MuonSpace

Muon Space - CondorXL0
FCC Part 5 Experimental License
Legal and Technical Narrative

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I. Introduction

Muon Space, Inc. ("Muon" or "Muon Space") respectfully requests authority to launch and operate a single experimental non-geostationary orbit ("NGSO") satellite, known as "CondorXL0," in a sun-synchronous low-Earth orbit ("LEO") at a nominal operational altitude of approximately 590 km, pursuant to 47 C.F.R. § 5.54(a)(1). CondorXL0 will serve as the maiden flight of Muon's new CondorXL satellite bus — a larger and more capable evolution of Muon's existing satellite platform.

During this experimental mission, Muon will:

- Commission and characterize the on-orbit performance of the CondorXL bus, including its propulsion, attitude control, electrical power, thermal, and command and data handling subsystems;
- Demonstrate the Starlink Mini-Laser optical communications subsystem in the operational thermal and radiation environment of LEO; and
- Validate operational concepts, ground system interfaces, and core roadmap components that will be relied upon for subsequent commercial CondorXL missions on behalf of Muon and its customers.

To support these activities, Muon seeks authority to operate in the 2025–2110 MHz band (Earth-to-space) for telemetry, tracking, and command ("TT&C") and high-speed data uplinks, and in the 8025–8400 MHz band (space-to-Earth) for telemetry and high-speed payload data downlinks. All operations in these bands will be conducted on a non-interference basis and will be coordinated with the relevant U.S. Federal agencies, as described in Section VII.D below.

Muon requests authorization by November 1, 2026, to allow adequate time to respond to any potential post-grant complications and to satisfy Muon's contractual obligations to its launch provider, which requires proof of licensure at least two months before launch.

II. Public Interest Statement

Grant of this experimental application will serve the public interest in several important respects.

First, the CondorXL0 mission will enable Muon to mature next-generation satellite hardware in the only environment where it can be fully validated: orbit. While Muon's bus, payload, and subsystem designs are subject to a rigorous program of ground testing, laboratory qualification, and environmental verification, the complex thermal and radiation conditions of LEO cannot be fully replicated on the ground. On-orbit demonstration through CondorXL0 is therefore essential to retiring residual technical risk for the CondorXL platform before it is relied upon for operational customer missions.

Second, the CondorXL platform is being developed in direct response to growing market demand for turnkey, mission-tailored remote sensing solutions. By making advanced satellite capabilities available to entities that would otherwise be unable to design, build, and operate their own space assets, Muon broadens the pool of public- and private-sector organizations that can derive value from space-based data and provide their services to the public. By validating the CondorXL bus and demonstrating advanced optical communications capabilities through CondorXL0, Muon will be positioned to deliver more capable, more reliable, and more cost-effective space-based data products to a diverse set of commercial, scientific, and government customers, including those engaged in Earth observation, climate and weather monitoring, disaster response, and other applications of substantial public benefit.

Third, demonstration of the Starlink Mini-Laser optical communications subsystem will help advance the state of the art in space-to-ground optical communications. Maturing optical communications technology supports more efficient use of the radio-frequency spectrum by reducing reliance on RF downlinks for high-volume payload data, which in turn helps preserve scarce spectrum resources.

For these reasons, Muon respectfully submits that grant of this application would serve the public interest, convenience, and necessity.

III. Applicant Description

Muon is a Delaware C Corporation headquartered in Mountain View, California. The company is an end-to-end space systems provider that designs, builds, and operates mission-tailored LEO satellite constellations. Muon provides comprehensive satellite mission design, construction, and deployment services, alongside sophisticated space-based data and analytical products.

To meet the diversifying needs of its customers and the rapidly evolving space market, Muon is currently developing the CondorXL, a larger and more capable satellite bus designed to complement the existing Muon product line. The CondorXL represents a significant scaling of Muon's architecture, offering:

- **Enhanced Payload Flexibility:** A larger structural volume to accommodate a wider array of sophisticated sensors and customer instruments.
- **Expanded Power Capabilities:** Increased power generation and storage to support high-duty-cycle operations and power-intensive payloads.
- **Operational Flight Heritage:** The experimental phase of the CondorXL is critical for gaining early flight heritage on core roadmap components. While ground testing and laboratory validation are rigorous, the complex thermal and radiation environments of LEO provide a unique validation set that is essential for the maturation of Muon's next-generation space hardware.

Through the CondorXL0 experimental mission, Muon seeks to bridge the gap between theoretical performance and orbital reality, ensuring that the CondorXL platform provides the reliability and performance required for the next generation of Earth observation and data-collection missions.

Muon notes that it has received several licenses from the Commission in the past, including licenses for its MuSat-2, MuSat-3, and MuSat-4 satellites,[1] FireSat System,[2] and its experimental SERT-3 mission.[3] As a satellite

[1] *See* Grant, Muon Space, Inc., Call Sign S3173, ICFS File No. SAT-MOD-20250924-00300 (re-issued May 19, 2026) ("MuSat Grant").
[2] *See* Grant, Muon Space, Inc., Call Sign S00763, ICFS File No. SAT-LOA-20251119-00332 (re-issued May 19, 2026) ("FireSat Grant").
[3] *See* Grant, Muon Space, Inc., Call Sign WQ2XBG, ELS File No. 1040-EX-CN-2025 (Feb. 4, 2026) ("SERT-3 Grant").

manufacturer and commercial operator, the Commission has also processed applications for Muon's customers, including the Sierra Nevada Company.[4] The CondorXL0 mission described herein represents the next step in maturation of Muon's vertically integrated, end-to-end space systems offering.

IV. Mission Description

The CondorXL0 mission is the maiden flight of Muon's CondorXL satellite bus and consists of a single experimental spacecraft. As described in Section I above, the mission's three principal objectives are (i) on-orbit commissioning and characterization of the CondorXL bus and its core subsystems; (ii) demonstration of the Starlink Mini-Laser optical communications subsystem; and (iii) demonstration of operational concepts that will support subsequent commercial CondorXL missions. This section describes the operational sequence by which Muon will accomplish those objectives.

A. Launch and Deployment

CondorXL0 will be launched no earlier than February 1, 2027, as a rideshare payload aboard the SpaceX Falcon 9 Transporter-19 mission, likely from Vandenberg Space Force Base. The launch vehicle will insert CondorXL0 into a sun-synchronous orbit at an altitude between approximately 480 and 620 km and an inclination of approximately 98°. A summary of expected launch and deployment parameters is provided in Table 1 below.

Because the precise RAAN and LTAN/LTDN are influenced by the precise timing of the launch, it is not possible to provide an accurate value at the time of filing. Muon has provided estimates primarily based on preliminary parameters as contracted with SpaceX and parameters from previous, similar missions and will provide a final RAAN and LTAN/LTDN closer to the time of launch.

Table 1: Summary of CondorXL0 Launch and Deployment Parameters

Target Launch Date:	NET February 1, 2027
Launch Vehicle:	SpaceX - Falcon 9 Transporter-19
Launch Site:	TBD; likely Vandenberg Space Force Base, CA
Orbit:	NGSO, sun-synchronous
Insertion Apogee (km):	500-600 ± 20
Insertion Perigee (km):	500-600 ± 20
Inclination (°):	98° ± 1°
LTAN/LTDN:	TBD; typically either LTAN of 11:00 ± 30 min (LTDN of 23:00 ± 30 min) or LTAN of 14:00 ± 30 min (LTDN of 02:00 ± 30 min)

[4] *See* Grant, Sierra Nevada Company, LLC, Call Sign S3214, ICFS File No. SAT-LOA-20241205-00275 (Aug. 1, 2025).

Right Ascension of the Ascending Node (RAAN) (°):	To be determined based on final launch timing; typically either 116.9° ± 7.5° or 161.9° ± 7.5° (assuming 2/1/2027 00:00:00 UTC launch time)
Epoch:	2/1/2027 00:00:00 UTC

B. Initial Commissioning

Following deployment, CondorXL0 will make contact with the third-party ground station network described in Section VII.A, Earth Station Network, below. Initial ephemeris produced by the launch provider will be used to schedule the first contact pass; thereafter the spacecraft's onboard TT&C and navigation system will provide precise position data used to refine orbital determination throughout the mission. As needed, the spacecraft will use its onboard propulsion to raise or lower its altitude to the nominal operational orbit of approximately 590 km. During the initial commissioning phase, Muon will perform a thorough evaluation and systems check of the bus, including verification of the attitude control system (which uses four reaction wheels, three magnetorquers, two star trackers, a magnetometer, a sun sensor, a gyroscope, and a Global Navigation Satellite System receiver to maintain three-axis control), the electrical power system, the thermal subsystem, the command and data handling system, and both of the spacecraft's redundant Hall-effect propulsion systems. Muon will confirm nominal performance of each subsystem before transitioning to the primary experimental phase of the mission.

C. Primary Experimental Operations

Once commissioning is complete, CondorXL0 will operate at a nominal circular sun-synchronous orbit of approximately 590 ± 5 km in a local-vertical/local-horizontal ("LVLH") attitude, with occasional controlled slews to track ground station receivers for RF communications and to track the sun for enhanced power generation. During this phase, Muon will conduct the following experimental campaigns:

- <u>Bus Characterization:</u> Muon will exercise the CondorXL bus across its operational envelope to gather flight-heritage data on subsystem performance, thermal behavior, and power generation under realistic LEO conditions. Selected propulsion testing and demonstration maneuvers may be conducted, which may include limited shifts in the spacecraft's LTAN/LTDN within the tolerances identified in Table 1 above.
- <u>Optical Communications Demonstration:</u> CondorXL0 will demonstrate the Starlink Mini-Laser optical communications subsystem in the operational LEO environment. The results of this demonstration will inform integration of optical communications technology on future Muon and Muon-customer missions and contribute to the maturation of space-to-ground optical communications more broadly.
- <u>Operational Concepts Demonstration:</u> Muon will exercise the end-to-end mission operations chain, including ground network scheduling, on-orbit tasking, telemetry processing, and high-speed data downlink, to validate the operational concepts and ground-system interfaces that will support subsequent commercial CondorXL missions.

Mission operations will be conducted and monitored from Muon's Satellite Control Centers at its headquarters in Mountain View, California and at its facility in San Jose, California.

D. Mission Completion and Disposal

Following the nominal 5-year operational lifetime, CondorXL0 will be actively decommissioned and disposed of via atmospheric re-entry, as described in detail in the Orbital Debris Mitigation Plan ("ODMP") and Assessment Report submitted concurrently with this application. In summary, Muon will use the spacecraft's onboard propulsion to lower its altitude to approximately 380 km over a period of approximately two months post-mission, after which the spacecraft will transition to a high-drag orientation and allow its orbit to passively decay until atmospheric re-entry. Total post-mission orbital lifetime is expected to be approximately 5.5–7 months under nominal conditions, well within the 5-year disposal window under § 5.64(b)(7)(iv)(A). Muon will maintain the satellite's power flux density ("PFD") levels within applicable interference protection limits throughout the disposal phase by reducing transmitter power on a graduated basis as the satellite approaches re-entry altitude.

V. Orbital Debris Mitigation Summary

CondorXL0 has been designed from the outset to comply with the Commission's orbital debris mitigation rules under 47 C.F.R. § 5.64, the U.S. Government Orbital Debris Mitigation Standard Practices, and the technical framework of NASA-STD-8719.14C. The full technical showings required by § 5.64, including the underlying calculations, NASA Debris Assessment Software ("DAS") v3.2.6 outputs, and disposal trajectory plots, are provided in the ODMP. This section provides a high-level summary.

