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 California, and has more than 6,000 employees based at various facilities around the United States, including California, Texas, Florida, Washington, and the District of Columbia.

On November 15, 2016, SpaceX applied to the U.S. Federal Communications Commission ("FCC") for operating authority for a constellation of non-geostationary orbit ("NGSO") satellites for provision of broadband services. As a development step towards this initiative, SpaceX seeks authority to launch and operate two test and demonstration satellites over the course of 24 months. These are experimental engineering verification vehicles that will enable the company to assess the satellite bus and related subsystems, as well as the space-based and ground-based phased array technologies. The company may seek further authority for subsequent test and demonstration satellites.

The first phase of testing will include two satellites: Microsat-2a and Microsat-2b. These two satellites are intended to be launched as early as 2017.[1] Both of these satellites will be deployed in one mission aboard a SpaceX Falcon 9 launch vehicle into an orbital plane of 514 km circular at 97.44 degrees inclination. After insertion, the satellite orbits will be raised to the desired mission altitude of 1125 km circular. The designed lifetime of each satellite is 20 months. If this lifetime is exceeded, SpaceX plans to continue operation until such time as the primary mission goals can no longer be met, at which point the spacecraft will be deorbited. Both Microsat-2a and Microsat-2b are identical in their construction and operation.

The primary structure for the Microsat-2a and -2b test spacecraft will be a box design measuring 1.1m x 0.7m x 0.7m and carries the spacecraft flight computer, power system components, attitude determination and control components, propulsion components, GPS receiver, and broadband, telemetry, and command receivers and transmitters. The primary bus is mounted on the payload truss system, which also carries communications panels, inter-satellite optical link transmitters and receivers, star trackers, and a telemetry antenna. There are two 2x8 meter solar panels. Each demonstration spacecraft has a total mass of approximately 400kg.

The attitude of each spacecraft is 3-axis stabilized, and is dynamically controlled over each orbit to maintain attitude position for two pointing modes of operation: broadband antenna (antennas to nadir for testing) and solar array (solar arrays facing sun for charging). Power is provided by solar panels designed to deliver sufficient power at the predicted end of spacecraft life to not impair any test objectives. The Thermal Control System ensures that components are kept within operational temperature ranges.

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[1] SpaceX had previously been granted authority for two other experimental satellites (Microsat-1a and -1b) operating with different orbital parameters in the 2GHz, 8 GHz, and 14 GHz bands. See Call Sign WH2XWB, File No. 0356-EX-PL-2015 (granted July 22, 2016). Because SpaceX has made revisions to the design of its hardware and constellation since it applied for that authorization, it has opted to seek authority for different experimental satellites that will provide a better test bed.

Microsat-2a and -2b Test Objectives

In addition to proving out the development of the satellite bus and related subsystems, the test program for the Microsat-2a and -2b spacecraft will also validate the design of a phased array broadband antenna communications platform (primary payload) that will be included in the final spacecraft design for the proposed NGSO constellation. SpaceX intends 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"). With the orbit profile provided, broadband array tests (Ku-band) will be conducted on average once every 0.9 days for less than 15 minutes. The primary Telemetry, Tracking, and Command ("TT&C") ground station will be located near the primary test site in Redmond, WA to facilitate and control the broadband array testing. 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 demonstrated in Exhibit 3, the Ku-band uplink and downlink operations of the Microsat mission will comply with relevant FCC and ITU limitations on power flux-density ("PFD") of emissions. Given the low transmit times, techniques to avoid the geostationary orbit ("GSO") arc, and adaptable power levels, SpaceX is confident that Microsat will not affect any terrestrial or satellite services. In the wholly unlikely case that there is a confirmed interference to a fixed or mobile user by SpaceX, SpaceX will cease transmission on the relevant frequency and work with the FCC and other relevant parties to mitigate future occurrences. As discussed below, SpaceX has redundant command receivers and thus has redundant paths for any "cease emissions" command.

The following table lists the transmitting sources on each satellite.

