TECHNICAL APPENDIX

Application of Kuiper Systems LLC
for Authority to Launch and Operate a
Non-Geostationary Satellite Orbit System
in V-band and Ku-band Frequencies

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TECHNICAL APPENDIX

Pursuant to Section 25.114 and other relevant provisions of the Federal Communications Commission's ("FCC" or "Commission") rules,[1] this Technical Appendix provides an overall description of the facilities, operations, and services of Amazon's proposed non-geostationary satellite orbit ("NGSO") system using V-band and Ku-band frequencies (the "Kuiper-V System"); addresses compatibility with co-frequency terrestrial fixed services ("FS"), geostationary satellite orbit ("GSO") and other NGSO fixed-satellite service ("FSS") operations; and details operational strategies and design for orbital debris mitigation and post-mission disposal.

I. OVERALL SYSTEM DESCRIPTION

Amazon's Kuiper-V System is comprised of 7,774 satellites utilizing V- and Ku-band frequencies at five inclination and orbital altitude combinations between 590 km and 650 km. The Kuiper-V System will provide high-speed, low-latency satellite broadband service, and will both supplement and expand Amazon's authorized constellation of Ka-band satellites (the "Kuiper-Ka System")[2] (together, the two systems are referred to hereinafter as the "Kuiper System") by increasing the total bandwidth available to customers, improving the quality of service, and providing greater coverage over vital geographic areas. Importantly, the Kuiper-V System will facilitate vital connectivity for Americans in rural and underserved areas.

A. Constellation Design

The Kuiper-V System will consist of: (1) 6,472 satellites operating in three orbital shells at 590 km, 610 km, and 630 km; and (2) two polar shells of satellites operating at altitude and inclination combinations of 640 km and 72º, and 650 km and 80º. The Kuiper-V System will both

[1] 47 C.F.R. § 25.114(d).

[2] *See Kuiper Systems LLC*, Order and Authorization, 35 FCC Rcd 8324 (2020).

supplement the Kuiper-Ka System with additional or independent V-band payloads aboard the 3,236 satellites currently licensed for Ka-band use, and also support both V-band and Ku-band payloads for the provision of global satellite services. Table 1, below, describes the distribution of the Kuiper-V System satellites within the planes of each of the five orbital shells.[3]

Table 1. Constellation Design: Altitudes and Inclinations

Altitude (km)	Inclination (deg)	Planes	Number of Satellites per Plane	Number of Satellites	Payloads Previously Licensed	Payloads Current Application
590	33	28	28	784	Ka-band	V-band
610	42	36	36	1296	Ka-band	V-band
630	51.9	34	34	1156	Ka-band	V-band
590	33	28	28	784	None	V-band Ku-band
610	42	36	36	1296	None	V-band Ku-band
630	51.9	34	34	1156	None	V-band Ku-band
640	72	652	1	652	None	V-band Ku-band
650	80	325	2	650	None	V-band Ku-band
Total				*7774*		

The Kuiper-V System's orbital architecture is designed to maximize capacity and coverage for customers at full constellation deployment. Thus, like the Kuiper-Ka System, the Kuiper-V System will utilize its authorized spectrum efficiently to maximize the number of customers it can service while also effectively sharing with other systems operating in this spectrum.

[3] Because the full Kuiper-V System constellation consists of 7,774 satellites, Amazon did not include the mean anomaly for every satellite in every plane of the five orbital shells in the Schedule S form. Instead, only the first orbital plane of each of the five orbital shells was provided in the form. The information for the complete set of orbital planes, including mean anomaly for each satellite within each plane, is provided in a spreadsheet attached to the Schedule S form, as a more efficient way to provide this information.

The Kuiper-V System will comply with all Commission regulations and any conditions and obligations imposed related to the safe operation of NGSO systems, including with respect to coordination of physical operations for the purpose of limiting collision risk, minimizing operational impacts, and helping to ensure space safety. The Kuiper-V System will operate with long-term control tolerances for apogee and perigee of 9 km and 0.1 degree for both inclination and right ascension of the ascending node ("RAAN"). These tolerances are proposed to ensure consistency with space safety principles both between constellations as well as with all other space objects that may intersect with the Kuiper-V System's orbital shells. Moreover, all satellites in the Kuiper-V System will have a nominal operational lifetime of 7 years. Amazon will actively deorbit the Kuiper-V System satellites at the end of their operational lifetime.

B. Frequency and Polarization Plan

The Kuiper-V System's overall spectrum usage plan is detailed and depicted below in Table 2 and Figure 1. The Kuiper-V System will conduct its customer terminal communications in Ku-band and V-band frequencies with gateway and telemetry, tracking, and control ("TT&C") communications conducted in V-band frequencies. All of the Kuiper-V System links will utilize dual-polarization through both left-handed and right-handed circular polarization ("LHCP & RHCP") methods.

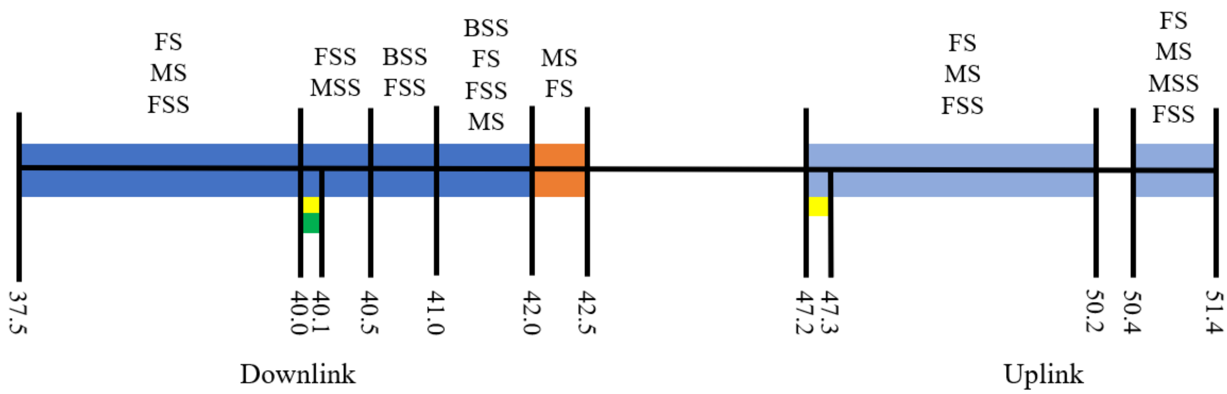
Table 2. Frequency Bands used by the Kuiper-V System[4]

Type of Link and Transmission Direction	Frequency Band	Frequency Ranges
Satellite to Gateway	V-band	37.5 – 42.0 GHz *42.0 – 42.5 GHz (non-U.S. only)*

[4] Out of an abundance of caution, Amazon has submitted in this Application a request for waiver of the U.S. Table of Frequency Allocations, to the extent necessary, to use the 42.0 – 42.5 GHz band for space-to-Earth communications outside of the U.S. only. *See* Legal Narrative, Section IV.A.

Gateway to Satellite	V-band	47.2 – 50.2 GHz 50.4 – 51.4 GHz
Satellite to Customer Terminal	Ku-band and V-Band	10.7 – 12.7 GHz 37.5 – 42.0 GHz[5] *42.0 – 42.5 GHz* *(non-U.S. only)*
Customer Terminal to Satellite	Ku-band and V-Band	12.75 – 13.25 GHz[6] 14.0 – 14.5 GHz 47.2 – 50.2 GHz[7] 50.4 – 51.4 GHz[8]
TT&C Downlink & Beacon	V-band	40.0 – 40.1 GHz
TT&C Uplink	V-band	47.2 – 47.3 GHz

V-band Beams



[5] Per 47 C.F.R. § 25.202(a)(1)(ii), use of the 37.5 – 40 GHz band for Fixed-Satellite Service downlinks is limited to individually licensed earth stations, and earth stations licensed in this band must not be ubiquitously deployed and must not be used to serve individual consumers. The Kuiper-V System will comply with these conditions.

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

[7] Per 47 C.F.R. § 25.136(d), use of the 47.2 – 48.2 GHz band is limited to individually licensed earth stations. The Kuiper-V System will comply with this condition.

[8] Per 47 C.F.R. § 25.136(e), use of the 50.4 – 51.4 GHz band is limited to individually licensed earth stations. The Kuiper-V System will comply with this condition.

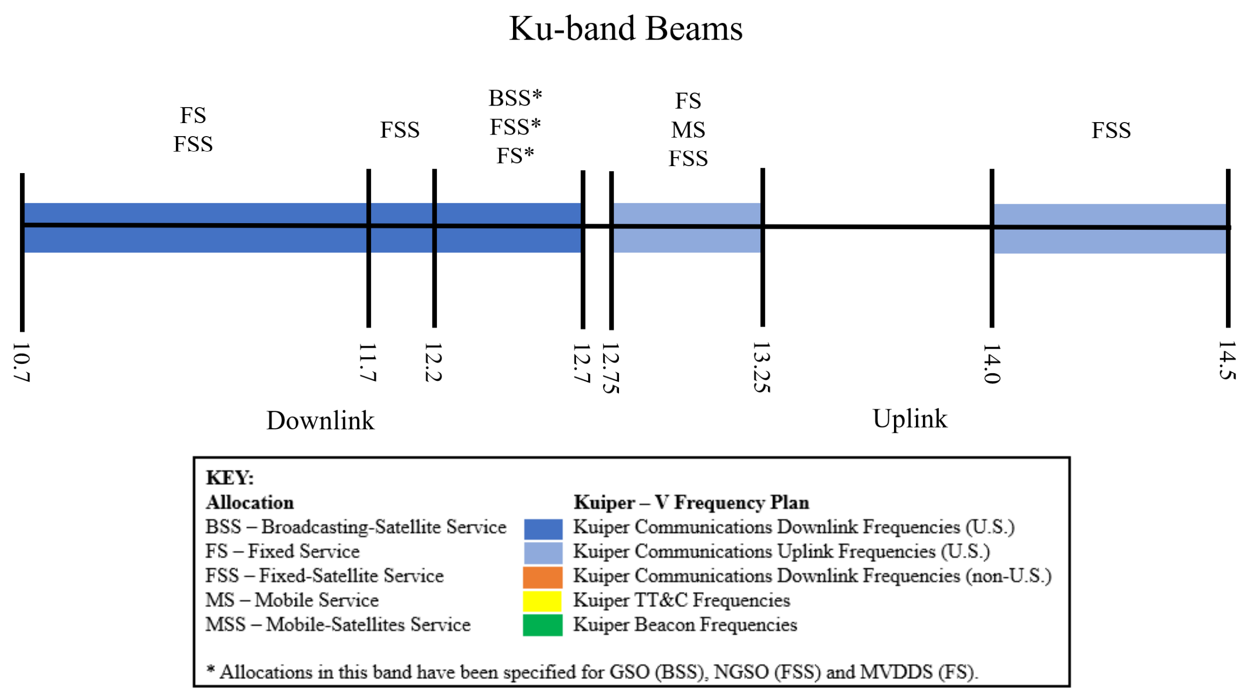


Fig. 1. Frequency Bands Used by the Kuiper-V System

The Kuiper-V System TT&C beams will primarily be used during launch and early operations ("LEOP"), during satellite anomalies, and during satellite decommissioning. These beams will require no more protection than normal traffic in these frequencies and will not create any additional interference, in compliance with the requirements of Section 25.202(g).[9]

C. Cessation of Emissions

To meet Section 25.207 requirements,[10] the control of all antenna beams (sub-system and power amplifier) can be enabled or disabled individually via ground control commands sent over TT&C links under both on-orbit and deorbit conditions. If all communications to ground stations cease for a pre-determined wait period, the satellite executes an automatic cease transmission to prevent the possibility of a satellite failing in a transmitting state.

