TECHNICAL ATTACHMENT

Polar Kuiper System

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TECHNICAL APPENDIX

Amazon holds authority from the Federal Communications Commission ("FCC" or "Commission") to launch and operate a constellation of non-geostationary satellite orbit ("NGSO") low-Earth orbit ("LEO") satellites across three orbital shells (the "Gen 1 Kuiper System"),[1] and using Ka-band frequencies for gateways ("GWs"), customer terminals ("CTs"), and tracking, telemetry, and control ("TT&C"). In 2021, Amazon submitted an application ("V-band Application") to the Commission, which sought authority for NGSO LEO satellites in polar orbits (the "Polar Kuiper System") that would build upon the Gen 1 Kuiper System and offer enhanced communication services to additional consumers above 56°N and below 56°S. As a part of the V-band Application, Amazon requested to use Ku-band and V-band frequencies for the Polar Kuiper System. This Amendment now seeks to: (1) adjust the orbital parameters of the Polar Kuiper System to reflect design improvements since 2021; (2) add additional Ka-band and 17 GHz Band frequencies; and (3) supplement the requested V-band frequencies for the Polar Kuiper System, as set forth in the V-band Application, with the 51.4 – 52.4 GHz band.

I. DESCRIPTION OF THE POLAR KUIPER SYSTEM

A. Orbital Reconfiguration

As described in Table 1, below, the V-band Application sought authority for a Polar Kuiper System consisting of two orbital shells with 1,302 satellites. In order to provide better coverage near the poles, this Amendment now seeks to reconfigure some of the orbital parameters from the original application and reduce the total number of satellites by 10. Table 1, below, summarizes

[1] *See Kuiper Systems LLC, Request for Modification of the Authorization for the Kuiper NGSO Satellite System*, Order and Authorization, 39 FCC Rcd 3987 (SB 2024).

the revised orbital parameters requested herein. Detailed orbital parameters are provided in an attachment to this application.

Table 1. Constellation Design Showing Altitudes and Inclinations

		Original Parameters			Amended Parameters		
Altitude (km)	**Inclination (deg)**	**Number of Planes**	**Satellites per Plane**	**Total Satellites**	**Number of Planes**	**Satellites per Plane**	**Total Satellites**
600	82	-	-	-	4	38	152
620	66	-	-	-	40	20	800
640	72	652	1	652	-	-	-
650	80	325	2	650	170	2	340
		Total Satellites		**1302**	*Total Satellites*		**1292**

B. Frequency and Polarization Plan

In the V-band Application, Amazon sought authority for the Polar Kuiper System to use V-band and Ku-band payloads. In addition to the V-band frequencies (37.5 – 42.5 GHz, 47.2 – 50.2 GHz, and 50.4 – 51.4 GHz) requested in the V-band Application, Amazon now asks to additionally supplement the Polar Kuiper System with 1 GHz of additional V-band spectrum (51.4 – 52.4 GHz). Moreover, as a result of evolving design changes, the Polar Kuiper System will also use Ka-band frequencies, including the newly allocated spectrum in the 17.3 – 17.8 GHz band (the "17 GHz Band"). Table 2, below, provides a detailed overview of the requested Polar Kuiper System frequency bands.

Table 2. Frequency Bands used by the Polar Kuiper System

Type of Link and Transmission Direction	Original Frequencies	Additional Amended Frequencies
Satellite to Gateway	37.5 – 42.0 GHz *42.0 – 42.5 GHz (non-U.S. only)*	17.3 – 18.6 GHz 18.8 – 20.2 GHz

Gateway to Satellite	47.2 – 50.2 GHz 50.4 – 51.4 GHz	27.5 – 30.0 GHz 51.4 – 52.4 GHz
Satellite to Customer Terminal	10.7 – 12.7 GHz 37.5 – 42.0 GHz *42.0 – 42.5 GHz (non-U.S. only)*	17.3 – 18.6 GHz 18.6 – 18.8 GHz 18.8 – 19.4 GHz 19.4 – 19.6 GHz 19.6 – 20.2 GHz 20.2 – 21.2 GHz
Customer Terminal to Satellite	12.75 – 13.25 GHz[2] 14.0 – 14.5 GHz 47.2 – 50.2 GHz 50.4 – 51.4 GHz	28.35 – 29.1 GHz 29.5 – 30.0 GHz 30.0 – 31.0 GHz 51.4 – 52.4 GHz
TT&C Downlink & Beacon	40.0 – 40.1 GHz	19.25 – 19.4 GHz
TT&C Uplink	47.2 – 47.3 GHz	27.5 – 28.05 GHz 28.6 – 29.1 GHz

The Polar Kuiper System's ground segment will consist of Ku-band customer terminals and both V-band and Ka-band gateways, customer terminals, and TT&C.[3] All of the Polar Kuiper System links will utilize dual-polarization through both left-handed and right-handed circular polarization ("LHCP & RHCP") methods. The Polar Kuiper System will perform TT&C functions in either Ka-band, V-band or both bands. The Polar Kuiper System will use TT&C beams primarily during launch and early operations ("LEOP"), satellite anomalies, and satellite decommissioning.

C. Cessation of Emissions

To meet Section 25.207 requirements,[4] the control of all antenna beams (sub-system and

[2] Per 47 C.F.R. § 2.106 n.NG57, use of the 12.75 – 13.25 GHz band for Fixed-Satellite Service is limited to individually licensed earth stations. The Gen 2 Kuiper System will comply with this condition.

[3] *See id.* §§ 25.115, 25.130. Additionally, Amazon recognizes that 37.5-40 GHz FSS space-to-Earth transmissions must be restricted "to individually licensed earth stations," which "must not be ubiquitously deployed and must not be used to serve individual consumers," 47 C.F.R. § 25.202(a)(1)(ii), and will use such transmissions consistent with the Commission's rules.

[4] *See id.* § 25.207.

power amplifier) can be enabled or disabled individually via ground control commands sent over TT&C links under both on-orbit and deorbit conditions.

II. SPECTRUM SHARING

A. Space Station Beam Contours and Information

The Polar Kuiper System will operate gateway beams, service beams, and TT&C beams in both V-band and Ka-band. All Polar Kuiper System space station gateway and service beams are independently steerable within the satellite field-of-view. In compliance with Section 25.210(f),[5] the Polar Kuiper System space stations will employ state-of-the-art full frequency reuse for gateway and service beams; TT&C beams will be low-gain and non-directional. The Polar Kuiper System earth stations will only communicate with satellites when above the minimum elevation angle indicated in Table 3, below.

Tables 3 and 4, below, summarize the Polar Kuiper System space station transmit and receive beams. These values represent the range of beams the Polar Kuiper System will employ, and include the use of beams with gain values between the minimum and maximum values shown. The space station beam information and antenna gain contours are provided in the Schedule S Attachment to this application. Annex B includes the detailed beam and channel IDs for the Polar Kuiper System. The TV1 – TV5, TK1 – TK2, RV1 – RV5, and RK1 – RK2 beams were previously included in the V-band Application and have not been modified from the original request. The TK3 – TK7 and RK3 – RK7 refer to the Ka-band beams and have been updated from the V-band Application.

[5] *See* 47 C.F.R. § 25.210(f).

