SPACEX 2 GHZ MOBILE-SATELLITE SYSTEM
NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A
TECHNICAL INFORMATION TO SUPPLEMENT SCHEDULE S

A.1 SCOPE AND PURPOSE

This attachment contains the information required for SpaceX's use of the 2000-2020 MHz and 2180-2200 MHz bands (the "2 GHz band") with a non-geostationary orbit ("NGSO") satellite system offering Mobile-Satellite Service ("MSS") required under Part 25 of the Commission's rules that cannot be fully captured by the Schedule S software. The accompanying Schedule S reflects the system as it will operate once modified and fully deployed.

A.2 OVERALL DESCRIPTION

This information is generally available in Attachment A ("Technical Information to Supplement Schedule S") to the previous applications related to SpaceX's first-generation Fixed-Satellite Service constellation (the "Gen1 FSS system").[1] Under the modification proposed herein, SpaceX would add a 2 GHz MSS payload to each satellite in that system.

Orbital Parameters

The SpaceX 2 GHz Mobile-Satellite Service system ("2 GHz MSS") is an NGSO satellite system that will consist of a payload flown on the 4,408 satellites in SpaceX's Gen1 FSS system as set forth below.[2]

---

1 *See* Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, IBFS File No. SAT-LOA-20161115-00118 (Nov. 15, 2016); Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System Supplement, IBFS File No. SAT-LOA-20170726-00110 (July 26, 2017); Application for Modification of Authorization for the SpaceX NGSO Satellite System, IBFS File No. SAT-MOD-20181108-00083 (Nov. 8, 2018); Application for Modification of Authorization for the SpaceX NGSO Satellite System, IBFS File No. SAT-MOD-20200417-00037 (Apr. 17, 2020). These materials are collectively referred to herein as the "Previous Applications."

2 *See Space Exploration Holdings, LLC*, 36 FCC Rcd. 7995 (2021) ("Gen1 FSS Authorization").

SpaceX 2 GHz MSS System					
Orbital Planes	72	72	36	6	4
Satellites per Plane	22	22	20	58	43
Altitude	550 km	540 km	570 km	560 km	560 km
Inclination	53°	53.2°	70°	97.6°	97.6°

Table A.2-1. 2 GHz Mobile-Satellite Service System Orbital Parameters

Operation of the 2 GHz MSS system as a payload on these already-licensed satellites will have no effect on their orbital characteristics, which will remain as described in the Previous Applications and the Gen1 FSS Authorization.

Technology and Operations

The 2 GHz MSS system will utilize advanced phased array beam-forming and digital processing technologies onboard each satellite payload in order to make highly efficient use of spectrum resources and share spectrum flexibly with other space-based and terrestrial-licensed users. The 2 GHz MSS services will be available for residential, commercial, institutional, and governmental users in the U.S.

In making this application, SpaceX seeks to leverage its existing space resources to provide even more ubiquitous connectivity options to Americans with a goal of "global affordable connectivity." This includes the proposed 2 GHz MSS system, which follows SpaceX's expansion into this mobile services arena with its acquisition of Swarm Technologies, Inc. ("Swarm"), a company authorized to deploy and operate 150 small NGSO MSS satellites designed to provide narrowband services in the very-high frequency ("VHF") 137-138 MHz and 148-150.5 MSS bands.[3] Swarm has already launched most of its authorized satellites and is offering services to customers in the agriculture, maritime, energy, environmental, and transportation sectors, among others in need of global satellite connectivity for IoT devices. The combination of the proposed 2 GHz MSS system and the Swarm IoT connectivity solutions will truly encompass all ranges of data rates and power levels for devices around the world.

Spectrum

The frequency plan and satellite downlink parameters are provided in the associated Schedule S. The 2 GHz MSS system satellites will transmit with right-hand circular polarization ("RHCP") and left-hand circular polarization ("LHCP").

As discussed below, SpaceX will operate its 2 GHz MSS system without causing harmful interference to any other service duly licensed in the 2 GHz bands.

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS

All 2 GHz MSS downlink spot beams on each SpaceX satellite are independently steerable. The antenna gain contours for the transmit and receive beams for a representative 2 GHz MSS payload operating at 540 km, 550 km, 560 km, and 570 km are embedded in the associated Schedule S, as required by Section 25.114(c)(4)(vi)(B). Information on TT&C beam contours is available in Attachment A to the Previous Applications.

