Technical Narrative

Theia Satellite Network
V-Band Amendment

1.0 Scope and Purpose

In accordance with the Commission's rules, this Technical Narrative describes the additions and changes to the Theia Satellite Network ("TSN") non-geostationary satellite orbit ("NGSO") system application[1] associated with the amendment to add V-band gateway and other high-capacity links (the "Amendment"). The addition of such V-band communications capabilities will enhance the operational flexibility and efficiency of the TSN by enabling the use of additional bands to support critical gateway functionality and serve customers (including potential government users) with very high data requirements.

Importantly, because TSN satellites will operate V-band links using existing spacecraft antennas, only minimal changes to the TSN satellite design are necessary. All other information associated with system design and operations set forth in the TSN Application, including basic satellite design, orbital configuration, launch and operation of the TSN, and orbital debris and satellite end-of-life analysis, will not change materially. To the extent necessary, it is hereby incorporated by reference for inclusion in this satellite application processing round.

2.0 System Description

The overall configuration of the TSN is unchanged as described in the TSN Application. All constellation parameters, spacecraft operations, remote sensing, user terminals, operations centers, TT&C stations and communications services remain the same.

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[1] *See* Application of Theia Holdings A, Inc. 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, File No. File No. SAT-LOA-20161115-00121, Call Sign S2986 ("TSN Application").

Modifications to the TSN satellites to support V-band gateway communications and other high-capacity communications links are minimal.

2.1 TSN Services

In addition to the information set forth in Section 2.1 TSN Services in the TSN Application, Theia seeks to operate gateway and gateway-like links in V-band frequencies. These V-band links will provide access for high-bandwidth communications between TSN satellites and the terrestrial network or large enterprise or government users. They will also supplement free space optical ("FSO") and Ka-band links, particularly in areas where FSO operations may be impractical (e.g., due to climatological conditions) or where FSO or Ka-band operations may be otherwise limited (e.g., due to national allocation restrictions, frequency congestion, etc.).

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 additional frequency bands for TSN operations:

Gateway Links	Frequency Band
FSS (E-to-s)	47200 MHz – 50200 MHz
FSS (E-to-s)	50400 MHz – 51400 MHz
FSS (s-to-E)	37500 MHz – 42000 MHz
FSS (s-to-E)	42000 MHz – 42500 MHz

The types of service to be provided by the TSN are described above in Section 2.1 and in the TSN Application. Specific channel center frequencies, bandwidths and polarizations for all beams are detailed in Schedule S attached to this Amendment.

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 the proposed V-band communications capability and its operation are provided in sections 3.1.2 Communications Payload and 3.3 Gateway Earth Stations, herein. Additional descriptive information regarding operations and services is provided above.

Because the TSN satellite payloads are regenerative, there is no specific relationship between V-band uplink frequency bands and downlink frequency bands. Moreover, there is no explicit, fixed relationship between satellite input ports and satellite output ports as there are with transponder satellites. The 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 frequencies for uplink or downlink operations, 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 gateway 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. Thus, the addition of V-band frequencies greatly enhances the flexibility and capacity of the TSN.

2.4 TSN Constellation

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

These parameters remain unchanged from the TSN Application.

2.5 System Implementation

This description remains unchanged from the TSN Application.

3.0 TSN Elements

In addition to the information set forth in Section 3.0 TSN Elements in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies in addition to Ka-band frequencies.

3.1 Satellites

This information remains unchanged from the TSN Application.

3.1.1 Remote Sensing Payload

This information remains unchanged from the TSN Application.

3.1.2 Communications Payload

In addition to the information set forth in Section 3.1.2 Communications Payload in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies. V-band communications will be achieved by employing the same reflectors as used for Ka-band communications. A multi-band coaxial feed will provide dual circularly polarized fixed geometry transmit and receive beams for each of Ka-band and V-band. Ka-band beam contours and Ka-band communications services performance parameters remain unchanged from the TSN Application.

The payload equipment suite will include V-band electronics modules to support link operations. 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 will also include routing to/from the V-band link.

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

V-band technical characteristics are detailed in Schedule S attached to this Amendment.

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

V-band technical characteristics are detailed in Schedule S attached to this Amendment.

3.1.2.3 Contour Maps for Receive and Transmit Beams

V-band technical characteristics are detailed in Schedule S attached to this Amendment.

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.

This information remains unchanged from the TSN Application.

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

This information remains unchanged from the TSN Application.

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

This information remains unchanged from the TSN Application.

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.

In addition to the information set forth in Section 3.1.2.7 in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies. The TSN gateways may communicate with the constellation via one or more of Ka-band, V-Band or FSO links. V-band communications with TSN satellites are designed to minimize interference with 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-hemispherical patterned antennas. In all cases, communication between the SOC and satellite is secured.

For TT&C information communicated via means (i) above, between the SOC and the satellite over a conventional gateway link, this link may be achieved with Ka-band or V-band RF. Should this be the case, this link would not be established at band edge like those Ka-band only links established between TT&C sites and satellites via means (ii) above. Rather, this gateway communication (means (i)) would use normal gateway Ka-band or V-band RF frequencies (not specifically the Ka band edges) and would be processed in a manner indistinguishable from other gateway traffic.