Table 3. Polar Kuiper System Space Station Transmit Beams

Beam ID	Band	Link Type	Minimum Elevation Angle (deg)	Maximum Steering Angle from 600km Space Station Nadir (deg)	Peak Gain (dBi)
TV1	V-band	Gateway	20	59.2	35.7
TV2	V-band	Gateway	20	59.2	42.0
TV3	V-band	Gateway, Customer Terminal	20	59.2	34.0
TV4	V-band	Gateway, Customer Terminal	20	59.2	44.0
TV5	V-band	TT&C	5	0	5.0
TK1	Ku-band	Customer Terminal	30	52.3	32.0
TK2	Ku-band	Customer Terminal	30	52.3	42.0
TK3	Ka-band	Gateway	20	59.2	34.4
TK4	Ka-band	Gateway	20	59.2	36.9
TK5	Ka-band	Customer Terminal	20	59.2	35.0
TK6	Ka-band	Customer Terminal	20	59.2	45.0
TK7	Ka-band	TT&C	5	0	13.5

Table 4. Polar Kuiper System Space Station Receive Beams

Beam ID	Band	Link Type	Minimum Elevation Angle (deg)	Maximum Steering Angle from 600km Space Station Nadir (deg)	Peak Gain (dBi)
RV1	V-band	Gateway	20	59.2	37.5
RV2	V-band	Gateway	20	59.2	43.7
RV3	V-band	Gateway, Customer Terminal	20	59.2	34.0
RV4	V-band	Gateway, Customer Terminal	20	59.2	44.0
RV5	V-band	TT&C	5	0	5.0
RK1	Ku-band	Customer Terminal	30	52.3	32.0

RK2	Ku-band	Customer Terminal	30	52.3	42.0
RK3	Ka-band	Gateway	20	59.2	38.2
RK4	Ka-band	Gateway	20	59.2	40.7
RK5	Ka-band	Customer Terminal	20	59.2	35.0
RK6	Ka-band	Customer Terminal	20	59.2	45.0
RK7	Ka-band	TT&C	5	0	13.5

Amazon notes that, due to data entry limitations in the Schedule S Attachment, Amazon supplied beams meant to be interpreted as bounding beams: for each beam type, Amazon submitted minimum and maximum gain values which are not meant to preclude the use of beams with gain values in between the bounds. Similarly, transmit and receive channel information supplied in the Schedule S Attachment rely on a single channel size. Amazon requests the flexibility to use variable channel sizes other than the simple set specified in the Schedule S Attachment.

B. Interference Protection for FS Systems

Amazon has designed the Polar Kuiper System to co-exist with terrestrial fixed service ("FS") operations. Polar Kuiper System earth stations and satellites operate at high elevation angles and angles of arrival, limiting the amount of RF energy that is transmitted tangentially to the Earth's surface and fixed service operations. Both the Commission and the ITU have established limits on the Power Flux-Density ("PFD") of satellite downlink transmissions at the Earth's surface in order to protect terrestrial fixed service systems operating in the V-band, Ka-band, and Ku-band. As explained and demonstrated below, the Polar Kuiper System's PFD levels will comply with all applicable PFD limits with the exception of the Ka-band downlink TT&C beams, which will sporadically have a PFD larger than the limits at low elevation angles. Amazon requests a waiver to the rule for this scenario as outlined below.

1. Ka-band

Section 25.146(a)(1) of the Commission's rules and Article 21, Section V, Table 21-4 of the ITU Radio Regulations provide PFD limits for emissions from NGSO FSS space stations in the 17.7 – 19.3 GHz and 19.3 – 19.7 GHz bands. The PFD limits for NGSO FSS Systems in the Ka-band frequencies are described below in Table 5. Section 25.146(a)(1)(i) directs applicants to comply with the 17.7 – 19.3 GHz limits for the 19.3 – 19.4 GHz and 19.6 – 19.7 GHz bands. Section 25.146(a)(1)(ii) also directs applicants to comply with the 17.3 – 17.7 GHz band limits for the 17.7-17.8 GHz bands. Section 25.208(d) provides additional PFD limits for use in the 18.6 – 18.8 GHz band.

Table 5. NGSO FSS Ka-band PFD Limits from Article 21, Table 21-4

ITU Frequency Band	**FCC Frequency Band(s)**	**Limit in dB(W/m²) for Angles of Arrival (δ) Above the Horizontal Plane**			**Reference Bandwidth**
		0° - 5°	**5° - 25°**	**25° - 90°**	
17.7 – 19.3 GHz	17.3 – 17.8 GHz 17.8 – 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
19.3 – 19.7 GHz	19.4 – 19.6 GHz	-115	-115 + 0.5(δ – 5)	-105	1 MHz
18.6 – 18.8 GHz[6]	18.6 – 18.8 GHz	-95			200 MHz

Where X is a constant defined as a function of N, the number of satellites in the Constellation, and is calculated as follows:

Number of Satellites, N	**N ≤ 50**	**50 < N ≤ 288**	**288 < N ≤ 1000**	**1000 < N ≤ 6000**	**N > 6000**

[6] ITU RR Art. 21 n.8 (21.16.2).

X [dB]	0	(5/119)*(N-50)	(1/69)*(N+402)	max {20.3, 10*LOG10(Nv)}	10*LOG10(Nv) + 1

Where N_v is the maximum number of visible space stations – considering a minimum elevation angle equal to 0 degrees – from any location on the surface of the Earth and within the service area of the NGSO system.

The Polar Kuiper System gateway and customer terminal downlinks operating in the 17.3 – 19.7 GHz bands will not exceed a PFD of -110 dBW/m2/MHz for angles of arrival greater than 30 degrees. For angles of arrival between 20 and 30 degrees, the PFD generated by the Polar Kuiper System will not exceed a log-linear level that results in -118 dBW/m2/MHz at 20 degrees. For angles of arrival below 20 degrees, the PFD generated by the Polar Kuiper System downlinks will be a function of the Polar Kuiper System satellites' off-axis EIRP. Figure 1, below, demonstrates compliance to these PFD limits for all Polar Kuiper System transmit beam types.

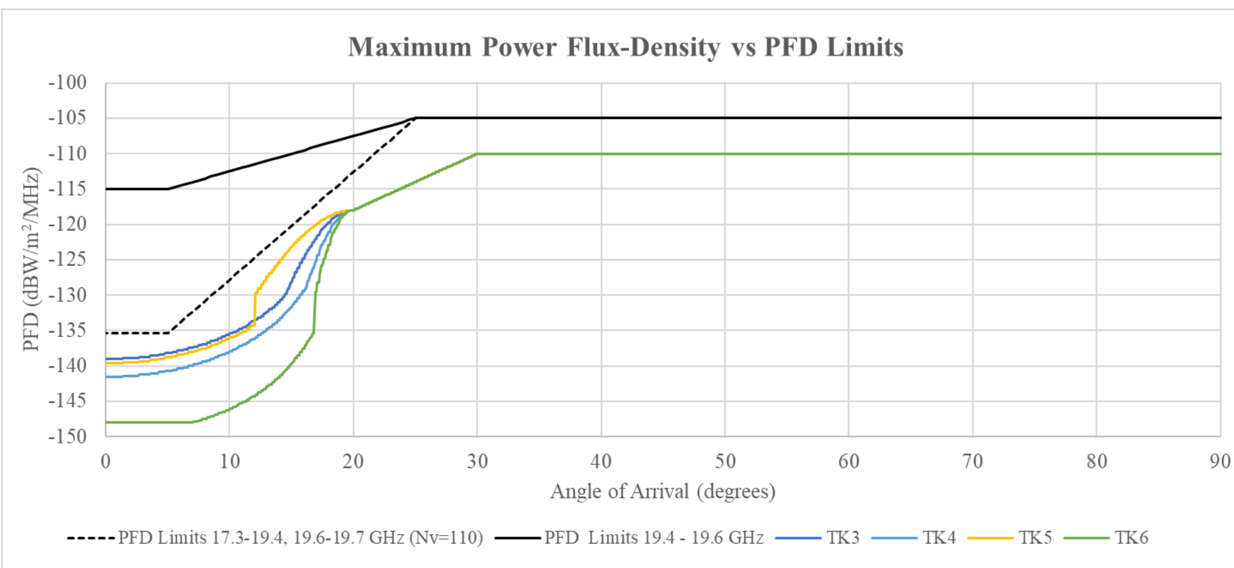

Figure 1. Polar Kuiper Satellite GW and CT Downlink Power Flux-Density Levels in the 17.3 – 19.7 GHz Band

The power flux-density across the 200 MHz band 18.6 – 18.8 GHz produced at the Earth's surface by emissions from a space station under assumed free-space propagation conditions shall not exceed −95 dB (W/m^2) for all angles of arrival.[7] The Polar Kuiper System downlink emissions in the 18.6 – 18.8 GHz band will not exceed -95 dBW/m^2 across the 200 MHz band. Figure 2, below, demonstrates that the planned use of the service beams in the 18.6 – 18.8 GHz band complies with the PFD limits in this band.

