Kuiper Systems LLC

Request for Experimental Authorization

Narrative Statement

November 1, 2021

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NARRATIVE STATEMENT

Pursuant to Section 5.54(a)(1) of the Federal Communications Commission's rules,[1] Kuiper Systems LLC, a wholly owned subsidiary of Amazon.com Services LLC ("Amazon"), requests an experimental license to launch and operate two satellites, KuiperSat-1 and KuiperSat-2 (collectively, the "KuiperSats"), at 590 km using Ka-band frequencies for testing and demonstration purposes.[2] Amazon further requests authority to operate customer terminal units and telemetry, tracking, and control ("TT&C") and gateway Earth stations, which will communicate with the satellites (collectively, the "Experimental Kuiper System"). Finally, Amazon requests authority to provide launch and early orbit phase ("LEOP") services for the KuiperSats. Amazon seeks authorization for an initial two-year license term, the standard for conventional experimental radio licenses.[3]

This testing is an important step toward Amazon's goal of delivering high-capacity, low-latency broadband communications services to tens of millions of unserved and underserved consumers and businesses through the deployment of Amazon's constellation licensed under Part 25 of the Commission's rules (the "Kuiper System"). Licensed by the Commission on July 30, 2020, the Kuiper System will comprise 3,236 satellites at altitudes of 590 km, 610 km, and 630 km.[4] Amazon's constellation will use frequencies in the Ka-band to provide Fixed-Satellite Services ("FSS") and Mobile-Satellite Services ("MSS") to customers globally.[5] Amazon has committed to invest at least $10 billion to support the Kuiper System, and it continues to progress toward its goal of providing affordable, reliable broadband to customers and communities around the world. Last December, Amazon revealed designs for a small, affordable customer terminal antenna. In April, Amazon announced an agreement with United Launch Alliance to secure nine Atlas V launch vehicles to support its deployment schedule. Amazon is designing and testing the Kuiper System in an all-new, 219,000-square-foot facility in Redmond, Washington, which serves as the primary prototype and qualification facility, and it is adding another 20,000-square-foot facility to provide additional capacity. There are now more than 700 employees working on the Kuiper System at Amazon, and the team is continuing to grow quickly.

With this application for an experimental license, Amazon requests authority to launch and operate KuiperSat-1 and KuiperSat-2 for testing and demonstration purposes. The KuiperSats will

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1 47 C.F.R. § 5.54(a)(1).

2 Amazon also requests authorization to use L-band frequencies for purposes of launch and early orbit phase operations and on an as-needed basis thereafter, as described below.

3 *See* 47 C.F.R. § 5.71(a)(1).

4 *See Kuiper Systems, LLC Application for Authority to Deploy and Operate a Ka-band Non-Geostationary Satellite Orbit System*, Order, 35 FCC Rcd 8324 (2020) ("*Kuiper Authorization*").

5 The FCC has licensed Amazon to provide FSS in the 17.7-17.8 GHz, 17.8-18.6 GHz, 18.8-19.3 GHz, 19.3-19.7 GHz, 19.7-20.2 GHz, 27.5-28.6 GHz, 28.6-29.1 GHz, 29.1-29.5 GHz, and 29.5-30.0 GHz bands, and to provide MSS, in addition to FSS, in the 19.7-20.2 GHz and 29.5-30.0 GHz bands. The FCC has also licensed Amazon to use MSS feeder links in the 19.4-19.6 GHz and 29.1-29.5 GHz bands, subject to certain conditions. *Id.*

operate at 590 km, one of three orbital altitudes licensed for use by the Kuiper System, and in Ka-band frequencies that have also been licensed for use by the Kuiper System. While operating under the experimental license, the KuiperSats will communicate with TT&C Earth stations in South America, the Asia-Pacific region, and McCulloch, Texas, as well as with customer terminal units and a single gateway Earth station located in McCulloch, Texas.

Grant of this application will serve the public interest by allowing Amazon to collect critical data used to validate Amazon's hardware and software engineering, launch operations, and satellite mission management before deployment of the Kuiper System. Such data will enable Amazon to further enhance the design of its satellites for the Kuiper System. Ultimately, this testing will enable faster deployment of the Kuiper System, accelerating Amazon's efforts to close the digital divide in the United States and globally through the delivery of low-latency, high-speed broadband connectivity. It will also accelerate Amazon's efforts to bring connectivity to enterprise customers with the Kuiper System, enabling growth in local economies, improving access to government services, and supporting public safety and disaster relief communications.

I. EXPERIMENTAL KUIPER SYSTEM MISSION OVERVIEW AND OBJECTIVES

The overarching purpose of Amazon's test program is to validate the design of the Kuiper System ahead of commercial deployment. To do so, the proposed testing seeks to confirm several system elements that Amazon will include in the design of its NGSO constellation. Among other system elements, the Experimental Kuiper System will enable Amazon to test and demonstrate:

- RF payload expectations, including expectations for multi-beam phased array transceivers, for parabolic transceivers, and round-trip payload capability using a combination of phased array and parabolic transceivers;
- Phased array and parabolic beam tracking capabilities;
- Launch protocol;
- Satellite thermal design capabilities;
- Over-the-air software update capabilities;
- Power system capabilities, including capabilities to safely generate, store, and distribute power for bus, payload, and propulsion operations;
- Propulsion capabilities;
- Satellite attitude control capabilities; and
- Capabilities of the satellite to detect and remedy or mitigate anomalies.

The Experimental Kuiper System will provide meaningful data to validate hardware and software engineering, launch operations, and satellite mission management. Amazon will collect, for example, performance, diagnostic, and telemetry data from satellite bus and payload components, including avionics endpoints, bus voltages, batteries, and phased array panels. The two-year experimental license will allow Amazon to assess and corroborate degradation metrics and system design for components operating on orbit. Amazon will also collect data from its ground station antennas, including customer terminals and gateway and TT&C Earth stations, as part of end-to-end testing.

Space safety considerations are central to the design and operations of the KuiperSats. The KuiperSats will be equipped with on-board propulsion and attitude control. They will also have a Fault Detection, Isolation, and Recovery ("FDIR") system capable of detecting certain system anomalies and, in many cases, correcting and even disabling a malfunctioning subsystem in the unlikely event an anomaly should occur. Amazon has also designed the KuiperSats to demise upon atmospheric reentry. Amazon will perform a propulsive de-orbit at the end of the mission, resulting in expected demise within one year. If propulsive deorbit is unsuccessful, under the most likely operational failure scenario, the KuiperSats will nevertheless de-orbit passively in approximately 3.5 years. Amazon's ground systems will also be ready to support the mission, backed by trusted gateway and TT&C Earth stations. We discuss space safety considerations in more detail in Appendix 6.

As demonstrated in the attached appendices, Experimental Kuiper System operations will protect existing operators and services from harmful interference.[6] Amazon will conduct operations under the experimental license on a non-interference basis consistent with Section 5.84 of the FCC's rules.[7] Amazon will abide by all existing interference limits, including criteria applicable to satellite operations in the 17.8-18.6 GHz, 19.3-19.4 GHz, and 19.6-20.1 GHz space-to-Earth bands, and in the 27.5-27.6 GHz, 28.6-29.1 GHz, and 29.5-30.0 GHz Earth-to-space bands.[8] Additionally, prior to commencing operations, Amazon will communicate with co-frequency operators to ensure that Amazon's testing does not interfere with authorized operations. Because the KuiperSats will pass over corresponding Earth stations only for brief periods—resulting in connectivity for a maximum of six minutes depending on the trajectory of the satellite and the location of the ground antenna—there will be limited potential for harmful interference. In the unlikely event that interference should occur, Amazon will take immediate steps to resolve the interference. Such steps include, but are not limited to, ceasing transmission of all interfering frequency operations and coordinating with all relevant parties to mitigate the risk of future interference.

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[6] *See* Appendices 2-5.

[7] 47 C.F.R. § 5.84.

[8] *See, e.g.*, 47 C.F.R. §§ 25.146(a)(1) (requiring certification of compliance with applicable PFD levels in Article 21, Section V, Table 21-4 of the ITU Radio Regulations) and 25.146(c) (requiring receipt of a "favorable" or "qualified favorable" finding by the ITU Radiocommunication Bureau, in accordance with Resolution 85 of the ITU Radio Regulations regarding ITU EPFD limits).

II. EXPERIMENTAL KUIPER SYSTEM DESCRIPTION

A. Space Segment

Through this application, Amazon respectfully requests Commission approval to launch and operate two KuiperSats at the 590 km orbital altitude and at 33-degree inclination by Q4 2022. Amazon plans to launch the satellites consecutively using two separate launch vehicles. It will inject both satellites into the 590 km orbital altitude at 33-degree inclination and subsequently conduct in-orbit testing at this altitude.

Table 1 below identifies the frequencies, channel characteristics, and power levels for the KuiperSat space-to-Earth links. Table 2 below identifies the frequencies, channel characteristics, and power levels for KuiperSat Earth-to-space links. Table 3 below identifies the frequencies, channel characteristics, and power levels for KuiperSat space-to-space links. Amazon provides antenna patterns for the KuiperSat transmissions to customer terminal, gateway, and TT&C ground stations in Appendix 1 below.

Table 1: Space-to-Earth Frequency Use

Operational Use	Frequency Range (GHz)	Modulation	Emission Designator	Maximum EIRP per Carrier (dBW)
User Links	17.8-18.6 GHz	OFDM	100MD7W	35.8
Gateway Links	19.6-20.1	SC-OFDM	480MD7W	36.0
TT&C Link	19.3-19.4	SC-OFDM	2M50D7W	10.0
TT&C Beacon (LEOP and Backup)	19.3-19.4	None	1K00N0N	10.0

Table 2: Earth-to-Space Frequency Use

Operational Use	Frequency Range (GHz)	Modulation	Emission Designator	Maximum EIRP per Carrier (dBW)
User Links	28.6-29.1 GHz	SC-OFDM	16M0D7W	46.0
Gateway Links	29.5-30.0	SC-OFDM	480MD7W	62.3
TT&C Link	27.5-27.6	SC-OFDM	2M50D7W	65.4

Table 3: Space-to-Space Frequency Use				
Operational Use	**Frequency Range (GHz)**	**Modulation**	**Emission Designator**	**Maximum EIRP per Carrier (dBW)**
Position Telemetry (LEOP and Backup)	1.61625	BPSK	2M50G1D	-7.0

Each satellite will be equipped with a set of three TT&C antennas. Upon deployment from the launch vehicle, the KuiperSats will begin transmitting an unmodulated Ka-band beacon signal to assist the TT&C Earth stations in identifying and initiating bi-directional TT&C communication with the spacecraft. Once a TT&C Earth station begins tracking the spacecraft, a command will be sent to the spacecraft to disable the unmodulated beacon downlink and to begin transmitting the modulated Ka-band telemetry downlink. After the spacecraft passes initial health and safety tests, the spacecraft will generally transmit on the telemetry downlink only when it is in view of the TT&C Earth stations.

The KuiperSats will have two Global Navigation Satellite System receivers for reception of space-to-space navigation signals while in flight. As an additional precautionary mechanism, the KuiperSats will be equipped with L-band transmitters that will transmit spacecraft position data immediately after separation from the launch vehicle to satellites in Globalstar's NGSO MSS constellation (Call Sign S2115) (the "Globalstar System").[9] That satellite position data will be relayed to the ground by the Globalstar System. This will provide accurate satellite position data to the Experimental Kuiper System ground segment before the first contact window between the KuiperSats and TT&C Earth stations. This transmission may be disabled at any time via a single ground command from the Near Space Launch Earth station (Call Sign WJ2XSU).[10]

The KuiperSats will be equipped with three phased array antennas for customer terminal links—two for transmit and one for receive communications. The phased array antennas will each produce independent steerable beams that will be used to track the customer terminal throughout a satellite pass. The KuiperSats will transmit multiple 100 MHz wide carriers within the 17.8-18.6 GHz band and will receive transmissions from customer terminals in the 28.6-29.1 GHz band. The KuiperSat customer terminal beams will be enabled when the satellites are above the customer terminal Earth stations' minimum elevation angle of 35 degrees.

The KuiperSats will have three parabolic antennas to communicate with the gateway Earth stations. The satellite gateway antennas will track the fixed ground station antenna, compensating

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9 *See Globalstar License LLC*, Stamp Grant, IBFS File No. SAT-MOD-20170411-00061, Call Sign S2115 (Aug. 8, 2017); *Satellite Policy Branch Information, Actions Taken*, Public Notice, Report No. SAT-01290, DA No. 17-1206 (Dec. 15, 2017) (authorizing Globalstar to commence repositioning of the remaining space stations of its first-generation NGSO MSS system within their respective orbital planes).

10 *See Near Space Launch Inc.*, Experimental Radio Station Construction Permit and License, ELS File No. 0019-EX-CM-2021, Call Sign WJ2XSU (June 21, 2021).

for orbital trajectory and yaw steering. The KuiperSat gateway beams will be enabled when the satellites are above the gateway Earth station's minimum elevation angle of 20 degrees.

B. Ground Segment

1. Customer Terminal

Amazon will operate four customer terminals in McCulloch, Texas—two 0.65-meter parabolic terminals and two phased array terminals. The latter two customer terminals will be prototypes of an innovative, low-cost customer terminal developed by Amazon. Each of the four terminals will operate as portable terminals from fixed locations within a 200 km radius from the geographic center point 31.0222°, -99.2189°. Amazon will relocate the terminals within this geographic area to execute various testing scenarios. Elevation angles for connectivity between the KuiperSats and customer terminals will be greater than or equal to 35 degrees.

Technical specifications for the customer terminals are identified in Table 4 below.

