Technical Narrative
Theia Satellite Network

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1.0 Scope and Purpose

This Technical Narrative describes the design and operational characteristics of the proposed non-geostationary satellite orbit ("NGSO") remote sensing system of Theia Holdings A, Inc. ("Theia") – the Theia Satellite Network ("TSN"). It provides information required by the rules of the Federal Communications Commission ("Commission"), 47 C.F.R. Part 25, that is not otherwise included in other portions of this Application.

The TSN system level design parameters included herein, as well as in Form 312 and Schedule S thereto that pertain to spectrum use, e.g., the effective isotropic radiated power ("EIRP"), antenna gain-to-noise temperature ratio ("G/T"), antenna contours, power flux density ("PFD") and equivalent power flux density ("EPFD"), are the committed performance levels for TSN. These are the values to which the system will be designed, built, tested and operated over its service lifetime. While specific satellite manufacturer(s) and launch provider(s) have not yet been selected by Theia, the overall satellite design and operational characteristics described herein are directly representative of those that will be implemented. Any potential adjustments to these parameters will enhance compatibility of the Theia system with other spectrum users and the Commission's rule and policies, and will be approved by the Commission as appropriate.

2.0 System Description

TSN is an integrated Earth observation and communications network designed to provide unique remote sensing and communications products and services to a variety of users in the United States and worldwide. TSN will employ a constellation of 112 operational satellites in low-Earth orbit ("LEO") that incorporate remote sensing, signal processing and communications payloads. TSN is designed to collect, process and deliver remote sensing information products directly to end users on demand, and to provide broadband communications necessary to the delivery of these products and services, including directly into machines via machine-to-machine

("M2M") communications interfaces. Monitor and control functionality for both the satellites and the ground terminals will ensure that TSN operations comply with all applicable domestic and international regulatory requirements.

2.1 TSN Services

TSN's products and services are revolutionary and have the potential to transform a wide range of commercial industries and governmental operations. Global in scope and operating on a 24/7 basis, TSN will provide end users with on-demand, real-time, processed geophysical information -- not simply raw remote sensing data. TSN satellites include sensors which capture:

- continuous visible (day) and medium wavelength infra-red (night) still and video imagery;
- hyperspectral imagery;
- L-band active radar imagery; and
- microwave radiometer measurements.

The remote sensing services provided by TSN involve full coverage of the Earth. The sensors and processed products from the TSN satellites provide services to end users with resolution on the order of 1 meter.   Products can be provided for single events or distributed over time (e.g., for monitoring changes).

Because each TSN satellite includes extensive onboard processing power, calibration, correction, processing and analysis may take place directly on the satellites, reducing large data sets to more valuable information products, facilitating spectrum efficiency for data transmission to ground stations and end users and vastly increasing the "value per bit" communicated to end users. TSN products and services will be of significant economic and social value to individual, commercial and government users in industries including, but not limited to, basic Earth and atmospheric sciences, agriculture, natural resources exploration, development and management, insurance, infrastructure protection, and support of economic and physical security.

The primary communications functions within the TSN will be served by a combination of radio frequency ("RF") user and gateway links, as well as high-bandwidth (10 Gbps) free space optical ("FSO") inter-satellite links ("ISLs").[1] TSN will operate user links in Ku-band frequencies and gateway links in Ka-band frequencies.[2]

2.2 §25.114(c)(7) Frequency Bands, Types of Service, and Coverage Areas and § 25.114(c)(4)(i) Center Frequencies, Bandwidths, and Polarization Plan

Theia seeks access to the following frequency bands for TSN operations:

Gateway Links	Frequency Band
EESS (s-to-E)	25500.0 MHz - 27000.0 MHz
FSS (E-to-s)	29500.0 MHz - 30000.0 MHz
FSS (E-to-s)	29100.0 MHz - 29500.0 MHz
FSS (E-to-s)	27500.0 MHz - 29100.0 MHz
FSS (s-to-E)	19700.0 MHz - 20200.0 MHz
FSS (s-to-E)	19300.0 MHz - 19700.0 MHz
FSS (s-to-E)	18800.0 MHz - 19300.0 MHz
FSS (s-to-E)	18300.0 MHz - 18600.0 MHz
FSS (s-to-E)	17800.0 MHz - 18300.0 MHz

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[1] TSN hopes to employ FSO gateway links that potentially may reduce the duty cycle of its use of Ka spectrum for RF gateway operations, subject to the resolution of technical and regulatory questions regarding the use of such FSO gateway links.

[2] Ka-band gateway links provide access for high bandwidth communications between TSN satellites and the terrestrial network and as a supplement to the FSO gateway links, particularly in areas where FSO gateway operations may be impractical (e.g., due to climatological conditions), where the Ka-band gateway links may in fact be the primary gateway link.

User Links	Frequency Band
FSS (E-to-s)	14000.0 MHz - 14500.0 MHz
FSS (E-to-s)	12750.0 MHz - 13250.0 MHz
FSS (s-to-E)	12200.0 MHz - 12700.0 MHz
FSS (s-to-E)	11700.0 MHz - 12200.0 MHz
FSS (s-to-E)	10700.0 MHz - 11700.0 MHz

Active Radar	Frequency Band
EESS (s-to-E)	1215.0 MHz - 1300.0 MHz

The types of service to be provided by the TSN are described above in Section 2.1.

TSN will provide global coverage, including of the contiguous 48 U.S. states, Alaska and Hawaii, and all U.S. Territories. Subject to the licensing requirements and restrictions of national administrations, all locations on the surface of the Earth can be observed and served by TSN.

Specific channel center frequencies, bandwidths and polarizations for all beams (including telemetry, tracking and command beams) are detailed in Schedule S attached to this Application. Furthermore, TSN's operations in each of the foregoing band segments is discussed more fully in Section 3.1.2 Communications Payload, below.

2.3 § 25.114(d)(1) Overall Description of System Facilities, Operations and Services and Explanation of How Uplink Frequency Bands Would Be Connected to Downlink Frequency Bands

The overall description of system facilities, operations and services is described throughout this section 2.0 System Description.

With regard to how TSN uplink frequency bands would be connected to downlink frequency bands, there is no specific relationship between these bands in the satellite payload. The TSN satellite payloads are regenerative, that is, all receive signals are down-converted, demodulated, decoded and processed to baseband (digital) data. This received baseband data contains a destination address. The destination address is used to route the data within the satellite to an appropriate destination, possibly for consumption by the satellite itself (e.g., a message addressed to that specific satellite), or to an off-board communications port (e.g., an adjacent satellite FSO ISL). As such, there is no explicit, fixed relationship between satellite input ports and satellite output ports as there are with transponder satellites. Consequently, signals received on any RF or optical port can be translated through this demodulation-baseband-routing-remodulation process and be retransmitted on any other RF or optical port employed by the satellite.

As to specific RF communications for uplink or downlink, for user links or for gateway links, TSN operations are governed by the geographic location of service and the regulations applicable to that location. For example, communications between a TSN satellite and a user terminal ("user terminal" or "UT") in the United Kingdom would be governed by UK spectrum access and remote sensing regulations and operational constraints (available frequency bands, power levels, etc.). TSN's operational flexibility enables it to comply with regulations that may vary on a country-by-country basis.

2.4 TSN Constellation

TSN employs a fully integrated constellation of custom satellites optimized to meet mission and safety requirements. The TSN constellation is configured as eight planes of 14 satellites each. All planes operate at a nominal altitude of 800 km, in sun-synchronous orbits, having an orbital period of approximately 6053 seconds and an inclination of approximately 98.6°. The orbital planes are distributed over 180° of right ascension, with 24.5° inter-plane spacing. Complete constellation parameters are provided in Schedule S.

The TSN constellation is capable of global, continuous coverage of the Earth for remote sensing data capture. The satellites in the TSN constellation are interconnected with FSO ISLs that enable dynamic routing and cross-constellation communications with TSN gateways. Multiple FSO and Ka-band gateways connect the TSN constellation to the terrestrial network, enabling global broadband communications capabilities, terrestrial distribution of volume-intensive remote sensing products and delivery of ground-processed remote sensing products directly to end users. Ku-band user terminals connect directly to the TSN constellation to access communications and remote sensing products and services, limited only by the requirement to avoid interference into GSO systems or other co-frequency operations.

Figure 1 below shows the global coverage of the constellation. Each satellite and its associated coverage area (yellow circle) is shown in Figure 1. All points on the surface of the Earth are in the service area of a satellite's sensors at all times. The satellites' orbits are nearly polar, that is, nearly vertical in Figure 1. The distortion in the coverage areas (yellow circles) near the top and bottom of the figure is an artifact of map distortion similar to that of all like maps that project spheres (the Earth) on to flat surfaces, e.g., the Mercator projection. With the near-polar orbit of the satellites, even the poles are provided with continuous services.

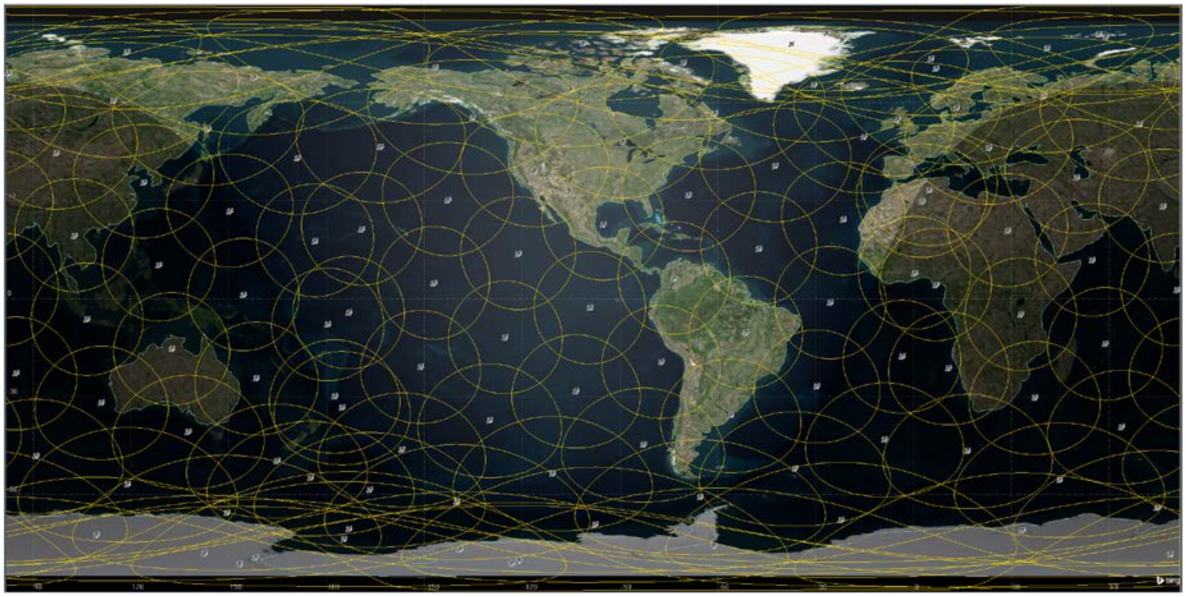

Figure 1 – TSN Constellation Global Coverage

TSN satellites are equipped with 10 Gbps FSO ISLs that connect adjacent satellites within the same plane, as well as adjacent satellites in the neighboring planes (with limited exceptions at the constellation "seam" as described below). This highly interconnected mesh of links provides ample pathways for flexibly routing high-volume TSN traffic[3]. This, in turn, permits TSN to operate with far fewer gateways than would otherwise be required.

Figures 2 and 3 show polar and equatorial views of the TSN constellation, depicting the planes as they are arranged around the Earth. The distribution of orbital planes in the constellation results in most satellites traveling in the same direction as their neighbors in adjacent planes. This makes the relative velocities between satellites and their adjacent plane neighbors relatively small, which is conducive to operating FSO ISLs across the inter-plane

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[3] The satellites in the constellation are "highly interconnected" because the majority of satellites have four high bandwidth (10 Gbps) FSO connections to adjacent satellites in orbit; left, right, forward, and aft. All satellites have at least three such connections. This connection geometry is described as a "mesh" network. Since there are so many paths for communications afforded to any satellite, the options available for routing traffic in the event of excess traffic or link failure are still substantial.

gap[4]. However, for two planes in the constellation geometry (the first and the last, planes 1 and 8), the satellites in one of the adjacent planes are not traveling in the same direction but rather in opposite (counter-rotating) directions, resulting in high relative velocities that make ISL communications challenging across the inter-plane gap. This inter-plane gap is called the "seam".[5]

Importantly, because a seam only occurs on one side of the two affected planes, FSO links can communicate readily with co-rotating satellites in the other adjacent plane to route traffic across the network as necessary.

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4 Smaller relative velocities permit the FSO terminals on the different satellites to mutually acquire one another's signals, lock on, and track their relative motions as they perform their normal communications operations.

5 This "seam" exists only between the first and last planes (1 and 8) on opposite sides of the Earth from one another and are an unavoidable result of a constellation of this general topology.

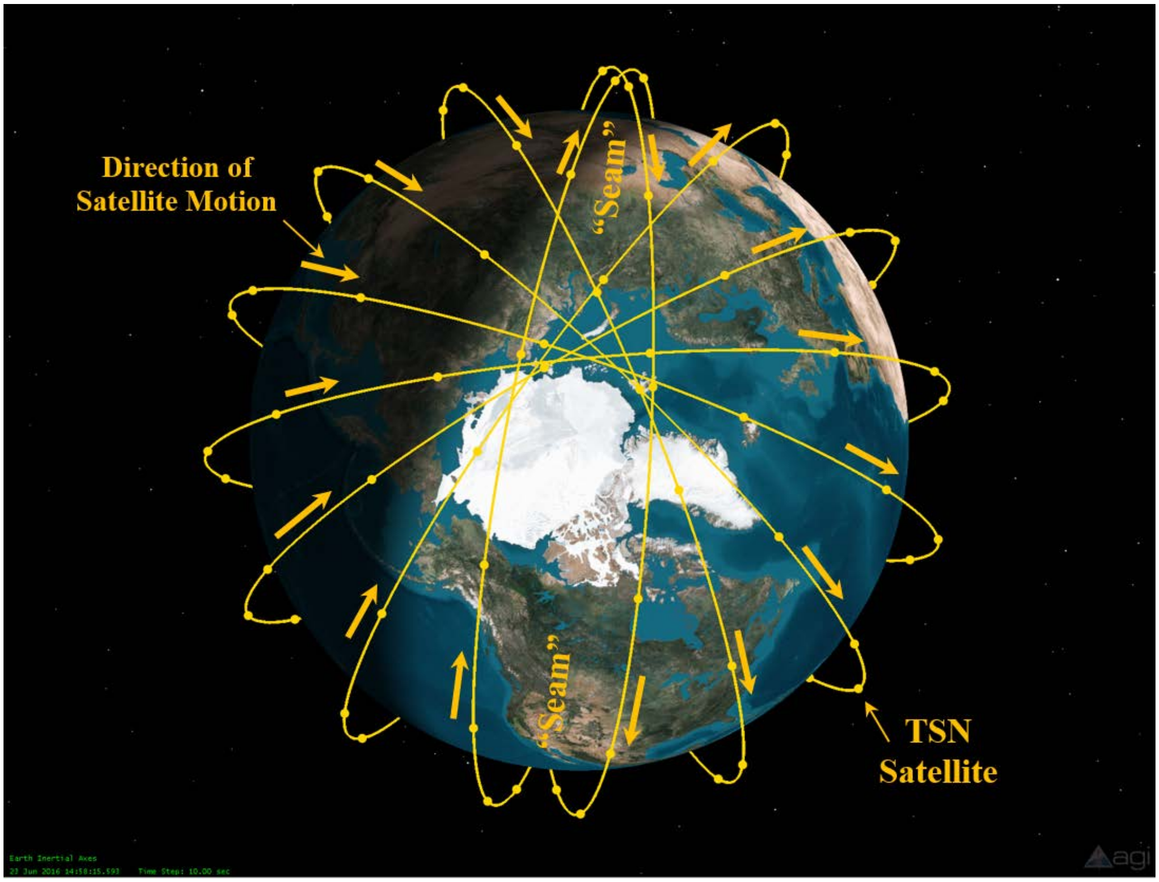

Figure 2 – Polar View of Constellation

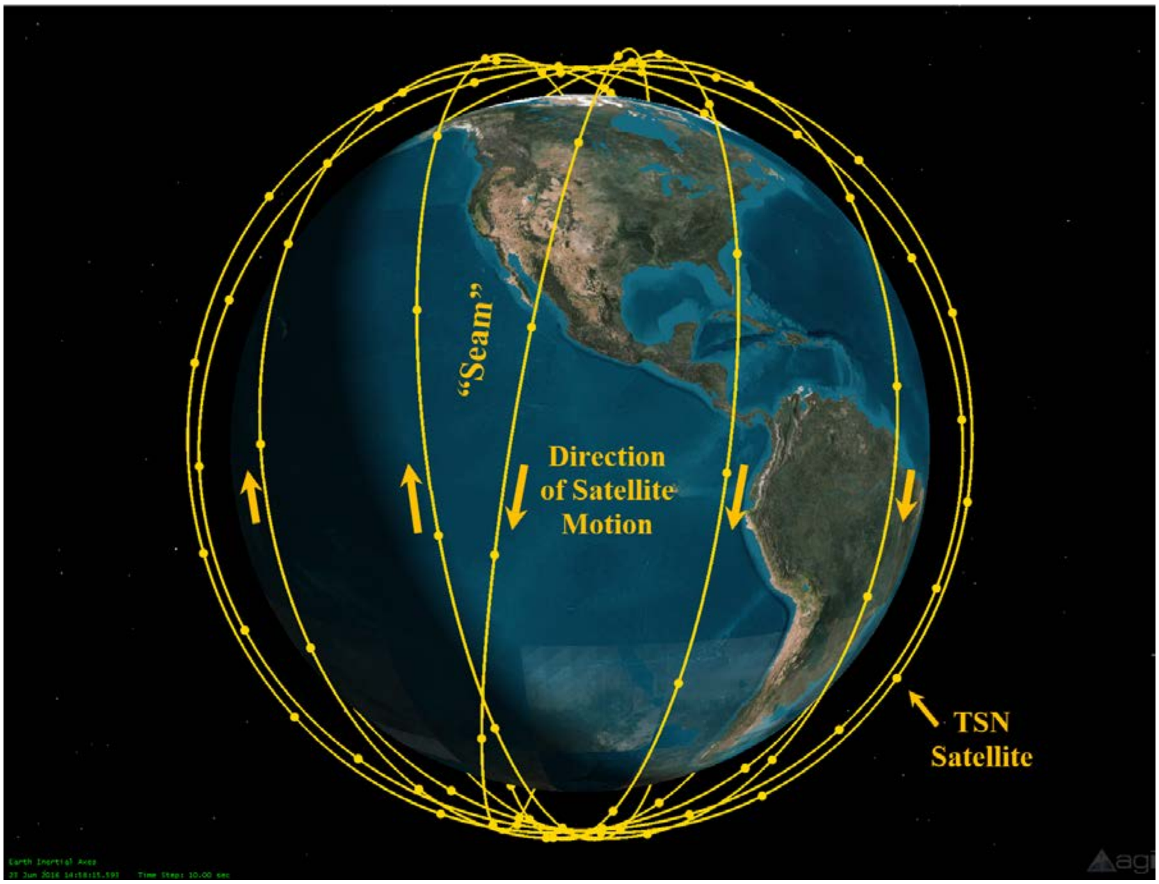

Figure 3 - Equatorial View of Constellation

The constellation provides full global coverage at all times, with substantially increasing overlap of coverage area at higher latitudes (both north and south) due to converging planes. As TSN satellites approach the poles, the satellites' coverage areas will be reduced dynamically depending on a variety of factors, such as individual satellite health and capability, battery charge state and service demand.

One spare satellite will be on orbit near each plane at an altitude of approximately 750 km and an orbital inclination of approximately 98.4° (matching the nodal precession of the active planes).

The constellation design has been created for operations in a safe and functional manner, minimizing the risks of damage to the constituent satellites as well as to other systems operating at nearby altitudes. Extensive altitude trades were conducted in the selection of this constellation design, considering such factors as orbital debris density distributions, atmospheric drag effects and the attendant burden of a compensating fuel load, the requirements of the Earth observation sensors as well as presence of other satellite systems that currently or may occupy nearby altitudes.

Within each TSN plane, the 14 satellites are equally spaced around the plane[6]. For coverage purposes, the phase relationships of satellite position are staggered from plane to plane by an amount that is close to one-half the in-plane spacing between *satellites*.[7] All TSN satellites are operated to position tolerances of less than +/- 10 km of nominal position in all three axes, radial, in-track and cross-track.

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6 That is, equally distributed in true anomaly.

7 This plane-to-plane phase relationship is not exactly one half the in-plane spacing to prevent satellites from arriving at the polar plane crossings at exactly the same times. These small differences in arrival times represent significant absolute differences in position relative to the size of the satellite control boxes, which effectively eliminates the possibility of collisions among satellites within the constellation without significantly affecting the coverage advantages of the half in-plane spacing arrangement.

2.4.1 § 25.114(c)(6) Orbital Parameters for the TSN Constellation

All constellation parameters are detailed in Schedule S attached to this Application. Key parameters are summarized here:

Constellation Parameter	TSN Value
Total Number of On-Orbit Satellites	120
Number of Active On-Orbit Satellites	112
Number of On-Orbit Spares (initial deployment, 750 km storage orbit)	8
Number of Planes	8
Number of Active Satellites per Plane	14
Average Altitude – Active Satellites	800 km
Orbit Type	Sun Synchronous
Inclination	98.6°
Active Service Arc	Active satellites may be active over their full 360° of true anomaly

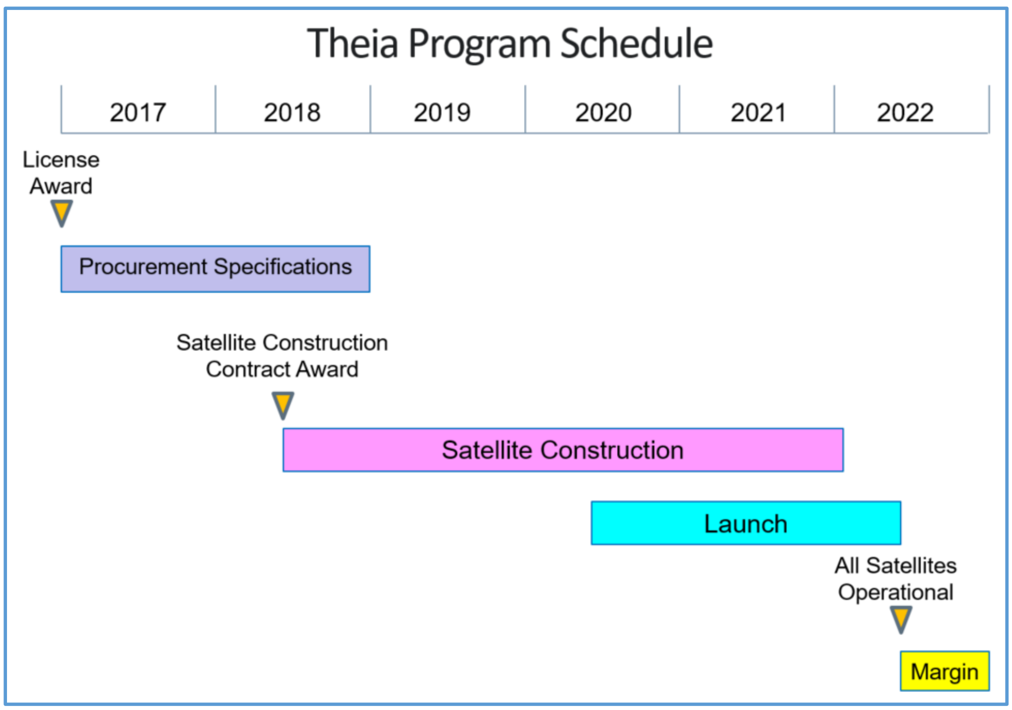
2.5 System Implementation

While TSN is a complex satellite system, Theia has high confidence that implementation of the system is well achievable in the timeframe allotted by the Commission. With respect to §25.164(b), that section requires that the license recipient:

> "*must launch the space stations, place them in the assigned orbits, and operate them in accordance with the station authorization no later than six years after the grant of the license*."

A nominal schedule for procurement, construction, and launch of the TSN constellation is presented below. Note that although the date of license award is indicated as the beginning of 2017, the TSN business plan is not strictly predicated on that specific date. It is simply a representative date for establishing the remainder of the implementation schedule. In any event, Theia will complete launch and operation of the space stations within six years of authorization.

The schedule shown allows for approximately three years from bulk satellite construction contract award to completion of the launch of the entire satellite constellation. It is expected that the first launch of satellites will be 'pathfinder' spacecraft in as little as two years from the beginning of satellite construction, with the next launches following soon thereafter. This additional time period provides a scheduled window for extensive full envelope testing on station to verify satellite design. Following this period, the full production and launch campaign will be completed. As is shown in the schedule, there is a planned margin in the schedule to account for unforeseen issues.



3.0 TSN Elements

TSN is comprised of the following subsystems:

- Three types of custom satellites with unique remote sensing instrumentation that share an advanced, technically identical communications payload;
- User terminals that communicate with the satellites using Ku-band frequencies;
- Gateway earth stations that provide high-bandwidth links between the satellites and terrestrial networks using Ka-band frequencies;
- Network operations centers (NOCs) that perform management functions for user terminal and gateway operations; and
- Satellite operations centers (SOCs) providing real-time monitoring and control of TSN satellites and the associated tracking, telemetry and control (TT&C) stations, as well as associated terrestrial communications network that interconnects NOCs, gateways, UTs, as well as SOCs and the TT&C stations.

3.1 Satellites

TSN satellites employ state-of-the-art technologies to maximize performance and minimize mass and cost. Each satellite is a three-axis stabilized platform that will be controlled to within +/- 0.1° of nominal in all three axes. Each satellite has a large nadir (Earth-pointing) panel that offers sufficient area to accommodate the earth observation sensors, the RF communications antennas for user terminals, the FSO Terminals for ground communications, and the FSO terminals for the inter-satellite links. RF communication with gateways is provided through deployable, steerable antennas.

The bus subsystem for the TSN satellites employ advanced technologies available for LEO satellites. The core structure constitutes a composite rigid frame assembly to which a number of individual structural composite honeycomb sandwich panels are attached to form the platform shape. The structure subsystem also includes a pair of internal composite honeycomb sandwich panels to support the large fuel tank needed for this design.

The electrical power system is designed with deployable rigid panel triple junction gallium arsenide (“GaAs”) solar arrays rated at over 30% beginning-of-life efficiency. The solar array wings also include composite yokes and panels, and include a two-axis drive mechanism for each wing. Redundant lithium-ion batteries comprised of individual modular cells are managed by electronic power controllers. These controllers and other avionics support power conditioning, fusing, and spacecraft power distribution for normal operations, as well as for eclipse operations and to serve peak power demands.The SV thermal subsystem encompasses several extremely mature and well-proven elements:

- Redundant thermistors and heaters;
- Multi-Layer Insulation (MLI) blankets;
- Second Surface Mirrors (SSMs);
- Paints, coatings and other surface finishes; and
- Heat pipes (embedded in primary structural panels) enabling substantial amounts of heat to be moved from localized heat sources to various nearby radiator surfaces for heat rejection.

Each satellite’s propulsion system employs chemical thrusters for orbital relocation, station keeping and end of life disposal. The TNS satellite uses a conventional monopropellant hydrazine blowdown system with the following elements:

- 10 1-N monopropellant hydrazine thrusters
- A large propellant tank sized for the substantial TSN SV delta-V needs; and
- Assorted particulate filters, lines, fill and drain valves, latch valves, and pressure transducers.

TSN satellite command / telemetry, data handling, orbit determination and attitude control are managed by a suite of redundant onboard processors, sensors, actuators, and communications equipment:

- The satellite control processor (SCP) is an internally redundant radiation-hardened processor unit responsible for managing all bus operations as well as performing all orbit determination and attitude control functions of the satellite. The SCP executes all commands issued to the satellite by the SOC, and the SCP sends all requested telemetry to the SOC.

- Satellite orbit determination and attitude control is performed by the SCP employing a suite of sensors and control mechanisms. The sensor suite includes GPS receivers, star tracker sensors, magnetometers, and sun sensors, as well as positional input data from the FSO terminals in communication with other satellites and the ground gateways.

Actuators include four for three redundant momentum/reaction wheel assemblies and three-axis magnetic torque rods. Thrusters are primarily intended for propulsive delta-V maneuvers. However, they can also be used for selected attitude control purposes for example, periodic de-saturating of momentum wheels should mission tasking induce momentum buildup that the satellite's torque rods cannot remove in the necessary timeframe.

TT&C communication between the SOC and the SCP is achieved in a different manner depending on the mission phase:

- In the case of initial deployment of the satellite, transfer orbit, or satellite anomaly, i.e., where ISL and gateway communication is not available, the TT&C communication is routed through one of two of Ka-band quasi-hemispherically patterned[8] transmit and receive antennas, one at either end of the satellite, to provide full spherical coverage regardless of satellite orientation. Command and data handling is managed through TT&C communications system electronics employing redundant Ka-band transmitters and receivers. These transmitters and receivers operate at the upper edge of the band (see Schedule S for specific frequencies). The TT&C receivers and transmitters interface directly with the SCP for all satellite command and control functions, from normal housekeeping to anomaly management functions for the satellite.

- In the case of normal on-station satellite operations, the satellite is connected into the FSO ISL mesh with other satellites, and connects with gateways from time to time as its orbital position permits. TT&C data is routinely exchanged with the SOCs via the gateway connection / ISL mesh, in the same manner as user traffic. The only difference being that the destination address for the TT&C traffic is the satellite SCP for commands or a SOC for telemetry, rather than a UT or a gateway for user traffic.

The TSN satellites are specified with a 92% reliability of de-orbit. De-orbit is achieved by a controlled lowering of the satellite's altitude in a manner that avoids collision risk with space borne debris and other operational satellites. The orbit is lowered until sufficient atmospheric drag is experienced by the satellite to achieve re-entry within 25 years. The specific de-orbit reliability analysis and related analyses are contained in Appendix 4 to this Attachment.

3.1.1 Remote Sensing Payload

The satellites in the TSN carry mission payloads for Earth observation. The remote sensing payloads are distributed as follows:

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[8] The term "quasi-hemispherically patterned' is employed here to indicate that while there is antenna operation over 2π steradians, the gain is not uniform over that range of operation. The specific antenna patterns are included in Schedule S.

- All satellites will carry a visible wavelength and mid-IR wavelength optical fixed-staring system which captures a complete picture of the 120° coverage cone of each satellite (approximately 60° half angle from nadir)

- 52 of the satellites will carry a hyperspectral optical sensor with 1.2 meter primary aperture,

- 52 of the satellites will carry an active L-band radar configured both for imaging and soil measurements, with approximately a 36 square meter antenna effective aperture, and

- Eight of the satellites will carry a passive offset microwave radiometer.