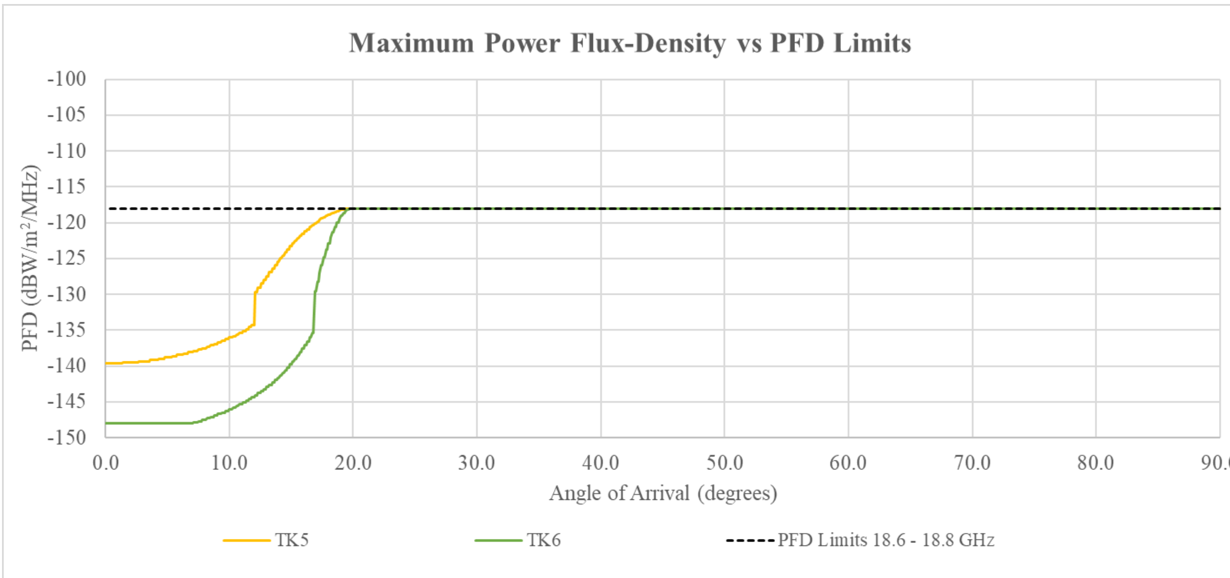

Figure 2. <u>Polar Kuiper Satellite CT Downlink Power Flux-Density Levels in the 18.6 – 18.8 GHz Band</u>

The Ka-band downlink TT&C PFD levels in the 19.25 – 19.4 GHz band are probabilistic in nature as they depend on the orientation of the spacecraft relative to the TT&C downlink earth station. These beams will operate with TT&C earth stations at a minimum elevation angle of 5° regardless of satellite altitude and produce a maximum EIRP density of -57.7 dBW/Hz in typical orientations and up to -43.5 dBW/Hz in limited situations.

[7] *See* 47 C.F.R. § 2.106, Table of Frequency Allocations, Footnote US255.

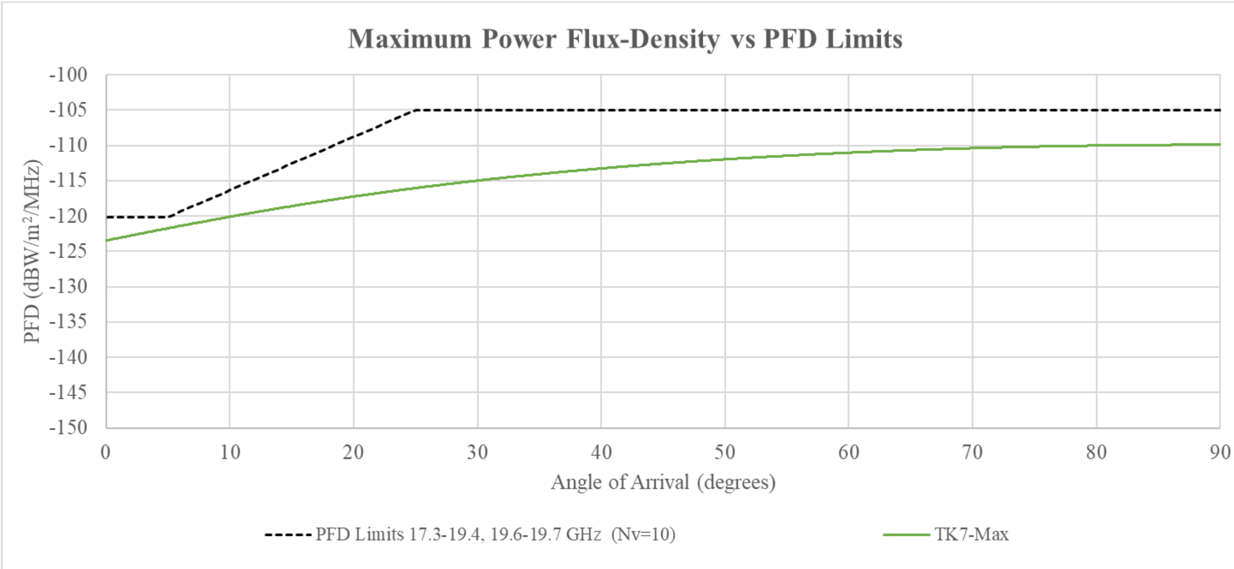

Figure 3. Polar Kuiper Satellite TT&C Downlink Power Flux-Density Levels in the 19.25 – 19.4 GHz Band

As shown in Figure 3, above, this results in emissions below the PFD limits for elevation angles above 25°. For elevation angles below 25°, the maximum PFD levels exceed the ITU PFD Limits described in Table 5. However, these limits factor in a Nv term used to compute the PFD limits below 25° elevation angles. The Nv term describes the number of visible satellites from a ground station perspective with a larger value resulting in more limiting PFD limits. During typical operations, TT&C downlink operations are not continuous as standard command and control will occur using standard gateway links. Thus, the number of simultaneous satellites operating TT&C downlinks will be a small percentage of the number of visible satellites in any given direction. For this reason, it is impractical to require the TT&C downlink PFD levels at low elevation angles to comply with the Nv based limits in order to protect the FS systems. FS systems will be protected from harmful interference due to the limited use of these services.

2. V-band

The Polar Kuiper System emissions in the 37.5 – 40.0 GHz band will comply with the PFD limits outlined in Sections 25.208(r)(1) and 25.208(r)(2). The Polar Kuiper System emissions in the 40.0 – 42.0 GHz band will comply with the PFD limits outlined in Sections 25.208(s) and 25.208(t). As the V-band downlink beam PFD values have not been modified from the original application, there is no change in PFD compliance. For detailed descriptions and charts showing V-band downlink compliance to PFD limits in these bands, refer to the original application.

