Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Kuiper Systems LLC	)	Call Sign ______
	)	
Application for Blanket-Licensed Earth Stations in Motion (ESIM)	)	File No. SES-LIC-___________
	)	
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APPLICATION FOR BLANKET-LICENSED EARTH STATIONS IN MOTION

On July 30, 2020, the Commission authorized Amazon[1] to deploy a non-geostationary satellite orbit ("NGSO") system to provide service using certain Fixed-Satellite Service ("FSS") and Mobile-Satellite Service ("MSS") Ka-band frequencies (the "Kuiper System").[2] As the basis for that authorization, the Commission determined that the Kuiper System would serve the public interest by expanding the availability of high-speed broadband service to individual, government, and business customers.[3]

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[1] Kuiper Systems LLC ("Kuiper"), a wholly owned subsidiary of Amazon.com Services LLC (collectively "Amazon").

[2] *See Kuiper Systems LLC, Application for Authority to Deploy and Operate a Ka-band Non-Geostationary Satellite Orbit System*, Order and Authorization, 35 FCC Rcd 8324 (2020) ("*Kuiper System Authorization*"). *See also Kuiper Systems LLC, Request for Modification of the Authorization for the Kuiper NGSO Satellite System*, Order and Authorization, ICFS File No. SAT-MOD-20211207-00186, DA 23-114 (rel. Feb. 8, 2023) ("*Kuiper Orbital Debris Modification Order*"); *Kuiper Systems LLC, Request for Modification of the Authorization for the Kuiper NGSO Satellite System*, Order and Authorization, ICFS File Nos. SAT-MOD-20230228-00043, SAT-AMD-20230613-00140, DA 24-224 (rel. Mar. 8, 2024) ("*Kuiper Orbital Parameters Modification Order*"); *Kuiper Systems LLC, Request for Modification of the Authorization for the Kuiper NGSO Satellite System*, Order and Authorization, ICFS File Nos. SAT-MOD-20210806-00095, SAT-AMD-20230329-00067, DA 24-376 (rel. Apr. 22, 2024) ("*Kuiper ITU Condition Modification Order*").

[3] *Kuiper System Authorization* ¶ 9; *Kuiper ITU Condition Modification Order* ¶ 1 ("Our action today serves the public interest by promoting rapid deployment of competitive low-earth orbit satellite broadband service for unserved and underserved areas of the United States, while

Since then, Amazon has invested heavily to quickly realize its goal of providing affordable, high-quality connectivity to customers and communities around the world. Among other achievements, Amazon has executed the largest commercial procurement of launch capacity in history; grown its workforce of highly skilled engineers and professionals; and expanded its research and manufacturing facilities, including most recently by breaking ground on a 100,000-square-foot satellite processing facility at the Kennedy Space Center.[4] Likewise, Amazon has made substantial progress toward completion of its 172,000-square-foot satellite production facility in Kirkland, Washington, which will provide the scale required to build as many as five satellites per day. Just months ago, Amazon launched its prototype satellites, which achieved successful results in testing of every one of Kuiper's major systems and subsystems.[5] Now, having validated the architecture and design of the Kuiper System, Amazon is poised to begin deploying the Kuiper System within months.[6]

The terrestrial components of the Kuiper System will match the groundbreaking innovation of its architecture in space. In its recent application seeking blanket authority to deploy fixed earth station customer terminals ("CTs") within the United States, Amazon explained how those CTs

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providing additional assurance of protection from harmful interference for operators of geostationary orbit (GSO) satellites.").

[4] *See generally Project Kuiper*, About Amazon, https://www.aboutamazon.com/what-we-do/devices-services/project-kuiper (last accessed Feb. 1, 2024) (providing regular updates on Amazon's progress in deploying the Kuiper System).

[5] Amazon Staff, *The Latest Updates from Project Kuiper's Satellite Test Mission*, About Amazon (Dec. 14, 2023), https://www.aboutamazon.com/news/innovation-at-amazon/amazon-project-kuiper-latest-updates.

[6] *See* Thomas Kohnstamm, *Everything You Need to Know About Project Kuiper, Amazon's Satellite Broadband Network*, About Amazon (Oct. 30, 2023), https://www.aboutamazon.com/news/innovation-at-amazon/what-is-amazon-project-Kuiper.

will be smaller, more affordable, and higher performance than legacy designs.[7] This application seeks to bring these innovations to customers requiring connectivity while in motion by requesting a blanket license authorizing operation of Vehicle-Mounted Earth Stations ("VMESs"), Earth Stations on Vessels ("ESVs"), and Earth Stations Aboard Aircraft ("ESAAs") (collectively, Earth Stations in Motion ("ESIMs")).[8] As explained in greater detail below, Amazon seeks authority to operate these ESIMs (1) as VMESs throughout the United States and its territories, (2) as ESVs in the territorial waters of the United States and aboard U.S.-registered vessels throughout international waters worldwide, and (3) as ESAAs on U.S.-registered aircraft operating worldwide and non-U.S.-registered aircraft operating in U.S. airspace. Like its fixed CTs, Amazon plans to offer three ESIM models: (1) an ultra-compact model ("Type I"), which will deliver speeds up to 100 megabits per second ("Mbps"); (2) a standard model ("Type II"), which will deliver speeds up to 400 Mbps; and (3) a larger, high-throughput model ("Type III"), which will deliver speeds up to 1 gigabit per second ("Gbps").

This narrative provides the technical and operational characteristics of Amazon's ESIMs, demonstrates that they will comply with the Commission's rules, and explains why authorizing these ESIMs will serve the public interest. Amazon provides further technical information in support of this application on FCC Form 312 and its attachments.[9] To support delivery of

[7] *See* Kuiper Systems LLC, Application for Blanket-Licensed Fixed Earth Stations, Call Sign E230164, ICFS No. SES-LIC-20231010-02222 (filed Oct. 10, 2023) ("Kuiper Fixed CT Application").

[8] *See* 47 C.F.R. § 25.103 (defining VMES, ESV, ESAA, and ESIM).