Theia is in the process of obtaining the authority to operate these remote sensing instruments and provide remote sensing products and services from the National Oceanic and Atmospheric Administration ("NOAA"), consistent with U.S. laws, regulations and policies governing commercial remote sensing systems.[9] Information regarding these instruments, including the transmit characteristics of the SAR payload, are included in this Application because the Commission has jurisdiction over U.S. space station licensing and spectrum access.

The TSN will deploy 52 of the 112 satellites that include hyperspectral imagers with nominal 1 meter resolution. The imagers will support hundreds of narrow bands from visible through infrared regions for the capturing of raw visible and non-visible image data.

The L-band RADAR package carried by 52 of the TSN satellites is a system similar in many respects to the JAXA PALSAR-2 payload on the ALOS-2 spacecraft. It provides synthetic aperture radar (SAR) strip imaging as well as spotlight imaging and sounding on single locations. The RADAR operates day or night, and is not affected by clouds or rain. This RADAR also has ground penetrating capabilities to measure terrestrial and sub-surface metrics.

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[9] *See* 15 C.F.R. Part 960.

Appendix 3 – Link Budgets includes the specific RF transmit and receive parameters for the L band radar payload. Further details regarding the emissions are described in Schedule S[10].

Eight of the TSN satellites will be equipped with a microwave radiometer used to measure thermal electromagnetic surface and atmospheric radiation.

Each satellite is also equipped with a dedicated onboard graphics processing unit ("GPU") with extensive processing power for general use in processing real-time data output from the onboard sensors, including real-time calibration and analytics creation. The processing power in-orbit can also convert certain captured raster data into vector formats for certain types of analytic products, dramatically reducing the amount of information necessary to be transmitted to users, thus maximizing efficient use of spectrum.

The remote sensing payloads are tasked through authorized order instructions for certain TSN products and services received directly from end user terminals, as well as through commands from the TSN NOC via gateway links. Analyzed remote sensing products are delivered directly to user terminals (for relatively small amounts of data) or via gateway links (for larger data packages), which can then be routed to users via terrestrial communications. Because some users may not have access to appropriate terrestrial connectivity, end user links may be the only communications path available to receive remote sensing products and associated communications services.

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[10] Schedule S contains entries for radar operating channels at 1233, 1240, 1250, 1260, 1270, and 1280 MHz center frequencies, with 32.06 and 16.06 MHz bandwidths. This set of channels is included in Schedule S to encompass the range of candidate operating channels that are under consideration in the coordination processing with the Radio Navigation Satellite Service community. These discussions are already underway. It is anticipated that the actual operating channel will be one or more of these included in Schedule S, based on the results of the coordination agreement.

This diverse suite of passive and active sensors uniquely provides the ability to integrate a global picture of nearly any man-made or natural process or event. Analytic data integration processes using the raw and processed data from each of the remote sensing capabilities will provide a detailed comprehensive image of individual events, locations, processes and activities.

3.1.2 Communications Payload

TSN satellites are capable of multiple modes of communications. Each satellite employs Ku-band antennas for user terminal communications, Ka-band steerable dish antennas for gateway communications, and Ka-band quasi-hemispherical antennas for TT&C communications. In addition, each satellite is equipped with FSO ISL terminals for inter-satellite connectivity, and a FSO gateway terminal for optical gateway connectivity. TSN satellites are all digitally regenerative satellites rather than "bent pipe" repeaters. Communications into the various ports are reduced to baseband data before they are routed digitally within the satellite or processed onboard.

Each satellite is equipped at launch with six FSO terminals – four for ISL communications (one forward in-plane, one aft in-plane, one each left and right adjacent plane)[11] one for gateway communications and one spare. The nominal data throughput for each of the FSO terminals is 10 Gbps.[12]

The Ku-band and Ka-band payload equipment suites are comprised of a number of different antennas and electronics modules:

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11 Note there is only one adjacent plane supporting ISL communications for planes 1 and 8 because those planes are next to the counter-rotating seams.

12 Theia provides the foregoing information because the FSO terminals are an integral part of the NGSO space stations to be licensed by the Commission.

The Ku-band communications suite includes:

- A multi-beam receive antenna with 169 fixed-pointed, dual-circularly polarized beams (approximately half LHCP, half RHCP), full bandwidth downconverters and analog-to-digital converters;
- Receive digital signal processing electronics with variable bandwidth, spectrum de-spreading and demodulation, decoding and de-interleaving;
- A baseband digital signal interface to an onboard router which provides data distribution within the satellite itself;
- Transmit digital signal processing electronics with variable bandwidth, coding and interleaving, modulation and spectrum spreading; and
- Transmit electronics with digital-to-analog converters, upconverters and an associated multi-beam antenna with shaped, steerable circularly polarized beams.

The Ka-band communications suite includes:

- Two steerable transmit / receive parabolic reflector antennas, each with a dual circularly polarized fixed geometry beam.
- Full bandwidth downconverters and analog-to-digital converters;
- Receive digital signal processing electronics with variable bandwidth, spectrum de-spreading and demodulation, decoding and de-interleaving;
- Baseband digital signal interface to the onboard router;
- Transmit digital signal processing electronics with variable bandwidth, coding and interleaving, modulation and spectrum spreading; and
- Transmit electronics with full bandwidth digital-to-analog converters, upconverters and amplifiers connected to the two steerable parabolic reflector antennas.

The satellite payload also performs baseband digital signal distribution within the satellite via a router to/from, any of the FSO ISL, the FSO gateway link, the gateway Ka-band link, the Ku-band user terminal links, the onboard remote sensing payload or the onboard satellite control processor itself.

3.1.2.1 § 25.114(c)(4)(ii) Maximum EIRP and Maximum EIRP Density for Transmitting Beams

All beams are identified, and EIRP and EIRP density for transmitting beams are detailed in Schedule S attached to this Application for each frequency band in which the transmitting antenna would operate. Please note that Schedule S does not capture nor report EIRP density in the same units as required by § 25.114(c)(4)(ii). Schedule S reports EIRP density in units of dBW/Hz, not per dBW/4 kHz or dBW/MHz. For bands below 15 GHz, the conversion to dBW/4 kHz is achieved by adding 36dB [10 * $\log_{10}$(4,000)] to the value reported in Schedule S in dBW/Hz. For bands at or above 15 GHz conversion to dBW/MHz is achieved by adding 60dB [10 * $\log_{10}$(1,000,000)] to the value reported in Schedule S in dBW/Hz.

3.1.2.2 § 25.114(c)(4)(v) G/T and SFD for Receive Beams

All receive beams are identified, and G/T at beam peak and minimum and maximum saturation flux density ("SFD") at beam peak are detailed in Schedule S attached to this Application[13]. Because SFD is a concept most applicable to bent-pipe transponder payloads and the TSN satellite payload (including command beams) is regenerative, an explanation of the minimum and maximum SFD value included with the Schedule-S is described herein for clarification.

The values provided for minimum and maximum SFD reflect the received flux-density to achieve the threshold bit error rate ("BER") performance for the lowest spectral density modulation/coding (for minimum SFD) and the highest spectral density modulation/coding (for

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13 At the time of this writing, the instructions in document 'Instructions for Schedule S vApr2016.pdf' indicate that SFD values should be entered in Schedule S in units of $dBW/m^2/MHz$. The 'FCC Schedule S System' online software for data entry specifies units of dBW/m^2. Further, the reporting of data values previously entered into this software is similarly specified with units of dBW/m^2. Consequently, we have elected to enter the values into the Schedule S online system in units of dBW/m^2 to reflect software specification.

maximum SFD) intended to be received by that beam. In both cases, these are minimum operating targets. User uplink will tend to operate a few dB above these levels to provide for power control error and tracking bandwidth while command uplinks will operate significantly above these levels to assure high link reliability (during the rare events when the backup TT&C uplink is employed).

Link budgets are included as Appendix 3 to this Application. The link budgets show representative RF parameters (including G/T) for the nadir and edge of coverage (EOC) cases for all link types (user terminal, beacon, gateway and TT&C).

3.1.2.3 Contour Maps for Receive and Transmit Beams

Beam contour diagrams are provided as part of Schedule S of this Application.

3.1.2.4 §25.114(c)(4)(vi): The gain of each transponder channel (between output of receiving antenna and input of transmitting antenna) including any adjustable gain step capabilities.

The TSN satellites do not have any adjustable gain steps for its receivers since the satellites employ onboard processors. There are also no transponder gains since the satellites employ regenerative payloads and do not have transponders. Such information is not applicable to regenerative payloads.

To the extent that a waiver is required, Theia hereby requests a waiver of Section 25.114(c)(4)(vi).

3.1.2.5 § 25.114(d)(12) Applications for NGSO FSS in the 10.7 - 14.5 GHz Bands Must Provide All Information Specified in §25.146

TSN is designed to provide interference protection to Ku-band and Ka-band GSO satellite networks required under Article 22 of the ITU Radio Regulations. For Ku-band NGSO FSS systems, these requirements are embodied in Section 25.146 of the Commission's rules.

Appendix 1 to this Technical Narrative, Ku-band and Ka-band EPFD Compliance Analysis, provides a detailed description of compliance with these ITU and FCC requirements, including those EPFD requirements in § 25.208.

3.1.2.6 § 25.202(e) Frequency tolerance, space stations.

Section 25.202(e) of the Commission's rules provides that "[t]he carrier frequency of each space station transmitter authorized in these services shall be maintained within 0.002 percent of the reference frequency." This requirement is well within common standards of practice. TSN satellites will comply with this requirement.

3.1.2.7 § 25.202 (g)(2) Frequencies, polarization and coding of TT&C transmissions must be selected to minimize interference into other satellite networks.

TT&C information will be communicated between the SOC and TSN satellites through two primary means: (i) gateway communication, or (ii) TT&C sites communicating with TSN satellites through onboard Ka-band quasi-hemispherically patterned antennas. In all cases, communication between the SOC and satellite is secured.

The first case, gateway communication, is the customary method for the operational satellites in the TSN network. In this method, the SOC routes commands through the terrestrial communications network to the appropriate gateway (i.e., a gateway with connectivity with the constellation). That gateway communicates with the constellation via either Ka-band RF or FSO gateway links. Unless the target satellite of the SOC command is the gateway's serving satellite at the time of gateway transmission, the satellites within the constellation route the data as needed through the ISL mesh to that target satellite. The target satellite receives the data through one of its ISL ports, and processes the command. Telemetry data takes the opposite route through the network, from satellite to SOC. In the second case above, the SOC command is routed through the terrestrial communications network to an appropriate TT&C site. This TT&C

site sends the command to the target satellite directly, via a band edge Ka-band RF link. Telemetry data is similarly downlinked to the TT&C site. It is the SOC's responsibility to manage contact times and TT&C site selections for individual satellite communications. This is particularly important for satellites that are not yet part of the constellation mesh, such as satellites just deployed in the launch sequence, or spare satellites in holding orbits.

Ka-band RF communications with TSN satellites are designed to minimize interference with other satellite networks. The TSN TT&C sites are planned for high latitude locations, to provide for better access to a larger number of satellites at any one time. The higher latitude locations limit or eliminate any interference with GSO systems, as the difference in pointing angles between the TSN satellite downlink and a victim earth station GSO downlink (the 'alpha angle') is expected to be very large, and as with any site, any interfering NGSO direct line of sight occurrence will be managed through the standard procedures established with the other operator.

Note that in the first communication method described above, with TT&C information communicated between the SOC and the satellite over a conventional gateway link, that this link may be achieved with Ka-band RF. Should this be the case, this link would not be established at band edge like those links described in the second method above. Rather, this gateway communication would use normal gateway Ka-band RF frequencies away from the band edges and would be processed in a manner indistinguishable from other gateway traffic. As such, Theia requests a waiver pursuant to §25.202(g)(1) for operation of TT&C traffic not at a band edge. These transmissions will cause no greater interference and require no greater protection from harmful interference than the communications traffic on the satellite network. Further, this use of a gateway in an NGSO system for TT&C traffic is consistent with the definition of '*NGSO*

FSS gateway earth station' in §25.103. To require strict compliance with this requirement would place an undue operational burden on the TSN. It would force all TT&C traffic to be carried via direct communications between the TT&C earth stations and each of the 112 satellites in the constellation individually. Under current design, the number of TT&C sites is limited. Further, the data rate of the direct TT&C link is relatively low, only permitting the minimum needed communications for the limited functions for those satellites operating out of the constellation (e.g., spares or in transition). To require band-edge communications only for all satellites would require a larger number of TT&C earth stations to achieve more frequent contact, as well as an increase in data rate of the link, to permit the exchange of the volume of data required during the limited contact times afforded by the direct connections.

Specific Ka-band TT&C uplink and downlink frequency ranges are provided in the associated Schedule S to this Application.

3.1.2.8 §25.207 Cessation of Emissions

Each active satellite transmission chain (element drivers and associated solid state power amplifier) can be individually turned on and off by ground command, or all can be turned on and off collectively by ground command, thereby satisfying the Section 25.207 cessation of emissions requirement.

3.1.2.9 §25.114(c)(8) and §25.208 Power Flux Density Limits

As discussed in detail in Appendix 2, TSN Power Flux Density Compliance, TSN will comply with the PFD requirements of Sections 25.114(c)(8) and 25.208 of the Commission's rules.

3.1.2.10 §25.210(f) – Full frequency re-use

Section 25.210(f) of the Commission's rules requires the space station to employ state-of-the-art full frequency reuse. The TSN satellites fully comply with this requirement. Ku-band user links employ four color[14] frequency reuse on the uplink distributed through the 169 uplink beams in the satellite footprint, an effective frequency reuse of more than 42 times. These user links employ both polarizations. Similarly, for the Ku-band downlink, the TSN satellites employ as many as 40 simultaneous downlink beams with full downlink data rate, providing a 40 times reuse factor.

Gateways are planned for locations at relatively high latitudes, affording simultaneous access to a number of satellites. This simultaneous access as well as the ability to communicate on both polarizations at Ka-band provides significant reuse of this spectrum as well.

3.2 User Terminals

TSN user terminals are the equipment employed at customer sites that access TSN products and services directly from the TSN constellation. For users that have no appropriate terrestrial connectivity options available (e.g., certain mobility or remote applications), the user terminal is the only viable means of service delivery. In other instances, user terminals may nevertheless be the best means of obtaining TSN products and services given latency requirements, traffic routing issues and other factors.

TSN user terminals will operate in Ku-band frequencies and will be available in fixed, transportable and mobility configurations. Fixed user terminals are designed for installation and long-term operation at a customer facility and will be equipped with standard interfaces such as USB and Ethernet to enable communication with local computer and/or routing equipment. Transportable user terminals will have similar operational features, but will be designed for

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[14] A 'color' in this context is a portion of the dual polarization radio frequency spectrum that is reusable within a given satellite's footprint. So, four color reuse means that the entire available spectrum is divided into four portions, and those portions reused throughout the footprint, without any two adjacent areas of the footprint having the same 'color', or portion of the spectrum, and hence without interference.

short-term use at a customer site and add optional wireless connectivity (e.g., Bluetooth, Wi-Fi) for local interface with the customer computer and routing equipment. Finally, given the Commission's well-settled rules governing Ku-band mobility applications,[15] Theia anticipates deploying TSN user terminals for remote mobility applications (e.g., communications to operational farm and mining equipment, as well as security/surveillance, unmanned systems support, and other applications).

TSN user terminals are fully enclosed weatherproof systems, which can be mounted on an appropriate skyward facing location. The user terminals are fully compliant with all regulatory requirements for human safety and appropriate operating instructions and labeling will be provided to ensure that no excessive exposure to RF radiation will occur[16]. User terminals include all capabilities required to operate with TSN, including such functions as satellite acquisition and tracking, link acquisition and maintenance (e.g., timing and Doppler compensation, demand assignment management, power control, etc.), and authentication functionality. Of course, the antenna and associated Ku-band electronics for communicating with TSN satellites are also included in the user terminal.

The TSN design incorporates user terminals with 40 cm and 80 cm equivalent aperture antennas and currently anticipates the use of electronically steered arrays.[17] The 40 cm and 80 cm UT are representative of the types of user terminals expected to operate in the TSN. While

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[15] *See, e.g.*, 47 C.F.R. §25.226.

[16] Maximum permissible exposure (MPE) analysis has been performed to indicate that adequate safety margins can be achieved with conventional UT design and manufacturing methods.

[17] Although Theia anticipates filing earth station applications with the Commission that fully detail the characteristics of the TSN user terminals at the appropriate time, at this time Theia can confirm that all user terminals will comply fully with applicable Ku-band earth station performance standards.

these are the principal UT classes, others are anticipated. See the link budgets in Appendix 3 which include information applicable to the expected performance of these UT.

Because the TSN satellites move across the sky relative to a user's location, user terminals will track the TSN satellite during its service period to that location and then acquire the next serving satellite. Theia anticipates a very brief switch-over period between serving satellites that will be consistent with the service requirements of its customers. Tracking of TSN satellites will be achieved through beacons and transmission of relevant ephemeris data to user terminals via the terrestrial communications network and/or satellite links, as appropriate, combined with positional information of the user terminal. Because all user terminals will know their own locations, the positions of relevant satellites, and emissions restrictions imposed by local regulations prior to commencing transmissions, it will be possible for the user terminal antenna to acquire and track the serving satellite without interference with other satellites or services.

TSN user terminals will operate at data rates up to the following rates depending on the specific needs of the user and/or geospatial/geophysical product being delivered:

Equivalent Antenna	**Direction**	**Bandwidth**	**Data Rate**
40 cm	Uplink	50 MHz (10 dBW RF Power)	38.2 Mbps
40 cm	Downlink	500 MHz	62.6 Mbps
80 cm	Uplink	500 MHz (10 dBW RF Power)	76.7 Mbps
80 cm	Downlink	500 MHz	234.7 Mbps

Further, user terminals are expected to be located within differing rain regions, requiring different levels of rain margin for the links in order to operate with adequate availability for TSN services. The combination of variation of user data rate along with variation in rain region results in the need for a variety of different sizes of outdoor antennas for the user terminals. In operation, the UTs and the TSN satellites monitor the link performance continuously. Adaptive power control as well as adaptive coding and modulation ("ACM") schemes are employed to ensure that the maximum error-free data transmission rates can be achieved through all atmospheric conditions. The specific Ku-band frequencies to be used by TSN user terminals in proposed operational regions are discussed in 2.1.1 § 25.114(c)(4)(i) Frequency Plan.

3.2.1 §25.209 Earth Station Antenna Performance Standards

All user terminal, gateway and TT&C earth station antennas will comply with Section 25.209 or other applicable earth station performance standards for all operations.

3.3 Gateway Earth Stations

TSN gateway earth stations link the TSN constellation and terrestrial communications networks. Traffic carried by these earth stations includes user traffic requiring terrestrial backhaul, management and control information for handling user traffic and TT&C communications.

Gateways may be located at high latitudes. High latitudes afford the gateway the opportunity to make contact with a greater number of TSN satellites simultaneously, as the planes of satellites converge near the poles. The links between a gateway facility on the ground and the constellation of TSN satellites are each very high bandwidth, whether FSO or RF. These high bandwidth links connect into the ISL mesh within the satellite constellation in space, and on the ground, the links connect to the terrestrial communications network to permit communications to users as well as control centers (NOCs and SOCs). As a result of this architecture, it is not expected that a large number of gateways will be required to support TSN operations. The specific number and location of gateways will be optimized when the final constellation is authorized by the Commission.

Gateway earth stations may operate FSO links, Ka-band links or both depending on location, network loading and other factors. The Ka-band gateway links function as primary, high-bandwidth connections to the terrestrial network or back-up for the FSO gateway links (where optical links can be employed effectively). TSN gateway sites will be fully coordinated pursuant to applicable Commission procedures and, given the limited number of gateway earth stations needed to serve the inter-connected TSN constellation and the potential use of FSO gateway links, Theia anticipates coordinating Ka-band gateway operations will be relatively straightforward.

TSN's gateway earth stations will vary in size among 1.6m, 3.2m, and 4.8m equivalent circular aperture sizes depending on specifics of climate, throughput, link availability requirements, and other factors. Each gateway earth station will employ multiple, steerable antennas to allow make-before-break connectivity with the TSN constellation. Specific RF parameters such as EIRP and G/T for the gateways are provided in detail in Schedule S.

3.4 Network Operations Centers (NOC)

User operations throughout the TSN are managed through a hierarchical arrangement of NOCs. The global NOC coordinates all user traffic operations, sets policies, rates, performs quality of service management, coordinates updates, manages or supervises the management of all UTs. One of the key functions of the NOC is the coordination of TSN operations with other NGSO systems and with GSO systems. This coordination ensures that the TSN operates according to regional and global regulations, and that the TSN operates in a manner consistent with sharing agreements.

Regional and national operations centers will be established as needed to serve the specific requirements of securing and maintaining “landing rights” within certain geographic areas, including responsibility for compliance with national regulations in each jurisdiction.

The NOC, regional, and national operations centers are interconnected through a secured terrestrial communications network. The gateways are interconnected with the same terrestrial network.

3.5 Satellite Operations Centers (SOC) and Tracking, Telemetry, and Control (TT&C) stations

The TSN SOC provides 24x7 monitoring & control of all satellites: operational, spare, in launch, deployment and transit, as well as decommissioning, deorbit and disposal. The SOC not only performs normal day-to-day operations functions for all satellites, but also manages anomalous events should they occur. Personnel at the SOC also provide Engineering and Analysis services to support all manner of routine and anomalous activities. The SOC provides constellation ephemeris data to the TSN for managing satellite acquisition and tracking. The SOC coordinates with government entities such as the Joint Space Operations Center and the United States Strategic Command to ensure that space situational awareness needs are maintained. The SOC maintains communications with other satellite operators to perform timely coordination for collision and interference avoidance as needed.

SOC facilities comprise a variety of dispersed locations. The primary satellite operations center is planned for an urban location, to be manned 24 hours per day with qualified satellite operations personnel. A backup SOC will also be installed, geographically separated from the primary SOC. It will be equipped identically to the primary SOC. The backup SOC includes all necessary elements and infrastructure to take over from the primary SOC at any time. All necessary data are mirrored and backed up in order to enable the backup to take over at any time with no warning. It is staffed with sufficient personnel to operate the satellites, but in a prolonged outage of the primary SOC, the operators from the primary would need to relocate to the backup.

Communications between the satellites and the SOCs is provided in one of two ways. For the constellation of connected, operational satellites, commands and telemetry are exchanged between SOCs and satellites through the TSN gateways. For the satellites that are not part of the connected ISL constellation (spares, launch, deployment and transit, decommissioning, deorbit and disposal, and those otherwise operational satellites which have suffered anomalies and are in 'safe mode'), communications are maintained through dedicated TT&C sites.

The TT&C sites are typically located at high latitude to permit access to a larger number of satellites at any one time. The sites are equipped with multiple 1.6 to 4.8 meter[18] transmit/receive antennas and associated electronics that communicate with TSN satellites through the spacecraft's Ka-band omni antennas. Attachment 3 – Link Budgets provides details for representative TT&C communications links.

The primary and backup SOCs are connected to a terrestrial communications network that includes connectivity with the TSN gateways and the TT&C sites. Similarly, as noted above, the NOCs and gateways are connected to the terrestrial communications network as well.

The terrestrial communications network is established to provide easily accessible communications services among the ground components of the TSN. It is made up of links of

[18] Antenna sizes will be chosen consistent with climate conditions at TT&C sites.

both the public Internet as well as private leased lines as required by the specifics of the connectivity. The network operations centers and gateways carry substantial volumes of traffic, and will likely require private leased lines for much of the network. User terminal traffic accessing gateways may be more economically served by direct connection to the public Internet. In all cases, TSN communications are performed over secured, encrypted protocols to ensure data security.

4.0 Sharing with Other Services

4.1 EESS Spectrum

4.1.1 EESS (s-to-E): 25.5 GHz - 27.0 GHz

The U.S. Table of Allocations provides that the band 25.5-27.0 GHz is allocated for non-Federal Earth Exploration-Satellite Service ("EESS") (space-to-Earth) operations on a primary basis.[19] Theia acknowledges that authorizations in this band are subject to a case-by-case electromagnetic compatibility analysis and will demonstrate that it will provide sufficient protection to existing and planned Federal Space Research Service ("SRS") and EESS operations in the context of any future gateway earth station application seeking to operate in this band.[20] Because Theia's use of this band will be limited to gateway earth station operations, compatibility with Federal and other non-Federal operations in this band should be achievable.

Theia will not claim protection from stations in the fixed ("FS") and mobile services operated by other administrations.[21] Theia will comply with the most recent version of Recommendation ITU-R SA.1862 and the guidelines put forth in Recommendation ITU-R SA.1278, Annex 1 regarding the methodology for ensuring sufficient separation distances between EESS earth stations and FS stations.[22]

As demonstrated in this Technical Narrative, Theia's space station transmissions in this band will meet the power flux density ("PFD") limits contained in Article 21 of the ITU Radio

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[19] *See* United States Table of Frequency Allocations, 47 C.F.R. § 2.106, footnote US258.

[20] *Amendment of Parts 2, 25, and 73 of the Commission's Rules to Implement Decisions from the World Radiocommunication Conference (Geneva, 2003) (WRC-03) Concerning Frequency Bands Between 5900 kHz and 27.5 GHz and to Otherwise Update the Rules in this Frequency Range,* ET Docket No. 04-139, Report and Order, FCC 05-70, ¶¶ 87 & 88 (2005) ("*EESS R&O*").

[21] *See* 47 C.F.R. § 2.106, footnote 5.536A.

[22] *EESS R&O* at ¶ 88.

Regulations to protect terrestrial operations and Section 25.208(p) of the Commission's rules, 47 C.F.R. § 25.208(p).[23] Theia also acknowledges that NASA uses this band for its tracking and data relay satellite system ("TDRSS") to provide communications to other spacecraft, to downlink telemetry for the Lunar Reconnaissance Orbiter and Solar Dynamics Observatory and broadband data communications from space-borne sensors.[24] In addition, the National Science Foundation ("NSF") uses this band for the radio astronomy research of various spectral-lines and continuum measurements,[25] and other allocated Federal uses include EESS, FS, ISL, mobile, SRS (space-to-Earth) operations, and secondary standard frequency and time signal-satellite services. Through coordination and consultation, Theia will ensure compatibility with the aforementioned Federal operations.

4.1.2 EESS (s-to-E): 1215 MHz – 1300 MHz

The U.S. Table of Allocations provides that the band 1215-1300 MHz is allocated for Federal EESS operations on a primary basis and non-Federal EESS operations are secondary.[26] Specifically, in the 1215-1240 MHz band, non-Federal EESS operations are permitted on a secondary basis to Federal EESS, radiolocation, radionavigation-satellite ("RNSS") and SRS

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23 *Id.* ¶ 89. Compliance with PFD should protect terrestrial Federal uses, including fixed and mobile microwave point-to-point communications links for voice, data, and video at various government facilities and laboratories, test ranges, and air traffic control facilities, and will operate in accordance with this co-primary allocation.

24 National Telecommunications and Information Administration, Office of Spectrum Management, "Federal Spectrum Use Summary, 30 MHz – 3000 GHz," June 21, 2010 ("NTIA Federal Spectrum Use Summary"), at 71, *available at:* http://www.ntia.doc.gov/files/ntia/publications/spectrum_use_summary_master-07142014.pdf.

25 *Id.*

26 Federal radiolocation in the band 1215-1300 MHz is primarily for the military services, however, limited secondary use is permitted by other Federal agencies to support experimentation and research programs. *See* United States Table of Frequency Allocations, 47 C.F.R. § 2.106, footnote G56.

operations.[27] Additionally, in the 1240-1300 MHz band, non-Federal EESS operations are secondary to Federal EESS, radiolocation, SRS, and aeronautical radionavigation operations, as well as non-Federal aeronautical radionavigation operations.[28]

In the band 1215-1300 MHz, Theia will not cause harmful interference to, claim protection from, or otherwise impose constraints on operation or development of the radiolocation service, the RNSS and other services allocated on a primary basis.[29] Further, in the 1240-1300 MHz, Theia will not cause interference to, claim protection from, or otherwise impose constraints on operation or development of the aeronautical radionavigation service.[30] Theia is currently engaged with Federal and non-Federal stakeholders regarding use of the 1215-1300 MHz band and anticipates that its proposed operations can be accommodated.

4.2 Ka-Band Gateway Operations

4.2.1 Uplink Bands (Earth-to-space)

Article 22 of the ITU Radio Regulations sets forth standards for interference protection of GSO satellite networks from NGSO satellite systems. As demonstrated in this Technical

[27] 47 C.F.R. § 2.106. The 1215-1240 MHz band is used by Federal agencies for operating various types of long-range radar systems, as well as various radionavigation-satellite systems. *See* National Telecommunications and Information Administration, Office of Spectrum Management, "1215-1240 MHz" (December 1, 2015), available at: https://www.ntia.doc.gov/files/ntia/publications/compendium/1215.00-1240.00_01DEC15.pdf.

[28] 47 C.F.R. § 2.106. The 1240-1300 MHz band is used by Federal agencies for operating various types of long-range radar. *See* National Telecommunications and Information Administration, Office of Spectrum Management, "1240-1300 MHz" (December 1, 2015), available at: https://www.ntia.doc.gov/files/ntia/publications/compendium/1240.00-1300.00_01DEC15.pdf.

[29] 47 C.F.R. § 2.106, nn. 5.332 and 5.335A; *see also id.* at nn. G56 (stating that "Federal radiolocation in the bands 1215–1300, 2900–3100, 5350–5650 and 9300–9500 MHz is primarily for the military services; however, limited secondary use is permitted by other Federal agencies in support of experimentation and research programs"), G132 ("Use of the radionavigation-satellite service in the band 1215–1240 MHz shall be subject to the condition that no harmful interference is caused to, and no protection is claimed from, the radionavigation service authorized under ITU Radio Regulation No. 5.331. Furthermore, the use of the radionavigation-satellite service in the band 1215– 1240 MHz shall be subject to the condition that no harmful interference is caused to the radiolocation service. ITU Radio Regulation No. 5.43 shall not apply in respect of the radiolocation service. ITU Resolution 608 (WRC–03) shall apply.").

[30] *Id.*, nn. 5.5332. 5.335.

Narrative, Appendix 1, Theia's earth station transmissions in the following bands will protect Federal and non-Federal space station receive operations by complying with all applicable $EPFD_{up}$ limits contained in Article 22 of the ITU Radio Regulations.[31]

The NSF uses portions of the 27.5-30.0 GHz band for the radio astronomy research of various spectral-lines and continuum measurements.[32] Theia will undertake coordination and consultation with NSF and Federal stakeholders as required to accommodate these operations.