Table 4: Customer Terminals	
Parabolic Terminals	
Manufacturer	Amazon
Model Number	N/A
Number of Units	2
Experimental Equipment	Yes
Frequencies	17.8-18.6 GHz (space-to-Earth) 28.6-29.1 GHz (Earth-to-space)
Total Input Power at Antenna Flange (Watts)	1.2 W
Total EIRP for All Carriers (EIRP)	46.0 dBW
Maximum EIRP per Carrier (dBW)	46.0 dBW
Maximum EIRP Density per Carrier (dBW/MHz)	34.0 dBW/MHz
Mean Output Power (ERP)	43.9 dBW
Mean or Peak (M/P)	Mean
Transmit Antenna Gain	45.3 dBi at 28.8 GHz
Receive Antenna Gain	43.0 dBi at 18.0 GHz
Frequency Tolerance	0.001 percent
Emission Designator	Transmit: 16M0D7W
Modulating Signal	SC-OFDM
Polarization	RHCP/LHCP
Phased Array Terminals	
Manufacturer	Amazon
Model Number	N/A
Number of Units	2
Experimental Equipment	Yes
Frequencies	17.8-18.6 GHz (space-to-Earth) 28.6-29.1 GHz (Earth-to-space)

Total Input Power at Antenna Flange (Watts)	3.5 W
Total EIRP for All Carriers (EIRP)	40.0 dBW
Maximum EIRP per Carrier (dBW)	40.0 dBW
Maximum EIRP Density per Carrier (dBW/MHz)	28.0 dBW/MHz
Mean Output Power (ERP)	37.8 dBW
Mean or Peak (M/P)	Mean
Transmit Antenna Gain	34.5 dBi at 28.8 GHz
Receive Antenna Gain	34.5 dBi at 18.0 GHz
Frequency Tolerance	0.001 percent
Emission Designator	Transmit: 16M0D7W
Modulating Signal	SC-OFDM
Polarization	RHCP/LHCP

Amazon does not propose to market its customer terminal devices under the requested experimental license. Where necessary, all experimental equipment will be labeled in accordance with Section 2.803 of the FCC's rules, bearing the following statement: "This device has not been authorized as required by the rules of the Federal Communications Commission. This device is not, and may not be, offered for sale or lease, or sold or leased, until authorization is obtained."[11]

2. Gateway Earth Stations

Amazon will operate a single, 2.4-meter gateway Earth station antenna in McCulloch, Texas in support of the Experimental Kuiper System. The Earth station antenna will be located at 31.0222°, -99.2189°. Elevation angles for connectivity between the KuiperSats and the gateway Earth station will be greater than or equal to 20 degrees.

Technical specifications for the gateway Earth station are identified in Table 5 below.

Table 5: Gateway Earth Station	
Manufacturer	Cobham
Model Number	Tracker 2400
Number of Units	1
Experimental Equipment	No
Frequencies	19.6-20.1 GHz (space-to-Earth) 29.5-30.0 GHz (Earth-to-space)
Total Input Power at Antenna Flange (Watts)	8.3 W
Total EIRP for All Carriers (EIRP)	62.3 dBW
Maximum EIRP per Carrier (dBW)	62.3 dBW
Maximum EIRP Density per Carrier (dBW/MHz)	35.5 dBW/MHz
Mean Output Power (ERP)	60.1 dBW
Mean or Peak (M/P)	Mean

[11] 47 C.F.R. § 2.803.

Transmit Antenna Gain	53.1 dBi at 30.0 GHz
Receive Antenna Gain	50.2 dBi at 20.2 GHz
Frequency Tolerance	0.001 percent
Emission Designator	Transmit: 480MD7W
Modulating Signal	SC-OFDM
Polarization	RHCP/LHCP

3. TT&C Earth Stations

Amazon will operate one 2.4-meter TT&C Earth station antenna in the United States. This Earth station will be located in McCulloch, Texas, at 31.0222°, -99.2189°. The Experimental Kuiper System will also have one TT&C site in South America and one in the Asia-Pacific region, to ensure that the KuiperSats perform correctly throughout their orbital path. Elevation angles for connectivity between the KuiperSats and the TT&C Earth station will be greater than or equal to 5 degrees.

Technical specifications for the TT&C Earth station in McCulloch, Texas are identified in Table 6 below.

Table 6: U.S.-Based TT&C Earth Station[12]	
Manufacturer	Cobham
Model Number	Tracker 2400
Number of Units	1
Experimental Equipment	No
Frequencies	19.3-19.4 GHz (space-to-Earth) 27.5-27.6 GHz (Earth-to-space)
Total Input Power at Antenna Flange (Watts)	18.4 W
Total EIRP for All Carriers (EIRP)	65.4 dBW
Maximum EIRP per Carrier (dBW)	65.4 dBW
Maximum EIRP Density per Carrier (dBW/MHz)	61.4 dBW/MHz
Mean Output Power (ERP)	63.2 dBW
Mean or Peak (M/P)	Mean
Transmit Antenna Gain	52.7 dBi at 27.5 GHz
Receive Antenna Gain	49.8 dBi at 19.3 GHz
Frequency Tolerance	0.001 percent
Emission Designator	Transmit: 2M50D7W
Modulating Signal	SC-OFDM
Polarization	RHCP/LHCP

[12] Amazon will also operate one TT&C site in South America and one in the Asia-Pacific region. Amazon will comply with the regulations of the relevant administrations regarding operation of these sites.

C. Overview of Operations

1. Launch and Deployment

Amazon plans to launch KuiperSat-1 and KuiperSat-2 on two separate launch vehicles, directly injecting both satellites into the 590 km altitude at 33-degree inclination. After deployment, each satellite will begin de-tumbling and establishing altitude control and sun pointing. While KuiperSat-1 and KuiperSat-2 will use TT&C during the de-tumbling process, the additional frequency channels on these satellites will become active only after this process is complete. After deployment, the satellites will fly in circular orbit, with orbital parameters defined in the following table:

Table 7: Orbital Parameters	
Perigee	590 km
Apogee	590 km
Orbit Period	96.5 minutes
Inclination	33 deg

2. Test Operations

Amazon will operate a gateway Earth station antenna in McCulloch, Texas, and customer terminal antennas at or near the gateway Earth station location, as described above. The spacecraft will only transmit customer terminal and gateway beams when it is above the operational minimum elevation angles listed above at the McCulloch, Texas Earth station site. The KuiperSats' beams will not transmit or receive between contacts. These minimum elevation constraints will therefore limit the total transmission time for the KuiperSats and Earth stations. In general, we expect that each of the satellites will be in view and transmitting fewer than five times per day. The maximum contact duration above the gateway link minimum elevation will be six minutes. The maximum contact duration above the customer terminal link minimum elevation angle will be four minutes. In total, we predict that each of the satellites will be transmitting or receiving gateway and customer terminal links fewer than 20 minutes per day.

The following table describes an example test sequence:

Table 8: Example Test Sequence		
Step	**Activity**	**Time (seconds)**
1	A satellite pass over the ground station is identified.	
2	When satellite is 5 degrees above the horizon, TT&C Earth station receives Ka-band telemetry from satellite and establishes a Ka-band command link with the satellite.	T0

3	When satellite rises to 20 degrees above the horizon, the satellite and gateway begin transmitting gateway downlink and uplink respectively.	T+145
4	When satellite rises to 35 degrees above the horizon, the satellite and customer terminal begin transmitting, and an end-to-end link is formed between the gateway Earth station antenna, satellite, and customer terminal antenna.	T+220
5	Broadband tests are conducted while the satellite is above 35 degree minimum elevation.	
6	Customer terminal links are disabled when the satellite sets below the 35 degree minimum elevation.	T+440
7	Gateway links are disabled when the satellite sets below the 20 degree minimum elevation.	T+510
8	The TT&C Earth station ceases transmissions and reception when the satellite sets below the 5 degree minimum elevation.	T+655

III. "STOP BUZZER" CONTACT INFORMATION

Pursuant to Section 5.308 of the Commissions' rules,[13] a point of contact at Amazon will be reachable with the contact information below at any time during the experiment to immediately address interference concerns:

KuiperSat Operations

Email: kuipersat-ops@amazon.com

Phone: (571) 400-5227

[13] 47 C.F.R. § 5.308.

TECHNICAL APPENDICES

APPENDIX 1: EXPERIMENTAL KUIPER SYSTEM ANTENNA PATTERNS

The antenna patterns for each transmitting antenna contained in this experimental license application are shown below. A summary of these transmitting antennas is contained in Table 9.

Table 9: Summary of Transmitting Antennas				
Antenna Type	**Antenna/Beam Type**	**Manufacturer**	**Gain [dBi]**	**Beamwidth [degrees]**
Earth Station	Gateway	Cobham	53.1	0.3
Earth Station	TT&C	Cobham	52.7	0.3
Earth Station	Customer terminal #1	Amazon	45.3	1.2
Earth Station	Customer terminal #2	Amazon	34.5	3.3
Satellite	Gateway	Amazon	35	2.8
Satellite	User	Amazon	39	1.8
Satellite	TT&C	Amazon	6.5	102.0
Satellite	L-Band	NearSpace Launch	4.0	100.0

The Amazon customer terminal and satellite user beam use phased array antennas and will experience scan-loss and beam widening when the beams are pointed off of zenith and nadir respectively. The charts below display the antenna patterns for each of these antenna patterns, capturing the maximum gain at 0 degree scan angles.

