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KEPLER NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A

Technical Narrative to Supplement Schedule S

A.1 SCOPE AND PURPOSE

This attachment contains the information required by the FCC's Part 25 rules that is not currently captured by the Schedule S online platform. More specifically this document provides supporting technical material for §25.114(d) and §25.146, in addition to supporting explanations for the parameters in Schedule S.

A.2 25.114 APPLICATION FOR SPACE STATION AUTHORIZATIONS

A.2.1 25.114(d)(1) OVERALL DESCRIPTION OF SYSTEM FACILITIES, OPERATIONS AND SERVICES AND EXPLAINATION OF HOW UPLINK FREQUENCY BANDS WOULD BE CONNECTED TO DOWNLINK FREQUENCY BANDS

The Kepler non-geostationary orbit (NGSO) satellite system (the "Kepler System") consists of up to 140 Low Earth Orbit (LEO) nanosatellites, deployed in phases, operating in polar orbits[1] within an altitude range of 500 - 650 km, as well as associated gateway earth stations, and end user terminals[2]. The planned constellation is shown in Figure 1. The Kepler System provides real-time connectivity for disparate sensor networks, both on and off the earth's surface. Terrestrial user terminals aggregate data from nearby sensors and backhaul the information through the Kepler System, while user terminals on-board other NGSO satellites provide those NGSO with access to the Kepler System's inter-satellite links to relay data to each other and the ground in real-time. The frequency ranges intended for use by the Kepler System are summarized in

Table **1** below.

[1] This includes sun-synchronous polar orbits based on launch vehicle availability
[2] The systems intended orbit is at 600 Km and where applicable this value is used for demonstration of compliance

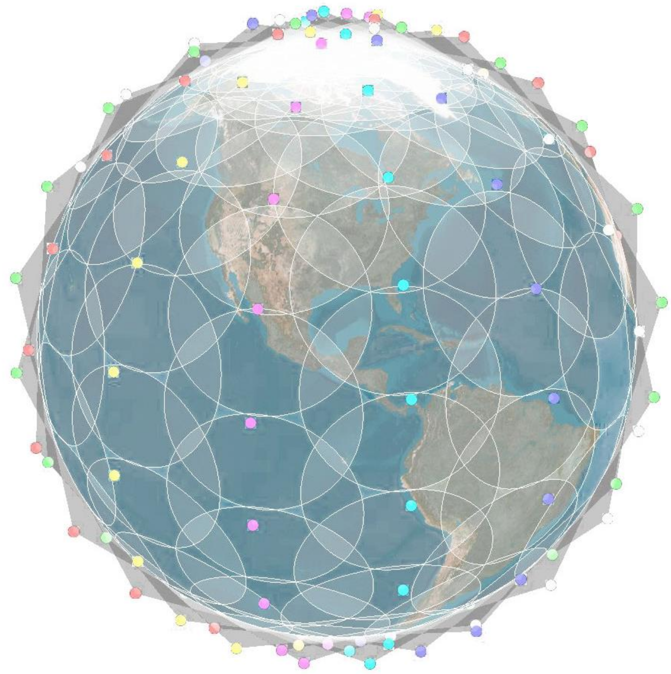


Figure 1: Representative satellite coverage of Kepler's System

Table 1: Table of frequencies used by system

Link	Frequency Range	Covered in this Application
Satellite-to-Satellite	25.25 - 27.5 GHz[3]	No
User terminal-to-Satellite	12.75 - 13.25 GHz[4]	No
	14.0 - 14.5 GHz	Yes
Satellite-to-User terminal	10.7 - 12.7 GHz	Yes
Satellite-to-Gateway	10.7 - 12.7 GHz	Yes
Gateway-to-Satellite	12.75 - 13.25 GHz[5]	No
	14.0 - 14.5 GHz	Yes

[3] Kepler will be working with the Canadian authorities to license inter-satellite links. Where required and on an as needed basis, Kepler will disclose to the FCC the operation of inter-satellite links with U.S. licensed operators

[4] Use of the 12.75 – 13.25 GHz band within the U.S. is not being requested at present and will be phased in at a later stage in the deployment of the Kepler System.

[5] Use of the 12.75 – 13.25 GHz band within the U.S. is not being requested at present and will be phased in at a later stage in the deployment of the Kepler System.

The Kepler System uses Ku-band for the RF links between satellites and terrestrial user terminals, as well as between satellites and gateways. Ka-band RF links are used for inter-satellite communication within the network and with space user terminals on-board other NGSOs. The Kepler Ku-band terrestrial user terminals use small electrically steerable antenna arrays (order of 30cm equivalent aperture diameter), and can be deployed in any remote region with optional equipment for solar panels or environmental enclosures. The Ku-band gateway stations use a 2.4m antenna or larger, depending on location and the associated propagation characteristics and service requirements.[6] The Ka-band inter-satellite links are achieved with small array antennas both on board the Kepler System spacecraft and other NGSO systems wishing to use the link. The present narrative will only detail the frequencies as specified in Table **1**, and thus will not further discuss the Ka-band, nor the 12.75 – 13.25 Ku-band link, and hereinafter "user terminals" will refer exclusively to terrestrially located user terminals.

The Kepler System is unique in that it is purpose-built for communication with machines, which changes the system architecture considerably, and hence spectrum utilization. More specifically, the types of services offered are characterized by a high uplink-to-downlink ratio[7], typically in the range of 100:1. For comparison, broadband satellite services have an uplink-to-downlink ratio on the order of 1:10. As a result, machine communication removes many taxing constraints on the satellite itself, making low-cost nanosatellites well suited to address this need as compared with large spacecraft, which are better suited for low uplink-to-downlink ratios. It also implies that spectrum utilization is more dominated by the earth-to-space direction, which greatly simplifies coordination.

The constellation of Kepler satellites will be launched using an incremental approach being opportunistic of any available secondary payload launches. To start, 2 satellites will be launched at the end of 2017.[8] The second deployment phase will consist of larger launches upwards of 20 satellites on a single launch vehicle, providing coverage within a single orbital plane. The final deployment phase will consist of

[6] It is observed that ITU RR footnote 5.502 stipulates a minimum antenna diameter of 4.5m for earth stations in the 13.75 – 14 GHz band. The present application is not considering this specific band, and thus this footnote does not apply

[7] Uplink and downlink at the user terminals, not the gateway stations

[8] Kepler may launch up to 5 satellites in Phase I of its system deployment

launches to multiple orbital planes until global, real-time coverage is reached with 140 satellites operating across 7 orbital planes.[9] For clarity, Table 2 depicts the anticipated rollout of Kepler's constellation.

Table 2: Planned rollout of Kepler's System.[10]

	Phase I	Phase II	Phase III
Minimum	2 Satellites	5 Satellites	14 Satellites
Maximum	5 Satellites	20 Satellites	140± Satellites
Timeframe	2017 - 2018	2018 - 2020	2018 - 2022

Gateway sites will provide connectivity between the satellite and the global internet. Typically, 2 or more earth stations will be co-located at each gateway; one leading and one trailing antenna to maintain continuous connectivity with the constellation. It is expected that a minimum of two gateway sites will be deployed, with the exact number depending on the market need. Moreover, the gateway earth stations will also transmit and receive control channels for the purpose of satellite control. Currently, there are no planned gateway sites for the USA, as shown in Table 3.[11] As such, the gateway links will not be covered in this narrative.

Table 3: List of planned gateway stations.

	Latitude	**Longitude**
Inuvik (Canada)	68.21 N	133.44 W
Esrange (Sweden)	67.88 N	21.13 E

Each Kepler satellite will have a total cone of coverage no greater than 64°, as shown in Figure 2, which implies a minimum elevation angle for user terminals of 10.4^0.[12] Each satellite and user terminal will be equipped with a "software defined radio" (SDR), and an antenna array. In practice, this implies a dynamic beam pattern, channel bandwidth, and output power (and thus, dynamic EIRP). This flexibility means that as additional satellites are added to the constellation, the transmit/receive characteristics and concept of operation of existing satellites in the constellation can be altered via software upgrades in order to remain compliant with PFD and EPFD limits. Note also that because Kepler is making use of an SDR, the center

[9] The number of satellites and orbital planes may increase as a result of system demand and to prevent interference. The Commission will be notified of any changes to the constellation.

[10] The data presented in this table is not meant to provide a defined rollout plan. At best, the data is representative given Kepler's position as a secondary payload on launch vehicles.

[11] Locations of gateway links have not been finalized and will be updated as required and on an as needed basis.

[12] The cone coverage presented is for the System's nominal operational altitude of 600km.

frequencies listed in Schedule S are merely representative. In practice, Kepler is able to adjust center frequency and channel bandwidth dynamically within the frequency ranges requested. This was also highlighted in the attached *Legal Narrative*.

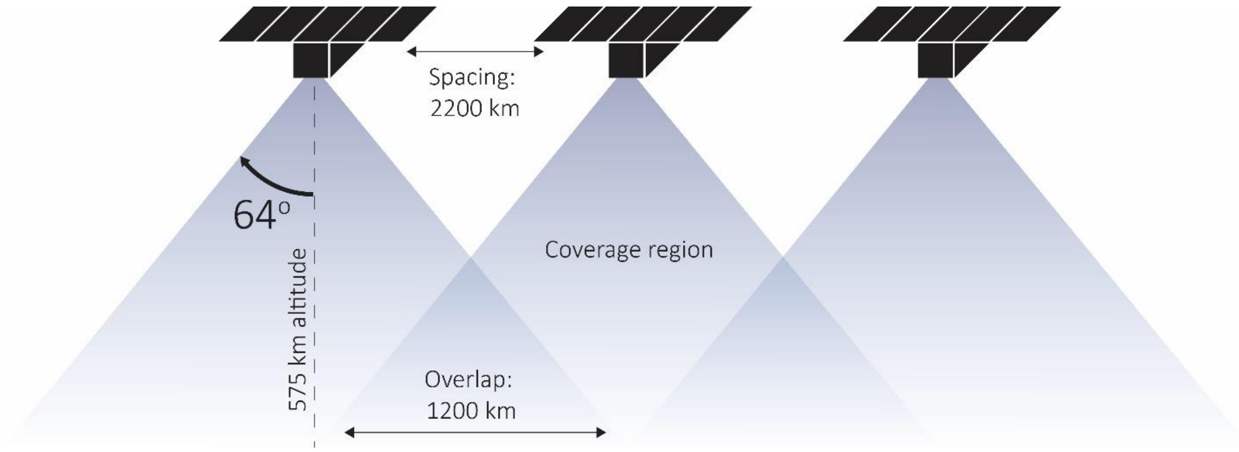


Figure 2: Cone of coverage for each satellite.

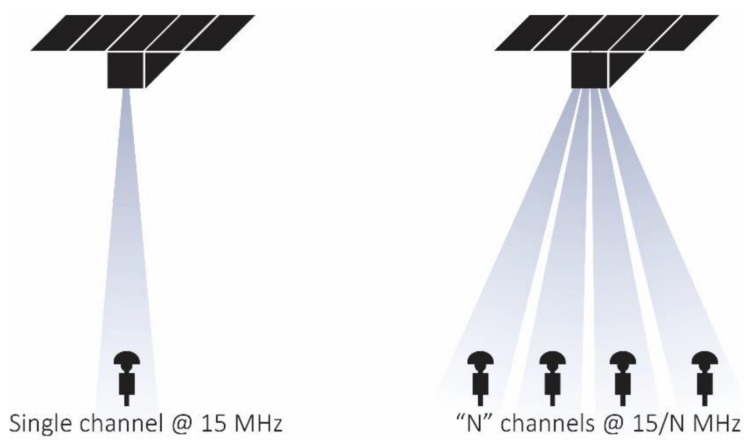
In the space-to-earth direction between the Phase I satellites and user terminals (designated channel "DUa1")[13], a single channel will occupy a maximum of 15 MHz. Through the use of the SDR, this can be allocated as a single channel of 15 MHz, or *N* channels each with a bandwidth of $\frac{15}{N}$ MHz. Practically, the minimum channel bandwidth will be 1kHz, implying upwards of 15,000 channels that the SDR on the satellite and user terminals would switch between.[14] The use of such small bandwidths would also allow the system to implement multiple access schemes, such as frequency hopping, which is widely used in WiFi and cellular networks. RF power output can be similarly adjusted, with a maximum output power of 22.6 dBm.

In the earth-to-space direction between the user terminals and the satellites (designated channel "UU1"), a single channel will occupy up to 50 MHz of bandwidth. In Phase I, the SDR is designed for 200 MHz of receive bandwidth, implying a range between 4 x 50 MHz channels to 200,000 x 1kHz channels that the

[13] Given the large number of channels, Schedule S includes the lowest, mid and highest channel for the space-to-earth user terminal communications. The commission should note the ability to dynamically change center frequency as well as bandwidth and the associated burden with inserting this data into Schedule S. *See* waivers in the associated legal narrative.
[14] A 1kHz channel is only provided as an example of the capability of the SDR. Operation in the Ku band at 1kHz is unlikely to occur

SDR would switch between.[15] The receive bandwidth is comparatively simple to increase by adding additional analog-to-digital converters on the SDR.[16] This is in contrast to the space-to-earth direction, where the total bandwidth is limited by available power and/or antenna gain on the satellite, which are comparatively difficult to increase. This further emphasizes the point that machine communications, characterized by high uplink-to-downlink ratios are well served by nanosatellite constellations because of their minimal constraints on satellite form factor. The uplink and downlink beam patterns are shown conceptually in Figure 3.

While the bandwidths noted above are representative of typical user cases anticipated in the market, Kepler's System is capable of scaling the bandwidth dynamically due to its SDR. By way of example, if a particular client required in excess of 200 MHz in the space-to-earth direction, this could be provided in several ways - a larger antenna on the user-terminal being the simplest.[17] It should thus be clear that Kepler's System is capable of fully utilizing the entire 10.7 – 12.7 GHz and 14.0 – 14.5 GHz spectrum allocations, and is not limited to the examples provided above. In compliance with 25.210(f) Kepler's System is capable of full frequency reuse through the use of orthogonal polarization and spatially independent beams.



[15] *See* id.
[16] The bottleneck would subsequently become the computing power onboard the satellite. Given the frequency at which the satellites are replaced, the onboard computing power is expected to significantly grow through each generation.
[17] Although not covered in this PDR, Kepler uses this capability when downlinking to its gateway

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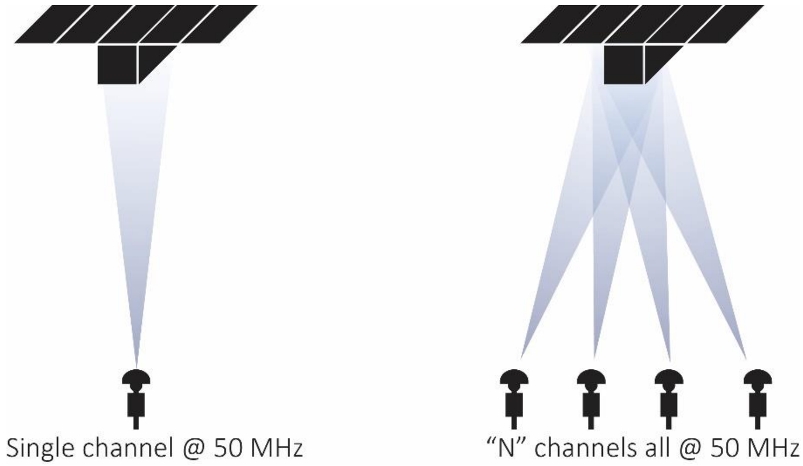

Figure 3: (Top) Downlink and (bottom) uplink channel sizes and antenna patterns

A.2.2 25.114(d)(6) PUBLIC INTEREST IN SUPPORT OF THE GRANT

This section is discussed in detail in the associated legal narrative.

A.2.3 25.114(d)(14)(v) DEBRIS MITIGATION PLANS

Kepler's orbital debris assessment report (ODAR) for the proposed System is presented in Annex II. As per §25.114(d)(14), Kepler is requesting market access and is subject to direct and effective regulatory oversight by ISED – the Canadian national licensing authority. Requirement 3.3.3 of the Canadian Licensing of Space Stations procedure requires the de-orbiting of NGSOs in accordance with best industry practices.[18] As such, Kepler's ODAR will be reviewed and accepted by said authority. The inclusion of Kepler's preliminary ODAR report for Phase I of the constellation is for reference only and provided in good faith. Note that the included ODAR is for the initial 2 planned launches with a nominal altitude of 600km, which is based on launch vehicle availability. If required, for future launches planned above these altitudes, Kepler will submit a modified ODAR to ISED ensuring compliance with orbital debris regulations.

[18] See Client Procedures Circular 2-6-02 – Licensing of Space Stations (CPC-2-6-02 http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html)

A.3 25.146 LICENSING AND OPERATING AUTHORIZATION PROVISIONS FOR THE NON-GEOSTATIONARY SATELLITE ORBIT FIXED-SATELLITE SERVICE (NGSO FSS) IN THE BANDS 10.7 GHZ TO 14.5 GHZ

A.3.1 25.146(a) EPFD LIMIT CALCULATIONS

Compliance with the ITU Article 22 and FCC §25.146 EPFD limits for the space-to-earth ($EPFD_{down}$), earth-to-space ($EPFD_{up}$) and inter-satellite ($EPFD_{IS}$) is ensured by the Kepler System, and supporting calculations are provided in Annex I. Note that the process of protecting GSO from interference also has the effect of protecting Kepler from interference from GSO, as the method is based on avoidance of inline and near-inline events.

In the 10.7 – 12.7 GHz space-to-earth direction, protection of GSO is achieved by avoiding transmissions from the Kepler satellites in predetermined NGSO-centric azimuth (α) and elevations (ε) as a function of sub-satellite latitudes in order to avoid inline event with the victim GSO earth stations, depicted in Figure 4. An inline event is defined as: when the minimum angle (γ) between a line connecting the NGSO, at some azimuth and elevation, and a point on the geostationary arc is below a set exclusion angle. Latitude-dependent exclusion angles will be set so as to avoid inline events that result in exceeding the $EPFD_{down}$ limits, and these values are provided in Table 4. The use of electrically steerable antennas on the satellite means simply that the transmitting beam will not steer to these exclusion zones during operation.

