APPLICATION FOR GATEWAY EARTH STATION

I. OVERVIEW

The Commission has authorized Space Exploration Holdings, LLC ("SpaceX") to launch and operate a constellation of 4,408 non-geostationary orbit ("NGSO") satellites (call sign S2983/S3018) using Ku- and Ka-band spectrum.[1] In doing so, the Commission recognized that granting the SpaceX Authorization would "allow SpaceX to make efficient use of valuable spectrum resources more safely, quickly, and cost-effectively as it initiates a new generation of broadband services available to customers worldwide, including those in areas previously underserved or even totally unserved by other broadband solutions."[2] In May 2019, SpaceX began launching satellites to populate its constellation.

This application, filed by a sister company, SpaceX Services, Inc. ("SpaceX Services"), seeks authority to operate a Ka-band gateway earth station that SpaceX will use to deliver broadband data between the satellites of its NGSO system and terrestrial Internet exchange points. Specifically, SpaceX Services seeks authority for eight technically identical 1.5-meter antennas in Molokai, Hawaii (the "Molokai Gateway"). Consistent with SpaceX's space station authorization, these earth stations will transmit in the 27.5-29.1 GHz and 29.5-30.0 GHz bands and receive in the 17.8-18.6 GHz and 18.8-19.3 GHz bands.

Below, we discuss certain spectrum sharing issues relevant to the operation of these earth stations. We then demonstrate that grant of this application would serve the public interest. Lastly,

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1 *See Space Exploration Holdings, LLC*, 33 FCC Rcd. 3391 (2018) ("SpaceX Authorization"); *Space Exploration Holdings, LLC*, 34 FCC Rcd. 2526 (IB 2019) ("SpaceX Modification"). These authorizations anticipate that Ka-band spectrum would be used for gateway communications.

2 SpaceX Modification, ¶ 1.

we provide technical information to supplement the information provided in Form 312. To support its ambitious timetable for launching satellites and deploying broadband services, SpaceX Services requests that the Commission grant the requested license as expeditiously as possible.

II. SPECTRUM SHARING ISSUES

Under the Commission's spectrum allocations and the plan adopted for the Ka-band in particular,[3] SpaceX Services will need to share with a variety of other systems operating in its bands. Below we demonstrate that the proposed Molokai Gateway will comply with all relevant sharing requirements.

A. Uplink Bands

The 27.5-28.35 GHz band has been designated for use by the Upper Microwave Flexible Use Service ("UMFUS") on a primary basis, with a secondary designation for FSS. The Technical Appendix in this document demonstrates that the Molokai Gateway will satisfy the criteria set forth in Section 25.136(a)(4) of the Commission's rules such that it may operate without providing additional interference protection to terrestrial UMFUS systems operating in the band.[4]

FSS is primary throughout the 28.35-29.1 GHz band, with NGSO designated as secondary to GSO in the 28.35-28.6 GHz portion and NGSO designated as primary in the 28.6-29.1 GHz portion. FSS is co-primary with Mobile Satellite Service ("MSS") in the 29.5-30.0 GHz band, with NGSO designated as secondary to GSO.[5]

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[3] *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 32 FCC Rcd. 7809, App. B (2017) ("*NGSO Update Order*").

[4] *See* 47 C.F.R. § 25.146(a)(4).

[5] *See id.*

The Comsearch Report submitted with this application confirms that SpaceX Services has coordinated with existing terrestrial licensees in these bands in compliance with the Commission's rules and can operate without causing harmful interference to any such deployments. SpaceX Services makes no claim of interference protection from U.S.-licensed GSO FSS systems in the 28.35-28.6 GHz and 29.5-30.0 GHz bands. In addition, SpaceX Services will comply with the applicable equivalent power flux-density ("EPFD") limits set forth in Article 22 and Resolution 76 of the ITU Radio Regulations, which the Commission has found to be sufficient to protect GSO systems against harmful interference.[6] SpaceX has demonstrated that its NGSO system will comply with these EPFD limits, and doing so is a condition of its Authorization.[7]

B. Downlink Bands

The Commission has allocated the 17.8-18.3 GHz band on a primary basis to the terrestrial fixed service ("FS") and on a secondary basis for FSS. The 18.3-18.6 GHz band is allocated on a primary basis to FSS, with NGSO secondary to GSO and subject to international EPFD limits. The 18.8-19.3 GHz band is allocated to FSS on a primary basis, with NGSO designated as primary.