Figure 1: Gateway Earth Station Antenna Pattern

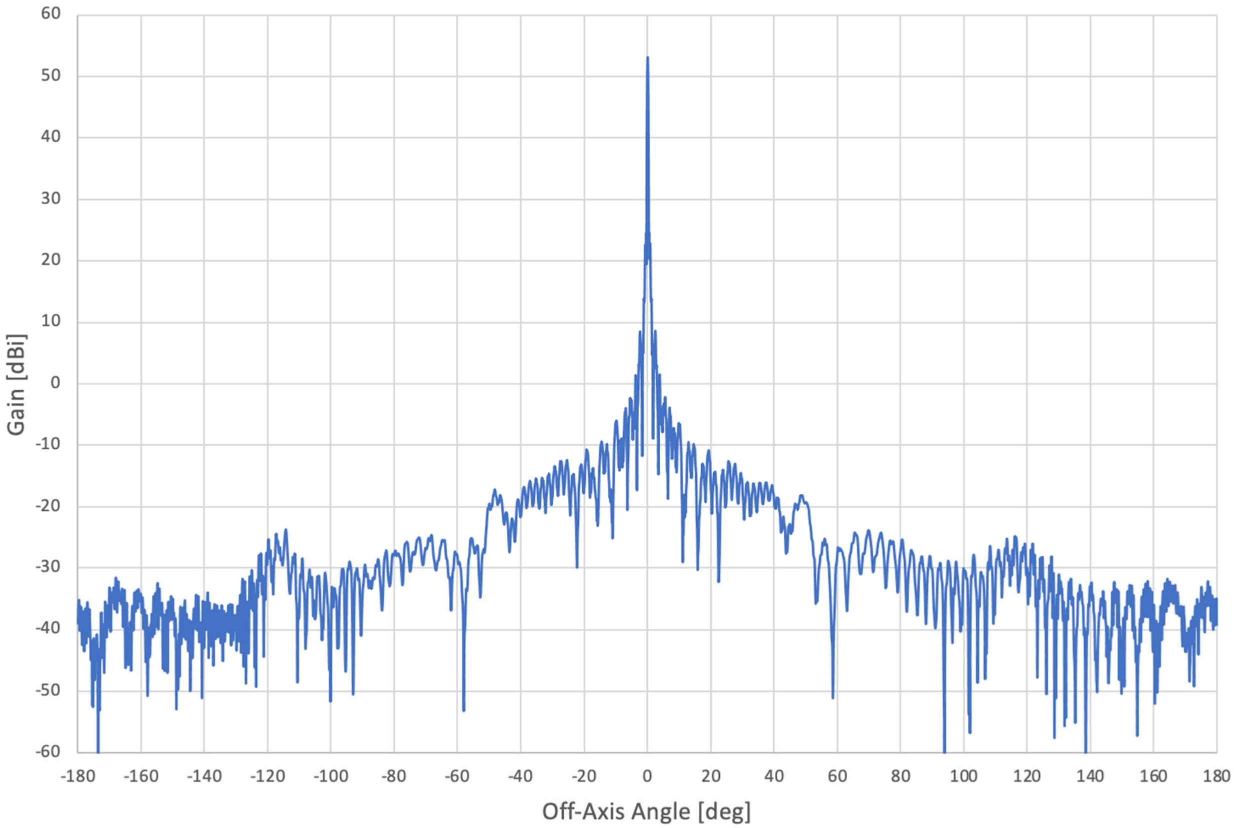


Figure 2: TT&C Earth Station Antenna Pattern

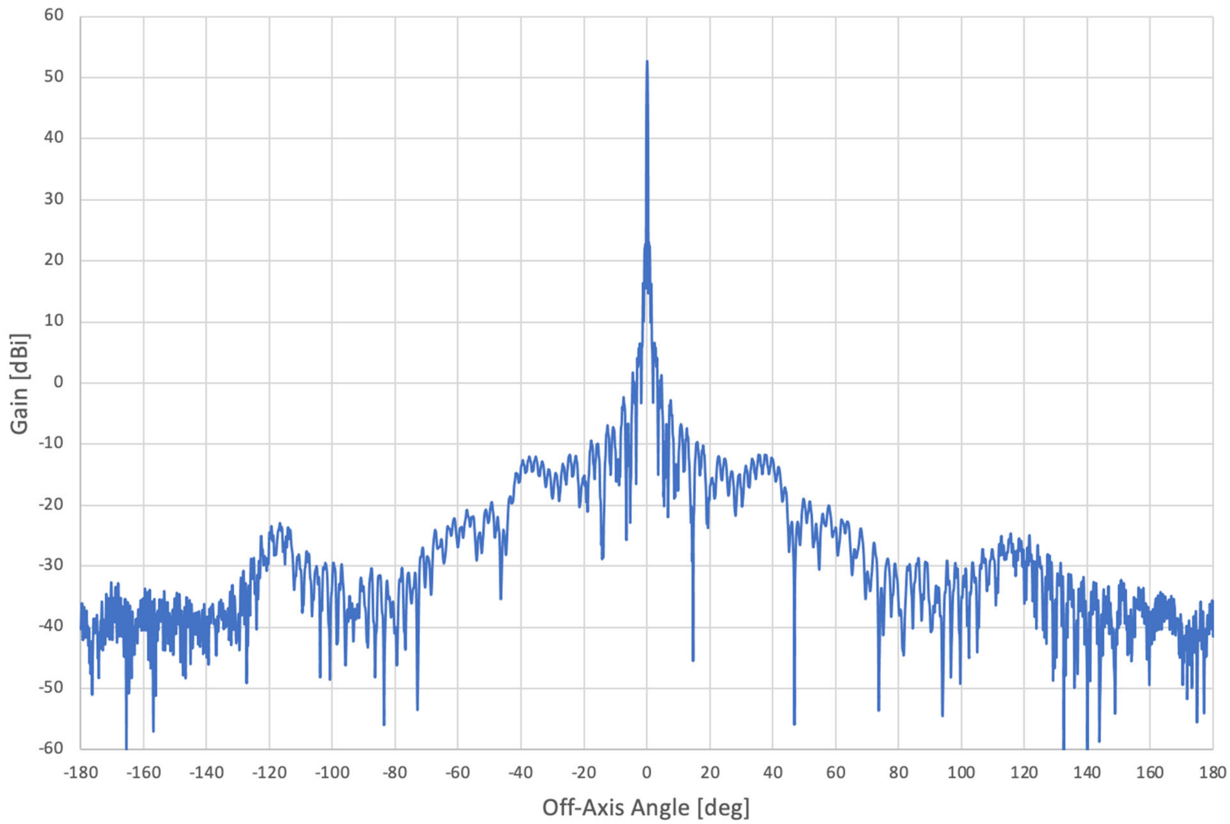


Figure 3: Customer Terminal #1 Antenna Pattern

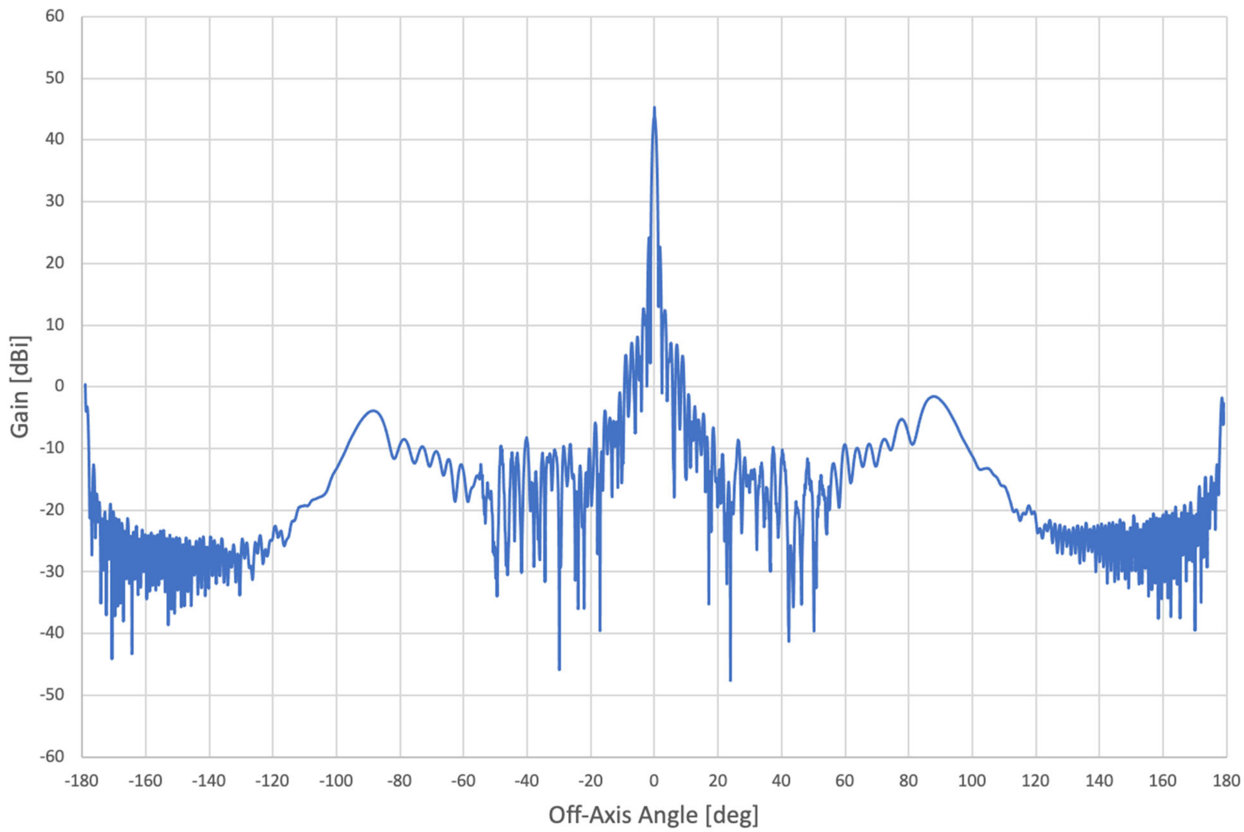


Figure 4: Customer Terminal #2 Antenna Pattern

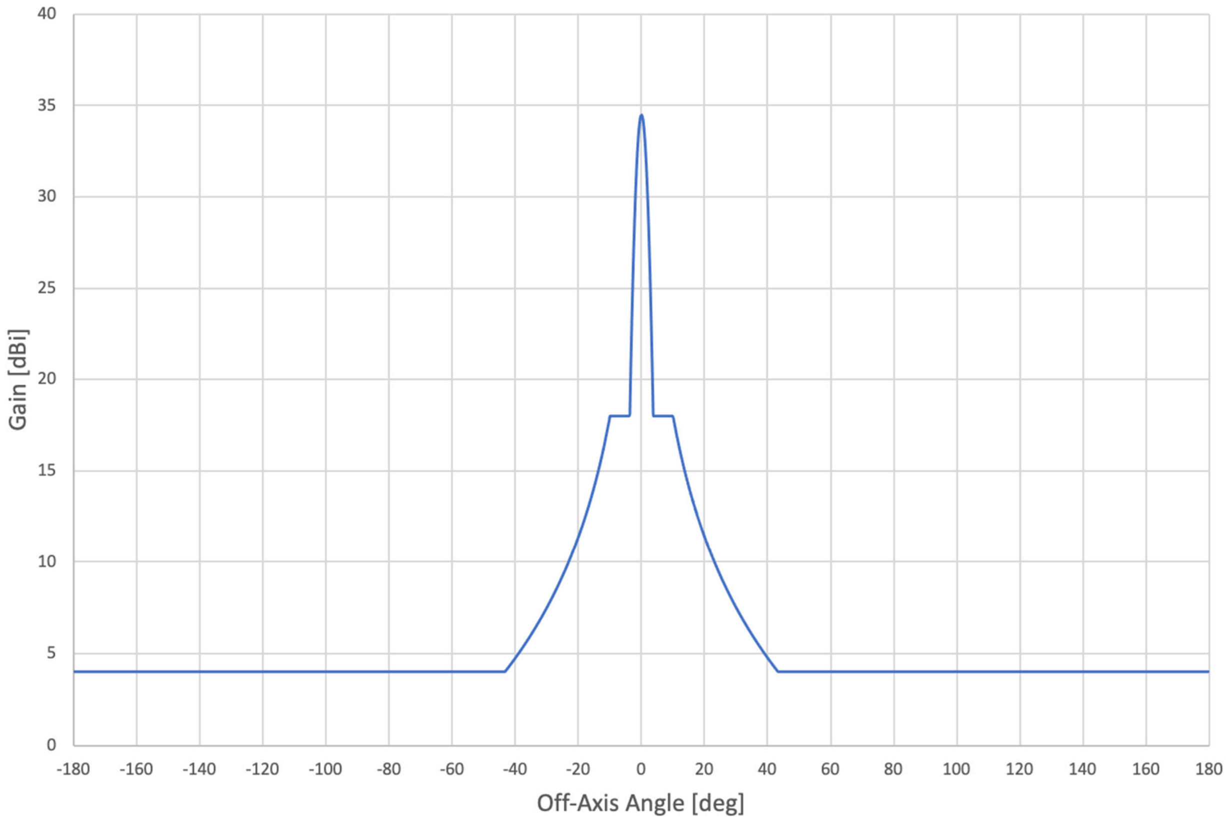


Figure 5: Satellite Gateway Beam Antenna Pattern

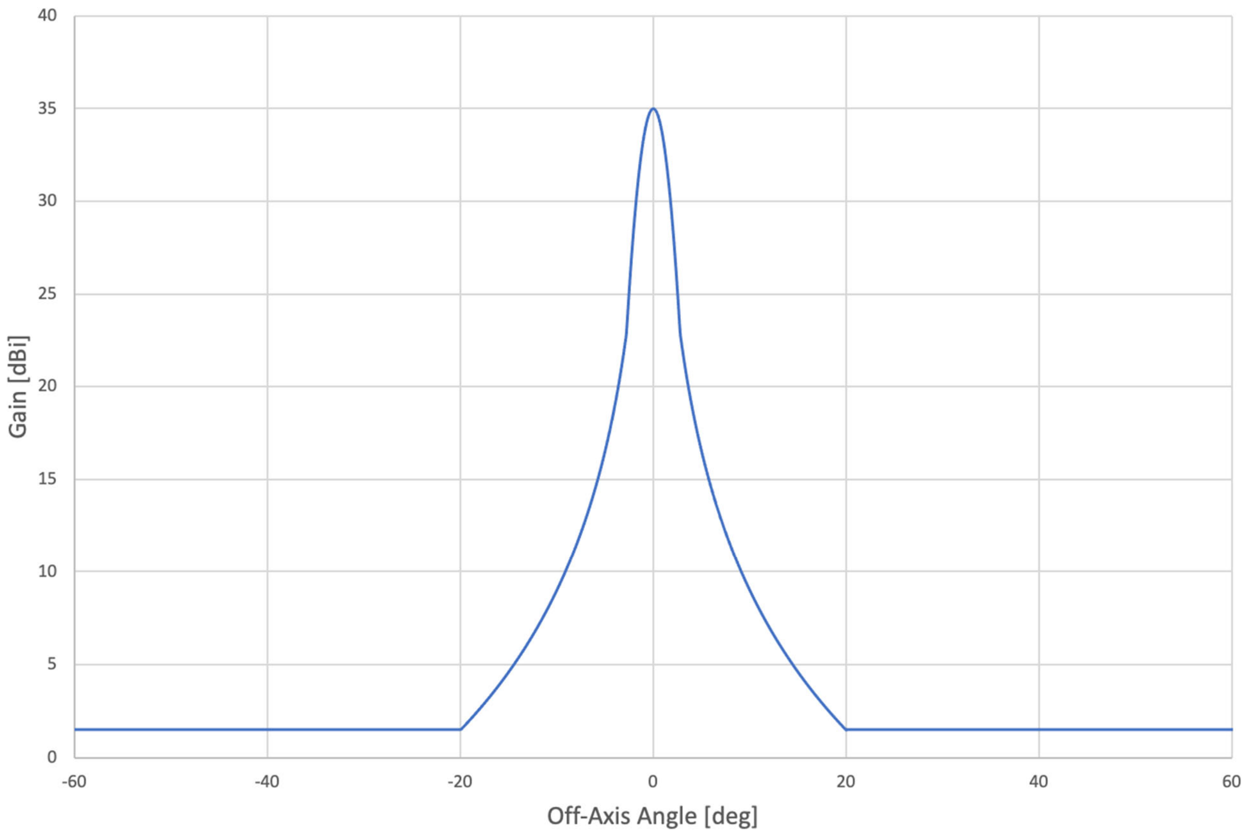


Figure 6: Satellite User Beam Antenna Pattern

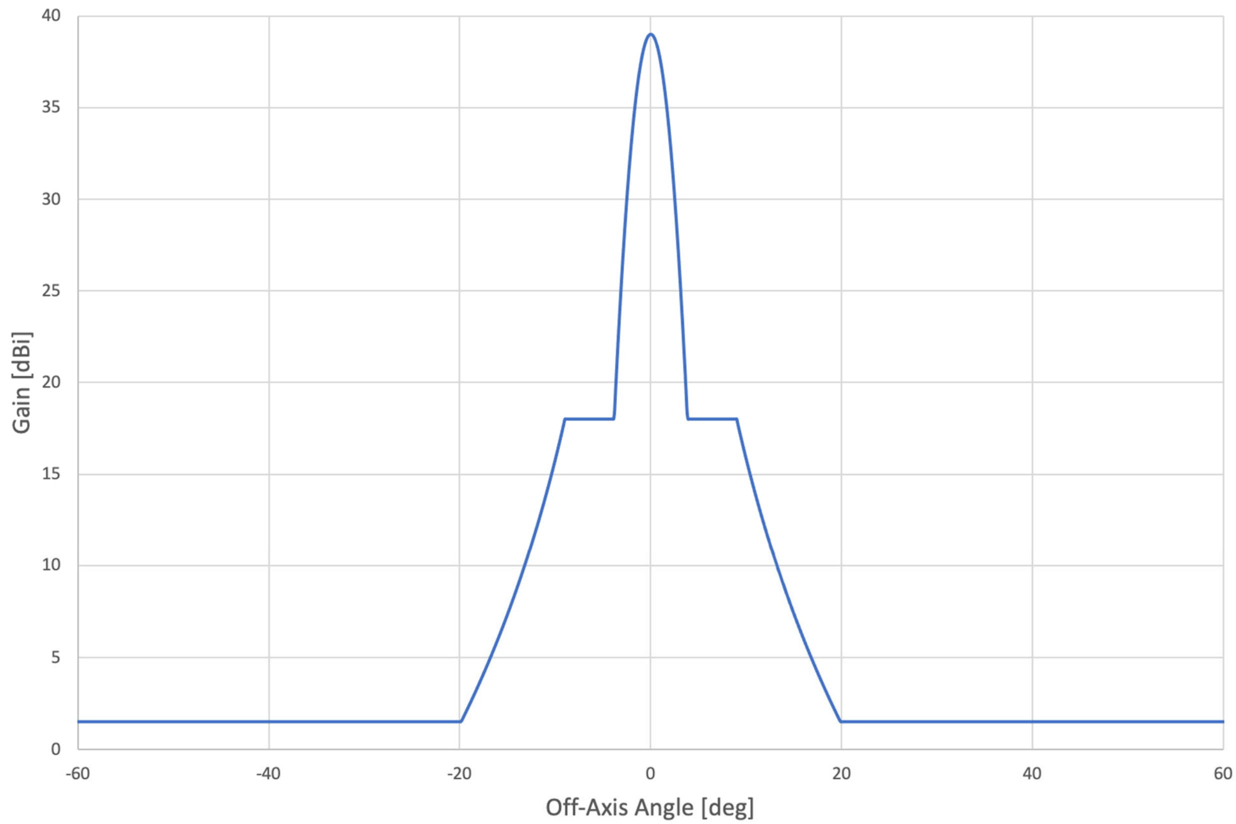


Figure 7: Satellite TT&C Antenna Pattern

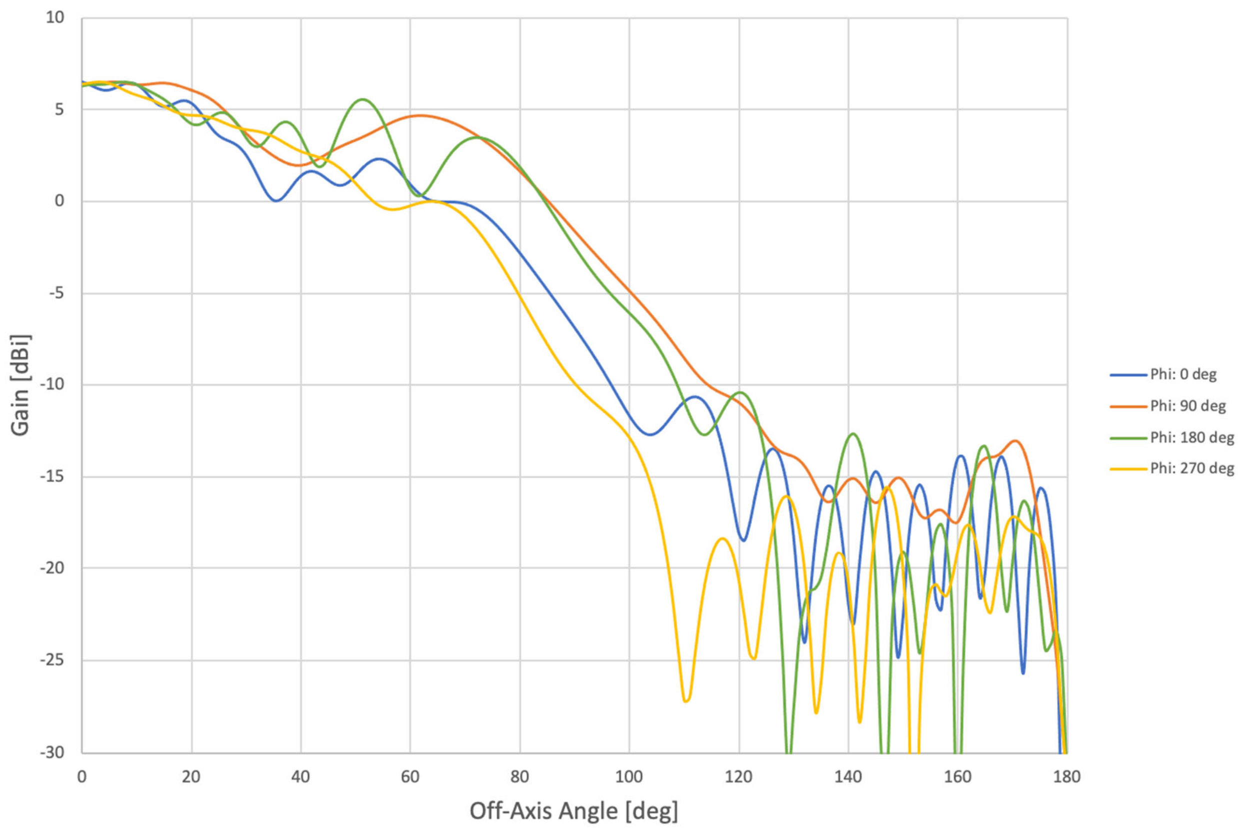
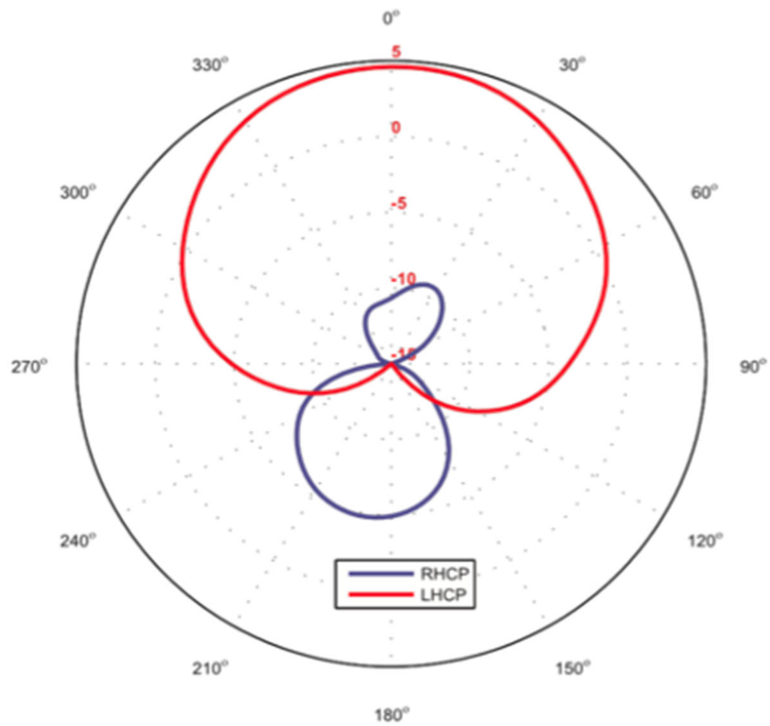


Figure 8: Satellite L-Band Antenna Pattern



Gain [dBi]

APPENDIX 2: INTERFERENCE PROTECTION FOR CO-FREQUENCY FIXED SERVICES

The KuiperSats are designed to co-exist with terrestrial fixed service ("FS") operations. As a measure to prevent harmful interference to FS operations, the KuiperSat downlink emission levels will comply with all applicable FCC and ITU power flux-density ("PFD") limits.

While this application for an experimental license is not made under Part 25, Amazon has used Part 25 as the guide for PFD limits. Amazon therefore demonstrates compliance with the provisions of 25.146(a)(1), which states that an NGSO FSS applicant must certify that it will comply with the power flux-density levels in Article 21, Section V, Table 21-4 of the ITU Radio Regulations, and that in the 19.3-19.4 GHz and 19.6-19.7 GHz bands applicants must certify that they will comply with the ITU PFD limits governing NGSO FSS systems in the 17.7-19.3 GHz band. The PFD limits listed in Table 21-4 of Article 21 of the ITU Radio Regulations that are applicable to KuiperSats operating in the 17.8-19.3 GHz, 19.3-19.4 GHz, and 19.6-19.7 GHz bands are described in Table 10:

Table 10: ITU PFD Limits

Frequency Band	Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
	0° – 5°	5° – 25°	25° – 90°	
17.7 – 19.3 GHz, 19.3 – 19.4 GHz, 19.6 – 19.7 GHz	*-115 – X*	*-115 – X + ((10 + X)/20)(δ - 5)*	*-105*	1 MHz

In the 17.8-19.3 GHz, 19.3-19.4 GHz, and 19.6-19.7 GHz bands, the PFD limits depend on the number of non-geostationary satellites, *N*, in the satellite constellation. The value of '*X*' is defined as a function in footnote 13 of Article 21. The number of KuiperSats that will operate under this experimental authorization is two. For $N \leq 50$, *X* is set to 0. Table 11 shows the PFD limits when X is set to 0.

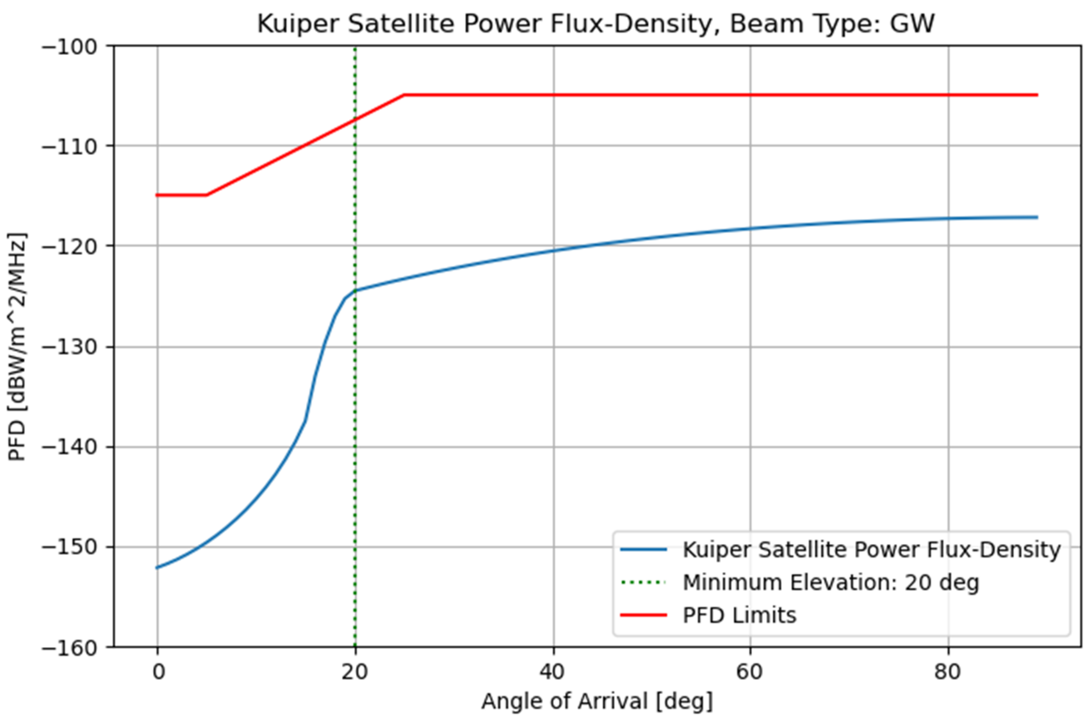