Nomenclature	Manufacturer	Part Number	Qty.
Broadband Transmitter (Ku-Band)	SpaceX	TT1-Ku-BB	2
Telemetry/Video Transmitter (Ku-Band)	SpaceX	TT1-Ku-TTC	2
Telemetry/Video Transmitter (Ka-Band)	SpaceX	TT1-Ka-TTC	2
Telemetry/Video Transmitter (X-Band)	SpaceX	TT1-X	2

The following table describes the command plan for the Microsat mission:

Link Type	Spacecraft	Band	Frequency	Modulation	Data Rate	Emissions Designator	Power
Command Uplink (Earth to Space)	Microsat-2a/b	Ku	13.875 GHz[2]	BPSK	15.36 Mbps 5 Mbps 1 Mbps	41M4D7W 13M5D7W 2M7D7W	40W
Command Uplink (Earth to Space)	Microsat-2a/b	Ku	13.925 GHz[2]	BPSK	15.36 Mbps 5 Mbps 1 Mbps	41M4D7W 13M5D7W 2M7D7W	40W
Command Uplink (Earth to Space)	Microsat-2a/b	Ku	13.975 GHz[2]	BPSK	15.36 Mbps 5 Mbps 1 Mbps	41M4D7W 13M5D7W 2M7D7W	40W
Command Uplink (Earth to Space)	MicroSat-2a/b	S	2085.0 MHz	BPSK	5Mbps	11M6G1D	50 W
Command Uplink (Earth to Space)	MicroSat-2a/b	S	2098.0 MHz	BPSK	5Mbps	11M6G1D	50 W

[2] As required under 47 C.F.R. § 2.106, n.US356, the earth station antenna diameter used for these frequencies is greater than 4.5 m.

The following table describes the telemetry and video plan for the Microsat mission:

Link Type	Spacecraft	Band	Frequency	Modulation	Data Rate	Emissions Designator	Power
Telemetry/Video Downlink (Space to Earth)	Microsat-2a/b	Ku	12.179 GHz	OQPSK	10 Mbps 1 Mbps 500 Kpbs 50 Kpbs	41M4D7W 1M35D7W 675KD7W 67K0D7W	3.5W
Telemetry/Video Downlink (Space to Earth)	Microsat-2a/b	Ku	12.221 GHz	OQPSK	10 Mbps 1 Mbps 500 Kpbs 50 Kpbs	41M4D7W 1M35D7W 675KD7W 67K0D7W	3.5W
Telemetry/Video Downlink (Space to Earth)	Microsat-2a/b	Ka	18.575 GHz	OQPSK	10 Mbps	41M4D7W	3.5W
Telemetry/Video 2a (Space to Earth)	MicroSat-2a	X	8035.0 MHz	OQPSK	10 Mbps 5Mbps 2.5Mbps 1Mbps 500Kbps	11M6G1D 5M80G1D 2M90G1D 1M16G1D 580KG1D	20W 20W 20W 8W 4W
Telemetry/Video 2b (Space to Earth)	MicroSat-2b	X	8050.0 MHz	OQPSK	10 Mbps 5Mbps 2.5Mbps 1Mbps 500Kbps	11M6G1D 5M80G1D 2M90G1D 1M16G1D 580KG1D	20W 20W 20W 8W 4W
Telemetry/Video 2a (Space to Earth)	MicroSat-2a	X	8065.0 MHz	OQPSK	10 Mbps 5Mbps 2.5Mbps 1Mbps 500Kbps	11M6G1D 5M80G1D 2M90G1D 1M16G1D 580KG1D	20W 20W 20W 8W 4W
Telemetry/Video 2b (Space to Earth)	MicroSat-2b	X	8080.0 MHz	OQPSK	10 Mbps 5Mbps 2.5Mbps 1Mbps 500Kbps	11M6G1D 5M80G1D 2M90G1D 1M16G1D 580KG1D	20W 20W 20W 8W 4W

The following table describes the Broadband frequency plan for the 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 62M5D7W 31M3D7W 15M6D7W	2.8 W 1.5 W 0.7 W 0.4 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 120MD7W 62M5D7W 31M3D7W 15M6D7W	5.6 W 2.8 W 1.5 W 0.7 W 0.4 W

Technical Description

The Ku broadband array platform on each of the Microsat-2a and -2b satellites consists of physically separated transmit and receive panels, each based on phased arrays antennas. Downlink beams are Right Hand Circularly Polarized (RHCP) and uplink beams are Left Hand Circular Polarized (LHCP). All beams can be pointed with an accuracy of +/-0.1 degrees at any angle from nadir to 40.62 degrees (corresponding to elevations ≥ 40deg from ground stations for an 1125 km altitude orbit). The transmit power of the broadband system is adjustable ensuring an Earth measured PFD of less than -140dBW/m^2/4kHz at all usable pointing directions (i.e., elevations over 40 degrees). The data contained in these transmissions will be a combination of test patterns, health and status of the vehicle and recorded video onboard of key events on the satellite such as slewing and solar array deployment.

