QUESTION 7: PURPOSE OF EXPERIMENT

NARRATIVE SUMMARY

Space Exploration Technologies Corp. ("SpaceX") is a U.S. space technology company that designs, manufactures, and launches advanced rockets and spacecraft. The company is headquartered in Hawthorne, California and has over 6,000 employees based in the United States.

On March 29, 2018, the Commission granted SpaceX's application for authority to launch and operate a constellation of non-geostationary orbit ("NGSO") satellites designed to provide high-speed, high-capacity, low-latency broadband services in the United States and around the world.[1] As a development step towards this initiative, SpaceX applied for and was granted on November 16, 2017 an experimental authorization for the launch and operation of two initial test and demonstration satellites (Microsat-2a and Microsat-2b) over the course of two years.[2] Both satellites were deployed on February 22, 2018 in the same launch mission aboard a SpaceX Falcon 9 rocket. These experimental engineering verification vehicles are currently engaged in the test regimen as authorized, in order to enable the company to assess the satellite bus and related subsystems, as well as the operation of space-based and ground-based phased array technologies. As of today, SpaceX has not received any interference notices from any authorized users in the spectrum bands that SpaceX has been authorized in the existing license by the FCC for the testing.

In this application, SpaceX seeks to modify the experimental authorization for Microsat-2a and -2b in order to reflect additional test activities undertaken with the federal government. The tests are designed to (1) demonstrate the ability to transmit and receive information between two ground sites ("Ground-to-Ground") and between the ground and an airborne aircraft ("Ground-to-Air") using Microsat-2a and -2b, and (2) communicate using an additional antenna at its Redmond, Washington test site. Nothing about the operation of and transmissions from the Microsat-2a or -2b satellites will change under this modification. The only change will be the addition of two new types of earth stations, one of which will transmit uplink signals to the Microsat satellites first from the ground and later from a moving aircraft. As discussed below, these proposed changes will not adversely affect any other authorized spectrum user, including geostationary orbit ("GSO") satellite systems.

SpaceX's Existing Experimental Authorization

SpaceX has been authorized to test the Microsat-2a and -2b communication paths utilizing five broadband array test ground stations located in the western United States, as well as three transportable ground stations that will be deployed near the fixed ground station locations, all within the contiguous United States ("CONUS") :

1. Hawthorne, California
2. Fremont, California
3. McGregor, Texas
4. Brownsville, Texas
5. Redmond, Washington

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[1] *See Space Exploration Holdings, LLC*, FCC 18-38 (rel. Mar. 29, 2018).

[2] *See* Call Sign WI2XTA, File No. 0298-EX-CN-2016 (granted Nov. 16, 2017).

6. Broadband Test Vans 1-3: Mobile earth station in CONUS

Under its current experimental authorization, SpaceX may operate these mobile earth stations at any point within 150 km of the five fixed test sites identified above. Ground passes are limited to a minimum of 40 degree elevation angles at each location for testing; thus, the spacecraft will only transmit at elevation angles of 40 to 90 degrees. This elevation angle constraint, combined with the geography of the ground stations, results in transmission times of less than 15 minutes every 0.9 days.

The testing will help to validate a number of design parameters including:

- RF characteristics of the satellite broadband platforms
- Link throughput
- Broadband array pointing and ground stations transitions (handoffs)

As SpaceX demonstrated in its original experimental application for these two satellites, the Ku-band uplink and downlink operations of the Microsat mission will comply with relevant limitations on power flux-density ("PFD") and equivalent power flux-density ("EPFD") of emissions imposed by the Commission and the International Telecommunications Union ("ITU"). Microsat-2a and -2b will implement techniques to avoid the GSO arc to protect against interference into GSO satellite systems, such as turning off the Ku-band transmit beam on the satellite and transmitting earth station whenever the angle between the boresight of a GSO earth station and the direction of the SpaceX satellite transmit beam is less than a specified amount.

