the secondary object owner/operator.
Collisions with Large Objects	
A statement that the space station operator has assessed and limited the probability of the space station becoming a source of debris by collisions with large debris or other operational space stations. *§ 25.114(d)(14)(iii), § 25.114(d)(14)(iv)*	SpaceX takes seriously the responsibility of deploying satellites into space and intends to lead the way in space sustainability, setting a positive example and continuing to evolve best practices for others to follow. 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.
A demonstration that the space station operator has assessed and limited the probability of collision between any space station of the system and other large objects (10 cm or larger in diameter) during the total orbital lifetime of the space station, including any de-orbit phases, to less than 0.001 (1 in 1,000). The probability shall be calculated using the NASA Debris Assessment Software (DAS) or a higher fidelity assessment tool. To obtain DAS, one must request NASA's Debris Assessment Software. Please ensure ample time to receive DAS and that you are using the latest version of DAS. *§ 25.114(d)(14)(iv)(A)(1)*	SpaceX will assess and limit the probability of collision between its satellites and other large objects to ensure it remains below 0.001 during all mission phases.
The collision risk may be assumed zero for a space station during the period of time when the satellite or space station is able to effectively conduct avoidance maneuvers. As a guideline, effective avoidance maneuvers reduce the probability of collision (Pc) by at least 1.5 orders of magnitude from the mitigation threshold (recommended to be 1E-4) while not creating any additional conjunctions with a Pc value above the mitigation threshold. The NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook utilizes this metric and can serve as a useful resource. In individual cases where there is evidence that a particular system or operator is unable to effectively conduct avoidance maneuvers or is only maneuvering at a risk threshold that raises reasonable questions about its ability to meet the 0.001 collision risk threshold, this assumption will not be applied, and further analysis would be	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 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. SpaceX will observe a risk threshold of less than or equal to 0.001% (1e-5) as the trigger for a collision avoidance maneuver, which is an order of magnitude more conservative than industry standards and those suggested in NASA's Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook. All satellites will

necessary. *§ 25.114(d)(14)(iv)(A)(1)*	have sufficient propellant and capability to perform any avoidance maneuvers required for all phases of the mission from deployment to disposal. The collision risk for active satellites in the system may be assumed to be zero, as SpaceX's collision avoidance system mitigates conjunctions with collision probability above a maximum of 1e-5 with mitigation target at 1e-6 or lower.
If there is a planned tether deployment, an assessment of large object collision risk with the tether deployment, the impact on deorbit time, and a statement as to whether the tether can be retracted.	SpaceX's satellite system will not deploy tethers.
Collisions with Small Objects	
A statement that the operator has assessed and limited the probability of the space station becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control that would prevent post mission disposal. A statement about whether this probability for an individual space station is 0.01 (1 in 100) or less, as calculated using the NASA DAS or a higher fidelity assessment tool. *§ 25.114(d)(14)(i), § 25.114(d)(14)(ii)*	SpaceX continues to make every effort to minimize the probability that its satellites will become a source of debris by collisions with small debris or meteoroids. Satellites in the system will exhibit a probability below 0.01 for the requested orbits in this Application as calculated using the NASA DAS or a higher fidelity tool.
Proximity Operations	
Satellites conduct proximity operations when they are intentionally located or maneuvering near another spacecraft or other large objects in space. A statement disclosing planned proximity operations, if any, and addressing debris generation that will or may result from the proposed operations, including any planned release of debris, the risk of accidental explosions, the risk of accidental collision, and measures taken to mitigate	Satellites in SpaceX's system do not conduct proximity operations.

those risks. *§ 25.114(d)(14)(vi)*	
Debris Released and Intentional Breakup	
A statement that the space station operator has assessed and limited the amount of debris released in a planned manner during normal operation. *§ 25.114(d)(14)(i)*	SpaceX has assessed and eliminated any debris from being released during normal operations.
Where applicable, this statement must include an orbital debris mitigation disclosure for any separate deployment devices (such as rings or other deployment vehicles, sometimes referred to as "free-flyers," but not including launch vehicles) used to deploy the spacecraft. *§ 25.114(d)(14)(i)*	SpaceX's system will not use any separate deployment devices.
Explosion Risk and End of Life Passivation	
A statement that the operator has assessed and limited the probability of accidental explosions during and after the completion of mission operations. *§ 25.114(d)(14)(ii), § 25.114(d)(14)(iii)*	SpaceX has designed its satellites 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 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.

This statement must include a demonstration that debris generation will not result from the conversion of energy sources on board the spacecraft into energy that fragments the spacecraft. Energy sources include chemical, pressure, and kinetic energy. *§ 25.114(d)(14)(ii), § 25.114(d)(14)(iii).* The Space Bureau generally will consider as sufficient a statement that the operator has assessed and limited the probability of accidental explosions during mission operations by means of a failure mode verification analysis or similar process.	SpaceX has assessed and limited the probability of accidental explosions during mission operations by means of failure mode analysis confirmed by operating over 10,000 satellites over the course of 7 years with only one low-velocity debris generating event that occurred shortly after deployment.
This statement should address whether stored energy will be removed at the spacecraft's end of life, by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in a permanent discharge state, and removing any remaining source of stored energy, or through other equivalent procedures specifically disclosed in the application. *§ 25.114(d)(14)(ii), § 25.114(d)(14)(iii)*	SpaceX will remove all stored energy when the satellites reach their disposal orbit.
A statement about whether the spacecraft will contain any liquids that if released either intentionally or unintentionally will persist in droplet form. In particular, the operator should identify any ionic liquids. If the operator identifies any such liquids that would not evaporate or sublimate if released, the statement should also address the length of time such liquid would remain in orbit, any natural processes that would result in dispersion of the droplets, how effectively the liquid is contained, and whether the propulsion system is shielded from micrometeoroid and debris strikes that may result in leakage are all relevant considerations and the type of information that could be included as part of this disclosure. *§ 25.114(d)(14)(iii)*	SpaceX's satellites do not contain liquids that if released will persist in droplet form.