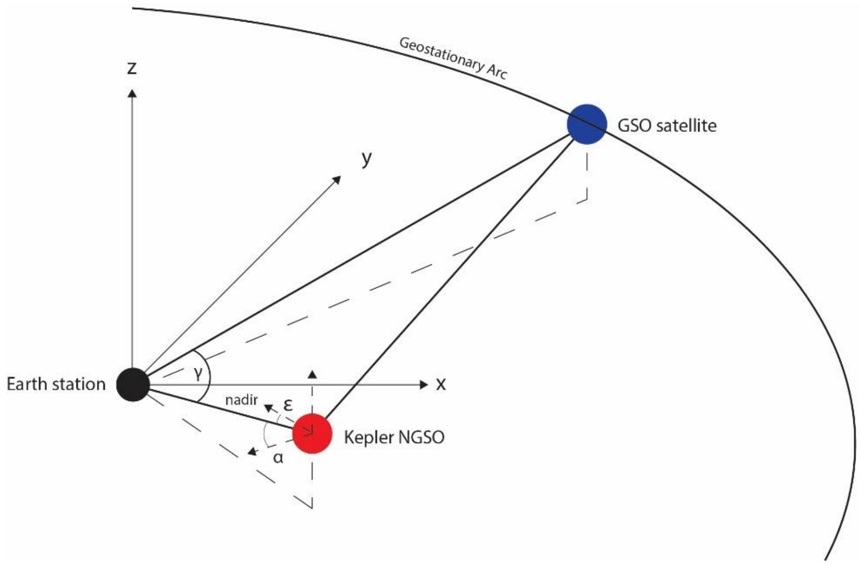

Figure 4: Depiction of angles between Kepler satellites and GSO satellites.

Table 4: Latitude-dependent exclusion angles used by the Kepler system in the space-to-earth direction

Latitude (S and N hemispheres)	Exclusion Angle
0 – 20	30
20 – 40	35
40 – 65	50
60 - 90	0

Similarly, in the 14 – 14.5GHz earth-to-space direction, protection of GSO is achieved by avoiding transmissions during inline events. This is achieved with a 20^{o} exclusion angle across all latitudes. $EPFD_{IS}$ compliance is also shown in Annex I as per ITU Article 22, even though this is not referenced in §25.146.

A.3.2 25.146(b), 25.146(g) AND 25.173 PRE-LAUNCH TECHNICAL NARRATIVE

Kepler will comply with the requirement to notify the Commission 90 days prior to launch and submit additional information, where required, in order to demonstrate EPFD compliance.

A.3.3 25.146(e) PROTECTION FROM GSO

Kepler confirms that it will not claim interference protection from GSO FSS and BSS networks operating in accordance with Part 25 of the FCC rules and the respective ITU Radio Regulations.

A.3.4 25.146(f) COORDINATION BETWEEN NGSO AND GSO

Kepler confirms that it will coordinate with GSO FSS earth stations in the 10.7 – 12.7 GHz band where the threshold conditions are met, as highlighted in sections (1) and (2) of §25.146(f) of the Commission's rules.

A.3.1 25.146(i) DEMONSTRATION OF COVERAGE

Kepler's proposed system uses polar orbits in order to provide coverage over the entire Earth's surface including the fifty states, Puerto Rico and the U.S. Virgin Islands. Given the proposed constellation of 140 satellites, the system is capable of providing real-time access to terrestrial assets around the globe. This includes at locations as far north as 70^o North Latitude, and as far south as 55^o South Latitude for at least 75 percent of every 24-hour period. A depiction of the system was provided previously in Figure 1.

In order to comply with 25.146(i)(3), the system operates with an overlap as depicted previously in Figure 2. This allows for continuous coverage despite cessation of transmission from a single satellite when within the aforementioned exclusion regions. The use of antenna arrays on both the satellite and user terminals allow for a seamless transition given the ability for a terminal to actively connect with more than one satellite at any given time.

It is noted that the first two phases of operation will not provide continuous coverage through the fifty states, including Puerto Rico and the US Virgin Islands, nor will it provide coverage as far north as 70^o North Latitude and as far south as 55^o South Latitude for at least 75 percent of every 24-hour period owing to an incomplete constellation deployment. Out of an abundance of care, Kepler is requesting a waiver for this requirement at initial phases of deployment.

A.4 25.164(b) AND 25.137(d)(4) MILESTONES & BOND

These sections are discussed in detail in the associated legal narrative.

A.7 25.202 FREQUENCIES, FREQUENCY TOLERANCE AND EMISSION LIMITS

A.7.1 25.202(g) TELEMETRY, TRACKING, AND COMMAND FUNCTIONS

Part of Kepler's application for its license to operate a satellite service requires its primary TT&C earth station to be located in Canada. This is a requirement by the Canadian authorities – through whom Kepler intends to license its constellation.[19] In keeping with the Canadian requirements, Kepler intends to operate its primary TT&C facility out of the Greater Toronto Area, Ontario, Canada. There is no intention at present to operate control facilities within the U.S. and as such, authorization to use the TT&C frequencies is not requested in this narrative.

As highlighted in the system description, Kepler's constellation will be rolled out in phases. Phase I will use off the shelf hardware in UHF/VHF for TT&C. Following suit, Phase II and Phase III will shift to communicate solely in the UHF band. The S band (Phase II) will be used for backup control while the 400 MHz range (Phase III) will be used as the primary TT&C frequency. For all intents and purposes, with respect to TT&C, Phase II and Phase III are combined and represent a single spacecraft design. The additional TT&C frequency bands will also provide spectrum flexibility for Kepler and allow for better coordination with other operators using the same frequencies.

Table 5: Progression of TT & C for Kepler's System

	Phase I	Phase II	Phase III[20]
Gateway-to-Satellite	148 – 149.9 MHz[21]	2025 – 2110 MHz[22]	449.75 – 450.25 MHz[23]
Satellite-to-Gateway	401 – 402.0 MHz	2200 – 2290 MHz[24]	401 – 402 MHz

[19] See Client Procedures Circular 2-6-02 – Licensing of Space Stations (CPC-2-6-02 http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html)
[20] Considered primary TT&C frequency for operation as of Phase II
[21] Kepler will coordinate with other operators as required by ITU RR §5.218
[22] Operation in this frequency is bidirectional. Placement in a given direction is for ease of representation only
[23] Kepler will coordinate with other operators as required by ITU RR §5.286
[24] Operation in this frequency is bidirectional. Placement in a given direction is for ease of representation only

A.8 25.207 CESSATION OF EMISSIONS

Each satellite transmission chain (power amplifier) can be individually switched on or off by ground telecommand, thus causing cessation of emission from the satellites as required by §25.207 of the Commission's rules.

A.9 25.208 POWER FLUX DENSITY LIMITS

The Kepler System complies with all applicable FCC and ITU Power Flux Density (PFD) limits for the Ku-band. §25.208(b) contains the limitations associated with the 10.7 – 11.7 GHz band in a 4kHz and 1MHz reference bandwidth, which are identical to those in Article 21 of the ITU RR. The limits are provided in Table 6, and it is noted that the 4kHz and 1MHz limits represent the same quantities, albeit in a different reference bandwidth.

Table 6: FCC (4kHz) and ITU (1MHz) PFD Limits for 10.7 – 11.7 GHz

Angle of arrival	Limit in dB(W/m^2) 4kHz ref.	Limit in dB(W/m^2) 1 MHz ref.
0 – 5	-150	-126
5 – 25	-150+(δ-5)/2	-126 + 0.5(δ -5)
25 – 90	-140	-116

The Kepler System PFD is shown in Figure 5 relative to the 4kHz FCC PFD limits, which also signifies compliance with the 1MHz limits. Again, it is worth emphasizing that the use of an SDR on the satellites allows transmit power and bandwidth, and thus EIRP, to be adjusted arbitrarily to meet limits. This gives rise to an EIRP that changes as a function of angle of arrival, and a rather atypical PFD profile as shown in Figure 5. The PFD profile was calculated at nominal 600km altitude, and EIRP can be decreased in operation in order to maintain compliance both as altitude deteriorates near end of life, and in the off-nominal operational altitudes. Bandwidth and power are capable of adjustments in 1kHz and 3.1e-3 W increments, respectively.

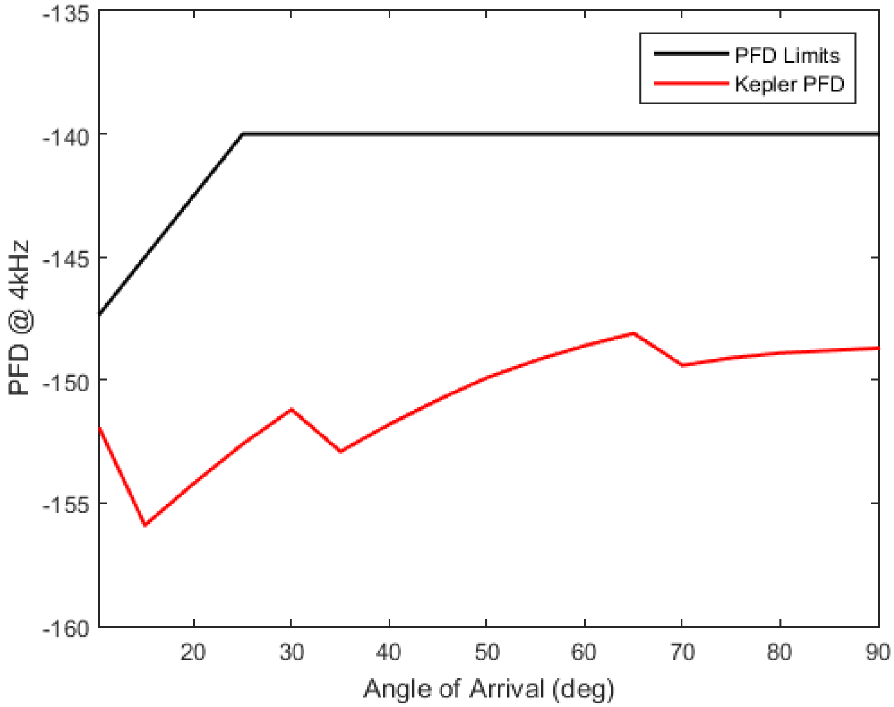

Figure 5: Kepler PFD relative to §25.208(b) limits in 4kHz reference bandwidth.

The Kepler system also complies with §25.208(o) for the 12.2 – 12.7 GHz band regarding low-angle PFD limits. These limits pertain to space-to-earth transmissions below 5° angle of arrival into an operational MVDDS receiver. As no emissions from the Kepler satellites are below 10.4° angle of arrival, the system is compliant with this regulation. Although not required by the commission, Kepler is also compliant with ITU Article 21 PFD limits for 11.7 – 12.7 GHz in Region 2. These limits are approximately 2dB greater than the PFD limits of §25.208(b), which have already been demonstrated to be in compliance.

A.9 25.261 PROCEDURES FOR AVOIDANCE OF IN-LINE INTERFERENCE EVENTS FOR NON-GEOSTATIONARY SATELLITE ORBIT (NGSO) NETWORK OPERATIONS IN THE FIXED-SATELLITE SERVICE (FSS) BANDS

Kepler has considered a number of technical solutions to avoid in-line interference that are made possible by the novel SDR and antenna array used on-board all of the Kepler satellites. In addition, Kepler is willing to seek out agreements with all other NGSO operators that will be licensed in the Ku-band to ensure that everyone can operate unencumbered during in-line events[25]. In case all of the technical solutions mentioned below do not adequately mitigate in-line interference, and other operators are not willing to seek suitable agreements, Kepler proposes to use FCC rules (§25.261) for band segmentation[26].

Dynamic Channel Shifting & Interference Detection

During an in-line interference event the Kepler user terminals and the Kepler satellites have the ability to dynamically and continuously shift channels and center frequencies being used. The channel and center frequency will be chosen a priori for a given latitude and longitude by identifying what NGSO systems will be operating in that location. This table of known operating NGSOs can be updated in the software of the SDRs at every ground pass ensuring Kepler can accommodate current and future deployments of both NGSO and GSO systems. In addition, later iterations of the SDR onboard the Kepler spacecraft will be capable of detecting interfering signals and dynamically changing channels, bandwidth, and center frequency to avoid producing harmful interference.

Beam Steering

In the event of in-line interference, the antenna array on-board the Kepler satellite will be capable of dynamically steering beams to provide service only at the edge of coverage of the spacecraft. Doing so enables the system to maintain a greater than 10° separation between links as seen from the user terminal (see Figure 6). Once the Kepler spacecraft moves a link within 10° of another NGSO system's link it will cease emission and Kepler spacecraft will hand off the link to a fore or aft spacecraft within the Kepler constellation that maintains an adequate separation distance.

[25] *Note* at present the FCC has not granted market access to any NGSO system nor has it licensed any NGSO to operate in the Ku-band. Although not licensed by the FCC, there is a US government NGSO satellite system with which coordination is required under FCC footnote 334. This is addressed in Section A.10.

[26] The Commission's Public Notice titled "International Bureau provides guidance concerning avoidance of in-line interference events among Ku-band NGSO FSS systems", dated October 20, 2015, states that the requirements of §25.261 (b)-(d), will also be added as conditions for authorization of Ku-band NGSO FSS systems, where previously they were strictly use in Ka-band licensing.

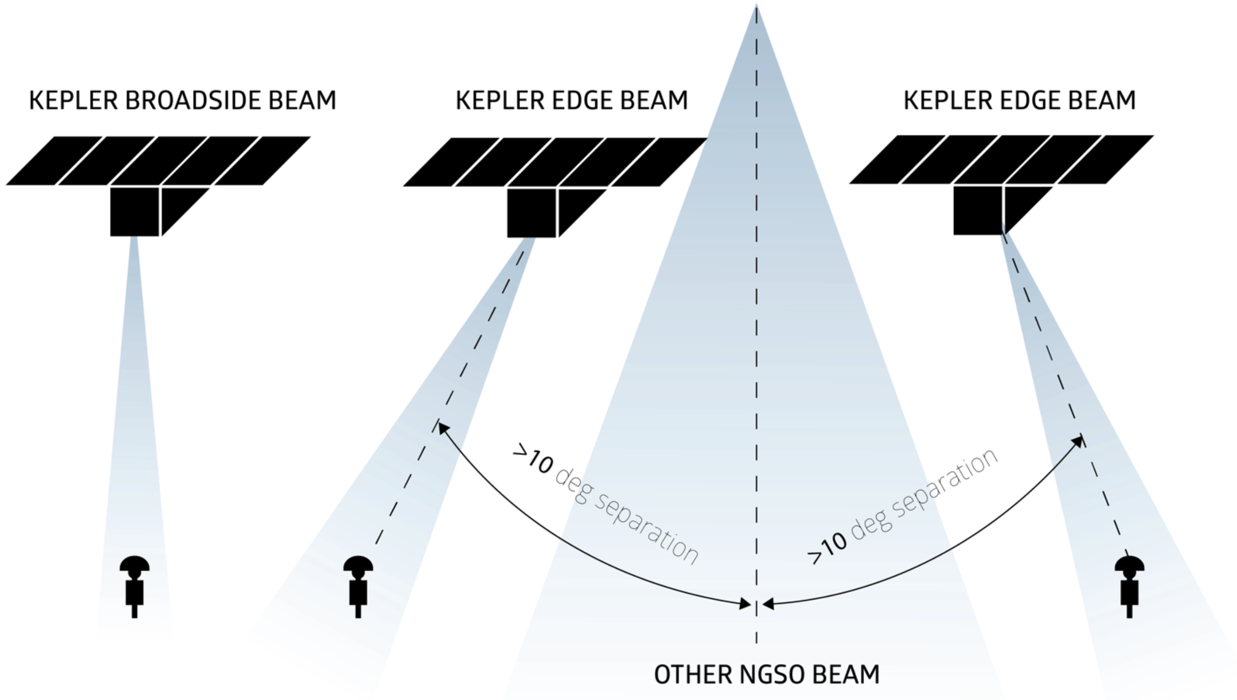

Figure 6: In-line interference avoidance. Kepler spacecraft dynamically steer beams to the edge of coverage to maintain at least 10-degree separation with other NGSO spacecraft links.

A.10 TERRESTRIAL INTERFERENCE

A.10.1 INTERFERENCE WITH RESPECT TO TERRESTRIAL NETWORKS IN THE 10.7 – 11.7 BANDS

The 10.7 – 11.7GHz band is shared on a co-primary basis between the FSS and FS services. As stated in the legal narrative, Kepler is requesting a waver for any potential restriction on the operation of user terminals (non gateways) in the band that were previously in place for the protection of FS for the following reasons. Compliance with FCC PFD limits has been demonstrated in Section A.9, where these limits have been deemed sufficient for protection of FS services.[27] In addition, as Kepler's System is capable of operating in the 11.7-12.7 GHz band as well, protection is not being sought for in the 10.7 – 11.7 segment. While interference is not expected, because the Kepler System does not communicate below a 10.4° angle of arrival, should interference arise user terminals will simply switch band.

[27] *See* FCC Order and Authorization "In the Matter of EchoStar KuX Corporation Application for Authority to Construct, Launch and Operate a Geostationary Satellite Using the Extended Ku-band Frequencies in the Fixed-Satellite Service at the 121° W.L. Orbital Location", September 30, 2004

A.10.2 INTERFERENCE WITH RESPECT TO TERRESTRIAL NETWORKS IN THE 12.2 – 12.7 GHz BAND

Within the 12.2-12.7 GHz band there exist 46 grandfathered FS links whose licenses were issued under old FCC allocations. Kepler's satellites will comply with the PFD limits as demonstrated in Section A.9 and thus protection of FS services is assured.