Table 11: ITU PFD Limits Where *X* = 0

Frequency Band	Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
	0° – 5°	5° – 25°	25° – 90°	
17.7 – 19.3 GHz, 19.3 – 19.4 GHz, 19.6 – 19.7 GHz	*-115*	*-115 + 0.5(*δ - 5)	*-105*	1 MHz

I. PFD Compliance for Gateway Downlink Beam

Figure 9 shows the maximum PFD produced by the KuiperSat gateway downlink beams. The PFD levels are well below the ITU limits (shown in red). These beams will operate with a maximum EIRP density of 9.2 dBW/MHz when above the minimum elevation of 20°, which produces a maximum PFD of -117.2 dBW/m^2/MHz at an angle of arrival of 90°. The PFD at angles of arrival below 20° are computed by evaluating the off-axis EIRP of the satellite downlink beam when pointing directed at its minimum elevation of 20°.

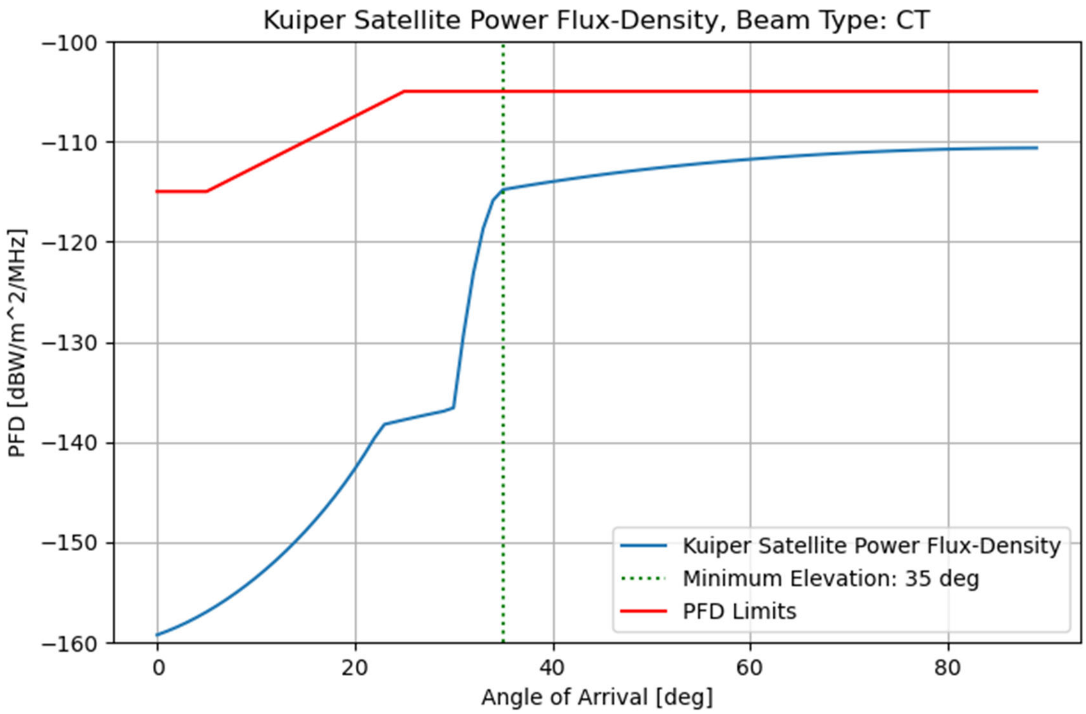
Figure 9: Maximum PFD Produced by the KuiperSat Gateway Downlink Beams



II. PFD Compliance for Customer Terminal Downlink Beam

Figure 10 shows the maximum PFD produced by the KuiperSat customer terminal downlink beams. The PFD levels are well below the ITU limits (shown in red). These beams will operate with a maximum EIRP density of 15.8 dBW/MHz when above the minimum elevation of 35°, which produces a maximum PFD of -110.6 dBW/m^2/MHz at an angle of arrival of 90°. The PFD at angles of arrival below 35° are computed by evaluating the off-axis EIRP of the satellite downlink beam when pointing directed at its minimum elevation of 35°.

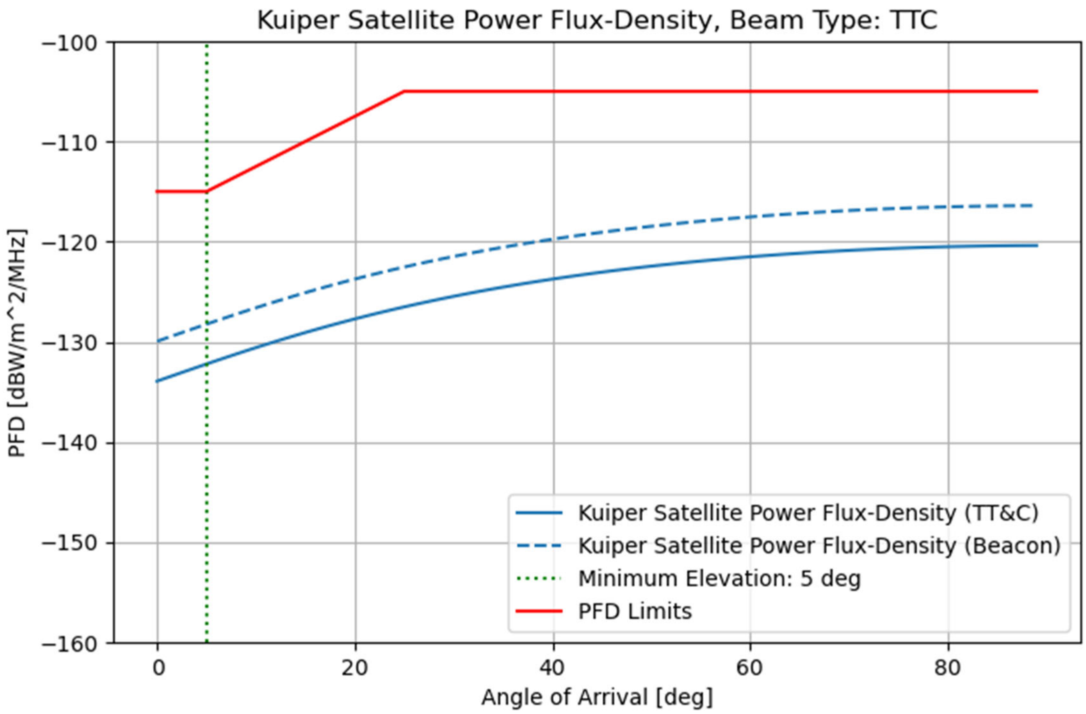
Figure 10: Maximum PFD Produced by the KuiperSat Customer Terminal Downlink Beams



III. PFD Compliance for TT&C Downlink Beam

Figure 11 shows the maximum PFD produced by the KuiperSat TT&C downlink beams. The satellite downlink TT&C beam will operate with an EIRP density of 6.0 dBW/MHz, which produces a maximum PFD of -120.4 dBW/m^2/MHz at an angle of arrival of 90°. The TT&C Earth station will operate with a minimum elevation angle of 5°, however the satellite TT&C antennas are low-gain and have low transmit gain discrimination, which prevent the PFD from rolling off sharply at angles of arrival below the minimum elevation angle as the gateway and customer terminal PFD levels do. The satellite downlink beacon will operate with the same EIRP as the modulated TT&C channel, but over a smaller bandwidth. The maximum PFD of the beacon will be -116.4 dBW/m^2/MHz. Figure 11 shows that the KuiperSat TT&C and beacon downlinks satisfy the ITU PFD limits by a significant margin.