SpaceX has previously demonstrated that its NGSO system will protect terrestrial fixed stations in the 17.8-18.6 GHz and 18.8-19.3 GHz bands, in compliance with a condition placed on its license.[8] Moreover, the Comsearch report submitted with this application confirms that there should be no additional limitations placed on operations of the Molokai Gateway. Similarly,

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[6] *See, e.g.*, *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*, 16 FCC Rcd. 4096, ¶ 77 (2000) (concluding that implementation of EPFD limits "will adequately protect GSO FSS networks"); 47 C.F.R. § 25.289 (NGSO satellite systems that comply with EPFD limits will be deemed not to cause unacceptable interference to any GSO network). SpaceX believes that the EPFD limits designed to protect GSO FSS systems will also protect GSO MSS systems in the band.

[7] *See* SpaceX Authorization, ¶¶ 40(b), (d), and (e); 47 C.F.R. § 25.115(f)(1) (incorporating certification requirement in 47 C.F.R. § 25.146(a)(2)).

[8] *See* SpaceX Modification, ¶ 29.

SpaceX has demonstrated that its NGSO system will comply with the relevant EPFD limits in the 18.3-18.6 GHz band, which the Commission considers sufficient to protect GSO networks from unacceptable interference.[9]

III. GRANT OF THIS APPLICATION WOULD SERVE THE PUBLIC INTEREST

Granting this application would serve the public interest by helping to speed broadband deployment throughout the United States by authorizing the ground-based component of SpaceX's satellite system. U.S. and worldwide demand for broadband services and Internet connectivity continues to increase with escalating requirements for speed, capacity, and reliability and ongoing adaptations for usage. The volume of traffic flowing over the world's networks has exploded, with one report estimating that annual global Internet protocol traffic reached 1.5 zettabytes in 2017 – meaning that approximately 1,500 billion gigabytes of data were exchanged worldwide that year.[10]

Yet, as the Commission has recognized, many communities across the United States and the world still lack access to reliable broadband connectivity, preventing them from fully participating in economic, social, and civic activities.[11] To help close this digital divide, SpaceX

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9 *See* SpaceX Authorization, ¶ 9.

10 *See* Cisco Visual Networking Index: Forecast and Methodology, 2017-2022, at 1, CISCO (Nov. 26, 2018), https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paperc11-741490 html.

11 *See, e.g., Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion*, 33 FCC Rcd. 1660, ¶ 50 (2018) (noting that "over 24 million Americans still lack fixed terrestrial broadband at speeds of 25 Mbps/3 Mbps," and that "the gap in rural and Tribal America remains notable: 30.7 percent of Americans in rural areas and 35.4 percent of Americans in Tribal lands lack access to fixed terrestrial 25 Mbps/3 Mbps broadband"). Internationally, the disparities between broadband access and absence are even greater, with 4.2 billion people (or 57% of the world's population) offline. *See* BROADBAND COMMISSION FOR SUSTAINABLE DEVELOPMENT, "Open Statement from the Broadband Commission for Sustainable Development to the UN High-Level Political Forum (HLPF)" (July 11, 2016), http://broadbandcommission.org/Documents/publications/HLPF-July2016.pdf. *See also* BROADBAND COMMISSION FOR SUSTAINABLE DEVELOPMENT, "The State of Broadband 2015," at 8 (Sep. 2015), http://www.broadbandcommission.org/Documents/reports/bb-annualreport2015.pdf ("A large body of evidence has now been amassed that affordable and effective broadband connectivity is a vital enabler of economic growth, social inclusion and environmental protection."

is designing, constructing, and deploying an innovative, cost-effective and spectrum-efficient satellite system capable of delivering robust broadband service to customers around the world. SpaceX has already secured U.S. authority for the space station components of its NGSO system. This application takes the next step by seeking authority for one of the gateway earth stations that will connect the satellite system to the terrestrial Internet. Accordingly, an expeditious grant of this application would serve the public interest.

Respectfully submitted,

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TECHNICAL APPENDIX

In this Technical Appendix, SpaceX Services provides additional information on the proposed operations of its gateway earth station to supplement the data provided in Schedule B to Form 312 filed with this narrative application.[12]

A. Minimum Elevation Angle

SpaceX Service's gateway earth stations will communicate only with those SpaceX satellites that are visible on the horizon above a minimum elevation angle. This angle may be as low as 25 degrees, and thus SpaceX Services has used this minimum elevation angle in its analysis in order to capture the full potential range of service.

B. UMFUS Coordination - Section 25.136(a)(4)

Section 25.136(a)(4) of the Commission's rules defines four elements that, if met, permit an earth station licensee to operate without providing additional interference protection to terrestrial systems in the Upper Microwave Flexible Use Service ("UMFUS") operating in the 27.5-28.35 GHz band.[13] As demonstrated below, the proposed Molokai Gateway satisfies these criteria, and the Commission should authorize this earth station without requiring additional protection for future UMFUS systems.