4.2.1.1 FSS (E-to-s): 27.5 GHz – 29.1 GHz

4.2.1.1.1 27.5 GHz – 28.35 GHz

The Commission's Table of Allocations and Ka-band Plan, together with the *Spectrum Frontiers Order*, provide that Local Multipoint Distribution Service ("LMDS") systems operate on a primary basis and FSS systems on a secondary basis in the 27.5-28.35 GHz (Earth-to-space) band.[33] The Commission also recently adopted rules under which FSS is secondary to the newly created Upper Microwave Flexible Use Service ("UMFUS") in the 27.5-28.35 GHz band.[34] The Commission extended UMFUS mobile rights and protections to all existing LMDS licensees and now requires that FSS earth stations provide certain interference protection to existing and future UMFUS licensees. Theia intends to comply with these rules.

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31 *See contactMEO Communications, LLC*, 21 FCC Rcd 4035, 4043-4044 (IB 2006) (where the Commission held that compliance with the ITU's EPFD limits provides a sufficient basis for an NGSO FSS system to operate on a non-interference basis in a band in which GSO FSS systems are primary).

32 *See* NTIA Federal Spectrum Use Summary at 71.

33 47 C.F.R. §25.202(a)(1); s*ee also Rulemaking to Amend Parts 1, 2, 21, and 25 of the Commission's Rules to Redesignate the 27.5-29.5 GHz Frequency Band, to Reallocate the 29.5-30.0 GHz Frequency Band, to Establish Rules and Policies for Local Multipoint Distribution Service and for Fixed Satellite Services*, 11 FCC Rcd. 19005, ¶¶ 59-62 (1996) ("*Ka-band Plan R&O"); Redesignation of the 17.7-19.7 GHz Frequency Band, Blanket Licensing of Satellite Earth Stations in the 17.7-20.2 GHz and 27.5-30.0 GHz Frequency Bands, and the Allocation of Additional Spectrum in the 17.3-17.8 GHz and 24.75-25.25 GHz Frequency Bands for Broadcast Satellite-Service Use*, 15 FCC Rcd 13430, ¶ 28 (2000) ("*Redesignation of Ka-band Plan R&O*").

34 *See Spectrum Frontiers Order* at ¶ 50.

Theia's proposed gateway operations in the 27.5-28.35 GHz band are consistent with the Commission's view that FSS gateway operations that would not cause harmful interference to primary LMDS stations in the band.[35] The Commission has previously stated that FSS operations in this band are limited to "gateway" operations because ubiquitous terminals could interfere with LMDS operations.[36] Theia's proposed operations in this band will be limited to gateway earth stations and the Commission recently created a framework for FSS licensees to "deploy additional FSS earth stations in the band without harming terrestrial operations."[37]

Under the rules recently adopted in the *Spectrum Frontiers Order*, FSS earth stations must now demonstrate to the Commission that they comply with minimum UMFUS interference protection criteria.[38] Theia intends to choose sites for its gateway earth stations in this band and coordinate with existing UMFUS licensees in accordance with the limitations and processes set forth in the *Spectrum Frontiers Order*[39] and other applicable Commission rules. By doing so, Theia may operate its NGSO system on a secondary basis to UMFUS licensees in the 27.5-28.35 GHz band without meeting additional UMFUS protection conditions.[40]

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35 *Spectrum Frontiers Order* at ¶ 47 (Within certain limits, "while allowing new earth stations in the 28 GHz band is not without cost to terrestrial licensees, we believe that the small area encumbered by a new earth station . . . will minimize such costs and will allow both satellite and terrestrial services to expand and coexist.").

36 The Commission's references to "gateway-type" service in the 27.5-28.35 GHz band are not intended as a requirement that all earth stations in the band serve as gateway earth stations. Rather, the mention of "gateway-type" service in the 27.5-28.35 GHz band serves as an example of what the Commission's envisions as the type of service that FSS operators would be able to provide on a secondary basis without causing interference to primary LMDS stations in the band. *See Rulemaking to Amend Parts 1, 2, 21, and 25 of the Commission's Rules to Redesignate the 27.5- 29.5 GHz Frequency Band, to Reallocate the 29.5-30.0 GHz Frequency Band, to Establish Rules and Policies for Local Multipoint Distribution Service and for Fixed Satellite Services, Third Report and Order*, 12 FCC Rcd 22310, 22327, ¶ 42 (1997).

37 *Spectrum Frontiers Order* at ¶ 51.

38 *Id.* ¶ 54.

39 *Id.* at ¶ 54 (including PFD limits).

40 *See id.* at ¶ 58.

4.2.1.1.2 28.35 GHz – 28.6 GHz

The Commission's rules and Ka-band Plan provide that in the 28.35-28.6 GHz (Earth-to-space) band, GSO FSS systems operate on a primary basis and NGSO FSS systems on a secondary basis.[41] Theia demonstrates in this Technical Narrative that it can operate gateway earth stations without causing harmful interference to authorized spectrum users and agrees to accept any harmful interference from primary GSO FSS operations while operating on a secondary basis in the 28.35-28.6 GHz band.

4.2.1.1.3 28.6 GHz – 29.1 GHz

The 28.6-29.1 GHz (Earth-to-space) band may be used by NGSO FSS systems on a primary basis and by GSO FSS systems on a secondary basis.[42] Theia intends to use this band pursuant to this primary allocation.

4.2.1.2 FSS (E-to-s): 29.1 GHz – 29.5 GHz

The U.S. Table of Allocations and Section 25.202 of the Commission's rules, 47 C.F. R. § 25.202, permit use of the entire 29.1-29.5 GHz band on a primary basis for NGSO Mobile-Satellite Service ("MSS") feeder links on a primary basis.[43] In the 29.1-29.25 GHz portion of this band, that allocation is co-primary with LMDS service.[44] In the 29.25-29.5 GHz portion of this band, that allocation is co-primary with GSO FSS service.[45] Throughout this band, NGSO FSS systems are non-conforming.

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[41] 47 C.F.R. §25.202(a)(1); *Ka-band Plan R&O* at ¶ 42*; see also Redesignation of Ka-band Plan R&O* at ¶ 28.

[42] 47 C.F.R. §25.202(a)(1); *Ka-band Plan R&O* at ¶¶ 57-58 and 78*; Redesignation of Ka-band Plan R&O* at ¶¶ 28 and 34.

[43] 47 C.F.R. § 2.106; 47 C.F.R. § 25.202(a)(1) (nn. 4-5).

[44] 47 C.F.R. § 25.202(a)(1) (n.4).

[45] 47 C.F.R. § 25.202(a)(1) (n.5).

Theia intends to use the 29.1-29.5 GHz band for conforming MSS feeder links.[46] While some TSN operations meet the definition of FSS because Theia earth stations will be operated at fixed "given positions,"[47] it will also support mobility applications that may be considered MSS.[48] Thus, Theia's access to MSS feeder link spectrum comports with the U.S. Table of Allocations and Part 25 of the Commission's rules. Theia will coordinate with existing and future MSS feeder links operating in the band.

To the extent that the Commission concludes that Theia's proposed operations in this band do not constitute MSS feeder links, Theia has requested a waiver elsewhere in this Application, and will operate its gateway earth stations on a non-conforming basis in the 29.1-29.5 GHz band. As described in connection with that waiver request, Theia will not claim protection from conforming uses of the spectrum and agrees to accept any harmful interference from such conforming uses.

Theia will also follow the procedures as established by Section 25.261 of the Commission's rules for avoiding any possible in-line interference event with NGSO FSS systems.[49] Finally, Theia will immediately terminate any gateway operations upon notification that such operations are causing harmful interference to any lawfully authorized radio system in the 29.1-29.5 GHz band operating in conformance with the U.S. Table of Allocations.

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[46] The TSN will also utilize vehicle-mounted earth stations ("VMES") operating pursuant to the blanket licensing provisions of Section 25.226 of the Commission's rules, 47 C.F.R. §25.226.

[47] *See* 47 C.F.R. § 25.103 (defining "Fixed-Satellite Service" to include "radiocommunication service between earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas").

[48] 47 C.F.R. § 25.103 (defining "Mobile-Satellite Service" as "radiocommunication service: (i) Between mobile earth stations and one or more space stations, or between space stations used by this service; or (ii) Between mobile earth stations, by means of one or more space stations," and a "Mobile Earth Station" as "[a]n earth station in the Mobile-Satellite Service intended to be used while in motion or during halts at unspecified points").

[49] 47 C.F.R. § 25.261.

4.2.1.3 FSS (E-to-s): 29.5 GHz – 30.0 GHz

The U.S. Table of Allocations and Ka-band Plan provide that in the 29.5-30.0 GHz (Earth-to-space) band, GSO FSS systems operate on a primary basis and NGSO FSS systems on a secondary basis.[50] As a secondary user, Theia's proposed NGSO FSS operations in the 29.5-30.0 GHz band must not cause interference to primary GSO FSS systems. Theia will follow the procedures as established by Section 25.261 of the Commission's Rules for avoiding any possible in-line interference event with NGSO FSS systems.[51]

4.2.2 Downlink Bands (space-to-Earth)

As demonstrated in this Technical Narrative, Appendix 1, Theia's space station transmissions in the following bands will protect Federal and non-Federal GSO earth station receive operations by complying with all applicable $EPFD_{down}$ limits contained in Article 22 of the ITU Radio Regulations. In addition, as demonstrated in this Technical Narrative, Appendix 1, Theia's space station transmissions in the following bands will protect Federal and non-Federal GSO space station receive operations by complying with all applicable $EPFD_{is}$ inter-satellite limits contained in Article 22 of the ITU Radio Regulations.

Finally, as demonstrated in this Technical Narrative, Appendix 2, Theia's space station transmissions in the following bands will protect Federal and non-Federal terrestrial operations by complying with all applicable PFD limits contained in Article 21 of the ITU Radio Regulations.

According to the NTIA Federal Spectrum Use Summary, NSF uses portions of the 17.8-18.6 GHz and 18.8-20.2 GHz bands for the radio astronomy research of various spectral lines

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50 *Ka-band Plan R&O* ¶ 42*; see also Redesignation of Ka-band Plan R&O* ¶ 28.

51 47 C.F.R. § 25.261.

and continuum measurements, and military agencies use this band as a downlink for some satellite networks. Theia will undertake coordination and consultation as required to ensure its proposed operations are compatible with Federal uses. To the extent required, Theia will coordinate its non-Federal gateway earth station operations in this band with Federal FSS systems operating on a primary basis. Additionally, in the event that Theia seeks to operate an earth station at a location allocated for primary Federal operations – that is, Denver, Colorado; Washington, DC; San Miguel, California; and Guam – prior to commencing operations, Theia will assist the FCC with any information it may need in order to complete coordination with NTIA.[52]

4.2.2.1 FSS (s-to-E): 17.8 GHz – 18.3 GHz

The Table of Allocations and the Commission's Ka-band Plan provide that the 17.8-18.3 GHz band may be used by FS systems on a primary basis and NGSO FSS systems are non-conforming.[53] Accordingly, Theia has requested a waiver elsewhere in this Application, and will operate its gateway earth stations on a non-conforming basis in the 17.8-18.3 GHz band and agrees to accept any harmful interference from these services, and not to cause any harmful interference to these services, while operating on a non-conforming, unprotected basis.

As described in that waiver request, there is little to no potential for interference to existing and future FS systems by Theia's proposed receive-only gateway earth stations operations. In any event, Theia will not claim protection from conforming uses of the spectrum and agrees to accept any harmful interference from such conforming uses.

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[52] *See* 47 C.F.R. § 2.106, n. US334.

[53] *See Redesignation of Ka-band Plan R&O* ¶¶ 28 and 34.

4.2.2.2 FSS (s-to-E): 18.3 GHz – 18.6 GHz

The Table of Allocations and Ka-band Plan provide that in the 18.3-18.6 GHz band, FSS services are limited to GSO FSS operations.[54] In addition, terrestrial FS operations are co-primary with GSO FSS in the 18.3-18.58 GHz portion of the band. Accordingly, Theia will operate its NGSO system on a non-conforming basis in the 18.3-18.6 GHz band. Elsewhere in this Application, Theia seeks a waiver to the extent necessary to allow its gateway earth stations operations in this band.

There is little to no potential for interference to existing and future FS systems by Theia's proposed gateway operations. This band will be used to support receive-only gateway earth station operations. Theia will not claim protection from conforming uses of the spectrum and agrees to accept any harmful interference from such conforming uses, and will immediately discontinue any gateway operations in the band upon notification that such operations are causing harmful interference to any lawfully authorized radio system in the 18.3-18.6 GHz band.

4.2.2.3 FSS (s-to-E): 18.8 GHz – 19.3 GHz

The Table of Allocations and the Commission's Ka-band Plan provide that the 18.8-19.3 GHz (space-to-Earth) band may be used by NGSO FSS operations on a primary basis, as well as for certain limited Federal uses.[55] Theia will operate in this band in accordance with this allocation.

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[54] 47 C.F.R. § 2.106, n. NG164.

[55] *See* 47 C.F.R. § 2.106, n. NG165; *Ka-band Plan R&O* ¶¶ 59-62; *see also Redesignation of Ka-band R&O* ¶ 28. Note that low power point-to-multipoint terrestrial fixed systems may continue to be licensed and operate on a co-primary basis with NGSO/FSS in the 18.82-18.87 GHz and 19.16-19.21 GHz bands.

4.2.2.4 FSS (s-to-E) 19.3 GHz – 19.7 GHz

The Commission's rules allocate this band for primary FSS (space-to-Earth) use for both Federal and non-Federal users, and TSN will operate in this band in accordance with this allocation.[56] Additionally, pursuant to note NG166 to the U.S. Table of Allocations, "[t]he use of the band 19.3–19.7 GHz by the fixed-satellite service (space-to-Earth) is limited to feeder links for the mobile-satellite service."[57]

As indicated above, the TSN incorporates FSS, MSS, and VMES functionalities. Therefore, Theia believes that its use of this band conforms to the requirements of this rule with respect to the MSS and VMES functionalities supported by using spectrum in this band. In addition, elsewhere in this Application, Theia seeks a waiver to the extent required to allow it to use these feeder links to support additional functionalities of its system, in addition to those explicitly permitted under this rule.

If required, based on the Commission's action on that waiver request, Theia will operate its NGSO system on a non-conforming basis in this band. As is the case with the feeder links operating at 29.1-29.5 GHz, discussed above, there is no incremental risk of interference as a result of Theia's operation of the associated gateways at 19.3-19.7 GHz to support the additional functionalities of the TSN because the gateways will operate at the same frequencies, locations and power levels, as they will to support the services contemplated by the Table of Allocations and the Commission's rules. Theia will not claim protection from conforming uses of the spectrum and agrees to accept any harmful interference from conforming services.

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[56] *See Ka-band Plan R&O* ¶¶ 59-62; *see also Redesignation of Ka-band R&O* ¶ 28.

[57] 47 C.F.R. § 2.106, n. NG166.

4.2.2.5 FSS (s-to-E): 19.7 GHz – 20.2 GHz

The Commission's rules allocate this band for primary FSS (space-to-Earth) use for both Federal and non-Federal users, and TSN will operate in this band in accordance with this allocation. More specifically, the Table of Allocations and the Commission's Ka-band Plan provide that the 19.7-20.2 GHz band (space-to-Earth) may be used by GSO FSS operations on a primary basis with no designation for NGSO FSS systems.[58] Elsewhere in this Application, Theia seeks a waiver to the extent necessary to allow its NGSO FSS operations in this band and agrees to accept any harmful interference from these services while operating on a non-conforming, unprotected basis.

As described in connection with that waiver request, it is highly unlikely that such operations will interfere with existing conforming uses. There is little to no potential for interference to existing and future GSO systems by Theia's proposed gateway earth station operations. Theia also will immediately terminate gateway operations in the band upon notification that such operations causing harmful interference to any lawfully authorized radio system in the 19.7-20.2 GHz band.

4.3 Ku-Band Terminals

4.3.1 Uplink Bands (Earth-to-space)

As demonstrated in this Technical Narrative, Appendix 1, Theia's earth station transmissions in the following bands will protect Federal and non-Federal space station receive operations by complying with all applicable $EPFD_{up}$ limits contained in Article 22 of the ITU Radio Regulations and Sections 25.146 and 25.208 of the Commission's rules, 47 C.F.R. §§ 25.146, 25.208.

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58 *See Ka-band Plan R&O* ¶¶ 59-62; *see also Redesignation of Ka-band R&O* ¶ 28.

4.3.1.1 *FSS (E-to-s): 12.75 GHz – 13.25 GHz*

The U.S. Table of Allocations identifies conditions for spectrum use by FSS in the 12.75-13.25 GHz band. The Table of Allocations provides that the 12.75-13.25 GHz band is shared on a co-primary basis with terrestrial FS and FSS operations and NGSO system operations are limited to gateway earth station transmissions.[59] In addition, the Table of Allocations requires that the use of the band 12.75-13.25 GHz (Earth-to-space) by a NGSO FSS system is subject to coordination with other NGSO FSS systems.[60] In the sub-band 13.15-13.2125 GHz, NGSO FSS gateway uplink transmissions shall be limited to a maximum EIRP of 3.2 dBW towards 0° on the radio horizon.[61]

The U.S. Table of Allocations identifies certain types of FS operations considered primary in the 12.75-13.25 GHz band.[62] Theia will not claim protection from lawfully operating GSO FSS networks when operating on a primary basis and will ensure compatibility with other lawfully operating co-primary FSS and FS users. Elsewhere in this Application, Theia has requested a waiver of the Commission's rules to the extent necessary to use this band for non-

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[59] 47 C.F.R. § 25.202(a)(1) (n.6).

[60] 47 C.F.R. § 2.106, footnote 5.441. NGSO systems also cannot claim protection from lawfully operating GSO FSS networks, irrespective of the dates of receipt by the Commission of complete coordination or notification information, as appropriate, for the NGSO or GSO networks. *Id.*

[61] 47 C.F.R. § 2.106, n. NG53.

[62] Specifically, in the band 13.15-13.25 GHz, the following provisions apply: (i) the sub-band 13.15-13.2 GHz is reserved for television pickup ("TVPU") and cable television relay service ("CARS") pickup stations inside a 50 km radius of the 100 television markets delineated in 47 C.F.R. § 76.51; and (ii) outside these areas, TVPU stations, CARS stations and NGSO FSS gateway earth stations shall operate on a co-primary basis. In the sub-band 13.2-13.2125 GHz, TVPU stations are co-primary and CARS pickup stations are secondary inside a 50 km radius of the 100 television markets delineated in 47 C.F.R. § 76.51; and outside these areas, TVPU stations and NGSO FSS gateway earth stations operate on a co-primary basis and CARS stations shall operate on a secondary basis. 47 C.F.R. § 2.106, n. NG53; *Amendment of Parts 2, 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band*, ET Docket No. 98-206, Second Memorandum Opinion and Order, FCC 03-25, 18 FCC Rcd 2324 (2003), at ¶¶ 7-17. In addition, NSF uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars. *See* NTIA Federal Spectrum Use Summary at 61.

gateway operations in order to communicate with Theia user terminals and M2M/IoT terminals. As described in connection with that waiver request, it is highly unlikely that such operations will interfere with existing conforming uses. If granted the waiver as requested, Theia will operate its NGSO system in this band in such a way that minimizes the possibility of interference to existing conforming uses and rapidly eliminates any unacceptable interference that may occur as a result of the operation of TSN user terminals, including by terminating such operations.[63]

4.3.1.2 FSS (E-to-s): 14.0 GHz – 14.5 GHz

The Commission's rules allocate this band on a primary basis to Ku-band FSS operations. Theia will operate Ku-band user terminals in this band in accordance with these rules,[64] and shall take all practicable steps to protect the activities in this band of radio astronomy observatories, as required by footnotes US113 and US342 to the U.S. Table of Allocations.[65] Specifically, Theia will ensure it coordinates with astronomy observations of the formaldehyde line frequencies in the 14.47-14.5 GHz band and, should its assignment of this band result in harmful interference to these observations, Theia will remedy the situation to the extent practicable.[66]

Federal agencies use the 14.4-14.5 GHz band for fixed point-to-point microwave relay communications for voice, data, and video as well as airborne downlink data transmissions.

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63 *Id.* n. 5.441

64 *E.g.*, 47 C.F.R. § 25.115(c)(1) (governing licensing of earth stations).

65 47 C.F.R. § 2.106, nn. US113 and US342.

66 Theia also acknowledges that Federal civilian and military agencies operate communications satellite earth stations for voice, data, and video signals using commercial GSO satellites in the band. Specifically, in the 14.0-14.2 GHz band, the NOAA utilizes the band for satellite uplinks for the transmissions of meteorological information as part of the automated weather distribution system ("SAWDS") through non-Federal satellite systems. Additionally, NASA uses this band for spacecraft communications downlinks involving space research as well as TDRSS to provide communications to spacecraft, and NSF uses this band for radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars. NTIA Federal Spectrum Use Summary, at 62. NSF also uses parts of the 14.2-14.47 GHz band for similar purposes. *Id.* at 61-62.

Additionally, NASA conducts research in the 14.47-14.5 GHz band on ground-to ground transmissions of digital data, digital audio, and digital data to and from water mobile telemetry and precision tracking vans.[67] Theia will work to ensure compatibility of any of the above mentioned Federal operations in the 14.0-14.5 GHz band.

4.3.2 Downlink Bands (space-to-Earth)

As demonstrated in this Technical Narrative, Appendix 1, Theia's space station transmissions in the following bands will protect Federal and non-Federal GSO earth station receive operations by complying with all applicable $EPFD_{down}$ limits contained in Article 22 of the ITU Radio Regulations and Section 25.208 of the Commission's rules, 47 C.F.R. § 25.208. In addition, as demonstrated in this Technical Narrative, Appendix 1, Theia's space station transmissions in the following bands will protect Federal and non-Federal GSO space station receive operations by complying with all applicable $EPFD_{is}$ inter-satellite limits contained in Article 22 of the ITU Radio Regulations.

Finally, as demonstrated in this Technical Narrative, Appendix 2, Theia's space station transmissions in the following bands will protect Federal and non-Federal terrestrial operations by complying with all applicable PFD limits contained in Article 21 of the ITU Radio Regulations and Section 25.146 of the Commission's rules, 47 C.F.R. §25.146.

4.3.2.1 FSS (s-to-E): 10.7 GHz – 11.7 GHz

The 11.7-12.2 GHz band is allocated on a primary basis to FSS operations and the Commission adopted note 6 to Section 25.202(a)(1) of the Commission's Rules to limit use of this band by NGSO FSS systems to transmissions to or from gateway earth stations. Theia

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[67] *Id.* at 62.

proposes to operate its user terminals in the 10.7-11.7 GHz band and, therefore, to the extent necessary, requests a waiver elsewhere in this Application to permit these additional uses of its earth stations in this band. Additionally, prior to commencing operations in the lower portion of the 10.7-11.7 GHz band, Theia will consult with the radio astronomy observatories identified in the Commission's rules in order to achieve a mutually acceptable agreement on the protection of the radio telescope facilities operating in the adjacent 10.6-10.7 GHz band.[68]

Further, Theia acknowledges that Federal, civilian, and military agencies operate satellite earth stations for voice, data, and video signals using commercial geostationary satellites in this band.[69] Additionally, NOAA uses the 10.7-10.8 GHz band for passive sensing of the Earth from space using numerous sensing instruments such as radiometers, imagers, sounders, and temperature and water vapor profilers, etc. Accordingly, Theia will not claim protection from Federal uses in the band and will protect such operations from harmful interference.

4.3.2.2 FSS (s-to-E): 11.7 GHz – 12.2 GHz

The 11.7-12.2 GHz band is allocated on a primary basis to FSS operations and Theia will use this band to support its user terminal operations. Theia acknowledges that Federal, civilian, and military agencies operate communications satellite earth stations for voice, data, and video signals using commercial geostationary satellites and will work to ensure its primary operations are compatible with Federal operations in the band.[70]

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[68] 47 C.F.R. § 2.106, n. US131.

[69] NTIA Federal Spectrum Use Summary, at 60 ("Federal civilian and military agencies operate communications satellite earth stations for voice, data, and video signals using commercial geostationary satellites. These Federal agencies operate earth stations that receive voice, data, and video signals. [NOAA] uses the 10.7-10.8 GHz band for passive sensing of the Earth from space using numerous sensing instruments such as radiometers, imagers, sounders, and temperature and water vapor profilers, etc.").

[70] NTIA Federal Spectrum Usage Summary, at 60 ("Federal civilian and military agencies operate communications satellite earth stations for voice, data, and video signals using commercial geostationary

4.3.2.3 FSS (s-to-E): 12.2 GHz – 12.7 GHz

Pursuant to the Table of Allocations, the 12.2-12.7 GHz band is allocated to the FSS on a primary basis, however it is limited to NGSO systems.[71] Theia will operate in this band consistent with its primary allocation and will not claim protection from GSO networks in the broadcasting-satellite service ("BSS") and rapidly eliminate unacceptable interference that may occur during TSN operations.[72]

Additionally, there are currently 46 grandfathered FS links in the 12.2-12.7 GHz band that have legacy licenses under old FCC allocations. Understanding that no new FS links will be authorized by the Commission in this band, Theia agrees to accept any interference from these 46 legacy FS links and will ensure there is no downlink interference into these 46 legacy FS links.

The Commission has also authorized the Multichannel Video Distribution and Data Service ("MVDDS") for one-way terrestrial wireless transmissions in the 12.2-12.7 GHz band. The technical and service rules for MVDDS in the 12 GHz band specifically state that MVDDS providers will share the 12 GHz band with new NGSO FSS operators on a co-primary basis.[73]

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satellites. This band is the downlink that is paired with the uplink in the 14.0-14.5 GHz band. The NSF uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.").

[71] 47 C.F.R. § 2.106, n. 5.487A.

[72] *Id.*, n. 5.441.

[73] *See 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; Amendment of the Commission's Rules to Authorize Subsidiary Terrestrial Use of the 12.2-12.7 GHz Band by Direct Broadcast Satellite Licensees and Their Affiliates; and Applications of Broadwave USA, PDC Broadband Corporation, and Satellite Receivers, Ltd. To Provide A Fixed Service in the 12.2-12.7 GHz Band*, ET Docket No. 98-206, RM-9147, RM-9245, Memorandum Opinion and Order and Second Report and Order, FCC 02-116 (2002) ("*MVDDS Second R&O*").

To account for the particular interference mechanisms between MVDDS and NGSO systems, the Commission adopted the following operating requirements for both systems:

> *MVDDS Operating Requirements:*
>
> (i) PFD at a distance: To promote MVDDS and NGSO FSS band sharing, the PFD of an MVDDS transmitting system shall not exceed -135 dBW/m2/4 kHz measured and/or calculated at the surface of the earth at distances greater than 3 km from the MVDDS transmitting site.
>
> (ii) The maximum MVDDS EIRP shall not exceed 14 dBm per 24 MHz, but there is no restriction on the polarization of the MVDDS transmission.
>
> (iii) The MVDDS transmitting antenna may not be installed within 10 km of any pre-existing NGSO FSS receiver unless the affected licensees agree to a closer separation.
>
> *NGSO FSS Operating Requirements:*
>
> (iv) Later-in-time NGSO FSS receivers must accept any interference resulting from pre-existing MVDDS transmitting antennas.
>
> (v) Low angle PFD limits on NGSO FSS downlinks in 12.2-12.7 GHz band: For elevation angles from 0˚ to 2˚ above the horizontal plane, NGSO FSS downlinks must meet a reduced PFD level of -158 $dBW/m^2/4kHz$, and for elevation angles from 2˚ to 5˚ degrees above the horizontal plane, a reduced PFD level of -158 + 3.33 (δ-2) $dBW/m^2/4kHz$, where δ is the elevation angle in degrees.

To allow the sharing mechanisms of (i), (iii) and (iv) above to be implemented the MVDDS and NGSO FSS operators must maintain and share databases of their respective transmitters and receivers, as required by the *MVDDS Second R&O*.[74] Theia is committed to this sharing arrangement and will comply with the Commission's rules regarding coordination between NGSO FSS and MVDDS operations at 12.2-12.7 GHz. Theia will also comply with the

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[74] In this context, because Theia user terminals would be the victim of any MVDDS interference, and will be required to accept such interference, Theia will not constrain the growth of MVDDS. Therefore, although Theia is willing to maintain the required database, it does not expect interference issues to arise, even with respect to user terminals used in mobility applications.

requirements of (v) above concerning the low elevation angle PFD limits in the 12.2-12.7 GHz band, as demonstrated in above.

4.4 §25.261 Procedures for avoidance of in-line interference events for NGSO FSS satellite network operations.

TSN will operate in compliance with §25.261 and will follow the procedures as established by §25.261 for avoiding any possible in-line interference event. Specifically, Theia will coordinate with other NGSO operators in the 28.6-29.1 GHz and 18.8-19.3 GHz bands according to the coordination procedures in §25.261(d) to establish mutually acceptable levels of angular separation among operational links of the networks to avoid interference, as well as mutually acceptable frequencies of operation of operational links among the networks to avoid interference. Absent agreement among the operators, Theia will comply with the Commission's default procedure per §25.261(c).

Our preliminary orbital analysis suggests that Ku-band in-line interference events, as defined by the Commission[75], between the TSN and OneWeb constellations will occur approximately 1% of the time when both OneWeb and TSN select the highest visible satellite and neither system employs satellite diversity. During these, relatively rare, in-line interference events the spectrum usage plans of TSN and OneWeb should only result in a maximum of 25% probability that normal operations by both systems would result in an interference event since neither system is capable of using the Ku-band spectrum allocation at every location, all of the time. Both systems should be able to operate normally 99.75% of the time and only 0.25% of the time will the TSN system need to reduce bandwidth to users to accommodate NGSO sharing.

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[75] §25.261(b) defines an in-line interference-event as "the interference associated with an occurrence of any physical alignment of space stations of two or more satellite networks with an operating Earth station of one of these networks in such a way that the angular separation between operational links of the two networks is less than 10° as measured at the Earth station"

The TSN payload design is highly flexible and can easily accommodate dynamic band segmentation scenarios as envisioned by the Commission. The OneWeb payload offers less flexibility with regard to band segmentation, however, the OneWeb constellation provides extensive multiple coverage such that the probability of needing to accommodate band segmentation should be significantly less than 0.25% of the time.

In Ka-band, both OneWeb and TSN employ the spectrum for gateway communications only. As such, the probability of in-line interference events can be further reduced through coordination of gateway site locations such that mutually exclusive sites are selected whenever practical. The near-polar nature of the TSN constellation, coupled with our rich inter-satellite connectivity, motivates the placement of gateway sites at extreme North latitudes where a single gateway facility can simultaneously communicate with multiple satellites. While the OneWeb constellation is also nearly polar, the satellites are bent-pipe thus gateways must be distributed within areas where user services will be provided. The TSN gateway facilities that are placed at extreme North latitudes also eliminate the potential for in-line interference events with the O3b constellation. In cases where TSN does place gateway within the line of sight of the O3b equatorial MEO constellation, the site location will be coordinated with O3b to minimize the possibility for interference. The nature of the O3b payload is such that it cannot provide ubiquitous service. Therefore, site coordination should be readily achievable in most cases.

