

**Before the
Federal Communications Commission
Washington, D.C. 20554**

In the Matter of

Kepler Communications Inc., Petition for
Declaratory Ruling

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IBFS File No. SAT-LOI-20161115-00114
(Call Sign S2981)

**KEPLER'S RESPONSE TO
REQUEST FOR FURTHER INFORMATION**

Kepler Communications Inc. (Kepler) thanks the Commission for considering its non-geostationary satellite orbit (NGSO) fixed-satellite service (FSS) systems for market access to the US.

Itemized below, in line with the structure laid out by the Commission, are Kepler's recommendations, comments and concerns.

1. For clarification, as Kepler spacecraft operate in Low Earth Orbit (LEO), the geographic coverage of every phase is global. However, Kepler spacecraft suffer from a revisit time limitation as function of the number of spacecraft deployed in the constellation. As Kepler progresses through the listed phases, the revisit time to terrestrial stations will decrease. Figure 1 below provides guidance on the typical revisit time that would be seen by end users as the system scales.

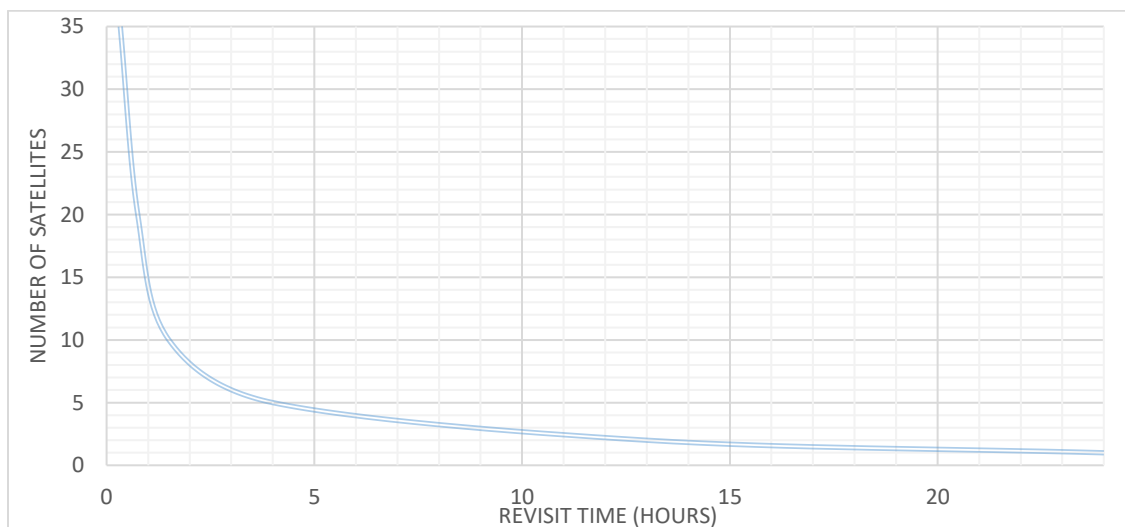


Figure 1: Revisit time as function of the number of operational satellites in the constellation

In direct response to the question, all three Phases provide global coverage with progressively lower revisit time.

2. Kepler's satellite is designed to maintain a target power-flux density ("PFD") at the surface of the earth as shown in Figure 5 of Kepler's petition for declaratory ruling¹. The output transmit power is adjusted when the transmitting beam is steered to compensate for the reduction in antenna gain and increase in path loss associated with the steering angle. As a result, the highest EIRP density for the beams in Kepler's constellation is -16.62 dBW/4kHz at 10° angle of arrival (corresponding to 64° of steering angle on the Kepler satellite). The contour of the transmitting beam configuration that results in the highest EIRP density for this beam is shown in Figure 16² of the attachments to this document.

Similarly, the antenna gain for the receiving beam is reduced when steered. Hence the highest gain-to-temperature ratio ("G/T") of -6.3 dB/K occurs at nadir, while the smallest G/T of -10.92 dB/K³ occurs at the edge of steering (i.e. 64° from nadir). The corresponding contour for the receiving beam configuration with the smallest G/T is shown in Figure 8⁴ in the attachment. Furthermore, as Kepler's system is not a bent-pipe satellite⁵ system, we believe the concept of saturation power flux density is not applicable.