[9] *See* 47 C.F.R. § 25.202(g).

[10] *See id.* § 25.207.

II. INTERFERENCE PROTECTION AND SPECTRUM SHARING

A. Space Station Beam Contours and Information

The Kuiper-V System will operate V-band gateway beams, V-band service beams, V-band TT&C beams, and Ku-band service beams. All Kuiper-V System space station gateway and service beams are independently steerable within the satellite field-of-view. In compliance with Section 25.210(f),[11] the Kuiper-V 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 Kuiper-V System earth stations will only communicate with Kuiper-V System satellites when above the minimum elevation angle indicated in Table 3, below, and each Kuiper-V System beam has a maximum steering angle from nadir.

Tables 3 and 4, below, summarize the Kuiper-V System space station transmit and receive beams. The space station antenna gain contours are provided in GIMS-readable data files attached to this Application.[12]

Table 3. Kuiper-V Space Station Transmit Beams

Beam ID	Link Type	Minimum Elevation (deg)	Maximum Steering Angle from Space Station Nadir[13] (deg)	Peak Gain (dBi)
TV1	Gateway	20	59.3	35.7
TV2	Gateway	20	59.3	42.0
TV3	Gateway, Customer Terminal	20	59.3	34.0
TV4	Gateway, Customer Terminal	20	59.3	44.0

[11] *See* 47 C.F.R. § 25.210(f).

[12] Gain contours are provided for satellites at the lowest and highest operating altitudes and at minimum and maximum scan angle for each beam type to show the full range of contour sizes. Amazon can supply additional contours to the Commission upon request.

[13] Calculated using lowest Kuiper-V orbital altitude of 590 km

TV5	TT&C	5	0	5.0
TK1	Customer Terminal	30	52.4	32.0
TK2	Customer Terminal	30	52.4	42.0

Table 4. Kuiper-V Space Station Receive Beams

Beam ID	Link Type	Minimum Elevation (deg)	Maximum Steering Angle from Space Station Nadir[14] (deg)	Peak Gain (dBi)
RV1	Gateway	20	59.3	37.5
RV2	Gateway	20	59.3	43.7
RV3	Gateway, Customer Terminal	20	59.3	34.0
RV4	Gateway, Customer Terminal	20	59.3	44.0
RV5	TT&C	5	0	5.0
RK1	Customer Terminal	30	52.4	32.0
RK2	Customer Terminal	30	52.4	42.0

B. Sharing with Fixed and Mobile Services

The Kuiper-V System is designed to co-exist with terrestrial fixed service ("FS") operations. Kuiper-V 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 and Ku-band. As explained and demonstrated below, the Kuiper-V System's PFD levels will comply with all applicable PFD limits.

[14] Calculated using lowest Kuiper-V orbital altitude of 590 km

1. Compliance with PFD Limits

a. *37.5 – 40.0 GHz Band*

Section 25.208(r) provides PFD limits for emissions from NGSO space stations in the 37.5 – 40.0 GHz band for both clear-sky conditions (in Section 25.208(r)(1)); and when under rain-fade conditions (in Section 25.208(r)(2)).[15] Figure 2, below, demonstrates that the Kuiper-V System downlink PFD levels will comply with Section 25.208(r)(1) under clear-sky conditions. The Kuiper-V System downlinks in the 37.5 – 40.0 GHz band will maintain a nominal PFD of -118 dBW/m^2/MHz for elevation angles above 40 degrees. When operating at elevation angles between 20 degrees and 40 degrees, the Kuiper-V System downlinks in the 37.5 – 40.0 GHz band will operate at a constant EIRP of 11.8 dBW/MHz. For angles of arrival below 20 degrees, the PFD generated by the Kuiper-V System downlinks in the 37.5 – 40.0 GHz band will be a function of the Kuiper-V System satellites' off-axis EIRP, as shown in Figure 2, below. The Kuiper-V System will modify its maximum PFD limits when under rain fade conditions to comply with 25.208(r)(2).

[15] *See* 47 C.F.R. § 25.208(r).

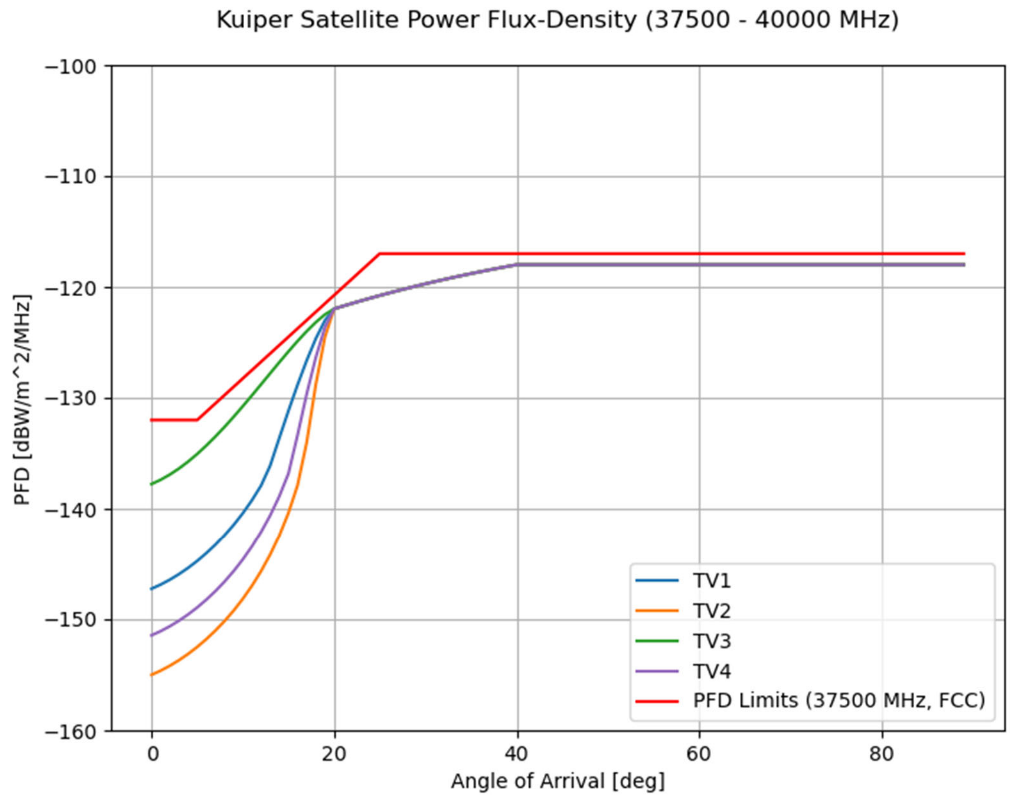


Fig. 2. Kuiper-V Satellite Downlink Power Flux-Density Levels in the 37.5 – 40.0 GHz Band

b. *40.0 – 42.5 GHz Band*

Sections 25.208(s) and 25.208(t) provide PFD limits for emissions from space stations in the 40.0 – 40.5 GHz and 40.5 – 42.0 GHz bands, respectively.[16] Figure 3, below, demonstrates that the Kuiper-V System downlink PFD levels will comply with the limits in Sections 25.208(s) and 25.208(t). Section 25.208 does not contain PFD limits for NGSO satellite systems in the 42.0 – 42.5 GHz band. However, the Kuiper-V System downlinks in the 42.0 – 42.5 GHz band will comply with the PFD limits listed in No. 21.16, Table 21-4, of Article 21 in the ITU Radio

[16] *See* 47 C.F.R. § 25.208(s), (t).

Regulations, as demonstrated in Figure 3, below.[17] The Kuiper-V System downlinks in the 40.0 – 42.5 GHz band will maintain a nominal PFD of -110 dBW/m^2/MHz for elevation angles above 20 degrees. For angles of arrival below 20 degrees, the PFD generated by the Kuiper-V System downlinks in the 40.0 – 42.5 GHz band will be a function of the Kuiper-V System satellites' off-axis EIRP, as shown in Figure 3, below.

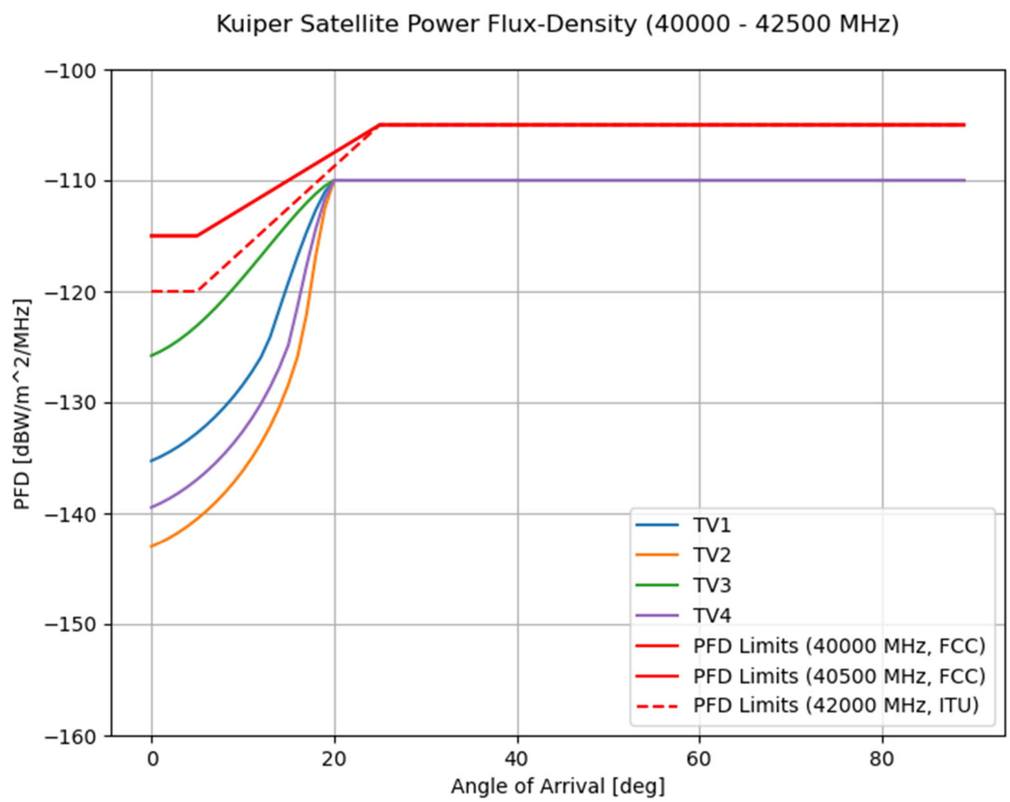


Fig. 3. Kuiper-V Satellite Downlink Power Flux-Density Levels in the 40.0 – 42.5 GHz Band

[17] *See* Int'l Telecomm. Union, Radio Regulations Art. 21 (2016) ("ITU RR Art. 21").