Theia acknowledges that the processing round is likely to draw other potential Ku and Ka-band non-GSO operators, some of which may deploy constellations. Theia is committed to working with all non-GSO operators that are granted licenses from the FCC to coordinate operational agreements that maximize varied opportunities to provide services in these bands.

4.5 §25.272 General inter-system coordination procedures.

The SOCs are equipped with the full suite of hardware and software to monitor space-Earth transmissions in the TSN. TSN operations shall coordinate transmissions with those of other systems to prevent harmful interference incidents, or, in the event of a harmful interference incident to identify the source of the interference and correct the problem promptly.

Appendix 1

Ku-Band and Ka-Band
EPFD Compliance Analysis

Equivalent power flux density ("EPFD") is a mechanism to enable the sharing of spectrum between non-geostationary satellite orbit ("NGSO") and geostationary satellite orbit ("GSO") systems without requiring the NGSO operator to coordinate with all GSO operators with co-frequency operations. The analysis set forth herein demonstrates how Theia Holdings A, Inc.'s ("Theia") proposed NGSO system, the Theia Satellite Network ("TSN"), will meet the EPFD requirements in the Ku-band and Ka-band. The operational constraints used for this analysis are applicable to those regions where Theia plans to operate without coordination with co-frequency GSO operators.

Section I of this Annex provides a detailed explanation of the downlink, uplink and inter-satellite EPFD levels produced by TSN satellite and earth station transmissions in the Ku-band. Section II of this annex provides a detailed explanation of the downlink, uplink, and inter-satellite EPFD levels produced by TSN satellite and earth station transmissions in Ka-band.

I. KU-BAND EPFD ANALYSIS

As demonstrated below, TSN Ku-band downlink and uplink EPFD levels comply with the single-entry EPFD validation limits outlined in 47 C.F.R. § 25.146(a)(1) and (2). The inter-satellite EPFD levels, which, while not mandated by the Federal Communications Commission ("FCC" or "Commission"), are also shown to comply. This discussion is organized with the relevant requirements of section 25.146 repeated (shown in italicized text below), followed by a demonstration of compliance with the requirement.

§25.146 Licensing and operating rules for the non-geostationary orbit Fixed-Satellite Service in the 10.7 GHz-14.5 GHz bands.

(a) A comprehensive technical showing shall be submitted for the proposed non-geostationary satellite orbit Fixed-Satellite Service (NGSO FSS) system in the 10.7-14.5 GHz bands. The technical information shall demonstrate that the proposed NGSO FSS system would not exceed the validation equivalent power flux-density (EPFD) limits as specified in §25.208 (g), (k), and (l) for $EPFD_{down}$, and $EPFD_{up}$. If the technical demonstration exceeds the validation EPFD limits at any test points within the U.S. for domestic service and at any points outside of the U.S. for international service or at any points in the geostationary satellite orbit, as appropriate, the application would be unacceptable for filing and will be returned to the applicant with a brief statement identifying the non-compliance technical demonstration. The technical showing consists of the following:

The technical information provided below demonstrates that TSN operations will not exceed the single-entry validation EPFD limits in Ku-band as specified in sections 25.208 (g), (k), and (l) of the FCC's rules for $EPFD_{down}$ and $EPFD_{up}$.[1]

> *(1) Single-entry validation equivalent power flux-density, in the space-to-Earth direction, ($EPFD_{down}$) limits. (i) Provide a set of power flux-density (PFD) masks, on the surface of the Earth, for each space station in the NGSO FSS system. The PFD masks shall be generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503, "Functional Description to be used in Developing Software Tools for Determining Conformity of Non-GSO FSS Networks with Limits Contained in Article 22 of the Radio Regulations." In particular, the PFD masks must encompass the power flux-density radiated by the space station regardless of the satellite transmitter power resource allocation and traffic/beam switching strategy that are used at different periods of a NGSO FSS system's life. The PFD masks shall also be in an electronic form that can be accessed by the computer program specified in paragraph (a)(1)(iii) of this section.*

$EPFD_{down}$:

In order to demonstrate compliance with the single-entry validation EPFD limits in the space-to-Earth direction ("$EPFD_{down}$"), Theia is providing the Commission with the database that contains the sets of Ku-band power flux-density ("PFD") masks, on the surface of the Earth, for each TSN space station. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503, which is S.1503-2, issued in December 2013. The PFD masks are one of the data inputs to the EPFD validation software program required to calculate the $EPFD_{down}$ levels in Ku-band. The PFD masks define the maximum satellite downlink PFD in Ku-band over the surface of the Earth that is visible to the satellite.

According to ITU-R Recommendation S.1503-2, the PFD masks can be expressed in two ways. The first option uses the avoidance angle (α) between this NGSO space station and the GSO arc, as seen from any point on the surface of the Earth; and the difference ΔL in longitude between the NGSO sub-satellite point and the point on the GSO arc where the α angle is minimized. The second option uses the azimuth ("AZ") and elevation ("EL") angles as viewed from the satellite towards the Earth relative to nadir direction. Theia uses the second option (azimuth/elevation) to describe the downlink PFD mask in the provided database.

(ii) Identify and describe in detail the assumptions and conditions used in generating the power flux density masks.

Theia uses the AZ/ EL option for the definition of its satellite Ku-band PFD masks that are provided with this Application. These masks have been generated using the following methodology and assumptions related to TSN's actual design and real-world operations:

(a) For a given satellite latitude, the coverage area is determined subject to a minimum elevation angle of 12° and a minimum GSO avoidance angle of α.

[1] 47 C.F.R. §§ 25.208(g), (k), and (l).

(b) A square, two-dimensional grid is created in AZ/EL coordinates to cover out to the Earth's limb.
(c) To determine the maximum aggregate PFD value for a given AZ/EL coordinate, a determination is made whether or not that specific coordinate lies within or outside the coverage area
    a. If the coordinate is inside, the PFD value is set to the beam center PFD plus the power increase due to all co-frequency reuses of the spectrum within the footprint, using the worst-case CCI allowance of 10.2 dB[2].
    b. If the coordinate is outside the coverage area, the closest location within the coverage area is identified. The PFD value is then determined from the aggregate effective isotropic radiated power ("EIRP") in the direction of the AZ/EL coordinate (closest beam transmit power plus the antenna discrimination plus the contribution from the other (up to 39) downlink beams assuming an average side-lobe level of -25 dB.

The coverage area changes continuously for latitudes between 61.7° S and 61.7° N, assuming an altitude of 800-km and 10° α-angle. Including masks for satellite latitudes separated by 1° helps reduce quantization errors. For example, Figure 1 shows the PFD mask for 10° α for TSN satellite at 30° N and 800 km altitude. The area in the gray indicates points that the TSN satellite can serve. The white area within the circle indicates points that the TSN satellite cannot serve because it would violate the 10° α constraint. The blue line is the GSO arc.

[2] The worst case CCI of 10.2 dB assumes 6 beams each at -18 dB.

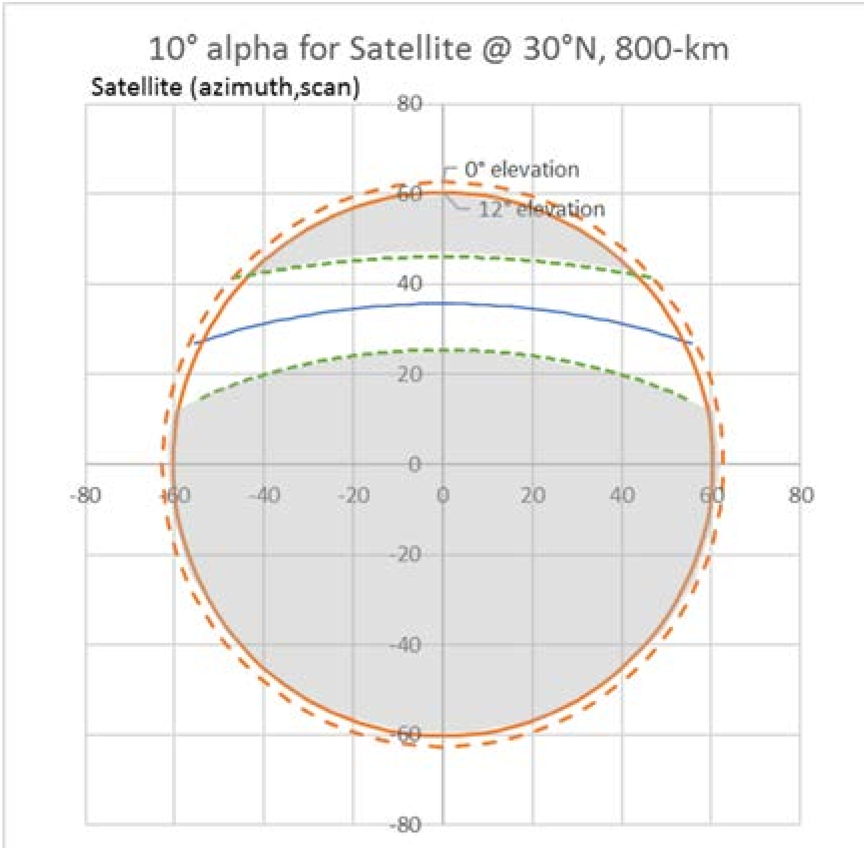

Figure 1. TSN Satellite PFD for 10° α for satellite at 30° N, 800 km

(iii) If a computer program that has been approved by the ITU for determining compliance with the single entry $EPFD_{down}$ validation limits is not yet available, the applicant shall provide a computer program for the single-entry $EPFD_{down}$ validation computation, including both the source code and the executable file. This computer program shall be developed in accordance with the specification stipulated in the most recent version of Recommendation ITU-R S.1503. If the applicant uses the ITU approved software, the applicant shall indicate the program name and the version used.

The ITU released a test version of a computer program for determining compliance with the single-entry downlink, uplink and inter-satellite EPFD validation limits in June 2016. The test package includes, but is not limited to a Graphical Interface for Batch Calculations ("GIBC") module, which can be used for EPFD examination and an EPFDResultsView tool, which can be used to visualize EPFD results. The GIBC software module used is version 9.0.0.24 May 2016.

Theia used the EPFD Validation package to determine compliance and to prepare the required data to be used for regulatory examination. Figure 2 shows the GIBC module start screen. The EPFD-validation software includes two implementations of the EPFD validation software: Transfinite and Agenium. Theia-generated PFD masks and EIRP masks used as input to the software are being provided with this application. Theia is prepared to provide all necessary assistance to the FCC in running the ITU-provided EPFD validation software program.

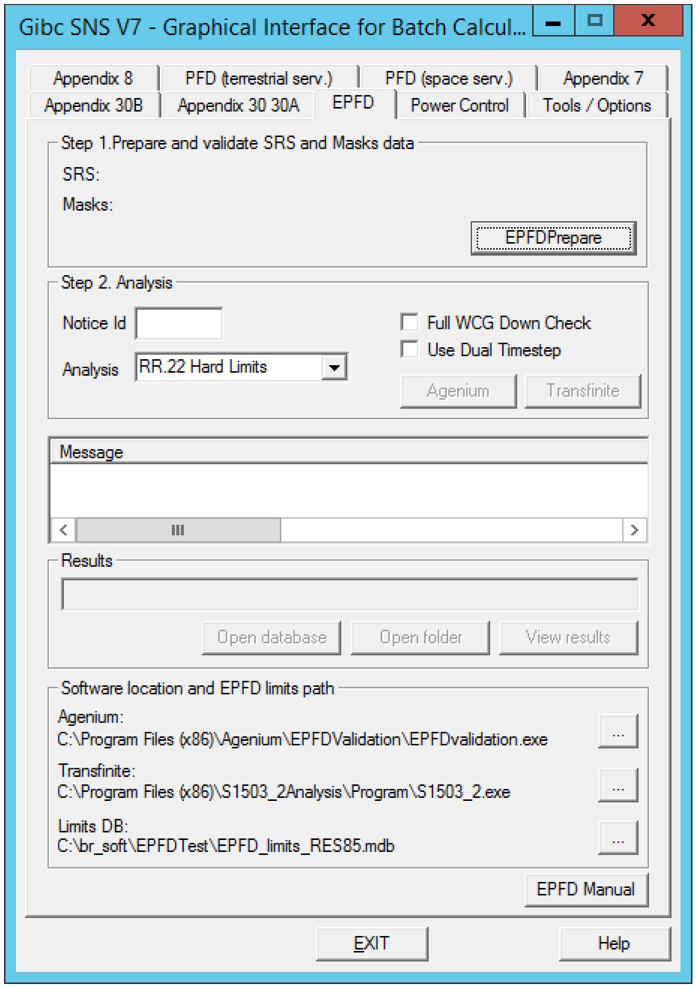

Figure 2. GIBC EPFD Start Screen GUI

(iv) Identify and describe in detail the necessary input parameters for the execution of the computer program identified in paragraph (a)(1)(iii) of this section.

Theia is providing to the Commission, with this Application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{down}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the TSN constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

1. The orbital parameters of the TSN constellation, consistent with the associated Schedule S submission;

2. The parameter titled "nbr_op_sat" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "sat_oper" Table). This is defined as "the maximum number of non-geostationary satellites transmitting with overlapping frequencies to a

given location in various latitude ranges." A value of 4 is proposed for all latitude ranges for Ku-band downlink;

3. The parameter titled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "grp" Table). This is defined as "the minimum elevation angle at which any associated non-geostationary satellite earth station can transmit to a non-geostationary satellite." A value of 12° is used for TSN for both uplink and downlink; and

4. The parameters titled "f_x_zone" and "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). The parameter "f_x_zone" is a flag indicating the type of zone: if the exclusion zone angle is the angle alpha [Y] or the angle X [N]. The alpha angle is chosen for TSN. The parameter "x_zone" is defined as "width of the exclusion zone in degrees" which is essentially the minimum GSO avoidance angle, α, measured at the surface of the Earth. For the TSN Ku-band user terminals, this parameter is set to 10° as this reflects the way the TSN system will be operated.

(v) Provide the result, the cumulative probability distribution function of EPFD, of the execution of the computer program described in paragraph (a)(1)(iii) of this section by using only the input parameters contained in paragraphs (a)(1)(i) and (a)(1)(iv) of this section.

The Ku-band $EPFD_{down}$ results obtained from the EPFD validation computer program using the input data explained above are illustrated below. Each plot corresponds to one of the GSO reference earth station antenna sizes from the EPFD limits. In particular, Figure 3, Figure 4, Figure 5 and Figure 6 show the lower Ku-band downlink (10.7 to 11.7 GHz) EPFD results for 0.6m, 1.2m, 10m and 3m antenna diameter, respectively. The lower Ku-band downlink is only for FSS.[3]

On the other hand, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14 show the upper Ku-band downlink (11.7 to 12.5 GHz) EPFD results for 0.3m, 0.45m, 0.6m, 0.9m, 1.2m, 1.8m, 2.4m, and 3m antenna diameter, respectively. The upper Ku- band downlink is for FSS and BSS.[4]

The plots provided were generated using the EPFDResultsView plotting tool. The red and orange curves represent the EPFD validation software output and EPFD limit, respectively. The labeling of each diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the size of the GSO reference earth station antenna (in meters) and whether this is a BSS/FSS or

[3] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 10.7 GHz is used for the lower Ku-band which ranges between 10.7 and 11.7 GHz.
[4] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 11.7 GHz is used for the upper Ku-band which ranges between 11.7 and 12.75 GHz.

FSS-only EPFD limit. Moreover, software type (Transfinite or Agenium) used for the validation is also indicated.

The EPFD validation software also outputs the worst-case geometry indicated by the earth-station (ES) location (latitude and longitude) and the GSO longitude. For all plots, it is shown that the limit is always to the right of the software calculated EPFD curve. Hence, the TSN system is compliant with the downlink Ku-band EPFD limits for all types of antenna diameter.

The results demonstrate that the TSN system complies with the Commission's and the ITU's $EPFD_{down}$ limits.