Figure 11: Maximum PFD Produced by the KuiperSat TT&C Downlink Beams



APPENDIX 3: INTERFERENCE PROTECTION FOR CO-FREQUENCY GSO SYSTEMS

The Experimental Kuiper System has been designed to fully comply with all applicable limits in Article 22 of the ITU Radio Regulations. In complying with these rules, the Experimental Kuiper System will protect geostationary ("GSO") FSS operations.

A summary of applicable equivalent power flux-density ("EPFD") limits that are assessed in this appendix are provided in Table 12:

Table 12: Applicable ITU EPFD Limits

Applicable Links	Frequency Band	EPFD Direction	ITU RR Reference
User (downlink)	17.8 - 18.6 GHz, 17.8 - 18.4 GHz	EPFD↓, EPFDis	Table 22-1B, Table 22-3
Gateway (downlink)	19.6 - 20.1 GHz	EPFD↓	Table 22-1C
TT&C (uplink)	27.5 - 27.6 GHz	EPFD↑	Table 22-2
Gateway (uplink)	29.5 - 30.0 GHz	EPFD↑	Table 22-2

The Experimental Kuiper System is capable of meeting the EPFD limits above by restricting transmission power density in addition to the pointing directions of all applicable space-to-Earth and Earth-to-space transmissions, and by observing a minimum elevation angle of operation with respect to the horizon and a minimum separation angle with respect to the GSO arc.

I. EPFD Compliance for Downlink Operations

To demonstrate compliance with the applicable EPFD↓ and $EPFD_{is}$ limits, Amazon has performed a set of simulations using the official EPFD analysis software developed by Transfinite and distributed by the ITU Radiocommunication Bureau. This software implements the EPFD calculation algorithms specified in Recommendation ITU-R S.1503.

As indicated in the space-to-Earth frequency usage table earlier in the narrative (see Table 1), Kuiper's experimental operations for user links overlap with the EPFD provisions listed in Table 22-1B and Table 22-3 of the ITU Radio Regulations. A summary of the EPFD scenarios attributable to Kuiper's experimental user downlink operations is provided below:

Table 13: Summary of EPFD Scenarios for Customer Terminal Downlink Operations

ITU RR Provision	EPFD Direction	EPFD Limit (dBW/m^2)	Reference Bandwidth (kHz)	Reference Antenna Pattern
Table 22-1B 17.8 – 18.6 GHz	EPFD↓	Statistical	40	ITU-R S.1428-1 (1m antenna size)
			1000	ITU-R S.1428-1 (1m antenna size)
			40	ITU-R S.1428-1 (2m antenna size)

			1000	ITU-R S.1428-1 (2m antenna size)
			40	ITU-R S.1428-1 (5m antenna size)
			1000	ITU-R S.1428-1 (5m antenna size)
Table 22-3 17.8 – 18.4 GHz	EPFDis	-160.0 (100%)	40	ITU-R S.672-4 (4°, L_s=-20 dB)

The results of the corresponding simulations for these scenarios conducted using the official ITU BR EPFD software are provided in the following figures. In each case, the EIRP density of the spacecraft transmissions for User Links is set to 15.8 dBW/MHz, consistent with the maximum EIRP density indicated in Table 1 of the narrative.

Figure 12: Downlink EPFD, GSO Earth Station Diameter: 1.0m

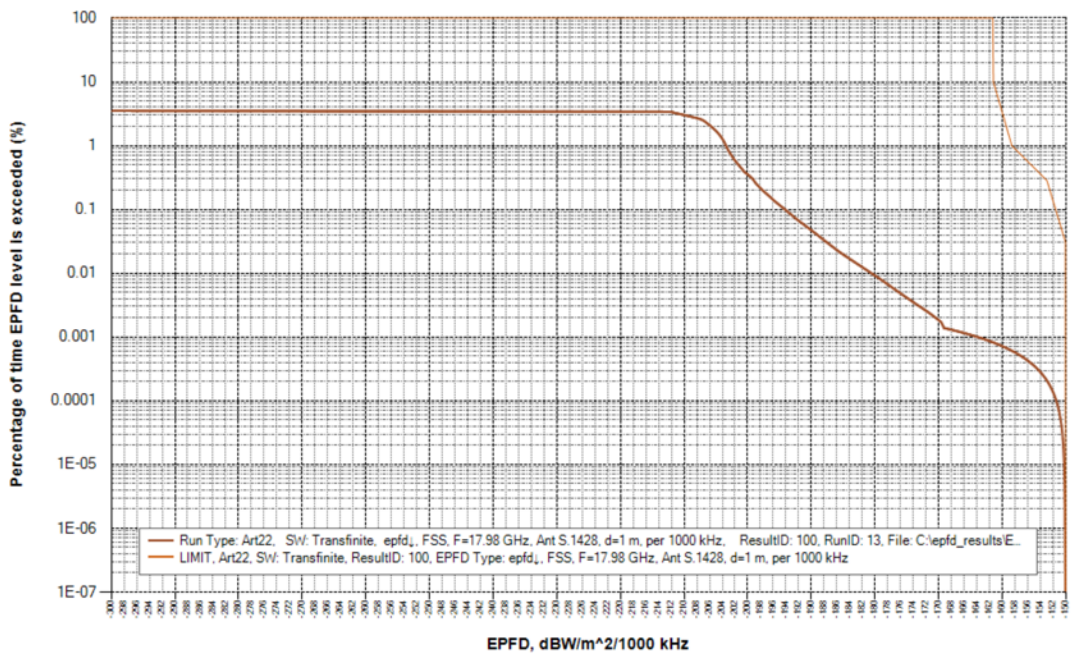


Figure 13: Downlink EPFD, GSO Earth Station Diameter: 2.0m

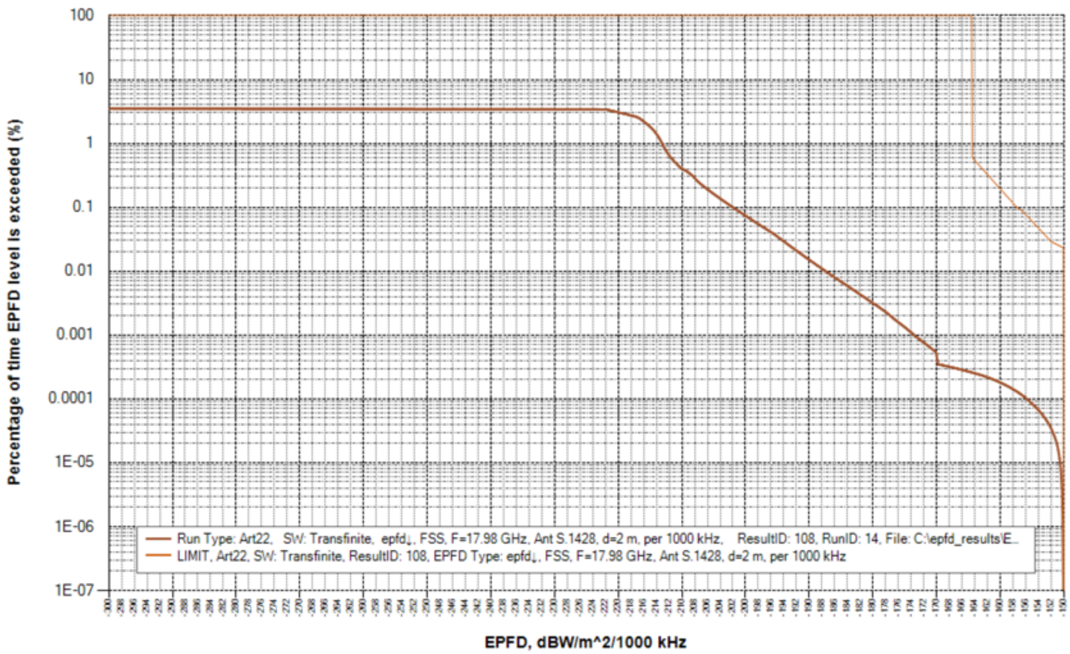


Figure 14: Downlink EPFD, GSO Earth Station Diameter: 5.0m

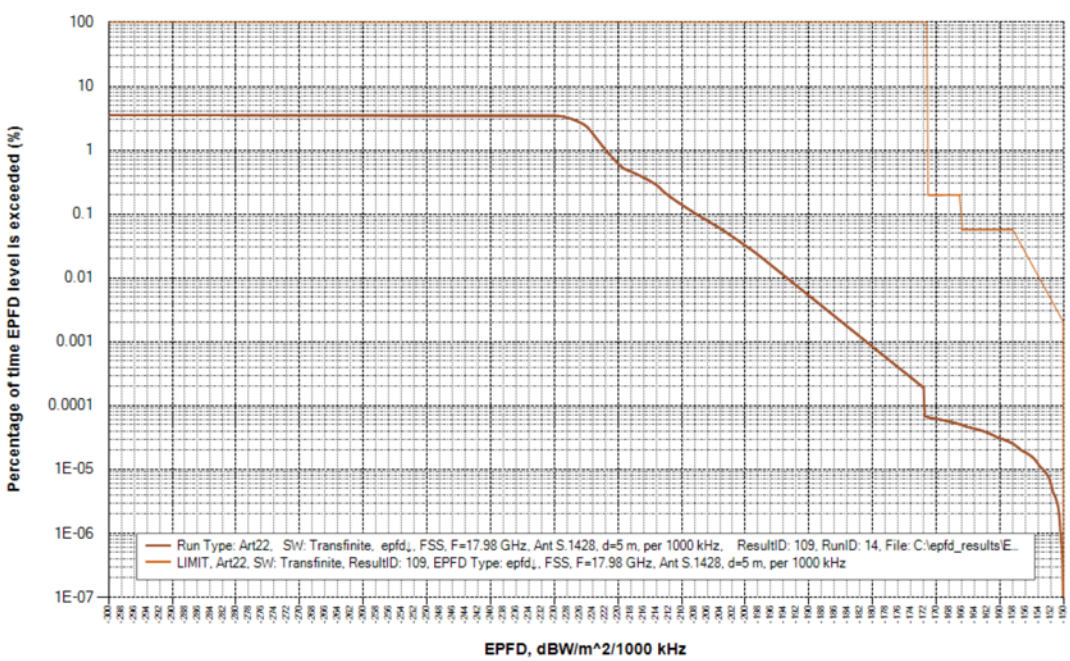
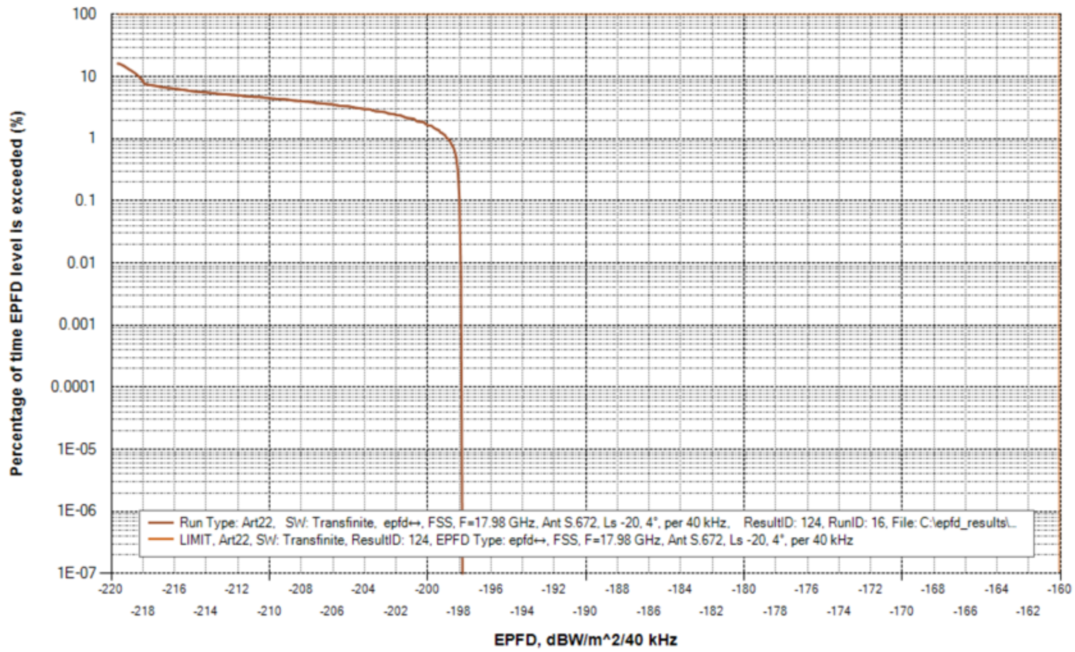


Figure 15: Inter-satellite EPFD



Kuiper's experimental gateway downlink operations in the space-to-Earth direction (see Table 1) also overlaps with the frequency range from Table 22-1C of the ITU Radio Regulations for the following EPFD↓ scenarios:

Table 14: Applicable ITU EPFD Limits for Gateway Downlink Scenarios				
ITU RR Provision	**EPFD Direction**	**EPFD Limit (dBW/m^2)**	**Reference Bandwidth (kHz)**	**Reference Antenna Pattern**
Table 22-1C 19.7 – 20.2 GHz	EPFD↓	Statistical	40	ITU-R S.1428-1 (70cm antenna size)
			1000	ITU-R S.1428-1 (70cm antenna size)
			40	ITU-R S.1428-1 (90cm antenna size)
			1000	ITU-R S.1428-1 (90cm antenna size)
			40	ITU-R S.1428-1 (2.5m antenna size)

			1000	ITU-R S.1428-1 (2.5m antenna size)
			40	ITU-R S.1428-1 (5m antenna size)
			1000	ITU-R S.1428-1 (5m antenna size)

The results of the corresponding simulations for the gateway downlink scenarios conducted using the official ITU BR EPFD software are provided in the following figures. In each case, the EIRP density of the spacecraft transmissions for Gateway Links is set to 9.2 dBW/MHz, consistent with the maximum EIRP density indicated in Table 1 of the narrative.