[9] Because the Commission does not require applications in the Ka-band to specify a maximum number of ESIMs, Amazon has entered a value of "0" in the accompanying FCC Form 312, Schedule B, Item E29. This value is entered merely to satisfy form-validation requirements, and is not intended to establish a maximum number of units that Amazon may deploy. *See Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Second Report and Order, 30 FCC Rcd 14713 ¶ 291 (2015).

broadband satellite services to earth stations in motion, Amazon requests that the Commission expeditiously grant this blanket license.[10]

I. INTRODUCTION AND BACKGROUND

As reflected in the FCC Form 312 submitted with this application, Amazon's ESIMs will be in many respects electrically identical to its fixed CTs. Both its fixed CTs and ESIMs, for example, will use the same radio-frequency sub-systems and have nearly identical uplink and downlink characteristics (such as equivalent isotropic radiated power ("EIRP"), bandwidths, and frequencies).[11] Consistent with the *Kuiper Orbital Parameters Modification Order*, these ESIMs will communicate with the Kuiper System in the frequency bands 28.4-28.6 GHz, 28.6-29.1 GHz and 29.5-30.0 GHz (Earth-to-space); and 17.8-18.6 GHz, 18.8-19.4 GHz and 19.7-20.2 GHz (space-to-Earth).[12]

II. ESIM TECHNICAL AND OPERATIONAL CHARACTERISTICS

The following data supplements the data provided in FCC Form 312, Schedule B.[13] While electrically nearly identical, Amazon's proposed ESIMs will differ from its fixed CTs in several

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[10] Amazon seeks authority to operate these earth stations to the full extent of the FCC's jurisdictional authority, including as (1) vehicle-mounted earth stations throughout the United States and its territories; (2) as earth station on vessels in the territorial waters of the United States and throughout international waters worldwide; and (3) as earth stations aboard aircraft on U.S.-registered aircraft operating worldwide and non-U.S.-registered aircraft operating in U.S. airspace.

[11] *See generally* Kuiper Fixed CT Application, Narrative and FCC Form 312.

[12] *See Kuiper Orbital Debris Modification Order* ¶ 3; *Kuiper Orbital Parameters Modification Order* ¶ 2.

[13] To the extent relevant, Amazon hereby incorporates the technical information submitted with its space station applications. *See* Application of Kuiper Systems LLC for Authority to Deploy and Operate a Ka-band Non-Geostationary Satellite Orbit System, ICFS File No. SAT-LOA-20190704-00057 (filed July 4, 2019); Application of Kuiper Systems LLC for Modification of Authorization for the Kuiper System, ICFS File No. SAT-MOD-20210806-00095 (filed Aug. 6, 2021). Additionally, the Commission's earth station licensing rules predicated on antenna performance standards do not apply to this application. *See, e.g.*, *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, Report and Order, 16 FCC Rcd 4096 ¶ 240 (2000) (declining to adopt reference patterns for use in licensing NGSO FSS user terminals).

respects to account for the unique conditions of their use and the Commission's ESIM-specific rules.[14] The mechanical packaging of its ESIMs will be adapted to the specific circumstances of their use. Similarly, the proposed ESIMs will incorporate systems capable of maintaining a link with a target satellite while in motion. Finally, as explained in greater detail below, the design and operation of the ESIMs will incorporate the additional tracking and control measures necessary to satisfy the Commission's rules.

Amazon's ESIMs will communicate only with satellites above a minimum elevation angle of 35 degrees in any azimuth direction. The ESIMs will consist of a flat panel with electronically steerable beams capable of tracking satellites within their field of view. Table 1 includes power and gain figures for each ESIM:

Table 1: Power and Gain[15] Figures

	ESIM Type I	ESIM Type II	ESIM Type III
Antenna Gain dBi (Tx)	31	34	38
Antenna Gain dBi (Rx)	30.1	31.4	37
Max EIRP Density (dBW/Hz)	-35.0	-29.5	-24.2
Boresight EIRP (dBW)	35	40.5	45.8

III. SPECTRUM USE AND SHARING

Consistent with the *Kuiper Orbital Parameters Modification Order*, the ESIMs will operate in the frequencies listed in Table 2. The Commission's rules allow blanket licensing in these bands.[16] Amazon will adhere to all International Telecommunication Union ("ITU")

[14] *See generally* 47 C.F.R. § 25.228.

[15] Maximum un-steered gain.

[16] 47 C.F.R. § 25.115(f)(2). Amazon acknowledges that the Commission's rules specify that blanket licensing in the 17.8-18.3 GHz band is on an unprotected basis with respect to the Fixed Service, *see id.*, as further described below. Amazon also intends to use the 17.7-17.8 GHz band for space-to-Earth customer links, but only outside the U.S. *See Kuiper ITU Condition Modification Order* ¶ 29.

requirements and the Commission's rules governing NGSO Ka-band customer terminals. Amazon will also operate the ESIMs consistently with the terms and conditions of its space station authorization, including by adhering to the conditions of that authorization governing spectrum sharing with other services and operators sharing these frequencies.[17]

Table 2: Kuiper ESIM Frequencies

Link Type	Frequencies (GHz)[18]
Broadband Uplink (Earth-to-space)	28.4-28.6
	28.6-29.1
	29.5-30.0
Broadband Downlink (space-to-Earth)	17.8-18.6
	18.8-19.4
	19.7-20.2

Amazon recognizes that the Earth-to-space operations of its ESIMs are secondary to geostationary orbit ("GSO") FSS operations in the 28.4-28.6 GHz and 29.5-30.0 GHz frequency bands.[19] Amazon will not claim interference protection from GSO FSS uplinks in these bands and certifies that it will comply with the applicable equivalent power flux-density ("EPFD") limits in ITU Radio Regulations Article 22 to ensure its proposed transmissions do not cause unacceptable

[17] *See Kuiper ITU Condition Modification Order* ¶¶ 20-21, 27, 30-34. With the exception of SpaceX and OneWeb, Kuiper has coordinated with each of the operational systems in the 2016/2017 processing round. *See generally* Letter from Julie Zoller, Global Head of Regulatory Affairs, Kuiper Systems LLC, an Amazon subsidiary, and Elisabeth Neasmith, Director, ITU and Regulatory, Telesat, to Marlene H. Dortch, Secretary, FCC, ICFS File No. SAT-LOA-20190704-00057 (filed Sept. 21, 2022); Letter from Julie Zoller, Global Head of Regulatory Affairs, Kuiper Systems LLC, an Amazon subsidiary, and Torstein Losnedahl, Group Legal Counsel/Contract Manager, Space Norway AS, to Marlene H. Dortch, Secretary, FCC, ICFS File No. SAT-LOA-20190704-00057 (filed Nov. 18, 2022); Letter from Julie Zoller, Global Head of Regulatory Affairs, Kuiper Systems LLC, an Amazon subsidiary, and Suzanne Malloy, VP, Legal and Regulatory Affairs, O3b, to Marlene H. Dortch, Secretary, FCC, ICFS File No. SAT-LOA-20190704-00057 (filed Dec. 7, 2023).

[18] *See* 47 C.F.R. § 2.106; *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, Report and Order and Further Notice of Proposed Rulemaking, 32 FCC Rcd 7809 (2017) ("*NGSO FSS Order*"); *id*. at 7850-51 Appendix B ("*Ka-band Plan*").