In compliance with the MVDDS Operating Requirements laid out by the Commission, Kepler will follow stipulations laid out in the Second Report and Order and respective sharing arrangement with respect to MVDSS.[28]

A.10.3 INTERFERENCE WITH RESPECT TO RADIO ASTRONOMY

Within the US table of frequency allocations there exist several footnotes that relate to operations in the 10.7 – 11.7 GHz band as well as the need to coordinate with Radio Astronomy Services (RAS) at given sites in the U.S. - Specifically footnotes US131, US211 (with further references to US74 and US385). Kepler will coordinate with, and protect, the relevant sites listed in the respective footnotes.

A.10 25.226 BLANKET LICENSING PROVISIONS FOR DOMESTIC, US VEHICLE-MOUNTED EARTH STATIONS (VMES) RECEIVING IN THE 10.95 – 11.2 GHZ (SPACE-TO-EARTH) BAND, OPERATING WITH GEOSTATIONARY SATELLITES IN THE FIXED SATELLITE SERVICE

A.10.1 25.226(c) COORDINATION WITH THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) AND THE NATIONAL SCIENCE FOUNDATION (NSF)

Kepler will coordinate with NASA regarding its TDRSS sites listed in the respective regulation in order to protect its receiving ground stations in the U.S. from transmissions originating from user terminals operating with Kepler's System.

[28] *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*, Memorandum Opinion and Order and Second Report and Order, 17 FCC Rcd 9614 (2002).

A.11 25.227 BLANKET LICENSING PROVISIONS FOR EARTH STATIONS ABOARD AIRCRAFT (ESAA) RECEIVING IN THE 10.95 – 11.2 GHZ (SPACE-TO-EARTH), 11.45 – 11.7 GHZ BAND, OPERATING WITH GEOSTATIONARY SATELLITES IN THE FIXED SATELLITE SERVICE

A.11.1 25.227(c) COORDINATION WITH THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) AND THE NATIONAL SCIENCE FOUNDATION (NSF)

Kepler will coordinate with NASA regarding its TDRSS sites listed in the respective regulation in order to protect its receiving ground stations in the U.S. from transmissions originating from user terminals operating with Kepler's System.

A.12 CONTROL OF TRANSMITTING STATIONS

A.12.1 25.271(e) REQUIREMENT FOR ELECTRONIC BULLETIN BOARD IN THE 10.7 – 14.5 GHz BANDS

As required by §25.271(e), Kepler will operate and maintain a website bulletin board that maintains an accurate list of orbital elements and satellite ephemeris data. The data will be presented using NORAD's two-line orbital element format. Once operational, the website will be accessible by visiting http://operations.keplercommunications.com and will be updated at least every three days.[29]

[29] URL may be subject to change

A.11 ITU FILINGS

Kepler's proposed satellite system is registered with the ITU through the Canadian administration under the network name "MULTUS". The ITU was informed of Kepler's intent to operate in the Ku band through its API filing in June of 2016. Kepler has its CR/C document completed and is currently waiting for the Canadian administration to forward the relative paperwork onto the ITU.[30] This will be processed between the 28th and 31st of December 2016 as required by CR/401.[31] The referenced API has been attached to this PDR's submission.

[30] See Kepler's request for waiver in the associated legal narrative.
[31] See Radiocommunication Bureau CR/401, 19 May 2016 and CR 376, 22 Dec 2014.

A.12 CERTIFICATOIN OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application and that it is complete and accurate to the best of my knowledge.

/s/ Nickolas G. Spina

Nickolas G. Spina, MEng

Manager of Launch & Regulatory Affairs

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ANNEX I DEMONSTRATION OF EPFD COMPLIANCE IN KU BAND

This annex details the calculations carried out by Kepler Communications to show compliance with the EPFD limits in §25.146(a)(1) and (2). The relevant rules are repeated below in a blue box, with Kepler's response immediately following inline.

> **§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 comprehensive technical showing below demonstrates that the Kepler System will not exceed the validation EPFD limits as specified in in §25.208 (g), (k), and (l) for $EPFD_{down}$, and $EPFD_{up}$. In addition, although not referenced in the FCC rules applicable to Ku-band, the technical showing below demonstrates compliance with $EPFD_{is}$ limits that exist in No. 22.5F of the ITU Radio Regulations.

B.1 EPFD$_{DOWN}$ COMPLIANCE

The technical showing consists of the following:
(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.

To demonstrate compliance with the single-entry validation equivalent power flux density, in the space-to-Earth direction (EPFD$_{down}$ limits) Kepler is providing the Commission with an electronic copy of the Ku-band Power Flux Density ("PFD") mask on the surface of the Earth, for each space station in the Kepler system (database file MASKS_KU.mdb). This mask was generated in accordance with the specification stipulated in the most recent version of the ITU-R Recommendation S.1503 issued in December of 2013.

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

As suggested in the ITU-R Recommendation S.1503, the PFD masks are expressed as a function of the azimuth ("Az") and elevation ("El") angles as viewed from the satellite towards the Earth relative to nadir direction (i.e. Option 3). Azimuth is in the east-west direction and elevation is in the north-south direction, as seen at the sub-satellite point (see Figure 7).

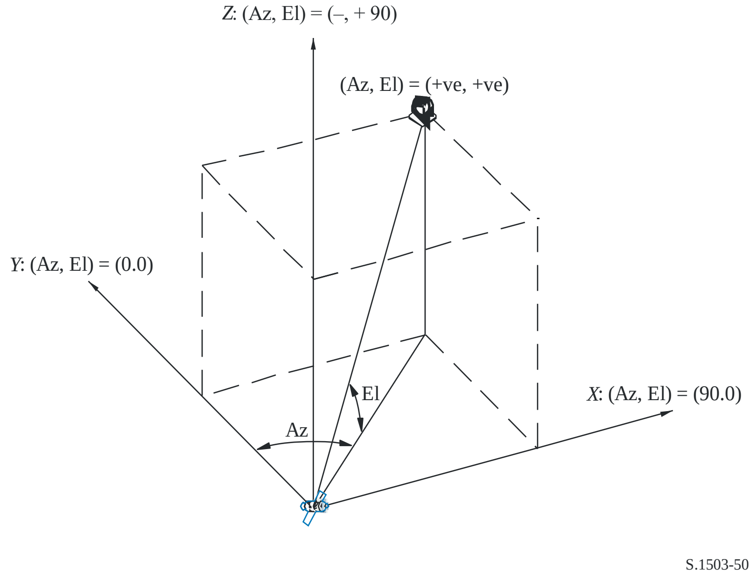


Figure 7: Az and El angle definition taken from ITU-R Recommendation S.1503

The Kepler PFD mask has been generated using the following method, which includes assumptions based on the current design and real-world operation of the Kepler System.

1. A gain mask at every NGSO azimuth and elevation angle is created. Within the 64° cone of coverage for each satellite, maximum gain is calculated as $G(\theta) = 10\log_{10}\left(10^{\frac{G_p}{10}}\cos\theta\right)$, where θ is the angle off boresight, and G_p is the peak gain at boresight. Outside of this 64° cone of coverage, gain is calculated at $29 - 25\log_{10}(\theta - 64)$.
2. The gain mask is converted into an EIRP mask (referenced at 40 kHz) using set transmit power and channel bandwidths (which are Az/El dependent). It should be noted that the maximum transmit power and bandwidths were assumed across all steering angles in order to create the maximum EIRP in all directions. In practice, channelization and beam steering will reduce this aggregate EIRP mask, and the results presented should be considered as a worst-case scenario
3. A set of exclusion angles, which are angles about which the Kepler System cannot communication, are then applied to the EIRP density mask as a function of satellite latitude.
4. The resulting EIRP density mask is then converted to a PFD mask (also as a function of Az/El) by taking into account the resulting spreading loss from the satellite to the surface of the earth at each angle.

(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 is currently in the process of approving a software package to validate single entry EPFD compliance but has not yet done so. In the interim the ITU has released a public beta[32] for administrations, which is both compliant with ITU-R S.1503 and close to the final software the ITU will approve. Kepler used this software to demonstrated EPFD compliance as it is presently the most accurate and reliable way for EPFD levels to be evaluated. Kepler is prepared to work with the Commission in order to run the computer program with all the inputs provided by Kepler.

(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.

In order to execute the software, four files are required, the Power Flux Density ("PFD") mask, the Space Radiocommunications Station ("SRS") database, and the two Equivalent Isotropic Radiated Power ("EIRP") density masks (Space Station and Earth Station). These masks, which are provided by Kepler to the Commission, are described in Table 7 below. In addition, separate input parameters are required which are described in Table 8 below.

[32] The software package can be downloaded here http://www.itu.int/en/ITU-R/software/Pages/epfd.aspx. The related circular is available here http://www.itu.int/md/R00-CR-CIR-0405/en

Table 7: List of files required to run ITU EPFD validation software.[33]

PFD mask (.xml file)	The PFD mask defines the maximum satellite downlink PFD in the Ku-band over the surface of the Earth visible to the satellite.
EIRP density masks (.xml file)	The EIRP density mask defines the maximum operational transmit EIRP level (for all conditions of modulation and traffic patterns) for a single Kepler Ku-band satellite transmit beam, and earth station transmit beam.
SRS mask (.mdb file)	The SRS mask defines all the orbital parameters of the entire Kepler constellation along with some operating parameters relevant to the system (e.g. earth station density).

Table 8: Inputs, in addition to the PFD mask, EIRP mask, and SRS database, required to run ITU EPFD validation software.

Input	**Description**	**Value Used**
nbr_op_sat (*ITU ref:* A.4.b.6.a)	Maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location within the latitude range.	4 satellites
elev_min (*ITU ref:* A.14.b.4)	Minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite or minimum elevation angle at which the radio astronomy station conducts single-dish or VLBI observations.	10.4 degrees

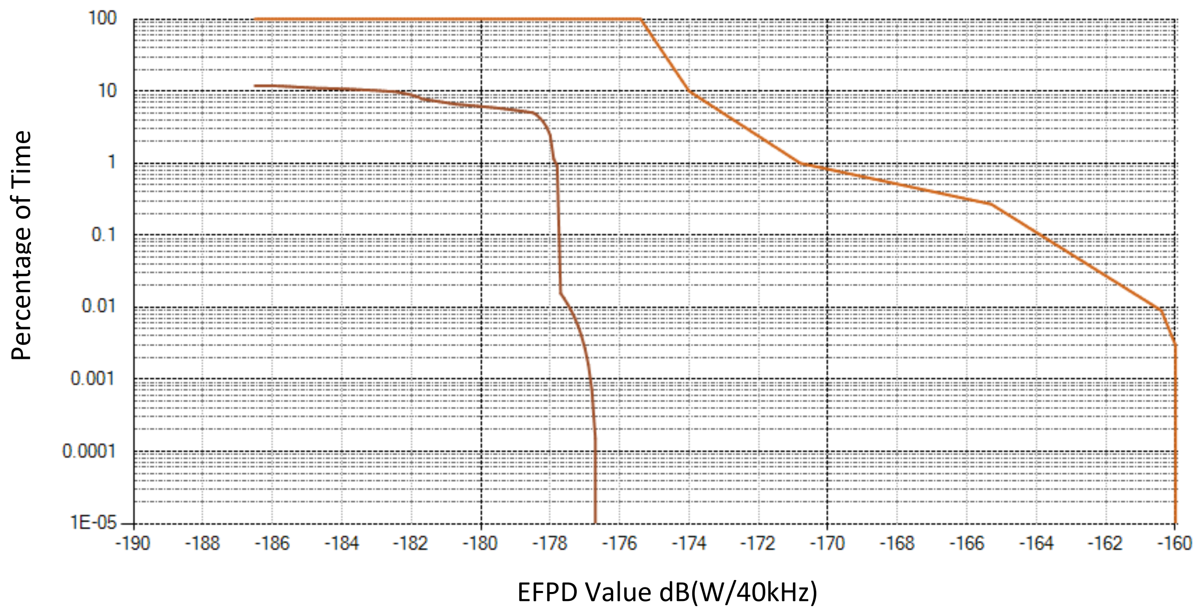
(v) Provide the result, the cumulative probability distribution function of EPFD, of the execution of the computer program described in paragraph (a)(1)(iii) of this section by using only the input parameters contained in paragraphs (a)(1)(i) and (a)(1)(iv) of this section.

To relieve the burden of review from the Commission, and consistent with the incremental approach in which the constellation will be deployed, Kepler is demonstrating the compliance of only the first (up to 5 satellites) and second phases (up to 20 satellites) of deployment. Prior to subsequent deployments of the Kepler constellation, Kepler will provide the Commission with the necessary compliance reports. Note that compliance is always easily achievable because of Kepler's novel Software Defined Radio and antenna

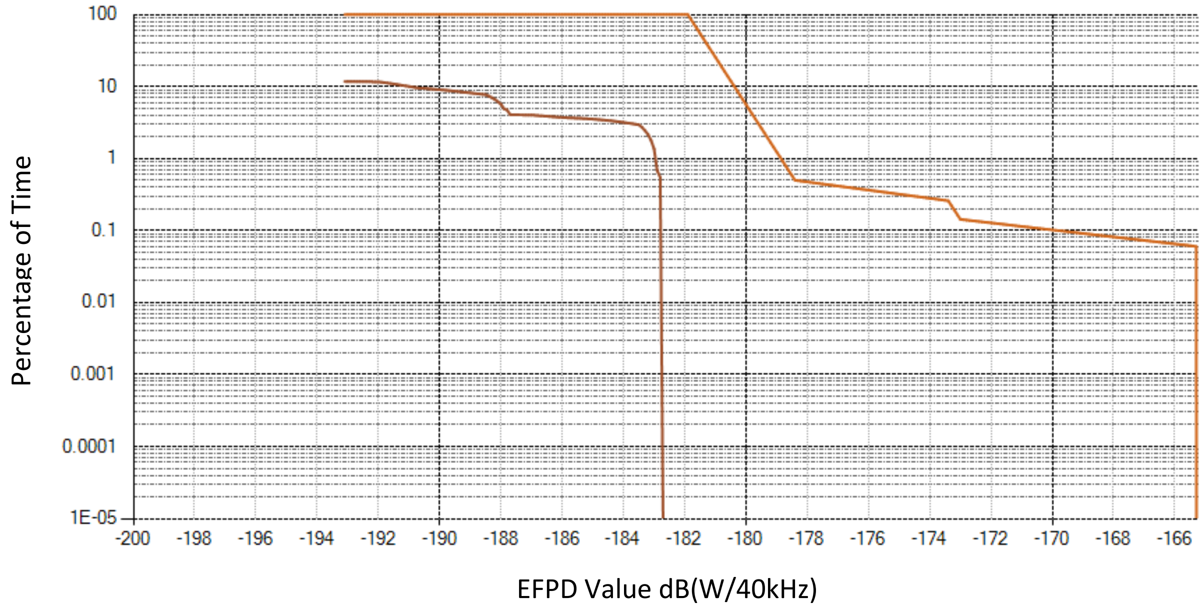
[33] See the following link for details on the file format.
http://www.itu.int/en/ITU-R/space/Pages/XMLmaskDataFile.aspx

array on-board the Kepler spacecraft, which enables Kepler to adjust individual satellite EIRP and exclusion angles while satellites are in operation.

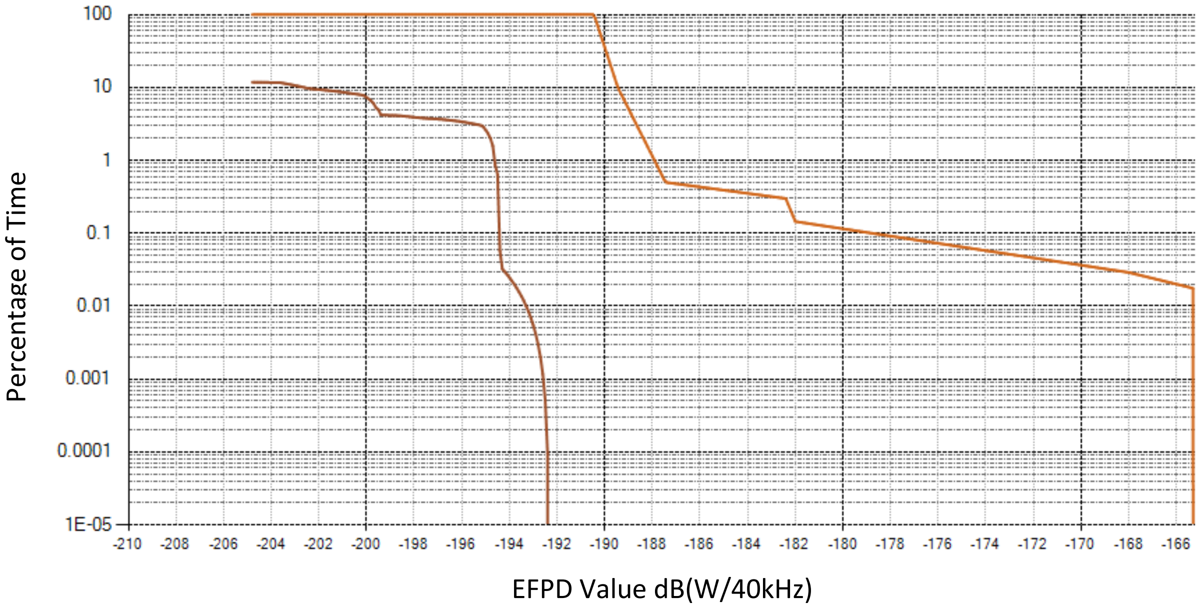
The Ku-band $EPFD_{down}$ results from the ITU software for these two phases of deployment, using the input data explained above, are shown below. Each plot corresponds to one of the GSO reference earth station antenna sizes from the ITU EPFD limits. Below each plot is a table that describes the reference earth station antenna size, the worst-case geometry defined by latitude of the GSO reference earth station, the frequency, the reference bandwidth, and whether this is a BSS or FSS EPFD limit. This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. On each plot the resulting EPFD level of the Kepler system is shown in brown and the EPFD limit that applies is shown in orange. The EPFD validation software also takes into account the high latitude EPFD limits given in Table 2G of §25.208(g) for the GSO FSS and Table 2L of §25.208(l) for the GSO BSS.