3. *Ku-band*

The Polar Kuiper System emissions in the 10.7 – 12.7 GHz band will comply with the PFD limits outlined in Section 25.208(o). As the Ku-band downlink beam PFD values have not been modified from the original application, there is no change in PFD compliance. For detailed descriptions and charts showing Ku-band downlink compliance to PFD limits in these bands, Amazon requests that the Commission refer to the V-band Application.

C. Interference Protections for GSO Systems

The Polar Kuiper System can operate in the same frequency bands as GSO systems. Polar Kuiper System beam emissions are highly directional and efficiently place the directed energy at Kuiper receivers and not GSO receivers. In addition, Polar Kuiper System earth stations can reduce EIRP density levels and for transmissions within a specified angular range of the GSO arc to minimize PFD levels toward GSO satellites. Similarly, Polar Kuiper System satellites can reduce EIRP density levels for transmissions within a specified angular range of the GSO arc to minimize PFD levels toward GSO earth stations. This ability ensures the Polar Kuiper System can protect GSO systems in both the uplink and downlink directions.

1. *Ka-Band*

NGSO FSS applicants are required to comply with EPFD limits as set forth in Section 25.146(a)(2) and (c) of the Commission's rules, and Article 22 of the ITU Radio Regulations. These limits were initially promulgated to protect to GSO FSS satellite networks in the Ka-band frequencies from harmful interference due to NGSO FSS satellite networks, but, in practice, are decades old, significantly overprotect GSO incumbents, and do not reflect current satellite technology—particularly for downlink operations. Both the ITU and the Commission have recognized this in their recent efforts to study how to modernize these limits. For this reason, Amazon requests a partial waiver to the Commission's rules in Section 25.146(c) regarding downlink EPFD compliance for Ka-band beams inside the United States. Amazon will bring the Polar Kuiper System operations into conformance with the outcome of any Commission or international proceeding that amends EPFD rules for downlink operations in the United States.[8] The Polar Kuiper System will comply with the Article 22 EPFD uplink and inter-satellite limits. Outside of the United States, the Polar Kuiper System will comply with Article 22 EPFD limits as required by local laws and licensing requirements. Annex A provides a detailed set of analyses to show how the Polar Kuiper System will protect GSO systems inside the United States.

2. V-band

The ITU adopted requirements for NGSO systems to prevent single-entry and aggregate interference to GSO systems in the 37.5 – 42.5 GHz (space-to-Earth), 47.2 – 50.2 GHz (Earth-to-space) and 50.4 – 51.4 GHz (Earth-to-space) bands at WRC-19. These were codified in the ITU Radio Regulations in No. 22.5L and No. 22.5M of Article 22.[9] The ITU does not yet have software available with the capability to evaluate NGSO system compliance with these limits. Amazon has used its own software to evaluate compliance, and certifies that the Polar Kuiper System will comply with the single-entry limits in No. 22.5L of Article 22. Amazon certifies that the Polar Kuiper System will comply with the aggregate limits in No. 22.5M of Article 22. The Polar Kuiper System will use a variety of methods to meet these limits, including by: (1) limiting the number of

[8] See Petition for Rulemaking of Space Exploration Holdings, LLC, RM-11990 (filed Aug. 9, 2024) ("SpaceX Petition").

[9] *See* ITU RR Art. 22, Nos. 22.5L, 22.5M.

satellites transmitting to and from earth station areas simultaneously on the same frequency and channel; (2) using space station and earth station antennas with narrow beamwidths; (3) using a GSO arc avoidance angle to prevent main-beam coupling between Polar Kuiper System and GSO space station and earth station beams; and (4) limiting the power flux-density and EIRP of Polar Kuiper downlinks and uplinks respectively.

3. Ku-band

Amazon previously demonstrated that the Ku-band frequencies requested in the V-band Application would comply with the EPFD limits set forth in Article 22 of the ITU Radio Regulations. Similar to the Ka-band EPFD limits, the Ku-band EPFD limits are outdated, and both the ITU and FCC are undertaking efforts to modernize these rules. To better facilitate the Commission's goal of providing the highest-quality broadband services to American consumers, Amazon requests a partial waiver to the Commission's rules in Section 25.146(c) regarding downlink EPFD compliance for Ku-band beams inside the United States. Amazon will bring the Polar Kuiper System operations into conformance with the outcome of any Commission or international that amends EPFD rules for downlink operations in the United States. The Polar Kuiper System will comply with the Article 22 EPFD uplink and inter-satellite limits. Outside of the United States, the Polar Kuiper System will comply with the Article 22 EPFD limits as required by local laws and licensing requirements. Annex B A provides a detailed set of analyses to show how the Polar Kuiper System will protect GSO systems inside the United States.

D. Interference Protections for NGSO Systems

Amazon designed the Polar Kuiper System with flexible mitigation parameters, including the ability to implement satellite avoidance angles and adjust the uplink EIRP and downlink PFD levels in selectable frequency bands. Amazon has participated in coordination discussions with other NGSO systems and can model the interference environment and perform reactive mitigation measures to protect the Polar Kuiper System and other systems from harmful interference.

The Polar Kuiper System will comply with the NGSO spectrum sharing rules outlined in section 25.261. Amazon will coordinate the Polar Kuiper System with other operational Ka-band, Ku-band, and V-band NGSO FSS systems in prior processing rounds or submit a compatibility showing demonstrating its operations will not cause harmful interference into those systems. For V-band and Ku-band frequencies, the interference from the Polar Kuiper System into other NGSO systems does not increase when compared to the original V-band Application. Amazon amended the Polar Kuiper System orbits only to reposition the number of orbital planes and number of satellites per orbital plane. The orbital altitudes and inclinations are unchanged, the maximum V-band and Ku-band beam PFD levels are unchanged, and the number of total satellites has decreased by 10.

E. Sharing with Other Co-frequency and Adjacent Band Users

1. Radio Astronomy Service Interference Mitigation

Radio Astronomy Service ("RAS") has either shared or dedicated bands adjacent to the ones used by the Polar Kuiper System. To ensure their protection, the Polar Kuiper System will comply with all relevant protections and limits to PFD levels and other technical parameters set forward by the Commission, and, by extension, the ITU.

2. Earth Exploration-Satellite Service (Passive) Interference Mitigation

The Polar Kuiper System will meet the unwanted emissions limits specified in both footnote US156 to Section 2.106 of the Commission's rules and ITU Resolution 750 established during WRC-19 to avoid interference to Earth exploration-satellite service ("EESS") (passive).

III. ORBITAL DEBRIS AND POST MISSION DISPOSAL PLAN

Section 25.114(d)(14) of the Commission's rules requires a description of the design and operational strategies that will be used to mitigate orbital debris.[10] Space safety is a core tenet for Amazon, and the Polar Kuiper System's satellite design and operational strategies will mitigate orbital debris risks.

A. Debris Release[11]

Amazon will design the Polar Kuiper System to limit the amount of debris released in a planned manner during normal operations. To limit the possibility that debris will be released during normal deployment, the Polar Kuiper System will not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release the satellite from the launch vehicle or to actuate deployable structures on the satellite. Amazon will additionally assess and limit the probability that the Polar Kuiper System will become a source of debris through collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal. Amazon will employ design approaches to minimize risk of a collision with non-trackable debris initiating a significant debris release event. Moreover, Amazon will use the National Aeronautics and Space Administration's ("NASA") Debris Assessment Software ("DAS") or a higher fidelity assessment tool to calculate the lifetime probability of collision with small debris.[12]

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[10] *See* 47 C.F.R § 25.114(d)(14).

[11] *Id.* § 25.114(d)(14)(i).

[12] Because the design for the Polar Kuiper System spacecraft is still at the pre-PDR (preliminary design review) level of maturity, it is not possible to accurately calculate the lifetime probability of collision with small debris using NASA's DAS.