By design, no debris will be released in a planned manner during normal operations. Separation from the launch vehicle and deployment of the solar arrays will be accomplished using debris-free, non-pyrotechnic mechanisms with extensive flight heritage, and CondorXL0 has no deployable antennas. The spacecraft has no pressurized vessels and no fluid systems on board; its two redundant Hall-effect propulsion systems use solid zinc propellant stored in unpressurized reservoirs, and all on-board sources of stored energy will be passivated at end of mission.[5] Per DAS v3.2.6, the small-object penetration risk is 0.0041, well below the 0.01 threshold of § 5.64(b)(2).[6]

CondorXL0 is highly maneuverable and equipped with two redundant propulsion systems capable of independent collision avoidance maneuvers. The probability of collision with large objects is well below the 0.001 threshold of § 5.64(b)(4)(i)(A) across all credible operational and failure scenarios.[7] Muon will register CondorXL0 with the 18th Space Defense Squadron prior to deployment, share owner/operator ephemeris and planned maneuver information via Space-Track.org, and coordinate with NASA and any other relevant parties to protect the inhabited space stations on an ongoing basis.[8] Upon receipt of any conjunction warning, Muon will take all available steps to assess and mitigate the collision risk consistent with § 5.64(b)(4)(i)(E).[9]

The CondorXL0 mission does not include any planned proximity operations. The CondorXL0 disposal concept of operations ("CONOPS") is summarized in Section IV.D, Mission Completion and Disposal above and described in full in the ODMP.[10] Per DAS v3.2.6, no spacecraft components are expected to survive re-entry with kinetic energy in excess of 15 J, resulting in a calculated human casualty risk below the 1-in-10,000 threshold of §

[5] *See* ODMP § V, 47 C.F.R. § 5.64(b)(3) — Accidental Explosions and Release of Liquids.
[6] *See* ODMP § V, 47 C.F.R. § 5.64(b)(2) — Collisions with Small Debris and Meteoroids.
[7] *See* ODMP § V, 47 C.F.R. § 5.64(b)(4)(i)(A) — Collision Probability with Large Objects.
[8] *See* ODMP § V, 47 C.F.R. § 5.64(b)(5) — Trackability and Information Sharing.
[9] *See* ODMP § V, 47 C.F.R. § 5.64(b)(4)(i)(E) — Conjunction Warning Response.
[10] *See* ODMP § V, 47 C.F.R. § 5.64(b)(7) — Disposal Plan and Propellant Reserve.

5.64(b)(7)(iv)(B)(2).[11] Muon's reliability analysis further demonstrates that the probability of successful disposal exceeds the 0.9 threshold of § 5.64(b)(7)(iv)(A).[12]

VI. Satellite Description

This section describes the physical and functional characteristics of the CondorXL0 spacecraft. Operational concepts, attitude control behavior, and propulsion concepts of operations are addressed in Section IV, Mission Description above and in the accompanying ODMP.

A. Physical Characteristics

CondorXL0 dimensions, stowed configuration:	2.56 m × 1.16 m × 1.64 m
CondorXL0 dimensions, with solar arrays deployed:	6.45 m × 5.52 m × 1.64 m
CondorXL0 mass at launch (incl. propellant):	~ 462 kg
CondorXL0 mass at launch (without propellant):	~ 422 kg
CondorXL0 mass at end-of-life:	~ 430 kg
CondorXL0 area-to-mass ratio, LVLH configuration (incl. propellant):	0.003 m^2/kg
CondorXL0 area-to-mass ratio, tumbling configuration (incl. propellant):	0.019 m^2/kg
CondorXL0 area-to-mass ratio, high-drag configuration (incl. propellant):	0.032 m^2/kg

The "tumbling configuration" refers to the controlled tumbling guidance mode that CondorXL0 enters by default on initial boot, in response to a critical anomaly, or after extended loss of contact, in which the spacecraft uses its magnetorquers to maintain a tumbling rate of two revolutions per orbit.

The spacecraft has no deployable antennas; the only deployable structures are its solar arrays.

[11] *See* ODMP § V, 47 C.F.R. § 5.64(b)(7)(iv)(B)(1)–(2) — Re-Entry Type and Human Casualty Risk.
[12] *See* ODMP § V, 47 C.F.R. § 5.64(b)(7)(iv)(A) — Disposal Reliability.

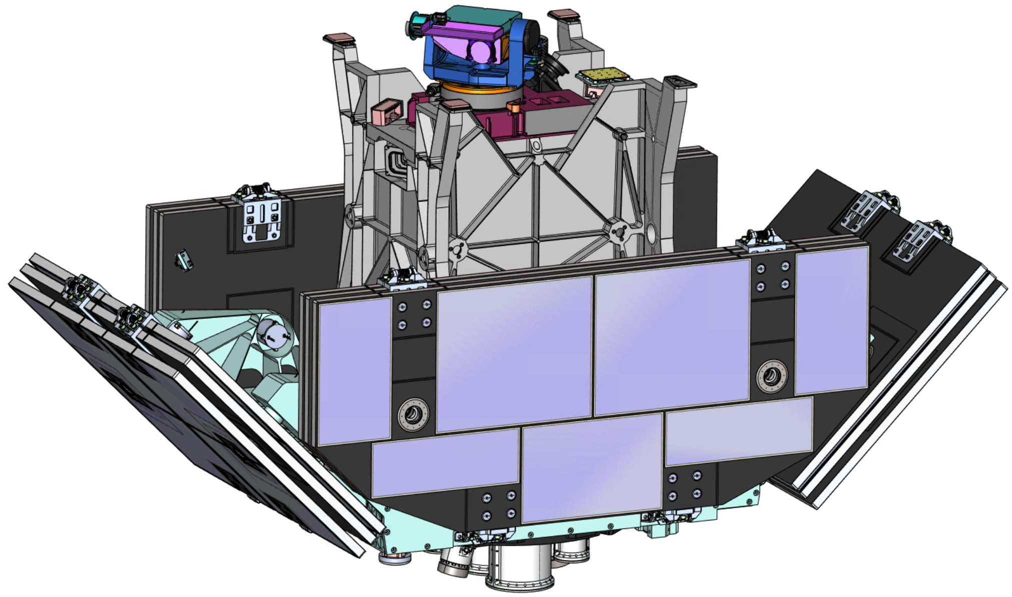

Figure 1: CondorXL0 in its stowed configuration

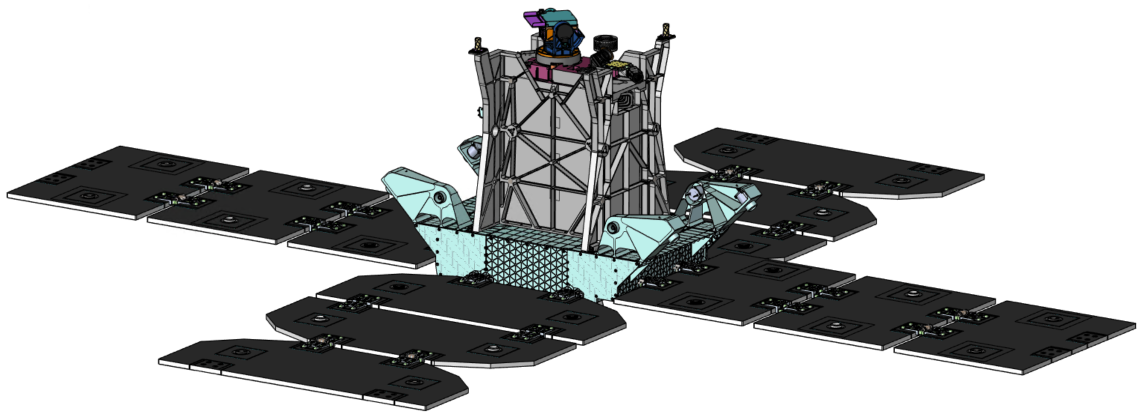

Figure 2: CondorXL0 in its deployed configuration

B. Electrical Power System

Power is generated by deployable arrays of single-junction solar cells, arranged in four arrays of three panels each, and stored in six 96-cell battery packs. Battery assemblies are charged prior to launch-vehicle integration, and on-board power management and distribution electronics control battery state-of-charge and the flow of power to the spacecraft's other subsystems.

C. Propulsion System

CondorXL0's two redundant Hall-effect propulsion systems use solid zinc as propellant stored in unpressurized reservoirs. CondorXL0 will launch with approximately 40 kg of propellant, supporting a maximum mission Δv capability of approximately 1,000 m/s. Of the 40 kg, approximately 12.7 kg is reserved for post-mission disposal and approximately 0.4 kg is reserved for collision-avoidance maneuvers, with the balance available for orbit-insertion corrections, routine station-keeping, and propulsion-related demonstration maneuvers. Because the propellant is stored as a solid in an unpressurized reservoir, the propulsion system contains no pressurized vessels. Propellant budgeting across station-keeping, collision avoidance, and post-mission disposal is detailed in the ODMP.[13]

D. Communications Subsystem

CondorXL0's RF communications subsystem supports TT&C and high-speed data links in the S-band (uplink) and X-band (downlink) frequencies identified in Section I above and detailed in Section VII, Communications System Description, below. The spacecraft also hosts the Starlink Mini-Laser optical communications subsystem as a demonstration payload.

During nominal operations, CondorXL0 does not transmit telemetry or data unless explicitly enabled by ground command. In the event the spacecraft is unable to make contact with the ground for longer than 12 hours, CondorXL0 will autonomously enter a low-duty-cycle "safe mode" beacon state in which it transmits 0.25-second bursts of satellite status data every 30 seconds (a duty cycle of approximately 0.8%), using the same X-band TT&C downlink carriers (TCD1 and TCD2), power levels, and bandwidths described in Section VII below. The beacon is not active during nominal operations, is expected to be infrequent, and can be disabled from mission control. Similar beacon operations have been authorized under Muon's license for its MuSat system (S3173) and its FireSat System (S00763).[14]

Muon intends to communicate with CondorXL0 from injection until re-entry into the atmosphere is imminent. Muon will maintain the satellite's PFD levels within the applicable ITU limits by reducing satellite transmitter power on a graduated basis as the satellite nears the Earth.

VII. Communications System Description

This section describes the technical characteristics of the CondorXL0 communications system, including the third-party ground station network that will support the mission, the requested frequency plan, and the band-by-band justification for Muon's planned spectrum use. CondorXL0 will share a common bus with Muon's and its customers' planned satellites and therefore, like them, will communicate in the S- and X- bands. The S-band (2025–2110 MHz) will be used for TT&C, while the X-band (8025–8400 MHz) will be used for both TT&C and payload data downlinks. The radio-frequency parameters described here are also reflected in the satellite antenna characteristics, predicted gain contour, out-of-band emissions ("OOBE"), and PFD showings provided in Sections VIII through XI below.

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[13] *See* ODMP § V, 47 C.F.R. § 5.64(b)(7)–(7)(iii) — Disposal Plan and Propellant Reserve.

[14] MuSat Grant, Call Sign S3173; FireSat Grant, Call Sign S00763.

A. Earth Station Network

CondorXL0 will be supported by a global network of third-party ground stations operated by Kongsberg Satellite Services ("KSAT") and Leaf Space ("Leaf"). This geographically diverse network provides frequent, well-distributed contact opportunities for both TT&C and high-speed payload data downlinks. A summary of the supporting ground stations is provided in Table 2 below.