Figure 16: Downlink EPFD, GSO Earth Station Diameter: 70cm

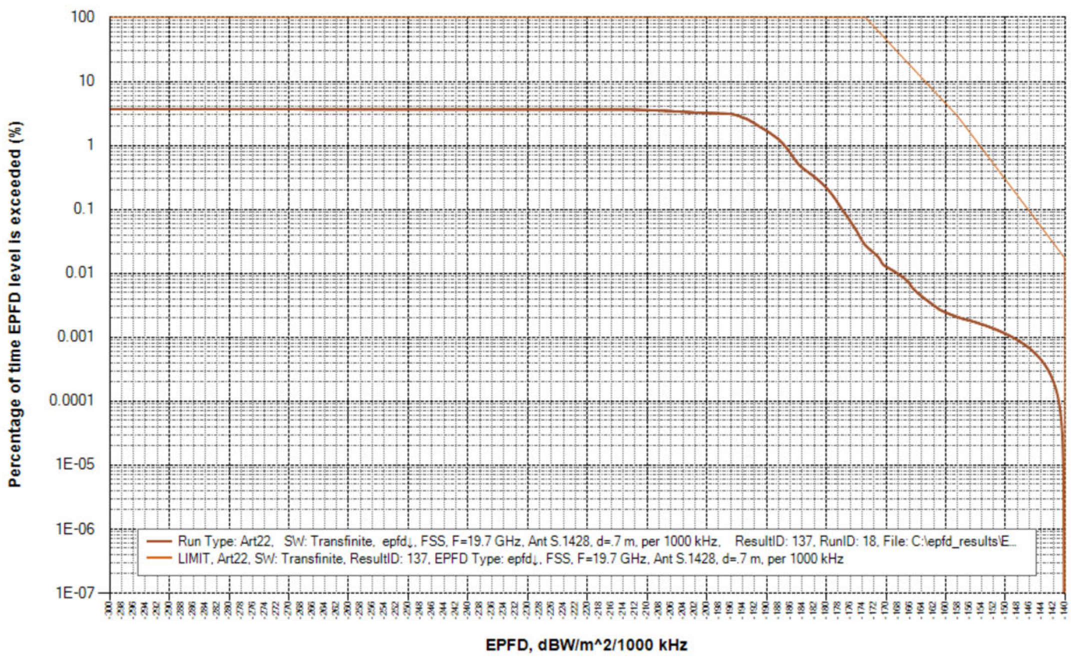


Figure 17: Downlink EPFD, GSO Earth Station Diameter: 90cm

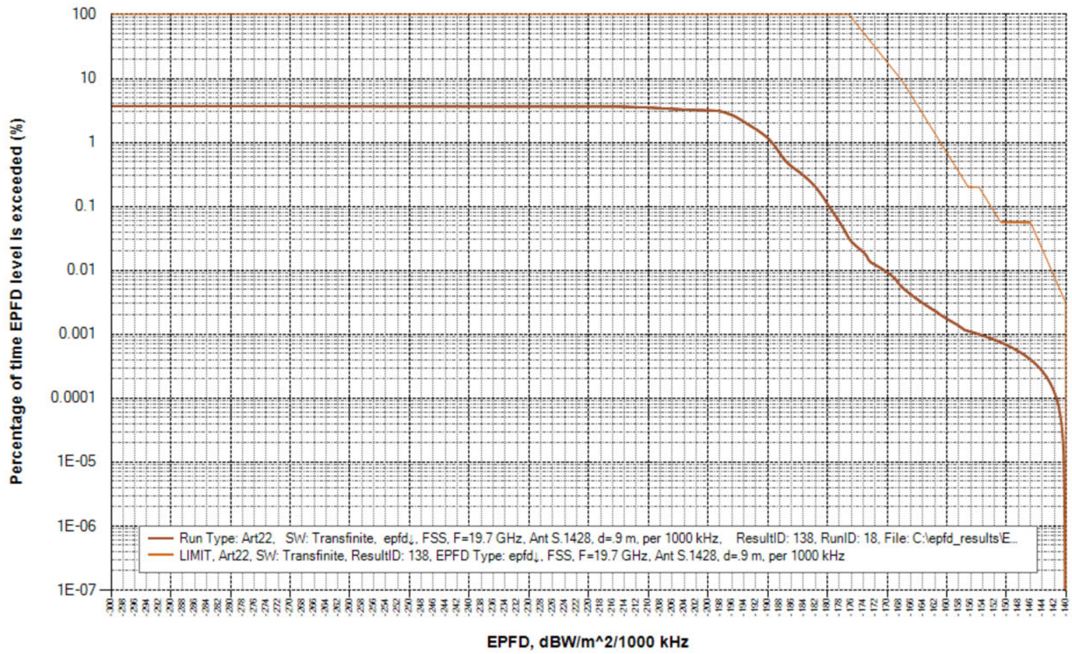


Figure 18: Downlink EPFD, GSO Earth Station Diameter: 2.5m

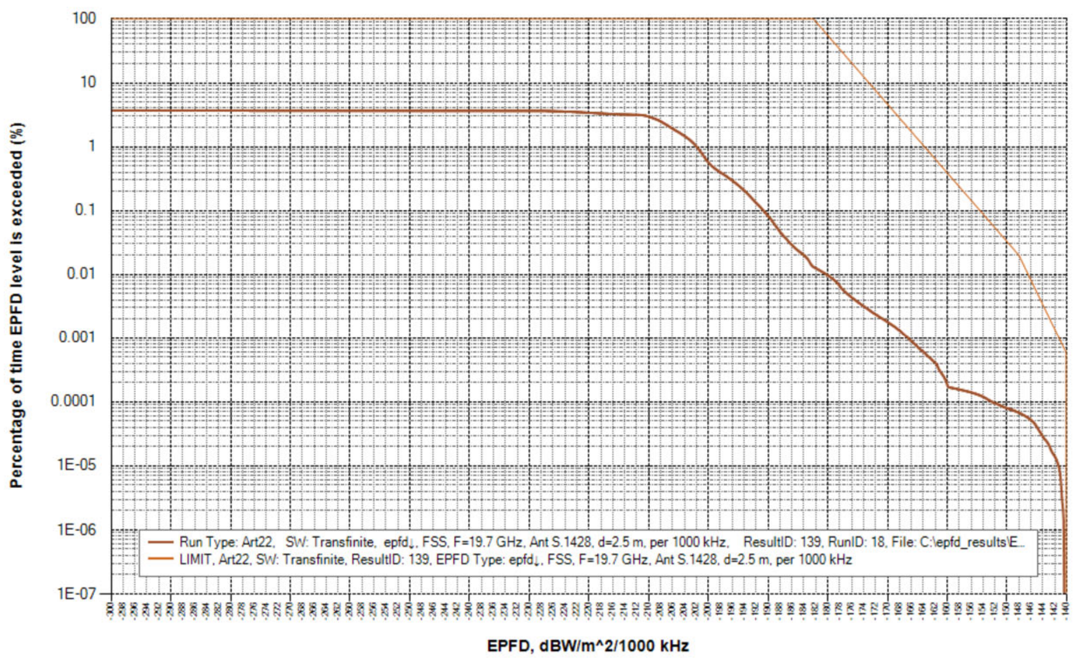
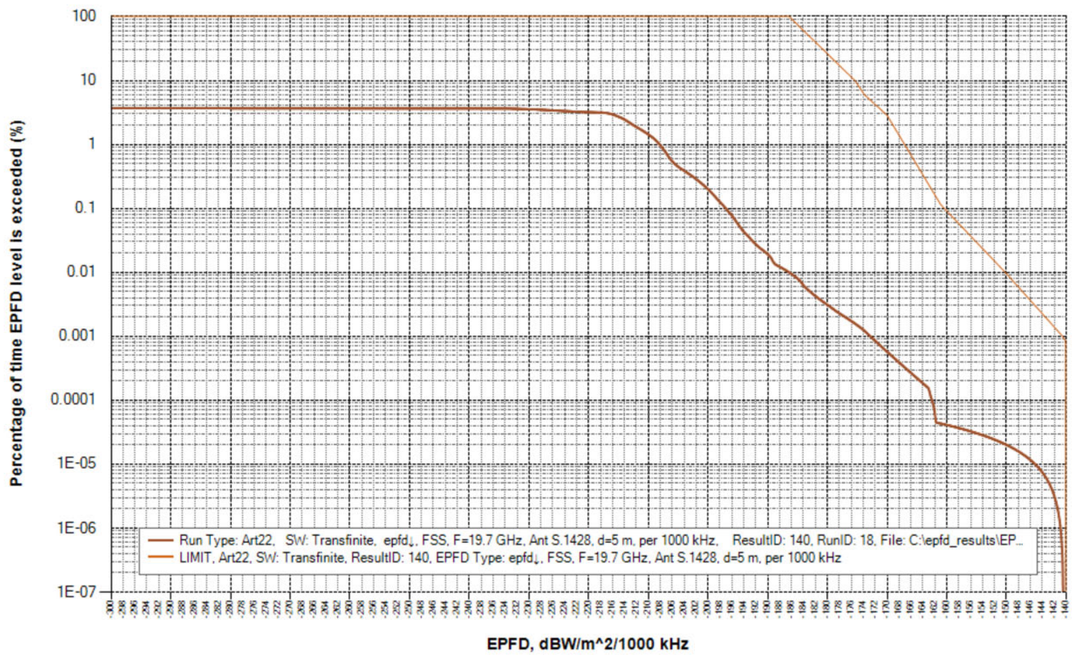


Figure 19: Downlink EPFD, GSO Earth Station Diameter: 5.0m



II. EPFD Compliance for Uplink Operations

As shown in Table 2, Kuiper's experimental operations for both gateway and TT&C links overlap in frequency with the EPFD↑ provisions listed in Table 22-2 of the ITU Radio Regulations. In these cases, Amazon has provided an analytical technical assessment to demonstrate compliance with the applicable limits.

A summary of the EPFD scenarios attributable to gateway uplink operations is indicated below:

Table 15: Summary of EPFD Scenarios for Gateway Uplink Operations

ITU RR Provision	EPFD Direction	EPFD Limit (dBW/m2)	Reference Bandwidth (kHz)	Reference Antenna Pattern
Table 22-2 29.5 – 30.0 GHz	EPFD↑	-162 (100%)	40	ITU-R S.672-4 (1.55°, L_s=-10 dB)

To assess the gateway uplink compliance with the above limits, the following table provides an analytical assessment of the uplink worst-case geometry, taking into account that the number of simultaneously operating gateway antennas does not exceed one ($N_{co} = 1$) and an envelope antenna pattern based upon Section 25.209(a) of the Commission's rules.[14] In this worst-case geometry assessment, the experimental gateway antenna is assumed to be co-located with the GSO Earth station, while the victim GSO satellite is assumed to be at the minimum propagation distance from the interference.

As indicated in the table below, the maximum possible EPFD as computed from the worst-case geometry is below the applicable EPFD limit.

Table 16: Maximum EPFD for Gateway Uplink Operations

Parameter	Units	Value	Notes
Transmit Power	W	8.3	
Transmit Power Density	dB(W/40kHz)	-31.6	
Peak Antenna Gain	dBi	53.1	
Peak EIRP Density	dB(W/40kHz)	21.5	
Distance to GSO Arc	km	36843.7	31 degrees latitude
Spreading Loss	dB(m^2)	162.3	
N_{co}		1	
GSO Arc Maximum Gain	dBi	9.5	
GSO Arc Minimum Off-axis discrimination	dB	43.6	
GSO Arc Maximum EIRP density	dB(W/40kHz)	-22.1	
Maximum GSO Arc EPFD	dB(W/m2/40kHz)	-184.4	

A summary of the EPFD scenarios attributable to TT&C uplink operations is indicated below:

Table 17: Summary of EPFD Scenarios for TT&C Uplink Operations

ITU RR Provision	EPFD Direction	EPFD Limit (dBW/m2)	Reference Bandwidth (kHz)	Reference Antenna Pattern
Table 22-2 27.5 – 28.6 GHz	EPFD↑	-162 (100%)	40	ITU-R S.672-4 (1.55°, L_s=-10 dB)

EPFD compliance for TT&C uplink is assessed using the same approach as for the gateway uplink compliance shown previously. The following table provides an analytical assessment of the worst-case geometry, taking into account that the number of simultaneously operating TT&C antennas does not exceed one ($N_{co} = 1$) and an envelope antenna pattern based upon 47 CFR 25.209(a). In this worst-case geometry assessment, the experimental TT&C antenna is assumed to be co-located with the GSO Earth station, while the victim GSO satellite is assumed to be at the minimum propagation distance from the interference.

As indicated in the table below, the maximum possible EPFD as computed from the worst-case geometry is below the applicable EPFD limit.

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[14] *See* 47 C.F.R. § 25.209(a).

Table 18: Maximum EPFD for TT&C Uplink Operations			
Parameter	**Units**	**Value**	**Notes**
Transmit Power	W	18.4	
Transmit Power Density	dB(W/40kHz)	-5.3	
Peak Antenna Gain	dBi	52.7	
Peak EIRP Density	dB(W/40kHz)	47.4	
Distance to GSO Arc	km	36843.7	31 degrees latitude
Spreading Loss	dB(m^2)	162.3	
N_{co}		1	
GSO Arc Maximum Gain	dBi	5.1	
GSO Arc Minimum Off-axis discrimination	dB	47.6	
GSO Arc Maximum EIRP density	dB(W/40kHz)	-0.2	
Maximum GSO Arc EPFD	dB(W/m2/40kHz)	-162.5	

APPENDIX 4: INTERFERENCE PROTECTION FOR CO-FREQUENCY NGSO SYSTEMS

The Experimental Kuiper System operations will protect all authorized NGSO systems from harmful interference. Amazon will conduct operations under the experimental license on a non-interference basis consistent with Section 5.84 of the FCC's rules.[15] Prior to commencing operations, Amazon will work with NGSO operators to ensure that its testing does not interfere with authorized operations. In the unlikely event that interference should occur, however, Amazon will take immediate steps to resolve the interference. Such steps include but are not limited to, ceasing transmission of all interfering frequency operations and coordinating with all relevant parties to mitigate the risk of future interference.