The Kuiper-V System TT&C beams will operate with a maximum fixed EIRP density of 14.4 dBW/MHz. This produces a maximum PFD of -112 dBW/m^2/MHz at a 90-degree angle of arrival and the lowest operational altitude of 590 km. The PFD at low angles of arrival is lower because the signal travels a longer distance and experiences greater path attenuation. The Kuiper-V System TT&C downlink PFD will comply with the 25.208(s) limits, as demonstrated in Figure 4, below.

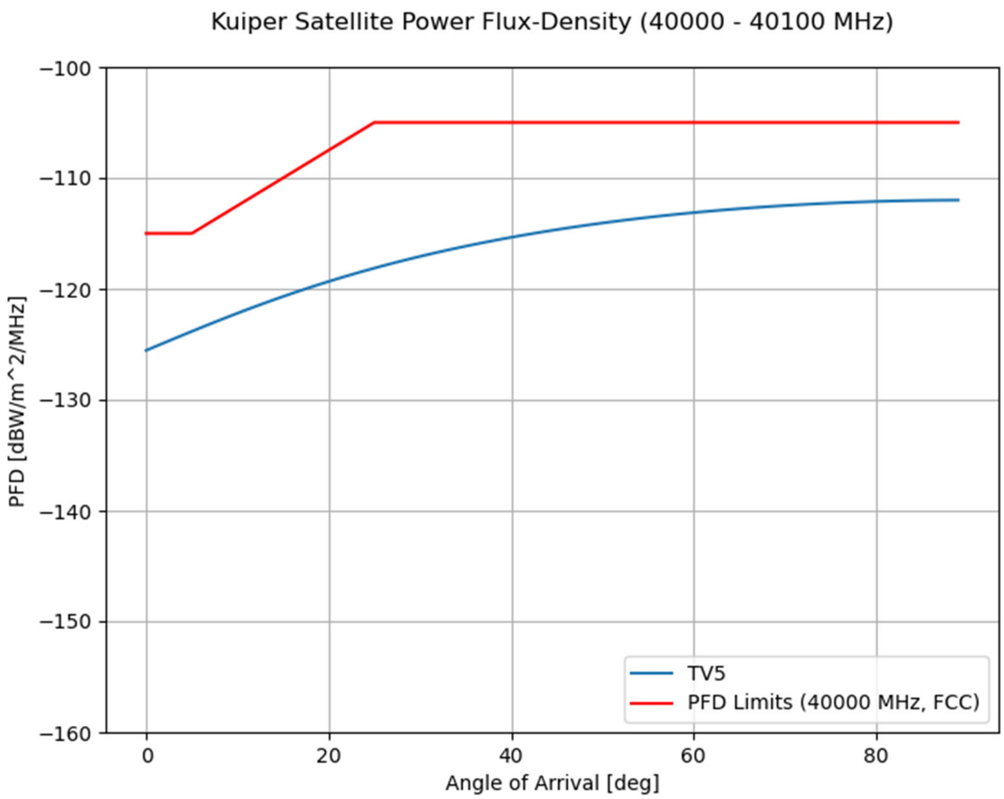


Fig. 4. Kuiper-V TT&C Downlink Power Flux-Density Levels in the 40.0 – 40.1 GHz Band

c. *10.7 – 11.7 GHz Band*

Section 25.208(b) provides PFD limits for emissions from NGSO space stations in the 10.7 – 11.7 GHz band.[18] Figure 5, below, demonstrates that the Kuiper-V System downlink PFD

[18] *See* 47 C.F.R. § 25.208(b).

levels will comply with the 25.208(b) limits. The Kuiper-V System downlinks in the 10.7 – 11.7 GHz band will operate a maximum PFD of -116.5 dBW/m^2/MHz for elevation angles above 30 degrees. The Kuiper-V System can produce a constant PFD by adjusting the EIRP based on the beam steering angle. For angles of arrival below 30 degrees, the PFD generated by the Kuiper-V System downlinks in the 10.7 – 11.7 GHz band will be a function of the Kuiper-V System satellites' off-axis EIRP, as shown in Figure 5, below.

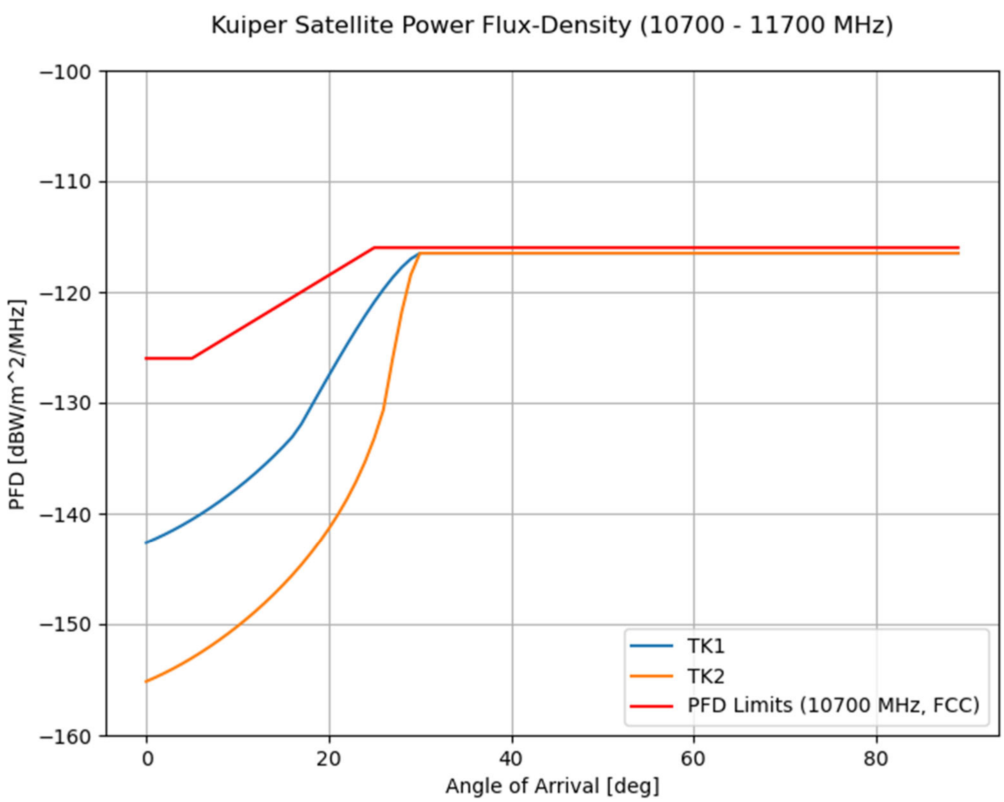


Fig. 5. <u>Kuiper-V Satellite Downlink Power Flux-Density Levels in the 10.7 – 11.7 GHz Band</u>

d. *11.7 – 12.2 GHz Band*

Section 25.208 does not contain PFD limits for NGSO satellite systems in the 11.7 – 12.2 GHz band. However, the Kuiper-V System downlinks in the 11.7 – 12.2 GHz band will comply with the PFD limits listed in No. 21.16, Table 21-4, of Article 21 in the ITU Radio Regulations, as demonstrated in Figure 6, below.[19]

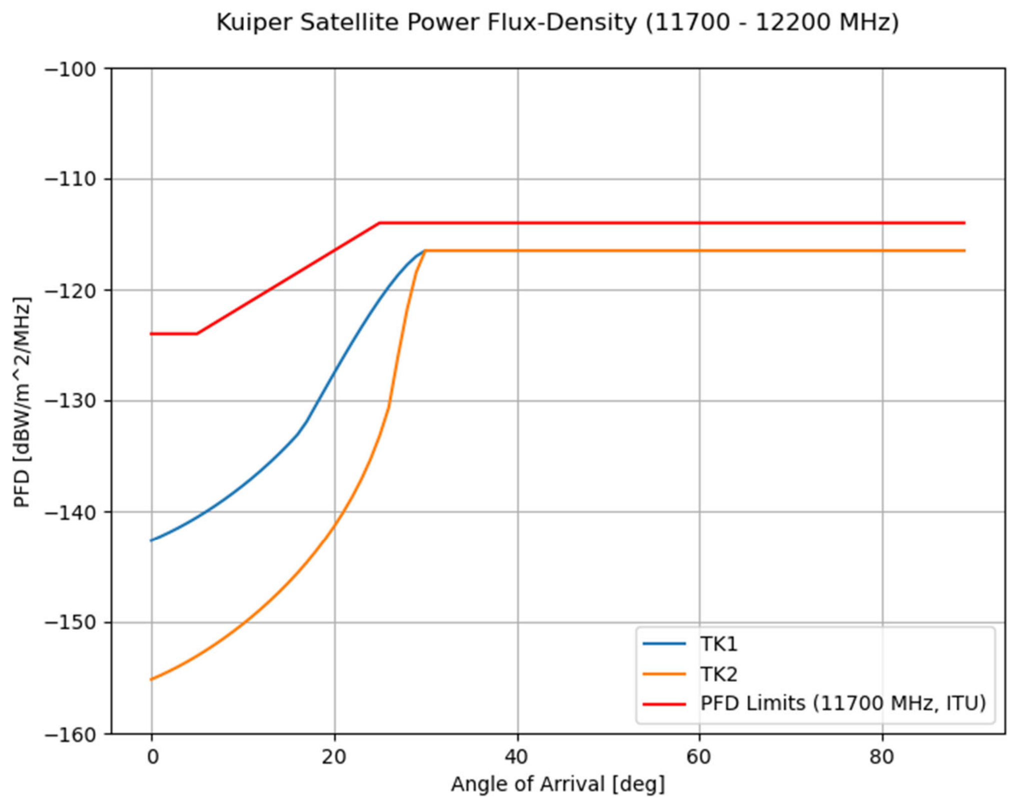


Fig. 6. <u>Kuiper-V Satellite Downlink Power Flux-Density Levels in the 11.7 – 12.2 GHz Band</u>

e. *12.2 – 12.7 GHz Band*

Section 25.208(o) provides PFD limits for emissions from NGSO space stations in the 12.2 – 12.7 GHz band for angles of arrival between 0 degrees and 5 degrees above the horizontal plane, in order to protect operational MVDDS receivers from interference.[20] Figure 7, below,

[19] *See* ITU RR Art. 21.