[19] *See* 47 C.F.R. § 2.106; *Ka-band Plan*.

interference to GSO FSS.[20] Amazon's NGSO FSS operations in the 28.6-29.1 GHz band operate on a primary basis.[21] Amazon will ensure the operations in the downlink frequency bands listed in Table 2 follow relevant spectrum sharing requirements in the Commission's rules as well as the terms of the *Kuiper ITU Condition Modification Order*.[22] These include compliance with relevant power flux-density ("PFD") and EPFD limits to protect fixed service ("FS") and GSO FSS operations in these bands.[23]

IV. COMPLIANCE WITH SECTION 25.228 OPERATING AND COORDINATION REQUIREMENTS FOR ESIM

Amazon's proposed ESIMs will fully comply with the Commission's rules governing the operation and coordination of ESIMs.[24] The proposed ESIMs will be self-monitoring, automatically ceasing transmissions within 100 milliseconds of exceeding any emission limit included in its license conditions and not resuming transmissions until it corrects the exceedance.[25] Further, each ESIM will be monitored and controlled by a network control and monitoring center ("NCMC") or equivalent facility located in the United States,[26] which will be able to terminate

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[20] *See* 47 C.F.R. §§ 2.106, 25.115(f)(1), 25.146(a)(2); *Ka-band Plan*; ITU Radio Regulations Article 22. *See also Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, First Report and Order and Further Notice of Proposed Rulemaking, 16 FCC Rcd 4096, 4129-30 ¶ 77 (2000) ("*2000 NGSO FSS Order*") (concluding that compliance with EPFD limits "will adequately protect GSO FSS networks").

[21] *See* 47 C.F.R. § 2.106; *NGSO FSS Order*; *Ka-band Plan*.

[22] Before operating in these bands, Amazon will complete coordination with U.S. Federal systems. *See* 47 C.F.R. § 2.106 n.US334; *Kuiper ITU Condition Modification Order* ¶ 35.

[23] To share with FS, Amazon will meet the PFD limits in ITU Radio Regulations Article 21. *See Kuiper ITU Condition Modification Order* ¶¶ 26-27. To share with GSO FSS, Amazon certifies it will comply with the applicable EPFD limits in ITU Radio Regulations Article 22 and Resolution 76.

[24] *See generally* 47 C.F.R. § 25.228.

[25] *See id.* § 25.228(b).

[26] *See id.* §§ 25.228(e)(2), (f). To the extent that Amazon uses the NCMC to communicate with ESVs on vessels of foreign registry, it will maintain detailed information on each such vessel's

transmissions within 100 milliseconds by issuing a "disable transmission" command.[27] As explained more fully in the exposure analysis filed with this application, Amazon will also ensure installation of ESIM terminals on vehicles by qualified installers who have an understanding of the antenna's radiation environment and the measures best suited to maximize protection of the general public and persons operating the vehicle and equipment, and will include any warning or labeling required by the Commission's rules.[28]

Amazon will also ensure compliance with the operational and coordination conditions specific to the land, aviation, and maritime use cases.[29] With respect to aviation, prior to operating its ESAAs on U.S.-registered aircraft within a foreign nation's airspace, Amazon will ascertain whether the relevant administration has operations that could be affected by ESAA terminals and determine whether that administration has adopted specific requirements concerning ESAA operations. When the ESAA-equipped aircraft enters foreign airspace, the ESAA terminal will operate under the Commission's rules, or those of the foreign administration, whichever is more constraining.[30] Where relevant administrations have identified geographic areas from which ESAA operations would not affect their radio operations, Amazon will operate within those identified areas without further action. Where a foreign administration has not adopted requirements regarding ESAA operations, Amazon will coordinate its operations with any potentially affected operations. Moreover, prior to providing ESIM-based services in any other

country of registry and a point of contact for the relevant administration responsible for licensing those ESVs. *Id.* § 25.228(e)(3).

[27] *See id.* § 25.228(c).

[28] *See id.* § 25.228(d).

[29] *See id.* §§ 25.228(e), (f) & (g).

[30] *See id.* § 25.228(g)(3).

country, Amazon certifies it will comply with the applicable laws, regulations, rules, and licensing procedures of that particular country.[31]

Finally, for all ESIMs, Amazon will maintain a point of contact in the United States, with phone number and address, available 24 hours a day, seven days a week, with authority and ability to cease all emissions.[32] In the unlikely event that Amazon's proposed ESIMs cause harmful interference, Amazon can be reached via its Kuiper network operations center via phone at (703) 691-5360 or email at kuipersat-ops@amazon.com, which will allow affected parties to reach technical personnel with authority and ability to cease all transmissions from Amazon's ESIMs on a 24/7 basis.

V. GRANT OF THIS APPLICATION WOULD SERVE THE PUBLIC INTEREST

In recent orders, including the *2020 ESIMs Second R&O & FNPRM*, the Commission has recognized the "growing demand for broadband communications to vessels, land vehicles, and aircraft."[33] The Commission further explained that "ESIMs enable the provision of very high data rate broadband communications, navigation, situational awareness, and other services to mobile platforms that often cannot be served using other communications technologies."[34] Indeed, another recent grant of ESIM authority recognized that authorizing new classes of ESIM terminals

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[31] *See Kuiper ITU Modification Order* ¶ 23.

[32] *See* 47 C.F.R. §§ 25.228(e)(2), (f), & (g). To the extent that Amazon uses the NCMC to communicate with ESVs on vessels of foreign registry, it will maintain detailed information on each such vessel's country of registry and a point of contact for the relevant administration responsible for licensing those ESVs. *Id.* § 25.228(e)(3).

[33] *Amendment of Parts 2 and 25 of the Commission's Rules to Facilitate the Use of Earth Stations in Motion Communicating with Geostationary Orbit Space Stations in Frequency Bands Allocated to the Fixed Satellite Service; Facilitating the Communications of Earth Stations in Motion with Non-Geostationary Orbit Space Stations*, Second Report and Order in IB Docket No. 17-95, Report and Order in IB Docket No. 18-315, and Further Notice of Proposed Rulemaking, 35 FCC Rcd 5137 ¶ 2 (2020) ("*2020 ESIMs Second R&O & FNPRM*").

[34] *Id.*

would further the public interest by "expand[ing] the range of broadband capabilities to meet the growing user demands that now require connectivity while on the move, whether driving an RV across the country, moving a freighter from Europe to a U.S. port, or while on a domestic or international flight."[35]

Grant of Amazon's ESIM terminals will further these important public interest objectives, bringing Amazon's uniquely innovative and customer-centric approach to mobility use cases that can enable smarter transportation by connecting vehicles, supporting the global supply chain by providing end-to-end connectivity to merchant shipping on oceans around the globe, and making connected airline travel more enjoyable.[36]

When the Commission originally authorized the Kuiper System, it "conclude[d] that grant of Kuiper's application would advance the public interest" because the Kuiper System was "designed to increase the availability of high-speed broadband service to consumers, government, and businesses."[37] The same public interest considerations that supported grant of the original space station application support granting this ESIM application. Amazon therefore respectfully requests expeditious grant of this application, which will allow Amazon's Kuiper System to extend its high-speed communication services to customers that require broadband communication while in motion on land, air and sea.