Contours for the transmitting and receiving beams steered from nadir to a maximum slant angle of 64° are provided in the attachment to this document. Note that the contours presented are for the initial design concept on Kepler's satellite and should be treated as the worst-case scenario⁶. As shown in the contours, the beams widen significantly when steered to the maximum slant angle of 64°. As a result, Kepler is currently undergoing an in-depth design effort to minimize the effect of beam widening at the edge of coverage and will provide updated contours to the Commission well in advance of launch. Kepler is aware of, and supports, SpaceX's intention of maintaining a

¹ See Kepler Technical Narrative

² Figures are referenced at the bottom right by page number

³ This is a conservative worst case value in the current design iteration of the Kepler satellite

⁴ Figures are referenced at the bottom right by page number

⁵ A bent-pipe satellite system is where the receive antenna and radio are connected to a corresponding transponder

⁶ Future iterations of Kepler's satellite will have improved antenna gain and performance over the range of steering angle through the use of deployable antenna technologies and RF switches.

constant antenna beamwidth with respect to steering angle⁷. However, given that the link distance increases when a beam is steered, increases in the size of spot beams on the ground is unavoidable. Kepler respectfully requests that the Commission advise on the minimum requirements or seek comment regarding the establishment of guidelines in designing steerable antenna for satellites in NGSO. Given that Kepler's satellites operate with a 64° cone, the maximum circular coverage area of a single satellite is approximately 1200 km⁸ for both the receive and transmit beams.

3. Kepler's Phase I Ku band communication link is accomplished using a SDR built around a 500 MSPS ADC and 2.5 GSPS DAC. This allows the satellite to cover over 200 MHz of instantaneous bandwidth, targeting a 400 Mbps data rate encoded using the FEC and modulations schemes specified in DVB-S2X. The front end of the satellite system is separated into Tx and Rx segments. Each is placed behind a passive Tx and Rx (microstrip) antenna array – note this only true for the first phase of operations, subsequent phases will include an electrically steerable antenna. A core advantage of this SDR architecture is that it allows Kepler to dynamically change the bandwidths, center frequencies and power. The Bandwidth can be changed in the digital signal processing done on the FPGA, by switching between different data rates and modulation options (e.g. QPSK, 8PSK, 16APSK, etc) the utilized bandwidths will change. Modification of the center frequency can occur in several areas of the SDR. If the frequency change is within the digital bandwidth of the back end, a different digital processing setting can be used to change the center frequency. Otherwise, the local oscillator on the front end is tunable and designed to support 1GHz of tunable range. The SDR also has the capability to change output power and hence the EIRP of the satellite. The Commission should note that the above is true for Phase I of Kepler's deployment. Kepler has publicly announced its partnership with Phasors and will be integrating phased array technology as of Phase II on board its satellites. In Phase I, beams are steered by dynamically changing the orientation of the satellite.
4. Kepler's description of global coverage in the Schedule S was intended for reference with the constellation rather than a single satellite. As noted in the Technical Narrative, the intended downlink beam would create a 64° cone. Kepler apologizes for the lack of clarity.

⁷ SpaceX NGSO Attachment A (Technical information to supplement schedule S) page 7.

⁸ Distance is representative of the radius of a cone

5. For Phase I and Phase II Kepler's service will primarily strap 11.2 – 12.2 to the 14.0 – 14.5 GHz. Within these segments, gateways are anticipated to use roughly 200MHz down and 100 MHz up. User terminals are heavily focused on upload bandwidth and use up to 50 MHz per terminal with download being nominal. In Phase III, dynamic changes with inter-satellite links allow for heavier use bi-directionally. At this point, the 2.25 GHz available for inter-satellite links allows for full use of both the up and down bandwidth available. The Commission should note that Kepler is in the process of filing for additional spectrum with the ITU for Phase III of its deployment. As Phases I and II of the deployment are not real-time ISL capable systems, band strapping remains relatively disproportionate up until the deployment of Phase III.

For further clarity, we point the Commission to the figure below which was in Kepler's original filing.

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
	12.75 - 13.25 GHz ⁵	No
Gateway-to-Satellite	14.0 - 14.5 GHz	Yes

Figure 2: Planned Spectrum usage for Phase I and Phase II

6. Kepler has calculated its target PFD based on system constraints and an attempt to centralize PFD around 151 dB (W/m²/4kHz). Through system design, this also provides a minimum margin to the PFD limits of 5 dB and average margin of 10 dB throughout the operational range of 10 to 90 degrees of elevation. The data presented in Figure 3 below represents the worst possible operational case. Gains have been used based on a beam contour when steered to a 64 degree azimuth which has been discussed under Kepler's response to question 2.