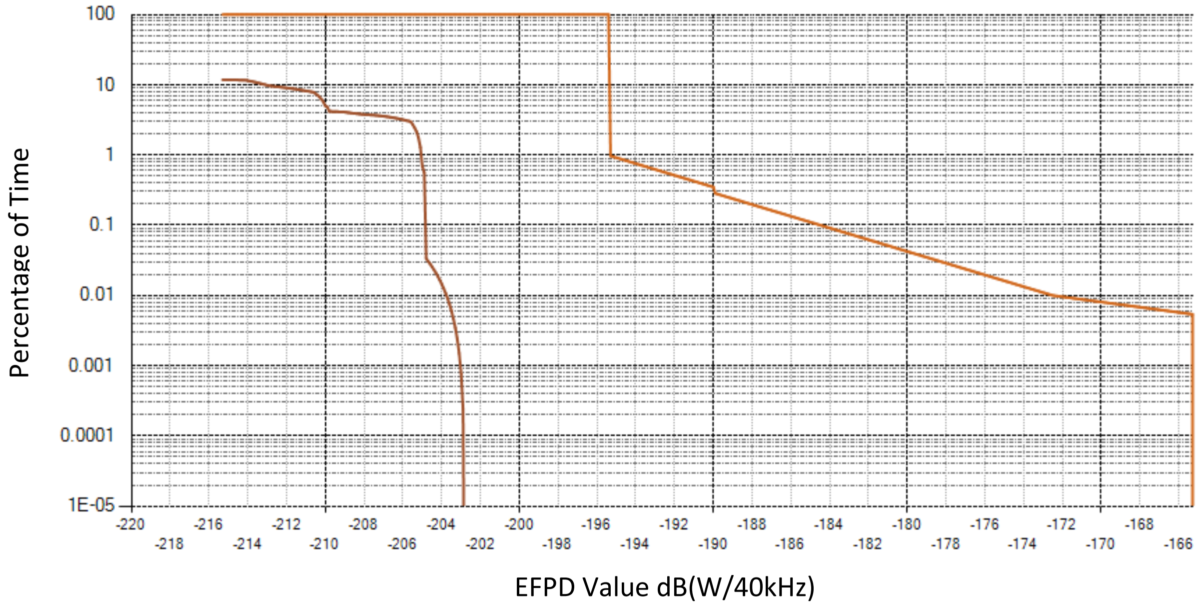
Reference GSO Earth Station Antenna Size	0.6m
Worst-case geometry GSO Earth Station location	Latitude: -74.68 Longitude: 78.47
Worst-case geometry GSO satellite location	Longitude: 47.56
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	5
Service	FSS



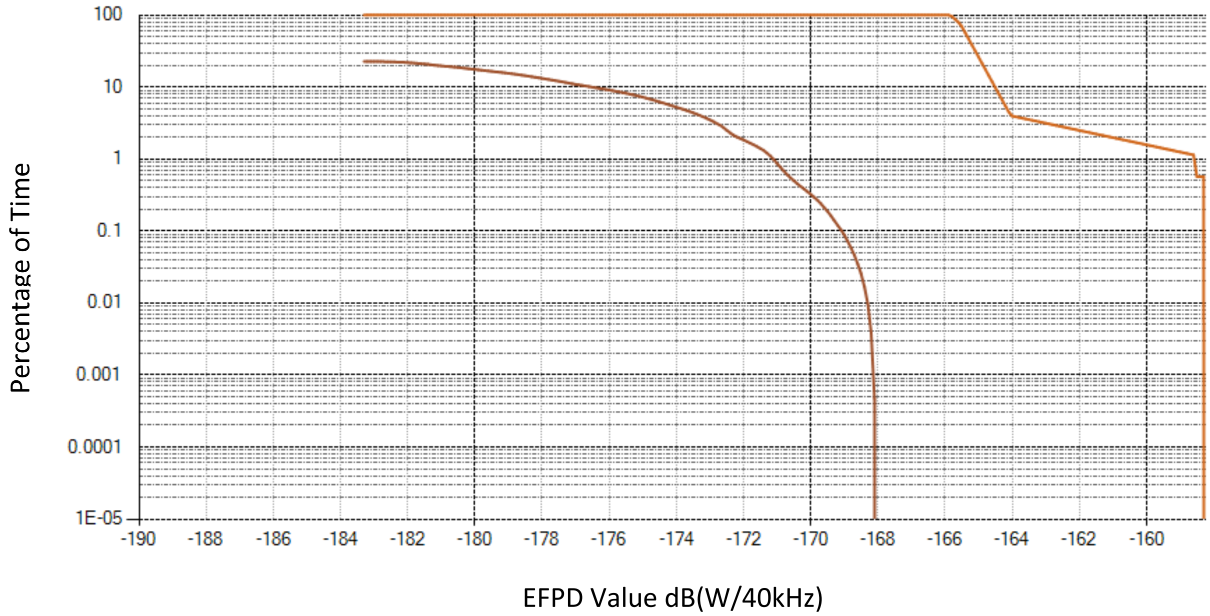
Reference GSO Earth Station Antenna Size	1.2m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.76
Worst-case geometry GSO satellite location	Longitude: 47.19
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	5
Service	FSS



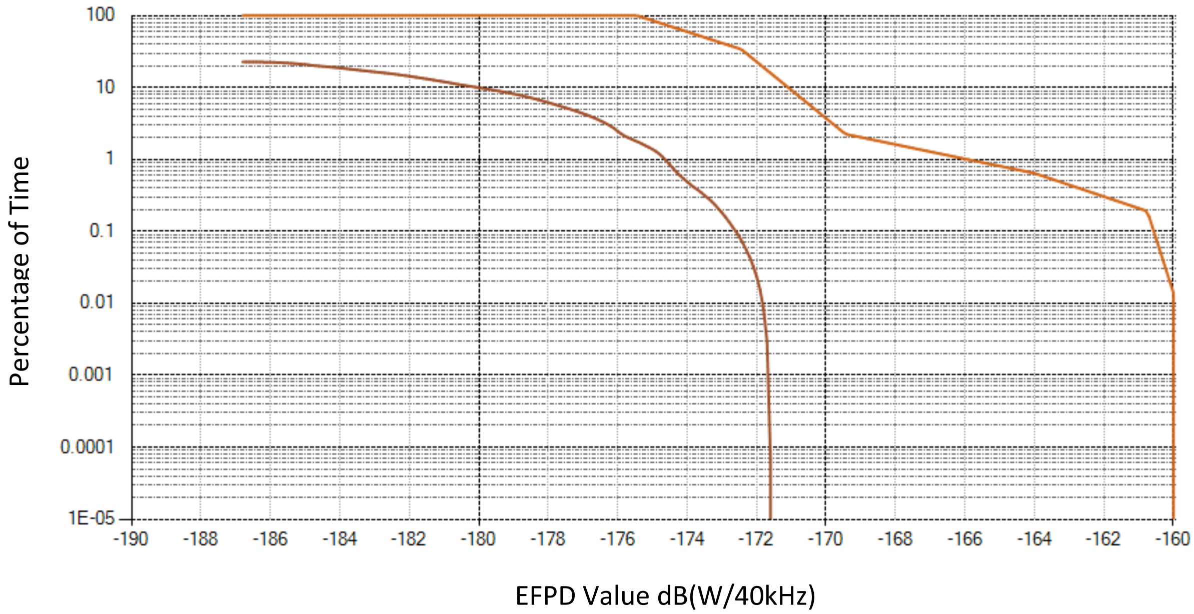
Reference GSO Earth Station Antenna Size	3m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.77
Worst-case geometry GSO satellite location	Longitude: 47.2
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	5
Service	FSS



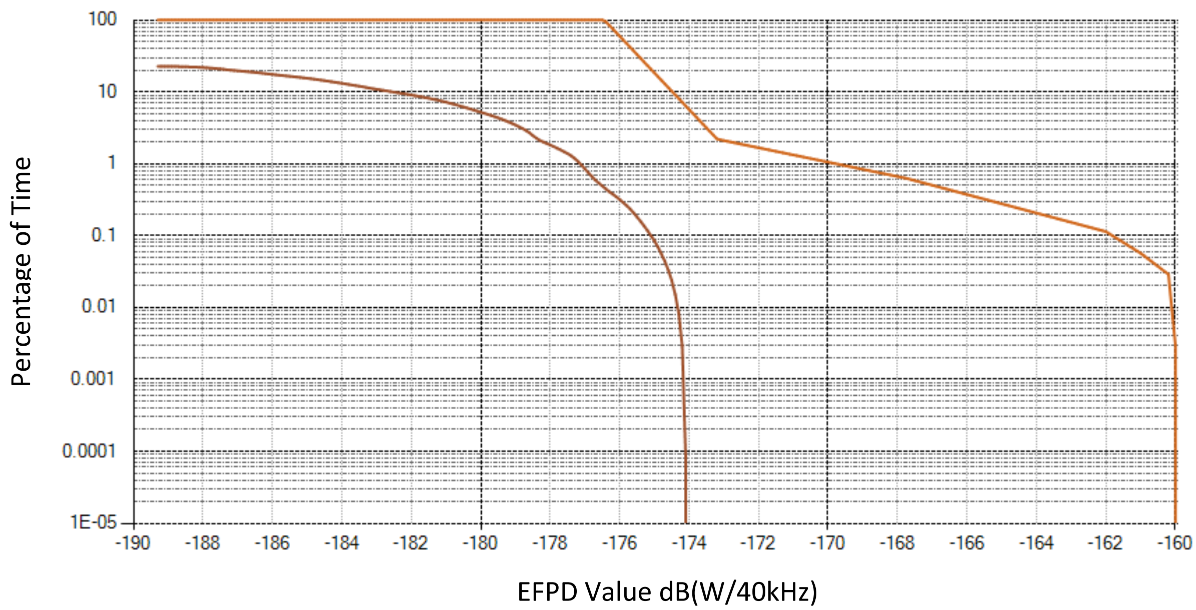
Reference GSO Earth Station Antenna Size e	10m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.77
Worst-case geometry GSO satellite location	Longitude: 47.2
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	5
Service	FSS



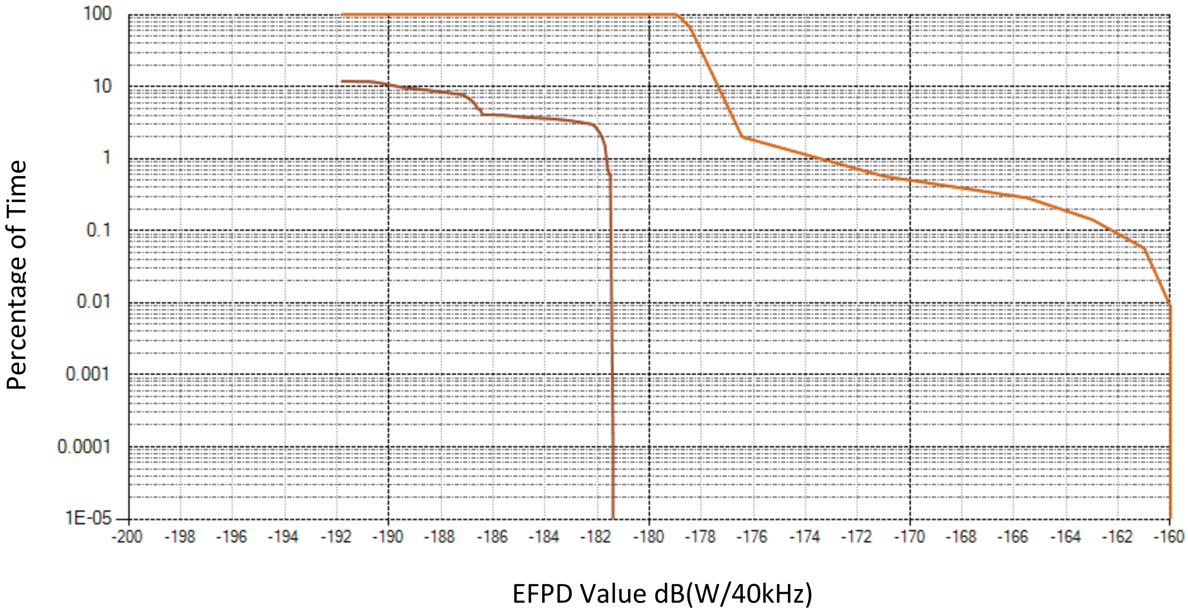
Reference GSO Earth Station Antenna Size	0.3m
Worst-case geometry GSO Earth Station location	Latitude: 79.59 Longitude: -40.62
Worst-case geometry GSO satellite location	Longitude: -73.77
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



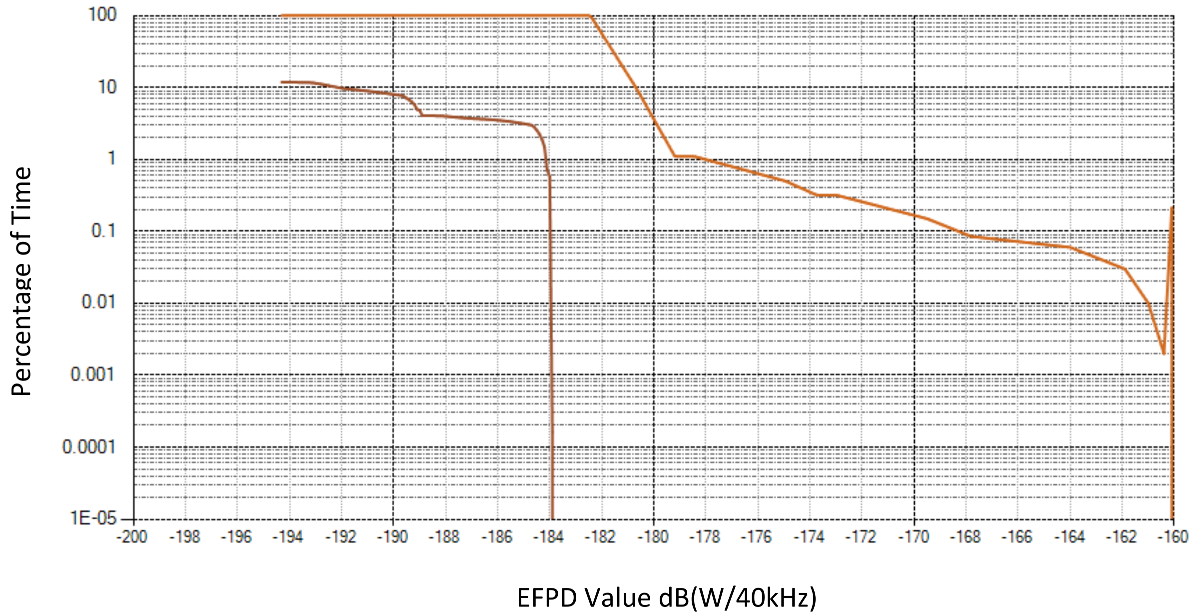
Reference GSO Earth Station Antenna Size	0.45m
Worst-case geometry GSO Earth Station location	Latitude: 79.59 Longitude: -40.61
Worst-case geometry GSO satellite location	Longitude: -73.76
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



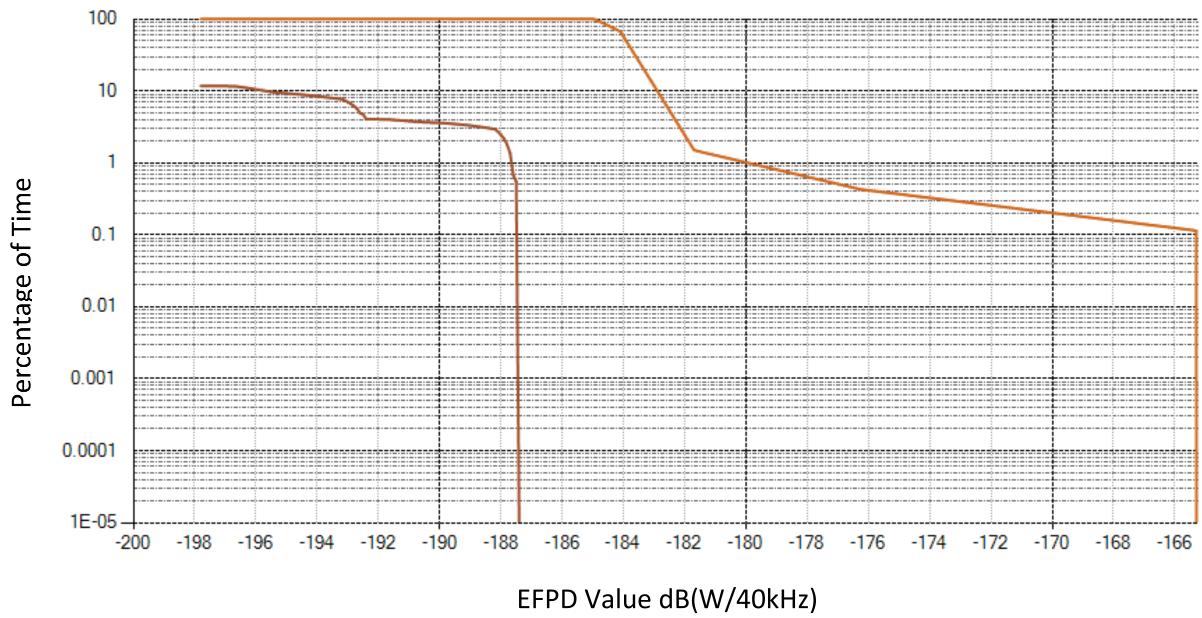
Reference GSO Earth Station Antenna Size	0.6m
Worst-case geometry GSO Earth Station location	Latitude: 79.59 Longitude: -40.61
Worst-case geometry GSO satellite location	Longitude: -73.76
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