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[35] *See SpaceX Services, Inc. Application for Blanket Authorization of Next-Generation Ku-Band Earth Stations in Motion et al.; Kepler Communications Inc. Application for Blanket Authorization of Ku-Band Earth Stations on Vessels*, Order and Authorization, 37 FCC Rcd 7640 ¶ 13 (2022).

[36] *See, e.g.*, *Topics: Mobility*, GSOA, https://gsoasatellite.com/topics/mobility/ (last accessed Feb. 1, 2024) (discussing the numerous and important use cases enabled by ESIMs).

[37] *Kuiper System Authorization* ¶ 3.

Respectfully submitted,

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EMF Exposure Assessment for Kuiper Earth Stations in Motion

I. Introduction

This analysis calculates the non-ionizing radiation levels for Amazon's proposed Earth Stations in Motion ("ESIMs"). The calculations performed in this analysis comply with the methods described in FCC Office of Engineering and Technology Bulletin, Number 65 (Edition 97-01) ("Bulletin 65"). This analysis demonstrates that the Amazon ESIMs will not result in exposure levels exceeding the applicable maximum permissible exposure ("MPE") limits.

II. Description of Amazon ESIMs

Amazon's ESIMs share the same antenna and RF subsystems as its Fixed Terminals, with the exception of the enclosure, mechanical mounting and motion compensation system needed for operation on land, sea and air platforms, thus the power densities and exposure assessments provided in the license application for the fixed CT are applicable here. Table 1 provides technical specifications for each ESIM type.

Table 1: EIRP and Physical Radiating Area of ESIMs

	ESIM Type I Ultra-Compact	ESIM Type II Standard	ESIM Type III High-Throughput
Antenna Gain dBi (Tx)	31	34	38
Boresight EIRP (dBW)	35	40.5	45.8
Physical Radiating Area (cm^2)	180	269	660
Maximum Transmit Duty Cycle (%)	30%	40%	50%

Each of these three models of ESIM is a flat-panel, phased array antenna. The ESIMs operate while stationary or in motion and establish communication links with the satellites and connect to the Internet via automated processes that align beams/pointing, obtain frequencies/channels and exchange security keys to establish a secure IP connection.

Each of the ESIMs and the Kuiper System as a whole have certain intrinsic operational characteristics that limit the potential for human exposure. *First*, an ESIM will not transmit until it successfully receives and decodes a message on the downlink that grants it permission to transmit. As discussed more fully below and validated by testing described in Appendix A, the presence of a human body will cause sufficient path attenuation to prevent the ESIM from successfully decoding the message that grants it permission to transmit, and any direct exposure to the person will be ceased within a millisecond of beam blockage.

Second, beams from the ESIMs are very narrow and in constant motion as they track NGSO satellites, operating at elevation angles between 35° and 90°. These narrow beams cause very little exposure outside the main-beam. The off-axis power density reduces by at least a factor of 100

(20 dB) immediately adjacent to the main-beam, and reduces by a factor of 10,000 (40 dB) at the rear of the antenna.

Third, effective operation of the ESIMs requires them to have unobstructed line-of-sight to the Kuiper System satellites, and Amazon will ensure installation of ESIM terminals on vehicles and vessels by qualified installers who have an understanding of the antenna's radiation environment and the measures best suited to maximize protection of the general public and persons operating the vehicle and equipment.

These factors ensure that persons will not experience continuous exposure from the ESIMs.

III. Explanation of the Analysis

At the Amazon ESIM operating frequency, the exposure assesment is based upon calculation of incident power density, S_{exp}, at the exposure location, and the amount of time that the body is illuminated.[38] OET's guidance expresses this time-averaging equation as follows:

$$\Sigma \; S_{exp} T_{exp} = S_{limit} T_{avg}$$

where: S_{exp} = power density level of expsosure (mW/cm^2)

S_{limit} = appropriate power density MPE limit (mW/cm^2)

T_{exp} = allowable time of exposure for S_{exp}

T_{avg} = approprate MPE averaging time.

Consistent with Bulletin 65, Amazon calculated power densities at the antenna surface, in the near-field, and in the far-field. Amazon then calculated the time-averaged exposure in the near-field and far-field by considering beam steering behavior of the antennas and the expected power density levels in the direction of a nearby person.

Bulletin 65 and Section 1.1310 of the Commission's rules specify two exposure limits: one for occupational workers in controlled areas and one for uncontrolled areas which the general population can access. While all ESIMs will be mounted and located in such a way to prevent access by the general population, we assume that the general public could gain access. Accordingly, this analysis considers the Maximum Permissible Exposure ("MPE") limit for General Population/Uncontrolled exposures for all three ESIM types, which for the Ka-band frequencies used by these ESIMs is a power density equal to 1 milliwatt per centimeter squared averaged over a thirty-minute period.

IV. Results of Analysis

The maximum power density levels at the antenna surface, in the near-field, and in the far-field are presented in Appendix A. As noted above, these power density levels are not representative of the time-averaged exposure that a person would experience, as they do not

[38] According to OET 65 bulletin equation 2: "The sum of the products of the exposure levels and the allowed times for exposure must equal the product of the appropriate MPE limit and the appropriate time-averaging interval."

account for the duration of exposure and other operational attributes of the antennas, such as their directional gain, dynamic beam steering, and auto-off functionality.

To ensure proper functioning of the ESIMs, they will be installed by trained technicians. Under these conditions, the general population could only be exposed to off-axis RF energy in the far-field, and main-beam illumination will not be possible. As demonstrated in Table 2, the off-axis far-field power density of each ESIM type is well below the general population MPE limit.

Table 3: Off-axis Power Density Levels

	Units	Type I	Type II	Type III
S_{ff} (off-axis)[39]	**mW/cm²**	0.003	0.004	0.0004
FCC MPE	**mW/cm²**	1.0	1.0	1.0
Meets MPE Limit		Yes	Yes	Yes

Amazon also calculated the time-averaged exposure to a person in close proximity and the same height of an ESIM, such that the ESIM transmit beam may directly illuminate the person. These time-averaged exposure levels include main-beam and off-axis exposure time intervals, and consider the above-described properties of the Amazon ESIMs that will intrinsically limit human exposure. The combined effect of (1) each ESIM's auto-off functionality when the main-beam is blocked by a nearby person, and (2) dynamic beam-steering that prevents continuous illumination by the main-beam, ensures that a person cannot be illuminated continuously by the ESIM main-beam.

Given that the ESIM beams will be in motion tracking Kuiper System satellites, the potential for human exposure will depend on an ESIM's position on earth relative to the satellites in the Kuiper System, and the position of a nearby person relative to the ESIM. While ESIMs in some locations will average higher elevation angles, ESIMs at certain latitudes may operate at lower elevation angles on average. To determine the worst-case beam steering scenario, Amazon simulated the beam steering for antennas at variety of latitudes and person positions relative to the antenna. Amazon performed these simulations over hundreds of 30-minute time windows to identify the worst-case exposure scenario, that in which a person could be directly illuminated the most times. For this worst-case scenario, Amazon modelled the power density in the direction of the person in one-second increments, then averaged this exposure level over the 30-minute time window.