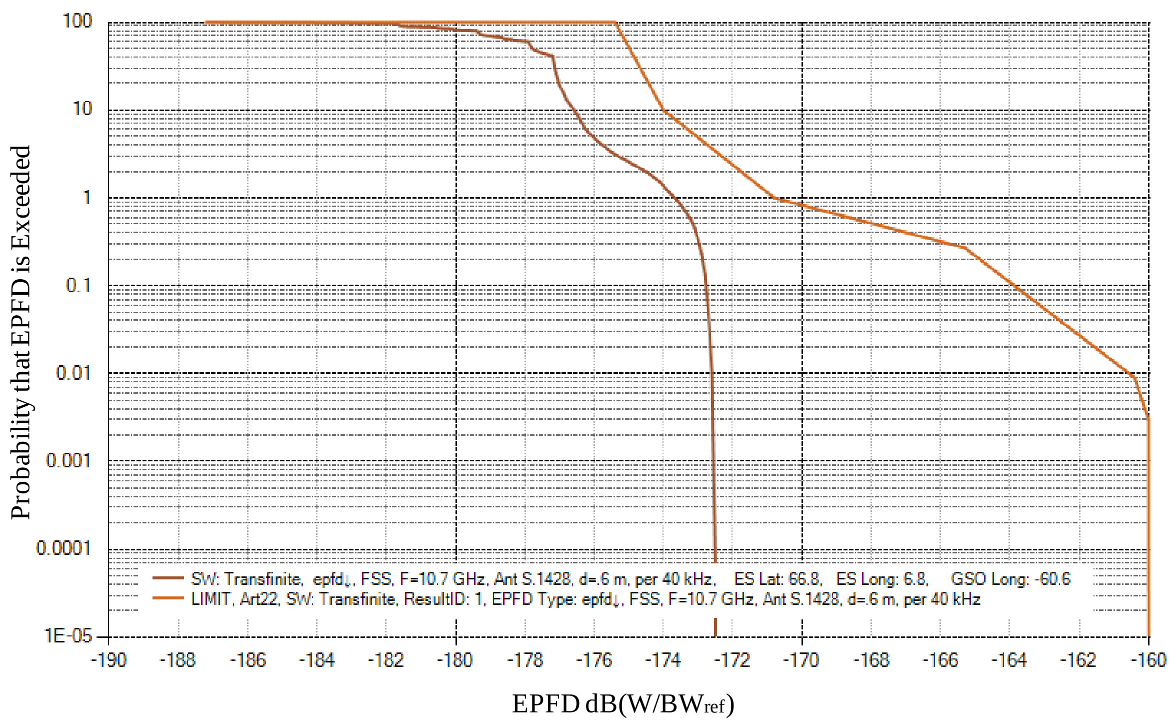

Figure 3. Ku-band Downlink: F=10.7 GHz, d=0.6m

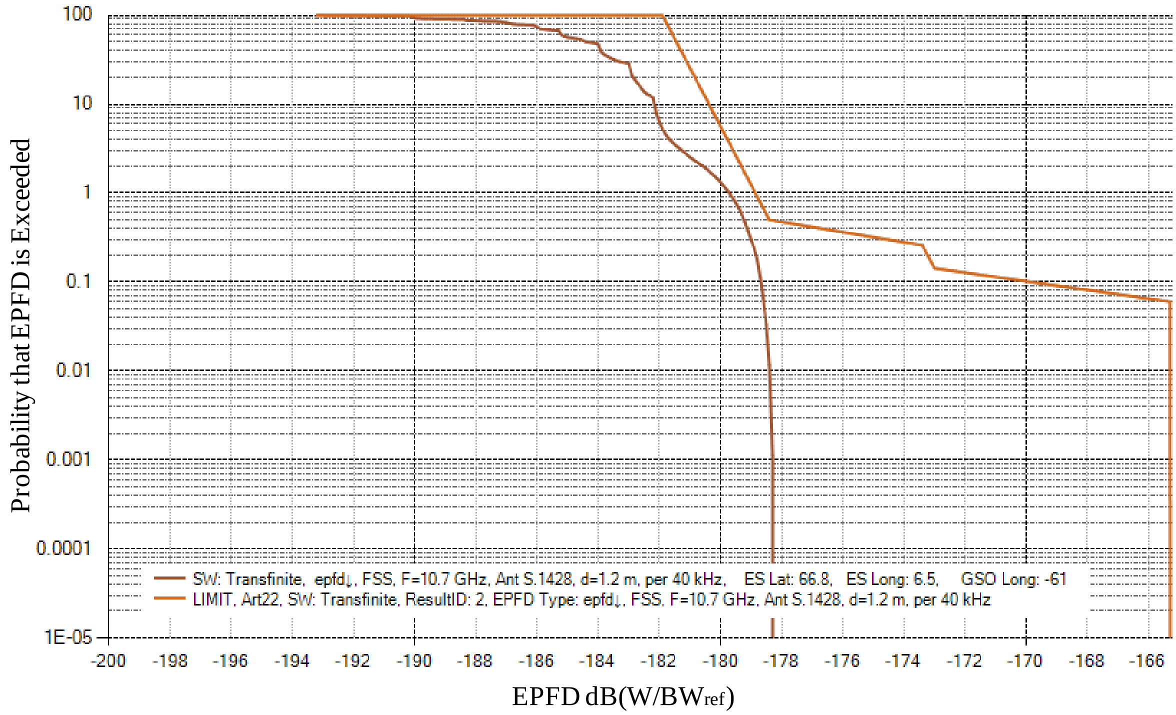

Figure 4. Ku-band Downlink: F=10.7 GHz, d=1.2m

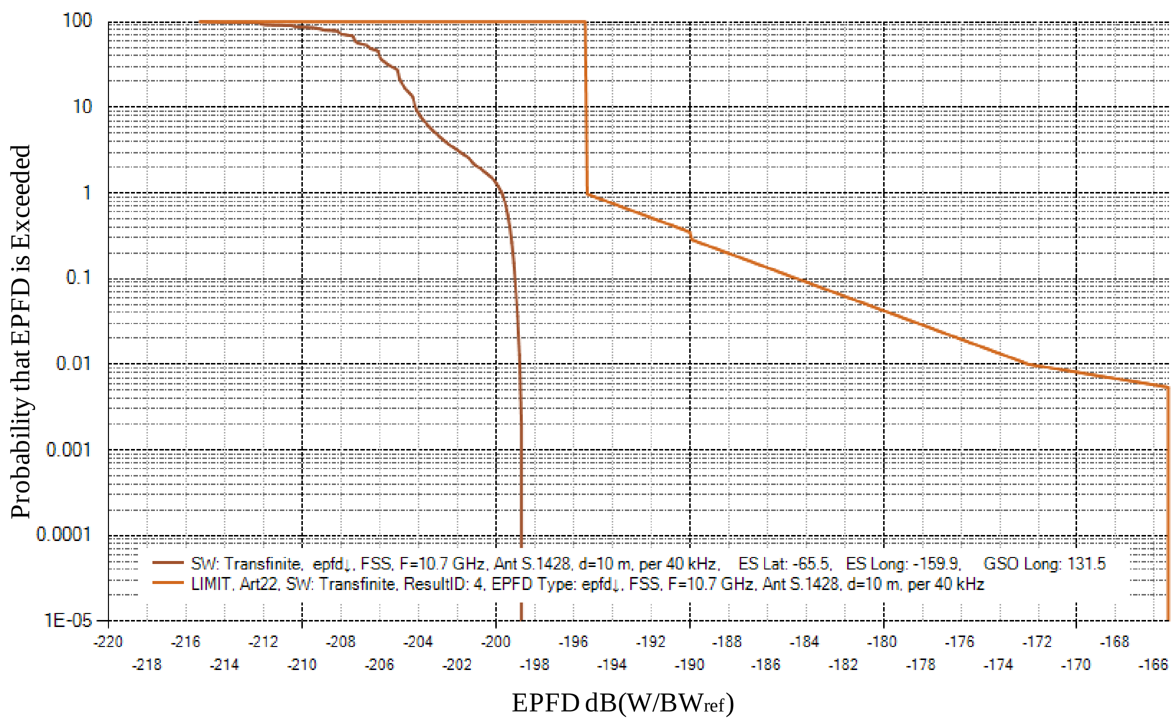

Figure 5. Ku-band Downlink: F=10.7 GHz, d=10m

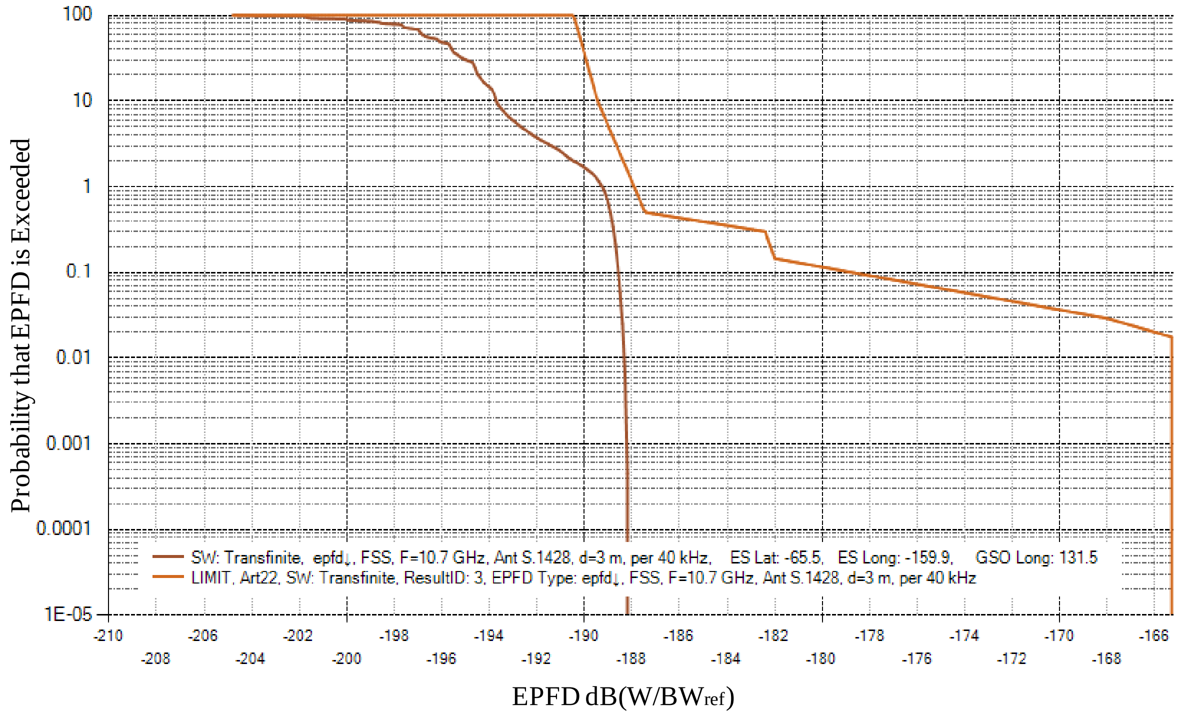

Figure 6. Ku-band Downlink: F=10.7 GHz, d=3m

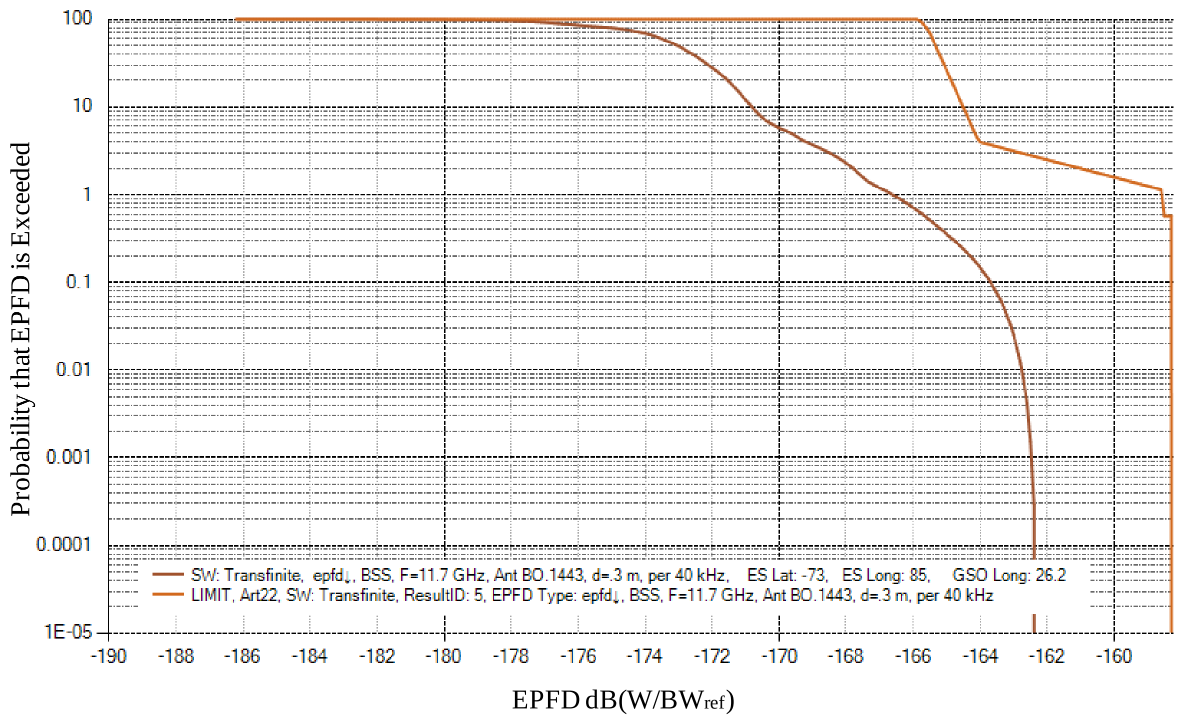

Figure 7. Ku-band Downlink: F=11.7 GHz, d=0.3m

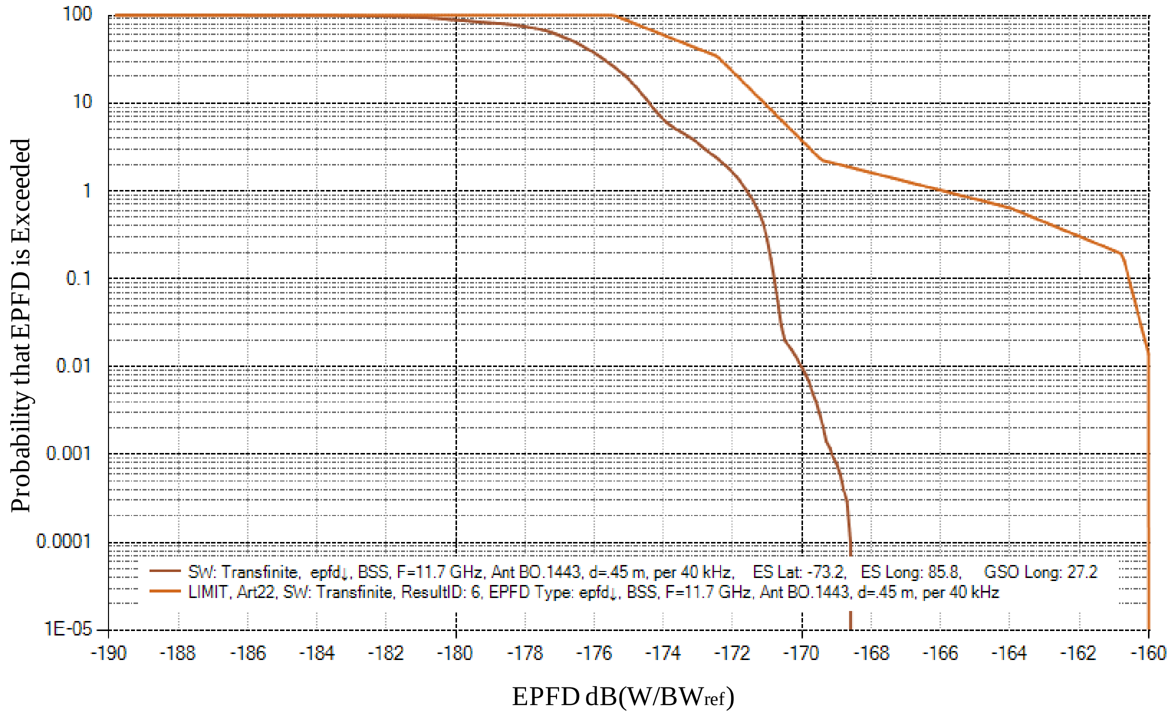

Figure 8. Ku-band Downlink: F=11.7 GHz, d=0.45m

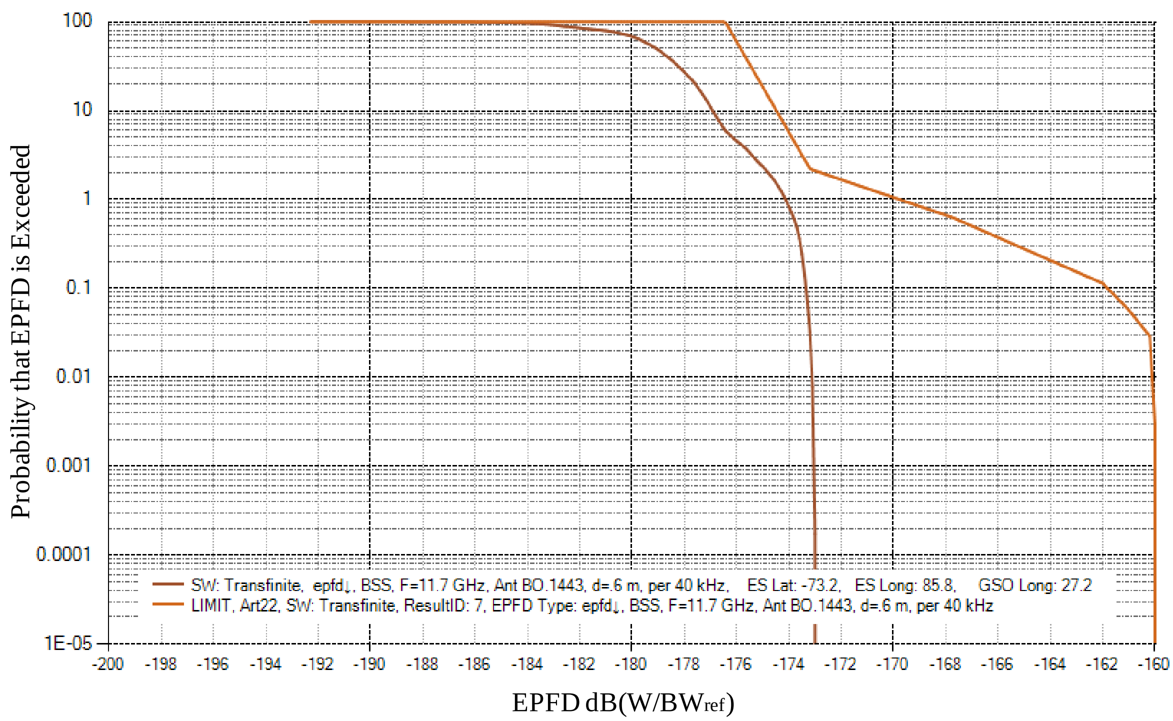

Figure 9. Ku-band Downlink: F=11.7 GHz, d=0.6m

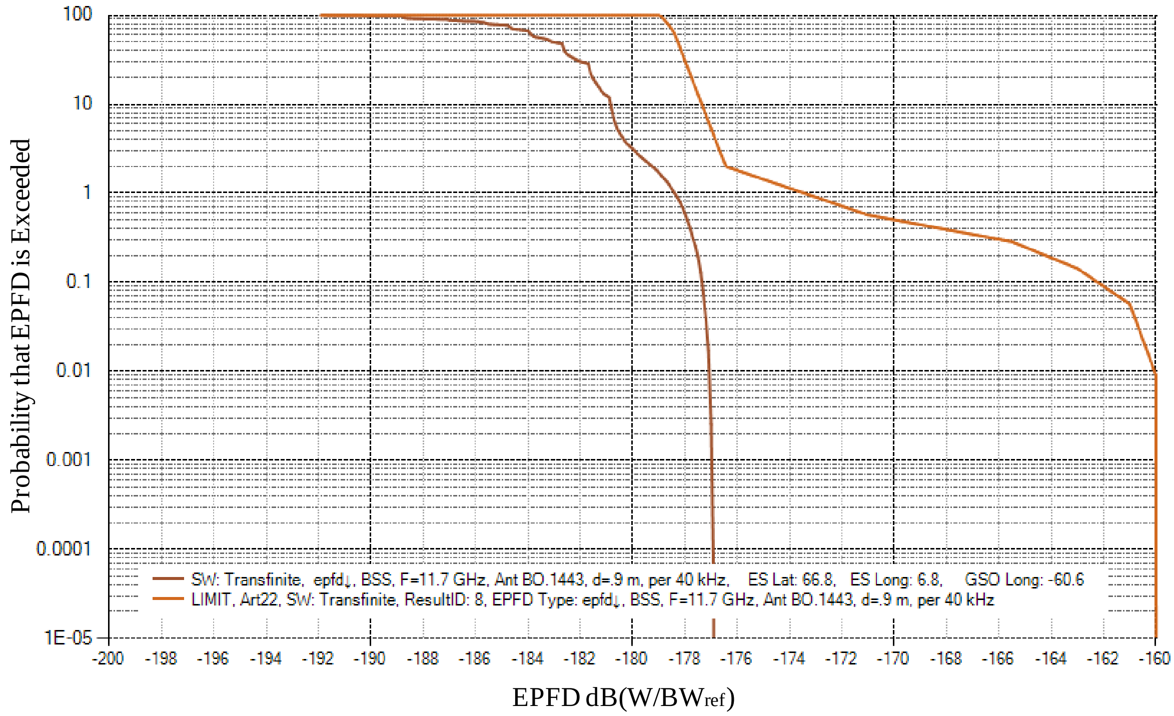

Figure 10. Ku-band Downlink: F=11.7 GHz, d=0.9m

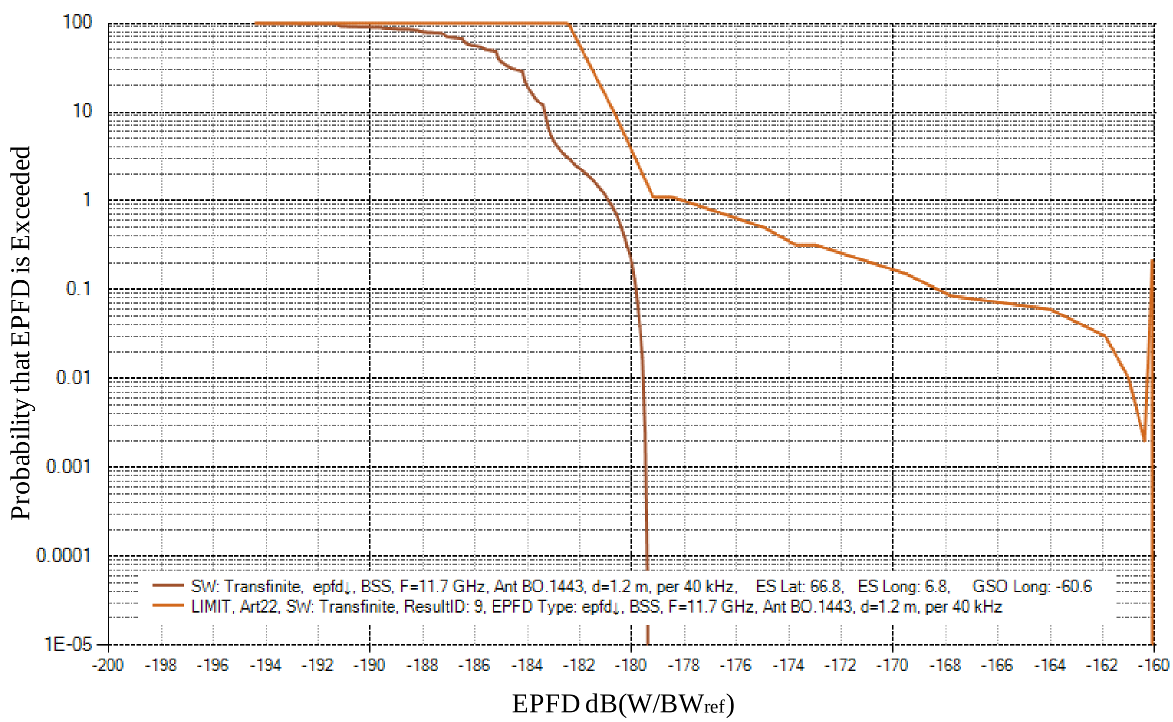

Figure 11. Ku-band Downlink: F=11.7 GHz, d=1.2m

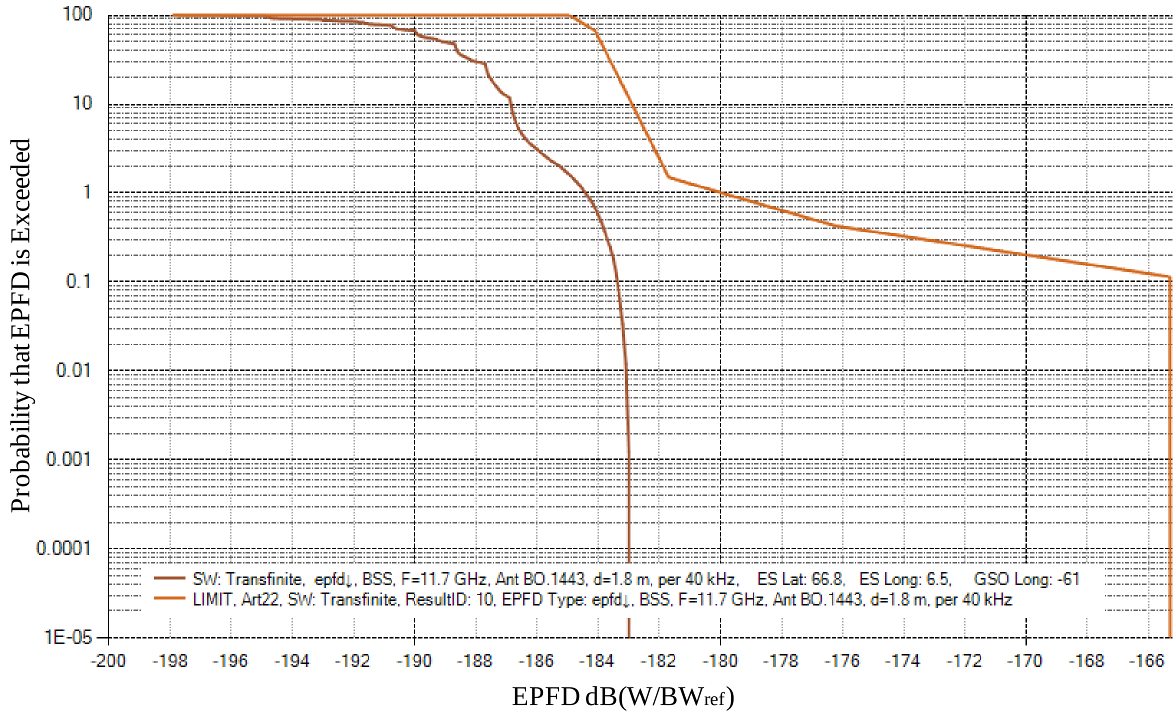

Figure 12. Ku-band Downlink: F=11.7 GHz, d=1.8m

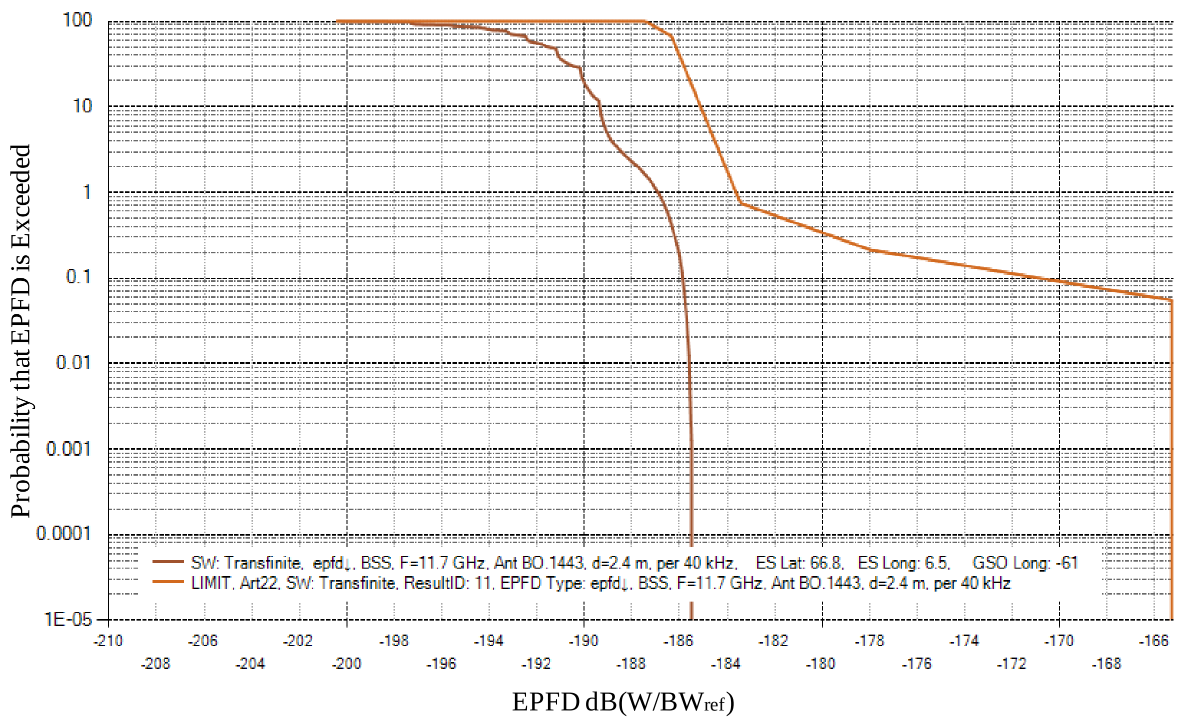

Figure 13. Ku-band Downlink: F=11.7 GHz, d=2.4m

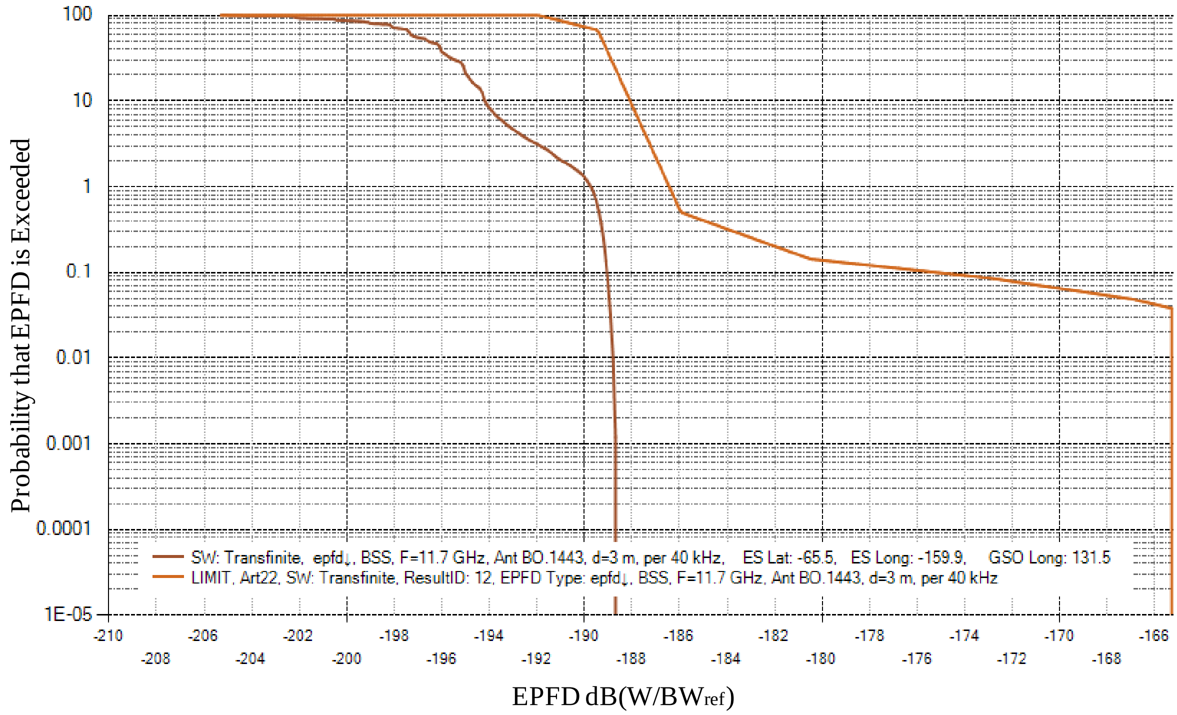

Figure 14. Ku-band Downlink: F=11.7 GHz, d=3m

(2) Single-entry validation equivalent power flux-density, in the Earth-to-space direction, $EPFD_{up}$ limits. (i) Provide a set of NGSO FSS earth station maximum equivalent isotropically radiated power (e.i.r.p.) mask as a function of the offaxis angle generated by a NGSO FSS earth station. The maximum e.i.r.p. mask shall be generated in accordance with the specification stipulated in the ITU-R Recommendation BO.1503. In particular, the results of calculations encompass what would be radiated regardless of the earth station transmitter power resource allocation and traffic/beam switching strategy are used at different periods of a NGSO FSS system life. The e.i.r.p. masks shall also be in an electronic form that can be accessed by the computer program contained in paragraph (a)(2)(iii) of this section.

$EPFD_{up}$:

In order to demonstrate compliance with the single-entry validation EPFD limits in the Earth-to-space direction ($EPFD_{up}$), Theia is providing the Commission with the database that contains the sets of Ku-band maximum off-axis EIRP masks for TSN Ku-band user terminals. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503, which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the $EPFD_{up}$ levels in Ku-band. The EIRP masks define the off-axis EIRP density of the Ku-band transmitting earth stations as a function of off-axis angle. They were derived for each earth station antenna diameter using the ITU reference earth station antenna pattern[5] and the maximum EIRP transmitted by each class of earth station antenna. The masks then assume the off-axis gain

[5] Specifically, ITU-R Recommendation S.1428-1: Reference FSS earth station radiation patterns for use in interference assessment involving NGSO satellites in frequency bands between 10.7 GHz and 30 GHz.

is rotationally symmetric around the boresight of the antenna, and therefore represent a worst-case situation. The EPFD validation software assumes that the same EIRP mask applies at all latitudes.

(ii) Identify and describe in detail the assumptions and conditions used in generating the maximum earth station e.i.r.p. mask.

These masks have been generated using the following methodology and assumptions related to TSN's actual design and real-world operations:

An EIRP mask is created for each reference Ku-band uplink earth station that represents the highest on-axis and off-axis EIRP density levels (per 40 kHz) for each Ku-band transmitting user terminal earth station. The earth station EIRP masks are the same for all latitudes and reflect all conditions of modulation and traffic patterns.

(iii) If a computer program that has been approved by the ITU for determining compliance with the single entry $EPFD_{up}$ validation limits is not yet available, the applicant shall provide a computer program for the single-entry $EPFD_{up}$ validation computation, including both the source code and the executable file. This computer program shall be developed in accordance with the specification stipulated in the most recent version of Recommendation ITU-R S.1503. If the applicant uses the ITU approved software, the applicant shall indicate the program name and the version used.

The same ITU provided EPFD Validator software that was used to determine compliance with the $EPFD_{down}$ limits was also used for $EPFD_{up}$. *See* comments in the $EPFD_{down}$ subsection, above, demonstrating compliance with the requirements of 47 C.F.R. § 25.146(a)(1)(iii).

(iv) Identify and describe in detail the necessary input parameters for the execution of the computer program identified in paragraph (a)(2)(iii) of this section.

Theia is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{up}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the TSN constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the TSN constellation, consistent with the associated Schedule S submission;
(b) The parameter titled "nbr_sat_td" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the maximum number of co-frequency tracked non-geostationary satellites receiving simultaneously". Assuming the worst-case scenario, this parameter is set to 4;
(c) The parameter titled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "grp" Table). This is defined as "the minimum elevation angle at which any associated non-geostationary satellite earth station can transmit to a non-geostationary satellite." A value of 12° is used for TSN for both uplink and downlink for this parameter;

(d) The parameters titled "f_x_zone" and "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). The parameter "f_x_zone" is a flag indicating the type of zone: if the exclusion zone angle is the angle alpha [Y] or the angle X [N]. The α angle is chosen for TSN. The parameter "x_zone" is defined as "width of the exclusion zone in degrees" which is essentially the minimum GSO avoidance angle, α, measured at the surface of the Earth. For the TSN Ku-band user terminals, this parameter is set to 10° as this reflects the way the TSN system will be operated;

(e) The parameter titled "density" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the average number of associated earth stations transmitting with overlapping frequencies per km^2 in a cell." The value of this parameter is related directly to the size of the aggregate beam coverage area from each TSN satellite and the maximum number of times an uplink frequency can be spatially re-used within this area. The density value for TSN is 0.000004 earth stations per km^2;

(f) The parameter titled "avg_dist" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the average distance between co-frequency cells in kilometers." The value of this parameter is directly related to the "density" value described above, and is in fact the square root of the inverse of the density value. This gives a value of 500 km as the average distance between co-frequency transmitting earth stations.

(v) Provide the result of the execution of the computer program described in paragraph (a)(2)(iii) of this section by using only the input parameters contained in paragraphs (a)(2)(i) and (a)(2)(iv) of this section.

The Ku-band $EPFD_{up}$ results obtained from the EPFD validation computer program using the input data explained above are illustrated below. Figure 15 shows the EPFD simulation results for the uplink. The red and orange curves respectively represent the EPFD validation software output and EPFD limit. The labeling of each diagram indicates the frequency (in GHz), and the reference bandwidth (40 kHz).[6] Moreover, software type (Transfinite or Agenium) used for the validation is also indicated.

The EPFD validation software also outputs the worst-case geometry. For the plot, it is shown that the limit is always to the right of the software calculated EPFD curve. Hence, TSN is compliant with the $EPFD_{up}$ limits.

[6] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 12.75 GHz is used for the Ku-band uplink which ranges between 12.5 and 14.5 GHz.

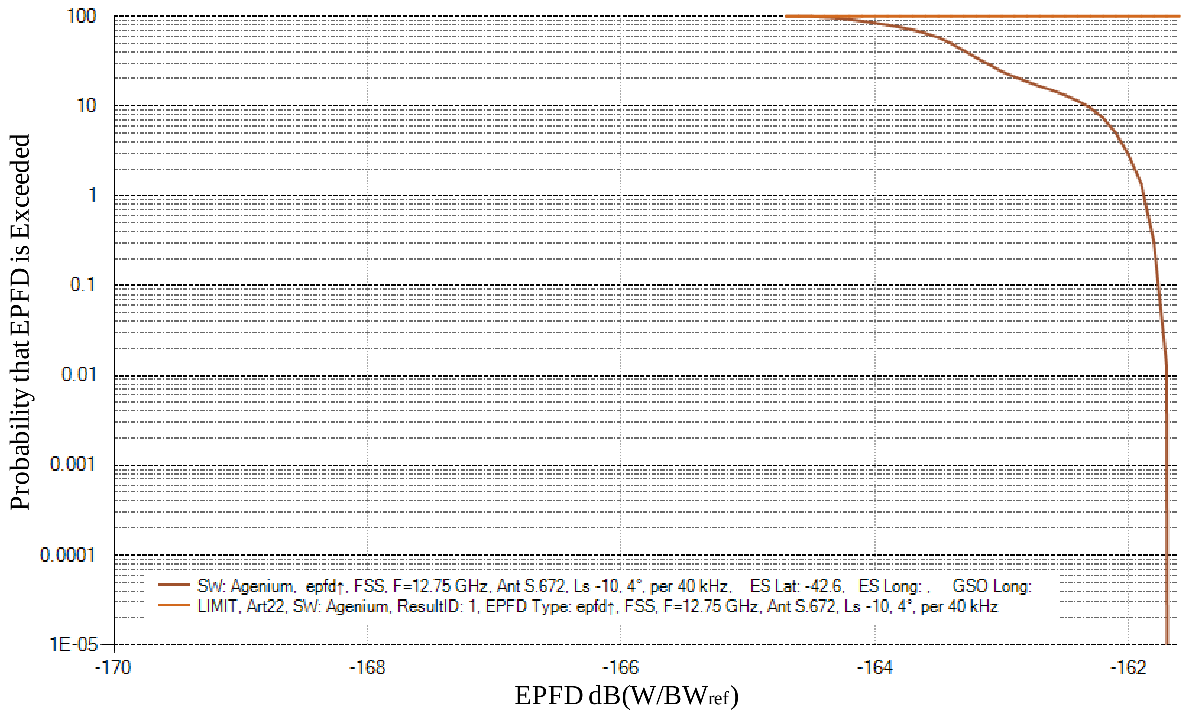

Figure 15. Ku-band Uplink: F=12.75 GHz

The results above demonstrate that TSN complies with the Commission's and the ITU's $EPFD_{up}$ limits.

$EPFD_{is}$:

The $EPFD_{is}$ limits in the ITU Radio Regulations are intended to protect GSO satellite receivers from interference from the space-to-Earth transmissions of NGSO satellites. In the Ku-band, the frequency ranges for $EPFD_{is}$ is from 10.7-11.7 GHz and 12.5-12.75 GHz.[7] In this subsection, we demonstrate that TSN complies with the $EPFD_{is}$ limits in the ITU Radio Regulations. These limits are contained in No. 22.5F, Table 22-3 of the Radio Regulations, which has been copied below. The $EPFD_{is}$ limits consist of a single, never to be exceeded, EPFD level at the GSO, defined as follows:

[7] Specifically, 10.7-11.7 GHz and 12.5-12.75 GHz in Region 1, and 12.7-12.75 GHz in Region 2.

Table 1. No. 22.5F, Table 22.3 of the Radio Regulation

22.5F 4) The equivalent power flux-density[18], $epfd_{is}$, produced at any point in the geostationary-satellite orbit by emissions from all the space stations in a non-geostationary-satellite system in the fixed-satellite service in the frequency bands listed in Table **22-3**, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, shall not exceed the limits given in Table **22-3** for the specified percentages of time. These limits relate to the equivalent power flux-density which would be obtained under free-space propagation conditions into a reference antenna and in the reference bandwidth specified in Table **22-3**, for all pointing directions towards the Earth's surface visible from any given location in the geostationary-satellite orbit. (WRC-2000)

TABLE **22-3** (WRC-2000)

Limits to the $epfd_{is}$ radiated by non-geostationary-satellite systems in the fixed-satellite service in certain frequency bands[19]

Frequency band (GHz)	$epfd_{is}$ (dB(W/m^2))	Percentage of time during which $epfd_{is}$ level may not be exceeded	Reference bandwidth (kHz)	Reference antenna beamwidth and reference radiation pattern[20]
10.7-11.7 (Region 1) 12.5-12.75 (Region 1) 12.7-12.75 (Region 2)	−160	100	40	4° Recommendation ITU-R S.672-4, $L_s = -20$
17.8-18.4	−160	100	40	4° Recommendation ITU-R S.672-4, $L_s = -20$

In order to demonstrate compliance with the single-entry validation equivalent power flux density ($EPFD_{is}$) limits, Theia is providing the Commission with the database that contains the sets of Ku-band maximum off-axis EIRP masks for the space stations in the TSN system. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the $EPFD_{is}$ levels in Ku-band. The EIRP masks define the off-axis EIRP density (per 40 kHz) of the Ku-band transmitting earth stations as a function of off-axis angle.

The same ITU-provided EPFD Validator software that was used to determine compliance with the $EPFD_{is}$ limits was also used for $EPFD_{down}$ and $EPFD_{up}$. *See* comments in the $EPFD_{down}$ subsection above demonstrating compliance with the requirements of 47 C.F.R. § 25.146(a)(1)(iii).

Theia is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{is}$ levels. The provided database is identical to the Ku-band $EPFD_{down}$ data, and $EPFD_{is}$ results from these input databases.

The Ku-band EPFDis results obtained from the EPFD validation computer program using the input data explained above are illustrated in Figure 16 below, which shows the EPFD simulation result for the inter-satellite link. The red and orange curves represent the EPFD validation software output and EPFD limit, respectively. The labeling of each diagram indicates the frequency (in GHz) and the reference bandwidth (40 kHz).[8] The software used for the EPFD validation is also shown.

The EPFD validation software also outputs the worst-case geometry. For all plots, it is shown that the limit is always to the right of the software calculated EPFD curve. Hence, TSN is compliant with the EPFDis limits in the Ku-band.