The TT&C subsystems of the satellite will consist of two Ku-band, two Ka-band, and two X-band transmitters, as well as two Ku-band and two S-band receivers.[3] The different telemetry options will be evaluated for usage in future missions and only one type will be used at a time. Omnidirectional antennas (antenna pairs with hybrid couplers) will be used to ensure telemetry and command links will close at any attitude relative to the ground. Each telemetry transmitter is capable of changing bit rates from 10Mbps to 50Kbps. The rate will be determined based on the expected performance to the ground. The data contained in this path will be a combination of health and status of the vehicle and recorded video onboard of key events on the satellite such as slewing and solar array deployment.

[3] The S-band uplink frequencies and the X-band downlink frequencies requested for TT&C operations were previously authorized in the Microsat 1a/1b experimental license.

Overview of Operations

Upon deployment of Microsat-2a and Microsat-2b, the relative separation rate imparted by the launch vehicle on each of the two satellites will be several meters per second. After deployment, each satellite will begin de-tumbling and establish attitude control and sun pointing. Broadband testing will commence at the insertion orbit prior to raising to the operational altitude. At insertion the orbital parameters are as defined in the following table:

Perigee	514	km
Apogee	514	km
Period	1.58	hrs
Inclination	97.44	deg

After system checkouts are performed and the system is evaluated as ready to proceed, the orbit-raising phase of the mission will commence. This segment will last approximately half a year depending on system performance. Once they reach mission altitude, the Microsat-2a and -2b satellites will fly in a circular orbit, with orbital parameters defined in the following table:

Perigee	1125	km
Apogee	1125	km
Period	1.80	hrs
Inclination	97.44	deg

All satellite operations will be administered at a satellite operations center in Redmond, WA. This operations center will also be the location of a broadband test station and near a TT&C station. The TT&C station in Washington State will be the primary station for initiating broadband array tests and can be used to disable transmission of the Ku-band array in the event of a problem.

<u>Broadband Test Operations (Ku-band)</u>

For the broadband downlink, SpaceX is utilizing ground terminal locations exclusively in CONUS. The ground stations include five fixed locations, and three transportable ground stations located near the fixed locations:

1. Hawthorne, California
2. Fremont, California
3. McGregor, Texas
4. Brownsville, Texas
5. Redmond, Washington
6. Broadband Test Vans 1-3: Transportable fixed Earth station in CONUS

The transportable ground stations TV 1 – 3, are fixed during operation.

At each location, three types of ground terminals will be evaluated over the course of the satellites' lifetime, but only one terminal will be operated at each location at a given time. 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 the aforementioned transmission times of less than 15 minutes every 0.9 days.

Microsat-2a and -2b will implement GSO arc avoidance to protect against interference into GSO systems. This will be accomplished by 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 12 degrees. This ensures the -160dB(W/m2)/40kHz limit is never exceeded.

Example test sequence:

1. Transition into Earth pointing attitude (broadband arrays nadir)
2. Satellite turns on Ku-band telemetry 2 degrees below the horizon from station
3. Receive telemetry on West Coast TT&C ground station
4. Establish and verify Ku-band command link to satellite from ground station
5. Wait for satellite to rise to 40 degrees elevation over test site
6. Initiate broadband test from ground
7. Perform broadband test with earth stations
    a. Broadband arrays (TX and RX) will point at each respective ground station as the satellite flies overhead
    b. During a transition to an adjacent ground station, the array will (near) instantaneously direct the beam to the next station (no mechanical slewing)
8. Final broadband station sets below 40 degrees elevation below test site
9. Satellite disables Ku-band broadband system
10. Link is lost from Ku-band telemetry
11. Satellite disables Ku-band telemetry at 3 degrees below the horizon

After thorough testing and sufficient confidence is gained, the broadband system may be used independently of the Washington State-based TT&C station to take full advantage of all ground passes over the aforementioned US ground test sites.

<u>Telemetry, Video, and Command Operations</u>

Housekeeping telemetry and video will be stored on-board each satellite and downlinked at appropriate intervals using the TT&C stations. Ku-band stations will be located in CONUS and at several additional non-U.S. locations including Argentina, New Zealand, and Norway, while X/S band communications will use stations in CONUS, along with other third-party TT&C facilities internationally.