This analysis is detailed in Appendix B and the results are summarized in Table 3. For the ESIM Type I and Type II antennas, the maximum computed time-averaged RF exposure meets the MPE limit for a person at the near-field boundary. For the Type III ESIM, a person at the near-field boundary and same height as the ESIM would never be directly illuminated by on-axis RF energy, as the ESIM's 35° minimum elevation angle ensures that the boresight of the transmitting

[39] Off-axis far-field power density calculated using 0 dBi off-axis gain and at the far-field boundary distance (R_{ff}) calculated in Appendix A.

beam would be above the person's head.[40] Therefore, for the Type III ESIM, a closer distance was analysed to demonstrate compliance with the time-average MPE limit.

Table 3: 30-minute Average RF Exposure at Close Proximity and Same Level to Operational ESIM

	ESIM Type	TYPE I	TYPE II	TYPE III
Exposure Region		Near-Field	Near-Field	Near-Field
Near-Field Boundary Distance (R_{nf})	**Meters**	0.60	0.83	3.24
Analysis Distance from Antenna	**Meters**	0.60	0.83	1.25
Time-Average Exposure	**mW/cm^2**	0.59	0.87	0.70
FCC MPE	**mW/cm^2**	1.0	1.0	1.0
Meets MPE Limit		Yes	Yes	Yes

V. Additional Safety Measures

Amazon will ensure installation of ESIM terminals on vehicles by qualified installers who have an understanding of the antenna's radiation environment and the measures best suited to maximize protection of the general public and persons operating the vehicle and equipment. To the extent that radiation exposure from Amazon's proposed ESIM terminals would exceed 1.0 mW/cm^2 in accessible areas, Amazon will ensure appropriate labelling consistent with the Commission's rules.[41]

VI. Conclusion

This analysis demonstrates that the Amazon ESIMs each satisfy Commission requirements to not exceed the MPE limit of 1 mW/cm^2 averaged over a thirty-minute period. Specifically, Amazon ESIMs will typically be mounted in locations not accessible to the general population, preventing main-beam human exposure. In the event that a human body is illuminated by the ESIM's main-beam, the intrinsic shut-off feature, which ceases transmission in the presence of a body blockage, and beam steering prevents continuous exposure. This EMF exposure assessment demonstrates that Amazon ESIMs will not exceed the general population maximum permissible exposure limits.

[40] For an ESIM transmitting at the minimum elevation angle of 35 degrees, a 1.8m-tall person would not be directly illuminated by on-axis RF energy at distances greater than 2.6m, as the Z-axis of the beam would be above the person's head.

[41] 47 C.F.R. § 25.228(d).

Appendix A. Detailed Power Density Calculations

Table A.1: Power Density from Type I ESIM Antenna

Calculated Variables	Formula	Unit	Value
Wavelength	$\lambda = \frac{c}{f}$	meters	0.01
Diameter of Antenna (Maximum Dimension)		cm	15.8
Area of Antenna		cm^2	180.0
Average Power into Antenna (includes transmit duty cycle of 30%)		W	0.75
Antenna Gain	$G_{dBi} = 10 * log_{10}(G)$	dBi	31.0
Near-Field Distance	$R_{nf} = \frac{D^2}{4\lambda}$	meters	0.60
Far-Field Distance	$R_{ff} = \frac{0.6D^2}{\lambda}$	meters	1.45
Power Density at Antenna Surface	$S_{surface} = \frac{4P}{A}$	mW/cm^2	16.7
Near-Field Power Density (Maximum, On-axis)	$S_{nf} = \frac{4P}{\eta A}$	mW/cm^2	21.2
Far-Field Max Power Density (On-axis)	$S_{ff} = \frac{PG}{4\pi R^2}$	mW/cm^2	3.6

Table A.2: Power Density from Type II ESIM Antenna

Calculated Variables	Formula	Unit	Value
Wavelength	$\lambda = \frac{c}{f}$	meters	0.01
Diameter of Antenna (Maximum Dimension)		cm	18.5
Area of Antenna		cm^2	268.8
Average Power into Antenna (includes transmit duty cycle of 40%)		W	1.8
Antenna Gain	$G_{dBi} = 10 * log_{10}(G)$	dBi	34.0
Near-Field Distance	$R_{nf} = \frac{D^2}{4\lambda}$	meters	0.83
Far-Field Distance	$R_{ff} = \frac{0.6D^2}{\lambda}$	meters	1.99
Power Density at Antenna Surface	$S_{surface} = \frac{4P}{A}$	mW/cm^2	26.8
Near-Field Power Density (Maximum, On-axis)	$S_{nf} = \frac{4P}{\eta A}$	mW/cm^2	34.1
Far-Field Max Power Density (On-axis)	$S_{ff} = \frac{PG}{4\pi R^2}$	mW/cm^2	9.1

Table A.3: Power Density from Type III ESIM Antenna

Calculated Variables	Formula	Unit	Value
Wavelength	$\lambda = \frac{c}{f}$	meters	0.01
Diameter of Antenna (Maximum Dimension)		cm	36.6
Area of Antenna		cm^2	660
Average Power into Antenna (includes transmit duty cycle of 50%)		W	3.0
Antenna Gain	$G_{dBi} = 10 * log_{10}(G)$	dBi	37.5
Near-Field Distance	$R_{nf} = \frac{D^2}{4\lambda}$	meters	3.24
Far-Field Distance	$R_{ff} = \frac{0.6D^2}{\lambda}$	meters	7.77
Power Density at Antenna Surface	$S_{surface} = \frac{4P}{A}$	mW/cm^2	18.2
Near-Field Power Density (Maximum, On-axis)	$S_{nf} = \frac{4P}{\eta A}$	mW/cm^2	30.8
Far-Field Max Power Density (On-axis)	$S_{ff} = \frac{PG}{4\pi R^2}$	mW/cm^2	2.2