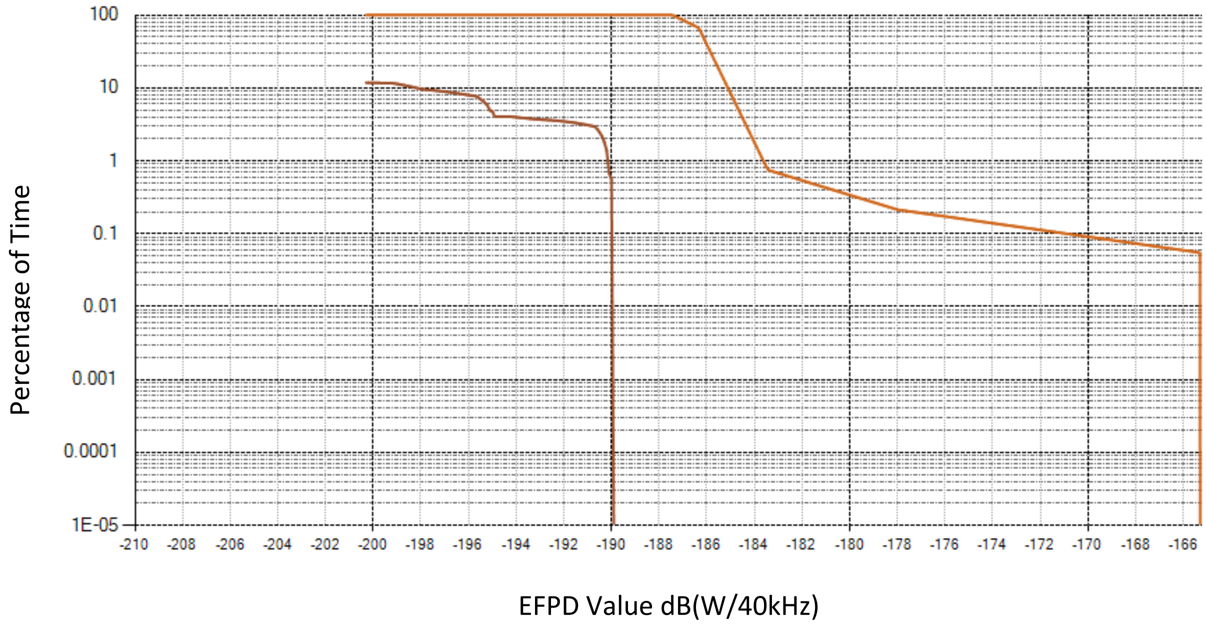
Reference GSO Earth Station Antenna Size	0.9m
Worst-case geometry GSO Earth Station location	Latitude: -74.68 Longitude: 78.49
Worst-case geometry GSO satellite location	Longitude: 47.58
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



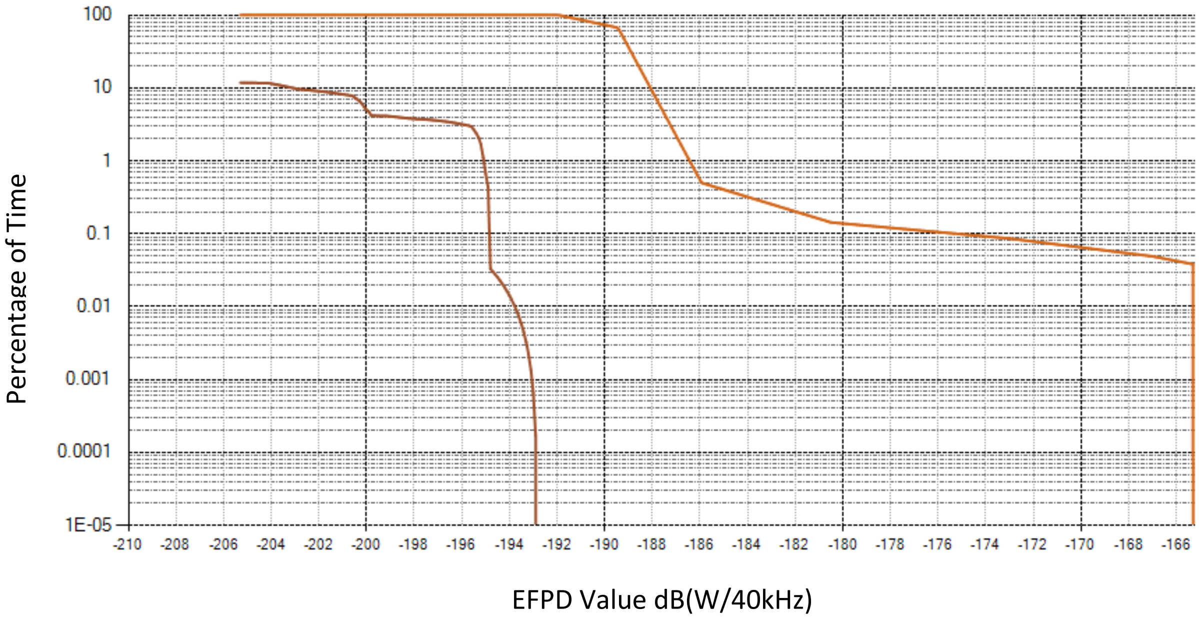
Reference GSO Earth Station Antenna Size	1.2m
Worst-case geometry GSO Earth Station location	Latitude: -74.68 Longitude: 78.48
Worst-case geometry GSO satellite location	Longitude: 47.57
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



Reference GSO Earth Station Antenna Size	1.8m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.77
Worst-case geometry GSO satellite location	Longitude: 47.19
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



Reference GSO Earth Station Antenna Size	2.4m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.76
Worst-case geometry GSO satellite location	Longitude: 47.19
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS



Reference GSO Earth Station Antenna Size	3m
Worst-case geometry GSO Earth Station location	Latitude: -74.62 Longitude: 78.77
Worst-case geometry GSO satellite location	Longitude: 47.2
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	5
Service	BSS

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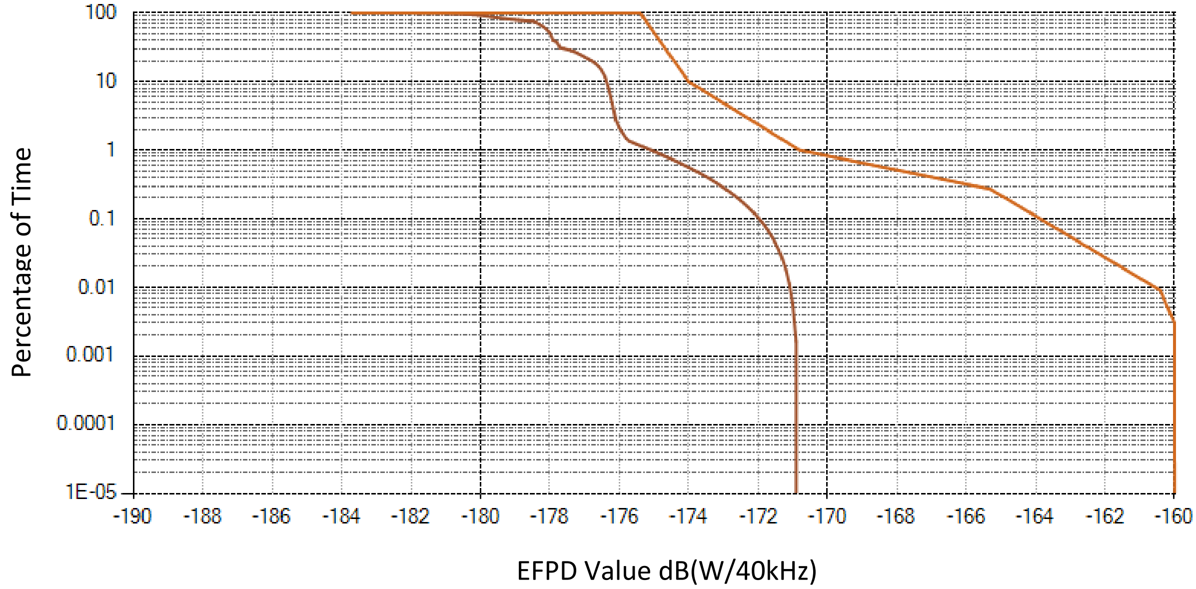

Reference GSO Earth Station Antenna Size	0.6m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.79
Worst-case geometry GSO satellite location	Longitude: 63.7
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	20
Service	FSS

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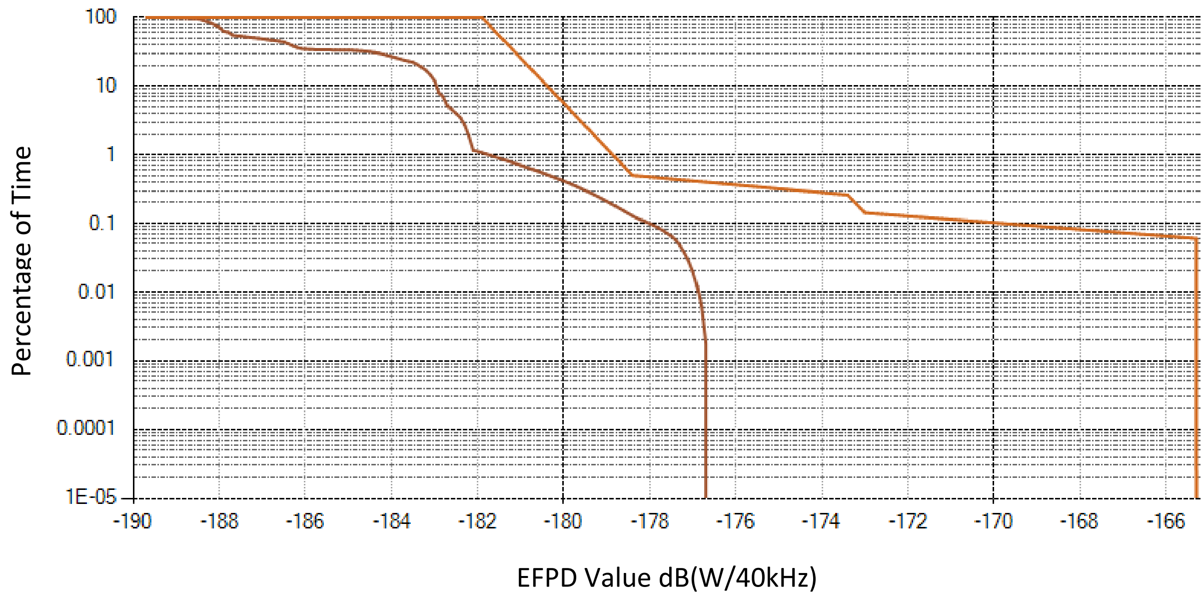
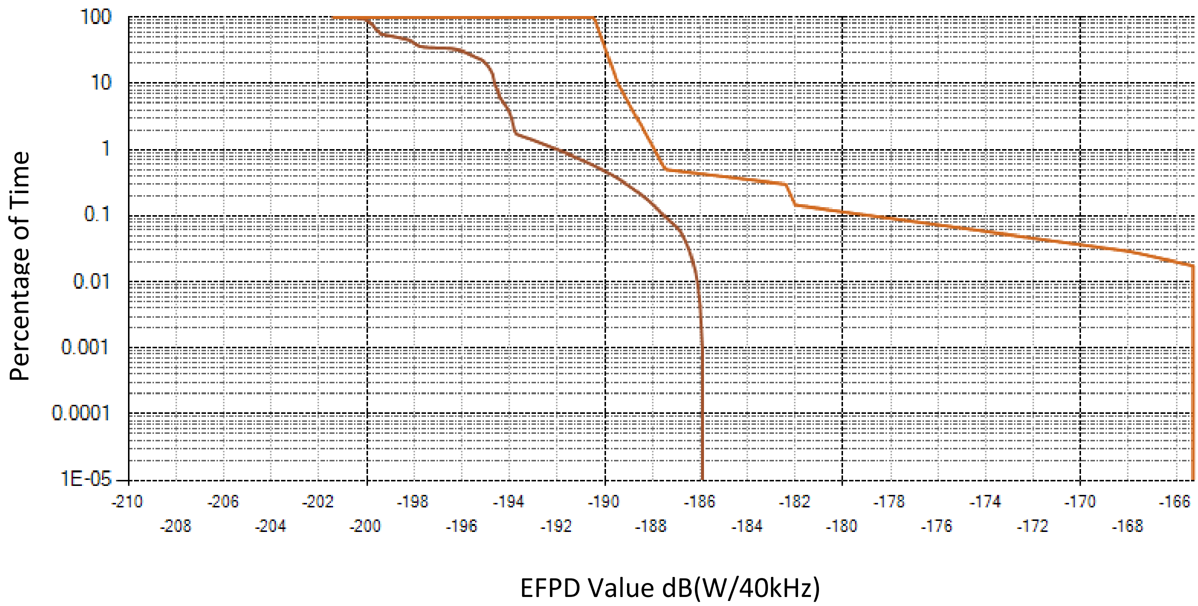
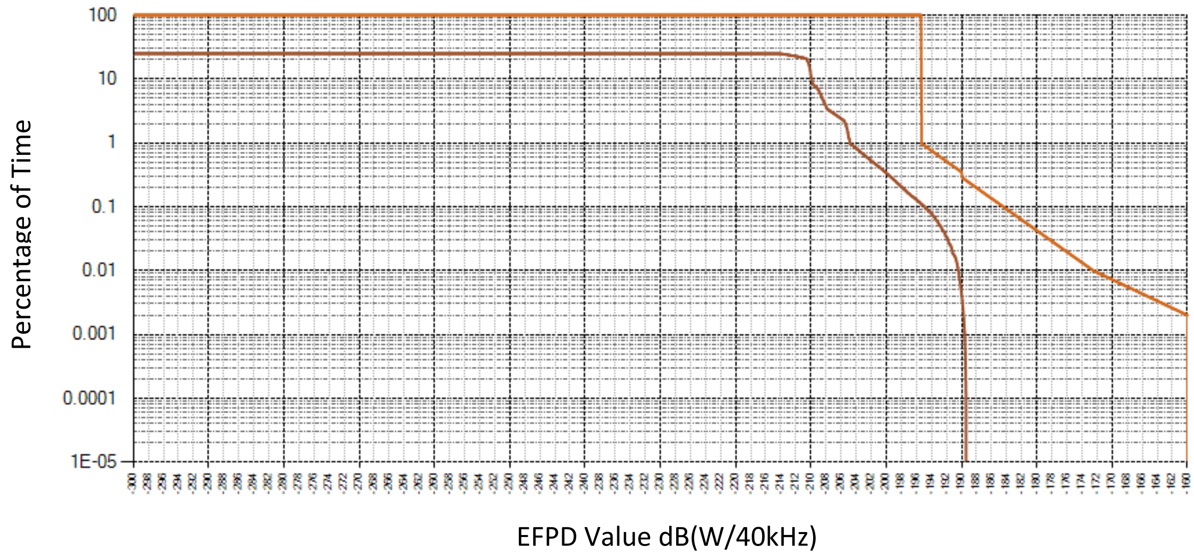


Reference GSO Earth Station Antenna Size	1.2m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	20
Service	FSS



Reference GSO Earth Station Antenna Size	3m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	20
Service	FSS



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Worst-case geometry GSO satellite location	Longitude: 19.26
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	20
Service	FSS

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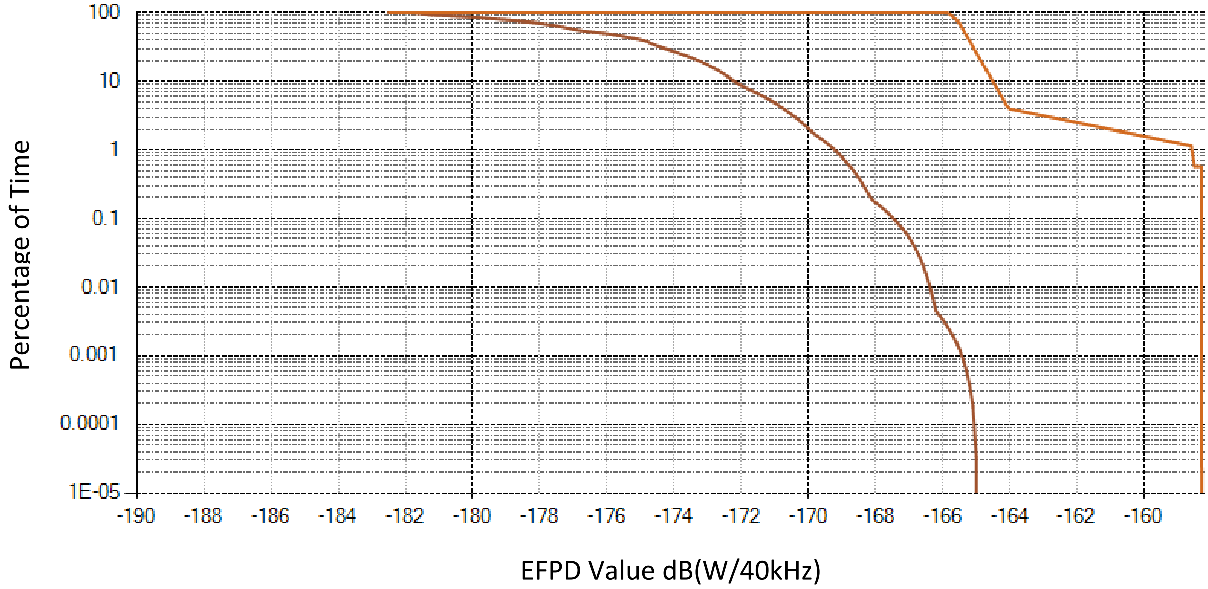
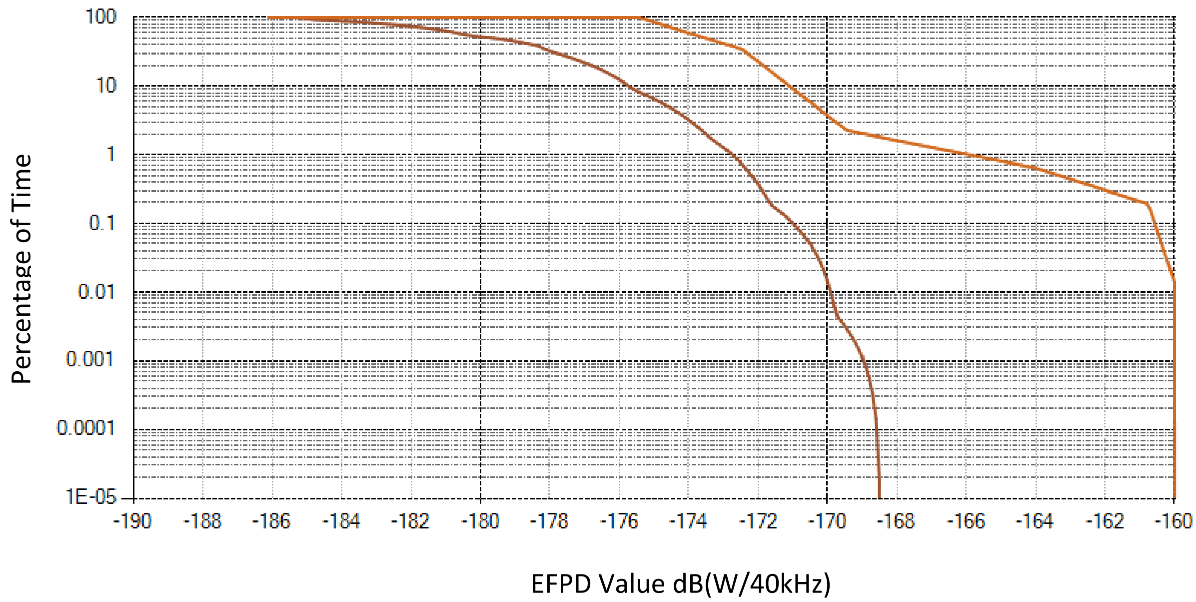