Post-Mission Disposal	
A statement detailing the disposal plans for the space station, including the quantity of fuel, if any, that will be reserved for disposal maneuvers. *§ 25.114(d)(14)(iv), § 25.114(d)(14)(vii)*	SpaceX's satellites will retain enough propellant to either lower for atmospheric reentry or raise to a disposal orbit while conducting collision avoidance maneuvers during transit.
For geostationary orbit space stations, the statement must disclose the altitude selected for a disposal orbit and the calculations that are used in deriving the disposal altitude. *§ 25.114(d)(14)(vii)(A)*	N/A
For space stations terminating operations in an orbit in or passing through the low- Earth orbit region below 2,000 km altitude, the statement must disclose whether the spacecraft will be disposed of through atmospheric re-entry, specifying if direct retrieval of the spacecraft will be used. The statement must also disclose the expected time in orbit for the space station following the completion of the mission. *§ 25.114(d)(14)(vii)(B).* Please note whether re-entry of the spacecraft will be completed as soon as practicable, but no later than five years following completion of the mission. *§ 25.114(d)(14)(vii)(D)(1).*	SpaceX plans to use a combination of atmospheric reentry and both Earth and heliocentric disposal orbits. Disposal orbit altitudes have not been selected but will ensure passive decay duration from disposal orbit to 2,000 km is > 200 years, passive decay collision probabilities are < 1e-2 for 100 years and optimized so cohabitation with existing debris or systems elicit low collision probabilities.
For non-GSO satellites and satellites NOT terminating operations in an orbit in or passing through the low-Earth orbit region below 2,000 km altitude, the statement must indicate whether disposal will involve use of a storage orbit or long-term atmospheric re-entry and rationale for the selected disposal plan. *§ 25.114(d)(14)(vii)(C).*	SpaceX satellites will use compliant disposal orbits above 2000 km and potentially beyond Earth orbit in order to (a) reduce overall collision risk because there is not a second transit through the more densely populated regions of LEO (b) minimize any atmospheric impacts resulting from the deorbit of a large number of spacecraft. In addition, SpaceX continues to develop approaches to strategically place decommissioned satellites within disposal orbits to enhance the management of space debris, which could

	create opportunities for future hardware recycling and material harvesting. SpaceX will also pursue the use of heliocentric disposal orbits as a means to further reduce the density of Earth disposal orbits.
For non-GSO satellites, a statement demonstrating that the probability of success of the chosen disposal method will be 0.9 or greater for any individual space station. For space station systems consisting of multiple space stations, the demonstration should include additional information regarding efforts to achieve a higher probability of success, with a goal, for large systems, of a probability of success for any individual space station of 0.99 or better. *§ 25.114(d)(14)(vii)(D)(1).*	SpaceX has demonstrated a greater than 99% planned disposal success probability for its satellites.
If at any time during the space station(s)' mission or de-orbit phase the space station(s) will transit through the orbits used by any inhabitable spacecraft, including the ISS, the statement must describe the design and operational strategies, if any, that will be used to minimize the risk of collision and avoid posing any operational constraints to the inhabitable spacecraft. *§ 25.114(d)(14)(iv)(A)(3)*	SpaceX actively coordinates with both NASA and the Chinese Manned Space Agency when its satellites transit through orbits used by ISS and CSS. SpaceX will continue to coordinate to ensure the safety of inhabited stations and spacecraft that visit inhabited stations.
A disclosure indicating whether the atmospheric re-entry will be an uncontrolled re-entry or a controlled targeted re-entry. *§ 25.114(d)(14)(vii)(D)(2)(i)*	In the unlikely case where a satellite reenters due to early mission failure or atmospheric reentry is used as disposal, SpaceX will attempt controlled reentry, but the fallback will be an uncontrolled re-entry.
Atmospheric Re-Entry Hazard	
If planned disposal is by atmospheric re-entry, the statement must also include:	SpaceX satellites will either be designed such that no components impacting the surface of the Earth will have kinetic

An assessment as to whether portions of any individual spacecraft will survive atmospheric re-entry and impact the surface of the Earth with a kinetic energy in excess of 15 joules, and that the calculated casualty risk for an individual spacecraft using the NASA DAS or a higher fidelity assessment tool is less than 0.0001 (1 in 10,000). § 25.114(d)(14)(vii)(D)(2)(ii). If the estimated human casualty risk is not zero, applicants should address whether design-for-demise approaches as well as other measures like targeted re-entry away from landmasses to further reduce re-entry human casualty risk were considered.	energy > 15 joules or SpaceX will show via NASA DAS or other higher fidelity assessment that the human casualty risk is < 1e-4.