As explained below, the design and operation of the Experimental Kuiper System makes the actual probability of such interference very low. In general, the design and operation of the Experimental Kuiper System minimizes each of the four elements that must be present to experience an in-line interference event—namely, satellites that are (i) geometrically aligned, (ii) using the same frequencies, (iii) operating at the same time, and (iv) communicating with Earth stations that are in geographic proximity. Here, the Experimental Kuiper System will involve only two satellites, operating for limited periods of time, and communicating with Earth stations that are geographically remote from other NGSO Earth stations. Collectively, these characteristics make the prospect of an actual in-line interference event vanishingly small. We examine each of these elements below.

(1) Geometric alignment of satellites

At the outset, the limited number of satellites in the Experimental Kuiper System dramatically reduces any possibility of geometric alignment. Harmful interference between NGSO satellite systems typically only occurs when there is an in-line event between the satellites and Earth stations of two NGSO satellite systems while both systems are transmitting. The limited nature of Kuiper's experimental operations—operation of only two satellites—will make this geometric and time alignment highly unlikely.

(2) Co-frequency transmission

An in-line interference event would also require that aligned satellites from involved systems were operating at the same frequency. Here, the KuiperSats will be using only a portion of the Ka-band frequencies authorized under Amazon's Part 25 license at any time. Because the KuiperSats, as well as many authorized systems, use emissions bandwidths smaller than the entire authorized band in each direction of transmission, it is possible that there will be no frequency overlap during an alignment event. Even with frequency overlap, systems operating with different polarizations may not experience harmful interference. The limited use of Ka-band frequency by the Experimental Kuiper System therefore reduces the probability of co-frequency transmission with other NGSO operators.

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15 47 C.F.R. § 5.84.

(3) Simultaneous operations

An actual in-line interference event would also require that aligned satellites be operating *at the same time*. Here, the KuiperSats, at an altitude of 590 km, will have an orbit period of 96.5 minutes. The KuiperSats will each have five or fewer active contact windows per day, and each active contact window will be on average less than six minutes in duration, i.e., less than 30 minutes per 1,440-minute day.

(4) Geographic Proximity of Earth stations

Finally, an in-line interference event would require geographic proximity of the Earth stations communicating with the aligned satellites. If the Earth stations are sufficiently separated, it is possible there will be no beam overlap or sufficient angular separation of the transmission paths to permit co-frequency operation. Here, the Experimental Kuiper System Earth station will enjoy a large separation distance with other NGSO Earth stations. In the downlink direction, the Earth station separation ensures that the KuiperSat off-axis downlink EIRP will be low in the direction of other NGSO Earth stations. In the uplink direction, the Earth station separation ensures that other NGSO satellites will have sufficient off-axis receive gain discrimination in the direction of the Experimental Kuiper System Earth station.

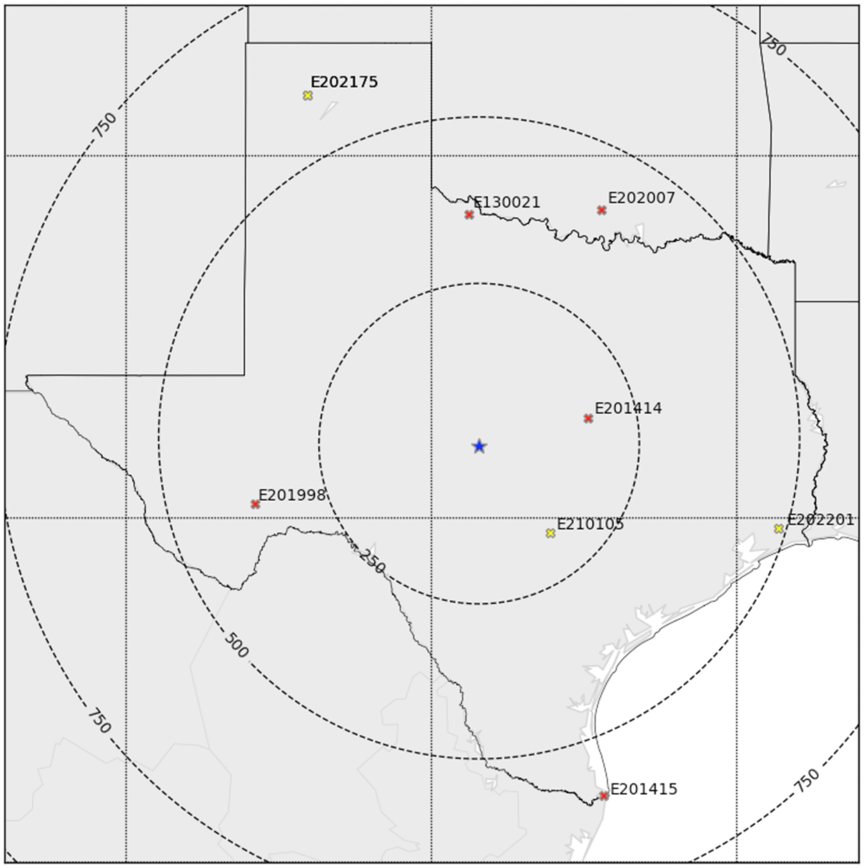
A review of the International Bureau Filing System database shows that there are no licensed NGSO Earth stations operating in the Ka-band within 150 km of the Experimental Kuiper System Earth station location in Texas.

There are only four licensed NGSO Earth stations operating in the Ka-band within 500 km of the Experimental Kuiper System Earth station in Texas and two additional applications for NGSO Earth stations within that radius currently pending. They are listed in Table 19 and shown in Figure 20.

Table 19: Licensed and Pending Earth Stations Within 500 km

Callsign	Licensee	Latitude	Longitude	Distance	Status
E201414	SpaceX	31° 24’ 17.7" N	97° 26’ 17.3" W	174.6	Authorized
E210105	SpaceX	29° 47’ 2.6" N	98° 3’ 2.8" W	177.5	Pending
E130021	O3b Networks	34° 13’ 4.7" N	99° 23’ 46.5" W	355.7	Authorized
E201998	SpaceX	30° 11’ 38.4" N	102° 53’ 24.0" W	363.2	Authorized
E202007	SpaceX	34° 16’ 6.6" N	97° 12’ 47.4" W	406.9	Authorized
E202201	SpaceX	29° 51’ 35.5" N	94° 18’ 44.4" W	487.8	Pending

Figure 20: Map of Licensed and Pending Earth Stations Within 500 km of Experimental Kuiper System Earth Station



Red = Authorized Earth Stations
Yellow = Pending Earth Stations

The design and operation of the Experimental Kuiper System will significantly limit the probability of having in-line interference events with other NGSO systems, due to the small number of deployed KuiperSats, small emission bandwidths, very low duty cycle of transmissions in any given day, and significant geographic separation of Experimental Kuiper System Earth stations from other operator Earth stations.

APPENDIX 5: INTERFERENCE PROTECTION FOR CO-FREQUENCY UMFUS SYSTEMS

The Experimental Kuiper System TT&C Earth-to-space transmissions will occur in the 27.5-27.6 GHz band. The band is allocated to the Upper Microwave Flexible Use Service ("UMFUS") on a primary basis. Amazon has identified local UMFUS licensees and will coordinate its use of the band with them. The design and operation of the Experimental Kuiper System makes the probability of harmful interference to local UMFUS systems very low for the following reasons:

(i) The Experimental Kuiper System TT&C Earth station location was selected to avoid major roadways and high population areas;

(ii) The Experimental Kuiper System TT&C channel bandwidth will be small;

(iii) The Earth station will only transmit when the KuiperSats are in-view of the Earth station, and this limits the duration of transmission to less than an hour each day; and

(iv) The Earth station will not transmit when the minimum elevation to the KuiperSats is less than 5 degrees. The average elevation angle of transmission will be significantly higher. The high elevation angle, as well as the varying azimuth angle, makes it unlikely that there will be main-beam alignment between the Earth station and an UMFUS base station in proximity to the Earth station.

APPENDIX 6: ORBITAL DEBRIS MITIGATION/POST-MISSION DISPOSAL PLAN

Space safety is fundamental to Amazon, including its KuiperSat satellites. Amazon's satellite design, and its operational strategies, will mitigate orbital debris risks, as required by Section 5.64(b) of the Commission's rules.

I. Debris Release[16]

Amazon has assessed and limited the amount of debris released in a planned manner during normal operations. The KuiperSats do not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release from the launch vehicle or to actuate deployable structures on the satellite. This approach limits the chance that debris will be released during normal deployment.

II. Small Debris[17]

Amazon has also assessed and limited the probability that a KuiperSat will become a source of debris by collisions with small debris or meteoroids that would cause loss of control and prevent disposal. Using the National Aeronautics and Space Administration's ("NASA") Debris Assessment Software ("DAS"),[18] Amazon examined the most likely operational failure scenario leading to loss of control. In that scenario, each of the KuiperSats would deorbit in approximately 3.5 years because, with an area to mass ratio of 0.04462 m^2/kg, there would be sufficient atmospheric drag at the satellites' planned orbital altitude (590 km) to assure passive deorbit even if all propulsive capability were lost. Therefore, a failure during operations resulting in loss of the ability to perform the planned post-mission disposal maneuver activity would not prevent mission

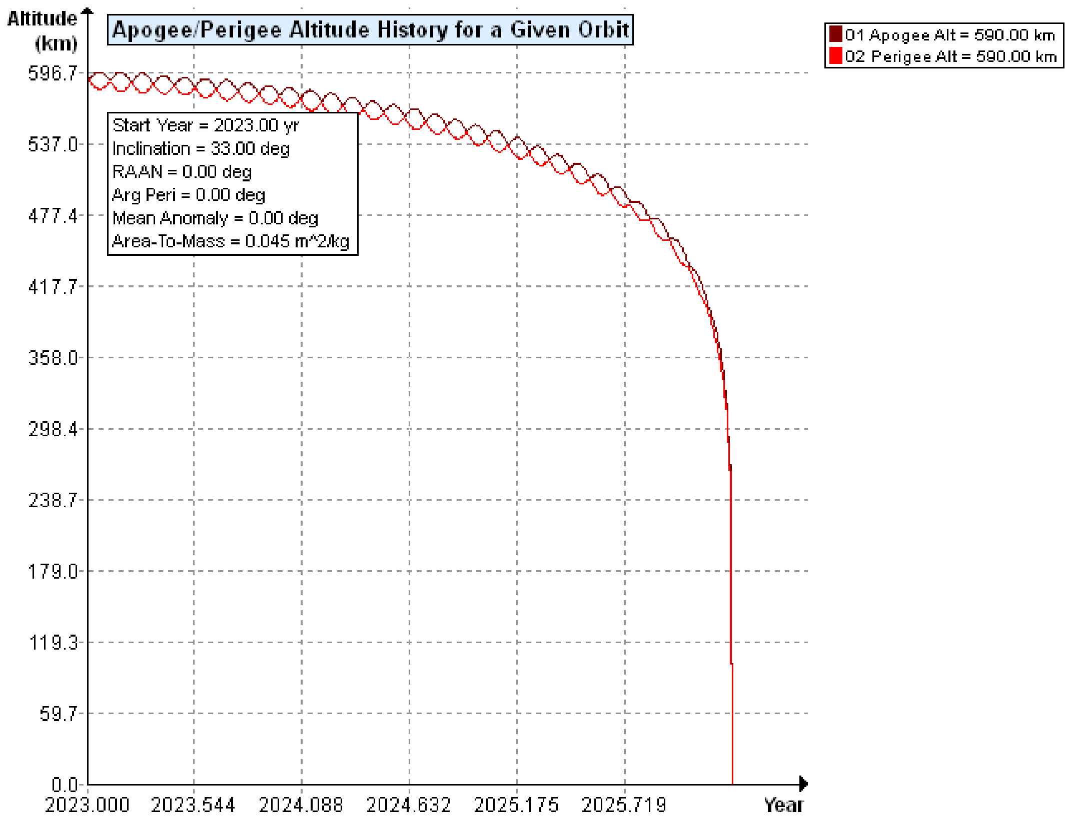
[16] 47 C.F.R. 5.64(b)(1).

[17] *Id.* § 5.64(b)(2).

[18] DAS Version 3.1.0 with solar flux file dated June 28, 2021.

disposal within 25 years. The DAS plot of the apogee and perigee altitude below in Figure 21 shows a theoretical failure in 2023, during mission life.

Figure 21: Apogee and Perigee Decay from Operational Altitude



Using DAS, Amazon determined that the probability that a KuiperSat could become a source of debris by collision with small debris or meteoroids that causes loss of control and prevents fast, active post-mission disposal is less than 1 in 100 (0.000672).[19] To meet this 1 in 100 metric, Amazon has shielded the spacecraft to withstand impact by small debris and remain operable. Amazon is using a combination of component design and Whipple shielding, which protects all components, especially the battery and the propellant tank. Additionally, the KuiperSats include built-in redundancies, such as independent solar panels and flight computers, to prevent loss of control in the event of a collision.

III. Accidental Explosions[20]

As with debris release, Amazon has also assessed and limited the probability, during and after completion of mission operations, of accidental explosions or of release of liquids that could

[19] Amazon calculated this probability using NASA's Orbital Debris Engineering Model ("ORDEM") 3.1, the same tool used by DAS 3.1.1.

[20] 47 C.F.R. § 5.64(b)(3).

persist in droplet form. In designing the KuiperSats, for example, Amazon worked to ensure that conversion of energy sources (chemical, pressure, and kinetic) onboard the spacecraft into energy that fragments the spacecraft will not result in debris generation. Amazon has tested the propellant tanks to demonstrate that even penetrating impacts will not cause rupture at pressures below expected operating pressure. In addition, each KuiperSat's propellant tank is designed to leak rather than burst in most failure mode conditions, even if the failure is caused by micrometeoroid orbital debris impact, and Amazon has tested the tanks' failure characteristics under high velocity impact to verify this result. The Krypton propellant itself is an inert noble gas, which significantly reduces the risk of accidental explosions, allows any residual molecules to blow away in the solar wind, and prevents droplet coalescence that could otherwise contribute to orbital debris generation. Furthermore, Amazon also designed the KuiperSat battery system to ensure that a battery cell failure would be contained to a single cell, further limiting the chance of thermal runaway, and in turn, accidental explosion.

As discussed in more detail below, KuiperSats will reserve inert gas propellant on board to reduce perigee altitude to 350 km at the end of mission life. The KuiperSats will then use the remaining propellant to further reduce apogee, continue collision avoidance maneuvers, and finally vent any residual fuel, leaving all fuel lines open, which will be followed by uncontrolled reentry and rapid demise.