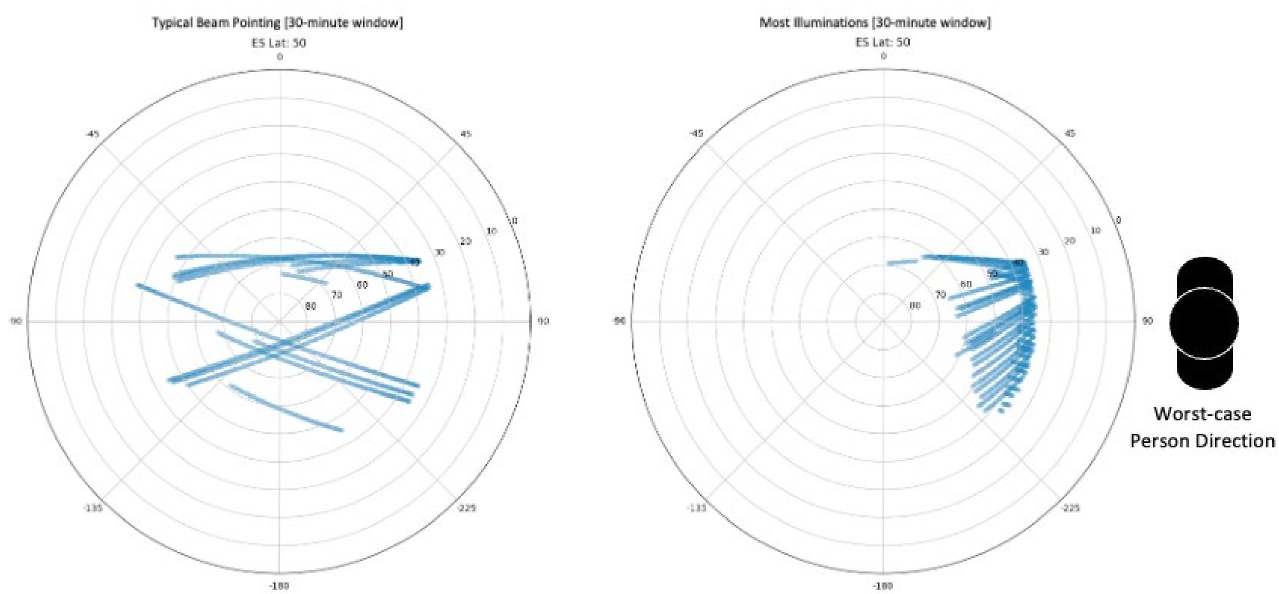
Appendix B. Time-Averaged Exposure Analysis

Amazon also calculated the time-averaged exposure to a person in close proximity of an ESIM, such that the ESIM may directly illuminate the person.

Given that the ESIM beams will be in motion tracking Kuiper System satellites, the potential for human exposure will depend on an ESIM's position on earth relative to the satellites in the Kuiper System, and the position of a nearby person relative to the ESIM. While ESIMs in some locations will average higher elevation angles, ESIMs at certain latitudes may operate at lower elevation angles on average. To determine the worst-case beam steering scenario, Amazon simulated the beam steering for antennas as they will track the real Kuiper Satellite constellation orbits, at a variety of latitudes and person positions relative to the antenna. Amazon performed these simulations over hundreds of 30-minute time windows to identify the worst-case exposure scenario, that in which a person would be directly illuminated the most times. Figure B.1 shows an ESIM's beam pointing throughout a 30-minute window on azimuth/elevation polar plots. The left figure shows a typical 30-minute window, whereas the right figure shows the pointing over a worst-case 30-minute window in which a person in close proximity to the ESIM could be directly illuminated by the ESIM's main-beam repeatedly.

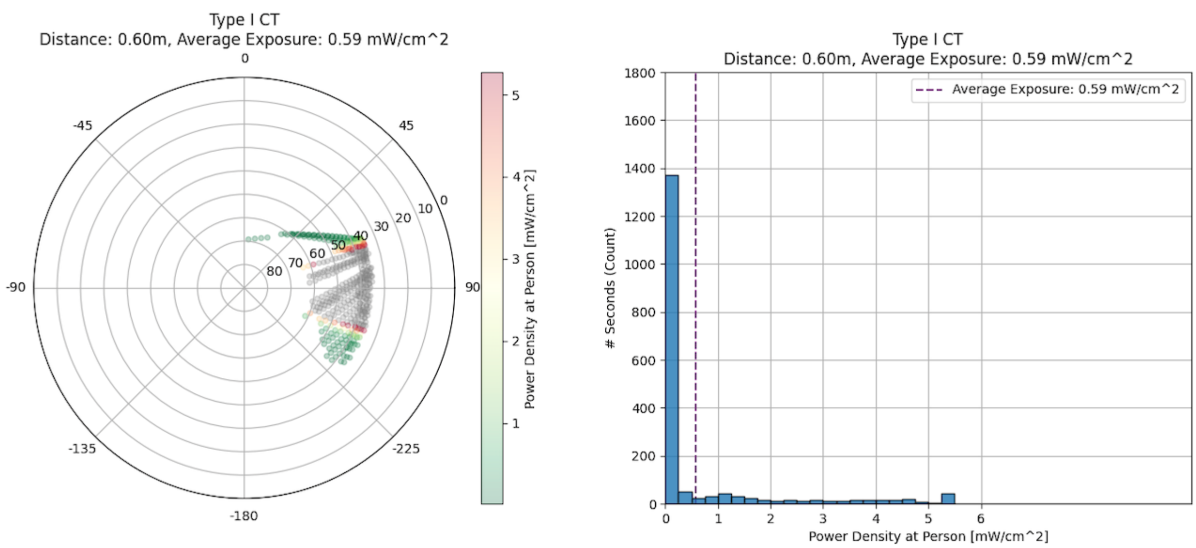
Figure B.1. ESIM Beam Pointing Examples

Polar plots represent antenna beam pointing in Azimuth and Elevation.



For the worst-case geometric scenario and time window represented above, Amazon modelled the precise beam steering behavior of the antenna and potential exposure to a nearby person in one-second increments. For each time step, Amazon calculated the power density along the main-beam axis and the power density in the direction of the person, applying off-axis power density reductions and spatial averaging as appropriate.[42] For periods when the beam is sufficiently blocked to cause the antenna to automatically cease transmissions,[43] the power density is set to 0 mW/cm^2. Amazon then averaged the exposure levels over the 30-minute time window. Below, the results are shown for the three ESIM antenna types at distances in the near-field for each. The figures below show (1) the received power density by beam pointing direction, using the same worst-case beam pointing scenario represented in Figure B.1 above, and (2) histograms of the power density in the direction of the person, along with the time-averaged exposure as a vertical line. These figures demonstrate that even in the conservative case, a nearby person would be exposed to low power density levels through most of the averaging time-window.

Figure B.2. Time Averaged RF Exposure for Type I Antenna at 0.6m Distance (Left: RF Exposure by Beam Pointing Direction; Right: Histogram of RF Exposure over 30-minute window)



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[42] For the near-field off-axis power density model, Amazon relied on previous work documented in Richard L. Lewis & Allen C. Newell, *An Efficient and Accurate Method for Calculating and Representing Power Density in the Near-Zone of Microwave Antennas*, NBSIR 85-3036 (1985).

[43] See Appendix C for demonstration that antenna blockage will cause antenna to cease transmission.