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[12] To the extent relevant, SpaceX Services hereby incorporates the technical information submitted with SpaceX's space station applications. *See* IBFS File Nos. SAT-LOA-20161115-00118, SAT-LOA-20170726-00110, SAT-MOD-20181108-00083, and SAT-MOD-20200417-00037.

[13] *See* 47 C.F.R. § 25.146(a)(4).

Section 25.136(a)(4)(i)

The Molokai Gateway complies with this section of the Commission's rules because there are no other earth stations authorized in the 27.5-28.35 GHz band operating in Maui County, Hawaii.

Section 25.136(a)(4)(ii)

Section 25.136(a)(4)(ii) provides that an earth station operator need not provide interference protection to future UMFUS systems if, in a UMFUS license area with a population between 6,000 and 450,000 people, no more than 450 people will be within the earth station's PFD contour that is equal to or exceeds -77.6 dBm/m^2/MHz. The Molokai Gateway is located in Maui County, which has a population of approximately 167,417 people.[14] As demonstrated below, the Molokai Gateway's PFD contour contains fewer than 450 people.

In order to conduct a technical analysis to determine the region around the Molokai Gateway site that would fall within the PFD contour defined by Section 25.136(a)(4), SpaceX used the Visualyse Professional software tool created by Transfinite Systems Ltd., which implements the standard ITU-R Rec. P.452.16 propagation model.[15] SpaceX accounted for clutter using the ITU-R P.452 model, as recommended by the Commission.[16] The ITU P.452 clutter category used in the analysis for this earth station was found to be the most appropriate based on satellite and street view imagery in Google Earth, as well as in-person surveys at the proposed earth station location. Details on the clutter category and related assumptions can be found in Table 1 below.

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14 *See* QuickFacts Maui County, Hawaii, United States Census Bureau, https://www.census.gov/quickfacts/mauicountyhawaii

15 Information on this software can be found at https://www.transfinite.com/content/professional.

16 Rec. ITU-R P.452, https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.452-16-201507-I!!PDF-E.pdf.

Because each of the eight antennas of the Molokai Gateway would track a different SpaceX satellite, SpaceX first determined the worst-case aggregate EIRP density toward the horizon to be -18.7 dBW/MHz.[17] Next, SpaceX defined a reference antenna at 10 meters height above ground with 50.24 dBi gain pointed toward the Molokai Gateway. This is necessary because Visualyse performs its calculations using receive power density rather than PFD. The 50.24 dBi gain effectively converts the receive power density value to a PFD value so that Visualyse can display the results in terms of PFD.[18] SpaceX also loaded information on the surrounding terrain at a 3-arc second resolution (approximately 90 meters by 90 meters) from NASA's SRTM Digital Terrain Elevation Data profile. No additional measures for radiofrequency shielding were deemed necessary for this gateway. Table 1 below summarizes the Molokai Gateway parameters used for the analysis.

With the inputs listed in Table 1 and an omni-directional pattern centered at the gateway site, SpaceX ran the Visualyse software implementing the ITU propagation model to develop a composite (eight antennas) PFD contour with a threshold of -107.6 dBW/m^2/MHz[19] at 10 meters above ground, as required under Section 25.136. The simulation works by moving the reference antenna in small steps all around the area surrounding the Molokai Gateway to measure the value of received power at each location step. The resulting contour can be exported as a .kml file for viewing with a range of GIS mapping software. Figure 1 and 2 show the PFD contour as calculated by Visualyse, superimposed on Google satellite imagery.

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17 This value is based on eight earth station antennas with -8 dBi gain toward the horizon, each operating at -20.7 dBW/MHz EIRP density toward the horizon, based on -19.7 dBW/MHz input power density.

18 This is the gain of a meter square antenna at 27.5 GHz ($G = 10*\log10(4\pi/\lambda^2)$), where λ=1.09 cm at 27.5 GHz). This is a physical quantity corresponding to an antenna with one-meter square effective area, necessary to convert Visualyse's calculation in terms of receive power density into power flux density.

19 This is equivalent to the -77.6 dBm/m2/MHz value used in Section 25.136(a)(4).

The PFD contour can also be used with other data sources to determine the population that falls within the contour. For this purpose, SpaceX used two sources for input data. First, it used the most recent version of NASA's Socioeconomic Data and Applications Center Gridded Population of the World ("GPWv4").[20] The GPWv4 data is based on population counts collected at the most detailed spatial resolution available from the results of the 2010 U.S. Census, which is also extrapolated to produce population estimates for 2020.