IV. Collision Risks with Large Objects [21]

Amazon has similarly assessed and limited the probability that a KuiperSat will become a source of debris by collision with large debris or other operational space stations.

1. *Collision Risk Standard* [22]

Amazon has assessed and limited the probability of collision between a KuiperSat and other large objects (10 cm or larger in diameter) during the total orbital lifetime of each KuiperSat, including any deorbit phases, to less than 0.001 (1 in 1,000). Specifically, Amazon's DAS analysis shows that, without operable propulsion, a KuiperSat's risk of collision with large objects is 0.0001395, well under the 0.001 metric.

The KuiperSats will be equipped with an onboard propulsion system that allows the spacecraft to remediate conjunction risks larger than 1 in 100,000 throughout mission life. Amazon will use this system for active avoidance of other spacecraft and tracked inert objects, including during deorbiting and at the post-mission disposal stage. Amazon's planned mission life for each KuiperSat is less than two years, further limiting the likelihood of a collision event with large objects. In addition to active mitigation measures, Amazon's comprehensive space debris avoidance program will also include: (1) an effective, timely response to data messages from the 18th Space Control Squadron that advise of conjunction risk; (2) use of a third-party debris

[21] *Id.* § 5.64(b)(4)(i).

[22] *Id.* § 5.64(b)(4)(i)(A).

tracking service to improve conjunction warning response; and (3) "full lifecycle" conjunction avoidance, from early operations after dispensing, to re-entry.

2. *Orbital Risks*[23]

The KuiperSats will use an orbit with a reference altitude of 590 km and an inclination of 33 degrees. For additional risk criteria, Amazon has investigated the existence of other satellites with near-identical orbit planes and altitudes. Based on a review of the existing U.S. Space Command Space Surveillance Network ("SSN") catalog, Amazon has not identified identical or near-identical space station orbits that create additional risk and require coordination.

3. *Inhabitable Spacecraft*[24]

KuiperSats will support NASA's International Space Station collision screening keep-out envelope restrictions, which are +/- 2 km radial, +/- 25 km local horizontal. In addition to maneuvering, KuiperSat activities will include deorbit timing selection to de-conflict planar conjunctions from inhabitable spacecraft.

4. *Orbital Parameters and Maneuverability*[25]

During ongoing operations, the ability of the KuiperSats to maintain strict operating altitudes also promotes safety. The KuiperSats will deploy and maintain apogee and perigee to 7 km of their nominal operational altitude (590 km). The natural motion imposed by Earth's oblateness, plus orbital eccentricity mean and variance—in combination with the satellites' ability to maneuver—result in no more than 9 km of cumulative altitude deviation. The RAAN of the satellites' orbit will exhibit secular precession and thus is not constrained to any specific value throughout the mission. The satellite orbit inclination will be subject to natural perturbations due to lunar-solar gravity but will stay within 0.1 degree of 33 degrees throughout the mission. The KuiperSats will maintain their respective orbits to a drag-free trajectory through propulsion and navigation systems. Orbital altitude will be maintained throughout mission life, with expected deorbit trajectory at the end of mission life consistent with the plot shown in Figure 21, above.

The KuiperSats will utilize onboard propulsion to enable station-keeping maneuvers that will maintain the reference orbit altitude. They will conduct both orbit adjust maneuvers that change orbit station during deorbit to lower altitudes and risk mitigation maneuvers to avoid collisions with other orbiting objects. The propulsion system is designed to deliver sufficient change in orbit velocity (delta-v) such that conjunction risk can be reduced by an order-and-a-half in magnitude, as recommended by NASA, to 3.0E-7 or lower at each conjunction event. A KuiperSat risk mitigation maneuver is projected to typically impart a 140 meter change in orbit altitude and a change in alongtrack position of over 650 meters after each successive orbit revolution, when compared to a no-maneuver trajectory. This level of maneuverability provides

[23] *Id.* § 5.64(b)(4)(i)(B).

[24] *Id.* § 5.64(b)(4)(i)(C).

[25] *Id.* § 5.64(b)(4)(i)(D).

ample capability over the mission lifetime to avoid collisions with other objects and helps ensure mission disposal of less than 1 year using propulsion.

5. *Space Situational Awareness Conjunction Warning*[26]

Upon receipt of a space situational awareness conjunction warning (a Conjunction Data Message or "CDM") from the 18th Space Control Squadron, Amazon certifies that it will review the data and take all possible steps to assess and mitigate the collision risk if necessary. As part of this process, Amazon will:

- Assess the data quality of the orbit station of the secondary object, either from the SSN or commercial data providers, or the owner/operator of the secondary object, if available, and calculate the probability of collision associated with the conjunction using Amazon data.

- Calculate the probability of collision associated with the conjunction using secondary owner operator data supplied to the 18th Space Control Squadron's Space-Track data portal, if available.

- Assess the risk posed using probability of collision, based on the best quality data available. If the probability of collision exceeds the Amazon risk threshold for conjunctions (1 in 100,000), Amazon will immediately begin planning and screening for a risk mitigation maneuver. This risk mitigation maneuver ("RMM") data will then be provided to Space-Track for spaceflight operators and space situational awareness monitors to assist in maintaining track custody of the KuiperSat. When a secondary object is a satellite, Amazon will provide the owner/operator of that satellite with the RMM information.

- Upon determining that a maneuver is necessary, Amazon will contact the operator of the second payload directly to coordinate response.

Amazon will also share ephemeris data and other appropriate operational information and, as necessary to mitigate collision risk, modify the KuiperSat altitude and/or operations.

All of these measures will span the phases of the KuiperSats' operations. Kuiper satellite launch and early operation procedures will be attentive to space debris concerns from the outset. When the KuiperSats separate from the launch vehicle, for example, debris release concerns will be paramount, and Amazon will take the mitigation measures discussed in this orbital debris mitigation plan.[27] After injection at 590 km and successful checkout, each satellite will initiate collision avoidance procedures that will continue throughout on-orbit operations, thus protecting

[26] *Id.* § 5.64(b)(4)(i)(E).

[27] As previously noted, the KuiperSats do not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release from the launch vehicle or to actuate deployable structures on the satellite, limiting the chance that debris will be released during normal deployment and thus minimizing collision risk.

previously launched space vehicles through active conjunction assessment and maneuvering as necessary. To further mitigate the risk of collision, Amazon will coordinate during operations, in real-time, with systems whose orbital altitudes the KuiperSats will transit while on-station and during deorbit.

In addition to automated data sharing, maneuver planning, and ephemeris exchange protocols, Amazon will promote and engage in manual interaction to support the flight dynamics activities of other active spacecraft. Again, each KuiperSat will keep conjunction risk below 1 in 100,000 by maneuvering against all trackable debris and spacecraft, throughout all mission phases.

V. Trackability[28]

Amazon will track each of the KuiperSats as described below.

1. *Identification and Tracking of Space Stations*[29]

After orbital insertion, Amazon will identify the KuiperSats from the ground. Following signal acquisition, Amazon will actively track these satellites through on-board telemetry, which will include identification and navigation data.

2. *Registration*[30]

Each KuiperSat will be registered with the 18th Space Control Squadron prior to launch. Injection orbit parameters, launch location, target date and time of launch will be provided to the 18th Space Control Squadron prior to launch to aid in detection, tracking, and custody of Kuiper satellites by the SSN.

3. *Information Sharing*[31]

Amazon's active tracking technique will produce updated satellite predictive ephemerides for, and Amazon will share planned maneuvers with, the 18th Space Control Squadron to assist with United States Space Command catalog updates and custody of the KuiperSats and for owner and operator distribution. In the very unlikely event that a KuiperSat becomes incapable of maintaining its orbital positioning, a "Non-Maneuverable" status for that satellite will be reported to 18th Space Control Squadron via Space-Track, which is available for registered satellite owners and operators, like Amazon.

As part of its space safety plans throughout these phases, Amazon has also described and explained its mission operations plans to government entities. For example, Amazon has discussed its conjunction assessment and risk mitigation techniques with the 18th Space Control Squadron, the NASA Conjunction Assessment and Risk Analysis program, NASA's Trajectory Operations

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[28] *Id.* § 5.64(b)(5).

[29] *Id.* § 5.64(b)(5)(i).

[30] *Id.* § 5.64(b)(5)(ii).

[31] *Id.* § 5.64(b)(5)(iii).

and Planning Office, and NASA's Earth Science Mission Operations Project to establish planning coordination with NASA spaceflight operations.

VI. Planned Proximity Operations[32]

There are no proximity operations planned for KuiperSats.

VII. Disposal Plans[33]

KuiperSats will further avoid creating orbital debris by actively de-commissioning and deorbiting through atmospheric reentry within one year after the active two-year mission lifetime. Amazon will not use direct retrieval. A number of safeguards will promote safety during the de-commissioning process. For example, the KuiperSats will continue to perform avoidance maneuvers consistent with on-going conjunction assessment plans and will maintain the same high standards as during the mission's operations phase.

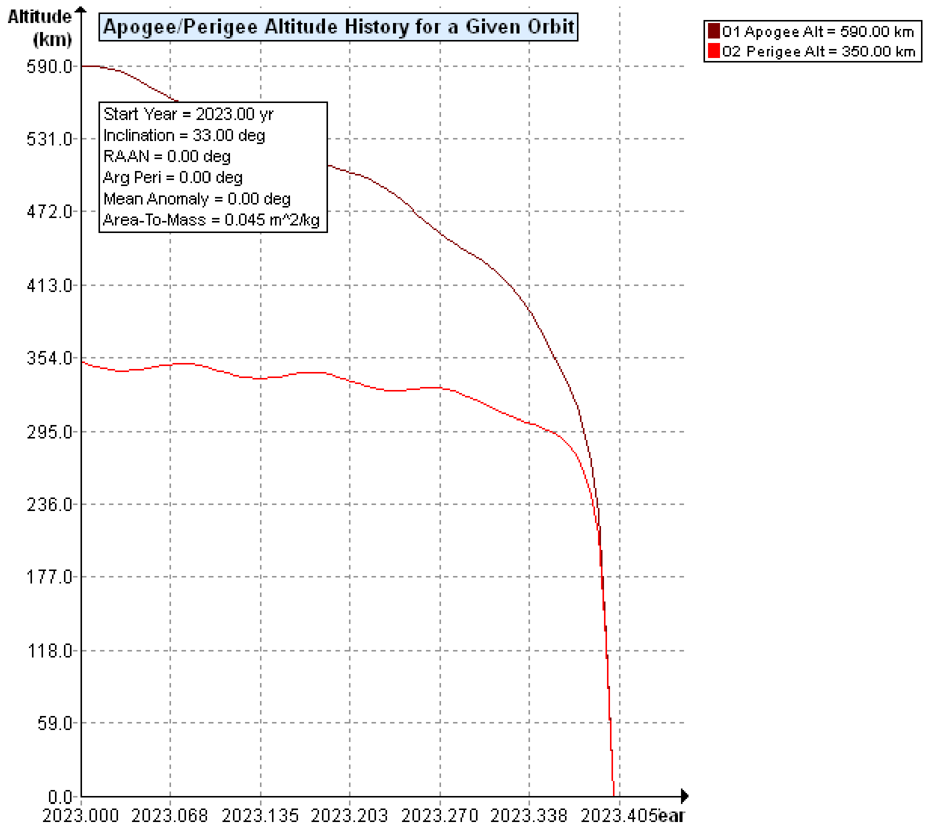
KuiperSats will also reserve limited amounts of inert gas propellant for post-mission disposal maneuvers, and will continue collision avoidance activities in a continued effort to ensure space safety. Specifically, at the end of their mission life, the KuiperSats will retain enough propellant on board to reduce perigee altitude to 350 km. If no further action were taken, a rapid, natural decay from the disposal orbit would occur in less than one year, as shown in Figure 22, illustrating the apogee and perigee altitudes using DAS. At that point, however, any residual propellant will be used to lower apogee and continue collision avoidance either until exhaustion, or until the point at which apogee is less than the altitude of the International Space Station. At that juncture, the KuiperSats will use the remaining propellant to further reduce apogee, and finally vent any residual fuel, which will be followed by uncontrolled reentry and rapid demise. The

[32] *Id.* § 5.64(b)(6).

[33] *Id.* § 5.64(b)(7).

KuiperSats will each reserve 6.7 kg of fuel for disposal maneuvers, which represents 185 meters/second of Delta-V budget.

Figure 22: Natural Decay from Disposal Orbit



During these orbit-lowering maneuvers, conjunction avoidance will be active through publication of predictive ephemerides, ongoing screening, and adjusted burn plans to respond to identified risks above the maneuver threshold, among other things. Additionally, if at any time failures render a satellite unable to perform deorbit and the failure impedes ground communications, the satellite will autonomously release any stored energy.

The probability of success of this disposal method for each KuiperSat is 0.999328, as derived from the small debris risk analysis described above. This probability of success exceeds the Commission's requirement of 0.9 or greater for any individual space station. It also exceeds the Commission's goal for large systems of achieving a probability of success for any individual space station of 0.99 or better.

Amazon's post-mission disposal approach complies with the NASA technical standard,[34] and the Commission's regulations,[35] requiring less than 1 in 10,000 risk of casualty from surviving components with impact kinetic energies greater than 15 joules. Amazon used the approved DAS software techniques to verify less than a 1 in 10,000 casualty risk for an individual spacecraft. Specifically, Amazon modeled 40 types of components per satellite, each with its own shape, material, mass, and dimensions, using DAS. The components were modeled in a highly conservative nested fashion, where a child component would not be exposed to aerodynamic heating until its parent component completely demised. For each KuiperSat, nine different types of components survived uncontrolled reentry to reach the surface of the Earth, eight of which had a kinetic energy of less than 15 joules and thus did not contribute to the casualty risk. One component (of which there are four per KuiperSat) survived uncontrolled reentry with a kinetic energy greater than 15 joules, as described in Table 20. The risk of human casualty was calculated as 1 in 18,600. This meets—and exceeds—the Commission's standard.

Table 20: Reentry Analysis

Component	**Quantity**	**Material**	**Mass [kg]**	**Total Debris Casualty Area [m^2]**	**Kinetic Energy [J]**
Reaction Wheel Rotor	4	Steel AISI 410	1.5	1.19	746.33

[34] *See* NASA Technical Standard, Process for Limiting Orbital Debris, NASA-STD-8719.14B, at 4.7.2.2 (Apr. 25, 2019), https://standards.nasa.gov/standard/nasa/nasa-std-871914.

[35] 47 C.F.R. § 5.64(b)(7).