Figure B.3. Time Averaged RF Exposure for Type II Antenna at 0.83m Distance (Left: RF Exposure by Beam Pointing Direction; Right: Histogram of RF Exposure over 30-minute window)

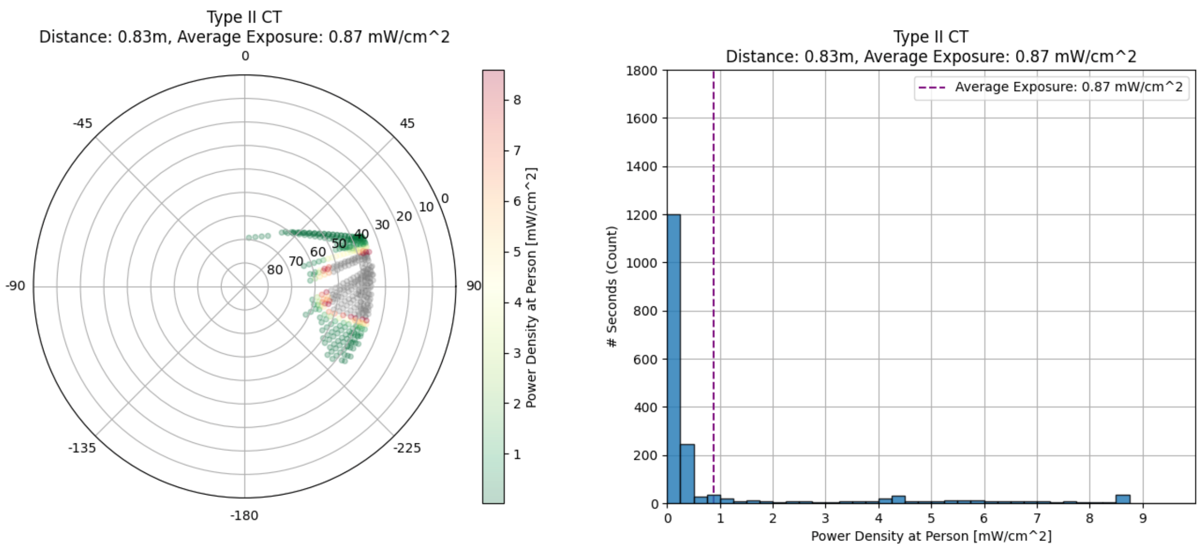
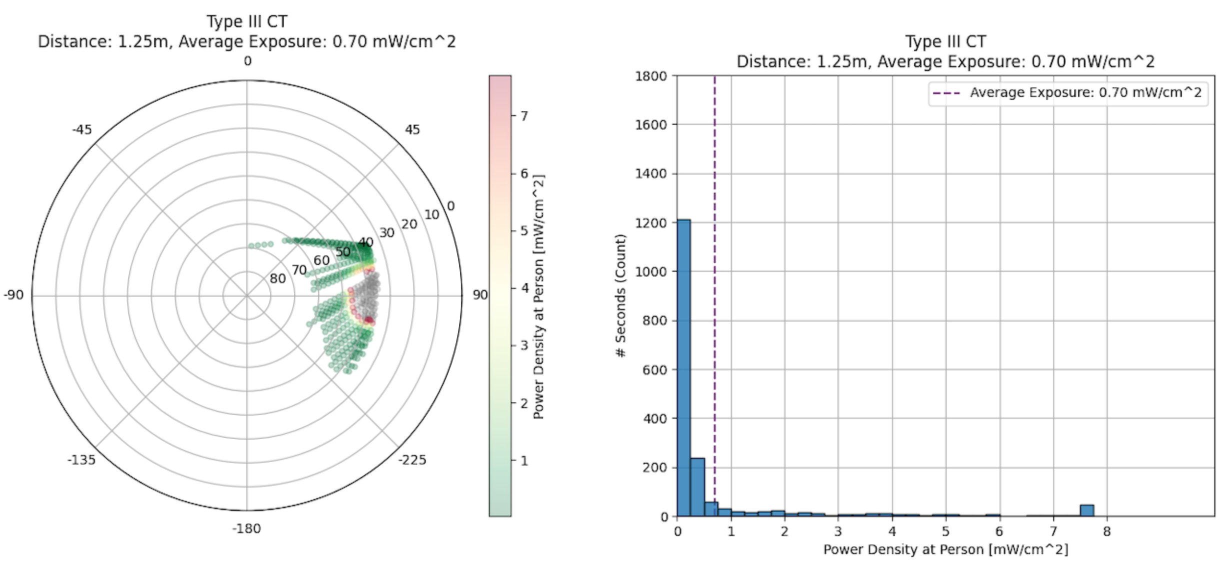


Figure B.4. Time Averaged RF Exposure for Type III Antenna at 1.25m Distance (Left: RF Exposure by Beam Pointing Direction; Right: Histogram of RF Exposure over 30-minute window)



In the above time-average exposure analysis, Amazon applied spatial averaging for near-field exposure. In an X-Y plane that represents a cross section of the beam normal to direction of propagation, Z, the power density contains peaks (e.g., 4P/Ae in OET 65 Eq 12) and nulls that occur with off-axis angle and oscillate with axial distance from the antenna which are caused by Fresnel zone diffraction.[44] The Amazon analysis uses the total transmitter power P, and the effective area, Ae, of the beam for its spatial average to calculate the total power density contained within the beam and which may radiate the body over a time window. This is consistent with

[44] Edward V. Jull, *Aperture Antennas and Diffraction Theory*, 46-47 (1981); *see also id.* chs. 4-5.

current Commission's rules and our application based upon the beam causing "whole body" exposure. The Commission addressed spatial-peak localized power density averaging noting that $4mW/cm^2$ (4X) may be applicable in the future.[45] We note that a factor of "4" would be consistent with current OET65 maximum, on-axis power density formula Eq 12 - 4P/Ae which peaks with a factor of "4." The Amazon calculation computes an upper bound of the power density over the beam cross sectional area, P/Ae, by assuming that all the transmitter power is real-valued, and is completely contained within the effective area of the beam – this approach results in the highest possible exposure to a "whole body."

[45] *Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields; Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies*, Resolution of Notice of Inquiry, Second Report and Order, Notice of Proposed Rulemaking, and Memorandum Opinion and Order, 34 FCC Rcd 11687 ¶ 127 (2019).

Appendix C. Body Loss Measurements

Background

An important feature of the Amazon Fixed CT and Mobile CT (ESIM) designs are that when the receive signal is lost due to signal blockage, the transmitter is shut down until the downlink is restored. The transmitter is shut down in less than 1 millisecond of the loss of the downlink. This auto-off feature prevents continuous human exposure by the CT main-beam at the antenna surface, in the near-field and in the far-field.

To prove the efficacy of the auto-off functionality to preventing continuous human exposure, Amazon measured the attenuation caused by human blocking the CT antenna beam. This appendix details the results of these measurements, and the results apply to the Mobile CT, which shares the same RF subsystems and operates identically with the satellite.