For TT&C information communicated via means (ii) above, there is no change from the means described in the TSN Application.

3.1.2.8 §25.207 Cessation of Emissions

This information remains unchanged from the TSN Application.

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

Appendix 2, TSN Power Flux Density Compliance, addresses V-band power flux density compliance considerations.

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

In addition to the information set forth in Section 3.1.2.10 in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies. 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 and V-band, provides significant reuse of this spectrum as well. Similarly, other V-band earth station sites will be selected to take advantage of TSN multiple-satellite coverage to maintain continuous service and employ full frequency re-use in both polarizations.

3.2 User Terminals

This information remains unchanged from the TSN Application.

3.3 Gateway/High-Capacity Earth Stations

In addition to the information set forth in Section 3.3 Gateway Earth Stations in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies. Gateway earth stations may operate FSO links, Ka-band links, and V-band links singly or together depending on location, network loading and other factors. The Ka-band and V-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). V-band high-capacity links will serve the needs of a limited number of large customers. As a result, Theia anticipates coordinating both Ka-band and V-band operations will be relatively straightforward.

3.4 Network Operations Centers (NOC)

This information remains unchanged from the TSN Application.

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

This information remains unchanged from the TSN Application.

4.0 Sharing with Other Services

4.1 EESS Spectrum

This information remains unchanged from the TSN Application.

4.2 Ka-Band Gateway Operations

This information remains unchanged from the TSN Application. Information regarding the operation of V-band gateways and other high-capacity links is set forth in Section 4.6, below.

4.3 Ku-Band Terminals

This information remains unchanged from the TSN Application.

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

This information remains unchanged from the TSN Application. *See also* Section 4.6.3 Sharing with GSO and NGSO Systems.

4.5 §25.272 General inter-system coordination procedures.

This information remains unchanged from the TSN Application.

4.6. V-Band Operations

Theia notes that the allocations and service rules applicable to V-band operations, including satellite and terrestrial service, are in a state of flux as a result of the ongoing Spectrum Frontiers proceeding. As noted herein and in the attached Amendment Narrative, many provisions are subject to reconsideration or at issue in the Further NPRM. Thus, Theia's ability to address sharing issues with significant clarity is limited.

That said, Theia highlights basic considerations associated with uplink and downlink portions of the V-band identified in this Amendment, and requests appropriate waivers to enable spectrum access regardless of the outcome of the ongoing Commission proceeding. In addition, because Theia seeks to operate in these bands outside the United States as well, it demonstrates compliance with applicable ITU requirement in these bands. Theia will comply with or seek appropriate waiver of other rules, including foreign regulatory requirements in nations in which it seeks to operate, that may be relevant to its proposed V-band operations.

4.6.1. Uplink Band Sharing

4.6.1.2. FSS (E-to-s): 47.2 GHz – 50.2 GHz

The U.S. Table of Allocations provides that the 47.2-48.2 GHz band is allocated to non-Federal FS, FSS, and mobile services on a co-primary basis, and designated in the United States primarily for terrestrial use. The 48.2-50.2 GHz band is shared between Federal and non-Federal users, with co-primary allocations for FS, FSS, and mobile services, is designated in the United States primarily for FSS use. The only satellite systems licensed by the Commission in this band were the previously surrendered by Hughes Network Systems and Northrop Grumman.[2]

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[2] *See* Application of Hughes Network Systems, LLC, File Nos. SAT-LOA-20111223-00248 (Aug. 3, 2012); Application of Northrop Grumman Space & Mission Systems Corporation, File Nos. SAT-LOA-19970904-00082 et al., *Order and Authorization*, DA 09-428 (Feb. 23, 2009).

The 47.2-49.2 GHz band is also available for BSS feeder links. In the 48.2-50.2 GHz band, there are also primary Federal allocations for fixed, mobile, and Fixed-Satellite (Earth-to-space) services. The 48.94-49.04 GHz band is also used by radio astronomy for spectral line observations, and all practicable steps must be taken to protect radio astronomy in that band from interference.[3] Given their limited deployment, Theia will coordinate gateway and high-capacity earth station operations with all potentially affected Federal[4] and non-Federal users.

Importantly, the entire 47.2-50.2 GHz band is the subject of the Further Notice of Proposed Rulemaking in the Commission's Spectrum Frontiers proceeding in which new licensing rules are proposed for terrestrial services in the band. The outcome of this proceeding cannot be known at this time, so Theia cannot comment meaningfully on how its proposed operations can share with future terrestrial services. In general, however, limited deployment of gateway and high-capacity earth stations should be possible without adversely affecting terrestrial access to the band. Once new rules for the bands are adopted

[3] Footnote 5.555 to the International Table also identifies the 48.94-49.04 GHz band as available for radio astronomy service. Theia will use ITU Recommendation RA.769-2 to protect radio astronomy sites that operate in this band. Theia generally would position its gateways outside of areas with known radio astronomy operations.