B. Accidental Explosions[13]

As with debris release, Amazon will assess and limit the probability of accidental explosions, both during and after completion of mission operations. In designing the Polar Kuiper System, Amazon will work to ensure that any conversion of energy sources (chemical, pressure, and kinetic) onboard the spacecraft will not result in debris generation. Amazon will design each satellite propellant tank to leak rather than burst in most failure mode conditions, even if the failure is caused by micrometeoroid orbital debris impact, and further test the tanks' failure characteristics under high velocity impact to verify this result. Amazon will design the Polar Kuiper System satellites' battery systems to ensure that a battery cell failure will be contained to a single cell, further limiting the chance of thermal runaway, and in turn, accidental explosion. Moreover, Amazon will disclose the quantity of fuel that will be reserved for post-mission disposal maneuvers, and will continue collision avoidance activities in an effort to ensure space safety after. Because the design for the Polar Kuiper System spacecraft is still at the pre-PDR (preliminary design review) level of maturity, it is not possible to accurately calculate the lifetime probability of collision with small debris using NASA's DAS.

C. Collision Risks with Large Objects[14]

Amazon will assess and limit the probability that a Polar Kuiper System satellite will become a source of debris by collision with large debris or other operational space stations. The Polar Kuiper System satellites 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 the active avoidance of other spacecraft and tracked inert objects, including

[13] 47 C.F.R § 25.114(d)(14)(ii).

[14] *Id.* § 25.114(d)(14)(iii)

during deorbiting and at the post-mission disposal stage. 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 tracking service to improve conjunction warning response; and (3) "full lifecycle" conjunction avoidance, from early operations after dispensing, to re-entry. The Polar Kuiper System satellites 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, the Polar Kuiper System satellite activities will include deorbit timing selection to de-conflict planar conjunctions from crewed vehicles.[15]

During ongoing operations, the Polar Kuiper System satellites will operate consistent with ITU Resolution 8 of WRC-23, which provides that an operator must maintain an operational orbital tolerance of +/- 30 km altitude and +/- 2 degrees.[16] The Polar Kuiper System will operate within this tolerance for both inclination and RAAN. Doing so will allow Polar Kuiper System satellites the flexibility to relocate planes in order to minimize collision risks with other systems in similar orbits. Additionally, this will allow Amazon to lower the altitude of a Polar Kuiper System satellite that may be at risk of losing maneuverability, in order to preserve low passive deorbit times. These tolerances do not intersect with any regions with crewed spacecraft. Additionally, as described below, Amazon will coordinate with any operators in similar orbits to ensure consistency with

[15] These activities are in addition to Amazon's orbit use coordination efforts with other operators prior to satellite operation.

[16] The Commission recently asked SpaceX to confirm compliance with this ITU requirement. See Letter from Kathyrn Medley and Merissa L. Velez, FCC, to Jameson Dempsey, SpaceX, ICFS File Nos. SAT-LOA-20200526-00055, SAT-AMD-20210818-00105, SAT-AMD-20221216-00175, SAT-MOD-20241011-00224, SAT-AMD-20241017-00228, at 3 (Jan. 7, 2025).

space safety principles both between constellations as well as with all other space objects that may intersect with the Polar Kuiper System's orbital shells.

All satellites in the Polar Kuiper System will have a nominal operational lifetime of 7 years. Amazon will actively deorbit the Polar Kuiper System satellites at the end of their operational lifetime. The Polar Kuiper System satellites will utilize onboard propulsion to enable station-keeping maneuvers that will maintain the reference orbit altitude, and will conduct orbit adjusting maneuvers that change orbit station during deorbit to lower altitudes and risk mitigation maneuvers to avoid collisions with other orbiting objects. The propulsion system will deliver sufficient change in orbit velocity (delta-v) such that the 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 Polar Kuiper System satellite risk mitigation maneuver is projected to typically impart a 140-meter change in orbit altitude and a change in along-track position of over 650 meters after each successive orbit revolution, when compared to a no-maneuver trajectory. This level of maneuverability provides ample capability over the mission lifetime to avoid collisions with other objects and helps ensure mission disposal of less than 1 year using propulsion.

These activities are in addition to Amazon's orbit use coordination efforts with other operators prior to satellite operation. Upon receipt of a space situational awareness conjunction warning (a Conjunction Data Message or "CDM") from the 18th Space Control Squadron, Amazon will review the data to assess and mitigate the collision risk if necessary. As part of this process, Amazon will:

(1) Assess the data quality of the orbit station of the secondary object, either from the space surveillance network ("SSN") or commercial data providers, or the owner/operator of the secondary object, if available.

(2) Calculate the probability of collision associated with the conjunction using Amazon data.

(3) 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.

(4) 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), planning and screening of a risk mitigation maneuver ("RMM") will immediately begin. This RMM data will then be provided to SpaceTrack for spaceflight operators and space situational awareness monitors to assist in maintaining track custody of the Polar Kuiper System satellite.

(5) When the second object is a satellite, the owner/operator of that satellite will also be provided with the RMM information.

Amazon will also share ephemeris data and other appropriate operational information and modify satellite altitude and/or operations as necessary.

All of these measures will span the phases of the Polar Kuiper System satellite operations. Amazon will undertake procedures for the launch and early operation of its satellites that are attentive to space debris concerns from the outset. For example, prior to launch, Amazon will analyze whether Polar Kuiper System satellites will be launched into an orbit that is similar to an orbit used by other space stations and, if relevant, will analyze the potential risk of collision, including measures Amazon would plan to take to avoid in-orbit collisions. When the Polar Kuiper System satellites separate from the launch vehicle, debris release concerns will also be paramount, and Amazon will effectuate the mitigation measures discussed in this orbital debris mitigation plan. After successful checkout, each satellite will initiate collision avoidance procedures that will continue throughout on-orbit operations, thus protecting 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 Polar Kuiper System satellites will transit during orbit raise, 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.

Amazon will track each of the Polar Kuiper System satellites. After orbital insertion, Amazon will identify the Polar Kuiper System satellites from the ground. Following signal acquisition, Amazon will actively track these satellites through on-board telemetry, which will include identification and navigation data. Each satellite will be registered with the 18th Space Control Squadron prior to launch. Amazon will also provide injection orbit parameters, launch location, target date and time of launch to the 18th Space Control Squadron prior to launch to aid in detection, tracking, and custody of Polar Kuiper System satellites by the U.S. Space Command Space Surveillance Network. Indeed, Amazon's active tracking technique will produce updated satellite predictive ephemerides for the 18th Space Control Squadron to assist with United States Space Command catalog updates and custody of the Polar Kuiper System satellites and for owner and operator distribution. In the unlikely event that any Polar Kuiper System satellite 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 will describe and explain its mission operations plans to appropriate government entities. For example, Amazon will discuss 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 and Planning Office, and NASA's Earth Science Mission Operations Project to establish planning coordination with NASA spaceflight operations.

D. Post Mission Disposal[17]

The Polar Kuiper System will further reduce orbital debris by actively de-commissioning and deorbiting within one year after the active mission lifetime. Specifically, at the end of their mission life, the Polar Kuiper System satellites will retain enough propellant on board to safely transit through crewed space to a target orbit where a rapid, natural decay will occur in less than one year. From this target orbit, any additional remaining propellant will be used to continue lowering altitude until the point where the satellites can no longer maintain attitude control and therefore cannot execute maneuvers. At that juncture, the satellites will vent any remaining propellant, followed by uncontrolled reentry and rapid demise.