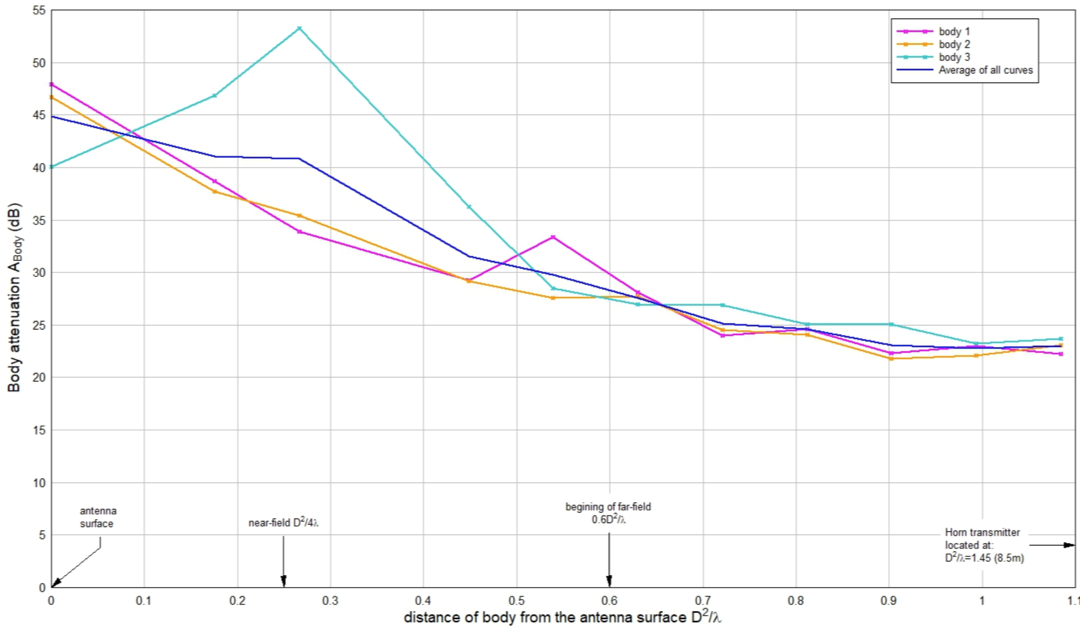
Test Setup

In an anechoic screened room, two paths were created: a physical path for a person to stand and radio beam path between a CT (receive antenna) and a horn antenna (transmitting antenna). The physical and radio beam paths were precisely aligned with laser range finder and by pointing CT and transmitting horn beams for maximum power. The beam was 1.5m above and parallel to the floor and illuminated the torso at chest height. At the transmitting end, a conical horn was used to radiate a constant power LHCP modulated signal at 18.5 GHz and at the receiving end a Type II CT was mounted at 60° to the floor with its beam electronically pointed precisely at the transmitting horn. This was done to ensure that the beam area and propagation path matched the actual condition that would be used in operations.

On-Axis Measurements

Without a body present, the signal power from the CT is recorded as P_1. A human body is then introduced into the center of the beam path at on-axis distances, every 0.5m. For each location, ten power measurements were made and logged by the spectrum analyser and the average calculated as P_2. The body loss at each distance, $A_{body} = P_1 - P_2$, was calculated and plotted in Figure C.1.

Figure C.1: Attenuation Caused by Body Blockage (On-Axis)



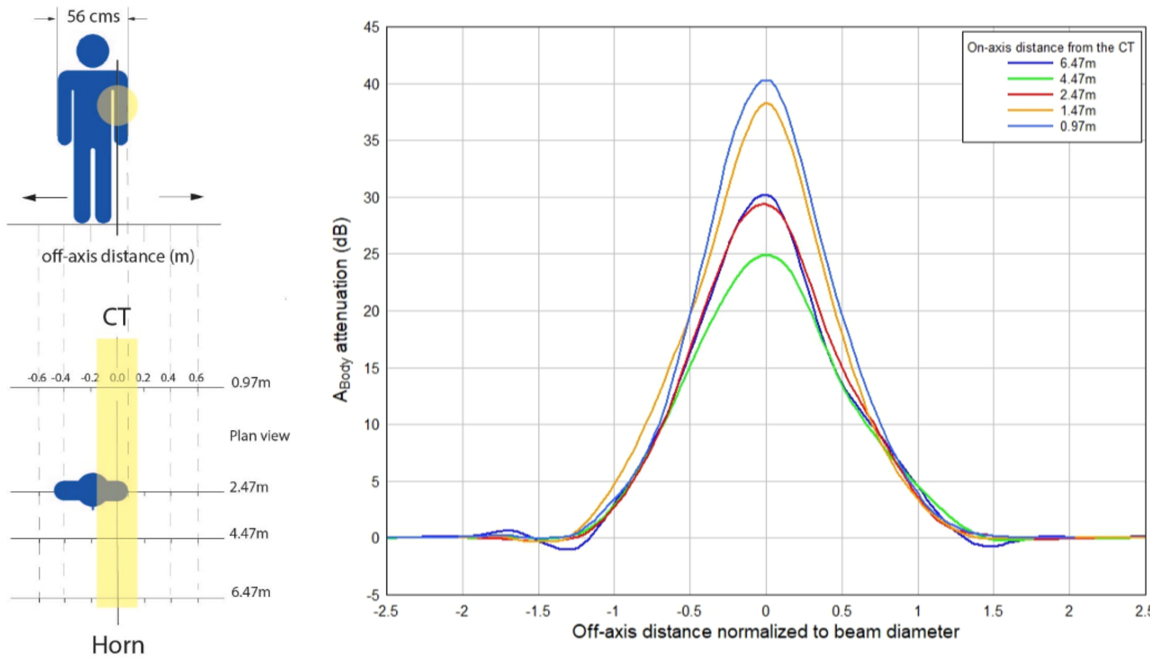
At all distances up to 2.4m[46] from the CT the body loss is ~ 30dB or greater, exceeding the attenuation threshold which causes the CT to cease transmitting.

Off-Axis Measurements

Measurements were taken with a body at various distances outside of the on-axis path. The results of these measurements are shown in Figure C.2 below. The off-axis measurements showed that when body #1 was moved out of the beam path by 60 cm the attenuation dropped, indicating that the beam is less affected by the body outside of a narrow path.

[46] 2.4m or greater is the distance at which the beam passes over a person's head.

Figure C.2: Attenuation Caused by Body Blockage (Off-Axis)



Measurement Conclusions

These measurements demonstrate that the attenuation caused by a body in the path of a Kuiper System downlink beam will be significant and will exceed the CT receive threshold which causes the CT to stop transmitting. The attenuation levels exceeded the CT receive threshold when the body is at the antenna surface, in the near-field, and in the far-field out to distances in which a human body may be directly illuminated by a CT at the same height as a person.