[4] Theia acknowledges that NSF conducts radio astronomy observations in this band, and NASA and the United States military agencies have previously reported using the 50-55 GHz band for radar research and development. Theia accepts that FSS earth stations in this band are subject to power limits to protect NASA and NOAA operations in the adjacent 50.2-50.4 GHz band and will ensure that the "unwanted emissions" from an earth station will not exceed -20 dBW/200 MHz. 47 C.F.R. § 2.106, n. US156.

by the Commission, Theia will operate in accordance with applicable rules or seek appropriate waivers.

4.6.1.1. FSS (E-to-s): 50.4 GHz – 51.4 GHz

The U.S. Table of Allocations provides that the 50.4-51.4 GHz band is allocated on a primary basis for FSS (Earth-to-space), but the band is not identified as available for FSS in Section 25.202(a)(1) of the Commission's Rules.[5] Accordingly, in the attached Amendment Narrative, Theia respectfully requests a waiver of Section 25.202(a)(1) to the extent necessary to permit proposed operations in the band.

Additionally, this band is a shared band between Federal and non-Federal users, with co-primary allocations for FS, FSS, MSS and mobile services. Theia is unaware of any licensed terrestrial or satellite operations in this band, and the only reported Federal uses include radar research and development in the 50.0-55.0 GHz band.[6] Theia will coordinate with these agencies as necessary to avoid interference to any such federal operations.

Like the 47.2-50.2 GHz band, the 50.4-51.4 GHz band is the subject of the Further Notice of Proposed Rulemaking in the Commission's Spectrum Frontiers proceeding in which new licensing rules are proposed for terrestrial services in the band. The outcome

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[5] *See* 47 C.F.R. § 2.202(a)(1).

[6] *See Federal Spectrum Use Summary, 30 MHz – 3000 GHz*, National Telecommunications and Information Administration, Office of Spectrum Management at 78 (Jun. 21, 2010) (*available at* https://www.ntia.doc.gov/files/ntia/Spectrum_Use_Summary_Master-06212010.pdf).

of this proceeding cannot be known at this time, so Theia cannot comment meaningfully on how its proposed operations can share with future terrestrial services. In general, however, limited deployment of gateway and high-capacity earth stations should be possible without adversely affecting terrestrial access to the band. Once new rules for the bands are adopted by the Commission, Theia will operate in accordance with applicable rules or seek appropriate waivers.

4.6.2. Downlink Bands (space-to-Earth)

4.6.2.1. <u>FSS (s-to-E): 37.5 GHz – 42.5 GHz</u>

4.6.2.1.1. FSS (s-to-E): 37.5 GHz – 40.0 GHz

In the recent Order and Further NPRM in the Spectrum Frontiers proceeding, the Commission adopt a wide range of new rules in Part 30 for the Upper Microwave Flexible Use Service ("UMFUS"), including the 37.0-38.6 GHz and 38.6-40.0 GHz bands. The Part 30 provisions establish licensing rules for terrestrial access to these bands. FSS operations are subject to more stringent space-to-Earth PFD limits in the 37.5-40.0 GHz band to accommodate terrestrial operations.[7] Theia understand that certain elements of these rules are the subject of petitions for reconsideration, and that the downlink PFD levels are the subject of the Further NPRM.

[7] Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band, RM-11664, et al., *Notice of Proposed Rulemaking*, FCC 15-138, ¶ 38 (2015) ("*Spectrum Frontiers NPRM").*

Given the pendency of the petitions for reconsideration and uncertainty regarding technical characteristics, it is difficult for Theia to address in detail sharing with future co-frequency terrestrial operations. However, as discussed in this Technical Narrative, TSN downlink operations in these bands can comply with the most stringent PFD requirements to ensure there is no potential for interference into terrestrial systems and services. Moreover, out of an abundance of caution, Theia seeks a waiver of Part 30 and other Commission rules to permit operations on an unprotected, non-conforming use basis. Because these earth station receive operations cannot cause interference to terrestrial operations, and because Theia's gateway and high capacity earth stations have substantial sidelobe discrimination, are limited in number and will likely be located in rural areas, there would be no adverse impact on UMFUS deployment in these bands. Theia reserves the right to further address licensing and sharing issues in these bands once the newly adopted rules are no longer subject to review.

With respect to Federal uses of the spectrum, NASA has proposed to use the 37.0-38.0 GHz band for exploration of the solar system and for the wideband data return links to the very long baseline interferometer, and the National Science Foundation ("NSF") also uses this band for radio astronomy research. NTIA reports the band is also used by the military for fixed microwave point-to-point communications systems at military test ranges and for transportable communications systems.[8] Theia will coordinate its limited earth

[8] *See Federal Spectrum Use Summary*.

station receive operations with Federal users and comply with applicable power limits to fully protect all Federal uses of the bands.