Table 2: Earth Stations for CondorXL0				
Operator	**Location**	**Coordinates (Latitude, Longitude)**		**Type**
KSAT	Fairbanks, AK, USA	64.81775	-147.71913	S-band Uplink, X-band Downlink
	Hawaii, USA	20.82000	-156.45000	S-band Uplink, X-band Downlink
	Las Cruces, NM, USA	32.27000	-106.91000	S-band Uplink, X-band Downlink
	Svalbard, Norway	78.23150	15.41110	S-band Uplink, X-band Downlink
	Puertollano, Spain	38.67000	-4.16000	S-band Uplink, X-band Downlink
	Hartebeesthoek, South Africa	-25.88599	27.70560	S-band Uplink, X-band Downlink
	Mingenew, Australia	-29.01000	115.34000	S-band Uplink, X-band Downlink
	Awarua, New Zealand	-46.52811	168.37919	S-band Uplink, X-band Downlink
	Punta Arenas, Chile	-52.93635	-70.87012	S-band Uplink, X-band Downlink
	Longovilo, Chile	-33.96000	-70.87012	S-band Uplink, X-band Downlink
Leaf	Anchorage, AK, USA	62.33300	-150.03162	S-band Uplink, X-band Downlink
	La Paz, Mexico	24.10000	-110.37000	S-band Uplink, X-band Downlink
	Santa Maria, Portugal (Azores)	36.99756	-25.13731	S-band Uplink, X-band Downlink
	Unst, United Kingdom	60.75000	-0.86000	S-band Uplink, X-band Downlink

	Blonduos, Iceland	65.65000	-20.25000	S-band Uplink, X-band Downlink
	Baku, Azerbaijan	40.46628	49.48581	S-band Uplink, X-band Downlink
	Ripailles, Mauritius	-20.13947	57.68706	S-band Uplink, X-band Downlink
	Pretoria, South Africa	-25.86033	28.45378	S-band Uplink, X-band Downlink
	Nangetty, Australia	-29.01042	115.34167	S-band Uplink, X-band Downlink
	Peterborough, Australia	-32.96200	138.84950	S-band Uplink, X-band Downlink
	Awarua, New Zealand	-46.52811	168.37919	S-band Uplink, X-band Downlink
	Punta Arenas, Chile	-53.04122	-70.84711	S-band Uplink, X-band Downlink

B. Spectrum Use and Frequency Plan

CondorXL0 will carry a single integrated communications subsystem consisting of S-band TT&C and high-speed data uplinks (Earth-to-space) and X-band TT&C and high-speed data downlinks (space-to-Earth).

Table 3 summarizes the requested channel assignments below.

Table 3: CondorXL0 Frequency and Channel Assignments

Usage	Channel ID	Link Direction	Service Band
TT&C Command Uplink	TCU1	Earth-to-space	EESS, S-band, 2025–2110 MHz
High-Speed Data Uplink	HSU1	Earth-to-space	EESS, S-band, 2025–2110 MHz
Nadir-Side TT&C Downlink	TCD1	space-to-Earth	EESS, X-band, 8025–8400 MHz
Zenith-Side TT&C Downlink	TCD2	space-to-Earth	EESS, X-band, 8025–8400 MHz
High-Speed Data Downlink	HSD5	space-to-Earth	EESS, X-band, 8025–8400 MHz

C. Band-by-Band Analysis

S-band Uplink (2025–2110 MHz) — TCU1 and HSU1

CondorXL0 will receive command and high-speed data uplinks in the 2025–2110 MHz band, which is allocated on a primary basis to the Earth Exploration-Satellite Service ("EESS"), the Space Operation Service, and the Space Research Service in the Earth-to-space direction. Muon seeks to operate two narrow uplink channels in this band for EESS — TCU1 (280 kHz centered at 2061.50 MHz) for command and HSU1 (980 kHz centered at 2062.50 MHz) for data uplink.

The following table identifies the requested center frequencies in the S-band for the CondorXL0 satellite:

Table 4: CondorXL0 S-band Uplinks (2025–2110 MHz)				
Channel ID	**Bandwidth**	**Center Frequency**	**Polarization**	**Antenna Gain**
TCU1	280 kHz	2061.50 MHz	RHCP	2 dBi
HSU1	980 kHz	2062.50 MHz	RHCP	2 dBi

X-band Downlink (8025–8400 MHz) — TCD1, TCD2, and HSD5

CondorXL0 will transmit TT&C telemetry and high-speed payload data in the 8025–8400 MHz band, which is allocated on a primary basis to the EESS in the space-to-Earth direction. CondorXL0 will operate two narrow TT&C downlink channels — TCD1 (2.8 MHz centered at 8385.0 MHz) on the nadir side and TCD2 (2.8 MHz centered at 8390.0 MHz) on the zenith side — together with a single 300 MHz high-speed data downlink (HSD5) centered at 8175.0 MHz.

The following table identifies the requested center frequencies in the X-band for the CondorXL0 satellite:

Table 5: CondorXL0 X-band Downlinks (8025–8400 MHz)				
Channel ID	**Bandwidth**	**Center Frequency**	**Polarization**	**Antenna Gain**
TCD1	2.8 MHz	8385.0 MHz	RHCP	2 dBi
TCD2	2.8 MHz	8390.0 MHz	RHCP	2 dBi
HSD5	300 MHz	8175.0 MHz	RHCP	17 dBi

D. Coordination with Federal Operators

Both the S-band uplink (2025–2110 MHz) and X-band downlink (8025–8400 MHz) bands requested for CondorXL0 are subject to coordination with U.S. Federal agencies. Muon has commenced this coordination prior to filing this application and understands that it must complete coordination before receiving a Commission authorization.

Muon anticipates that it will be able to successfully coordinate its proposed frequency use. The characteristics and duration of Muon's proposed use of spectrum are limited and consistent with other commercial missions, including Muon's SERT-3 mission, its operational MuSat satellites, and its FireSat System that have all completed coordination with Federal agencies in these same bands.[15] The center frequencies identified in Tables 4 and 5 have been selected based on rigorous RF analysis and prior guidance from NASA and NOAA regarding frequency ranges least likely to cause interference with Federal operations, and Muon's use of software-defined radios provides additional flexibility to refine carrier placement during the coordination process if necessary.

E. Cessation of Emissions

Consistent with 47 C.F.R. § 25.207, Muon has the capability to command CondorXL0 to cease emissions on each of its transmit channels (TCD1, TCD2, and HSD5). Cessation commands can be issued from mission control via any of the ground stations identified in Table 2. As described in Section VI.D, Communications Subsystem, above, CondorXL0 does not transmit telemetry or payload data during nominal operations unless explicitly enabled by ground command, and the autonomous safe mode beacon, the only transmission that occurs absent an affirmative ground command, can likewise be disabled from mission control.

VIII. Satellite Antenna Characteristics and Radiation Patterns

This section provides a summary of the radio-frequency parameters and radiation patterns for each antenna onboard CondorXL0. CondorXL0 carries three antenna types: a quadrifilar helical antenna for S-band uplink reception (used for both TCU1 and HSU1), a quadrifilar helical antenna for X-band TT&C downlink transmission (used for both TCD1 and TCD2, mounted on both nadir and zenith sides for full attitude coverage), and a higher-gain patch array antenna for the high-speed X-band data downlink (HSD5) on the nadir side. The relatively wide beamwidths of the S-band uplink and X-band TT&C antennas ensure reliable command and telemetry contact across a broad range of spacecraft attitudes, while the narrower-beam HSD5 patch array supports the higher effective isotropic radiated power ("EIRP") required for high-rate payload data downlink to ground station antennas.

A. S-band TCU1 and HSU1 Receiver Antennas

The same quadrifilar helical antenna design supports both the TT&C command uplink (TCU1) and the high-speed data uplink (HSU1) channels in the 2025–2110 MHz band. To provide reliable uplink reception in any spacecraft attitude, TCU1 reception is supported by quadrifilar helical antennas mounted on the nadir and zenith sides of the spacecraft; HSU1 reception uses the nadir-side antenna only.

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[15] *See* MuSat Grant , Call Sign S3173 (MuSat-2, MuSat-3, MuSat-4); FireSat Grant, Call Sign S00763 (FireSat System); SERT-3 Grant, Call Sign WQ2XBG (SERT-3).

Table 6: CondorXL0 S-band TCU1 and HSU1 Receiver Antenna Characteristics	
Type:	Quadrifilar Helical
Frequency:	2025–2110 MHz
Gain:	2.0 dBi, RHCP
3-dB Beamwidth:	160°
Location:	Both nadir and zenith for TCU1, one on nadir for HSU1

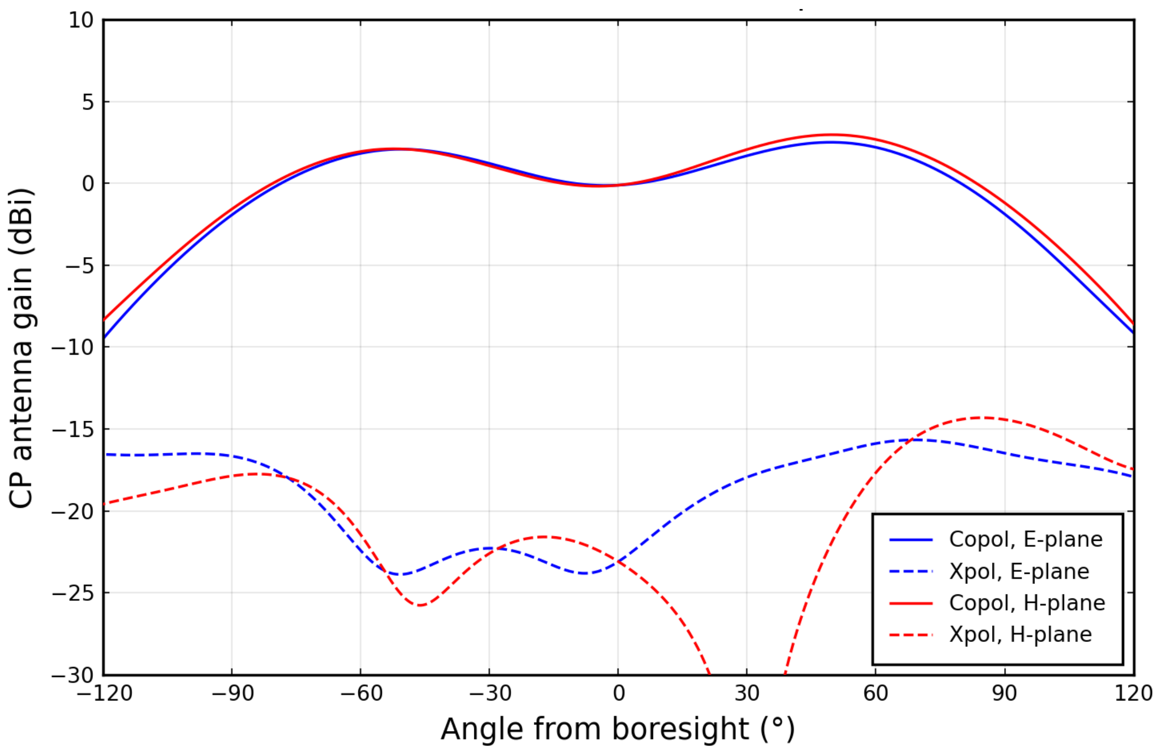

Figure 3: TCU1 and HSU1 S-band Receiver Antenna Radiation Pattern

B. X-band TCD1 and TCD2 Transmitter Antennas

CondorXL0's X-band TT&C downlink uses a quadrifilar helical antenna design mounted on the nadir (TCD1) and zenith (TCD2) sides of the spacecraft. This dual-antenna configuration ensures that CondorXL0 can maintain TT&C downlink contact with the ground regardless of spacecraft attitude, including during initial commissioning, controlled slews, propulsion testing, and any off-nominal attitude conditions.