By superimposing the PFD contour on the GPWv4 population distribution grid in Figure 3, SpaceX was able to integrate the population contained within the contour using projected 2020 total population with 30 arc-second resolution. Using this tool, the estimated population within the PFD contour is 25 people – less than the 450-person limit established in Section 25.136(a)(4)(ii).

Second, SpaceX used data from the 2010 U.S. Census in order to confirm the analysis based on the NASA data above. Here again, SpaceX was able to project the PFD contour onto a map of census blocks as shown in Figures 1 and 2 to determine which ones fall partially or totally within the contour, and then integrate the share of the population covered in each block to reach an aggregate figure. Using this approach, the estimated population within the PFD contour is 15 people – confirming compliance with the 450-person limit.

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[20] *See* NASA Socioeconomic Data and Applications Center, *Gridded Population of the World: Version 4*, http://sedac.ciesin.columbia.edu/data/collection/gpw-v4/maps/services.

Table 1: Molokai Gateway Parameters	
Site location	Molokai, Hawaii
County	Maui County, Hawaii
Site coordinates	21°6’33.6” N, 157°3’50.2” W
Simulation Frequency	27.5 GHz
Antenna sidelobe level toward horizon[21]	-8 dBi
Input power density[22]	-19.7 dBW/MHz
Number of active antennas	8
Height to midline of antenna	1.7m
ITU P.452 Clutter Category	Irregularly-spaced sparse trees
Nominal Height Clutter Assumption	4 m
Nominal Distance Clutter Assumption	100 m
Extra site shielding[23]	0 dB
Worst-case aggregate EIRP	-18.7 dBW/MHz

Section 25.136(a)(4)(iii)

The Molokai Gateway complies with this section of the Commission’s rules because its PFD contour does not contain any “major event venue, urban mass transit route, passenger railroad, or cruise ship port.” In addition, the PFD contour does not cross any roadways classified as “Other Freeways and Expressways or Other Principal Arterials.”

To make the certification regarding roadways, SpaceX uses QGIS software to conduct an analysis of a comprehensive dataset of roadways obtained from the 2017 release of the HPMS[24]

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[21] There have been changes over time in the antenna sidelobe level toward the horizon used in SpaceX’s earth station applications. The changes are due to improvements in SpaceX earth station antenna design over time.

[22] For this application, SpaceX conservatively uses worst-case input power density and does not change maximum power during rain fade conditions. Clear-sky maximum power is the same as during rain fade for this application.

[23] All ground-based SpaceX earth stations in the US are surrounded with a solid metal panel fence, which is 8 feet in height and is set 11 feet and 6 inches from the centerline of the outermost antennas. Each earth station is analyzed independently to determine the shielding value required to comply with 47 CFR § 25.136(a)(4)(ii) and 47 CFR § 25.136(a)(4)(iii), based on PFD contours. The independent nature of the analysis explains the variation in shielding values between applications. SpaceX installs shielding at all sites with effectiveness equal to or greater than the value required to remain in compliance with 47 CFR § 25.136(a)(4)(ii) and 47 CFR § 25.136(a)(4)(iii).

[24] Highway Performance Monitoring System

ARNOLD[25] dataset, belonging to the Federal Highway Administration of the Department of Transportation. To ensure compliance with 47 CFR § 25.136(a)(4)(iii), SpaceX analysis considers the following categories within the dataset: "Interstate," "Principal Arterial – Other Freeways and Expressways," and "Principal Arterial – Other". SpaceX uses QGIS and the comprehensive dataset of roadways to ensure that the PFD contour does not cross any roads classified as "Other Freeways and Expressways or Other Principal Arterials." According to the website from which the dataset is obtained[26]: "[the dataset] derives and is collected from State DOT road data. ARNOLD consists of locations of all roads in the U.S."

Section 25.136(a)(4)(iv)

The Comsearch Report submitted demonstrates that SpaceX completed coordination in compliance with the Commission's rules.

C. Antenna Patterns

SpaceX will comply with a mask similar to the one in Section 25.209(a)(3) applicable to earth station antennas operating in the 24.75-25.25 GHz and 28.35-30.0 GHz bands with geostationary satellites but will improve that pattern to -8 dBi (rather than 0 dBi) beyond 25 degrees off-axis. The mask can be stated as follows:

$29-25\log_{10}\theta$	dBi	for $2° \leq \theta \leq 7°$.
8	dBi	for $7° < \theta \leq 9.2°$.
$32-25\log_{10}\theta$	dBi	for $9.2° < \theta \leq 25°$.
-8	dBi	for $25° < \theta \leq 180°$.