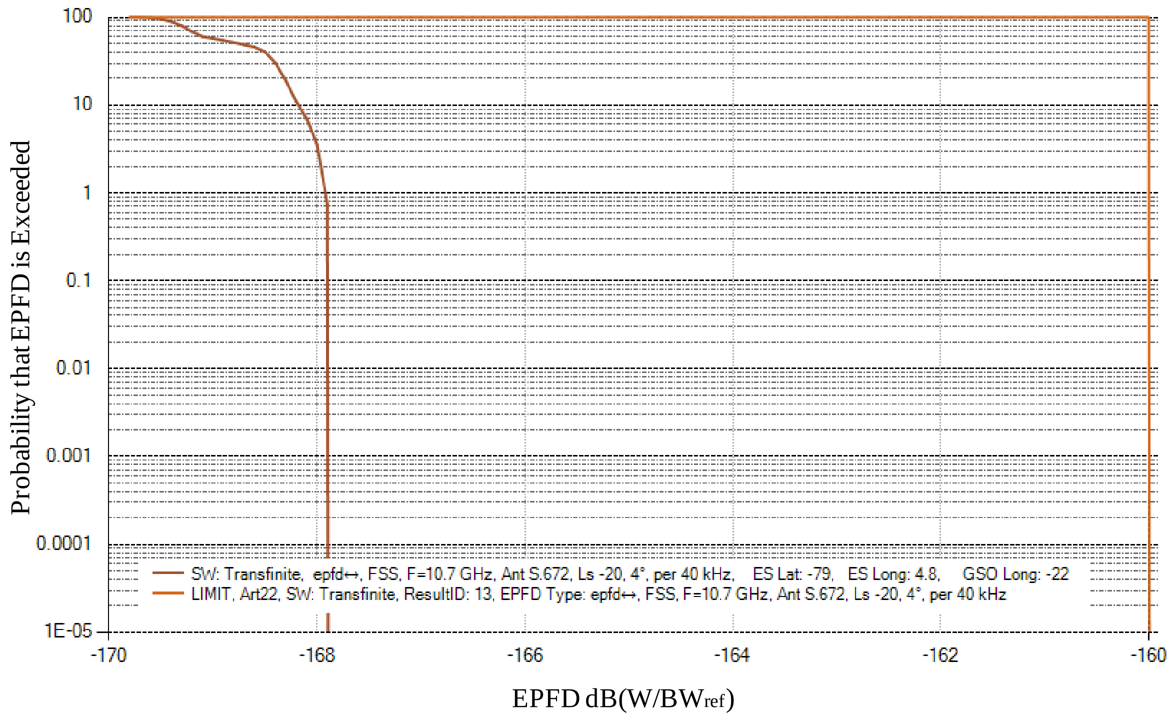

Figure 16. Ku-band IS: F=10.7 GHz

Other EPFD rules:

Theia will comply at the appropriate time with the rules in sections 25.146(b), (g), and 25.208(l), (j), and (i) of the Commission's rules, which require additional submissions on the part of Theia ninety days prior to the initiation of service to the public.

Theia confirms, consistent with sections 25.146(e) and 25.208(o), that it is not claiming interference protection from GSO FSS and BSS networks operating in accordance with the FCC Part 25 rules and the ITU Radio Regulations.

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[8] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 10.7 GHz is used for the inter-satellite Ku-band which ranges 10.7-11.7 GHz and 12.5-12.75 GHz in Region 1, and 12.7-12.75 GHz in Region 2.

Theia confirms it will coordinate with the very large GSO FSS earth stations in the 10.7-12.75 GHz band under the conditions described in section 25.146(f).

II. KA-BAND EPFD ANALYSIS

As demonstrated below, TSN Ka-band downlink and uplink EPFD levels comply with the single-entry EPFD validation limits in No. 22.5C, 22.5D and 22.5F of the ITU Radio Regulations.[9] It is further demonstrated below that the TSN Ka-band inter-satellite EPFD levels also comply with these requirements.

$EPFD_{down}$:
In order to demonstrate compliance with the single-entry validation EPFD limits in the space-to-Earth direction ($EPFD_{down}$), Theia is providing the Commission with the database that contains the sets of Ka-band PFD masks, on the surface of the Earth, for each TSN space station. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013.

The PFD masks are one of the data inputs to the EPFD validation software program required to calculate the $EPFD_{down}$ levels in Ka-band. The PFD masks define the maximum satellite downlink PFD in Ka-band over the surface of the Earth that is visible to the satellite. According to ITU-R Recommendation S.1503-2, the PFD masks can be expressed in two ways. The first option uses the separation angle α between this NGSO space station and the GSO arc, as seen from any point on the surface of the Earth and the difference ΔL in longitude between the NGSO sub-satellite point and the point on the GSO arc where the α-angle is minimized. The second option uses the AZ and EL angles as viewed from the satellite towards the Earth relative to nadir direction. Theia uses the second option to describe the downlink PFD mask in the provided database.

Theia uses the AZ/EL options described above for the definition of its satellite Ka-band PFD masks that are provided with this application. These masks have been generated using the following methodology and assumptions related to TSN's actual design and real-world operations:

(a) For a given satellite latitude, the coverage area is determined subject to minimum elevation and geosynchronous arc avoidance angle (α).
(b) A square, two-dimensional grid is created in AZ/EL coordinates to cover out to the Earth's limb.
(c) To determine the maximum aggregate PFD value for a given AZ/EL coordinate, a determination is made whether or not the coordinate lies within the coverage area or outside
    (i) If the coordinate is inside, the PFD value is set to the beam center PFD plus 3 dB to account for a coincident, cross-polarization beam. (Note - The 3 dB assumes no cross polarization discrimination for the interfered receiving station)

[9] There are no EPFD limits for Ka-band in the FCC Part 25 rules.

(ii) If the coordinate is outside the coverage area, the closest location within the coverage area is identified. The PFD value is then determined from the aggregate EIRP in the direction of the AZ/EL coordinate - closest beam transmit power plus the antenna discrimination plus the 3 dB to account for a coincident, cross-polarization beam.

The coverage area changes continuously for latitudes between 61.7°S and 61.7°N, assuming an altitude of 800 km and 10° α–angle. Including masks for satellite latitudes separated by 1° helps reduce quantization errors.

The same ITU-provided EPFD Validator software that was used to determine compliance with the $EPFD_{down}$ limits for Ku-band was also used for Ka-band. *See* comments in the Ku-band $EPFD_{down}$ subsection, above, demonstrating compliance with the requirements of 47 C.F.R. § 25.146(a)(1)(iii).

Theia is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{down}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the TSN constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

1. The orbital parameters of the TSN constellation, consistent with the associated Schedule S submission;

2. The parameter titled "nbr_op_sat" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "sat_oper" Table). This is defined as "the maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location in various latitude ranges." A value of 20 is proposed for all latitude ranges for Ka-band downlink, as the EPFD validation software will determine from the orbit geometry the maximum number of visible satellites up to the number provided;

3. The parameter titled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "grp" Table). This is defined as "the minimum elevation angle at which any associated non-geostationary satellite earth station can transmit to a non-geostationary satellite." A value of 12° is used for TSN for both uplink and downlink for this parameter;

4. The parameters titled "f_x_zone" and "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). The parameter "f_x_zone" is a flag indicating the type of zone: if the exclusion zone angle is the angle alpha [Y] or the angle X [N]. The α angle is chosen for TSN. The parameter "x_zone" is defined as "width of the exclusion zone in degrees" which is essentially the minimum GSO avoidance angle, α, measured at the surface of the Earth. For the TSN Ka-band user terminals this parameter is set to 10° as this reflects the way the TSN system will be operated.

The Ka-band $EPFD_{down}$ results obtained from the EPFD validation computer program using the input data explained above are illustrated below. Each plot corresponds to one of the GSO reference earth station antenna sizes from the EPFD limits. In particular, Figure 17, Figure 18 and Figure 19 show the lower Ka-band downlink (17.8 to 18.6 GHz) EPFD results for 1m, 2m, and 5m antenna diameter, respectively.[10] On the other hand, Figure 20, Figure 21, Figure 22 and Figure 23 show the upper Ka-band downlink (19.7 to 20.2 GHz) EPFD results for 0.7m, 0.9m, 2.5m and 5m antenna diameter, respectively[11].

The plots provided were generated using the EPFDResultsView plotting tool. The red and orange curves represent the EPFD validation software output and EPFD limit, respectively. The labeling of each diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), and the size of the GSO reference earth station antenna (in meters). The software used for the EPFD validation is also shown.

The EPFD validation software also outputs the worst-case geometry indicated by the earth-station (ES) location (latitude and longitude) and the GSO longitude. For all plots, it is shown that the limit is always to the right of the software-calculated EPFD curve. Hence, TSN is compliant with the downlink EPFD limits for all types of antenna diameter.

[10] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 17.8 GHz is used for the lower Ka-band which ranges between 17.8 and 18.6 GHz.

[11] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 19.7 GHz is used for the upper Ka-band which ranges between 19.7 and 20.2 GHz.

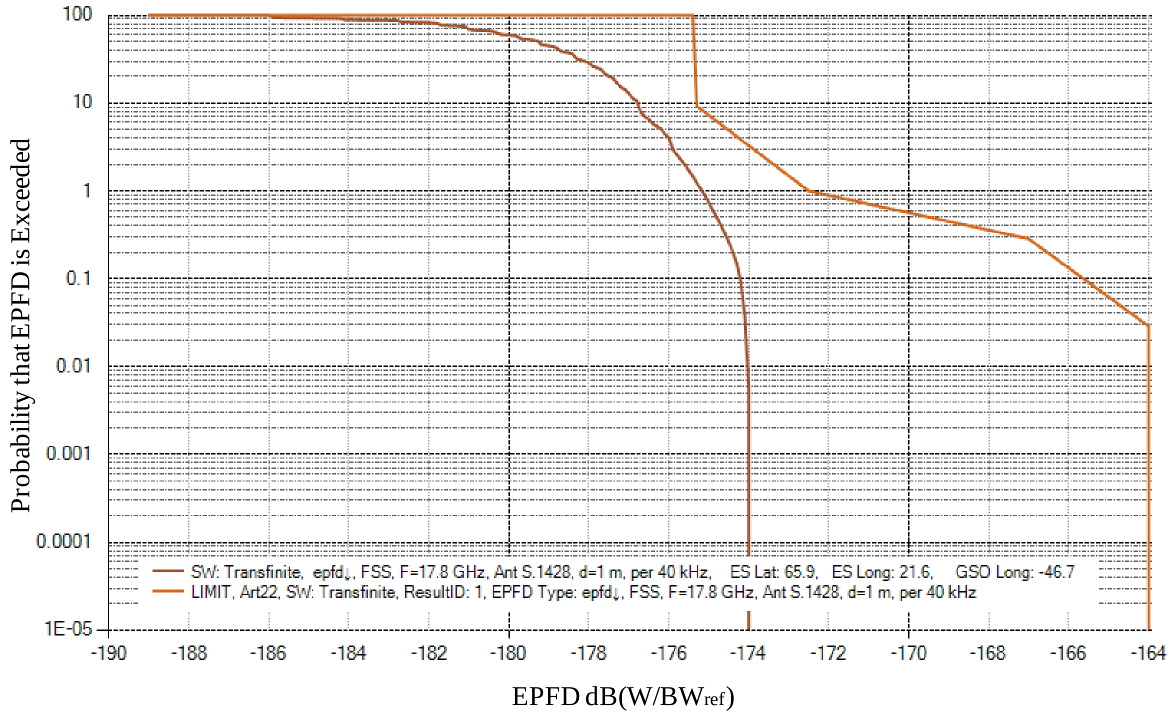

Figure 17. Ka-Band Downlink: F=17.8 GHz, d=1m

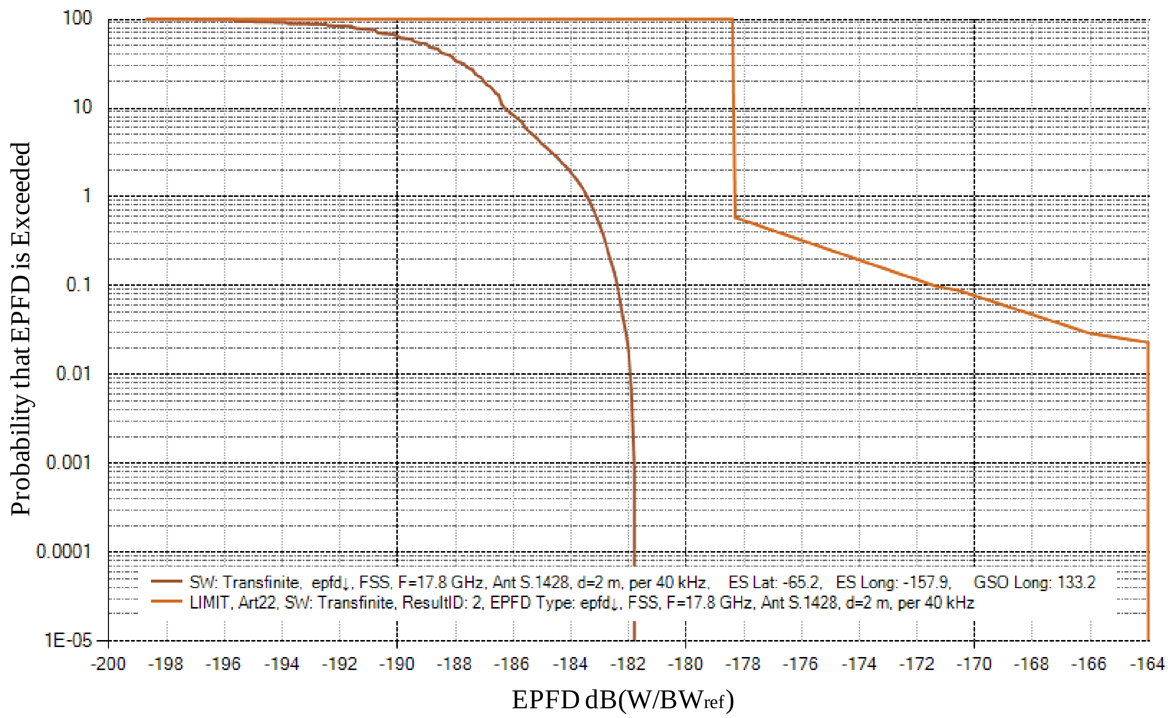

Figure 18. Ka-Band Downlink: F=17.8 GHz, d=2m

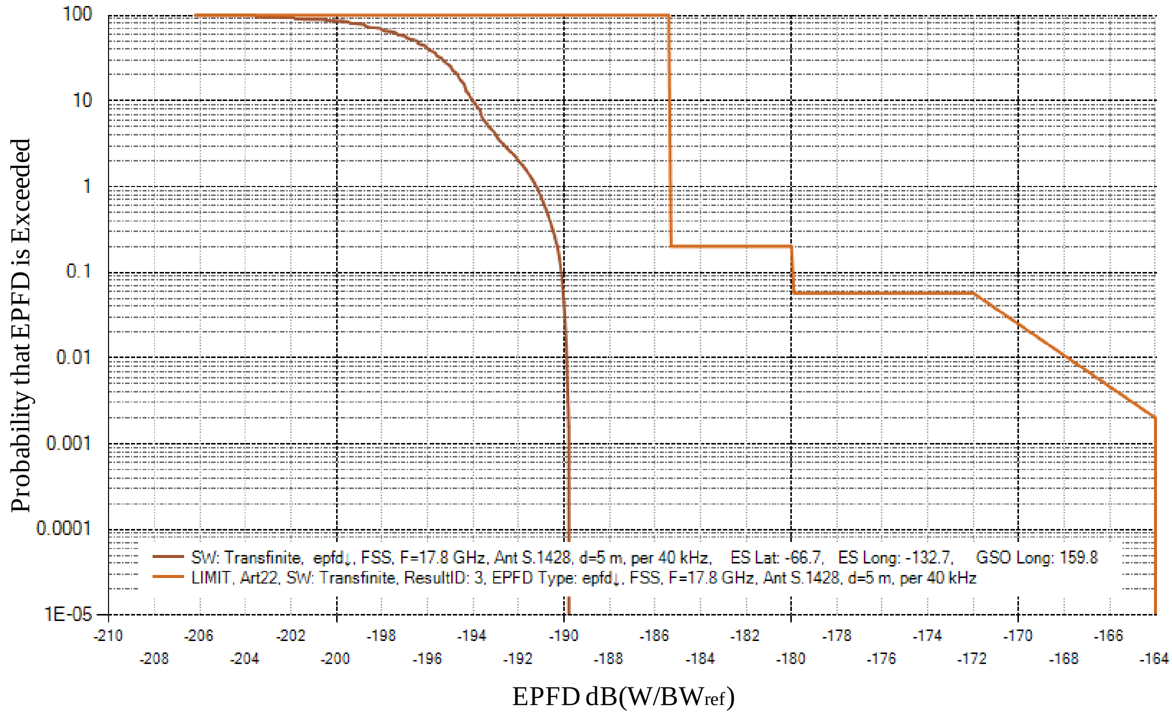

Figure 19. Ka-Band Downlink: F=17.8 GHz, d=5m

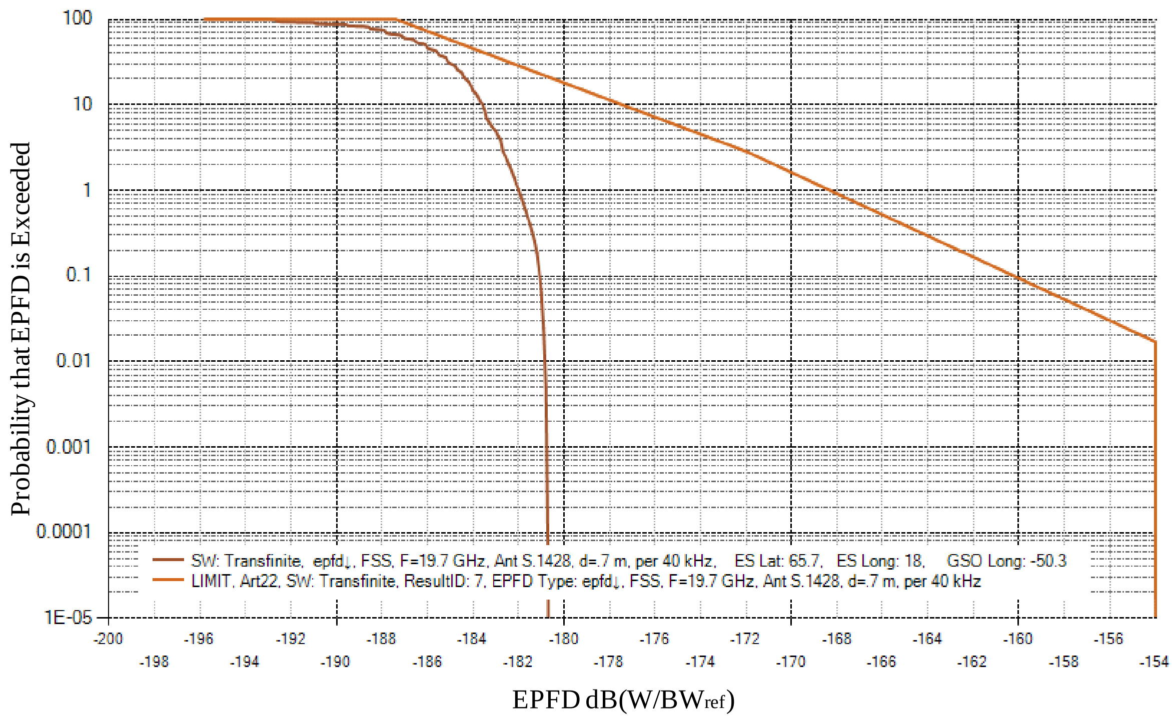

Figure 20. Ka-Band Downlink: F=19.7 GHz, d=0.7m

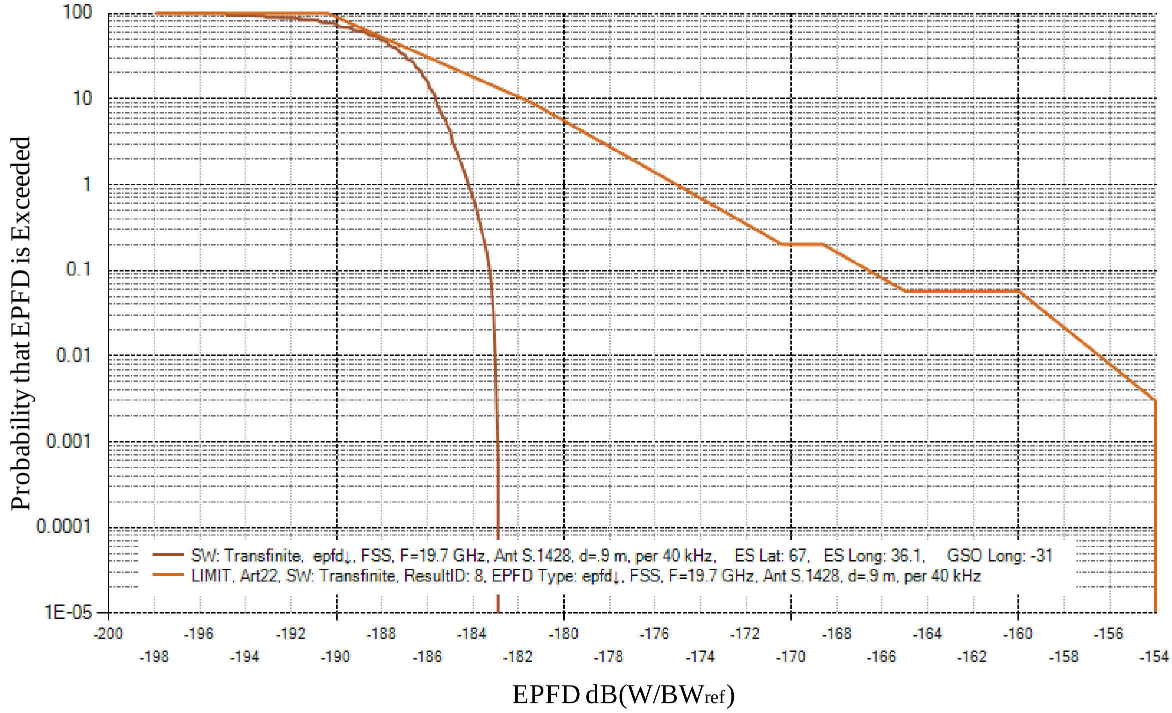

Figure 21. Ka-Band Downlink: F=19.7 GHz, d=0.9m

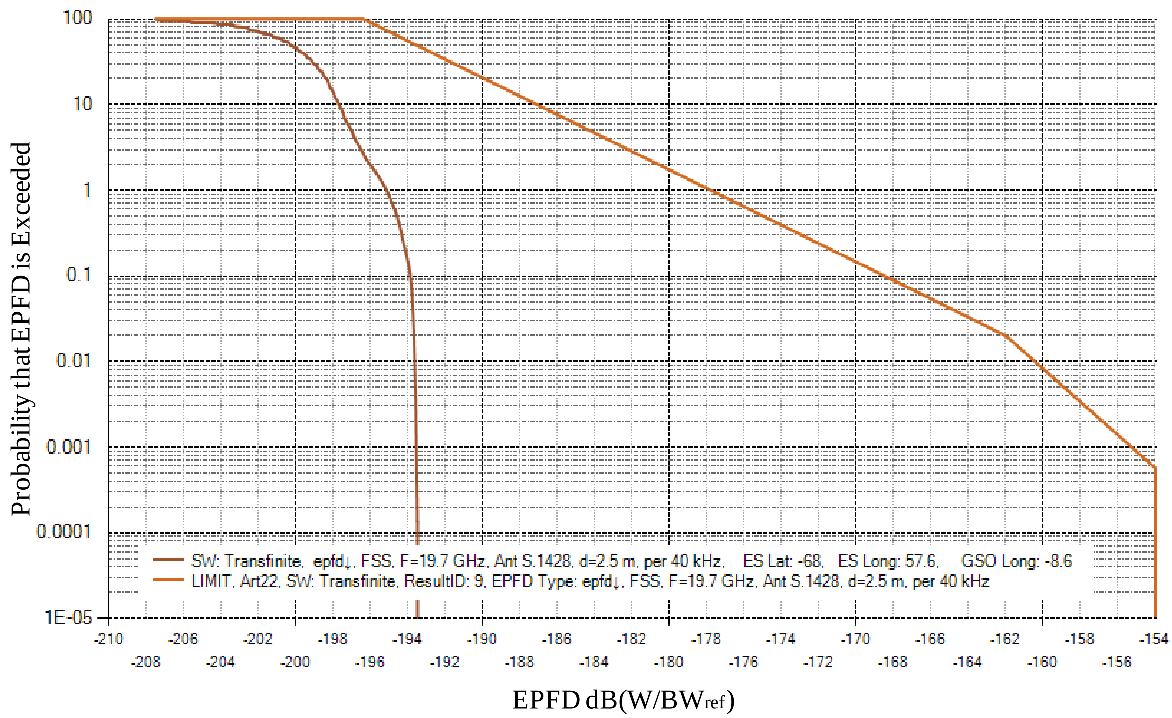

Figure 22. Ka-Band Downlink: F=19.7 GHz, d=2.5m

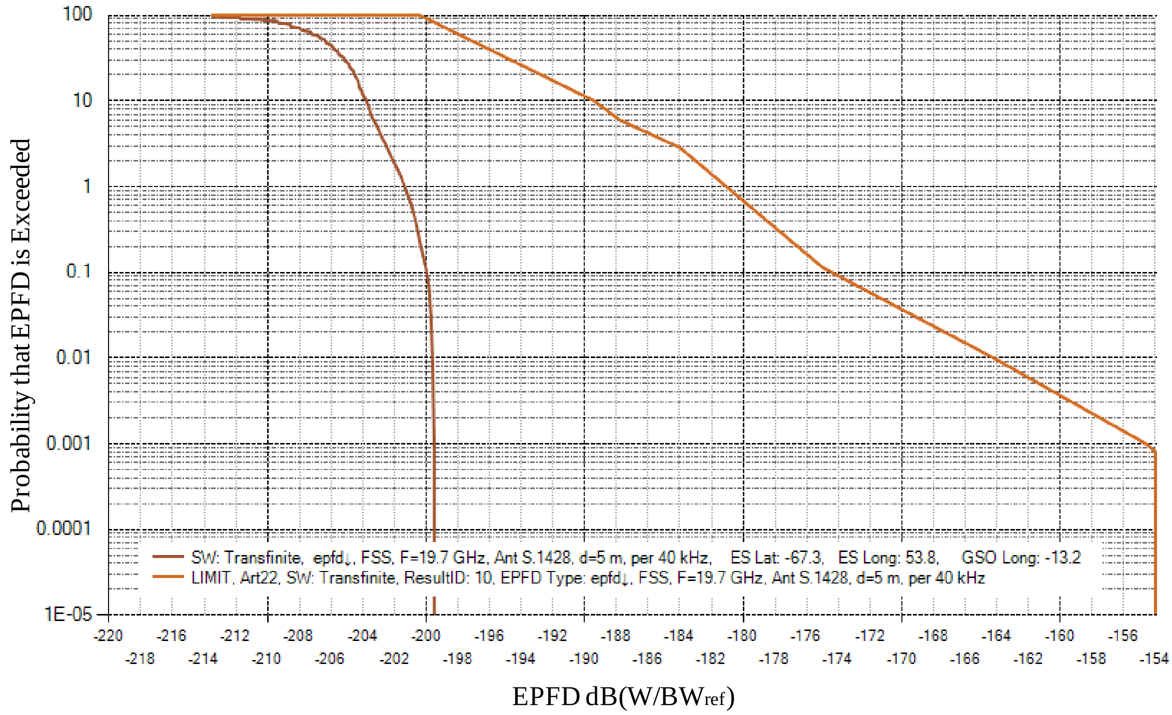

Figure 23. Ka-Band Downlink: F=19.7 GHz, d=5m

EPFD$_{up}$:

In order to demonstrate compliance with the single-entry validation EPFD limits in the Earth-to-space direction (EPFD$_{up}$), Theia is providing the Commission with the database that contains the sets of Ka-band maximum off-axis EIRP masks for TSN gateway earth stations. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the EPFD$_{up}$ levels in Ka-band. The EIRP masks define the off-axis EIRP density of the Ka-band transmitting earth stations as a function of off-axis angle. They were derived for each gateway earth station antenna diameter using ITU reference Earth station antenna pattern[12] and the maximum EIRP transmitted by each class of Earth station antenna. The masks then assume the off-axis gain is rotationally symmetric around the boresight of the antenna, and therefore represent a worst-case situation. The EPFD validation software assumes that the same EIRP mask at all latitudes.

The same ITU-provided EPFD Validator software that was used to determine compliance with the EPFD$_{up}$ limits for Ku-band was also used for Ka-band. *See* comments in the EPFD$_{down}$ subsection in Ku-band above demonstrating compliance with the requirements of 47 C.F.R. § 25.146(a)(1)(iii).

[12] Specifically, ITU-R Recommendation S.1428-1: Reference FSS earth station radiation patterns for use in interference assessment involving NGSO satellites in frequency bands between 10.7 GHz and 30 GHz.

Theia is providing to the Commission, with this Application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{up}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the TSN constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the TSN constellation, consistent with the associated Schedule S submission;

(b) The parameter titled "nbr_sat_td" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the maximum number of co-frequency tracked non-geostationary satellites receiving simultaneously". Assuming the worst-case scenario, this parameter is set to 20;

(c) The parameter titled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "grp" Table). This is defined as "the minimum elevation angle at which any associated non-geostationary satellite earth station can transmit to a non-geostationary satellite." A value of 12° is used for TSN for both uplink and downlink for this parameter;

(d) The parameters titled "f_x_zone" and "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). The parameter "f_x_zone" is a flag indicating the type of zone: if the exclusion zone angle is the angle alpha [Y] or the angle X [N]. The alpha angle is chosen for TSN. The parameter "x_zone" is defined as "width of the exclusion zone in degrees" which is essentially the minimum GSO avoidance angle, α, measured at the surface of the Earth. For the TSN Ka-band user terminals this parameter is set to 10° as this reflects the way the TSN system will be operated;

(e) The parameter titled "density" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the average number of associated earth stations transmitting with overlapping frequencies per km^2 in a cell." The value of this parameter is related directly to the size of the aggregate beam coverage area from each TSN satellite and the maximum number of times an uplink frequency can be spatially re-used within this area. The density value for TSN is 0.000004 earth stations per $km;^2$

(f) The parameter titled "avg_dist" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations under "non-geo" Table). This is defined as "the average distance between co-frequency cells in kilometers." The value of this parameter is directly related to the "density" value described above, and is in fact the square root of the inverse of the density value. This gives a value of 500 km as the average distance between co-frequency transmitting earth stations.

The Ka-band $EPFD_{up}$ results obtained from the EPFD validation computer program using the input data explained above are illustrated below. Figure 24 and Figure 25 show the EPFD results for the uplink. The plots provided were generated using the EPFDResultsView plotting tool. The red and orange curves represent the EPFD validation software output and EPFD limit, respectively. The labeling of each diagram indicates the frequency (in GHz), and reference bandwidth (40 kHz).[13] Moreover, the software used for the EPFD validation is also shown. The EPFD validation software also outputs the worst-case geometry. For the plot, it is shown that the limit is always to the right of the software calculated EPFD curve. Hence, TSN is compliant with the uplink EPFD limits for all types of antenna diameter for Ka-band.