Table 7: CondorXL0 X-band TCD1 and TCD2 Transmitter Antenna Characteristics	
Type:	Quadrifilar Helical
Frequency:	8025–8400 MHz
Gain:	2.0 dBi, RHCP
3-dB Beamwidth:	160°
Location:	Nadir (TCD1) and zenith (TCD2)

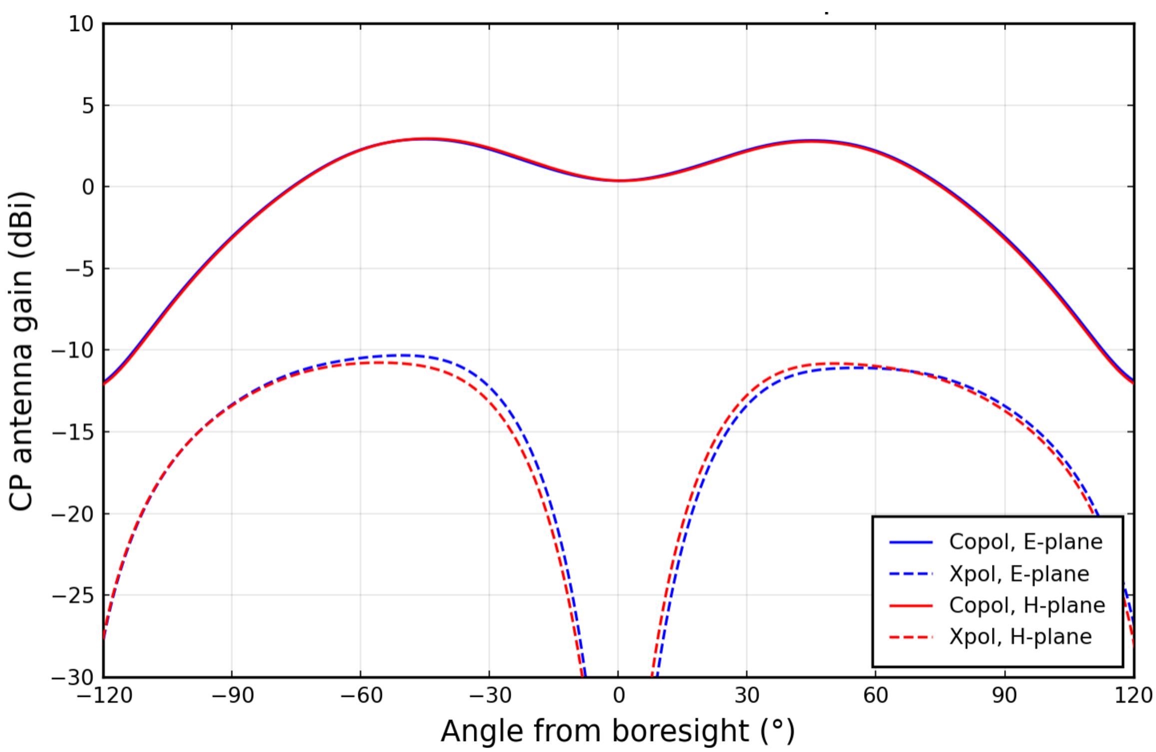

Figure 4: TCD1 and TCD2 X-band Transmitter Antenna Radiation Pattern

C. X-band HSD5 Transmitter Antenna

The high-speed X-band data downlink (HSD5) is supported by a higher-gain patch array antenna mounted on the nadir side of the spacecraft. The narrower beamwidth and higher gain of this antenna are appropriate for the high data rates supported by HSD5 and enable efficient delivery of payload data to ground station receivers when the antenna is pointed at the ground station during a contact pass.

Table 8: CondorXL0 X-band HSD5 Transmitter Antenna Characteristics	
Type:	Patch array
Frequency:	8025–8400 MHz
Gain:	17 dBi, RHCP
3-dB Beamwidth:	19°
Location:	Nadir

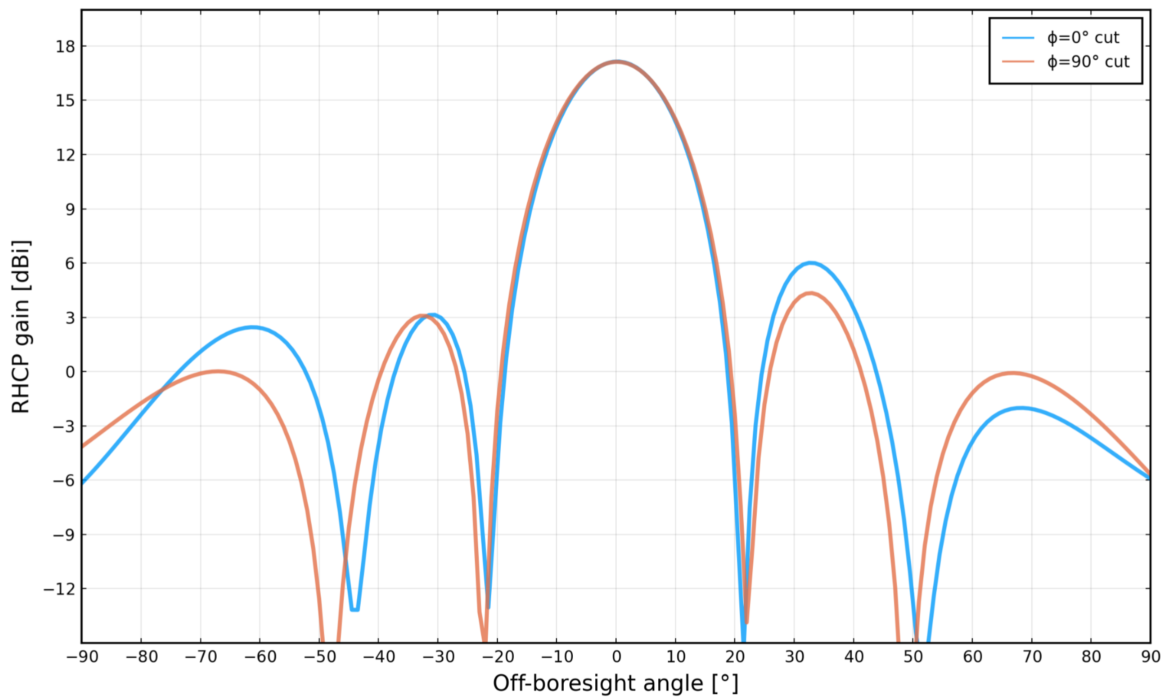

Figure 5: HSU1 X-band Transmitter Antenna Radiation Pattern

IX. Predicted Gain Contours

Consistent with 47 C.F.R. § 25.114(c)(4)(vi)(B), Muon provides below the predicted antenna gain contours for each of the CondorXL0 transmit and receive antennas.

CondorXL0's antennas can be grouped into two contour families based on their radiation patterns:

- <u>Wide-beam transmit and receive antennas (TCU1, HSU1, TCD1, and TCD2 beams):</u> the quadrifilar helical antennas described in Sections VIII.A and VIII.B above, which have 160° 3-dB beamwidths and 2.0 dBi peak gain; and
- <u>Narrow-beam transmit antenna (HSD5 beam):</u> the X-band patch array described in Section VIII.C above, which has a 19° 3-dB beamwidth and 17 dBi peak gain.

Contours for both families are provided for the satellite at nadir over a representative ground station, KSAT's Punta Arenas station, within the supporting network. In all plots, axis ticks are numbered in degrees of longitude and latitude.

A. Wide-beam Tx and Rx Antenna Footprints (TCU1, HSU1, TCD1, and TCD2)

The TT&C wide-beam quadrifilar helical antennas have a gain variation of less than 2 dB across the entire visible region footprint when pointed at nadir. The visible contours displayed below are for the +1 dB and +2 dB antenna gain levels; contours below +1 dB cannot be displayed because they fall beyond the Earth's limb at the satellite's operational altitude.

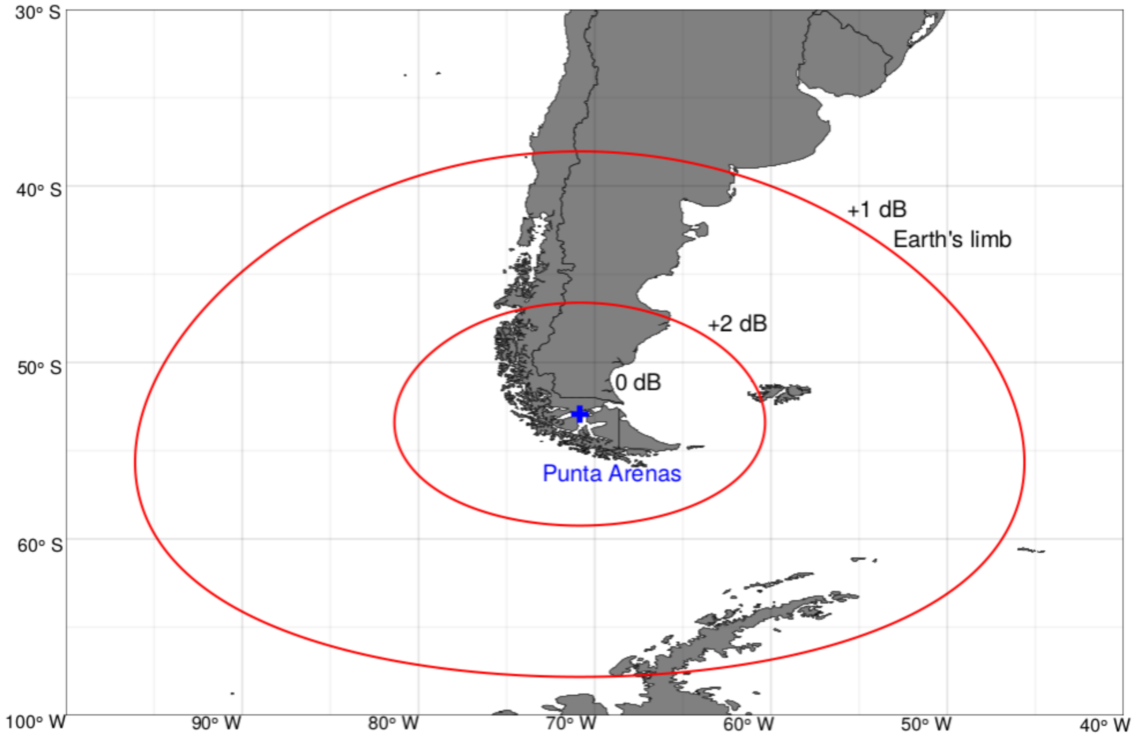

Figure 6: Wide-beam Tx/Rx Antenna Footprint Plot — Punta Arenas KSAT Station at Nadir

B. Narrow-beam Tx Antenna Footprint (HSD5)

The HSD5 patch array antenna footprint is plotted below at 2 dB intervals from -2 dB to -10 dB relative to the peak gain, with additional contours at -15 dB and -20 dB, when the antenna is nadir-pointing over the ground station.