4.6.2.1.2. FSS (s-to-E): 40.0 GHz – 42.0 GHz

The 40.0-42.0 GHz band covers several sub-bands with different allocations but broadly similar usage that can be considered together for efficiency. Each sub-band within this range contains a primary status FSS allocation for Federal and non-Federal users, accompanied by co-primary services in various sub-bands, including MSS (40.0-40.5 GHz), broadcasting and BSS (40.5-41.0 GHz band) and FS, mobile, broadcasting and BSS (41.0-42.0 GHz). FSS operations are subject to clear-sky PFD levels 12 dB higher than the level allowed in the 37.5-40.0 GHz band,[9] but the only satellite systems licensed by the Commission in this band were the previously surrendered Northrop Grumman and Hughes systems.[10]

The 40.0-42.5 GHz band was identified in the Commission's *Spectrum Frontiers Order & Further Notice* for consideration for the Upper Microwave Flexible Use Service ("UMFUS").[11] Accordingly, there is substantial uncertainty with respect to the spectrum access rules that may apply to this band in the future. Nonetheless, Theia notes that its

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[9] *Spectrum Frontiers NPRM* ¶ 125 (citing *V-Band Second Report and Order*, 18 FCC 25428, 25432 ¶¶ 8, 12-14 (2003)).

[10] *See supra*, n.4.

[11] Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, et al., Report and Order and Further Notice of Proposed Rulemaking, FCC 16-89, ¶ 400 (Jul. 14, 2016).

limited use of this downlink band for gateway and high-capacity receive earth station operations would be compatible with contemplated terrestrial uses of the band. Theia will comply with Commission rules that may be adopted governing such satellite access to the band, or seek appropriate waivers, if necessary.

With respect to Federal use, the primary use of this band appears to consist of NASA and NSF programs for solar system exploration and radio astronomy, including the Very Large Baseline Array ("VLBA"), which operates receivers in the 41.0-45.0 GHz range.[12] The 40.0-41.0 GHz sub-bands include an allocation for military FSS and MSS systems,[13] but Theia has not identified any current Federal systems operating in this band. Theia will coordinate its limited earth station receive operations with Federal users and comply with applicable power limits to fully protect all Federal uses of the bands.

This band is critical for its proposed operations so FSS access to the band should be preserved. At a minimum, Theia should be permitted to operate in this band outside the United States in accordance with international FSS allocations and applicable regulatory requirements.

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[12] *Federal Spectrum Use Summary* at 76-77; *Spectrum Frontiers NPRM*, ¶ 173 (noting that VLBA receivers include the 41.0-45.0 GHz band).

[13] 47 C.F.R. § 2.106 n.G117; *see also Spectrum Frontiers NPRM*, ¶ 169 (discussing protection measures for Federal MSS and FSS downlink, but not identifying any specific Federal users).

4.6.2.3. FSS (s-to-E): 42.0 GHz – 42.5 GHz

The U.S. Table of Allocations provide that the 42.0-42.5 GHz band is allocated as a non-Federal only band for FS, mobile, broadcasting and BSS services on a co-primary basis. There is no FSS allocation in this band and Theia respectfully requests a waiver to operate its FSS feeder link earth stations on a non-conforming basis in the band. Theia agrees to accept any harmful interference from these services while operating on a non-conforming, unprotected basis.

It appears that this band is among the frequencies used by the VLBA for radio astronomy observations,[14] and Footnote US211 of the U.S. Table requires any operations in this band to take all practicable steps to protect radio astronomy in this band.[15] Theia will coordinate its limited earth station receive operations with Federal users and comply with applicable power limits to fully protect all Federal uses of the bands.

In addition, like other V-band downlink spectrum, this band is critical for its proposed operations so FSS access to the band should be preserved. At a minimum, Theia

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[14] *Federal Spectrum Use Summary* at 77; *Spectrum Frontiers NPRM*, ¶ 173 (noting that VLBA receivers include the 41.0-45.0 GHz band).

[15] *See* 47 C.F.R. § 2.106, n. US211. Regarding radio astronomy usage, Theia would comply with the provisions of Footnote 5.551H and would follow the coordination process described in Resolution 743-2. For radio astronomy sites that confirm observation band capabilities in the 37.5-42.5 GHz band, Theia intends to complete the coordination process to protect observation capabilities at these selected locations and facilities. Theia will also suppress out-of-band emissions above 42.5 GHz to comply with the protection criteria identified in ITU Recommendation RA.769-2 to protect radio astronomy observation in the 42.5-43.5 GHz band.

should be permitted to operate in this band outside the United States in accordance with international FSS allocations and applicable regulatory requirements.

4.6.3. Sharing with GSO and NGSO FSS Systems

There are no other GSO or NGSO satellite systems currently licensed by the Commission or granted market access in the United States that operate within the V-band frequency ranges proposed to be used by Theia. Moreover, the Commission has not yet enacted band-specific service rules or NGSO/GSO sharing criteria for the V-band. To the extent required, Theia will coordinate with future GSO satellite operators and is confident that applying the GSO arc avoidance procedures with an appropriate alpha angle will enable sharing with any future V-band GSO networks.