A number of safeguards will promote safety during the de-commissioning process. For example, the satellites 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 in an effort to ensure space safety after mission life. As discussed above, Amazon will disclose the quantity of fuel that will be reserved for post-mission disposal maneuvers. Amazon will maintain active collision avoidance during the orbit-lowering process through the publication of predictive ephemerides, ongoing screening, and adjusted burn plans to respond to

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[17] 47 C.F.R § 25.114(d)(14)(iv).

identified risks above the maneuver threshold, among other things. Amazon's post-mission disposal approach will also comply with the U.S. Government Orbital Debris Mitigation Standard Practices[18] and the NASA Technical Standard[19] for debris reentry. Amazon plans post-mission disposal through atmospheric reentry and will conduct a casualty risk assessment using DAS or a higher fidelity assessment tool to verify a less than 1 in 10,000 risk of human casualty from surviving components with impact kinetic energies exceeding 15 Joules.

[18] *See* U.S. Gov't, Orbital Debris Mitigation Standard Practices, November 2019 Update (2019).

[19] *See* NASA Technical Standard, Process for Limiting Orbital Debris, NASA-STD-8719.14 Revision A with Change 1 (May 25, 2012).

ANNEX A: NGSO-GSO SPECTRUM COMPATIBILITY ANALYSIS

EPFD limits in the Ku-band and Ka-band downlink are outdated and overly stringent in their protection of GSO FSS systems from NGSO FSS system interference. In this annex, Amazon provides an alternative approach to demonstrate that the Polar Kuiper System will not cause harmful interference into GSO systems. In assessing the risk of interference from the Polar Kuiper System to GSO systems operating Ka-band space-to-Earth links over the territory of the United States, Amazon: (1) considered a variety of GSO reference links over the United States; (2) simulated the interference levels from the Polar Kuiper System Ka-band and Ku-band downlink emissions; and (3) computed short-term and long-term interference metrics into the reference GSO system links. As provided in greater detail in this Annex, the results demonstrate that GSO downlink transmissions in the Ka-band and Ku-band within the United States will not experience harmful interference from the Polar Kuiper System.

E. GSO Reference Links

Amazon reviewed GSO reference links from a multitude of sources, including the list of reference links collected by the ITU in the 1990s when the current Ku-band and Ka-band EPFD rules were studied. Amazon selected several GSO reference links for various ground antenna sizes found in the ITU Radio Regulations Resolution 76 (0.7m, 0.9m, 1.0m, 2.0m, 2.5m, and 5.0m for Ka-band reference links and 0.9m, 1.2m, 1.8m, 2.4m, 3.0m, and 10.0m for Ku-band reference links) to show that GSO FSS systems are protected from harmful interference. Amazon also considered a variety of target Carrier-to-Noise (“C/N”) ratios to account for a range of GSO reference links.

F. Protection Criteria

In order to demonstrate the adequacy of protection levels for GSO systems from NGSO systems with a dynamic interference environment, Amazon considered both short-term and long-term interference protection criteria. For the short-term protection criteria, Amazon evaluated the absolute increase in system unavailability of the GSO system. For long-term protection criteria, Amazon utilized two metrics: (1) time-averaged throughput degradation and (2) percentage of time-based Interference-to-Noise ("I/N") threshold values. The absolute increase in system unavailability and the time-averaged degraded throughput metrics are efficient ways to evaluate the interference of a NGSO system into other systems. These metrics, referenced in Section 25.261, ensure NGSO systems can efficiently and fairly share spectrum.[20] The Commission ruled that threshold values of no greater than 3% time-average degraded throughput and no greater than 0.4% absolute increase in unavailability would result in acceptable interference.[21] The ITU has adopted degraded throughput and increase in unavailability methodologies to assess V-band interference from NGSO systems into GSO systems;[22] accordingly, these methodologies can be used for Ka-band and Ku-band systems with adaptive coding and modulation. In addition to these protection criteria, Amazon considers a second long-term protection criteria to ensure GSO systems without the flexibility to adapt their link modulation and coding in real time are adequately protected. For this second long-term protection criterion, Amazon evaluated whether the downlink I/N from the Polar Kuiper System into a GSO system does not exceed a value of -10.5 dB for 80% of the time.

[20] *See* 47 C.F.R. § 25.261.

[21] *See Revising Spectrum Sharing Rules for Non-Geostationary Orbit, Fixed-Satellite Service Systems*, Second Report and Order and Order on Reconsideration, IB Docket No. 21-456, FCC 24-117 (rel. Nov. 15, 2024).

[22] *See* ITU RR Art. 22, Nos. 22.5L, 22.5M.

G. Ka-band Simulations

The Ka-band simulation results demonstrate that the Polar Kuiper System will sufficiently protect GSO downlink operations in Ka-band in the United States. Figure A-1, below, shows a complementary cumulative density function ("CCDF") of I/N from a Polar Kuiper System downlink into several reference Ka-band GSO System link downlinks; here, the I/N levels exceed -10.5 dB I/N less than 20% of the time. This is shown by the I/N curves never crossing the red dotted line in Figure A-1.

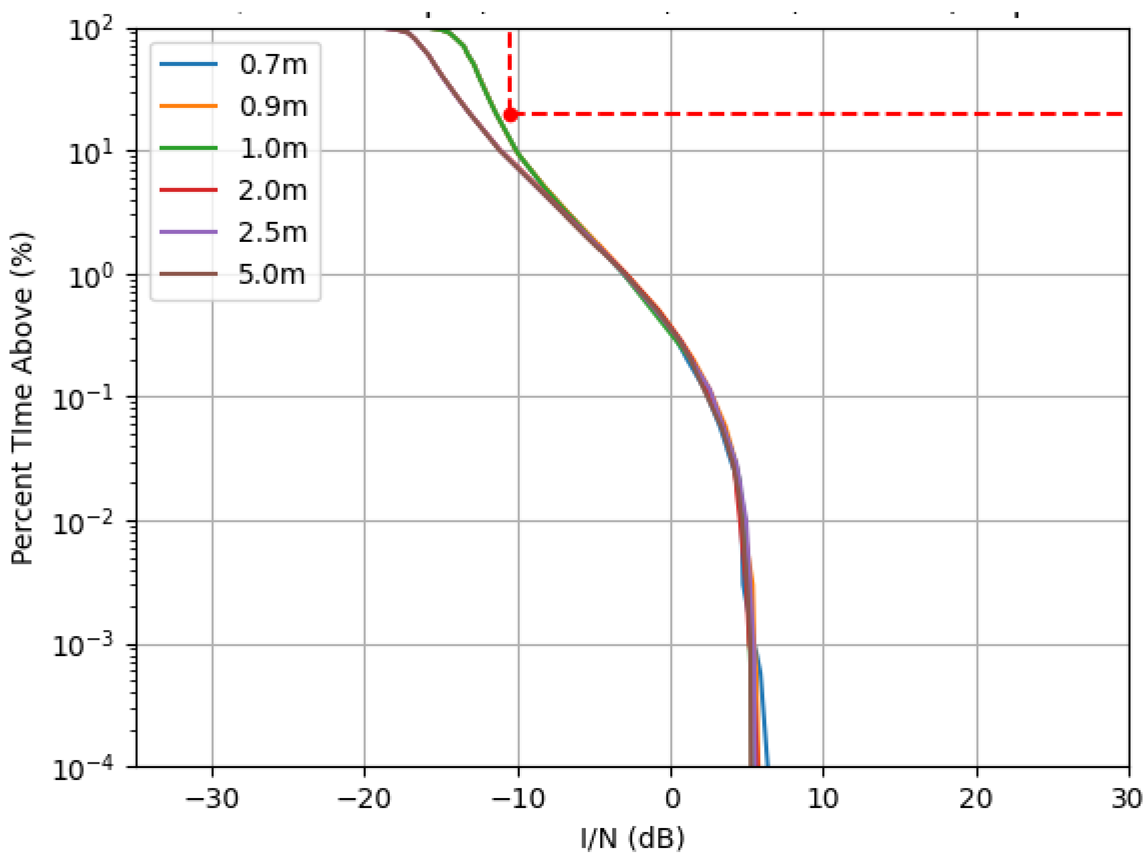

Figure A-1. <u>Polar Kuiper System Satellite Downlink I/N CCDF</u>

Similarly, Table A-1, below, shows the time-averaged throughput degradation and absolute increase in system unavailability for a variety of Ka-band GSO downlink PFD levels, where the time-averaged throughput degradation is well below 3% and the absolute increase in unavailability never exceeds 0%. These results demonstrate that Ka-band FSS GSO systems will be sufficiently protected from harmful interference.