[20] *See* 47 C.F.R. § 25.208(o).

demonstrates that the Kuiper-V System downlink PFD levels will comply with the 25.208(o) limits.

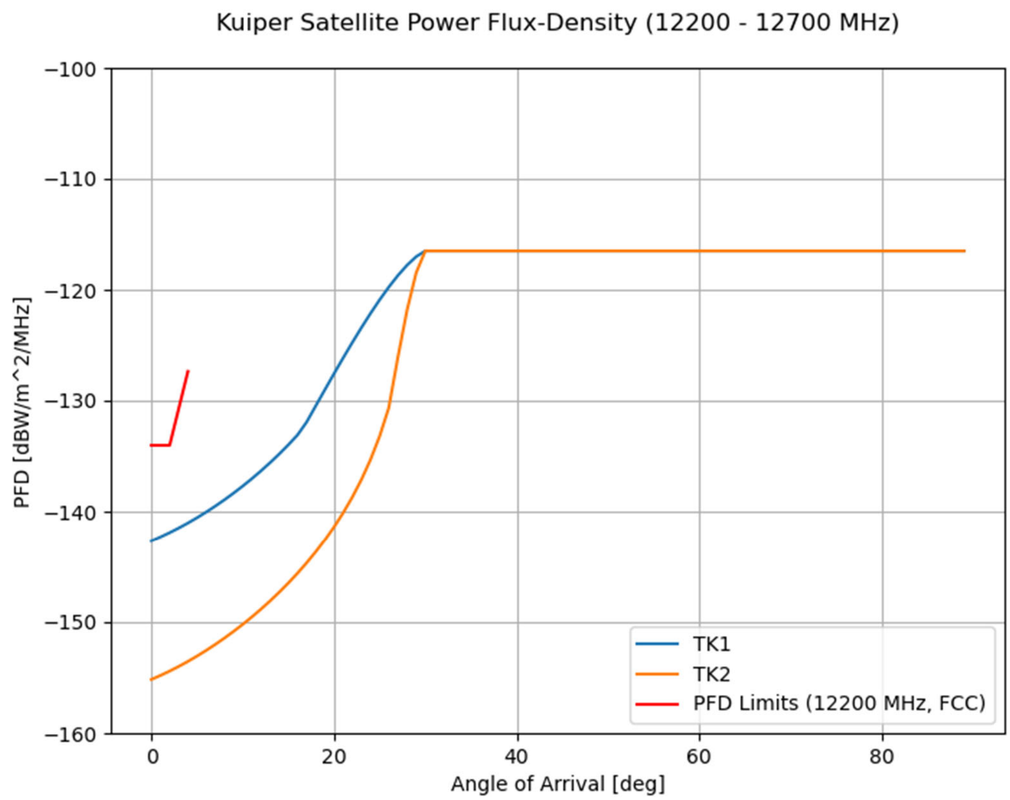


Fig. 7. Kuiper-V Satellite Downlink Power Flux-Density Levels in the 12.2 – 12.7 GHz Band

2. Sharing with the Upper Microwave Flexible Use Service

The 37.5 – 40.0 GHz, 47.2 – 48.2 GHz, and 50.4 – 51.4 GHz bands are allocated to the Upper Microwave Flexible Use Service ("UMFUS").[21] In the 37.5 – 40.0 GHz band, the Kuiper-V System will operate space-to-Earth links and will not claim protection from fixed, mobile, and UMFUS systems except when individually licensed earth stations are authorized under Section

[21] *See id.* § 2.106.

25.136(b) and 25.136(c).[22] In the 47.2 – 48.2 GHz and 50.4 – 51.4 GHz bands, the Kuiper-V System will limit its use to individually licensed earth stations and either operate on a secondary basis to UMFUS systems, or operate in conformance with Section 25.136(d),[23] (e)[24], or (f)[25].

C. Sharing with GSO FSS and BSS Systems

As required by Sections 25.146(a)(2) and 25.289, the Kuiper-V System will comply with applicable equivalent power flux-density ("EPFD") levels in Article 22, Section II and Resolution 76 of the ITU Radio Regulations, which have been incorporated by reference into the Commission's rules.[26] Although the Commission has not incorporated into its rules specific limits for protection of GSO FSS and Broadcasting Satellite Service ("BSS") systems in the V-band, the ITU Radio Regulations have provided limits in 22.5M and 22.5L of Article 22 with which the Kuiper-V System will comply.[27] This section further describes the methods the Kuiper-V System will use to prevent harmful interference to GSO systems in the Ku-band and V-band, both in the FSS and the BSS.

1. Ku-Band

The Kuiper-V System will use a variety of methods to meet requirements set forth in Article 22 of the ITU Radio Regulations ("Article 22"), including by: limiting the number of satellites simultaneously transmitting to and from earth station areas on the same frequency and channel; using space station and earth station antennas with narrow beamwidths; using a GSO arc

[22] *See id.* § 25.136(b), (c).

[23] *See id.* § 25.136(d) (special conditions applicable to operations specific to the 47.2 – 48.2 GHz band).

[24] *See id.* § 25.136(e) (special conditions applicable to operations specific to the 50.4 – 51.4 GHz band).

[25] *See id.* § 25.136(f) (providing for operations pursuant to private agreements with UMFUS licensees).

[26] *See id*. §§ 25.146(a)(2), 25.289.

[27] *See* Int'l Telecomm. Union, Radio Regulations Art. 22, Nos. 22.5M, 22.5L (2016) ("ITU RR Art. 22").

avoidance angle to prevent main-beam coupling between Kuiper-V and GSO space station and earth station beams; and limiting the power flux-density and EIRP of Kuiper-V downlinks and uplinks respectively. Utilizing the latest version of the ITU's Transfinite EPFD software application, Amazon has conducted analysis to verify that Kuiper-V System's Ku-band operations will comply with applicable EPFD limits in Article 22, as detailed further below.

a. *Downlink Operations*

Article 22, Table 22-1A specifies limits on the downlink EPFD radiated by NGSO systems into fixed-satellite service GSO earth stations.[28] Figures 8-11, below, depict the Kuiper-V System's EPFD results for Ku-band FSS earth stations, which comply with the limits prescribed in Table 22-1A.

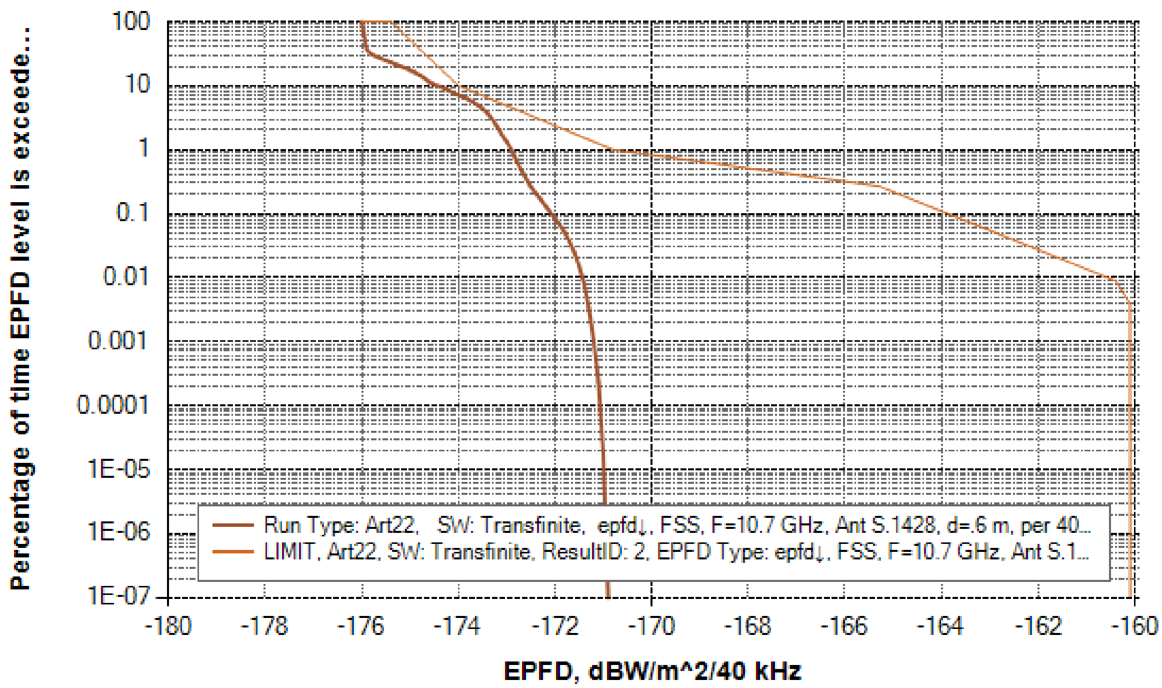


Fig. 8. Downlink EPFD: 10.7 GHz, FSS, 0.6m Earth Station Antenna

[28] *See* ITU RR Art. 22, Table 22-1A.