Theia is fully aware, however, of the technical studies being performed to develop EPFD limits pursuant to Resolution 159 (WRC-15) that would facilitate spectrum sharing between GSO satellite networks and NGSO satellite systems in this frequency band segment. The EPFD limits would identify the required levels to protect GSO satellite networks. These EPFD limits will be developed through a consensus-based processes involving both GSO and NGSO system operators and should therefore ensure an equitable spectrum sharing arrangement between these two categories of systems. Once these new V-Band EPFD levels are established, Theia will analyze TSN EPFD relative to these protection criteria and establish appropriate interference avoidance mechanisms to assure protection of GSO systems from excessive interference. The primary interference avoidance mechanism anticipated is GSO arc avoidance. The details of this avoidance (e.g.

the alpha angle) will be determined through detailed analysis against the GSO protection criteria once they have been established.

Regarding sharing with other NGSO systems, TSN has design and operational characteristics that ameliorate potential interference circumstances. In particular, the TSN includes highly directional V-band earth station beams (beam widths between 0.09° and 0.33°) and a limited number of V-band earth stations is anticipated. TSN satellites support a maximum of two (2) V-band earth station sites within its footprint, employing narrow, low-sidelobe satellite spot beams. Site diversity between TSN earth stations and potential victim stations can be employed to avoid interference events. All of these characteristics help minimize the probability of in-line events with the NGSO FSS earth stations communicating with other NGSO FSS satellites.

Theia notes that in Section 25.261 of the Commission's rules there are procedures established for in-line interference avoidance. Until the Commission publishes V-band specific GSO/NGSO sharing criteria, TSN will apply procedures similar to those detailed in Section 25.261 for the V-band frequencies outlined in this Amendment. Specifically, Theia will coordinate with other NGSO operators 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 links among the networks to avoid interference.

TSN design and operations are consistent with coordination with other NGSO systems described above. Due to the significant rain fades that are common in V-band, Theia is aware of the limited per-link availability and is planning on site diversity to achieve the necessary service availability. As such, the TSN architecture is robust to the outages or temporary bandwidth reductions that will occur as a result of both GSO arc avoidance and in-line interference events with other NGSO systems.

Appendix 1
EPFD Compliance Analysis

In addition to the information set forth in Appendix 1 Ku-Band and Ka-Band EPFD Compliance Analysis in the TSN Application, Theia seeks to operate gateway and other high-capacity links in V-band frequencies. EPFD considerations for V-band are described herein.

EPFD limits enable NGSO systems and GSO networks to share spectrum without requiring the NGSO system operators to coordinate with all GSO satellite operators. Technical studies have begun pursuant to ITU-R Resolution 159 (WRC-15) to develop EPFD limits for V-band. Currently there are no EPFD limits in effect for V-band in the FCC rules or Article 22 of the ITU Radio Regulations.

Theia recognizes that Article 22 that indicates that NGSO systems shall not cause unacceptable interference to, and shall not claim protection from, GSO networks. Theia will comply with all applicable V-band uplink, downlink and inter-satellite link EPFD levels whenever those new regulations are established.

In addition, currently there are no NGSO satellite systems licensed to operate in V-band. Theia plans to coordinate with future NGSO satellite system operators in order to share the V-band spectrum efficiently.

Appendix 2
COMPLIANCE WITH PFD LIMITS
(§25.208(b), §25.208(c), §25.208(e), §25.208(o), §25.208(p), §25.208(r), §25.208(s), and §25.208(t))

In addition to the information set forth in Appendix 2 Compliance with PFD Limits in the TSN Application, Theia seeks to operate gateway links in V-band frequencies. PFD considerations for V-band are described herein.

Downlink PFD Limits in V-band

The FCC's V-band downlink PFD limits are defined in §25.208(r), §25.208(s) and §25.208(t) and apply in various parts of the V-band downlink bands used by the TSN. In addition, the ITU PFD limits in Article 21, Table 21-4, notes 21.16.4 and 21.16.14, of the Radio Regulations cover the same frequency bands of the FCC PFD limits but include an additional frequency band between 42.0-42.5 GHz for which there are no FCC PFD limits. The specific FCC and ITU limits within all the V-band downlink sub-bands applicable to this amended filing are listed in Table 2. Figure 1 provides plots of the entire set of FCC and ITU PFD Limits.

Table 2 V-Band Downlink PFD Limits

V-band Downlink	Applicable PFD Limit
37.5 – 40.0 GHz	FCC §25.208(r) / ITU Article 21 (notes 21.16.4 & 21.16.14)
40.0 – 40.5 GHz	FCC §25.208(s) / ITU Article 21
40.5 – 42.0 GHz	FCC §25.208(t) / ITU Article 21 (notes 21.16.4 & 21.16.14)
42.0 – 42.5 GHz	No FCC PFD Limit / ITU Article 21 (notes 21.16.4 & 21.16.14)