A.4 TT&C CHARACTERISTICS

SpaceX will use the existing TT&C subsystem on its Gen1 FSS system for communications with the spacecraft during pre-launch, transfer orbit, and on-station operations, as well as during

[3] *See Satellite Policy Branch Information; Actions Taken*, Public Notice, DA 21-1238 (rel. Oct. 1, 2021) (confirming authority for Swarm transfer of control to SpaceX).

spacecraft emergencies, consistent with the Gen1 FSS Authorization. A complete description of the SpaceX TT&C subsystem is provided with the Previous Applications.[4]

A.5 Backhaul Operations

The SpaceX 2 GHz MSS system backhaul will use the gateway links in the Ka-band spectrum already licensed as part of its Gen1 FSS system, generating high-gain steered beams to communicate with multiple satellites within the constellations from a single gateway site. SpaceX also intends to deploy optical inter-satellite links and anticipates that they will provide seamless network management and continuity of service while minimizing the spectrum footprint of the system overall and facilitating spectrum sharing with other space-based and terrestrial systems.

A.6 Geographic Coverage

As required in Sections 25.143(b)(2)(ii) and (iii) of the Commission's rules, at least one SpaceX 2 GHz MSS satellite will be visible above the horizon at an elevation angle of at least 5° for at least 18 hours each day within the geographic area as far north as 70° North latitude and as far south as 55° South latitude. In addition, at least one satellite will be visible above the horizon at an elevation angle of at least 5° at all times within the fifty states, Puerto Rico, and the U.S. Virgin Islands.

A.7 Cessation of Emissions

Each active 2 GHz MSS satellite transmission chain 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.

---

[4] *See, e.g.,* Previous Applications, Sections A3.3, A.5, and Schedule S.

A.8 FREQUENCY TOLERANCE

The carrier frequency of each space station transmitter shall be maintained within 0.002 percent of the reference frequency, as required by Section 25.202(e) of the Commission's rules.

A.9 INTERFERENCE ANALYSES

The Commission has recognized that a proposed modification to an NGSO authorization should be granted where it "does not present any significant interference problems and is otherwise consistent with Commission policies."[5] As discussed in greater detail below, the advanced capabilities of SpaceX's proposed 2 GHz MSS system will enable effective and efficient spectrum sharing with other licensed users of the band.

Interference Protection for Geostationary Satellite Networks

The Terrestar-1 (111° W.L.) and DBSD G1 (92.85° W.L.) GSO satellites are currently authorized by the Commission to provide service in the 2000-2020 and 2180-2200 MHz bands, although there is scant evidence that they are actually providing service to anyone. SpaceX's proposed 2 GHz MSS system will have directional, electronically steerable beams that allow it to co-exist with other systems without causing harmful interference. SpaceX's proposed 2 GHz MSS system will use interference mitigation methods such as a GSO avoidance angle and cognitive radio techniques to determine whether any active user antennas communicating with Terrestar-1 or DBSD G1 are present in a local region before transmitting.

Large, directional antennas at fixed locations used as gateways by Terrestar-1 and DBSD G1 can be protected by the SpaceX 2 GHz MSS satellite system through simple GSO avoidance angle techniques. Such gateways will comply with the radiation pattern described in Section

---

[5] *Gen1 FSS Authorization* ¶ *8 (quoting Teledesic LLC*, 14 FCC Rcd. 2261, ¶ 5 (IB 1999)).

25.209 of the Commission's rules, which limits off-axis sidelobe levels and thereby promotes co-existence.[6] By operating so that its 2 GHz MSS system does not transmit when satellites and earth stations are aligned in the direction of Terrestar-1 or DBSD G1, SpaceX will ensure that its operations will not interfere with the Terrestar-1 and DBSD G1 satellites.

To protect small, low-gain blanket licensed mobile user antennas, SpaceX intends to use cognitive radio techniques to detect the presence of any active MSS user antennas within its localized spot beam. This would occur both before commencing and during the course of its communications. The SpaceX 2 GHz MSS satellite receive beam will have a G/T that is more than sufficient to detect any omni-directional user transmissions which are detectable by the Terrestar-1 and DBSD G1 satellites. The Terrestar-1 and DBSD G1 satellites have a maximum G/T of 21.8 and 18.0 dB/K respectively, as reported in the Schedule S for their respective systems.[7] The difference in path loss between the SpaceX 2 GHz MSS altitude of 540-570 km and the Terrestar-1 and DBSD G1 geostationary orbit is 30 dB or greater. As described in the Schedule S, the SpaceX 2 GHz MSS satellite receive antenna will easily exceed the equivalent G/T of -8.2 dB/K needed to match the sensitivity of Terrestar-1 after adjusting for path loss (max G/T of 21.8 dB/K minus 30dB).