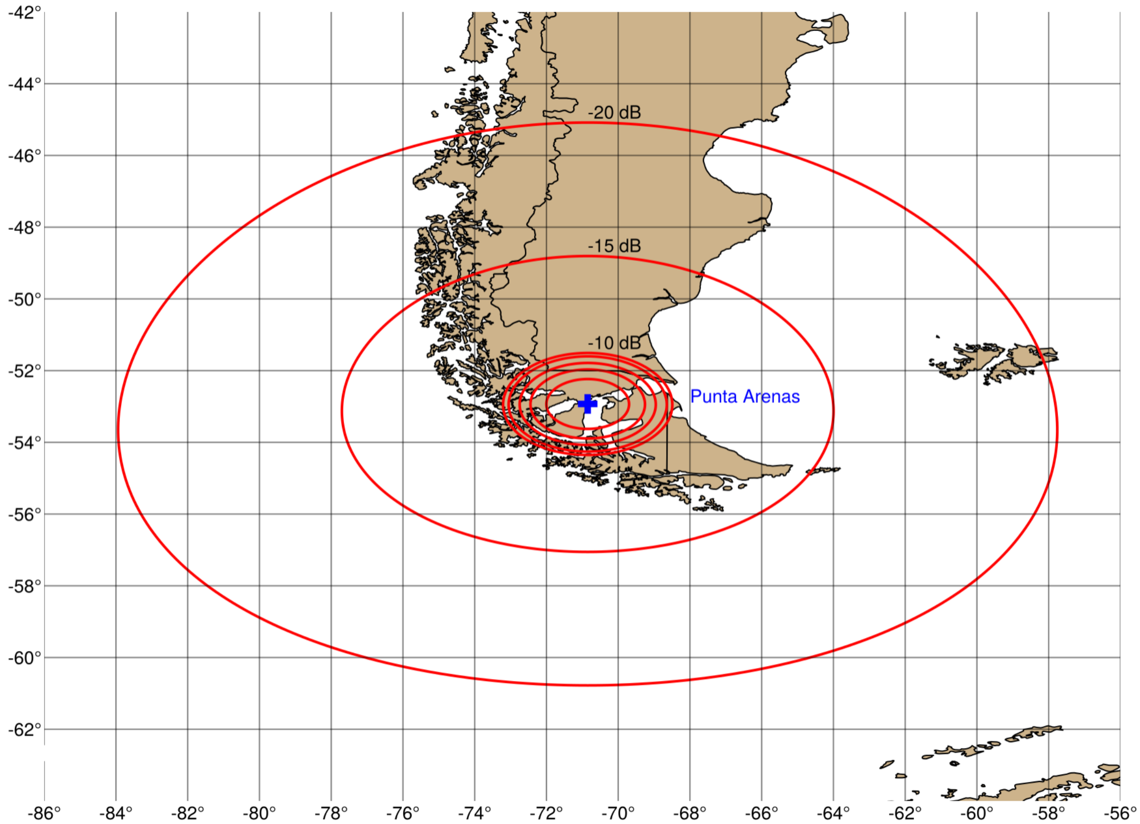

Figure 7: Narrow-beam Tx Antenna Footprint Plot — Punta Arenas KSAT Station at Nadir

X. Out-of-Band Emissions

CondorXL0 complies with all applicable OOBE and spurious-domain emission limits. Specifically, CondorXL0's downlink transmissions will satisfy the OOBE limits in 47 C.F.R. § 25.202(f)(1), (2), and (3), as well as the limits specified in the following ITU recommendations:

- Recommendation ITU-R SM.1541 (rev. 7, 09/2024): Unwanted emissions in the out-of-band domain (Annexes 2 and 5);
- Recommendation ITU-R SM.329 (rev. 13, 09/2024): Unwanted emissions in the spurious domain (Category A limits); and
- Recommendation ITU-R SA.1157 (rev. 1, 03/2006): Protection criteria for deep-space research.

Compliance with the deep-space research band protection criteria of ITU-R SA.1157 is addressed separately in Section XI, Power Flux Density Analysis, below, which contains the full PFD showing for the 8400–8450 MHz band. Compliance with the OOBE and spurious-domain limits is demonstrated below.

A. Compliance with 47 C.F.R. § 25.202(f) and ITU-R SM.1541

As illustrated by the transmitter output spectrum plots provided, CondorXL0 will comply with the OOBE limit masks of 47 C.F.R. § 25.202(f)(1), (2), and (3), as well as the corresponding limits in Recommendation ITU-R SM.1541, for each of its X-band downlink channels.