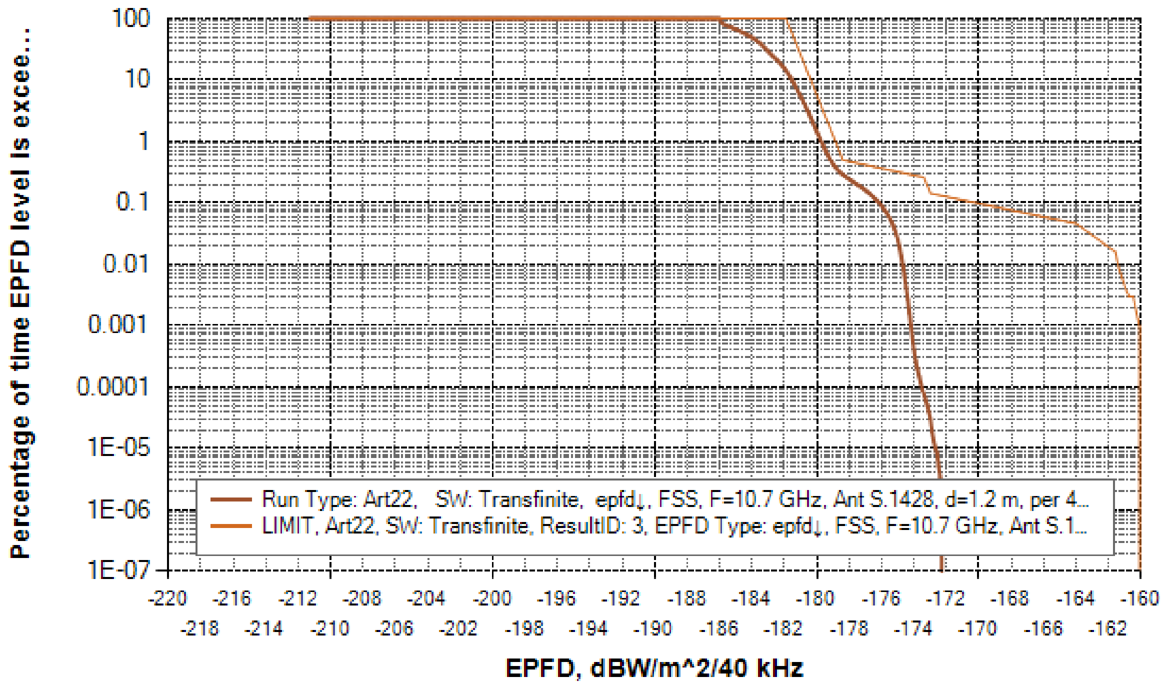


Fig. 9. Downlink EPFD: 10.7 GHz, FSS, 1.2m Earth Station Antenna

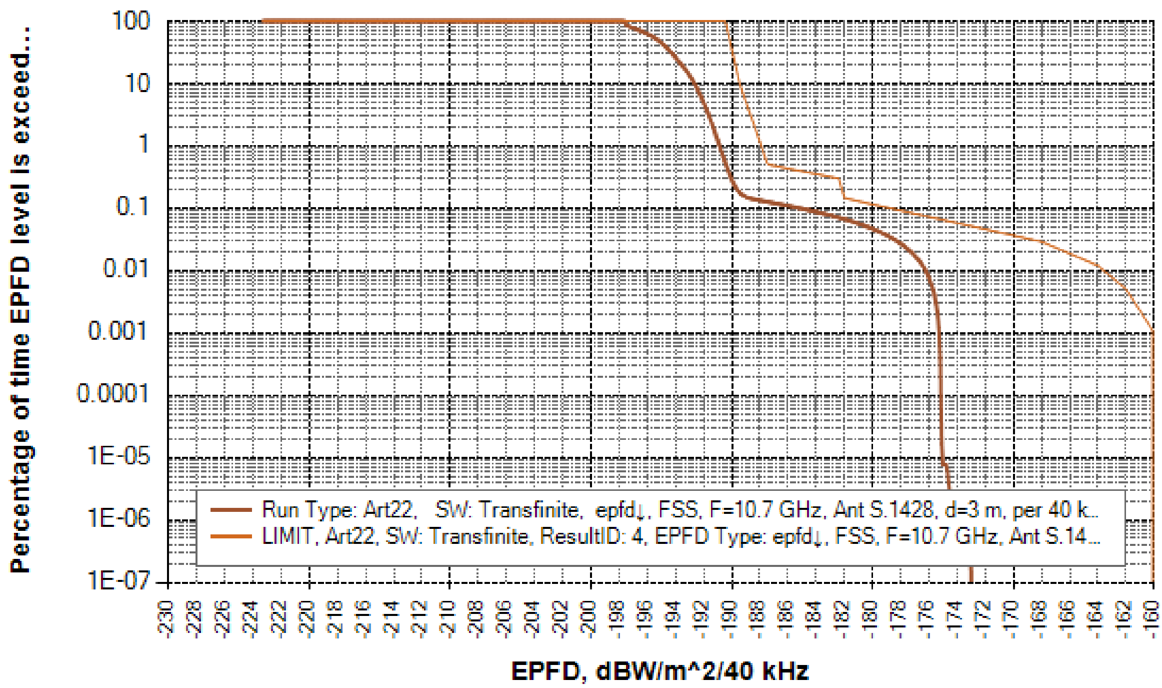


Fig. 10. Downlink EPFD: 10.7 GHz, FSS, 3.0m Earth Station Antenna

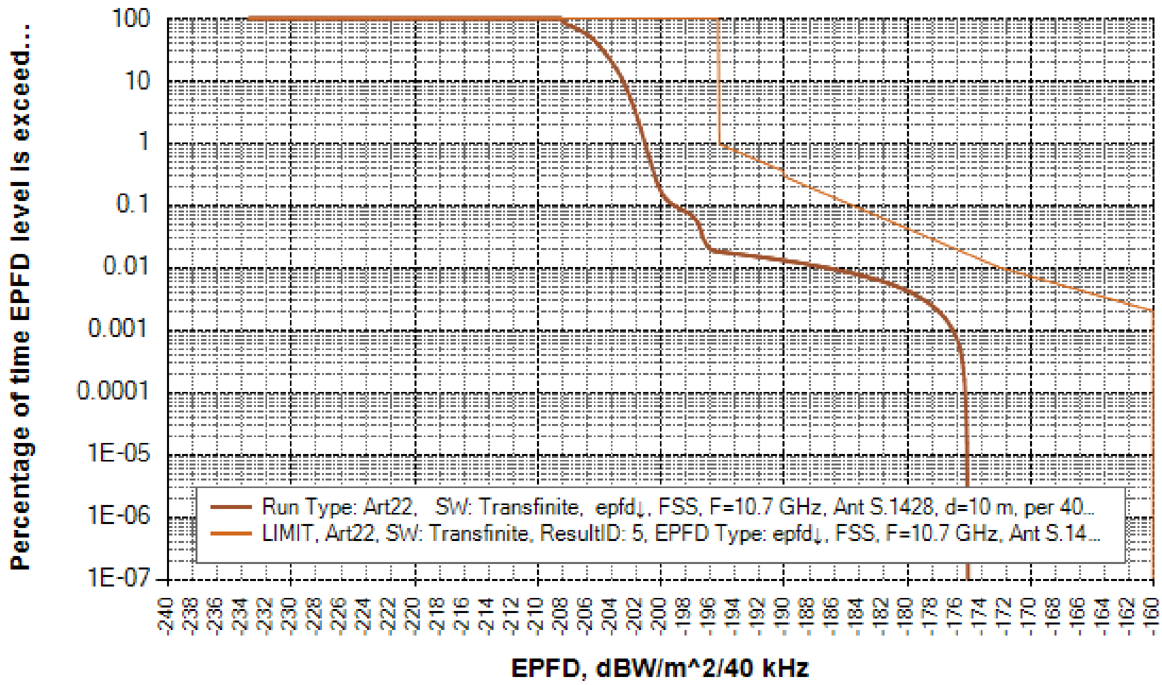


Fig. 11. Downlink EPFD: 10.7 GHz, FSS, 10.0m Earth Station Antenna

Similarly, Article 22, Table 22-1D specifies limits on the downlink EPFD into Broadcasting Satellite Service GSO earth stations.[29] Figures 12-19, below, depict the Kuiper-V System's EPFD results for Ku-band BSS earth stations, which comply with the limits prescribed in Table 22-1D.

[29] *See* ITU RR Art. 22, Table 22-1D.