Table 1 describes the broadband frequency plan for the existing Microsat mission:

Link Type	Spacecraft	Frequency	Modulation	Data Rate	Emissions Designator	Power
Broadband Downlink (Space to Earth)	Microsat-2a/b	11.075 GHz 11.325 GHz 11.825 GHz 12.075 GHz	Up to 64QAM	Up to 1440 Mbps 240Msym/sec	240MD7W	2.8 W
Broadband Uplink (Earth to Space)	Microsat-2a/b	13.0625 GHz 13.1875 GHz	Up to 64QAM	Up to 720 Mbps 120Msym/sec	120MD7W	2.8 W
Broadband Uplink (Earth to Space)	Microsat-2a/b	14.125 GHz 14.375 GHz	Up to 64QAM	Up to 1440 Mbps 240Msym/sec	240MD7W	5.6 W

Table 1. Microsat Frequency Plan

Proposed Modification

SpaceX seeks to modify its experimental authorization to allow testing of two different antennas, both of which will operate on the ground and one of which will also operate from a moving aircraft. This modification would not change any other parameters outlined in the experimental license, including the RF output power, frequencies used, emission bandwidth, and the locations in which the experiment will be conducted. Accordingly, this modification application focuses on the characteristics of the new uplink transmissions that will result from the proposed tests. Additional information on the antennas, including antenna gain patterns, are provided in Exhibit 1 to this application.

Antenna 1

For this effort, SpaceX is working with a manufacturer of conformal antennas for tactical aircraft, which will provide antennas required for aircraft testing. This will assist SpaceX in analyzing the data link performance and installation options for user terminals with conformal arrays.

To prepare for the Ground-to-Air testing, SpaceX will first test the SpaceX modem integrated with the inertially stabilized electronically steered array technology as part of the ground testing. This ground testing is expected to take place near other planned testing at SpaceX's Redmond, WA facilities. It will include interfacing the modem RF and antenna steering interfaces to the antennas. SpaceX will not begin Ground-to-Air integration and testing until it has performed sufficient characterization of the airborne antenna configuration with representative motion profiles. SpaceX will perform a series of tests with the integrated airborne prototype terminal that is similar to the tests contemplated with other fixed earth stations under its current authorization. These include antenna static angles from 0 to 40 degrees from boresight, and then varying motion for representative roll and pitch rates of a high performance aircraft.

For the Ground-to-Air scenario, an antenna will be built and integrated onto an aircraft. The antenna manufacturer is designing a custom installation kit consisting of mechanical plates for the low-profile antennas and fairings reducing wind drag in order to limit the impact to the aircraft for this installation. The antennas will interface with SpaceX test equipment to form a user terminal for the demonstration. The existing antenna design meets the required transmit effective isotropic radiated power and receive gain over temperature when using four transmit subarrays and six receive subarrays.[3]

SpaceX anticipates that the Ground-to-Air testing will require four to six weeks to complete. Air operations will consist of repeated short-duration sorties with flight operation during the satellite's test pass, contained within a relatively small operational area in close proximity to a currently authorized test site. Specifically, consistent with SpaceX's existing experimental authorization, the aircraft will operate no more than 150 km from the SpaceX broadband ground station in Redmond, WA.

Example test sequence for new antenna:

1. Wait for satellite to rise to 40 degrees elevation over test site
2. Initiate broadband test from ground
3. Perform broadband test with earth stations (either on ground or airborne)
4. Satellites set below 40 degrees elevation as viewed from test site
5. Satellite disables Ku-band broadband system

[3] For purposes of this test, the only change required is modification to the transmit array polarization from right hand circular polarization (RHCP) to left hand circular polarization (LHCP). This is a simple change with minimal impact to the array design.