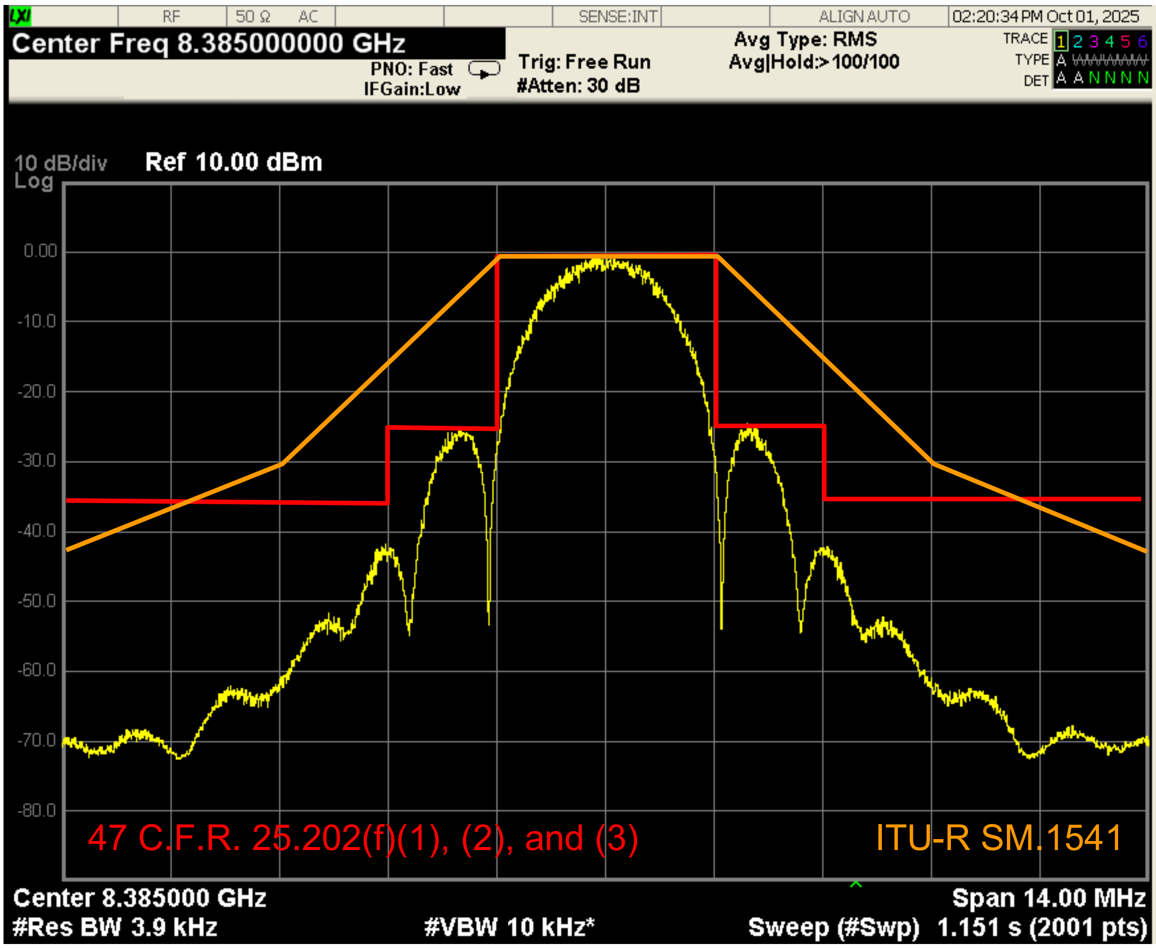

Figure 8: Out-of-band Emissions for TCD1

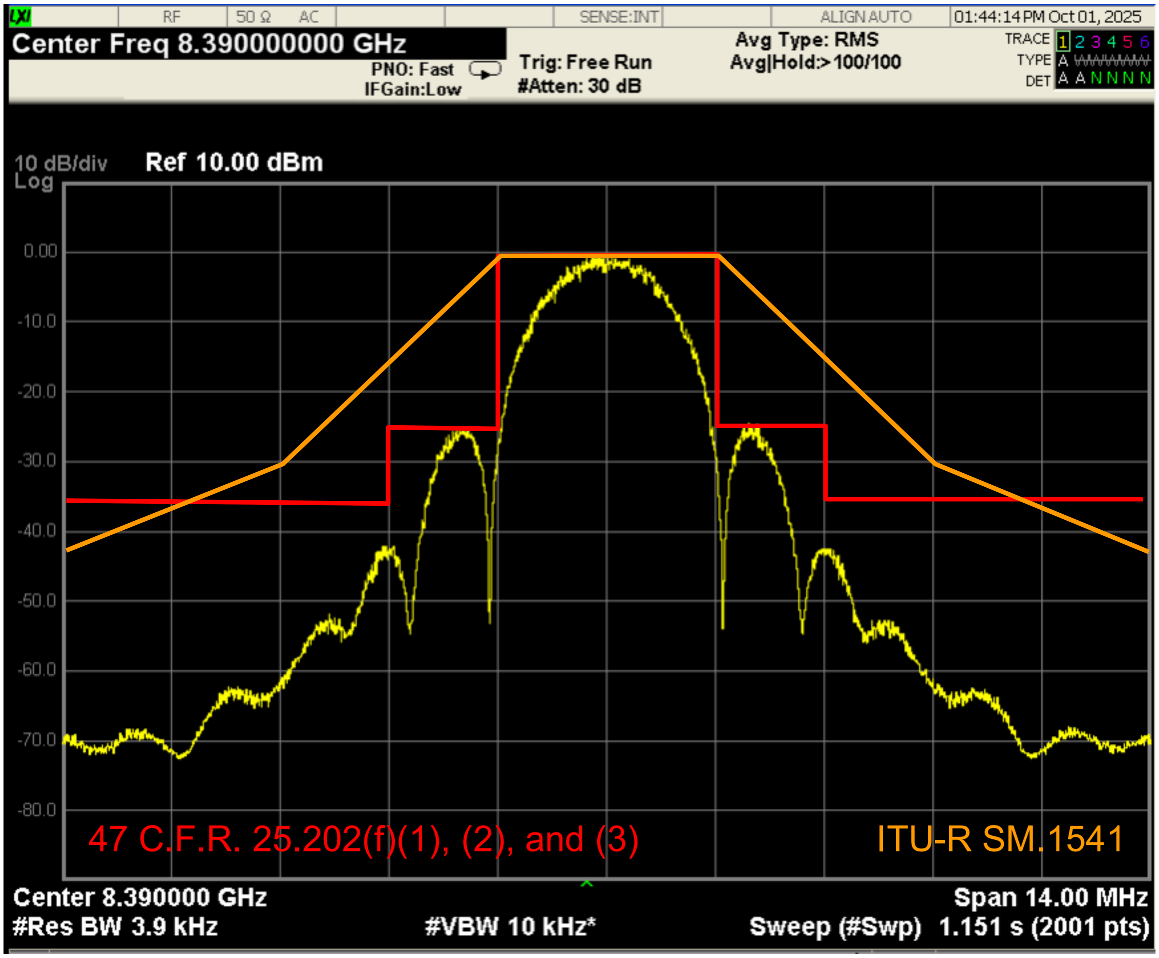

Figure 9: Out-of-band Emissions for TCD2

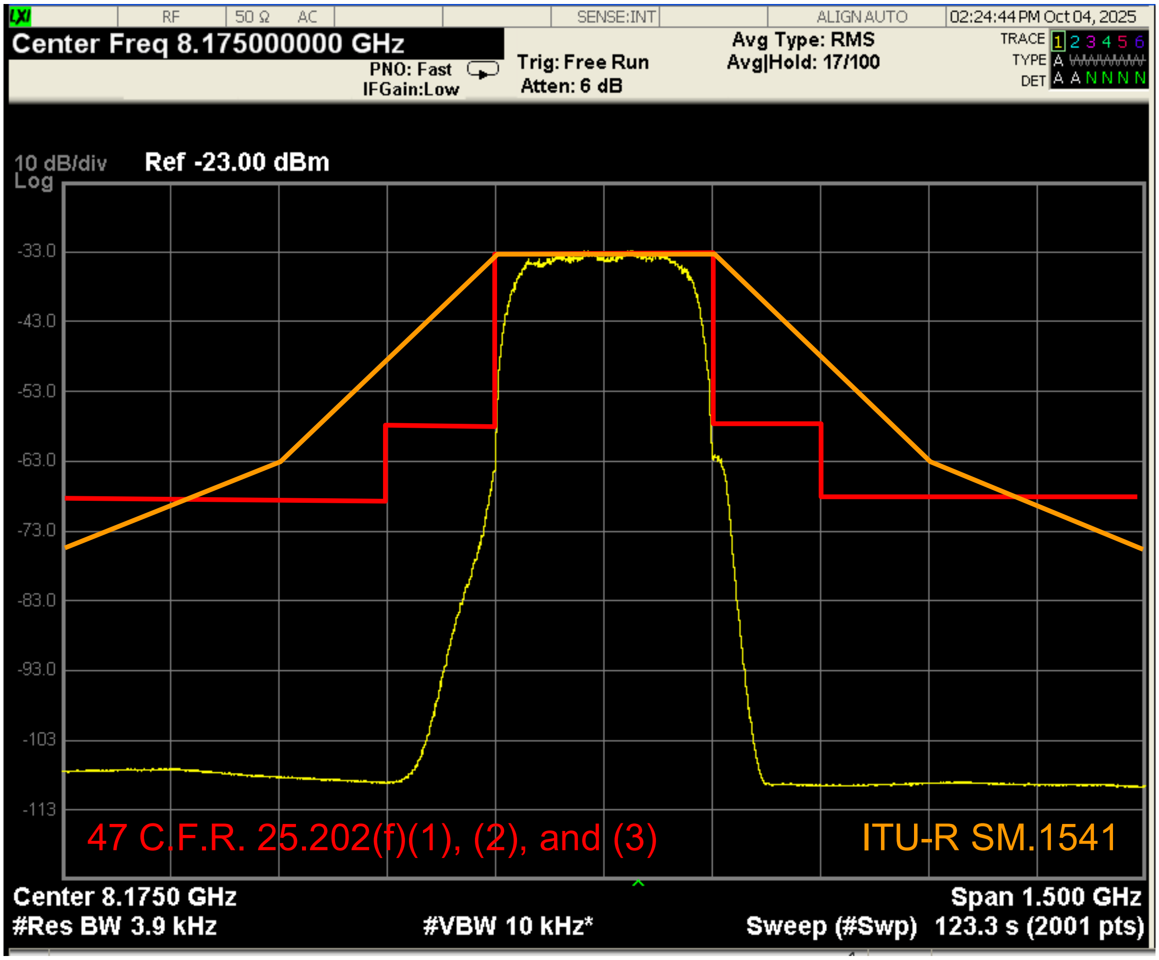

Figure 10: Out-of-band Emissions for HSD5

B. Compliance with Recommendation ITU-R SM.329

CondorXL0 will also comply with the spurious-domain emission limits in Recommendation ITU-R SM.329. The applicable limit is the Category A limit for space services (space stations), defined as 43 + 10 $\log_{10}$ (P), or 60 dBc, whichever is less stringent, where P is the mean power level applied to the antenna. The recommended reference bandwidth is 4 kHz; the closest bandwidth allowed by the measuring signal analyzer used for the showings below is 3.9 kHz.

For the TCD1 and TCD2 channels, the average power level at the antenna port is 10 $\log_{10}$ (P) = -5 dBW. For the HSD5 channel, the average power level at the antenna port is 10 $\log_{10}$ (P) = +2 dBW. The compliance plots below identify the in-band transmission carriers (TCD1 centered at 8385 MHz; TCD2 centered at 8390 MHz; HSD5 centered at 8175 MHz) and demonstrate that the spurious-domain emissions remain below the applicable Category A limit across the relevant frequency range.