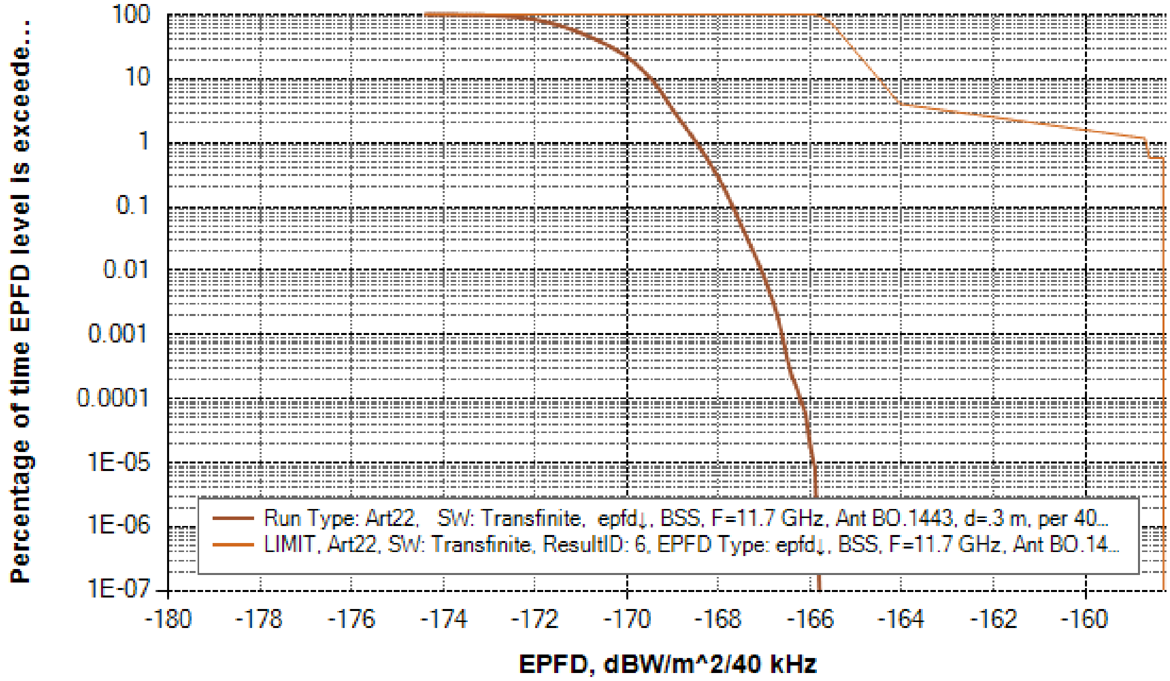


Fig. 12. Downlink EPFD: 11.7 GHz, BSS, 0.3m Earth Station Antenna

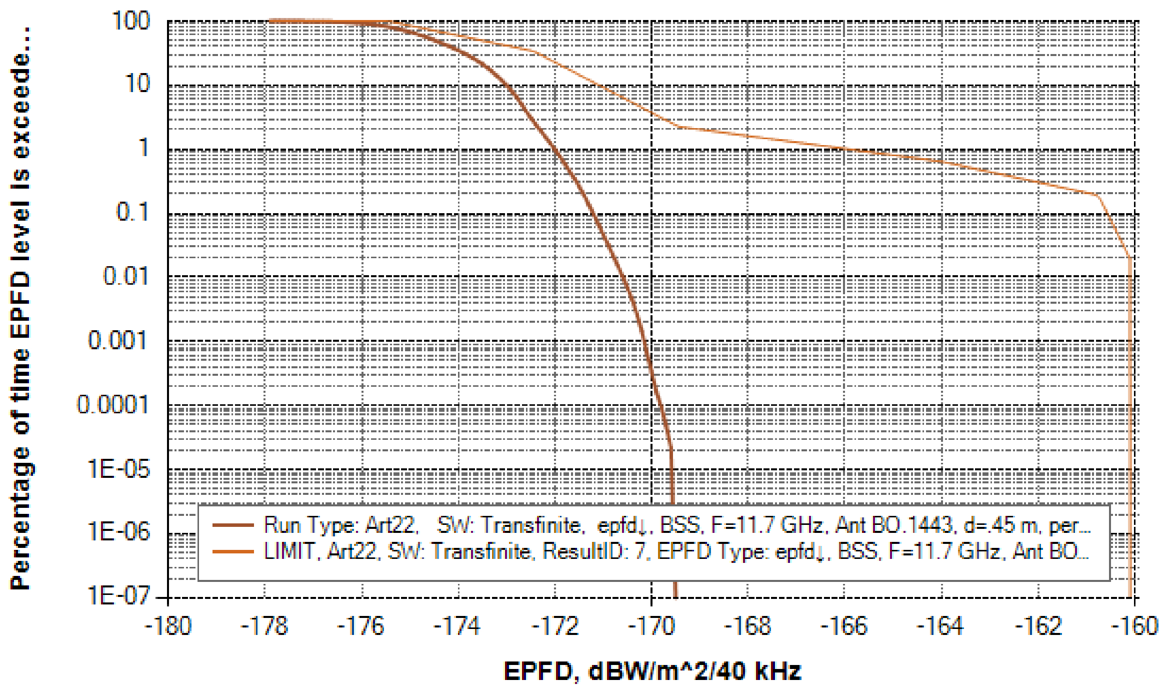


Fig. 13. Downlink EPFD: 11.7 GHz, BSS, 0.45m Earth Station Antenna

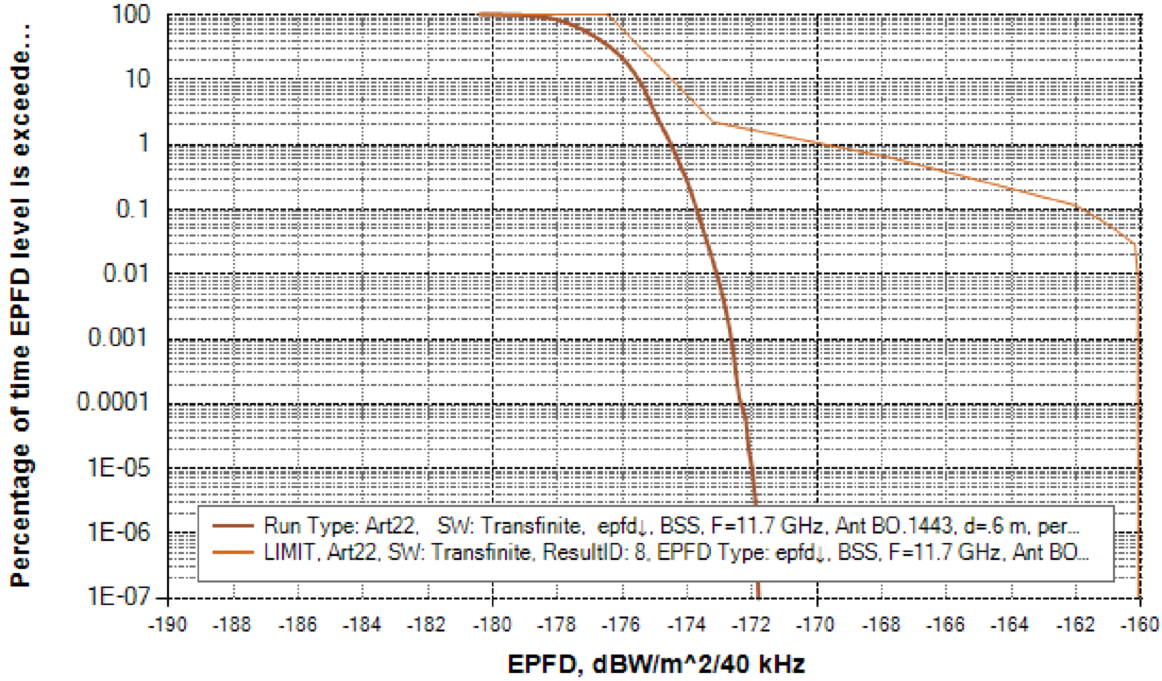


Fig. 14. Downlink EPFD: 11.7 GHz, BSS, 0.6m Earth Station Antenna

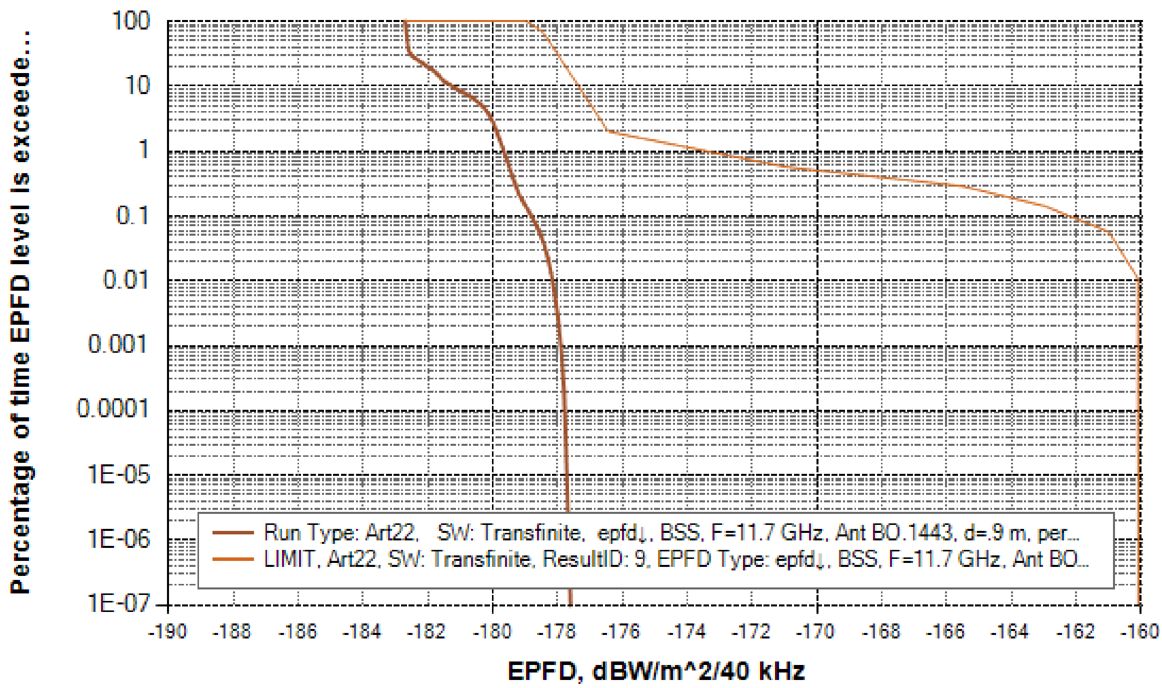


Fig. 15. Downlink EPFD: 11.7 GHz, BSS, 0.9m Earth Station Antenna

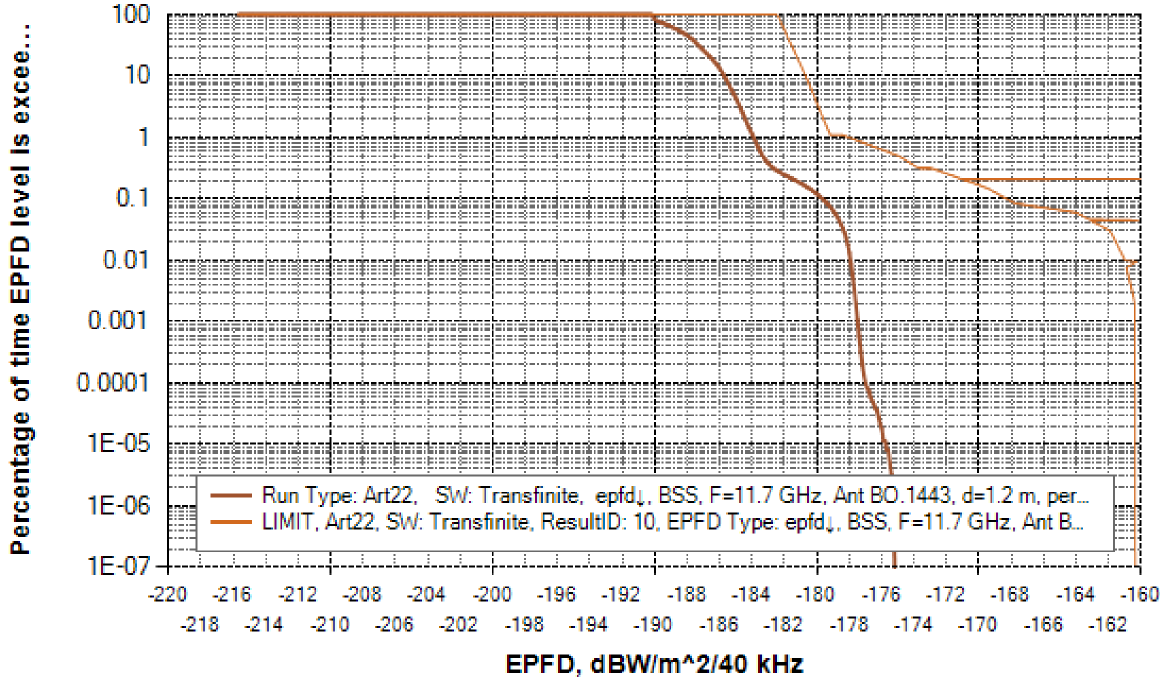


Fig. 16. Downlink EPFD: 11.7 GHz, BSS, 1.2m Earth Station Antenna

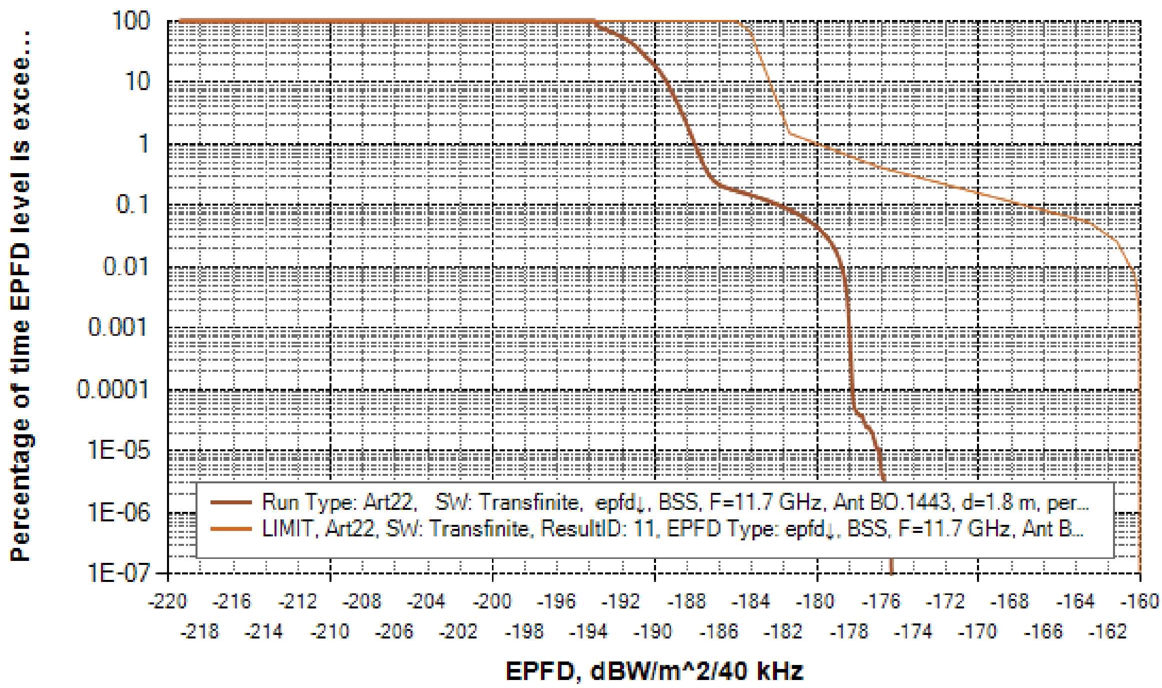


Fig. 17. Downlink EPFD: 11.7 GHz, BSS, 1.8m Earth Station Antenna

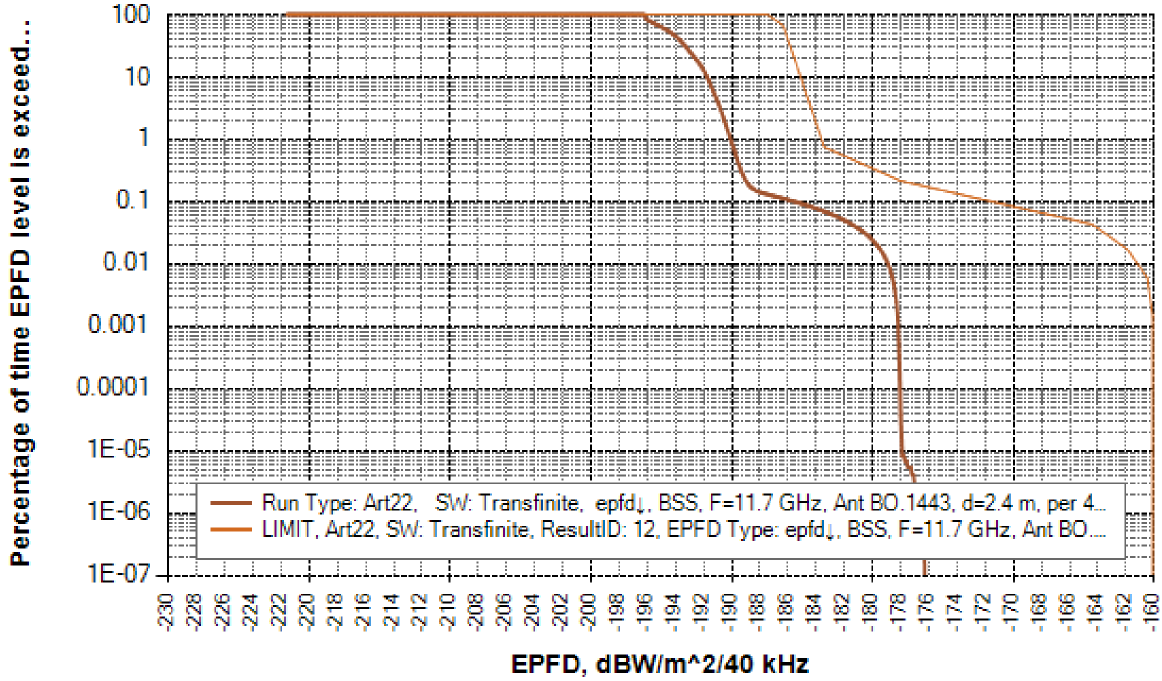


Fig. 18. Downlink EPFD: 11.7 GHz, BSS, 2.4m Earth Station Antenna

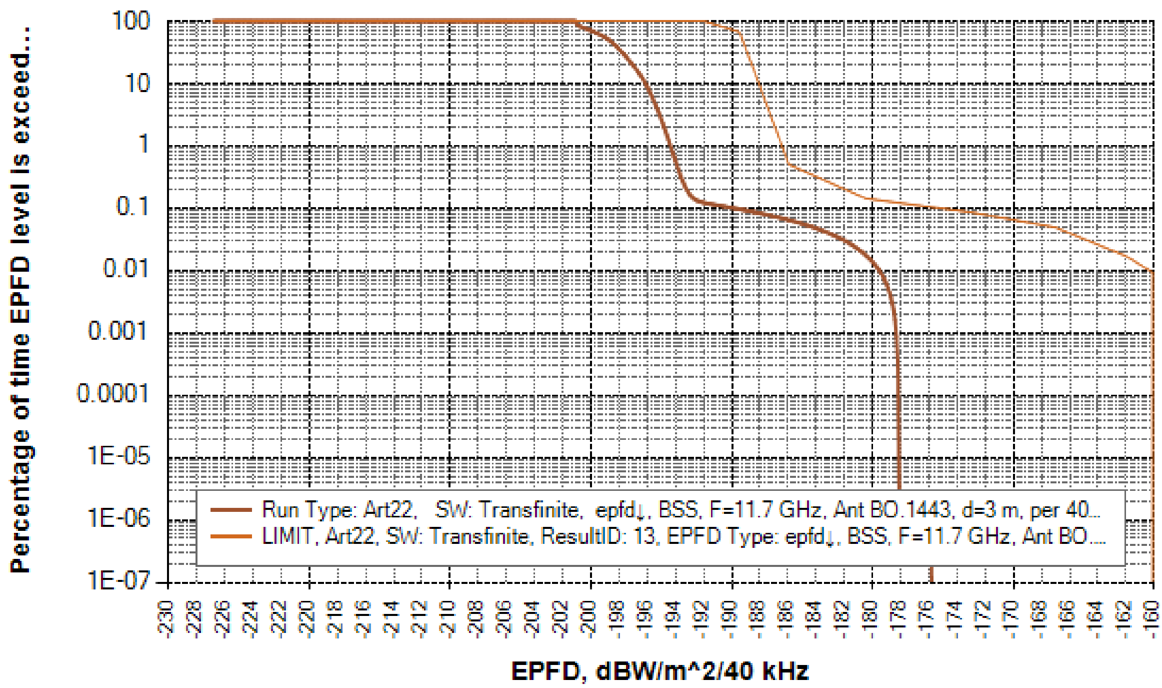