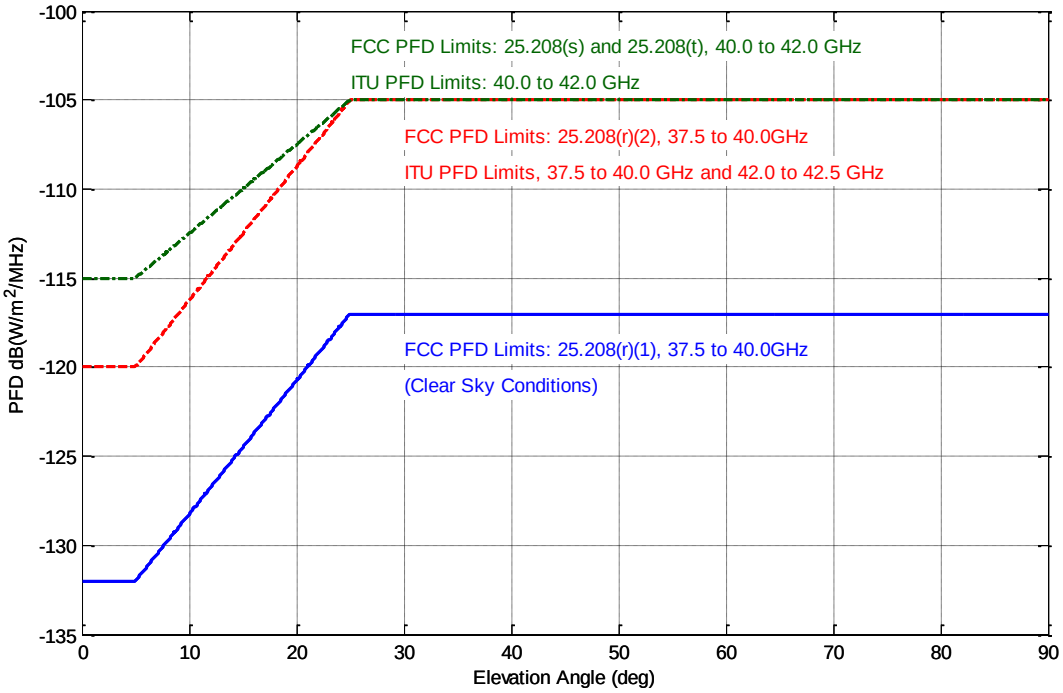

Figure 1: V-Band PFD Limits

The TSN is designed to comply with the PFD limits specified in §25.208(s) and §25.208(t) for NGSO FSS systems operating in the 40.0 to 40.5 and 40.5 to 42.0 GHz bands, respectively.

In clear sky conditions, no rain fade, the TSN system will meet the most restrictive PFD limits specified in the 25.208(r)(1) of the Commission rules for NGSO FSS systems operating in the 37.5GHz to 40GHz band. During limited periods of operation during rain fades, the TSN system will exceed the PFD limits specified in §25.208(r)(1) of the Commission rules for NGSO FSS systems operating in the 37.5-40 GHz band but easily meet the worst-case PFD limits for this band as specified in §25.208(r)(2).

Theia recognizes that the Commission is considering allowing systems to operate in the 37.5-40.0 GHz band using the PFD limits adopted by the ITU for this spectrum, which

are reflected in Article 21 (Table 21-4) of the Radio Regulations.[16] Should the Commission changes its rules to permit such higher-power downlinks, Theia reserves the right to seek authority for such high-power operatons.

Section 25.208 of the Commission's rules does not specify any PFD limits for FSS operations in the 42.0-42.5 GHz band. Thus, this Amendment contemplates TSN operations in this band using the applicable ITU PFD limits.

TSN satellites will use V-band downlink spectrum for communications with gateway and other high-capacity earth stations with very high G/T. Therefore, all of the remaining PFD limits will be easily met. To simplify the PFD, analysis only the most stringent V-Band downlink limits will be considered. By demonstrating compliance with the most stringent ITU limits, the other FCC and ITU PFD limits are also met.

The most constraining V-Band FSS downlink PFD limits under any condition defined by the ITU for the 37.5-40.0 GHz and 42.0-42.5 bands are:

- *-120 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*

- *-120 +0.75(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.*

The most constraining V-Band FSS downlink PFD limits under clear sky conditions defined by the FCC for the 37.5-40.0 GHz bands are:

- *-132 dB(W/m^2) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;*

- *-132 +0.75(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*

---

[16] TSN acknowledges that footnote 21.16.4 of Article 21 (Table 21-4) indicates that the PFD limits apply to emissions of NGSO satellites of systems operating with 99 or few satellites and further study may be necessary in order to apply them to systems operating with 100 or more satellites.

- *-117 dB(W/m^2) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.*

The TSN V-band downlink will operate in the same manner across the entire V-band, even though the PFD restrictions vary by sub-band. TSN employs downlink power control to combat rain fades and maintains a constant downlink EIRP density across the operational range of the elevation angles between 12° and 90° during clear sky conditions when downlink power control is not required. The maximum PFD at edge of coverage (EOC) of 12 deg is -124.08 dB(W/m^2/MHz) which corresponds to a target EIRP density level over the entire operational footprint of 13.86 dBW/MHz. This PFD reflects the TSN satellites operating at maximum power levels but assumes only free space propagation (e.g. no rain or atmospheric losses).

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 maximum PFD curves for the V-Band is illustrated in Figure 2.