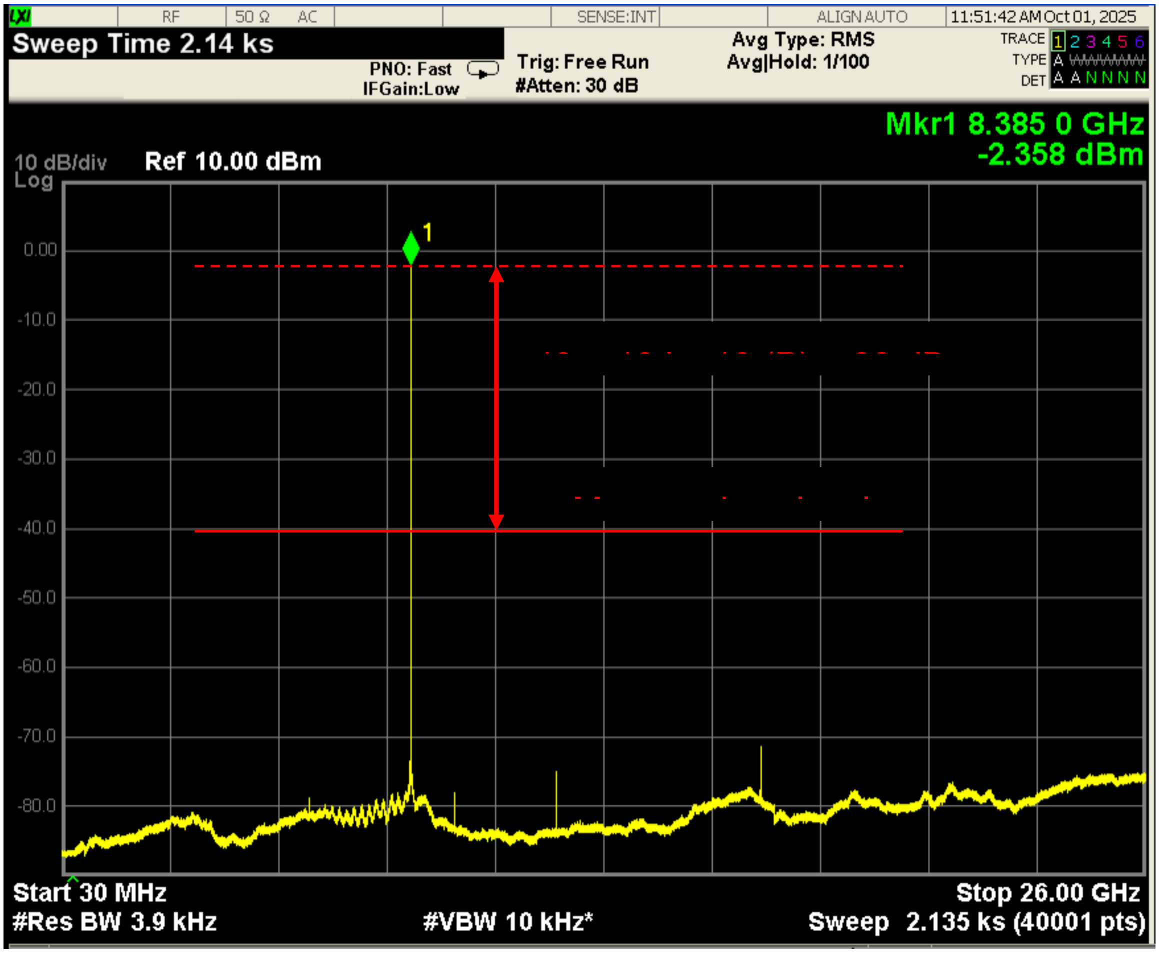

Figure 11: TCD1 ITU-R SM.329 Mask Compliance

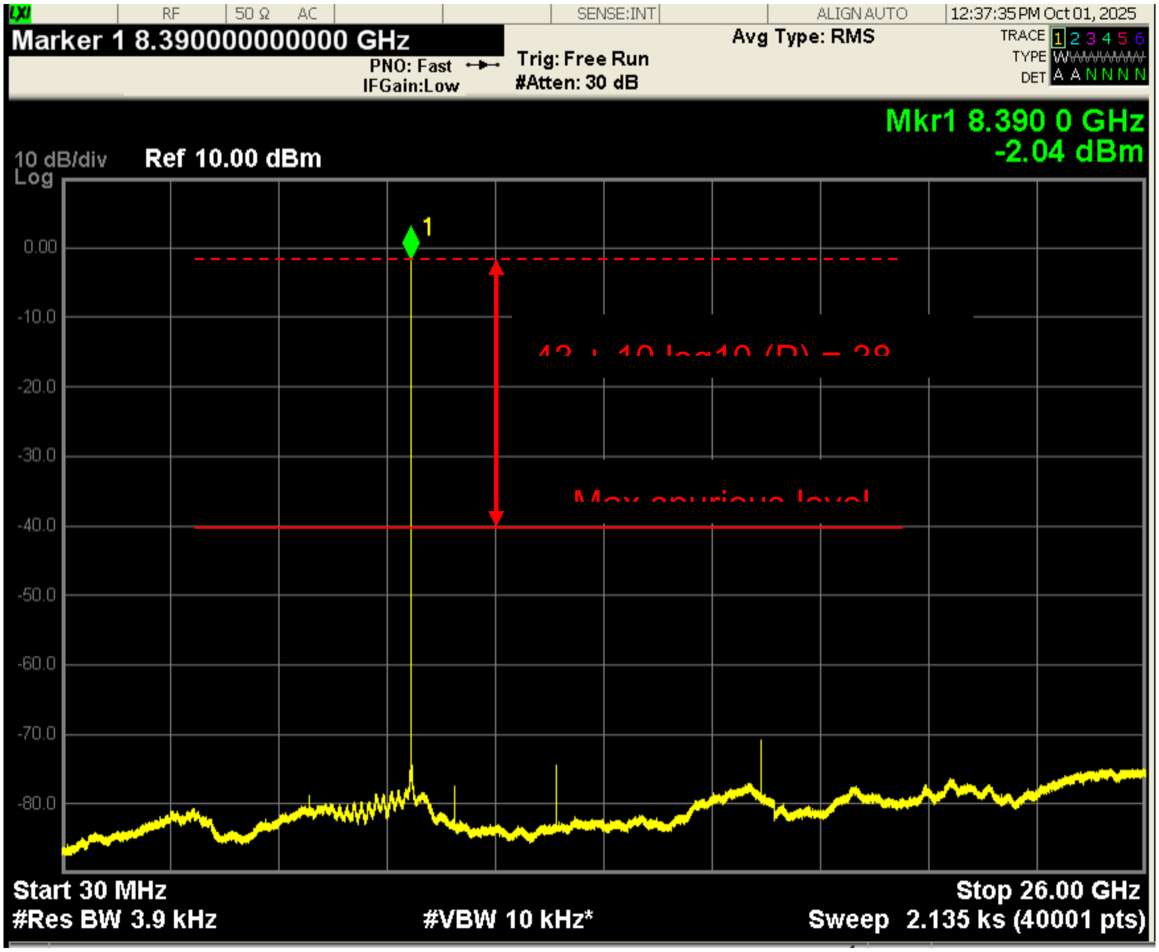

Figure 12: TCD2 ITU-R SM.329 Mask Compliance

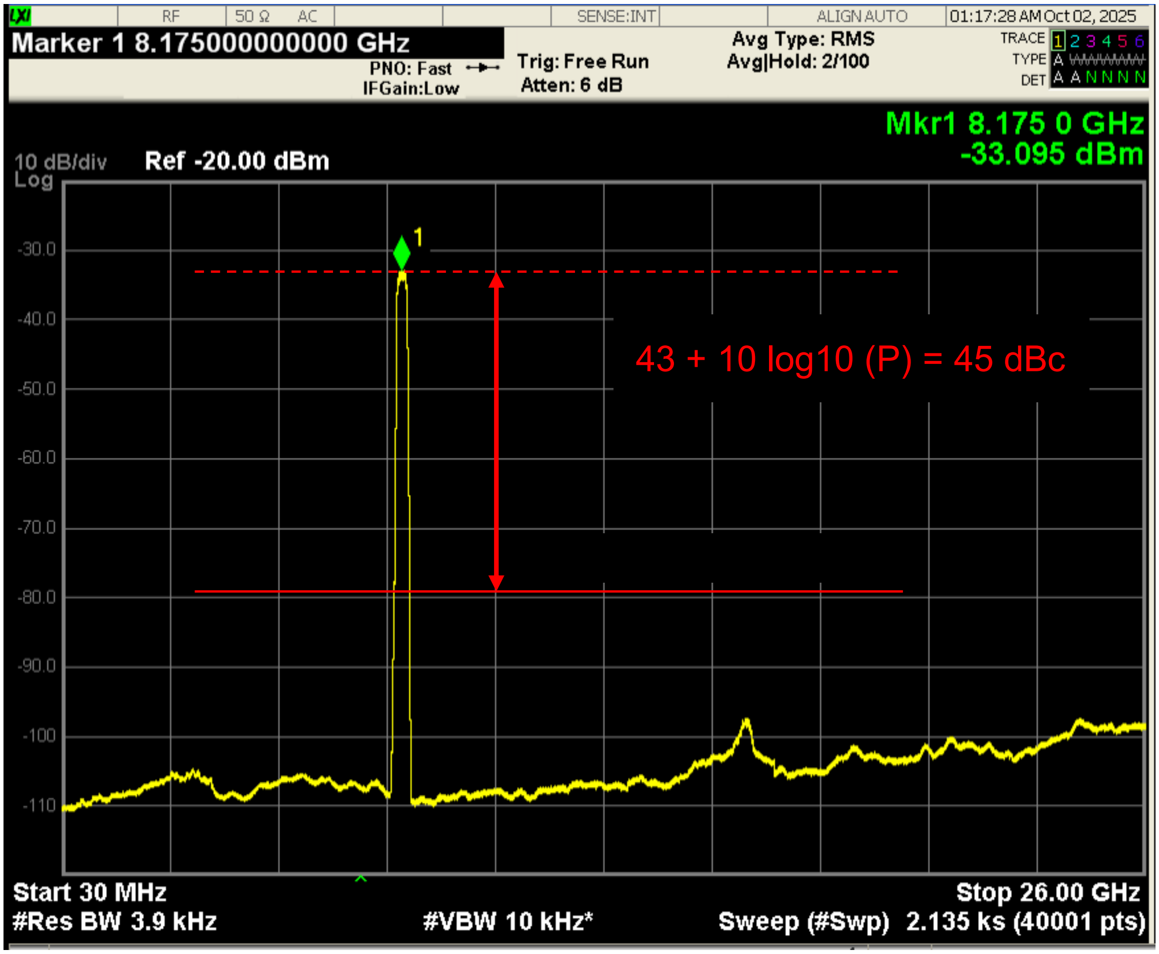

Figure 13: HSD5 ITU-R SM.329 Mask Compliance

XI. Power Flux Density Analysis

CondorXL0's downlink transmissions in the 8025–8400 MHz band comply with all applicable PFD limits, including the limits at the Earth's surface in Article 21 of the ITU-R Radio Regulations, the protection criteria for the adjacent 8400–8450 MHz deep-space research band in Recommendation ITU-R SA.1157, and the PFD limit at the geostationary orbit in ITU-R Radio Regulation No. 22.5. The analyses presented below assume an operational orbit altitude of 590 km, which is the nominal operational altitude for the CondorXL0 mission. Muon has the ability to dynamically adjust the transmit power of CondorXL0's transmitters on orbit and will use this capability to ensure compliance with all PFD limits during non-nominal scenarios, including any downlink transmissions that may occur at lower altitudes during the post-mission disposal phase.

A. PFD at the Surface of the Earth in the 8025–8400 MHz Band

Table 21-4 of Article 21 of the ITU-R Radio Regulations establishes that the PFD at the Earth's surface produced by emissions from an EESS space station in the 8025–8400 MHz band, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, must not exceed the following values:

- -150 dB(W/m²) in any 4 kHz band for angles of arrival between 0° and 5° above the horizontal plane;
- -150 + 0.5(δ - 5) dB(W/m²) in any 4 kHz band for angles of arrival δ (in degrees) between 5° and 25° above the horizontal plane; and
- -140 dB(W/m²) in any 4 kHz band for angles of arrival between 25° and 90° above the horizontal plane.

These limits relate to the PFD that would be obtained under free-space propagation conditions. As shown in the plots below, the PFDs at the Earth's surface produced by CondorXL0's TCD1, TCD2, and HSD5 transmissions satisfy the ITU PFD limits for all angles of arrival, with at least 10 dB of margin for orbital altitudes between 600 km and 300 km.

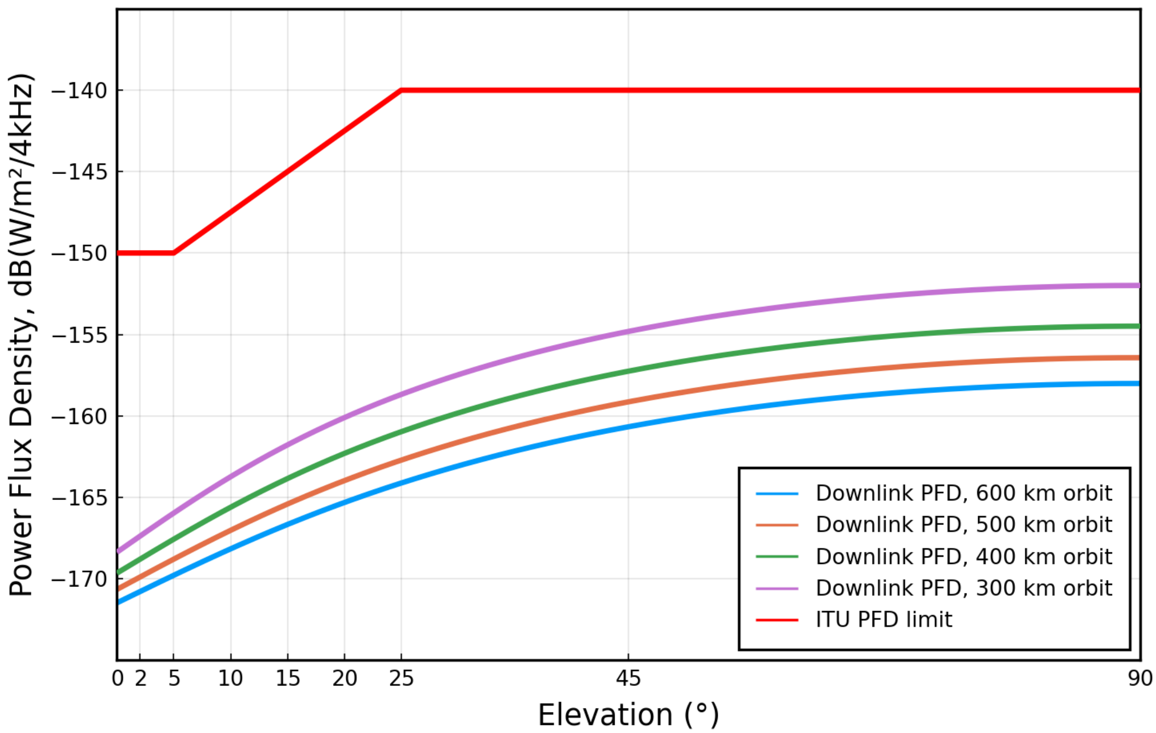

Figure 14: TCD1 and TCD2 Downlink PFDs

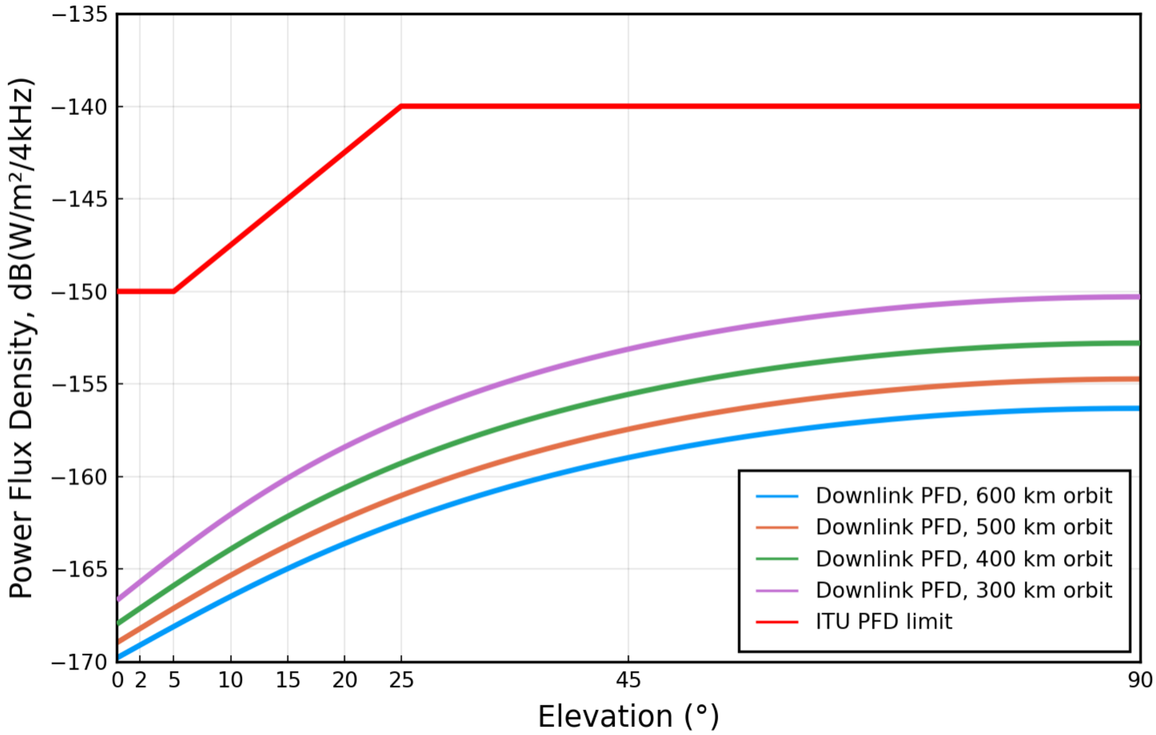

Figure 15: HSD5 Downlink PFD

B. PFD at the Surface of the Earth in the 8400–8450 MHz Deep-Space Research Band

Recommendation ITU-R SA.1157 specifies a maximum allowable interference power spectral flux density level at the Earth's surface of -255.1 dB(W/m²/Hz) in the 8400–8450 MHz band to protect ground receivers in the deep-space research ("DSR") band. CondorXL0 uses a combination of baseband digital filtering (root-raised cosine) and transmitter output bandpass filtering to achieve the recommended protection level for the DSR band. During the post-mission disposal phase, Muon will reduce the EIRP of CondorXL0's transmitters as needed to ensure that the DSR protection criteria continue to be met at all operating altitudes.

The maximum on-beam, in-band PFD levels generated by CondorXL0 are summarized in Table 9 below. These values conservatively assume that the spacecraft antennas are pointed at a DSR ground station at the minimum slant range and transmitting at nominal power and bandwidth.