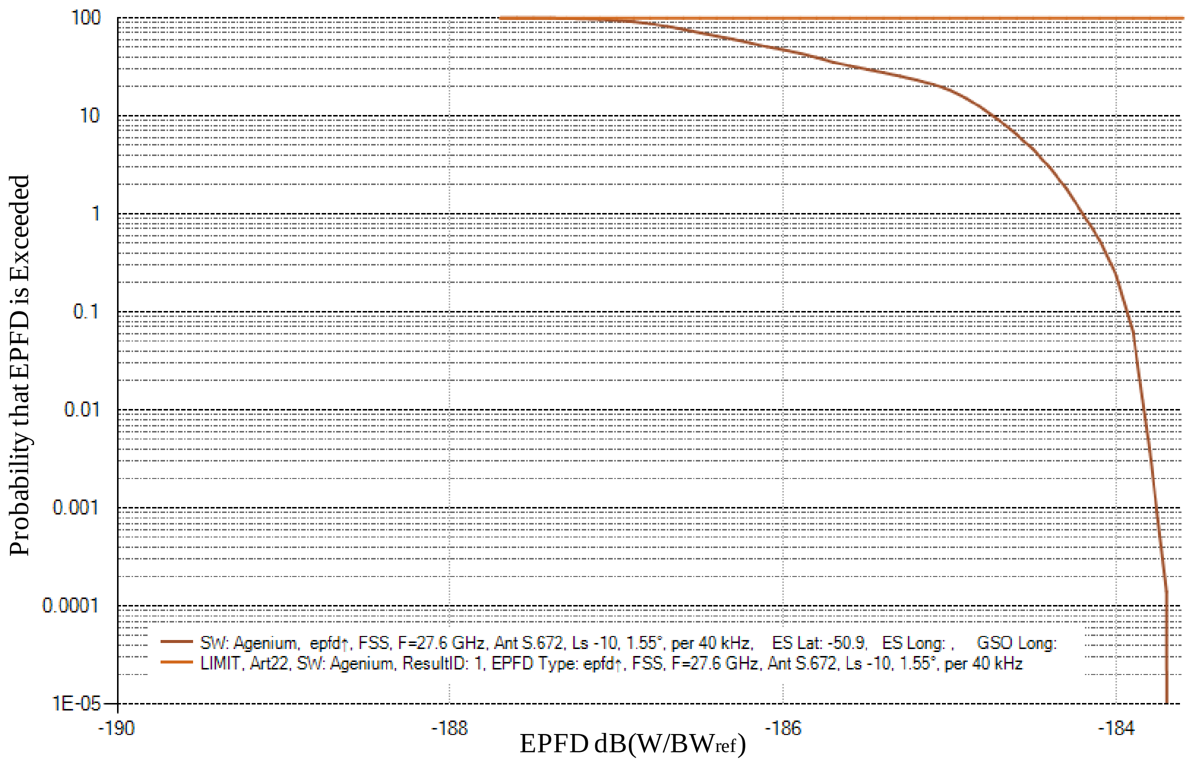

Figure 24. Ka-band Uplink: F=27.6 GHz

[13] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 27.6 GHz is used for the lower Ka-band which ranges between 27.5 and 28.6 GHz. Moreover, for the upper Ka-band, the frequency 29.5 GHz is used for the Ka-band which ranges between 29.5 and 30.0 GHz.

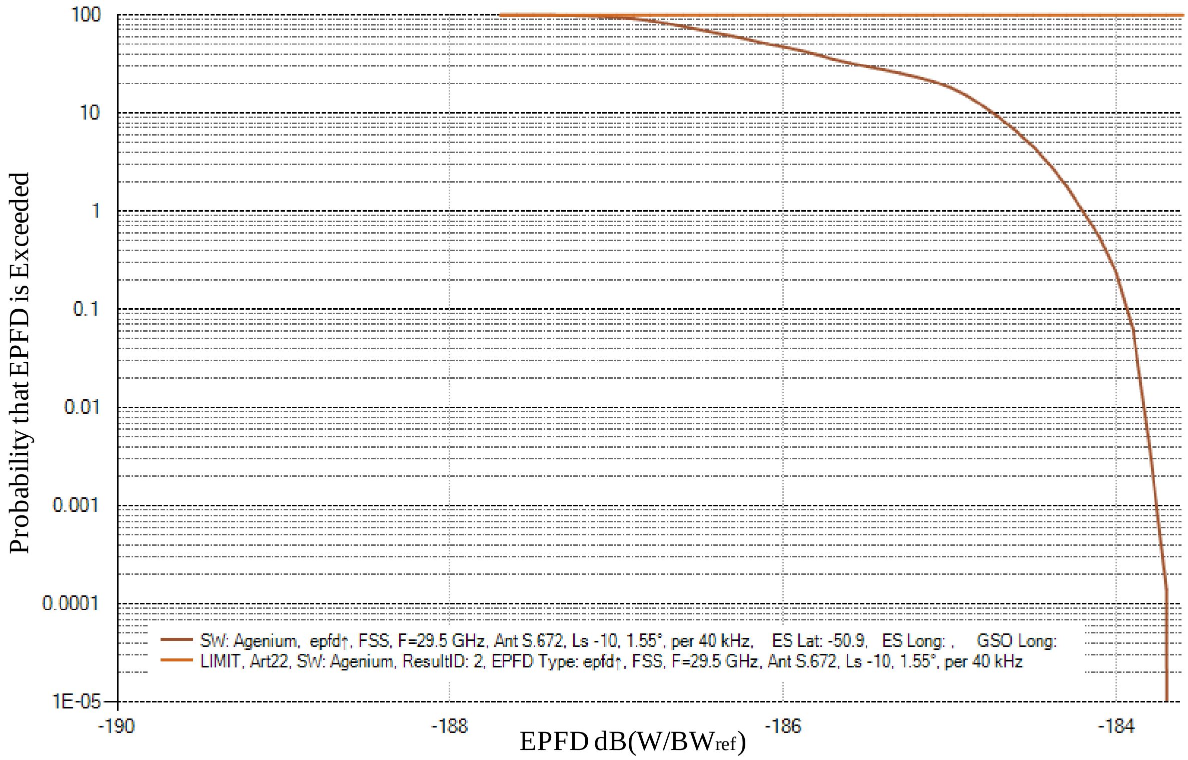

Figure 25. Ka-band Uplink: F=29.5 GHz

EPFD$_{is}$:

The EPFD$_{is}$ limits in the ITU Radio Regulations are intended to protect GSO satellite receivers from interference from space-to-Earth transmissions of NGSO satellites. In the Ka-band, the frequency range for EPFD$_{is}$ is from 17.8-18.4 GHz. In this subsection, we demonstrate that the TSN system complies with the EPFD$_{is}$ limits in the ITU Radio Regulations. These limits are contained in No. 22.5F, Table 22-3 of the Radio Regulations, which can be found in Table 1. The EPFD$_{is}$ limits consist of a single, never to be exceeded EPFD level at the GSO arc.

In order to demonstrate compliance with the single-entry validation EPFD$_{is}$ limit, Theia is providing the Commission with the database that contain the sets of Ka-band maximum off-axis EIRP masks for TSN space stations. These masks have been generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.1503 which is S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the EPFD$_{is}$ levels in Ka-band. The EIRP masks define the off-axis EIRP density (per 40 kHz) of the Ka-band transmitting satellites as a function of off-axis angle.

The same ITU-provided EPFD Validator software that was used to determine compliance with the EPFD$_{is}$ limits for Ku-band was also used here. *See* comments in the EPFD$_{down}$ subsection, above, demonstrating compliance with the requirements of 47 C.F.R § 25.146(a)(1)(iii).

Theia is providing to the Commission, with this application, the other necessary input data file needed to run the EPFD validation software program to validate the $EPFD_{is}$ levels. The provided database is identical to the Ka-band EPFD down data and the $EPFD_{is}$ results are from these input databases.

The Ka-band $EPFD_{is}$ results obtained from the EPFD validation computer program using the input data explained above are illustrated below. Figure 26 shows the results for the $EPFD_{is}$. The red and orange curves represent the EPFD validation software output and EPFD limit, respectively. The labeling of each diagram indicates the frequency (in GHz) and the reference bandwidth (40 kHz).[14] Moreover, the software used for the EPFD validation is also shown.

The EPFD validation software also outputs the worst-case geometry indicated by the earth-station (ES) location (latitude and longitude) and the GSO longitude. For all plots, it is shown that the limit is always to the right of the software calculated EPFD curve. Hence, TSN is compliant with the $EPFD_{is}$ limits for Ka-band.

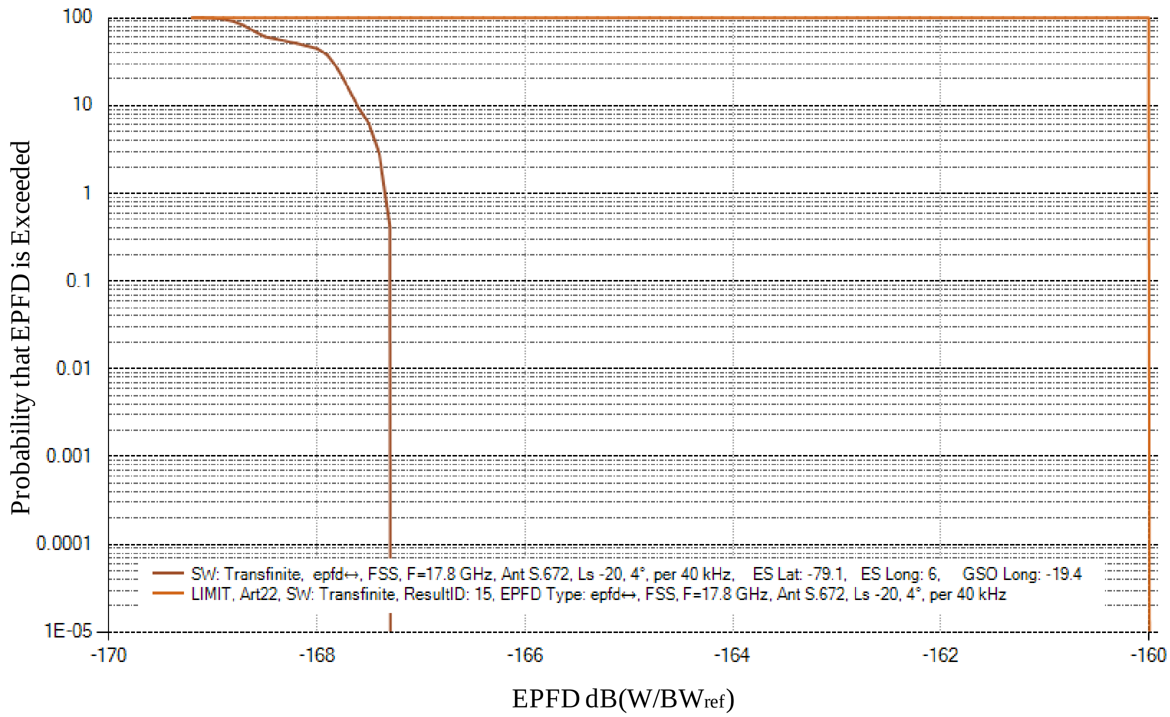

Figure 26. Ka-band IS: F=17.8 GHz

[14] The EPFD validation software determines the frequency used for the analysis and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency 17.8 GHz is used for the inter-satellite Ka-band which ranges between 17.8 and 18.4 GHz.

Other EPFD rules:

Theia confirms that it is not claiming interference protection from GSO FSS and BSS networks operating in accordance with the Commission's Part 25 rules and the ITU Radio Regulations.

Theia confirms it will coordinate with the very large GSO FSS earth stations in the 17.8-18.6 GHz and 19.7-20.2 GHz bands according to 9.7A and 9.7B of Table 5-1 of Appendix 5 of the ITU Radio Regulations.

Appendix 2

COMPLIANCE WITH PFD LIMITS (§25.208(b), §25.208(c), §25.208(e), §25.208(o), and §25.208(p))

The non-geostationary satellite orbit ("NGSO") system proposed by Theia Holdings A, Inc. ("Theia"), the Theia Satellite Network ("TSN"), complies with all applicable Federal Communications Commission ("FCC") and International Telecommunications Union ("ITU") power flux density ("PFD") limits, which are designed to protect the terrestrial fixed service ("FS") from downlink interference due to the satellite transmissions.

Downlink PFD Limits in Ku-band

The FCC's Ku-band downlink PFD limits in 10.7-11.7 GHz band, are provided in 47 C.F.R. § 25.208(b) and listed below:

- *-150 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*
- *-150+(δ-5)/2 dB(W/m$_2$) in any 4 kHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and*
- *-140 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.*

The ITU PFD limits, as shown in Table 21-4 of the ITU Radio Regulations, applicable to NGSO systems in the 10.7-11.7 GHz band with orbit altitude below 18,000 km are identical to the FCC PFD limits[1] described above. Compliance with the FCC/ITU PFD limits is demonstrated below.

The TSN Ku-band downlinks employ power control to create a constant effective isotropic radiated power ("EIRP") density on the Earth's surface over the range of operational user elevation angles from 12° to 90°. At elevation angles below the minimum operational elevation angle, the maximum PFD incident on the Earth's surface reflects the sidelobe energy of a beam scanned to the edge of coverage.

The maximum Ku-band downlink EIRP density for the TSN satellites is -16.6 dBW/4 kHz (7.4 dBW/MHz). The shortest distance from the TSN satellite to the Earth's surface (800 km) gives a worst case (i.e., smallest) spreading loss of 129.05 dB (i.e., $10*\log(4\pi(800x10^3)^2)$). The spreading loss at edge of coverage is 137.94dB. The maximum PFD from the TSN satellites will never exceed –145.6 dBW/m^2/4kHz (-121.6 dBW/m^2/MHz) at nadir and will never exceed -154.54 dBW/m^2/4kHz (-130.54 dBW/m^2/MHz) at the minimum operational elevation angle of 12 degrees. This translates to always operating at least 6 dB below the PFD limit at any elevation angle.

---

[1] The ITU PFD limits are defined over a reference bandwidth of 1MHz rather than the 4kHz reference bandwidth for the FCC PFD limit. However, for uniform distribution of power over the assigned frequency band, as is the case with the TSN waveforms, this correspond to the same relative PFD.

The PFD levels at the Earth's surface for all elevation angles are illustrated in Figure 1. These PFD levels for emissions in the 10.7-11.7 GHz band apply to all TSN satellites at any location on the Earth's surface. From this it can be seen that the TSN Ku-band downlink transmissions are compliant with the PFD limit in 47 C.F.R. § 25.208(b) with no less than 6 dB margin.

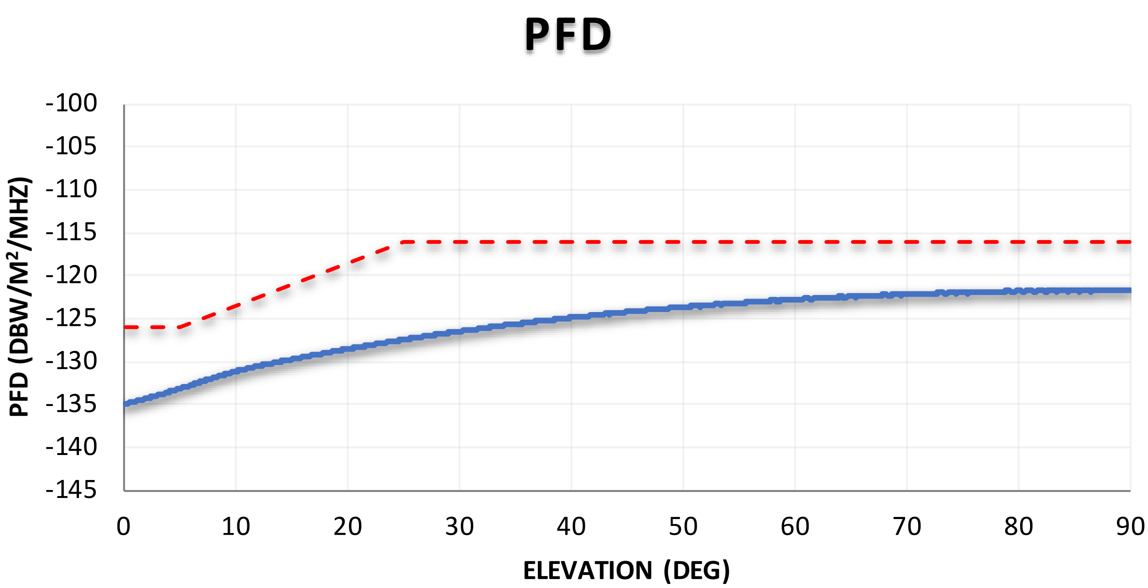

Figure 1. TSN Ku (10.7-11.7 GHz) PFD vs. Elevation Angle

The FCC does not impose any PFD limits at 11.7-12.7 GHz, but the ITU PFD limits in the 11.7-12.7 GHz band are 2 dB higher (more relaxed) than the FCC PFD limits at every elevation angle in the 10.7-11.7 GHz band. Because the TSN EIRP density profiled describe for the 10.7-11.7 GHz band is also applicable to the 11.7-12.7 GHz band, TSN will also be compliant with these ITU PFD limits with a margin of at least 8 dB.

The FCC has adopted specific low-elevation PFD limits in 47 C.F.R. § 25.208(o), which apply in the 12.2-12.7 GHz band in order to protect the terrestrial Multichannel Video Distribution and Data Service ("MVDDS"). These limits, which relate to the PFD into an actual operational MVDDS receiver, are defined as follows:

- *-158 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 2 degrees above the horizontal plane;*
- *-158+3.33(δ-2) dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 2 and 5 degrees above the horizontal plane.*

TSN compliance with the FCC's low-elevation-angle PFD limits in the 12.2-12.7 GHz band is illustrated in Figure 2. As demonstrated below, the TSN PFD is more than 0.25 dB below the limits set by section 25.208(o).

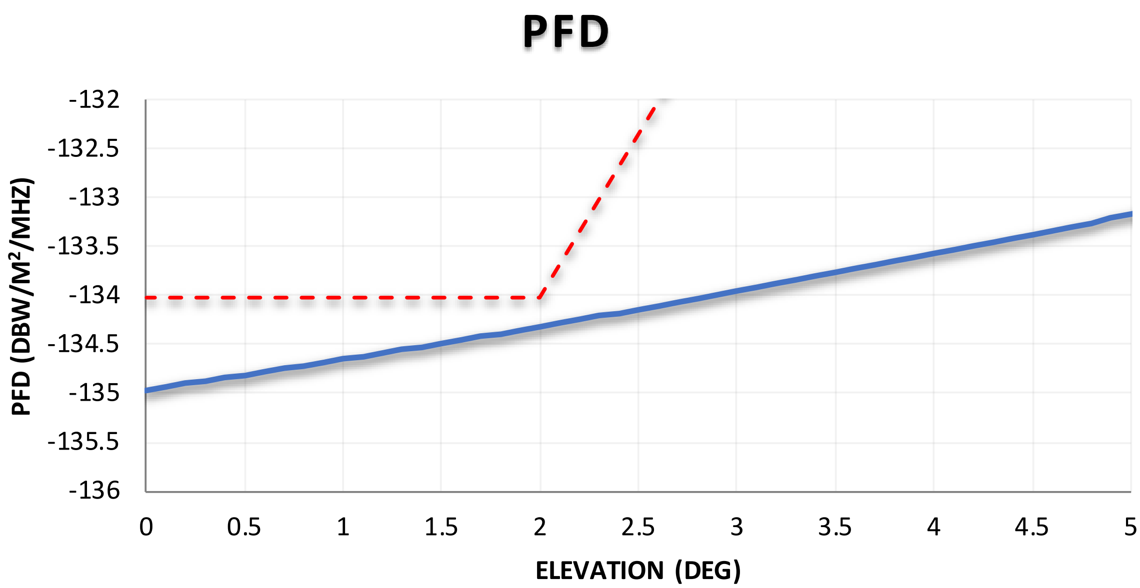

Figure 2. TSN Ku MVDDS (12.2-12.7 GHz) PFD vs. Elevation Angle

As illustrated by the analysis provided in this section, the TSN satellites comply with all the Ku-band FCC and ITU PFD limits.

Downlink PFD Limits in Ka-band

The FCC's Ka-band downlink PFD limits are defined in 47 C.F.R §§ 25.208(c) and (e) and apply in various parts of the Ka-band downlink bands used by TSN. In addition, the ITU PFD limits from Article 21, Table 21-4, note 21.16.6, of the Radio Regulations are identical to the Ka-band downlink PFD limits described in 47 C.F.R. § 25.208(e) but apply to different portions of the Ka-band downlink. Furthermore, certain sub-bands, such as 19.3-19.7 GHz and 25.5-27 GHz are subject to more relaxed ITU PFD limits defined by Article 21, Table 21-4, note 21.16.6B, of the Radio Regulations. The specific FCC and ITU limits within all the Ka-band downlink sub-bands applicable to this filing are listed in Table 1.

Table 1 Ka-Band Downlink PFD Limits

Ka Downlink Band	Applicable PFD Limit
17.8-18.3 GHz	ITU Article 21 (note 21.16.6)
18.3-18.6 GHz	47 C.F.R. § 25.208(c) / ITU Article 21 (note 21.16.6)
18.8-19.3 GHz	47 C.F.R. § 25.208(e) / ITU Article 21 (note 21.16.6)
19.3-19.7 GHz	4 C.F.R. § 25.208(c) / ITU Article 21 (note 21.16.6B)
19.7-20.2 GHz	No PFD Limit
25.5-27.0 GHz	47 C.F.R. § 25.208(p) / ITU Article 21 (note 21.16.6B)

The TSN satellites use Ka-band downlink spectrum (17.8-18.6 GHz and 18.8-20.2 GHz) for communications with gateway earth stations with very high G/T. Therefore, the PFD limits will be easily met. To simplify the PFD analysis in these bands, only the most stringent Ka-band downlink PFD limits (reflected identically by both 47 C.F.R. § 25.208(e) and Article 21, Table 21.4, note 21.16.6, of the ITU Radio Regulations) will be considered. By demonstrating compliance with the more stringent ITU/FCC PFD limits, the other FCC and ITU PFD limits are also met.

The TSN system will also use the EESS (space-to-Earth) band from 25.5-27.0 GHz to support the downlink of remote sensing data. PFD limits in this band are defined by both the FCC (47 C.F.R. § 25.208(p)) and the ITU (Article 21, Table 21-4, note 21.16.6B). These PFD limits are identical for the FCC and the ITU.

The most constraining Ka-band FSS downlink PFD limits are defined by 47 C.F.R. § 25.208(e) as follows:

- *-115-X dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*
- *-115-X+((10+X)/20)(δ-5) dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and*
- *-105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.*

Where X is defined as a function of the number of satellites in the NGSO FSS constellation, n, as:

- $X = 0$ dB for $n \leq 50$
- $X = (5/119)(n - 50)$ dB for $50 < n \leq 288$
- $X = (1/69)(n + 402)$ dB for $n > 288$

These PFD limits apply to each TSN satellite. The value of "n" is 112 for the TSN constellation and therefore X is equal to 2.61 dB according to the above formulae. For TSN, the PFD limits can be expressed in the simplified version below:

- *-117.61 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*
- *-117.61+0.63(δ-5) dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and*
- *-105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.*

In the Ka-band EESS downlink from 25.5-27.0 GHz, the FCC's PFD limits are defined in 47 C.F.R. § 25.208(p), which are identical to the ITU PFD limits provided in Article 21, Table 21.4, note 21.16.6B, of the Radio Regulations:

- *-115 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*
- *-115-X+0.5(δ-5) dB(W/m^2) in any 1 MHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and*
- *-105 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.*

TSN employs downlink power control to maintain a constant downlink EIRP density across the operational range of elevation angle between 12° and 90°. The PFD at edge of coverage ("EOC") of 12 degrees, along with the target EIRP Density levels at EOC and Nadir, are listed in Table 1.

Table 2 Ka-Band Downlink Constant EIRP Density – Maximum Levels

Ka Downlink Band	PFD (EOC) dBW/m^2/MHz	EIRP Density (Nadir) dBW/MHz	EIRP Density (EOC) dBW/MHz
17.8-18.6 GHz	-125.87	12.07	12.07
18.8-20.2 GHz	-125.87	12.07	12.07
25.5-27.0 GHz	-121.5	16.44	16.44

Based upon maintaining constant EIRP density across the range of operational elevation angles from 12° to 90° and accounting for beam roll-off beyond the edge of coverage, the PFD curves for the Ka-band segments (17.8-18.6 and 18.8-20.2 GHz, and 25.5-27.0 GHz) are illustrated in Figure 3, Figure 4, and Figure 5, respectively.

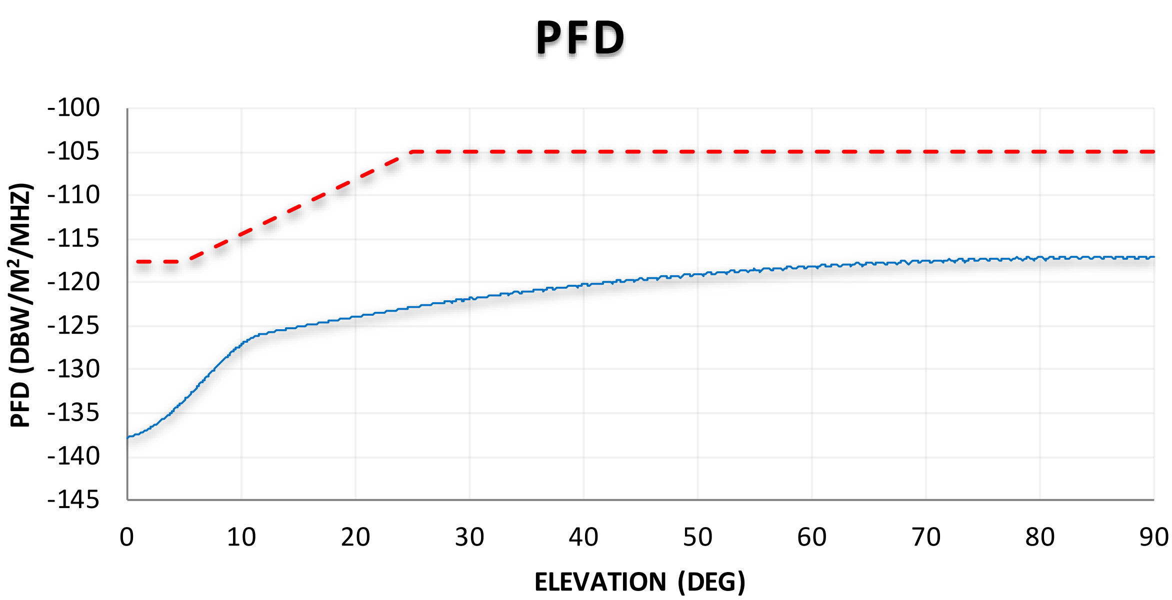

Figure 3. TSN Ka-Band Lower (17.8-18.6 GHz) PFD vs. Elevation Angle

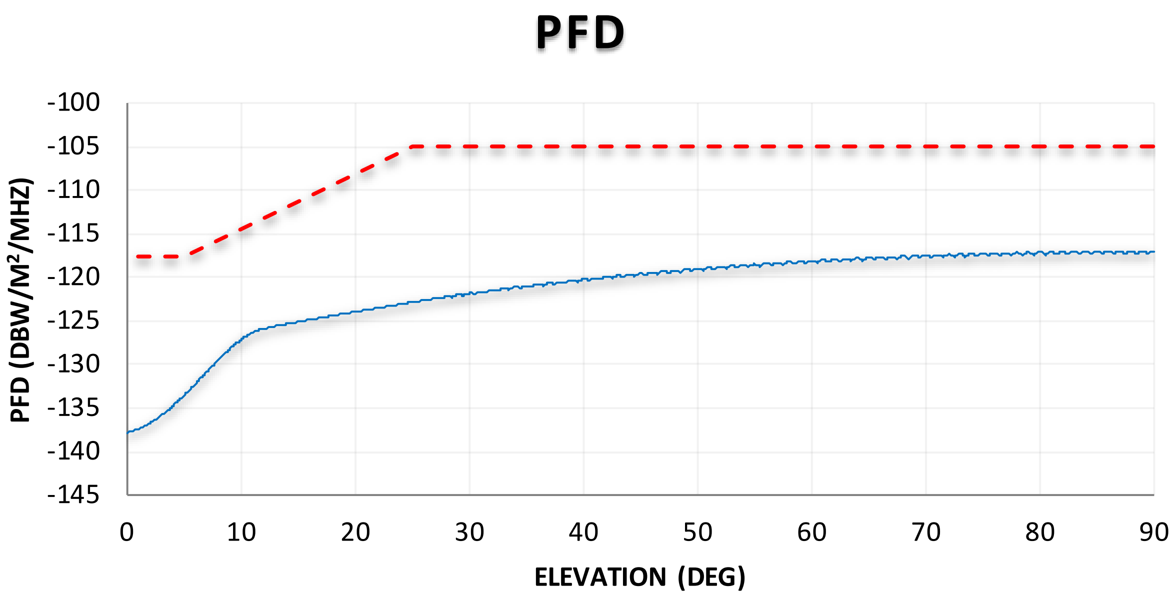

Figure 4. TSN Ka-Band Upper (18.8-20.2 GHz) PFD vs. Elevation Angle

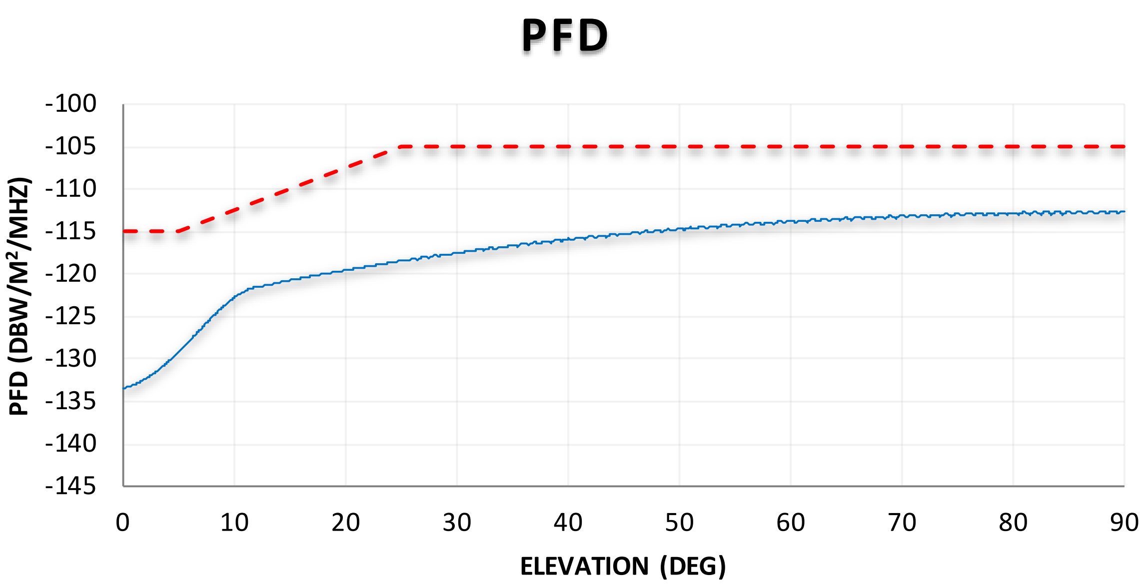

Figure 5. TSN Ka-Band EESS (25.5-27.0 GHz) PFD vs. Elevation Angle

As illustrated by the analysis provided in this section, the TSN satellites comply with all the Ka-band FCC and ITU PFD limits.