Table A-1. Throughput Degradation and Absolute Increase in Unavailability vs GSO Link PFD

GSO PFD	**-120 dBW/m²/MHz**			**-125 dBW/m²/MHz**		
GSO Ground Antenna Diameter	GSO C/N	Throughput Degradation	Increase in Unavailability	GSO C/N	Throughput Degradation	Increase in Unavailability
0.7 m	17.6	1.69%	0.00%	12.6	2.09%	0.00%
0.9 m	19.8	1.56%	0.00%	14.8	1.88%	0.00%
1.0 m	20.7	1.52%	0.00%	15.7	1.82%	0.00%
2.0 m	27.4	0.05%	0.00%	22.4	1.00%	0.00%
2.5 m	29.3	0.01%	0.00%	24.3	0.95%	0.00%
5.0 m	35.4	0.00%	0.00%	30.4	0.00%	0.00%

H. Ku-band Simulations

The Ku-band simulation results demonstrate that the Polar Kuiper System will sufficiently protect GSO downlink operations in Ku-band in the United States. Figure A-2, below, shows a complementary cumulative density function ("CCDF") of I/N from a Polar Kuiper System downlink into several reference Ku-band GSO System link downlinks. The I/N levels exceed -10.5 dB I/N less than 20% of the time. This is shown by the I/N curves never crossing the red dotted line in Figure A-2.

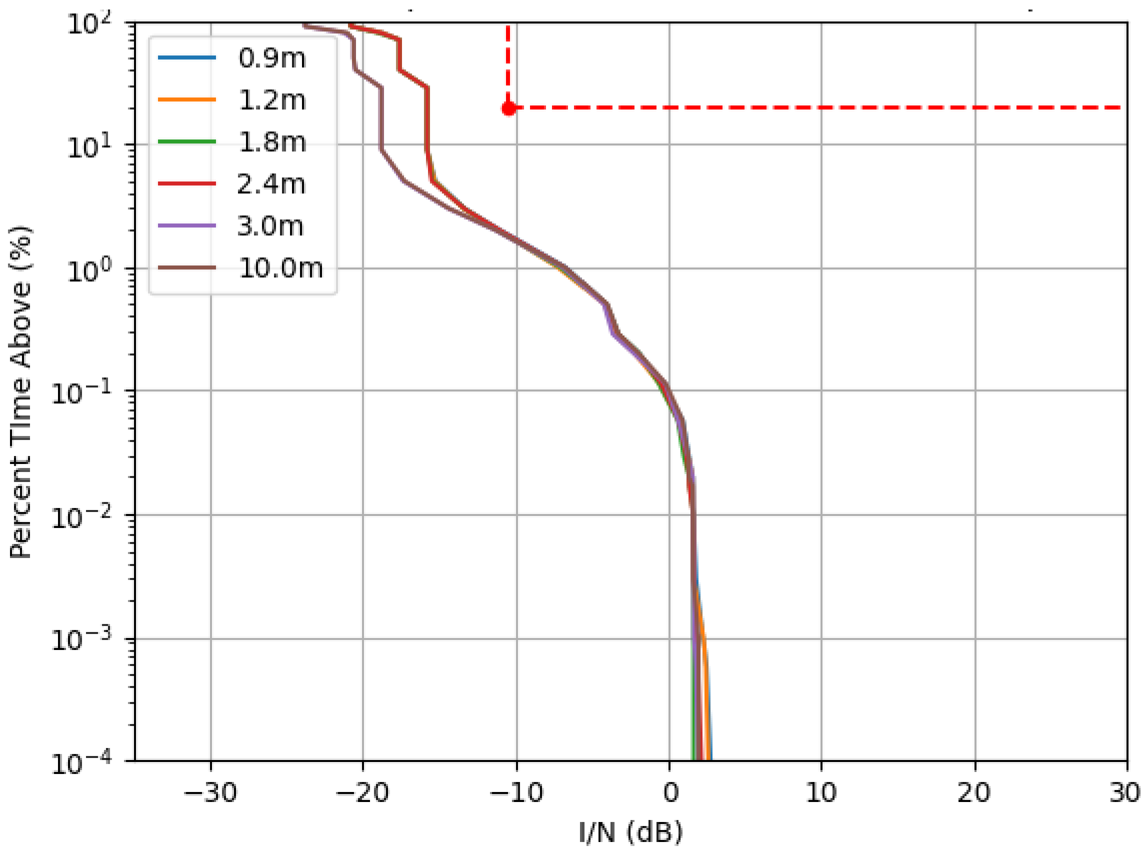

Figure A-2. Polar Kuiper Satellite Downlink I/N CCDF

Similarly, Table A-2, below, shows the time-averaged throughput degradation and absolute increase in system unavailability for a variety of Ku-band GSO downlink PFD levels, where the time-averaged throughput degradation is well below 3% and the absolute increase in unavailability never exceeds 0%. These results demonstrate that Ku-band FSS GSO systems will be sufficiently protected from harmful interference.

Table A-2. Throughput Degradation and Absolute Increase in Unavailability vs GSO Link PFD

GSO PFD	**-120 dBW/m^2/MHz**			**-125 dBW/m^2/MHz**		
GSO Ground Antenna Diameter	GSO C/N	Throughput Degradation	Increase in Unavailability	GSO C/N	Throughput Degradation	Increase in Unavailability
0.9 m	19.8 dB	0.57%	0.00%	14.8 dB	0.69%	0.00%
1.2 m	22.3 dB	0.52%	0.00%	17.3 dB	0.63%	0.00%

1.8 m	25.8 dB	0.056%	0.00%	20.8 dB	0.56%	0.00%
2.4 m	28.3 dB	0.002%	0.00%	23.3 dB	0.51%	0.00%
3.0 m	30.9 dB	0.00%	0.00%	25.9 dB	0.047%	0.00%
10.0 m	41.4 dB	0.00%	0.00%	36.4 dB	0.00%	0.00%

ANNEX B: SCHEDULE S ATTACHMENT MAPPING

The Schedule S Attachment includes receiving beams, receiving channels, transmitting beams, and transmitting channels for the Gen 1 Kuiper System, Gen 2 Kuiper System, and Polar Kuiper System. In order to clarify which beams and channels are associated with the Polar Kuiper System, Table B-1 and Table B-2 provide the ID's associated with the Polar Kuiper System.