The PFD in dB(W/m²/Hz) is computed as:

$$PFD = EIRP\ (dBW) - 10\log_{10}(Bandwidth\ in\ Hz) - 10\log_{10}(4\pi \times (Altitude\ in\ m)^2)$$

Table 9: Maximum On-Beam, In-Band PFD Levels for DSR Compliance Assessment						
Channel ID	**Center Frequency (MHz)**	**Bandwidth (MHz)**	**EIRP (dBW)**	**Altitude (km)**	**On-Beam, In-Band Earth PFD dB(W/m²/Hz)**	**Required Out-of-Band Suppression for DSR Compliance (dB)**
TCD1	8385.0	2.8	-3.0	590	-193.9	61.2
TCD2	8390.0	2.8	-3.0	590	-193.9	61.2
HSD5	8175.0	300	19.0	590	-192.2	62.9

TCD1 and TCD2 Deep-Space Research Compliance

For TCD1 and TCD2, the spectrum capture below shows the in-band carriers centered at 8385.0 MHz (TCD1) and 8390.0 MHz (TCD2), with Marker #1 (green diamond) placed at 8400 MHz (the start of the DSR band). The indicated power level at 8400 MHz is -68.6 dBm in a 100 kHz bandwidth, while the peak power density of the TCD1 and TCD2 beams (indicated by the horizontal display line) is +3.0 dBm in a 100 kHz bandwidth. The minimum required out-of-band suppression for TCD1 and TCD2 to meet the DSR protection criteria is 61.2 dB, while the suppression demonstrated in the spectrum capture is 3.0 - (-68.6) = 71.6 dB, providing approximately 10 dB of margin above the required protection level.

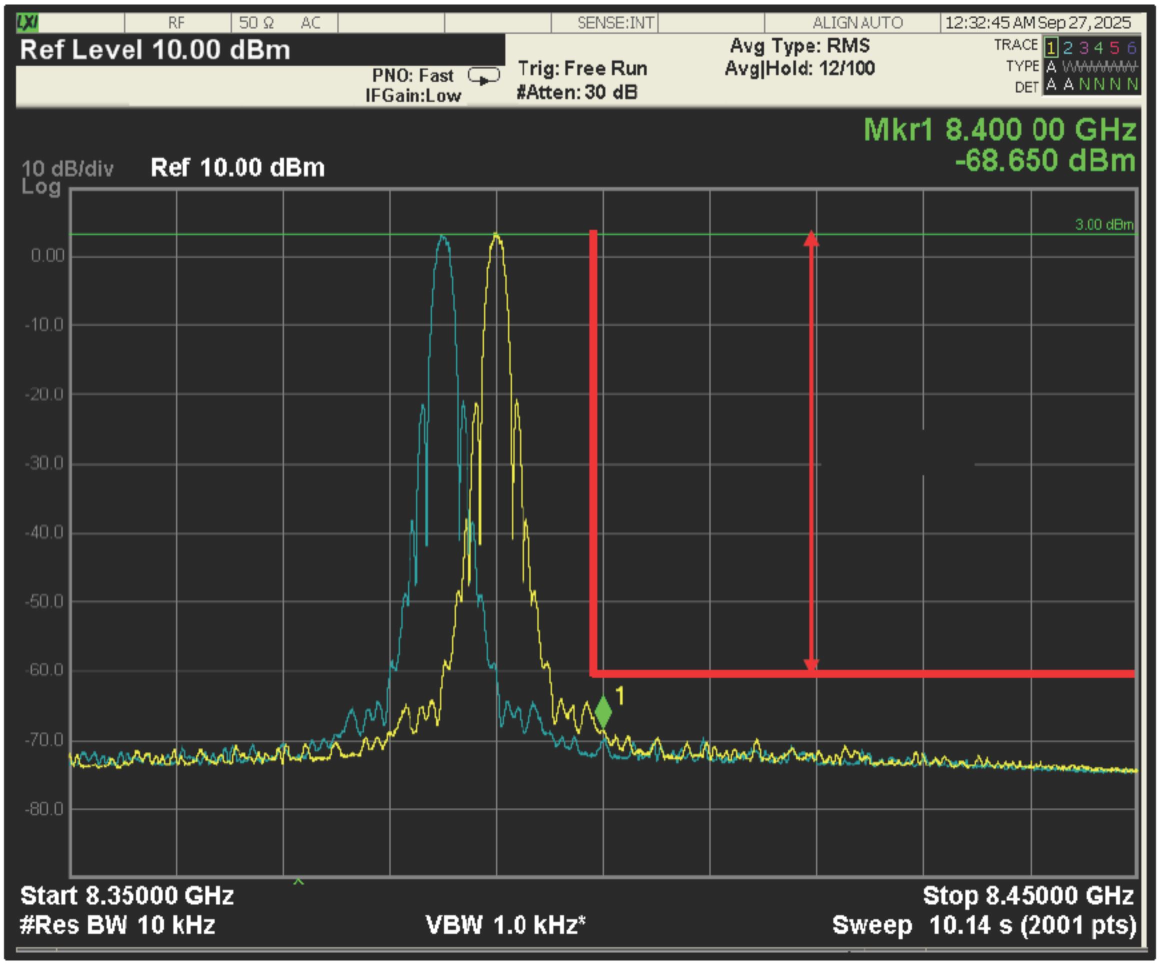

Figure 16: TCD1 and TCD2 Deep-Space Research Band Compliance Plot

HSD5 Deep-Space Research Compliance

For HSD5, the spectrum capture below shows the in-band carrier centered at 8175.0 MHz, with Marker #1 (green diamond) placed at 8400 MHz (the start of the DSR band). The indicated power level at 8400 MHz is -95.4 dBm in a 100 kHz bandwidth, while the peak power density of the HSD5 beam is -20.0 dBm in a 100 kHz bandwidth. The minimum required out-of-band suppression for HSD5 to meet the DSR protection criteria is 62.9 dB, while the suppression demonstrated in the spectrum capture is -20.0 - (-95.4) = 75.4 dB, again providing approximately 10 dB of margin above the required protection level.

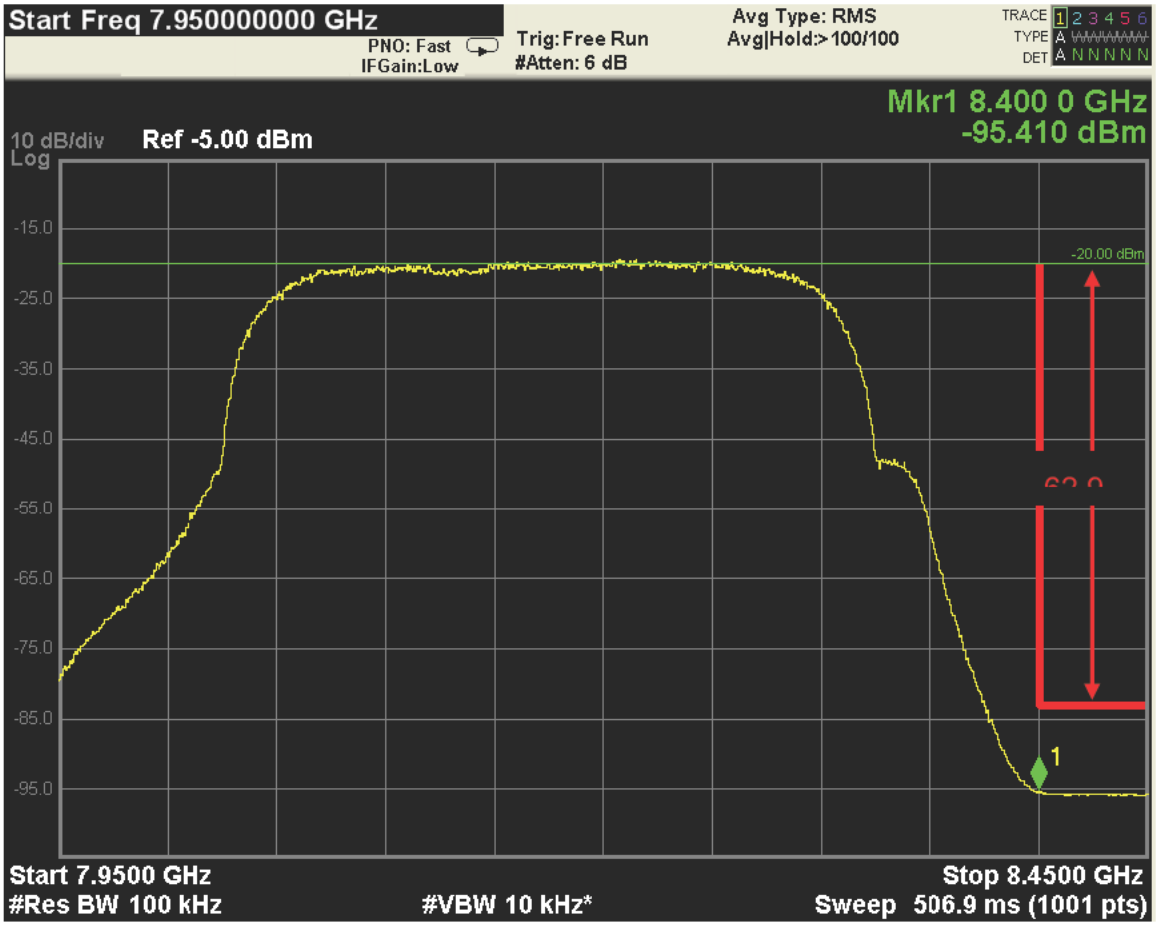

Figure 17: HSD5 Deep-Space Research Band Compliance Plot

C. PFD at Geostationary Orbit in the 8025–8400 MHz Band

ITU-R Radio Regulation No. 22.5 specifies that, in the 8025–8400 MHz frequency band, which EESS non-geostationary satellites share with the fixed-satellite service (Earth-to-space), the maximum PFD produced at the geostationary satellite orbit ("GSO") by any EESS space station shall not exceed -174 dB(W/m²) in any 4 kHz band.

The calculation below demonstrates that the PFD produced at the GSO by CondorXL0's transmissions does not exceed the ITU limit, even under a worst-case assumption that the satellite antenna is radiating at its peak EIRP directly toward the GSO. The PFD at the GSO produced by a CondorXL0 transmission is computed as:

$$PFD\ [dB(W/m^2/4\ kHz)] = EIRP\ [dBW] - 71 - 20\log_{10}(D) - 10\log_{10}(BW) - 24$$

Where:

- EIRP is the maximum EIRP of the transmission, in dBW;
- D is the distance between the satellite and the GSO, in km; and
- BW is the symbol bandwidth of the transmission, in MHz.

The minimum distance between CondorXL0 and the GSO at the nominal operational altitude of 590 km is 35,786 - 590 = 35,196 km.

Applying this calculation to CondorXL0's X-band downlink beams:

- TCD1 and TCD2: -3 dBW - 71 - 20 $\log_{10}$ (35,196) - 10 $\log_{10}$ (2.8) - 24 = -193.4 dB(W/m²/4 kHz)
  - Compliance margin: about 19 dB
- HSD5: 19 dBW - 71 - 20 $\log_{10}$ (35,196) - 10 $\log_{10}$ (300) - 24 = -191.7 dB(W/m²/4 kHz)
  - Compliance margin: about 18 dB

During post-mission disposal, the distance between CondorXL0 and the GSO will increase slightly as the satellite's altitude is lowered, so the compliance margin above will increase. Accordingly, GSO PFD compliance is not a concern at any phase of the CondorXL0 mission.