Interference with Respect to Other Non-Geostationary Satellite Systems

The ITU has procedures for coordination amongst NGSO systems.[8] 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

---

6 *See* 47 C.F.R. § 25.209 (establishing earth station antenna performance standards for FSS and feeder links for satellite services other than FSS).

7 Terrestar-1 Schedule S: https://licensing fcc.gov/myibfs/download.do?attachment_key=570360; DBSD G1 Schedule S: https://licensing fcc.gov/myibfs/download.do?attachment_key=593660.

8 *See* ITU Radio Regs., Ch. 2, Art. 9.12.

agreements.

Interference With Respect to Terrestrial Systems

In 2012, the Commission adopted rules for a flexible use terrestrial service in the 2 GHz band called AWS-4.[9] In doing so, however, the Commission also made clear that creation of the AWS-4 service was not meant to transform the 2 GHz band into primarily terrestrial spectrum.[10] To the contrary, under Section 27.1136, an AWS-4 terrestrial licensee must accept any interference received from duly authorized 2 GHz MSS operations and must protect MSS operations in the band from harmful interference.[11] Accordingly, 2 GHz MSS operators are under no obligation to protect AWS-4 operations. Nonetheless, SpaceX intends to engage in good faith efforts to develop coordination strategies so that all parties can make intensive and productive use of the band.

A.10 COORDINATION WITH U.S. GOVERNMENT NETWORKS

To the extent necessary, SpaceX will coordinate with the National Telecommunications and Information Administration ("NTIA") to protect any operations in this band from harmful interference and to ensure that they are compatible with federal uses. The U.S. Table of Frequency Allocations lists no federal allocations in the 2000-2020 and 2180-2200 MHz bands.

A.11 ITU FILINGS FOR SPACEX

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

---

9 *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands*, 27 FCC Rcd. 16102 (2012).

10 *See, e.g., id.* ¶ 180 ("nothing we do today eliminates the existing mobile satellite allocation for the 2 GHz MSS band or limits the licensees' continued satellite use rights for this spectrum" (footnote omitted)).

11 *See* 47 C.F.R. § 27.1136.

A.12 ORBITAL DEBRIS MITIGATION

An overview of orbital debris mitigation information is available in Attachment A to the Previous Applications. Because the 2 GHz MSS payloads will share the Gen1 FSS spacecraft without materially affecting the orbital debris characteristics of those spacecraft, the proposed modification will not require any supplement to or adjustment of the previously approved orbital debris mitigation showing.

SpaceX takes seriously the responsibility of deploying large numbers of satellites into space and intends to exceed industry best practices to ensure the safety of space. Through detailed and conscientious mission planning, SpaceX has carefully assessed and limited the probability of its Gen1 FSS system becoming a source of debris by collisions with large debris or other operational space stations. It will maintain the accuracy of its orbital parameters at a level that will allow operations with sufficient spacing to minimize the risk of conjunction with adjacent satellites in the constellation and other constellations. SpaceX has and will continue to work closely with the 18th Space Defense Squadron and other relevant agencies to ensure the service provided for conjunction assessment to SpaceX and all operators is robust, reliable, and secure. The propulsion system onboard can respond quickly and at high cadence, allowing SpaceX to coordinate in advance and respond to conjunction risks, whether with debris or other active spacecraft. SpaceX is willing to engage with any operators of nearby constellations to ensure safe and coordinated space operations.

Maneuverability

SpaceX confirms that it intends to perform collision avoidance procedures, including conjunction assessment, execution of avoidance maneuvers, trajectory planning and conjunction assessment for any planned alteration of satellite trajectory, and notification to other potentially affected operators of any planned alteration of a satellite's trajectory. SpaceX will perform conjunction screening and avoidance maneuvers for all phases of operations, including any planned alteration of satellite trajectory, prior to passive disposal. For this purpose, SpaceX will observe a risk threshold of 0.001% as the trigger for a collision avoidance maneuver, which is significantly stricter than industry standards. All satellites will have sufficient propellant and capability to perform any avoidance maneuvers required for all phases of the satellites' mission.[12]

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

Satellite Tracking

Prior to deployment, SpaceX will register its satellites with the 18th Space Defense Squadron (or a successor entity). Following deployment, SpaceX will identify its satellites using a network of ground stations located around the world that will establish contact with the satellites. SpaceX certifies that each of its space stations will have a unique telemetry marker allowing it to be distinguished from other satellites or space objects. Because SpaceX satellites will be larger than 10 cm in their smallest dimension, they are presumed to be trackable.[13] Nonetheless, SpaceX satellites autonomously estimate their own position using GPS and other sensors and regularly