Table B-1. Polar Kuiper System Beams

Beam ID	Schedule S Attachment Beam ID
RK1	RK1A, RK1B, RK1C, RK1D
RK2	RK2A, RK2B, RK2C, RK2D
RK3	RK3A, RK3B, RK3C, RK3D, RK3E, RK3F, RK3G, RK3H, RK3I, RK3J, RK3K, RK3L, RK3M, RK3N
RK4	RK4A, RK4B, RK4C, RK4D, RK4E, RK4F, RK4G, RK4H, RK4I, RK4J, RK4K, RK4L, RK4M, RK4N
RK5	RK5A, RK5B, RK5C, RK5D, RK5E, RK5F, RK5G, RK5H, RK5I, RK5J
RK6	RK6A, RK6B, RK6C, RK6D, RK6E, RK6F, RK6G, RK6H, RK6I, RK6J
RK7	RK7A, RK7B, RK7C, RK7D
RV1	RV1A, RV1B, RV1C, RV1D, RV1E, RV1F, RV1G, RV1H, RV1I, RV1J
RV2	RV2A, RV2B, RV2C, RV2D, RV2E, RV2F, RV2G, RV2H, RV2I, RV2J
RV3	RV3A, RV3B, RV3C, RV3D, RV3E, RV3F, RV3G, RV3H, RV3I, RV3J
RV4	RV4A, RV4B, RV4C, RV4D, RV4E, RV4F, RV4G, RV4H, RV4I, RV4J
RV5	RV5A, RV5B
TK1	TK1A, TK1B, TK1C, TK1D
TK2	TK2A, TK2B, TK2C, TK2D
TK3	TK3A, TK3B, TK3C, TK3D, TK3E, TK3F, TK3G, TK3H, TK3I, TK3J, TK3K, TK3L, TK3M, TK3N
TK4	TK4A, TK4B, TK4C, TK4D, TK4E, TK4F, TK4G, TK4H, TK4I, TK4J, TK4K, TK4L, TK4M, TK4N
TK5	TK5A, TK5B, TK5C, TK5D, TK5E, TK5F, TK5G, TK5H, TK5I, TK5J
TK6	TK6A, TK6B, TK6C, TK6D, TK6E, TK6F, TK6G, TK6H, TK6I, TK6J
TK7	TK7A, TK7B, TK7C, TK7D
TV1	TV1A, TV1B, TV1C, TV1D, TV1E, TV1F, TV1G, TV1H, TV1I, TV1J
TV2	TV2A, TV2B, TV2C, TV2D, TV2E, TV2F, TV2G, TV2H, TV2I, TV2J
TV3	TV3A, TV3B, TV3C, TV3D, TV3E, TV3F, TV3G, TV3H, TV3I, TV3J
TV4	TV4A, TV4B, TV4C, TV4D, TV4E, TV4F, TV4G, TV4H, TV4I, TV4J
TV5	TV5A, TV5B

Table B-2 Polar Kuiper System Channels

Direction	Band	Schedule S Attachment Channel ID
Transmit	Ku-band	TL1, TR1, TL2, TR2, TL3, TR3, TL4, TR4
Transmit	Ka-band	TL5, TR5, TL6, TR6, TL7, TR7, TL8, TR8, TL9, TR9, TL10, TR10, TL11, TR11, TL12, TR12, TL13, TR13, TL14, TR14, TL15, TR15, TL16, TR16, TL17, TR17, TL18, TR18, TL19, TR19, TL20, TR20, TL21, TR21, TL22, TR22, TL23, TR23, TL24, TR24, TL25, TR25, TL26, TR26, TL27, TR27, TL28, TR28, TL29, TR29, TL30, TR30, TL31, TR31, TL32, TR32, TL33, TR33, TL34, TR34, TL35, TR35, TL36, TR36, TL37, TR37, TL38, TR38, TL39, TR39, TL40, TR40, TL41, TR41, TL42, TR42, TL43, TR43, TL44, TR44, TL45, TR45, TL46, TR46, TL47, TR47, TL48, TR48, TL49, TR49, TL50, TR50, TL51, TR51, TL52, TR52, TL53, TR53, TL54, TR54, TL55, TR55, TL56, TR56, TL57, TR57, TL58, TR58, TL59, TR59, TL60, TR60, TL61, TR61, TL62, TR62, TL63, TR63, TL64, TR64, TL65, TR65, TL66, TR66, TL67, TR67, TL68, TR68, TL69, TR69, TL70, TR70, TL71, TR71, TL72, TR72, TL73, TR73, TL74, TR74, TL75, TR75, TL76, TR76, TL77, TR77, TL78, TR78, TL79, TR79, TL80, TR80, TL81, TR81, TL82, TR82, TL83, TR83, TL84, TR84
Transmit	V-band	TL85, TR85, TL86, TR86, TL87, TR87, TL88, TR88, TL89, TR89, TL90, TR90, TL91, TR91, TL92, TR92, TL93, TR93, TL94, TR94, TL95, TR95, TL96, TR96, TL97, TR97, TL98, TR98, TL99, TR99, TL100, TR100, TL101, TR101, TL102, TR102, TL103, TR103, TL104, TR104, TL105, TR105, TL106, TR106, TL107, TR107, TL108, TR108, TL109, TR109, TL110, TR110, TL111, TR111, TL112, TR112, TL113
Receive	Ku-band	RL1, RR1, RL2, RR2
Receive	Ka-band	RL3, RR3, RL4, RR4, RL5, RR5, RL6, RR6, RL7, RR7, RL8, RR8, RL9, RR9, RL10, RR10, RL11, RR11, RL12, RR12, RL13, RR13, RL14, RR14, RL15, RR15, RL16, RR16, RL17, RR17, RL18, RR18, RL19, RR19, RL20, RR20, RL21, RR21, RL22, RR22, RL23, RR23, RL24, RR24, RL25, RR25, RL26, RR26, RL27, RR27, RL28, RR28, RL29, RR29, RL30, RR30, RL31, RR31, RL32, RR32, RL33, RR33, RL34, RR34, RL35, RR35, RL36, RR36, RL37, RR37, RL38, RR38, RL39, RR39, RL40, RR40, RL41, RR41, RL42, RR42, RL43, RR43, RL44, RR44, RL45, RR45, RL46, RR46, RL47, RR47, RL48, RR48, RL49, RR49, RL50, RR50, RL51, RR51, RL52, RR52, RL53, RR53, RL54, RR54, RL55, RR55, RL56, RR56, RL57, RR57, RL58, RR58, RL59, RR59, RL60, RR60, RL61, RR61, RL62, RR62, RL63, RR63, RL64, RR64, RL65, RR65, RL66, RR66, RL67, RR67, RL68, RR68, RL69, RR69, RL70, RR70, RL71, RR71, RL72, RR72, RL73, RR73, RL74, RR74, RL75, RR75, RL76, RR76, RL77, RR77, RL78, RR78, RL79, RR79, RL80, RR80, RL81, RR81, RL82, RR82, RL83, RR83, RL84, RR84, RL85, RR85, RL86, RR86, RL87, RR87, RL88, RR88, RL89, RR89, RL90, RR90, RL91, RR91, RL92, RR92, RL93, RR93,

		RL94, RR94, RL95, RR95, RL96, RR96, RL97, RR97, RL98, RR98, RL99, RR99, RL100, RR100, RL101, RR101, RL102, RR102, RL103, RR103, RL104, RR104, RL105, RR105, RL106, RR106, RL107, RR107, RL108, RR108, RL109, RR109, RL110, RR110, RL111, RR111, RL112, RR112, RL113, RR113, RL114, RR114, RL115, RR115, RL116, RR116, RL117, RR117, RL118, RR118, RL119, RR119, RL120, RR120, RL121, RR121, RL122, RR122, RL123, RR123, RL124, RR124, RL125, RR125, RL126, RR126, RL127, RR127
Receive	V-band	RL128, RR128, RL129, RR129, RL130, RR130, RL131, RR131, RL132, RR132, RL133, RR133, RL134, RR134, RL135, RR135, RL136, RR136, RL137, RR137, RL138, RR138, RL139, RR139, RL140, RR140, RL141, RR141, RL142, RR142, RL143, RR143, RL144, RR144, RL145, RR145, RL146, RR146, RL147, RR147, RL148, RR148, RL149, RR149, RL150, RR150, RL151, RR151, RL152, RR152, RL153, RR153, RL154, RR154, RL155, RR155, RL156, RR156, RL157, RR157, RL158, RR158, RL159, RR159, RL160, RR160, RL161, RR161