Appendix 3

TSN Link Budgets

User Link Uplink Link Budgets:

		40cm UT		80cm UT	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	km	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	deg	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	deg	60.36	0.00	60.36	0.00
Slant Range	km	2224.06	800.00	2224.06	800.00
Link Frequency	GHz	14.50	14.50	14.50	14.50
Channel Symbol Rate	Msps	41.67	41.67	41.67	41.67
Bandwidth Efficiency	bps/Hz	0.92	0.92	1.84	1.84
Burst Information Data Rate	Mbps	38.19	38.19	76.66	76.66
ModCod		QPSK 9/20	QPSK 9/20	8APSK 26/45-L	8APSK 26/45-L
Effective EIRP	dBW	44.44	44.44	50.46	50.46
Free Space Loss	dB	182.62	173.74	182.62	173.74
Effective G/T	dBi/K	-5.2	-5.2	-5.2	-5.2
Receive Power	dBW	-116.71	-107.83	-110.69	-101.81
Received C/N	dB	9.06	17.94	15.08	23.96
C/I	dB	11.50	11.50	11.50	11.50
Required C/(N+I)	dB	2.48	2.48	7.12	7.12
Required C/N	dB	3.06	3.06	9.08	9.08
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	5.0	13.9	5.0	13.9

User Link Downlink Link Budgets:

		40cm UT		80cm UT	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	km	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	deg	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	deg	60.36	0.00	60.36	0.00
Slant Range	km	2224.06	800.00	2224.06	800.00
Link Frequency	GHz	12.20	12.20	12.20	12.20
Channel Symbol Rate	Msps	415.83	415.83	415.83	415.83
Spreading	Chips/Sym	3.00	3.00	1.00	1.00
Bandwidth Efficiency	bps/Hz	0.15	0.15	0.56	0.56
Burst Information Data Rate	Mbps	62.16	62.16	234.71	234.71
Mod Cod		QPSK 2/9	QPSK 2/9	QPSK 2/9	QPSK 2/9
Effective EIRP	dBW	33.08	33.08	33.08	33.08
Free Space Loss	dB	181.12	172.24	181.12	172.24
Effective G/T	dBi/K	4.7	4.7	10.7	10.7
Receive Power	dBW	-116.93	-108.05	-110.91	-102.03
Received C/N	dB	-0.95	7.93	5.07	13.95
C/I	dB	12.00	12.00	12.00	12.00
Required C/(N+I)	dB	-1.38	-1.38	-0.20	-0.20
Required C/N	dB	-5.95	-5.95	0.07	0.07
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	4.0	12.9	4.0	12.9

Feeder Link Uplink Link Budgets:

		1.6m Gateway Terminal		4.8m Gateway Terminal	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	km	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	deg	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	deg	60.36	0.00	60.36	0.00
Slant Range	km	2224.06	800.00	2224.06	800.00
Link Frequency	GHz	28.75	28.75	28.75	28.75
Channel Symbol Rate	Msps	2083.33	2083.33	2083.33	2083.33
Bandwidth Effciency	bps/Hz	2.17	2.17	4.16	4.16
Burst Information Data Rate	Mbps	4522.65	4522.65	8668.02	8668.02
ModCod		8PSK 13/18	8PSK 13/18	32APSK 7/9	32APSK 7/9
Effective EIRP	dBW	74.59	74.59	84.23	84.23
Free Space Loss	dB	188.57	179.68	188.57	179.68
Effective G/T	dBi/K	8.5	8.5	8.5	8.5
Receive Power	dBW	-78.33	-69.45	-68.70	-59.82
Received C/N	dB	29.95	38.84	39.59	48.47
C/I	dB	18.00	18.00	18.00	18.00
Required C/(N+I)	dB	8.44	8.44	15.27	15.27
Required C/N	dB	8.95	8.95	18.59	18.59
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	20.0	28.9	20.0	28.9

Feeder Link Downlink Link Budgets:

		17.8 GHz to 18.6 GHz			
		1.6m Gateway Terminal		4.8m Gateway Terminal	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	**km**	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	**deg**	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	**deg**	60.36	0.00	60.36	0.00
Slant Range	**km**	2224.06	800.00	2224.06	800.00
Link Frequency	**GHz**	18.20	18.20	18.20	18.20
Channel Symbol Rate	**Msps**	666.67	666.67	666.67	666.67
Bandwidth Efficiency	**bps/Hz**	1.19	1.19	3.28	3.28
Burst Information Data Rate	**Mbps**	**791.40**	**791.40**	**2183.97**	**2183.97**
ModCod		QPSK 11/20	QPSK 11/20	16APSK 7/9	16APSK 7/9
Effective EIRP	**dBW**	**39.80**	**39.80**	**39.80**	**39.80**
Free Space Loss	**dB**	184.59	175.71	184.59	175.71
Effective G/T	**dBi/K**	**19.7**	**19.7**	**29.2**	**29.2**
Receive Power	**dBW**	-98.17	-89.29	-88.63	-79.74
Received C/N	**dB**	15.24	24.12	24.78	33.66
C/I	**dB**	18.00	18.00	18.00	18.00
Objective C/(N+I)	**dB**	4.06	4.06	12.39	12.39
Required C/N	**dB**	4.24	4.24	13.78	13.78
External Interference Loss	**dB**	1.00	1.00	1.00	1.00
Clear Sky Link Margin	**dB**	**10.0**	**18.9**	**10.0**	**18.9**

		18.8 GHz to 20.2 GHz			
		1.6m Gateway Terminal		4.8m Gateway Terminal	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	**km**	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	**deg**	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	**deg**	60.36	0.00	60.36	0.00
Slant Range	**km**	2224.06	800.00	2224.06	800.00
Link Frequency	**GHz**	19.50	19.50	19.50	19.50
Channel Symbol Rate	**Msps**	1166.67	1166.67	1166.67	1166.67
Spreading		**3.00**	**3.00**	**1.00**	**1.00**
Bandwidth Efficiency	**bps/Hz**	0.19	0.19	1.29	1.29
Burst Information Data Rate	**Mbps**	**225.50**	**225.50**	**1500.73**	**1500.73**
ModCod		QPSK 13/45	QPSK 13/45	QPSK 11/20	QPSK 11/20
Effective EIRP	**dBW**	**33.23**	**33.23**	**33.23**	**33.23**
Free Space Loss	**dB**	185.19	176.31	185.19	176.31
Effective G/T	**dBi/K**	**20.3**	**20.3**	**29.8**	**29.8**
Receive Power	**dBW**	-104.74	-95.86	-95.20	-86.31
Received C/N	**dB**	6.24	15.12	15.78	24.66
C/I	**dB**	18.00	18.00	18.00	18.00
Objective C/(N+I)	**dB**	-0.06	-0.06	4.58	4.58
Required C/N	**dB**	-4.76	-4.76	4.78	4.78
External Interference Loss	**dB**	1.00	1.00	1.00	1.00
Clear Sky Link Margin	**dB**	**10.0**	**18.9**	**10.0**	**18.9**

		25.5 GHz to 27.0 GHz			
		1.6m Gateway Terminal		4.8m Gateway Terminal	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	**km**	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	**deg**	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	**deg**	60.36	0.00	60.36	0.00
Slant Range	**km**	2224.06	800.00	2224.06	800.00
Link Frequency	**GHz**	26.25	26.25	26.25	26.25
Channel Symbol Rate	**Msps**	1250.00	1250.00	1250.00	1250.00
Bandwidth Efficiency	**bps/Hz**	2.09	2.09	4.10	4.10
Burst Information Data Rate	**Mbps**	**2615.29**	**2615.29**	**5118.87**	**5118.87**
ModCod		8PSK 25/36	8PSK 25/36	32APSK 7/9	32APSK 7/9
Effective EIRP	**dBW**	**46.90**	**46.91**	**46.90**	**46.91**
Free Space Loss	**dB**	187.78	178.89	187.78	178.89
Effective G/T	**dBi/K**	**22.9**	**22.9**	**32.4**	**32.4**
Receive Power	**dBW**	-91.07	-82.18	-81.53	-72.64
Received C/N	**dB**	19.61	28.50	29.15	38.04
C/I	**dB**	18.00	18.00	18.00	18.00
Objective C/(N+I)	**dB**	8.14	8.14	15.07	15.07
Required C/N	**dB**	8.61	8.61	18.15	18.15
External Interference Loss	**dB**	1.00	1.00	1.00	1.00
Clear Sky Link Margin	**dB**	**10.0**	**18.9**	**10.0**	**18.9**

Beacon Link Budgets:

		40cm UT		80cm UT	
		EOC	NADIR	EOC	NADIR
Orbit Altitude	km	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	deg	12.00	90.00	12.00	90.00
Nadir (Scan) Angle	deg	60.36	0.00	60.36	0.00
Slant Range	km	2224.06	800.00	2224.06	800.00
Link Frequency	GHz	12.70	12.70	12.70	12.70
Channel Symbol Rate	ksps	833.33	833.33	833.33	833.33
Spreading		31.00	31.00	31.00	31.00
Bandwidth Efficiency	bps/Hz	0.01	0.01	0.01	0.01
Burst Information Data Rate	kbps	11.72	11.72	11.72	11.72
ModCod		QPSK 2/9	QPSK 2/9	QPSK 2/9	QPSK 2/9
Effective EIRP	dBW	6.64	-2.24	6.64	-2.24
Free Space Loss	dB	181.47	172.59	181.47	172.59
Effective G/T	dBi/K	5.0	5.0	11.0	11.0
Receive Power	dBW	-143.37	-143.37	-137.35	-137.35
Received C/N	dB	-0.41	-0.41	5.61	5.61
C/I	dB	20.00	20.00	20.00	20.00
Required C/(N+I)	dB	-1.53	-1.53	-1.53	-1.53
Required C/N	dB	-16.41	-16.41	-16.41	-16.41
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	15.0	15.0	21.0	21.0

TT&C Uplink Link Budgets:

		1.6m TT&C Terminal			4.8m TT&C Terminal		
		EOC	EOC	NADIR	EOC	EOC	NADIR
Orbit Altitude	**km**	800.00	800.00	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	**deg**	12.00	12.00	90.00	12.00	12.00	90.00
Nadir (Scan) Angle	**deg**	60.36	60.36	0.00	60.36	60.36	0.00
Slant Range	**km**	2224.06	2224.06	800.00	2224.06	2224.06	800.00
Link Frequency	**GHz**	30.00	30.00	30.00	30.00	30.00	30.00
Channel Symbol Rate	**ksps**	8.33	8.33	8.33	8.33	8.33	8.33
Bandwidth Effciency	**bps/Hz**	1.21	1.21	1.21	3.43	3.43	3.43
Burst Information Data Rate	**ksps**	**10.08**	**10.08**	**10.08**	**28.57**	**28.57**	**28.57**
ModCod		QPSK 11/20	QPSK 11/20	QPSK 11/20	16APSK 77/90	16APSK 77/90	16APSK 77/90
Effective EIRP	**dBW**	**46.96**	**46.96**	**46.96**	**56.51**	**56.51**	**56.51**
Free Space Loss	**dB**	188.94	188.94	180.05	188.94	188.94	180.05
Effective G/T	**dBi/K**	**-32.1**	**-22.1**	**-22.1**	**-32.12**	**-22.12**	**-22.12**
Receive Power	**dBW**	-146.97	-136.97	-128.09	-137.43	-127.43	-118.55
Received C/N	**dB**	15.30	25.30	34.18	24.84	34.84	43.72
C/I	**dB**	20.00	20.00	20.00	20.00	20.00	20.00
Required C/(N+I)	**dB**	4.18	4.18	4.18	12.90	12.90	12.90
Required C/N	**dB**	4.30	4.30	4.30	13.84	13.84	13.84
External Interference Loss	**dB**	1.00	1.00	1.00	1.00	1.00	1.00
Clear Sky Link Margin	**dB**	**10.0**	**20.0**	**28.9**	**10.0**	**20.0**	**28.9**

TT&C Downlink Link Budgets:

		1.6m TT&C Terminal			4.8m TT&C Terminal		
		EOC	EOC	NADIR	EOC	EOC	NADIR
Orbit Altitude	km	800.00	800.00	800.00	800.00	800.00	800.00
Grazing (Elevation) Angle	deg	12.00	12.00	90.00	12.00	12.00	90.00
Nadir (Scan) Angle	deg	60.36	60.36	0.00	60.36	60.36	0.00
Slant Range	km	2224.06	2224.06	800.00	2224.06	2224.06	800.00
Link Frequency	GHz	20.20	20.20	20.20	20.20	20.20	20.20
Channel Symbol Rate	ksps	8.33	8.33	8.33	8.33	8.33	8.33
Bandwidth Effciency	bps/Hz	1.23	1.23	1.23	3.45	3.45	3.45
Burst Information Data Rate	kbps	10.24	10.24	10.24	28.79	28.79	28.79
ModCod		QPSK 11/20	QPSK 11/20	QPSK 11/20	16APSK 77/90	16APSK 77/90	16APSK 77/90
EIRP	dBW	-7.06	2.94	2.94	-7.06	2.94	2.94
Free Space Loss	dB	185.50	185.50	176.62	185.50	185.50	176.62
Effective G/T	dBi/K	20.6	20.6	20.6	30.1	30.1	30.1
Receive Power	dBW	-145.04	-135.04	-126.16	-135.49	-125.49	-116.61
Received C/N	dB	17.40	27.40	36.28	26.94	36.94	45.83
C/I	dB	20.00	20.00	20.00	20.00	20.00	20.00
Required C/(N+I)	dB	4.28	4.28	4.28	12.98	12.98	12.98
Required C/N	dB	4.40	4.40	4.40	13.94	13.94	13.94
External Interference Loss	dB	1.00	1.00	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	12.0	22.0	30.9	12.0	22.0	30.9

SAR Link Budgets:

Parameters	Spot mode
Frequency, Hz	1.286E+09
Power transmitted, dBW	33.8
Antenna Gain, dBi	38.33
Target Length, dihedral	2.00
σ, radar cross section, dBsm	38.7
Range, m	922737
Chirp Bandwidth, Hz	2.80E+07
Pulse length, sec	0.000016
PRF, kHz	3.99E+00
Pulse bandwidth, Hz	62500
Expected IF Bandwidth, Hz	1.94E+08
Noise Figure	2
Losses, dB	2.5
Boltzmanns constant, k	1.38E-23
Ant temp,T	290
System Temp	817.33
Thermal noise power in receiver, dBW	-116.60
SNR before coherent integration, dB	-18.48
Processing gain, dB	43.60
SNR after coherent processing gain, point tgt	**25.12**
SNR for Distributed Target, e.g. terrain	**-15.02**

Parameters	**Strip mode**
Frequency, Hz	1.286E+09
Power transmitted, dBW	33.8
Antenna Gain, dBi	38.33
Target Length, m	4.00
σ, radar cross section, dBsm	50.73
Range, m	1115863
Chirp Bandwidth, Hz	1.40E+07
Pulse length, sec	0.000016
PRF, kHz	3.71E+00
Pulse bandwidth, Hz	62500
Expected IF Bandwidth, Hz	1.98E+08
Noise Figure	2
Losses, dB	2.5
Boltzmanns constant, k	1.38E-23
Ant temp,T	290
System Temp	817.33
Thermal noise power in receiver, dBW	-116.51
SNR before Processing Gain, dB	8.25
Processing Gain, dB	7.65
SNR after processing gain, dB	**15.90**
SNR for Distributed Target, e.g. terrain	**-18.27**

Appendix 4

TSN Orbital Debris and Deorbit Analysis

This Appendix is intended to provide information regarding the orbital debris mitigation plans for the proposed non-geostationary satellite orbit ("NGSO") system of Theia Holdings A, Inc. ("Theia"), the Theia Satellite Network ("TSN"), required by Sections 25.114(d)(14) and 25.283(c) of the rules of the Federal Communications Commission.

Spacecraft Hardware Design

Theia is familiar with the orbital debris mitigation requirements set forth in Section 25.114(d)(14) of the Commission's rules and is incorporating these requirements into the baseline TSN spacecraft design. Moreover, in developing TSN satellite requirements, Theia has worked closely with satellite manufacturers, engineering firms and other satellite industry participants that have designed, manufactured, launched and operated spacecraft pursuant to numerous FCC space station authorizations. Thus, TSN satellites benefit from the in-depth understanding of orbital debris mitigation of Theia and its system design partners.

The TSN design features described herein will be imposed on the system satellite contractor as firm requirements and flowed down to all subcontractors. The satellite contractor and subcontractors will be required to incorporate into their designs explicit features for minimization of orbital debris.

Finally, the design features and operational procedures described herein reflect the current state-of-the-art in NGSO spacecraft manufacturing and operations. They are intended to serve as minimum thresholds for the design and operation of TSN satellites. Any potential updates to these design features or operational procedures will seek to enhance the orbital debris mitigation characteristics of TSN satellites and will be authorized by the Commission as appropriate.

Limiting Orbital Debris Mitigation During Planned Operations and the Risk of Collisions with Small Debris or Meteoroids – Section 25.114(d)(14)(i)

Theia has assessed the risk of debris release during normal operations and designed the TSN satellite to ensure that no debris will be released during any mission phase. Although Theia has not selected a satellite manufacturing contractor for its proposed NGSO system, it has consulted with numerous design partners in developing its current baseline design. The TSN satellite design incorporates, for example, the use of non-debris generating appendage hold down and release mechanisms, selection of appropriate construction materials including external thermal control surfaces and coatings, and operational procedures.

In addition, the probability of the Theia space stations becoming a source of debris by collisions with small debris or meteoroids smaller than one centimeter in diameter that could cause loss of control and prevent post-mission disposal will also be assessed and limited.

Mitigating Accidental Explosions – Sections 25.114(d)(14)(ii) and 25.283(c)

Theia has assessed the probability of accidental explosions during and after completion of mission operations and has limited these risks in the TSN satellite design. Sources of stored energy on the TSN satellites include:

Chemical/pressure:

- Pressurized monopropellant hydrazine fuel tank (1 per satellite),
- Lithium-ion battery, and
- Constant conductance heat pipes.

Kinetic:

- Reaction wheels (4 per satellite),
- Solar array drive motors (4 per satellite: 2 solar array panels, each with a 2-axis drive mechanism),
- Feeder link drive motors (4 per satellite: 2 gimbaled feeder link antennas, each with a 2-axis drive mechanism),
- Free space optical (FSO) heads (6 per satellite),
- Passive offset microwave radiometer spin table (8 satellites), and
- Hyper-spectral optical sensor telescope single-axis gimbal (52 satellites).

During the TSN satellite design and development program, the prime satellite contractor and satellite subcontractors will be required to perform failure modes and effects analyses (FMEA) to demonstrate acceptably low probability of failure from all possible sources. These analyses shall include the probability of failure of pressure vessels resulting in an accidental explosion. Suitable design safety margins shall be required and formally verified in order to demonstrate the achievement of acceptably low probabilities of occurrence of such failure modes.

At TSN satellite end-of-life, mission operational rules and procedures will call for the maneuvering of the satellite to a disposal orbit, followed by passivation of all stored energy sources. This includes de-spinning of the reaction wheels, venting of residual propellant and pressurant to the extent possible by opening all thruster valves, and connection of onboard electrical loads sufficient to cause the satellite's battery to fully discharge (which also results in the passivation of all other onboard kinetic energy sources).

The propulsion system design includes a fuel tank with a bladder. At the beginning of life (BOL), the tank is loaded with up to 450 kg of hydrazine propellant. After the fuel has been loaded, the fill/drain (F/D) valve is closed and manually secured with a screw-on safety cap. The bladder portion of the tank system is then pressurized with approximately 4.5 kg of inert gaseous nitrogen to a maximum expected operation pressure (MEOP) of 24.5 bar using the fill/vent valve (F/V)[1]. After pressurization, the F/V is mechanically closed, and after this point there is no possible mechanism for completely depressurizing the system. When the spacecraft is mated to the launch vehicle and on the launch pad, the latch valve (LV) is commanded open to allow fuel into the propulsion system between the LV and thrusters. During nominal operations throughout space vehicle life, the LV is never closed.

Throughout the life of the satellite, fuel is consumed for various maneuvers. At the end of operational life, the satellite is commanded into a deorbit maneuver with a depletion burn to exhaust all available fuel. At the completion of this maneuver, the 4.5 kg of inert nitrogen pressurant will remain on the "dry" side of the bladder in the tank, at a residual pressure of approximately 6 bar. Also, a small amount of fuel will remain in the propellant lines of the system in vapor form, which presents no hazard of escaping or causing later rupture, as it will reach the vapor pressure of hydrazine, about 0.28 bar at 25°C when all lines are opened at the thruster valves to passivate the system. This vapor will remain in the lines when the valves are closed upon removal of electrical power. In the unlikely event of a small particle (debris or meteor) puncturing the tank, the residual gaseous nitrogen would be released in a rapid manner, similar to a cold gas thruster, with a theoretical maximum delta-V of less than 5 m/s. In the extraordinarily unlikely event of a particle striking a passivated SV on precisely the line required to puncture both the fuel portion of the tank and the bladder, the maximum theoretical delta-V is about 7 m/s. Given that the orbital velocity during disposal is on the order of 7 km/s, this delta-V will have no noticeable effect on the orbit of the satellite, or alter the possibility of space vehicle breakup in any fashion.

The batteries used on the TSN satellites are based on Lithium-ion cells. Each cell is roughly the size and shape of a conventional "D" battery, and will incorporate a "leak before burst" safety disk to prevent explosion in the event of overcharge. The heat pipes used in the construction of the Theia space stations are sealed aluminum tubes filled with anhydrous ammonia. Per NASA-STD 8719.14, §4.4.4.1.2.f, sealed heat pipes do not need to be depressurized at end of mission.

Safe Flight Profiles - Section 25.114(d)(14)(iii)

The probability of the Theia satellites becoming a source of debris by collisions with large debris or other operational space stations has been assessed and limited. The TSN orbit design took into account the probability of collision with large debris, including other operational Theia

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[1] It should be noted that all propulsion systems shall be proof tested to 1.5 x MEOP (36.75 bar in this case), and the design burst tested to 2 x MEOP (49 bar).[1]

satellites and spacecraft of other satellite systems. In particular, the phasing offsets selected for TSN satellites in adjacent orbital planes were specifically analyzed and selected so as to minimize collision probabilities at the convergent polar crossings that occur each orbit.

The 112 individual TSN satellites in their approximately 800 km near-circular mission orbit will be maintained within specific orbital tolerances. Each TSN satellite's mission altitude will be maintained via periodic propulsive station-keeping burns to a nominal orbital period of 6053 seconds and an eccentricity of 0.00126. The in-plane position along the velocity direction will be nominally maintained to ± 6 kilometers. Theia satellites will be maintained in frozen orbits[2] with perigee near the North pole and apogee near the South pole. The cross-track or the Right Ascension of the Ascending Node will be maintained to ± 0.08 degrees with respect to the satellites' in-plane neighbors. Occasionally, various mission operational considerations will result in different tolerances for individual satellites on a case-by-case basis.

Theia will use specialized software in its mission control facility to regularly evaluate collision risks with other space stations, based on the most current available space station orbital element sets maintained and disseminated by USSTRATCOM. Collision avoidance maneuvers will be executed as required to reduce probabilities below NASA recommended thresholds. Experience with other NGSO satellites indicates the vast majority of potential collisions can be alleviated by changing the timing of an existing orbit maintenance maneuver (at zero impact to fuel budget). Nonetheless, a portion of TSN's mission orbit maintenance fuel budget is specifically reserved for collision avoidance maneuvers that cannot be accommodated by timing changes to planned maintenance maneuvers.

Whenever TSN satellites are required to undergo orbital maneuvers, pre-maneuver coordination with USSTRATCOM will be accomplished so that the appropriate authorities are aware of the maneuver plans and can advise Theia whether such maneuvers pose any risks. This includes screening planned launch trajectories and ascent from injection orbit to storage, transfer, or mission orbit. Theia intends to actively coordinate orbital activities with other owner-operators in their orbital regime, especially Iridium.

Orbit control and orbit knowledge will be specified to support TSN operations and support collision avoidance. TSN satellites will incorporate precision GPS navigation equipment to provide the best available orbit knowledge.

Post-Mission Disposal -- Section 25.114(d)(14)(iv)

Theia's orbital debris mitigation plans and procedures call for placing TSN satellites in a disposal orbit at end-of-life. Sufficient fuel (over 120kg or 27% of the overall fuel budget) will be reserved to accomplish the disposal maneuver sequence described below. Post-mission disposal will be carried out by propulsive maneuvering of the satellite into a lower orbit whose lifetime is consistent with NASA and international guidelines for LEO systems, *i.e.*, a predicted

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[2] A frozen orbit limits the altitude range to be occupied by TSN satellites, reducing the number of objects with which conjunctions are possible. A frozen orbit, popularly used by other polar orbiting earth observation satellites and Iridium, also will allow Theia space stations to safely co-exist at smaller altitude separations with these other satellites.

orbital lifetime of less than 25 years until atmospheric re-entry occurs as a result of natural orbital decay processes. At the end of a nominal mission, sufficient fuel margin should exist to further lower the orbit and achieve approximately 10 years until re-entry. This constitutes an uncontrolled re-entry.

Post-mission disposal will be performed in three phases. In Phase 1, the TSN satellites' orbit altitude is lowered by approximately 50 km to 750 km to remove them from the operational altitude.[3] This orbit lowering process is estimated to consume approximately 40 kg of fuel (9% of total budget). The satellites will be designed with a 98% probability of success for this phase.

In Phase 2, the perigee of the approximately 750 km circular Phase 1 orbit is successively lowered until a perigee altitude of no more than 540 km is achieved. This orbit lowering process is estimated to consume 83 kg of fuel (18% of total budget). This disposal orbit results in a predicted orbital lifetime of less than 25 years. Predictions were performed assuming a year 2035 disposal and 0.01 m^2/kg area-to-mass ratio. Predictions were performed using DAS (Debris Assessment Software from NASA), STELA (Semi-analytic Tool for End of Life Analysis from CNES), and STK (Systems Tool Kit from AGI) with good agreement between the models. The satellites will be designed with a 94% probability of success for this phase.

In Phase 3, any remaining fuel margin will be expended in a series of apogee-reducing maneuvers until fuel is expended and the satellite is passivated. The nominal fuel reserve is estimated to be near 59 kg (13% of total budget), and should support a final disposal orbit of 610 km apogee and 540 km perigee, with an estimated orbital lifetime near 10 years. Apogee lowering maneuvers are planned to remove the satellite from the vicinity of other operational constellations above 700 km altitude. As performance for this phase relies on the fuel margins of individual TSN satellites at end-of-life, no specific probability of success has been assigned. However, since the orbit lowering maneuvers of Phase 2 result in compliance with the maximum 25-year predicted orbital lifetime requirement, any further orbit lowering achieved during Phase 3 should be viewed as non-mandatory, additional effort by Theia to improve post-mission disposal characteristics of TSN satellites.

Following the Phase 3 disposal maneuvers, the satellite will be fully passivated by opening all thruster valves, turning off all electro-mechanical actuators, discharging the batteries, and isolating satellite power systems from the solar arrays to prevent inadvertent recharge of the satellite. The satellites will be designed with a 98% probability of success for full passivation at end-of-life and disposal. A casualty risk assessment for uncontrolled atmospheric re-entry of TSN satellites has been conducted using the NASA-supplied DAS (Debris Assessment Software) code (as suggested by FCC 04-130, footnote 19). As inputs to the DAS software, each TSN satellite was modeled as one of the three remote sensors (hyperspectral imager, active radar and passive radiometer), in addition to a common collection of 188 primitive objects (boxes, cylinders, and flat plates) representing the satellite bus and the common optical remote sensing apparatus installed on every TSN satellite. Appropriate material properties were established for each object.

[3] This 750 km altitude is also below the operational altitude of the Iridium system.

These items were assumed (by the DAS software) to break-up and start reentry at a default altitude of 122 km (not editable in DAS). Reentry inclination was set to 98.6 degrees and reentry year set to 2050 (latest year supported by DAS demographics). Applying these assumptions in DAS, it was determined that up to 549.6 kg of the satellite might survive reentry, with a total casualty area of $15.8m^2$. Using this information, DAS calculated a raw casualty risk figure of 1:5200, which assumes the entire world's population is in the open and unsheltered. Because the kinetic energy of the fragments *vis-á-vis* how the population is sheltered affects the casualty risk, additional analysis was performed to account for population sheltering.

Heavy sheltering is assumed to protect persons from impact energies up to 100 kJ (kilojoules); light sheltering is expected to provide protection from about 50 J to 5 kJ. 19% of the population is assumed to be unsheltered, 59% light sheltered, and 22% heavy sheltered ("Safety Design for Space Operations", T. Sgobba editor in chief, 2013. ISBN 978-0-08-096921-3). Consistent with these assumptions, and applying the population demographics embedded in DAS for the year 2050, the estimated casualty risk for each of the remote sensing configurations is as follows:

Object	**Risk**	
Satellite + Hyperspectral Imager	8.96E-05	1:11,200
Satellite + Active Radar	8.19E-05	1:12,200
Satellite + Passive Radiometer	8.73E-05	1:11,500

These values are consistent with the 1:10,000 objective applied in this circumstance.

Technical Certification

I, Joseph D. Fargnoli, hereby certify that I am the technically qualified person responsible for the preparation of the technical information contained in the Theia Holdings A, Inc.'s Application for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Fixed-Satellite Service, Mobile-Satellite Service, and Earth-Exploration Satellite Service, that I am familiar with Part 25 of the Commission's Rules (47 C.F.R. Part 25), and that I have either prepared or reviewed the technical information submitted in this application and found it to be complete and accurate to the best of my knowledge and belief.

/s/ Joseph D. Fargnoli
Joseph D. Fargnoli
Chief Technology Officer
Theia Holdings A, Inc.

November 15, 2016