---

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

[13] *See Orbital Debris Mitigation Update Order*, ¶ 58.

report that information to enhance active tracking. SpaceX plans to share information regarding initial deployment, ephemeris, and planned maneuvers with the 18th Space Defense Squadron (or a successor entity) and other entities that engage in space situational awareness or space traffic management functions. SpaceX will also share ephemeris data with other NGSO system operators through spacetrack.org. SpaceX is the first operator to optimize the usefulness of this data by supplementing it with co-variance data, which allows other operators to better assess the collision risk between their own vehicles and SpaceX satellites.

Collision Risk

SpaceX has made clear that it intends to conduct active maneuvers to avoid collisions with both debris and other spacecraft throughout the life of its satellites, even through the de-orbit phase until the spacecraft enters the atmosphere. As the Commission has recognized, because SpaceX has invested in advanced propulsion capabilities for its satellites, collision risk with large objects is considered to be zero while the spacecraft are capable of maneuvering.[14] While SpaceX expects its satellites to perform nominally and deorbit actively as described below, in the unlikely event a vehicle is unable to finish its planned disposal maneuver, the denser atmospheric conditions at the low altitudes used by the Gen1 FSS system provide fully passive redundancy to SpaceX's active disposal procedures.

The natural orbital decay of a satellite at these altitudes will take less than two years—and in most scenarios, less than a few months—even considering worst-case assumptions. Due to the very lightweight design of the spacecraft, SpaceX achieves a very high area-to-mass ratio on its vehicles. Combined with the natural atmospheric drag environment at lower altitude, this high ratio ensures rapid decay even in the absence of the nominally planned disposal sequence. Thus,

---

14 *See, e.g., id.*, ¶ 35.

even assuming an extreme worst-case scenario—i.e., the spacecraft fails while in the operational orbit, has no attitude control, and solar activity is at a minimum—the expected decay time is two to four years, which will more than satisfy the aspirational goal recently set by the Commission for safe operation of large constellations.[15] Nonetheless, SpaceX's nominal disposal plan that it anticipates for every spacecraft will result in a lifetime of less than 70 days after SpaceX initiates disposal, an advantage of operating at the low altitudes proposed in this application.

These short demise times significantly limit the risk of collision in the event that a satellite loses maneuverability while in operational orbit. Table A.11-1 below shows the demise time and probability of collision between a space object larger than 10 cm in diameter and a 2 GHz MSS system satellite at each of the operating altitudes proposed herein, assuming that the satellite has lost all maneuver capability and attitude control (i.e., is tumbling), as determined using the most recently released version of NASA's Debris Assessment Software ("DAS").

Altitude (km)	Demise Time (yrs)	Collision Risk
540	2.57	1.02E-04
550	2.86	1.10E-04
560	3.12	1.64E-04
570	3.62	1.49E-04

Table A.11-1. Demise Time and Collision Risk Assuming No Maneuver Capability On-Orbit

As this table demonstrates, the collision risk of a 2 GHz MSS satellite in all cases falls well below the 0.001 benchmark recently adopted by the Commission.[16] Of course, even these collision risk calculations present an overly pessimistic picture since the vast majority of SpaceX satellites will not fail in orbit and will continue to maneuver to achieve an effective collision risk of zero.

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

---

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

[16] *See id.* ¶¶ 33-34.

when possible,[17] in the unlikely event any satellites after the initial launch experience immediate failure upon deployment, they would decay to the point of demise very quickly even under worst-case conditions. Table A.11-2 below shows the demist time and probability of collision between a space object larger than 10 cm in diameter and a SpaceX satellite if rendered totally incapacitated immediately following orbital injection.

	Inclination (deg)	Demise Time (yrs)	Collision Risk
Stowed Configuration	53	0.221	5.18E-06
	70	0.221	5.70E-06
	97.7	0.221	7.16E-06
Deployed Configuration	53	0.040	1.65E-06
	70	0.040	1.81E-06
	97.7	0.040	2.28E-06

Table A.11-2. Demise Time and Collision Risk Assuming Incapacitated Satellite at Injection

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

In order to determine whether the normal operation of any other planned or operational space stations pose a risk of collision with the 2 GHz MSS system, SpaceX undertook a review of the list of licensed systems and systems that are under consideration by the Commission for the orbital altitudes it has requested. The Commission has authorized a number of operators to deploy cubesats at altitudes from 400 km to 650 km with orbits that will naturally decay to lower altitudes due to lack of propulsion, including Astro Digital US, Inc., Spire Global, Inc., Swarm Technologies, Inc., and Kepler Communications, Inc.,[18] and has granted market access to the non-

17 SpaceX intends to inject satellites into an elliptical orbit of approximately 210 km by 370 km. Though it is possible that injection parameters may vary slightly in a small number of cases, the maximum altitude is not planned to be more than 370 km.