Equivalent Power Flux Density at the Geostationary Satellite Orbit in the Ku band (12.75-14.5GHz)

The Commission and the ITU have adopted EPFD limits designed to protect GSO satellite systems against harmful interference from NGSO satellite systems. Section 25.146(a)(2) of the Commission's rules provides that NGSO FSS systems operating in the 10.7-30 GHz frequency range must meet the EPFD limits set forth in Article 22 of the ITU Radio Regulations.[4] In the 12.75-14.5 GHz band, the EPFD in the Earth-to-space direction ($EPFD_{up}$), produced at any point on the GSO arc by the emissions from all co-frequency earth stations in an NGSO FSS system, for all conditions and for all methods of modulation, shall not exceed -160 dBW/m^2 in 40 kHz bandwidth.[5]

The calculations in Table 2 below demonstrate that the $EPFD_{up}$ produced by the transmissions from the proposed earth stations, whether on the ground or operating while airborne, will never exceed the relevant ITU limit. An occupied bandwidth of 240 MHz is used. Note that the earth station transmitter is turned off whenever (1) there is no experimental satellite in view at an elevation angle of at least 40 degrees, or (2) the direction of the SpaceX earth station transmit beam and the GSO arc is separated by less than 12°. In addition, the sidelobes of the antenna patterns are at least 15dB down from the main lobe at 12° separation or more.

	Earth Station on Ground	**Earth Station Airborne**
GSO altitude [km]	35786	35778.4
EIRP @ zenith [dBW]	38.8	38.8
EIRP density @ zenith [dBW/Hz]	-45.0	-45.0
EIRP in 40kHz [dBW]	1.0	1.0
Sidelobe level towards GSO arc [dB]	-15.0	-15.0
Spreading loss [dB]	-162.07	-162.07
EPFD_up [dB(W/m^2)/40kHz]	-195.0	-195.0

Table 2. $EPFD_{up}$ for the proposed Antenna 1 earth stations

As demonstrated above, the brief transmit times, GSO arc avoidance techniques, and adaptable power levels used by the Microsat satellites and the associated earth stations ensure the system never exceeds the applicable -160dB(W/m^2)/40kHz uplink EPFD limit. Accordingly, SpaceX is confident that the proposed modification will not affect any GSO satellite services. In the wholly unlikely case that there is a confirmed interference to a GSO system by SpaceX, SpaceX will cease transmission on the relevant frequency and work with the Commission and other relevant parties to mitigate future occurrences. SpaceX has redundant command receivers and thus has redundant paths for any "cease emissions" command.

[4] *See* 47 C.F.R. § 25.146(a)(2).

[5] *See* ITU Radio Regs. No. 22.5D and Table 22-2.

Antenna 2

In addition, SpaceX will augment its experimental regimen by adding a parabolic antenna to the group previously authorized. Like those other antennas, Antenna 2 will interface with a SpaceX modem and test equipment to demonstrate transmitting and receiving capabilities with the Microsat satellites from the Redmond, WA test site.

The calculations in Table 3 below show that $EPFD_{up}$ produced by the transmissions from the Antenna 2 broadband earth station never exceeds the ITU limit. An occupied bandwidth of 240 MHz is used. Note that the earth station transmitter is turned off whenever (1) there is no experimental satellite in view at an elevation angle of at least 40 degrees, or (2) the direction of the SpaceX earth station transmit beam and the GSO arc is separated by less than 8°. Based on these separation angles, the sidelobes of the broadband antenna patterns are at least 34 dB down from the main lobe.

	Earth Station on Ground
GSO altitude [km]	35786
EIRP @ zenith [dBW]	50.9
EIRP density @ zenith [dBW/Hz]	-32.9
EIRP in 40kHz [dBW]	13.1
Sidelobe level towards GSO arc [dB]	-34
Spreading loss [dB]	-162.07
EPFD_up [dB(W/m^2)/40kHz]	-182.9

Table 3. $EPFD_{up}$ for the proposed Antenna 2 earth stations

Here again, the brief transmit times, GSO arc avoidance techniques, and adaptable power levels used by the Microsat satellites and the associated earth stations ensure the system never exceeds the applicable -160dB(W/m^2)/40kHz uplink EPFD limit. Accordingly, SpaceX is confident that the proposed modification will not affect any GSO satellite services. In the wholly unlikely case that there is a confirmed interference to a GSO system by SpaceX, SpaceX will cease transmission on the relevant frequency and work with the Commission and other relevant parties to mitigate future occurrences. SpaceX has redundant command receivers and thus has redundant paths for any "cease emissions" command.