Fig. 19. Downlink EPFD: 11.7 GHz, BSS, 3.0m Earth Station Antenna

b. *Uplink Operations*

Table 22-2 in Article 22 of the ITU Radio Regulations specifies limits on the uplink EPFD radiated by NGSO systems in the 12.75 – 13.25 GHz and 14.0 – 14.5 GHz bands.[30] Figure 20, below, depicts the Kuiper-V System's EPFD results for Ku-band uplink operations, which complies with the limits prescribed in Table 22-2.

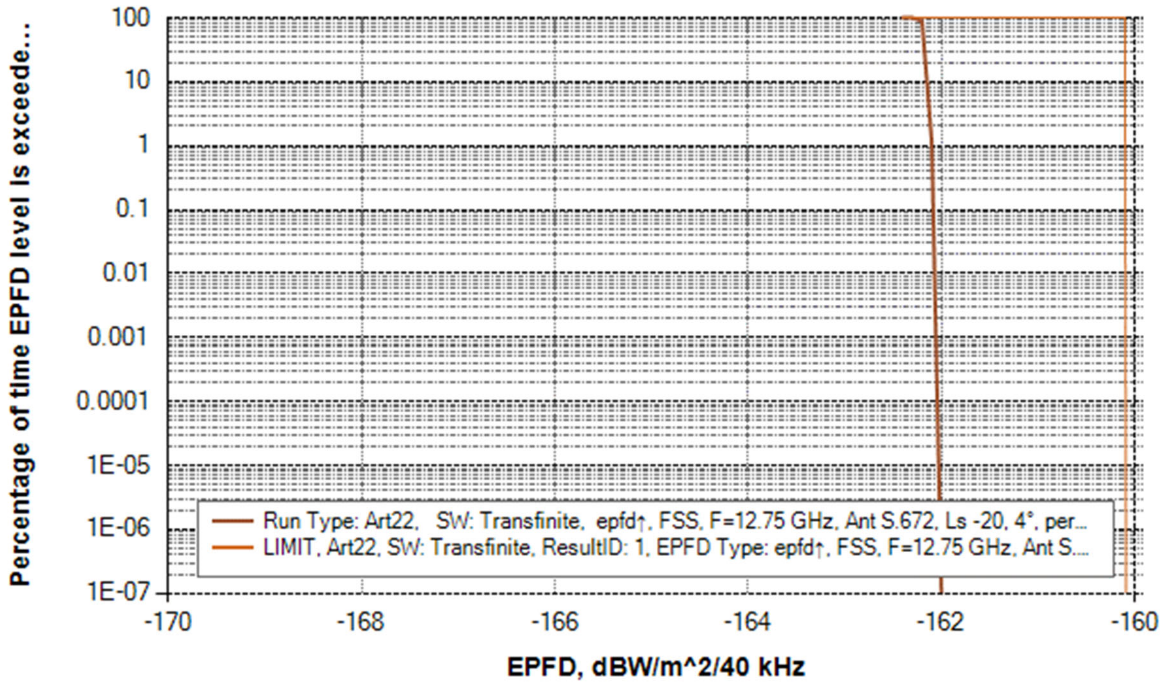


Fig. 20. Uplink EPFD: 12.75 GHz

c. *Intersatellite*

Table 22-3 in Article 22 of the ITU Radio Regulations specifies limits on the intersatellite EPFD radiated by NGSO systems in the 10.7 – 11.7 GHz and 12.5 – 12.75 GHz bands.[31] Figure 21, below, depicts the Kuiper-V System's EPFD results for Ku-band intersatellite operations, which complies with the limits prescribed in Table 22-3.