Reference GSO Earth Station Antenna Size	0.3m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.79
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS



Reference GSO Earth Station Antenna Size	0.45m
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Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS

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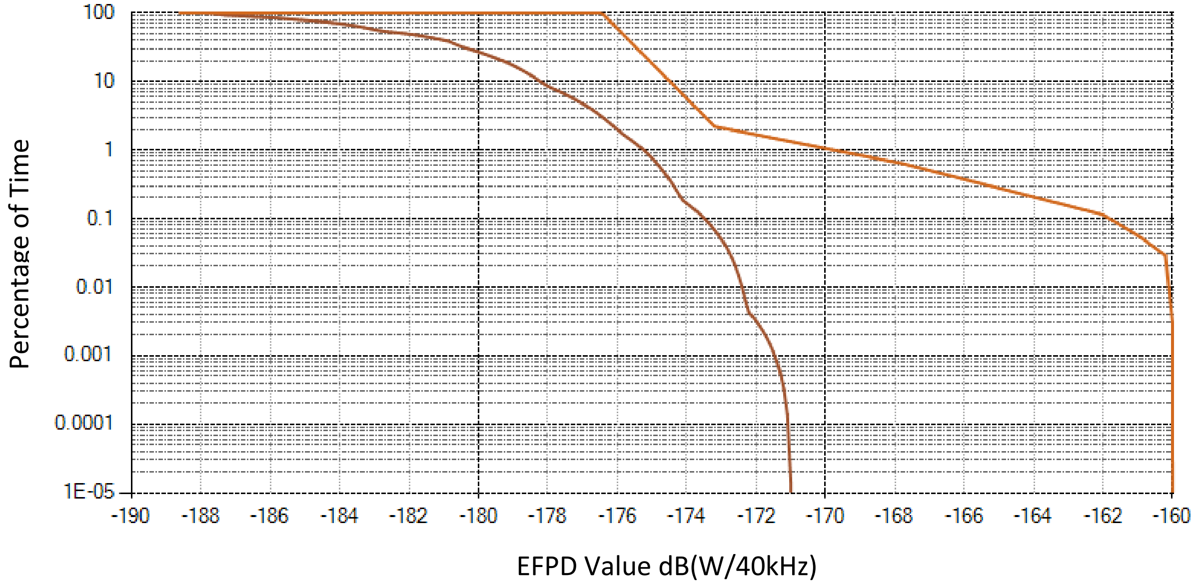

Reference GSO Earth Station Antenna Size	0.6m
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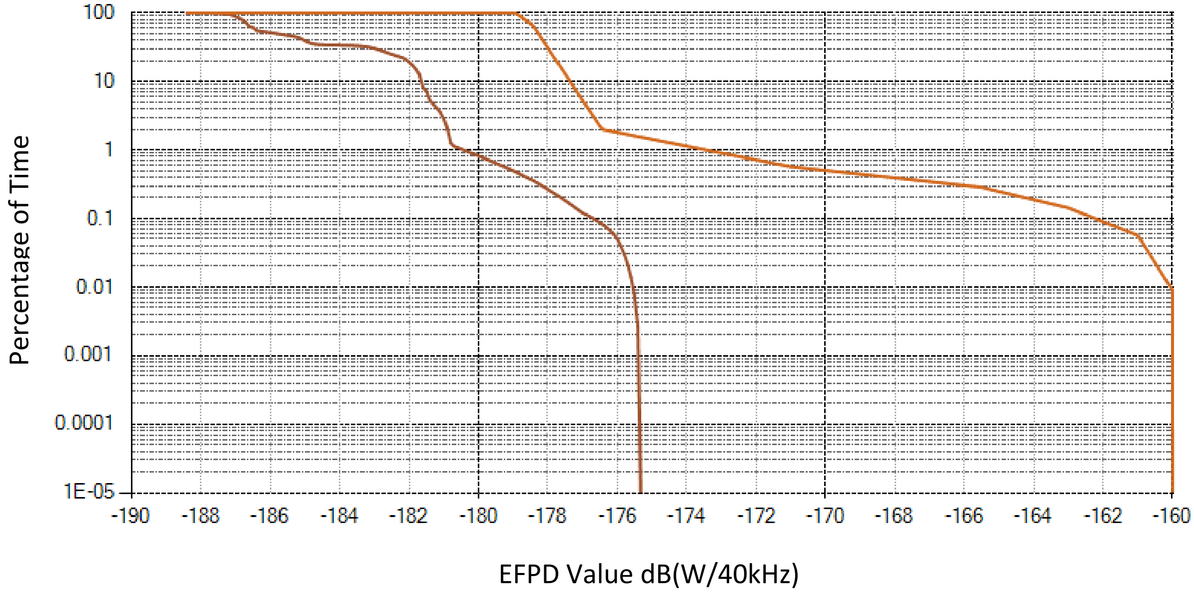
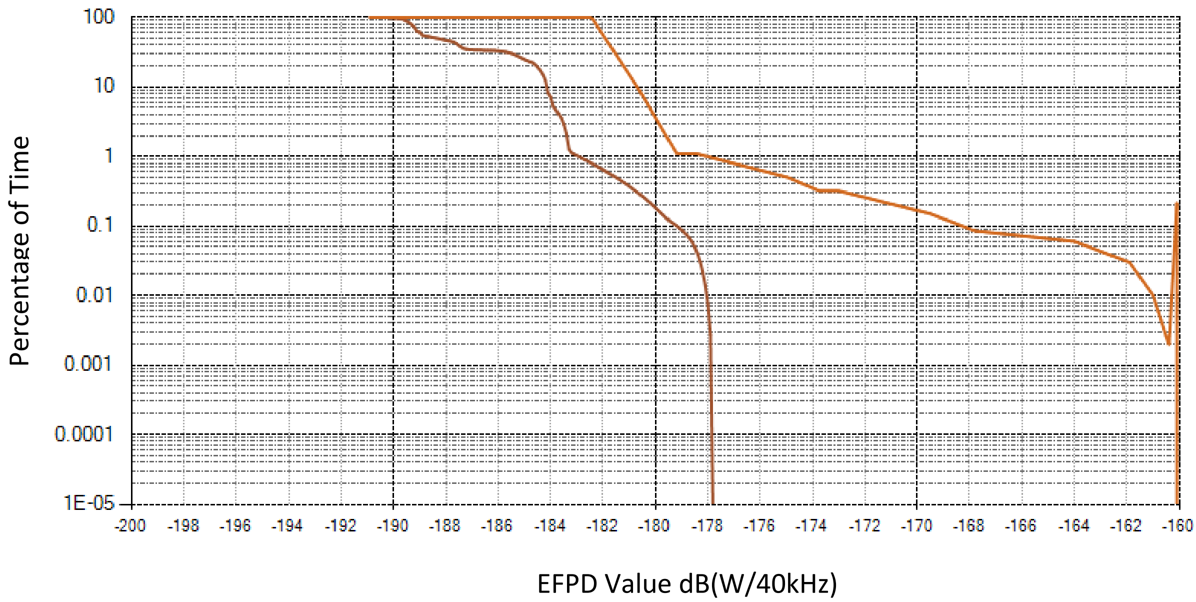
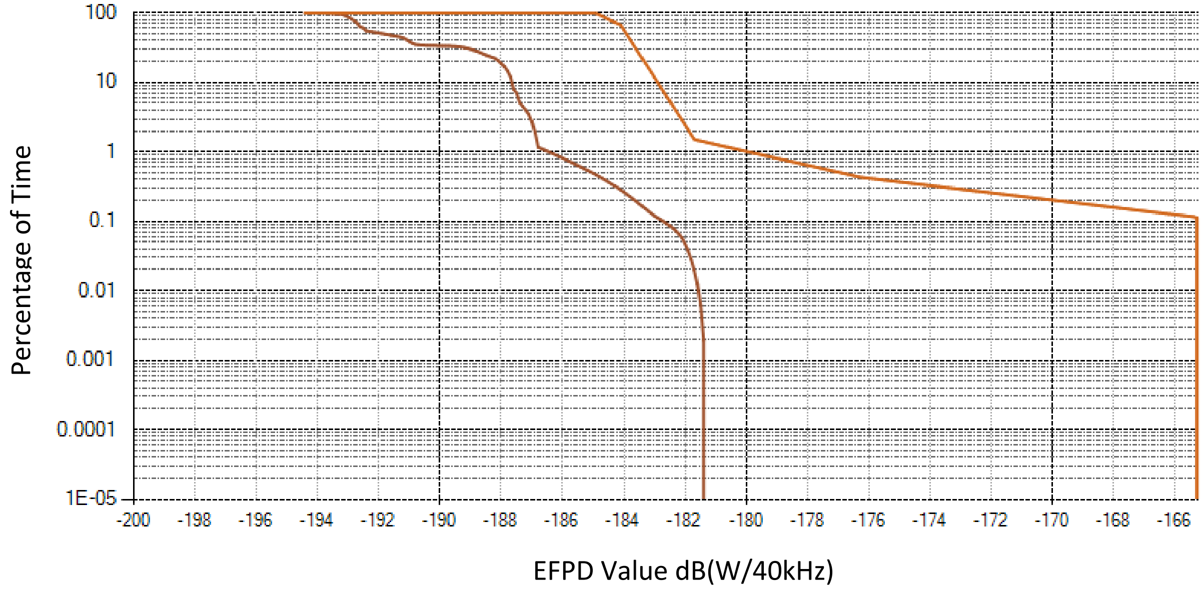
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS



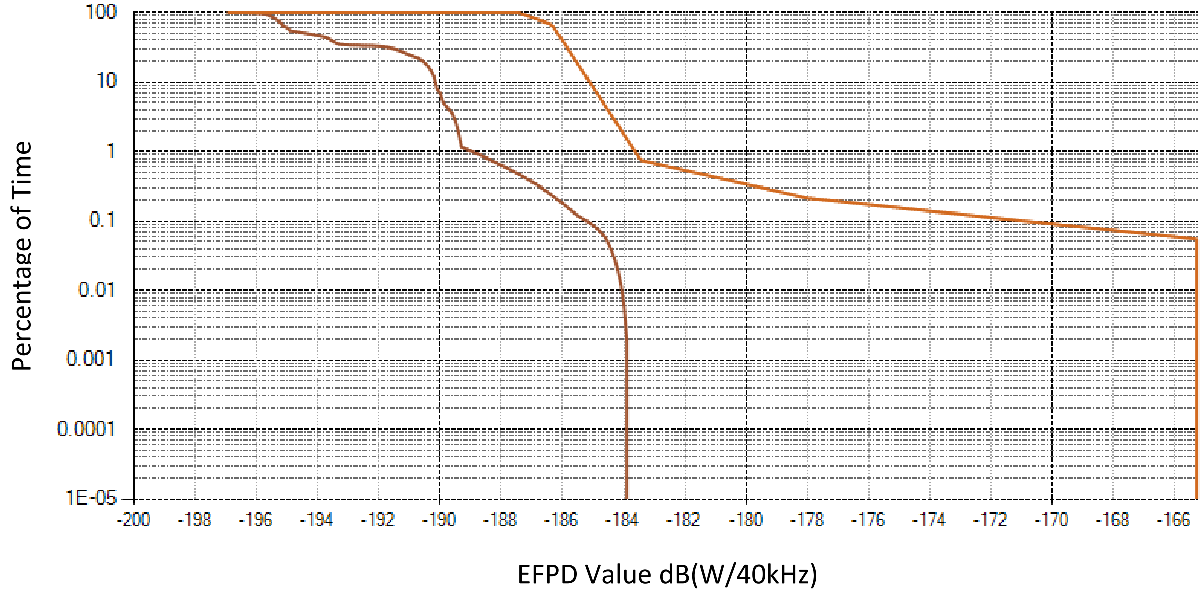
Reference GSO Earth Station Antenna Size	0.9m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS



Reference GSO Earth Station Antenna Size	1.2m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS



Reference GSO Earth Station Antenna Size	1.8m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS



Reference GSO Earth Station Antenna Size	2.4m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS

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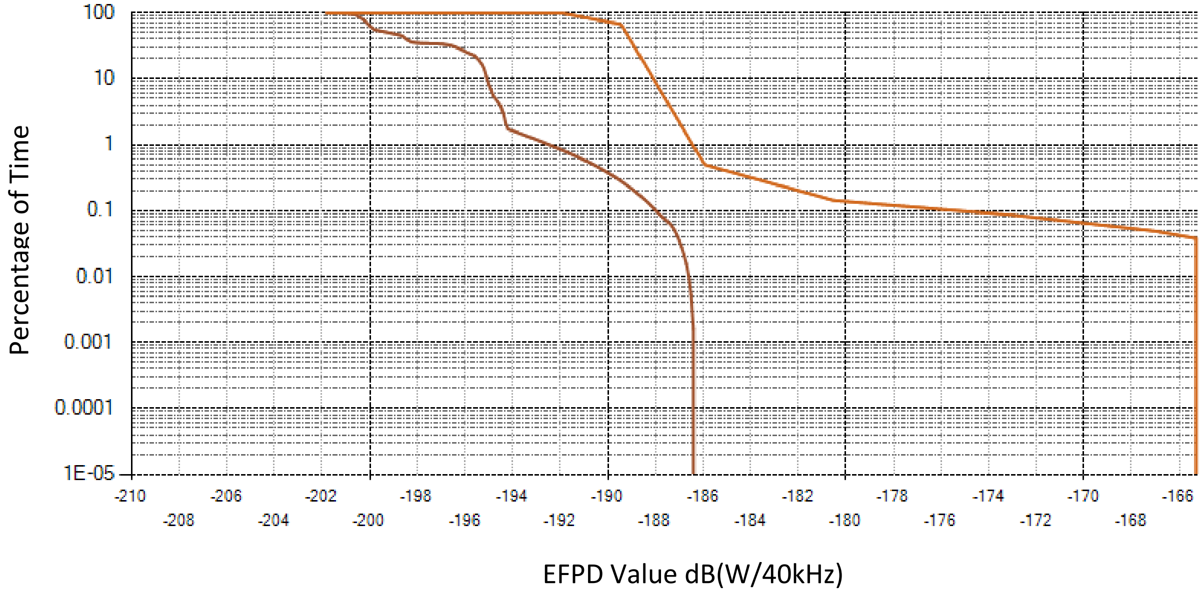

Reference GSO Earth Station Antenna Size	3m
Worst-case geometry GSO Earth Station location	Latitude: -80.57 Longitude: 64.8
Worst-case geometry GSO satellite location	Longitude: 63.71
Reference bandwidth	40 kHz
Frequency	11.7 GHz
Number of Satellites	20
Service	BSS

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B.2 EPFD$_{UP}$ COMPLIANCE

(2) Single-entry additional operational equivalent power flux-density, in the space-to-Earth direction, (additional operational EPFD$_{down}$) limits. (i) Provide a set of NGSO FSS earth station maximum equivalent isotropically radiated power (EIRP) masks as a function of the off-axis angle generated by an NGSO FSS earth station. The maximum EIRP mask shall be generated in accordance with the specification stipulated in the most recent version of ITU-R Recommendation S.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 an NGSO FSS system's life. The EIRP masks shall be in an electronic form that can be accessed by the computer program specified in paragraph (a)(2)(iii) of this section. **(ii)** Identify and describe in detail the assumptions and conditions used in generating the maximum earth station e.i.r.p. mask.

A single EIRP mask is created that represents the highest EIRP density levels (per 40 kHz) as function of the Earth station's azimuth and elevation angles. This EIRP mask is applicable to any Ku-band transmitting user terminal and is inclusive of 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.

See comments above in response to §25.146(a)(1)(iii) as the same computer program is used in determining compliance with the EPFD$_{up}$ limits.

(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.