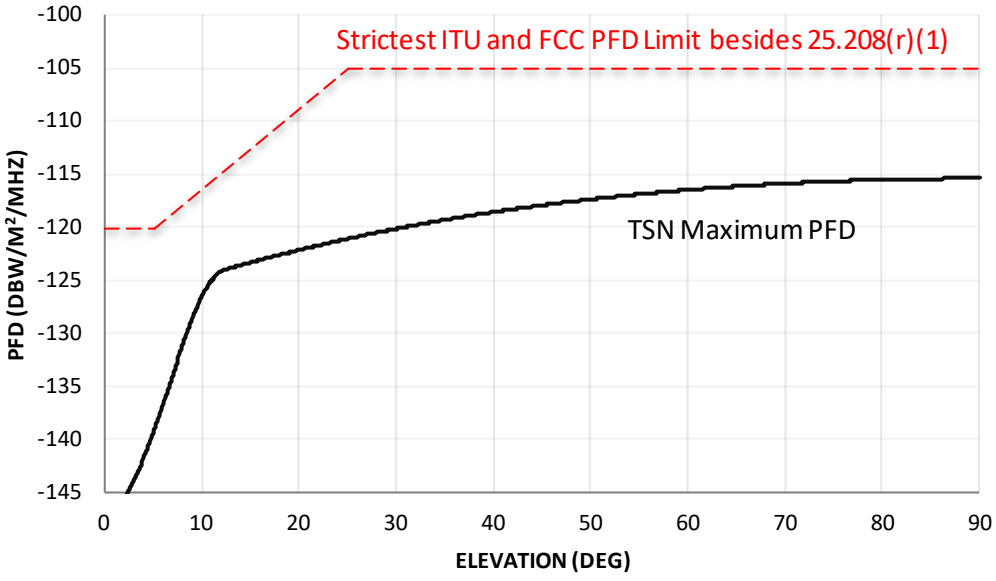

Figure 2: TSN V-Band Maximum PFD vs. Elevation Angle

As illustrated by the analysis provided in this Appendix, the TSN satellites easily comply with all the V-band FCC and ITU worst-case PFD limits. During nominal operation, when the link to the earth station is not experiencing any rain fade, the TSN system will operate with a constant EIRP density across the footprint that is 8 dB lower. As illustrated in Figure 3, this operation assures compliance with 25.208(r)(1).

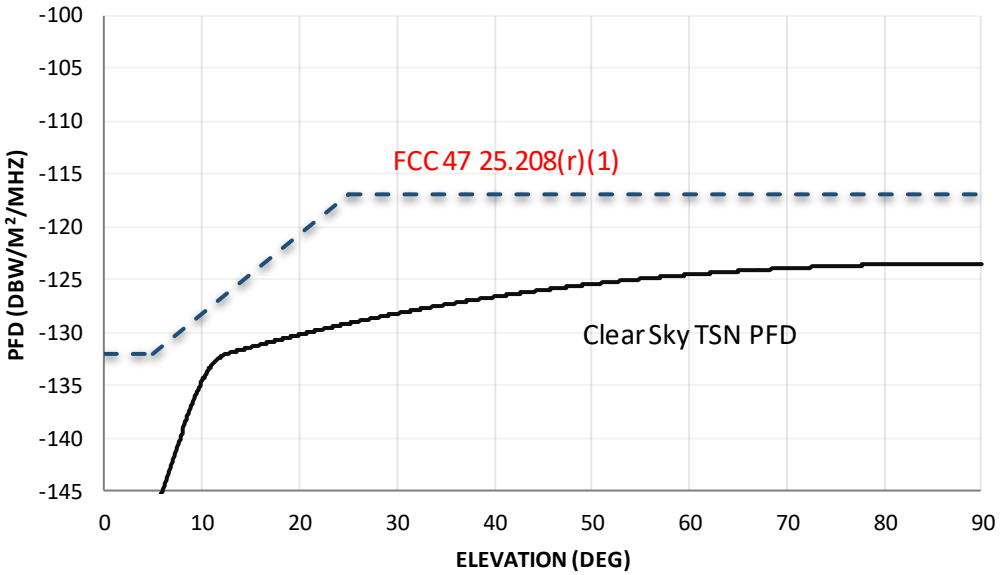

Figure 3: TSN clear sky PFD versus Elevation angle.

Appendix 3
TSN V-band Link Budgets

In addition to the information set forth in Appendix 3 TSN Link Budgets in the TSN Application, Theia seeks to operate gateway links in V-band frequencies. Link budgets for V-band gateways, on a band-specific basis, are included below. Links budgets for similarly sized high-capacity earth stations would be identical to those included below.