18 *See, e.g.*, Grant Stamp, IBFS File No. SAT-LOA-20170508-00071 (granted Aug. 1, 2018) (deployment altitude

U.S. licensed cubesat system of Myriota Pty. Ltd.[19]

In addition, in order to address non-U.S. licensed systems, SpaceX has reviewed the list of NGSO satellite networks filed with the ITU by other administrations that have a perigee within the range of altitudes used by the Gen2 System for which a request for coordination has been published by the ITU. The results, summarized in Annex 1 hereto, show that there are 33 non-U.S filings, of which two-thirds propose six or fewer satellites at the relevant orbital altitudes.

From this good faith review, SpaceX concludes that physical coordination should be practicable, facilitated by the maneuverability of its system and its willingness to share information on the operations of its system. SpaceX has already begun discussions with some of the existing licensees identified above and will engage these and any other systems seeking to operate at the same nominal orbital ranges sought by SpaceX to carefully coordinate physical operations to ensure that their respective constellations can coexist safely.

Post-Mission Disposal

Each satellite in the 2 GHz MSS system is designed for a useful lifetime of five to seven years. SpaceX intends to dispose of satellites through uncontrolled atmospheric re-entry at end of life. As discussed above, SpaceX anticipates that its satellites will reenter the Earth's atmosphere within approximately 70 days after completion of their mission under normal circumstances, and even in a worst case would de-orbit within less than two years—much sooner than the international standard of 25 years. Accordingly, the probability of successful disposal of each SpaceX satellite

---

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

[19] *See Myriota Pty. Ltd.*, 35 FCC Rcd. 5475 (IB 2020). Myriota also has another market access petition pending. *See* IBFS File No. SAT-PDR-20191118-00135.

as defined by the Commission is deemed to be 100%—surpassing the goal set by the Commission for large NGSO systems.[20]

Casualty Risk Assessment

The spacecraft's small mass and predominantly aluminum construction maximize the likelihood of atmospheric demise on re-entry. To verify this, SpaceX used NASA's DAS to perform a re-entry survivability analysis. This analysis confirmed that all 2 GHz MSS satellites are fully demisable upon atmospheric re-entry, and no components would be expected to survive to reach the Earth's surface with a kinetic energy in excess of 15 joules. Accordingly, the calculated risk of human casualty is zero.

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

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.

Mihai Albulet

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

July 25, 2022

Date

ANNEX 1

POTENTIALLY RELEVANT NON-U.S. NGSO SYSTEMS

The table below lists the NGSO satellite networks filed with the ITU by administrations other than the United States that have a perigee within the range of altitudes that could be used by the 2 GHz MSS system for which a request for coordination has been published.

NGSO Network	Administration	Relevant Altitude(s) (km)	Number of Satellites
ARCSAT	NOR	525	1
JUVENILE-OFO	CHN	546	1
LS-1	CHN	550	1
MSTD	J	520	1
SATELIOT_UHF	E	550	1
TY1-07	CHN	535	1
UPMSAT-2	E	525	1
ZW-1	CHN	539	1
SAMSON-2	ISR	525	1
FFZ	CHN	550	2
HOL-NGSO1-B-S	HOL	530	2
INSIGHTP-C	CHN	550	2
ULLORIAZ	DNK	540	2
XINGYUN-2	CHN	568	2
ZDWT-1	CHN	550	2
SAMSON-2	ISR	550	2
KOREASAT G-1	KOR	560	4
TYVAK-210A	NOR	550	4
JUVENILE-5C	CHN	546	5
TY3-05	CHN	535	5
PIESAT-1	CHN	538	6
QS1	CHN	540	6
MN200	CHN	550	8
TY-SKYLAB	CHN	535	8
AISTECH	E	550	12
NORTHSTAR2	CAN	575	12
SATELIOT_L_S	E	550	100
SI-SAT-KURUKURU	SLM	525, 577	100
STERNOLA-BLOCK-1	DNK	550	120
D-ISPIPELE-C	D	575	175
SKY-G3	RRW	575	209
SNZ-NGSO-1	NZL	550	280
EN-C	G	525, 575	539