The majority of necessary inputs are described earlier in Table 7 and Table 8. In addition, the following inputs were used in executing the software package:

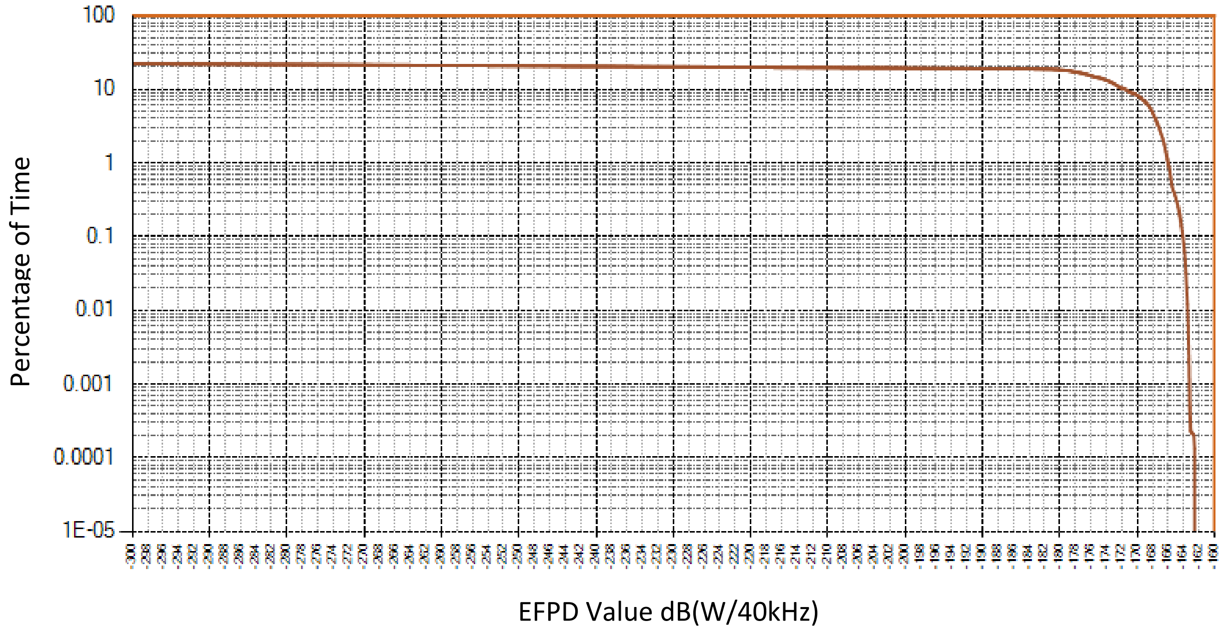
Table 9: Additional inputs required for $EPFD_{up}$ limits validation.

Input	Description	Value Used
nbr_sat_td (*ITU ref:* A.4.b.7.a)	Maximum number of co-frequency tracked non-geostationary satellites receiving simultaneously. The worst-case condition for Kepler is two spacecraft that could have overlapping service areas as well as frequencies.	2 satellites
density (*ITU ref:* A.4.b.7.b)	Average number of associated earth stations transmitting with overlapping frequencies per km^2 in a cell. This parameter directly relates to the total coverage region of each Kepler spacecraft, which is approximately 441,601km^2, and the maximum number of times a simultaneous co-frequency emission occurs is 2 times. Therefore, the density is given as 2/441,601 or 0.000045 user terminals per km^2.	0.000045 user terminals per km^2
avg_distance (*ITU ref:* A.4.b.7.c)	Average distance between co-frequency cells in kilometers. This parameter is square root of the inverse of "density" (i.e. $\sqrt{1/density\ (\frac{satellite}{km^2})}$)	470 km
x_zone (*ITU ref:* A.4.b.7.d.2)	The minimum GSO avoidance angle measured at the surface of the earth.	20 degrees

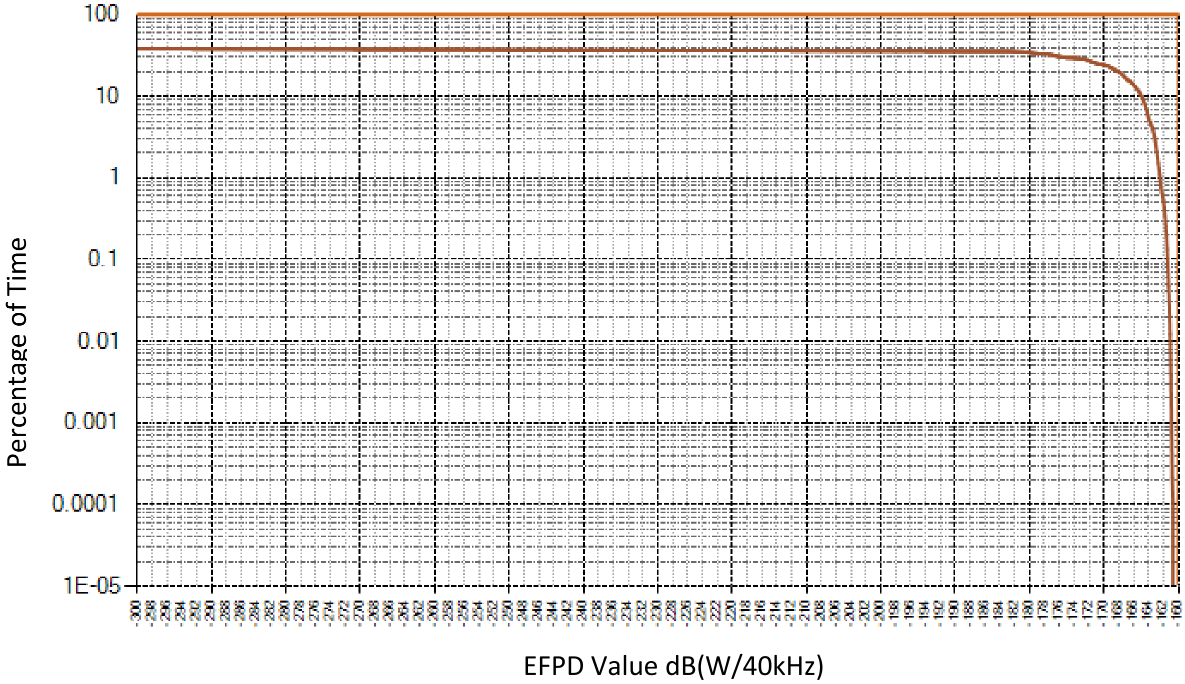
(v) Provide the result of the execution of the computer program described in paragraph (a)(2)(iii) of this section by using only the input parameters contained in paragraphs (a)(2)(i) and (a)(2)(iv) of this section.

To relieve the burden of review from the Commission, and consistent with the incremental approach in which the constellation will be deployed, Kepler is demonstrating the compliance of only the first (up to 5 satellites) and second phases (up to 20 satellites) of deployment. Prior to subsequent deployments of the Kepler constellation, Kepler will provide the Commission with the necessary compliance reports. Note again that compliance is always easily achievable because of Kepler's novel Software Defined Radio and antenna array on-board the Kepler spacecraft, which enables Kepler to adjust individual satellite EIRP and exclusion angles while satellites are in operation.

The Ku-band $EPFD_{up}$ results from the ITU software for these two phases of deployment, using the input data explained above, are shown below. Below each plot is a table that describes the reference earth GSO receive antenna beam width, the worst-case geometry defined by latitude of the GSO pointing direction, the frequency, the reference bandwidth, and where this is a BSS or FSS EPFD limit. This worst-case geometry has been determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. On each plot the resulting Kepler EPFD level is shown in brown and the EPFD limit that applies is shown in orange.



Reference GSO Antenna	S.672
Beam width	4 degrees
Ls	-20
Worst-case geometry GSO Earth Station location	Latitude: 42.55
Worst-case geometry GSO satellite location	Longitude: -99.4
Reference bandwidth	40 kHz
Frequency	14 GHz
Number of Satellites	5
Service	FSS



Reference GSO Antenna	S.672
Beam width	4 degrees
Ls	-20
Worst-case geometry GSO Earth Station location	Latitude: 42.55
Worst-case geometry GSO satellite location	Longitude: -99.4
Reference bandwidth	40 kHz
Frequency	14 GHz
Number of Satellites	20
Service	FSS

B.3 $EPFD_{IS}$ COMPLIANCE

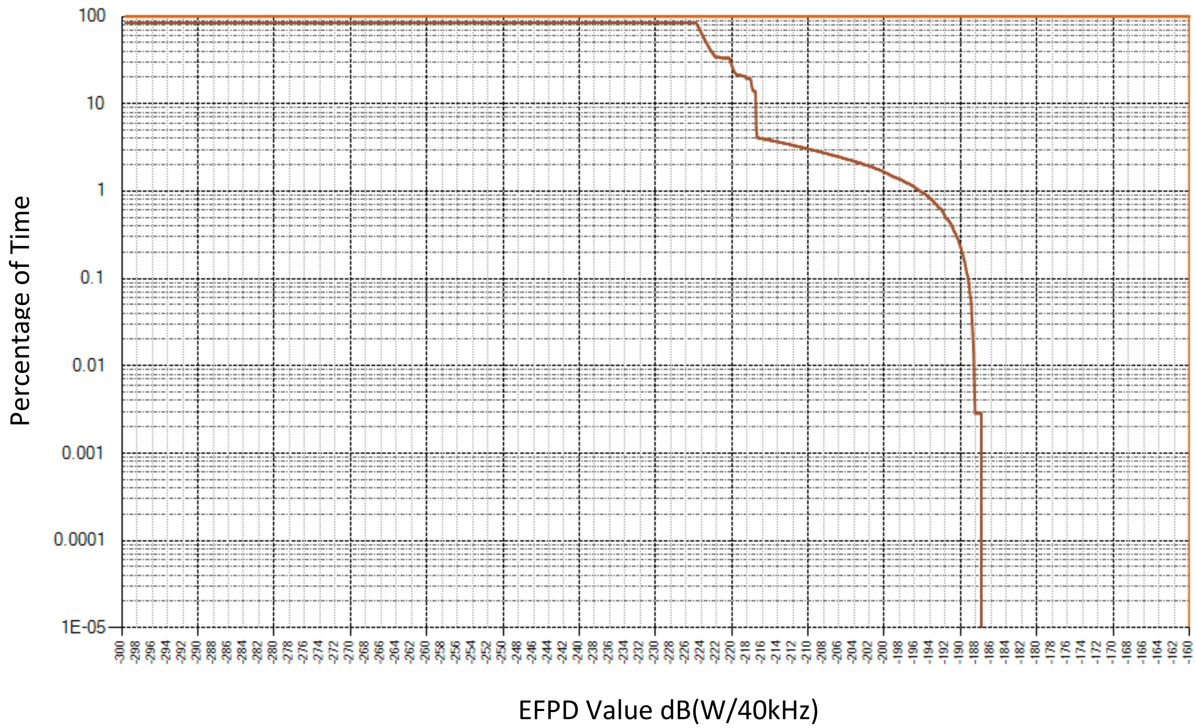
Although the FCC rules applicable to a Ku-band NGSO FSS system do not include any reference to the inter-satellite EPFD limits ($EPFD_{IS}$), Kepler is providing a technical showing below that the system complies with ITU Radio Regulations No. 22.5F shown below.

> The equivalent power flux-density, $EPFD_{IS}$, 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)

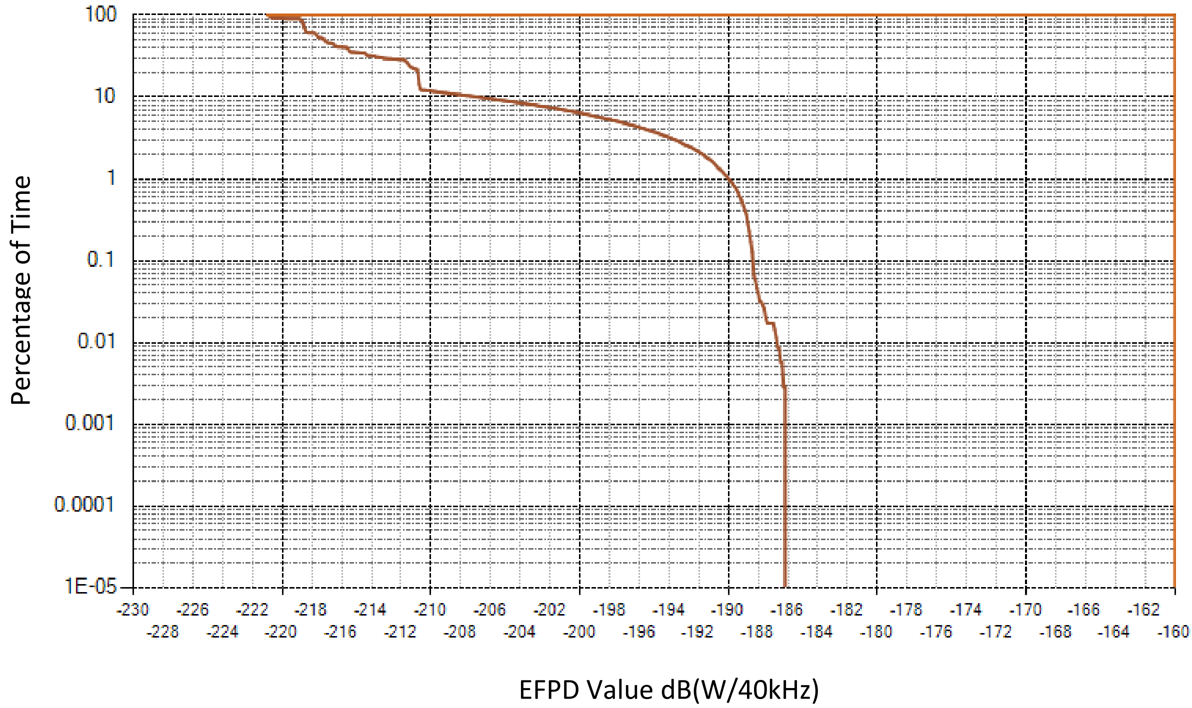
TABLE 22-3 (WRC-2000) Limits to the $EPFD_{IS}$ radiated by non-geostationary-satellite systems in the fixed-satellite service in certain frequency bands

Frequency band (GHz)	$EPFD_{IS}$ (dB(W/m))	Percentage of time during which $EPFD_{IS}$ level may not be exceeded	Reference bandwidth (kHz)	Reference antenna beam width and reference radiation pattern
10.7-11.7 (Region 1) 12.5-12.75 (Region 1)	-160	100	40	4° Recommandation ITU-R S.672-4, Ls = -20
12.7-12.75 (Region 2)				
17.8-18.4	-160	100	40	4° Recommandation ITU-R S.672-4, Ls = -20

Using the same inputs described in Table 7, and Table 8 with the EPFD software provided by the ITU, Kepler is able to demonstrate compliance with these requirements. The plots below show the $EPFD_{IS}$ values for both the first and second phases of the Kepler system deployment. Below each plot a table describes the relevant parameters. The brown line indicates the EPFD value of the Kepler system while the orange line shows the EPFD limits described in 22.5F of the ITU radio regulations.



Reference GSO Antenna	S.672
Beam width	4 degrees
Ls	-20
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	5
Service	FSS



Reference GSO Antenna	S.672
Beam width	4 degrees
Ls	-20
Reference bandwidth	40 kHz
Frequency	10.7 GHz
Number of Satellites	20
Service	FSS

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ANNEX 2 ORBITAL DEBRIS ASSESSMENT REPORT

This report is presented in compliance with NASA-STD-8719.14, APPENDIX A.

Report Version: 1.0, 15/11/2016

Document Data is Not Restricted

This document contains no proprietary, ITAR, or export controlled information

DAS Software Version Used in Analysis: v2.0.2

STK Software Version Used in Analysis: 10.1.3

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C.1 SELF-ASSESSMENT OF THE ODAR USING THE FORMAT IN APPENDIX A.2 OF NASA-STD 8719.14

An assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14

Orbital Debris Self-Assessment Report Evaluation: Kepler System

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non-Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			X		X			No debris released in LEO
4.3-1.b			X		X			No debris released in LEO
4.3-2			X		X			No debris released in GEO
4.4-1			X		X			No credible scenario of explosion
4.4-2			X		X			No credible scenario of explosion
4.4-3			X		X			No planned breakups
4.4-4			X		X			No planned breakups
4.5-1			X		X			Collision probability within compliance requirements
4.5-2			X		X			Collision probability within compliance requirements
4.6-1(a)			X		X			Atmospheric re-entry within 10.6 year from start of mission
4.6-1(b)			X		X			Atmospheric re-entry within 10.6 year from start of mission
4.6-1(c)			X		X			Atmospheric re-entry within 10.6 year from start of mission
4.6-2			X		X			Spacecraft not in GEO
4.6-3			X		X			Spacecraft not between LEO and GEO
4.6-4			X		X			No EOM subsystem required
4.7-1			X		X			No controlled reentry
4.8-1			X		X			No tethers used

C.2 ASSESSMENT REPORT FORMAT

This ODAR follows the format recommended in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each Sections 2 through 8 for the first satellites in Phase I of the Kepler System, as the specific launch vehicle for this missions has been procured. Section 9 through 14 apply to the launch platform, and are not covered here.

C.3 PROJECT MANAGEMENT AND MISSION OVERVIEW

Project Manager: Kepler Communications Inc.

Foreign government or space agency participation: The first satellite will be launched by by the Indian Space Agency (ISRO), and the second and will the China Great Wall Industry Corporation (CGWIC), therefore involve representatives of the participating space agencies.

Mission Milestones:

Launch I: Q4 2017, PSLV (Indian) vehicle

Launch II: Q1 2018, Long March (Chinese) vehicle (TBC)

Anticipate Launch Vehicle and Site:

Satellite 1: PSLV, Satish Dhawan Space Centre, India, 600km

Satellite 2: Long March, Jiuquan Satellite Launch Center, China, 600km

Mission Overview: The Phase I Kepler nanosatellites will be delivered to a polar orbit at an altitude of 600km on two separate launch vehicles. The satellites operations lifetime is planned for up to 3 years, with a time until disposal a maximum of 10.6 years after start of mission.