V-Band Uplink Link Budgets:

		47.2GHz to 50.2GHz			
		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	48.70	48.70	48.70	48.70
Channel Symbol Rate	Msps	2500.00	2500.00	2500.00	2500.00
Bandwidth Effciency	bps/Hz	2.12	2.12	4.11	4.11
Burst Information Data Rate	Mbps	5304.52	5304.52	10287.11	10287.11
ModCod		16APSK 8/15-L	16APSK 8/15-L	32APSK 7/9	32APSK 7/9
Effective EIRP	dBW	75.17	75.17	84.71	84.71
Free Space Loss	dB	193.14	184.26	193.14	184.26
Effective G/T	dBi/K	12.1	12.1	12.1	12.1
Receive Power	dBW	-77.76	-68.88	-68.21	-59.33
Received C/N	dB	28.74	37.62	38.28	47.16
C/I	dB	18.00	18.00	18.00	18.00
Objective C/(N+I)	dB	8.25	8.25	15.13	15.13
Objective C/N	dB	8.74	8.74	18.28	18.28
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	19.0	27.9	19.0	27.9

		50.4GHz to 51.4GHz			
		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	50.90	50.90	50.90	50.90
Channel Symbol Rate	Msps	833.33	833.33	833.33	833.33
Bandwidth Effciency	bps/Hz	2.16	2.16	4.14	4.14
Burst Information Data Rate	Mbps	1797.77	1797.77	3448.42	3448.42
ModCod		8PSK 13/18	8PSK 13/18	32APSK 7/9	32APSK 7/9
Effective EIRP	dBW	70.56	70.56	80.10	80.10
Free Space Loss	dB	193.53	184.65	193.53	184.65
Effective G/T	dBi/K	12.5	12.5	12.5	12.5
Receive Power	dBW	-82.37	-73.49	-72.83	-63.95
Received C/N	dB	28.90	37.78	38.44	47.32
C/I	dB	18.00	18.00	18.00	18.00
Objective C/(N+I)	dB	8.39	8.39	15.20	15.20
Objective C/N	dB	8.90	8.90	18.44	18.44
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	19.0	27.9	19.0	27.9

V-Band Downlink Link Budgets:

		V-Band (37.5 to 42.5)			
		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	40.00	40.00	40.00	40.00
Channel Bandwidth	MHz	5000.00	5000.00	5000.00	5000.00
Bandwidth Efficiency	bps/Hz	0.98	0.98	3.00	3.00
Burst Information Data Rate	Mbps	4070.66	4070.66	12500.02	12500.02
ModCod		QPSK 9/20	QPSK 9/20	16APSK 13/18	16APSK 13/18
Effective EIRP	dBW	49.55	49.56	49.55	49.56
Free Space Loss	dB	191.43	182.55	191.43	182.55
Effective G/T	dBi/K	25.5	25.5	35.0	35.0
Receive Power	dBW	-88.42	-79.53	-78.88	-69.99
Received C/N	dB	16.00	24.89	25.54	34.43
C/I	dB	18.00	18.00	18.00	18.00
Objective C/(N+I)	dB	2.86	2.86	11.45	11.45
Objective C/N	dB	3.00	3.00	12.54	12.54
External Interference Loss	dB	1.00	1.00	1.00	1.00
Clear Sky Link Margin	dB	12.0	20.9	12.0	20.9

Appendix 4

TSN Orbital Debris and Deorbit Analysis

In addition to the information set forth in Appendix 4 TSN Orbital Debris and Deorbit Analysis in the TSN Application, Theia seeks to operate gateway links in V-band frequencies in addition to Ka-band frequencies. Further TSN Orbital Debris and Deorbit Analysis considerations for V-band are discussed herein.

Modifications to the TSN satellite needed to add the V-band communications capability are modest in scope:

- A dual Ka-band/V-band feed replaces the Ka-band only feed on the two steerable reflectors.
- Appropriate cabling is added to provide intermediate frequency (IF) signals between the satellite body and the feed assemblies.
- Additional Local Oscillator frequencies are generated.
- An additional suite of transmit / receive electronics that are identical to the Ka-band electronics are added in the satellite body for V-band.
- Another port on the baseband router is added to provide digital data to/from the V-band electronics.

The size, weight, and power (SWaP) impacts of these changes are negligible at this stage of satellite design. This addition is comfortably accommodated in SWaP budget tolerances already established for the satellites. These additions are not expected to alter satellite cost, development and production schedules, launch considerations, or satellite operations in any significant way.

The addition of a V-band communications capability employs satellite hardware that is essentially identical in form to the Ka-band electronics. As such, it does not represent any increase in risk of debris generation or risk of collision with orbital debris or meteoroids.

The same construction standards employed for TSN satellite subsystems will apply to the V-band suite.

By the very nature of the V-band electronics, there is no additional energy storage, chemical or pressurization energy, kinetic energy, or any other energy mechanism that would cause an explosion or similar debris generation event.

The addition of the V-band electronics suite will not materially affect satellite post-mission retirement / deorbit considerations. The addition of the electronic does not alter the prediction of an orbital lifetime of less than 25 years until atmospheric re-entry occurs as a result of natural orbital decay processes.

The addition of the V-band electronics suite will not materially affect risk of casualty on the earth from atmospheric re-entry because the electronics suite is predicted to have a demise altitude of 70 to 76 km. Consequently, no additional debris is expected to reach the Earth's surface, and the casualty risk analysis from the TSN Application remains unchanged.