Consistent with Section 25.209(a)(3), "[t]his envelope may be exceeded by up to 3 dB in 10% of the range of θ angles from ±7-180°, and by up to 6 dB in the region of main reflector spillover

[25] All Road Network of Linear Referenced Data
[26] Source: https://www.bts.gov/geography/geospatial-portal/NTAD-direct-download

energy."[27] In addition, the half power beamwidth for the proposed antenna is 0.5 degrees at 30 GHz.

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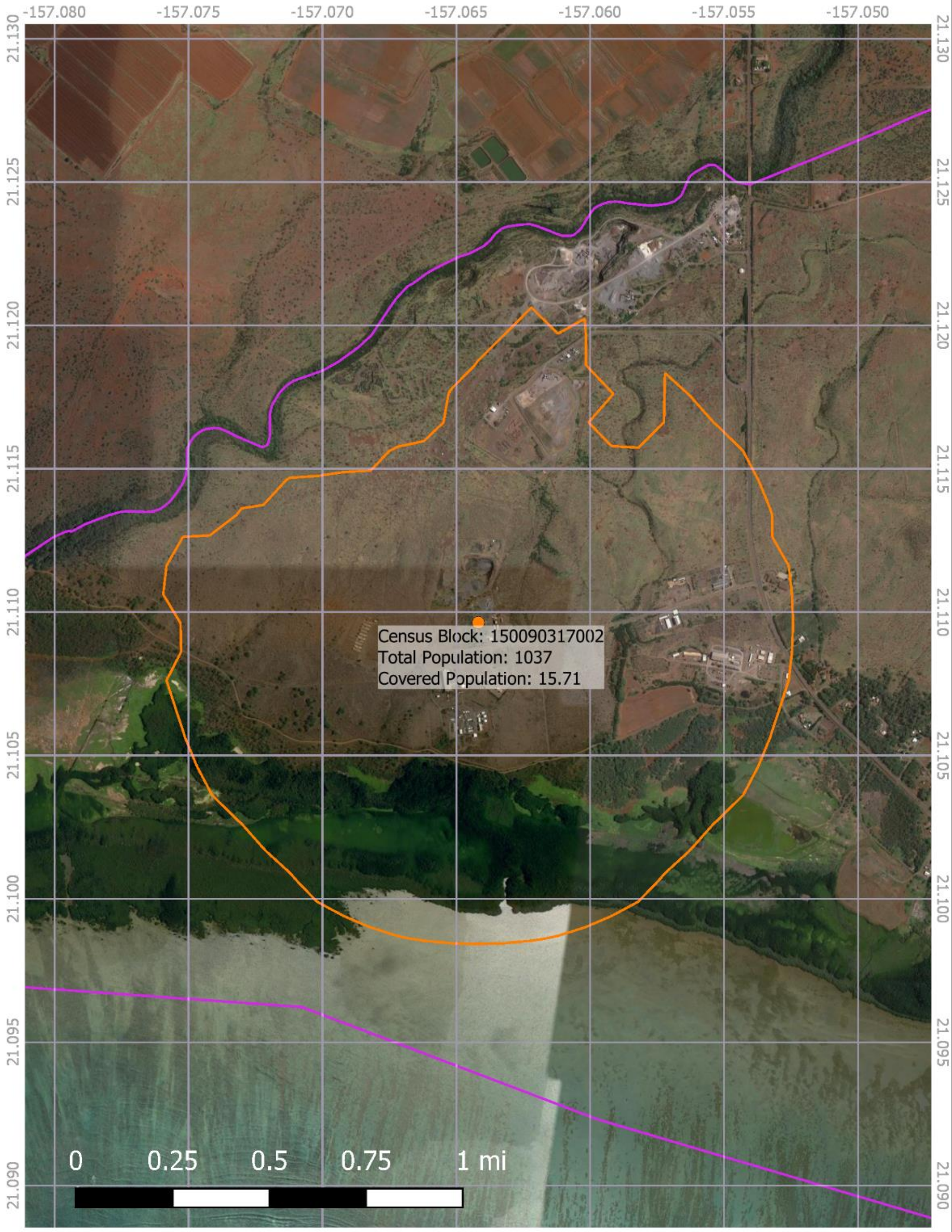
[27] *Id.* § 25.209(a)(3).

Figure 1. Wide-area View showing Census Block and County Boundaries

Figure 2. PFD Contour and Population Coverage



Census Block ID	Total Block Population	Covered Area	Covered Block Population
150090317002	1037	1.52%	15.71

Total Covered Population = 15.71

Figure 3. PFD Contour Projected Onto GPWv4 Population Grid