Description of the launch and deployment profile: The Kepler satellites will deploy into a sun-synchronous polar orbit, from which they will naturally decay due to atmospheric drag. The satellites are not equipped with propulsion and thus do not actively change orbits, and there is no parking or transfer orbit. After the mission duration, each spacecraft will transition into an aerodynamic breaking attitude to allow for re-entry within acceptable time limits. The deployment altitudes vary between launch vehicles, so the altitude range below is considered in this analysis:

Nominal deployment: **Apogee:** 600 km **Perigee:** 600 km
Inclination: 98.6 degrees (sun-synchronous)[34]

Reason for orbit selection: Ground track and launch availability

C.4 SPACECRAFT DESCRIPTION

Physical Description: The Kepler satellites are variants of the 3U CubeSat specification, with a mass of 5.0 kg and physical dimensions of 100 x 100 x 340 mm^3. The CubeSats will contain two deployable solar arrays of deployed planar dimensions 240 x 300 mm^2. The solar arrays are spring loaded, and actuated via burn wire. Power storage will be provided by a Lithion-Ion battery. The batteries will be recharged via solar cells mounted on the external chassis, and the deployed solar array. Battery dimensions are 40 x 10 x 10 mm with a weight of 335 g.

Total satellite mass at launch, incl. propellants and fluids: 5.0 kg

Dry mass at mass, excluding propellants and fluids: 5.0 kg

Description of propulsion systems: None

[34] Polar Orbits are used for Phase II and Phase III

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Fluids in Pressurized Batteries: N/A. Satellite batteries are unpressurized standard COTS Li-Ion cells.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: Satellite attitude is controlled by a combination of magnetorquers and reaction wheels. Mission operations includes three attitude modes, shown in Figure 8. Nominal and Low Drag modes are use during mission operations, and Brake is used during end-of-life de-orbit operations, and is dynamically stable.

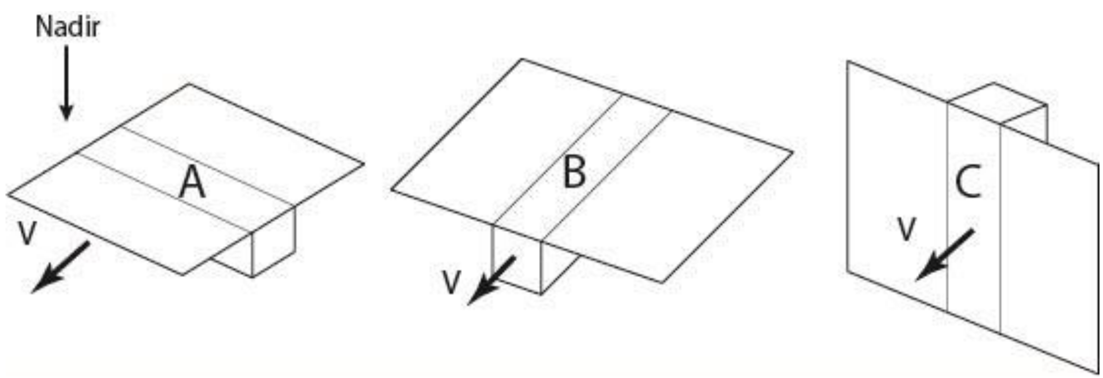

Figure 8: Attitude modes used for Kepler satellites. A – Nominal, B – Low Drag, C – Brake

Description of any range safety or other pyrotechnic devices: No pyrotechnic devices are used.

Description of the electrical generation and storage system: Electrical power is generated via body mounted Ga-As solar panels. Power storage is done via a Li-Ion battery. The electrical power subsystem manages battery charging, battery balancing, and protects against over/under current conditions.

Identification of any other sources of stored energy not noted above: None.

Identification of any radioactive materials on board: None.

C.5 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

Not applicable as there are no intentional releases of debris.

C.6 ASSESSMENT OF SPACE INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

Potential causes of spacecraft breakup during deployment and mission operations: There is no foreseen scenario in which the spacecraft would breakup during normal deployment and operations.

Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion: The only foreseen risk of explosion would be as a result of battery overheating and the resulting low probability of cell explosion. A FMEA (failure mode and effects analysis) was done to demonstrate the combined, mutually exclusive failures that must occur in order to result in the potential for accidental explosion of the batteries. Seven independent scenarios were analyzed to consider the risk that battery explosion could occur, with an exceptionally low cumulative probability that explosion will occur.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions: No planned breakups

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated: None. Batteries will not be passivated at end-of-mission as the total combined stored energy is less than 288 kJ when fully charged.

Rationale for all items which are required to be passivated, but cannot be due to their design: Chemical storage devices, such as batteries, are required to be passivated at EOM. However, the low total stored energy combined with being affixed to the spacecraft container minimized the risk of debris generation because of the lack of penetrating energy. Thus, batteries will not be passivated at EOM.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental Orbital Debris explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

Compliance statement:

Required Probability: 0.001.

Expected probability: << 0.001.

Supporting Rationale and FMEA details:

Battery explosion:

Effect: The following presents all failure modes that may theoretically result in battery explosion, with the possibility of debris generation. However, in the unlikely event of battery explosion the low stored chemical energy combined with being located internal to the spacecraft container minimizes the risk of debris generation because of the lack of penetration energy.

Probability: Extremely low. Battery explosion in all failure modes requires two simultaneous faults or systematic user failure that are of extremely low probability in themselves.

Failure mode 1: Short circuit

Mitigation: Functional testing of charge/discharge, as well as environmental testing including shock, vibration, thermal cycling, and vacuum testing to prove no internal short circuit sensitivity exists. Cells & protection circuits are COTS which have flight heritage.

Combined Faults Required: Failure of environmental testing **AND** failure for functional testing to discover short circuit sensitivities **AND** failure of COTS vendor in testing components.

Failure Mode 2: Above-nominal current draw inducing battery thermal rise

Mitigation: Thermal cycling on cells to test upper temperature limits, testing of batteries at above-nominal discharge levels.

Combined Faults Required: Inaccurate spacecraft thermal design **AND** over-current failure to detect off-nominal discharge rates

Failure Mode 3: Terminal contact with conductors not at battery voltage levels causing above-nominal current draw.

Mitigation: Qualification-test short circuit protection on each circuit, design of battery holders to ensure to unintended conductor contact without mechanical failure, minimize risk of mechanical failures via shock, vibration testing.

Combined Faults Required: Mechanical failure induced short circuit **AND** failure of over-current protection.

Failure Mode 4: Inoperable vents on battery holders.

Mitigation: Battery vents are not inhibited by the battery holder design or the spacecraft.

Combined Faults Required: Final assembler fails to install proper venting.

Failure Mode 5: Batteries are crushed during operation

Mitigation: No moving parts in proximity of battery. Spacecraft is tested to simulate launch loadings to ensure no damage to cells.

Combined Faults Required: A catastrophic mechanical failure has occurred **AND** the failure must be sufficient to cause a crushing of the batteries, leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time of crushing.

Failure Mode 6: Low level current leakage or short circuit through battery holder due to moisture-induced degradation of insulators
Mitigation: Non-conductive plastic for battery holders, operation in vacuum thus moisture cannot affect insulators
Combined Faults Required: Failure of battery insulators **AND** dislocation of batteries in holder **AND** failure to detect fault in environmental testing

Failure Mode 7: Thermal rise due to space environment and high discharge combined
Mitigation: Spacecraft thermal design to prevent situation, testing of batteries above expected operating conditions, use of COTS components with flight heritage
Combined Faults Required: Inaccurate thermal design **AND** failure to detect fault in thermal cycling and environmental testing **AND** failure of COTS supplier to provide qualified batteries.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement: In the unlikely event of a battery explosion, the low stored chemical energy combined with being located internal to the spacecraft container minimizes the risk of debris generation because of the lack of penetration energy.

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups

Compliance statement:

N/A as there are no planned breakups

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups

Compliance statement:

N/A as there are no planned breakups

C.6 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISION

Requirement 4.5-1: Limiting debris generated by collisions with large objects when operating in Earth orbit:

For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

A probability of collision analysis was performed using NASA's DAS 2.0.2 software. This analysis was done for single satellite over a mission duration of 10.6 years at an altitude of 600 km. The mission duration of 10.6 years is used as this is maximum lifetime prior to reentry, as will be shown in Section 6. As density of space objects decreases steadily below 800 km altitude, the high insertion scenario of 600 km apogee was considered as a worst-case scenario.

Large Object Impact and Debris Generation Probability:

Collision Probability: 0.000003; COMPLIANT

```
==============
Run Data
==============

**INPUT**

        Space Structure Name = Kepler1
        Space Structure Type = Payload
        Perigee Altitude = 600.000000 (km)
        Apogee Altitude = 600.000000 (km)
        Inclination = 98.600000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass Ratio = 0.026400 (m^2/kg)
        Start Year = 2017.000000 (yr)
        Initial Mass = 5.000000 (kg)
```

```
        Final Mass = 5.000000 (kg)
        Duration = 10.60000 (yr)
        Station-Kept = False
        Abandoned = True
        PMD Perigee Altitude = -1.000000 (km)
        PMD Apogee Altitude = -1.000000 (km)
        PMD Inclination = 0.000000 (deg)
        PMD RAAN = 0.000000 (deg)
        PMD Argument of Perigee = 0.000000 (deg)
        PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

        Collision Probability = 0.000003
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range
        Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
```

Supporting Deployment and Collision Risk Analysis

In addition, STK's Conjunction Analysis Toolkit (STK/CAT) was used to perform a conjunction analysis for the satellite deployment and orbit. The scenario of Kepler vs. All TLEs was considered.

The satellite had an assumed covariance that resulted in a fixed threat volume ellipsoid defined as 10 km tangential (along-track), 2 km cross-track, and 2km normal (nadir) to the trajectory. The Kepler satellite was assumed as hard spheres of diameter 1 m, and all other satellites were assumed as hard spheres with 2 m diameters. This was done for the orbit extreme (i.e. 600 km altitude), and across the entire 10.6-year satellite lifetime.

600 km collision probability:	1.44E-05	COMPLIANT

> ***Requirement 4.5-2:*** Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit**:**
>
> For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal requirements is less than 0.01 (Requirement 56507).

The Kepler satellites are to be deployed into LEO, where the density of resident space objects, and therefore the probability of collisions, reduces with altitudes below ~800 km. Therefore, the "high insertion" scenario, where satellites are deployed at 600 km, represents the highest collision probability insertion scenario, and the DAS analysis was performed for this scenario.

Small Object Impact and Debris Generation Probability:

Collision Probability (single satellite): 0.000163 COMPLIANT

```
=================================================
Spacecraft = Kepler1
Critical Surface = WallX
=================================================

**INPUT**

       Apogee Altitude = 600.000000 (km)
       Perigee Altitude = 600.000000 (km)
       Orbital Inclination = 98.600000 (deg)
       RAAN = 0.000000 (deg)
       Argument of Perigee = 0.000000 (deg)
       Mean Anomaly = 0.000000 (deg)
       Final Area-To-Mass = 0.026400 (m^2/kg)
       Initial Mass = 5.000000 (kg)
       Final Mass = 5.000000 (kg)
       Station Kept = No
       Start Year = 2017.000000 (yr)
       Duration = 10.600000 (yr)
       Orientation = Fixed Oriented
```

```
        CS Areal Density = 2.700000 (g/cm^2)
        CS Surface Area = 0.030000 (m^2)
        Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
        CS Pressurized = No
        Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**

        Probability of penetration = 0.000163
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range

==================================================
Spacecraft = Kepler1
Critical Surface = WallY
==================================================

**INPUT**

        Apogee Altitude = 600.000000 (km)
        Perigee Altitude = 600.000000 (km)
        Orbital Inclination = 98.600000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass = 0.026400 (m^2/kg)
        Initial Mass = 5.000000 (kg)
        Final Mass = 5.000000 (kg)
        Station Kept = No
        Start Year = 2017.000000 (yr)
        Duration = 10.600000 (yr)
        Orientation = Fixed Oriented
        CS Areal Density = 2.700000 (g/cm^2)
        CS Surface Area = 0.132000 (m^2)
        Vector = (0.000000 (u), 0.000000 (v), 1.000000 (w))
        CS Pressurized = No
        Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**

        Probability of penetration = 0.000065
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range
```

```
==================================================
Spacecraft = Kepler1
Critical Surface = WallZ
==================================================

**INPUT**

        Apogee Altitude = 600.000000 (km)
        Perigee Altitude = 600.000000 (km)
        Orbital Inclination = 98.600000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass = 0.026400 (m^2/kg)
        Initial Mass = 5.000000 (kg)
        Final Mass = 5.000000 (kg)
        Station Kept = No
        Start Year = 2017.000000 (yr)
        Duration = 10.600000 (yr)
        Orientation = Fixed Oriented
        CS Areal Density = 2.700000 (g/cm^2)
        CS Surface Area = 0.010000 (m^2)
        Vector = (1.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No
        Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.200000 (cm)

**OUTPUT**

        Probability of penetration = 0.000000
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range
```

Identification of all systems or components required to accomplish any post mission disposal operation, including passivation and maneuvering: None

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C.7 ASSESSMENT OF SPACECRAFT POST-MISSION DISPOSAL PLANS AND PROCEDURES

Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry within a maximum of 10.6 years after start of mission, as described below.

Plan for any spacecraft maneuvers required to accomplish post mission disposal: Operational lifetime of the spacecraft is estimated to be up to 3 years from the date of deployment. At which time the spacecraft will be oriented into its Break configuration via on-board attitude control system in order to ensure rapid atmospheric reentry. Reentry will occur at a maximum of 8.3 years after end of mission operations. Moreover, as the Break configuration is the dynamically stable configuration, in the event of attitude control failure the spacecraft will passively orient in this attitude.

Calculation of area-to-mass ratio after post mission disposal, if the controlled reentry option is not selected:

Spacecraft Mass:	5 kg	
Cross-Sectional Area:	Nominal configuration:	0.03 m^2 (drag area)
	Low Drag configuration:	0.01 m^2 (drag area)
	Break configuration:	0.132 m^2 (drag area)
Area to mass ratio:	Nominal configuration:	0.006 m^2/kg
	Low Drag configuration:	0.002 m^2/kg
	Break configuration:	0.0264 m^2/kg

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0.2 and NASA-STD-8719.14 section):

Requirement 4.6-1: Disposal for space structures passing through LEO:

A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option:

- Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or

- Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission

At the end of operational life, the Kepler satellites will be oriented via on-board attitude control systems to the Break configuration, which will allow for atmospheric reentry (Option "a"). End of operational life will commence after 3 years of on-orbit operations, during which time the spacecraft is in Nominal configuration. Moreover, in the event of an actuator failure, the spacecraft will passively orient towards a Break configuration. STK was used to estimate expected on-orbit lifetime, as described below. Min and max operational lifetimes take into account space weather fluctuations, assuming a solar flux sigma level of σ = 0.5 to 1.0, and the high insertion case of 600 km is assumed as a worst-case scenario. As shown, maximum possible lifetime is 10.6 years, which is well within the disposal requirements.

Case Name	High Insertion Case	
Drag Coefficient	2.2	
Drag Area	Mission: 0.03 m^3 End of Operations: 0.132 m^2	
Initial Orbit	600 x 600 km	
	Low Solar Activity (σ = 0.5)	High Solar Activity (σ = 1.0)
Lifetime	10.6 years	9.8 years

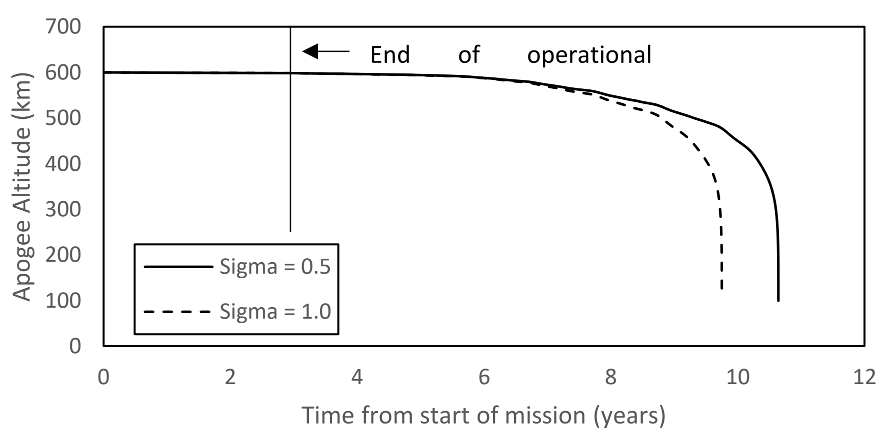

Figure 9: Spacecraft apogee from mission onset until reentry.

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Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO**.**

Analysis: Not applicable.

Requirement 4.6-4. Reliability of Post mission Disposal Operations

Analysis: Not applicable.

C.8 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

Requirement 4.7-1: Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules: a) For uncontrolled re-entry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Analysis performed using DAS v2.0.2 shows that no part of the satellite is expected to survive re-entry, therefore the risk of human casualty is ~0.

```
*********Processing Requirement 4.7-1
       Return Status :  Passed

***********INPUT****
 Item Number = 1

name = Kepler1
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 5.000000
Thermal Mass = 5.000000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Payload
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Structure
```

```
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 1.500000
Thermal Mass = 1.500000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = SolarPanels
quantity = 7
parent = 1
materialID = 24
type = Box
Aero Mass = 0.200000
Thermal Mass = 0.200000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.025000

name = Batteries
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 0.300000
Thermal Mass = 0.300000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = Avionics
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.800000
Thermal Mass = 0.800000
Diameter/Width = 0.100000
Length = 0.200000
Height = 0.100000
```

```
*************OUTPUT****
Item Number = 1

name = Kepler1
Demise Altitude = 77.997472
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload
Demise Altitude = 72.714058
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure
Demise Altitude = 73.132183
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SolarPanels
Demise Altitude = 77.647324
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batteries
Demise Altitude = 74.769879
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Avionics
Demise Altitude = 75.535136
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
=============== End of Requirement 4.7-1 ===============
```

Requirement 4.7-1, b) For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

Not applicable as there is no use of controlled reentry

Requirement 4.7-1 c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

Not applicable as there is no use of controlled reentry

C.9 ASSESSMENT FOR TETHER MISSIONS

Not applications as there are no tethers in this mission.