[30] *See* ITU RR Art. 22, Table 22-2.

[31] *See* ITU RR Art. 22, Table 22-3.

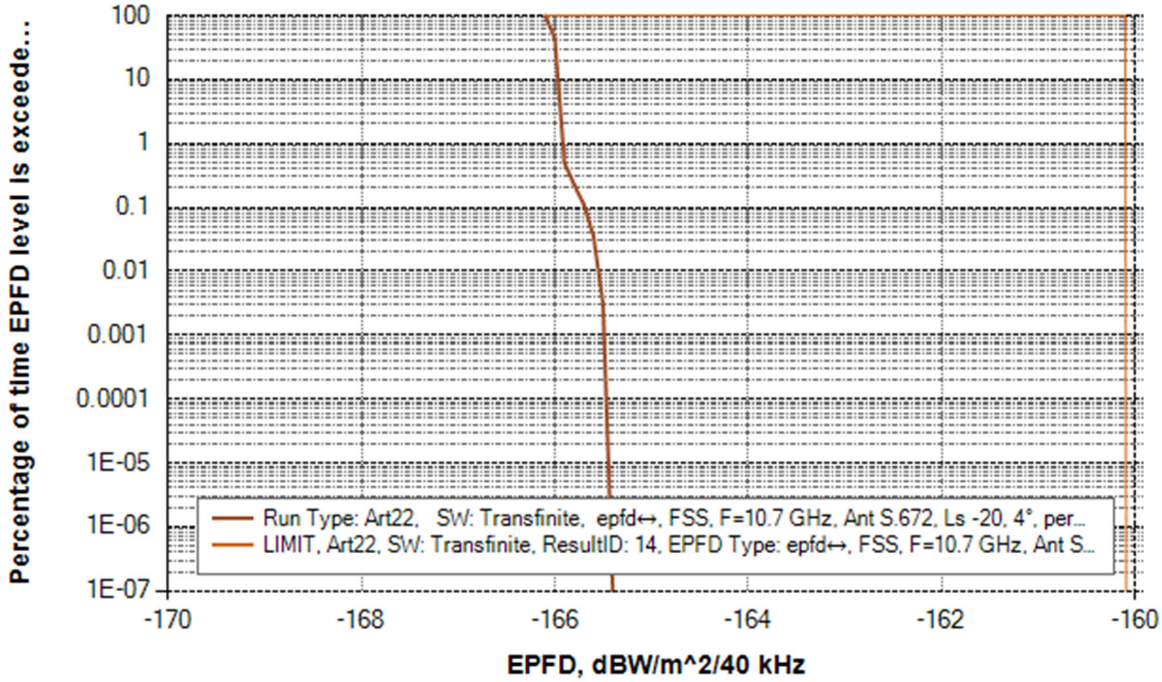


Fig. 21. Intersatellite EPFD: 10.7 GHz

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.[32]

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 Kuiper-V System will comply with the single-entry limits in No. 22.5L and aggregate limits in No. 22.5M of Article 22. The Kuiper-V System will use a variety of methods to meet these limits, including by: limiting the number of satellites transmitting to and from earth station areas simultaneously on the same frequency and channel; using space station and earth

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

station antennas with narrow beamwidths; using a GSO arc avoidance angle to prevent main-beam coupling between Kuiper-V and GSO space station and earth station beams; and limiting the power flux-density and EIRP of Kuiper-V downlinks and uplinks respectively.

D. Sharing with NGSO Systems

Section 25.261 of the Commission's rules and Commission precedent cover the sharing among NGSO FSS space stations operating with earth stations that include directional antennas anywhere in the U.S. under a grant of U.S. market access or anywhere in the world under a Commission license.[33] In accordance with Section 25.261(b) and Commission precedent, the Kuiper-V system will coordinate in good faith with other authorized NGSO operators utilizing frequencies that overlap with those outlined in this application.

In combination with good-faith operations, the Kuiper-V System's small and steerable spot beams, satellite selection strategies, and channelization capabilities[34] will facilitate spectrum sharing and coordination with other NGSO satellite systems. Given this commitment to coordination combined with the system's technical flexibility, Amazon is confident that the proposed Kuiper-V System will be able to successfully share spectrum with other NGSO systems.

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 Kuiper-V System.[35] To ensure their protection, the Kuiper-V System will comply

[33] *See* 47 C.F.R. § 25.261.

[34] Amazon has provided notional channel definitions in the associated Schedule S. In accordance with Section 25.275(b), the Kuiper-V system may operate any number of carriers on any discrete frequencies within the authorized frequency bands in accordance with the other terms and conditions of the authorization and the requirements under Part 25 of the Commission's rules. *See id.* § 25.275(b).

[35] *See* 47 C.F.R. § 2.106.

with all relevant protections and limits to PFD levels and other technical parameters set forward by the Commission, and, by extension, the ITU. Specifically, the Kuiper-V System will operate on a non-interference basis to RAS in the 48.94 – 49.04 GHz band in accordance with footnote 5.555 to Section 2.106 of the Commission's rules.[36] Amazon will also actively coordinate with RAS users where required, including as specified in US131 prior to commencing operations in the 10.7 – 11.7 GHz band.[37]

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

The Kuiper-V 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 ("EEES") (passive).[38]

II. ORBITAL DEBRIS MITIGATION/SATELLITE END-OF-LIFE 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.[39] Space safety is a core tenet for Amazon, and the Kuiper-V System's satellite design and operational strategies will mitigate orbital debris risks.

A. Debris Release[40]

Amazon will design the Kuiper-V System to limit the amount of debris released in a planned manner during normal operations. The Kuiper-V System will not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release the satellite from

[36] *See id.* § 2.106 n.5.555.

[37] *See id.* n.US131.

[38] *See id.* n.US156; Int'l Telecomm. Union, Res. 750 (2020).

[39] *See* 47 C.F.R. § 25.114(d)(14).

[40] 47 C.F.R. § 25.114(d)(14)(i).

the launch vehicle or to actuate deployable structures on the satellite. This approach limits the possibility that debris will be released during normal deployment. Amazon will also assess and limit the probability that the Kuiper-V 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. Design approaches will be employed 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.[41]

B. Accidental Explosions[42]

As with debris release, Amazon will assess and limit the probability, during and after completion of mission operations, of accidental explosions. In designing the Kuiper-V System, Amazon will work to ensure that conversion of energy sources (chemical, pressure, and kinetic) onboard the spacecraft will not result in debris generation.[43] Amazon will test the propellant tanks, and each satellite's tank will be designed to leak rather than burst in most failure mode conditions, even if the failure is caused by micrometeoroid orbital debris impact. Amazon will test the tanks' failure characteristics under high velocity impact to verify this result. Amazon will design the Kuiper-V System satellites' battery system 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.

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

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[41] Because the design for the Kuiper-V 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.

[42] 47 C.F.R. § 25.114(d)(14)(ii).

[43] *Id.*

mission life.[44] Specifically, at the end of their mission life, the Kuiper-V System satellites will retain enough propellant on board to reduce perigee altitude to 350 km. If no further action is taken at that point, a rapid, natural decay from the disposal orbit will occur in less than one year. At that juncture, Amazon expects to use any residual propellant to lower apogee and continue collision avoidance. The satellites will then use the remaining propellant to further reduce apogee, vent any residual fuel, and begin uncontrolled reentry and rapid demise.

C. Collision Risks with Large Objects[45]

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

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[44] 47 C.F.R. § 25.114(d)(14)(iv).

[45] *Id.* § 25.114(d)(14)(iii).

selection to de-conflict planar conjunctions from crewed vehicles.[46] During ongoing operations, the ability of the Kuiper-V System satellites to maintain strict operating altitudes is yet another factor promoting safety.

As discussed above, the Kuiper-V System will operate with long-term control tolerances for apogee and perigee of 9 km and 0.1 degree for both inclination and RAAN. These tolerances are planned to ensure consistency with space safety principles both between constellations as well as with all other space objects that may intersect with the Kuiper-V System's orbital shells. Moreover, all satellites in the Kuiper-V System will have a nominal operational lifetime of 7 years. Amazon will actively deorbit the Kuiper-V System satellites at the end of their operational lifetime.

The Kuiper-V System satellites will utilize onboard propulsion to enable station-keeping maneuvers that will maintain the reference orbit altitude. They will conduct 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 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 Kuiper-V 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.

[46] 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 Space-Track for spaceflight operators and space situational awareness monitors to assist in maintaining track custody of the Kuiper-V 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 Kuiper-V System satellite operations. Kuiper's satellite launch and early operation procedures will be attentive to space debris concerns from the outset. Prior to launch, Amazon will analyze whether Kuiper-V 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 Kuiper would plan to take to avoid in-orbit collisions. When the Kuiper-V System satellites separate from the launch vehicle, debris release concerns will also be paramount, and Amazon will take 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 Kuiper-V 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 Kuiper-V System satellites. After orbital insertion, Amazon will identify the Kuiper-V 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. Injection orbit parameters, launch location, target date and time of launch also will be provided to the 18th Space Control Squadron prior to launch to aid in detection, tracking, and custody of Kuiper-V 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 Kuiper-V System satellites and for owner and operator distribution. In the unlikely event that any Kuiper-V 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[47]

The Kuiper-V System will further reduce orbital debris by actively de-commissioning and deorbiting within one year after the active mission lifetime. 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.

As discussed above, 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 mission life. Any residual propellant will then 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 satellites will use the

[47] 47 C.F.R. § 25.114(d)(14)(iv).

remaining propellant to further reduce apogee and vent any residual fuel, followed by uncontrolled reentry and rapid demise.

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. Finally, when the satellites reach an altitude at which they can no longer maintain attitude control and therefore cannot execute maneuvers, the satellites will vent any remaining propellant. Additionally, if at any time failures render a satellite unable to perform de-orbit and the failures impede ground communications, the satellite will autonomously release any stored energy.

Amazon's post-mission disposal approach will comply with the U.S. Government Orbital Debris Mitigation Standard Practices[48] and the NASA Technical Standard[49] 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 chance of risk of human casualty from surviving components with impact kinetic energies exceeding 15 Joules.

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

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

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this Application of Kuiper Systems LLC for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in V-band and Ku-band Frequencies, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge and belief.

/s/ David Kaufman
David Kaufman
Principal, Regulatory Policy and Analysis
Kuiper Systems LLC

Date: November 4, 2021