Figure 3: EPFD Calculations Using 64 Degree Steering Gain

	10° Elevation	90° Elevation
EIRP Density (dBW/Hz)	-52.64	-58.51
EIRP (dBW/4kHz)	-16.62	-22.49
EIRP (dBW/1MHz)	7.36	1.49
Distance to Earth (Km)	1783	575
Spreading Loss (dB)	-136.01	-126.19
PFD (dB(W/m ² /4kHz))	-152.62	-148.69
PFD (dB(W/m ² /1MHz))	-128.64	-124.69

7. Kepler filed its CRC in December of 2016 and is currently waiting for the ITU to respond to its application. As mentioned previously, Kepler is in the process of filing for additional spectrum with the ITU, including but not limited to its TT&C bands. At present, given the uncertainty with ITU NGSO filings with regards to notification and the bringing into use of systems presently under discussion in WP4A, Kepler has filed up to its Phase 2 constellation⁹. Kepler is aware that its filing is presently under review and is expecting to hear back from the ITU shortly with regards to their findings. At this time, Kepler will have three months to respond to the ITU with its EPFD assessment based on any findings. In line with the ITU, Kepler respectfully request that the Commission extend Kepler's request for waiver of demonstrating EPFD compliance for Phase II of its constellation until three months post ITU findings¹⁰. Such a request for waiver does not undermine the merit of Kepler's system given that it is an ITU requirement, which if not satisfied would prohibit Kepler from operating¹¹. With regards to phase III, Kepler respectfully reiterates it's request for a waiver until it has finalized the constellation architecture with inter satellite links. The demonstration of EPFD compliance with non-inter-satellite links would differ substantially from a system that does – to the point where such a demonstration at present would be non-representative and have to be revised in the future. Kepler's preliminary EPFD results which cover

⁹ Conversation with the ITU has suggested that Kepler may expand the filing in the future and maintain priority provided that it demonstrates no additional interference to other systems.

¹⁰ It is Kepler's belief that the ITU will submit its findings by the end of April at which point Kepler will have until July 2017 to demonstrate EPFD compliance both to the ITU and the Commission, should it accept Kepler's request for waiver.

¹¹ Kepler also notes that it has provided the commission with EPFD results to demonstrate compliance for its first two satellites.

phase II, as filed with the ITU, have been attached for the Commission to review. These results demonstrate EPFD compliance for Kepler's planned operations well into 2020¹².

8. Kepler believes this question is covered by its response to point 7 above.
9. Kepler notes that the information related to orbital debris and the criteria which ISED assesses in assigning a license is publicly available¹³. The Commission has alluded that its concern surrounds matters such as orbital debris, prevention of accidental explosions and collision risks. Despite Kepler's belief that ISED sufficiently oversees all concerns raised by the Commission, answers have been provided to all questions posed by the Commission.
 - a. As publicly displayed on ISED's CPC 2-6-02 documentation page, license applicants must comply with the UN space debris mitigation guidelines¹⁴ – within which, the Commission's concerns are covered¹⁵. Kepler has contacted ISED and confirms that it imposes these orbital debris mitigation requirements through its conditions of license. Kepler can facilitate a discussion between the Commission and ISED for further clarity if required.
 - b. ISED continues to uphold its moratorium, preventing Kepler from filing its request for a space license and subsequently submitting any orbital debris report. Kepler was originally of the belief that the moratorium would be lifted as of February 2017 however, this did not materialize. Further conversation with ISED puts the anticipated lifting date around the June timeframe. This factors in the current state of commenting to be completed by April

¹² The Commission should note that this filing and EPFD demonstration is for 80 satellites – well beyond what is expected within Phase II of operations.

¹³ <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01385.html>

¹⁴ *While Industry Canada's focus is on de-orbiting satellites in a manner that minimizes risk to operating satellites, applicants should also be aware of and work toward compliance with the broader United Nations (UN) space debris mitigation guidelines. These guidelines cover many elements, including limiting debris released during normal operations; minimizing the potential for break-ups during operational phases; limiting the probability of accidental collision in orbit; avoiding intentional destruction and other harmful activities; minimizing potential for post-mission break-ups resulting from stored energy; limiting the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission; and limiting the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission*, ISED CPC-2-6-02 — Licensing of Space Stations, Issue 3 (November 21, 2013)

¹⁵ See The United Nations' space debris mitigation guideline at www.unoosa.org/pdf/bst/COPUOS_SPACE_DEBRIS_MITIGATION_GUIDELINES.pdf

18th, time for ISED to assess comments and direct questions to relevant parties, responses to ISED's questions and subsequently the time to publish revised regulations.

- c. Kepler has run simulations on several platforms to provide a solid basis for its orbital lifetime claim. For a 600 km orbit the following results have been computed:

Table 1: Orbit lifetime predicted by commercially available propagators

	Full Deploy Stable Brake configuration	Random Tumble Configuration	Solar Panel Undeployed Stabilized
Average Cross Sectional area (m ²)	0.21	0.083	0.03
DAS modeled Orbital life (years)	4.6	7.0	25.2
HPOP Modeled Orbit life (years)	3.1	4.6	26.8
SGP4 Modeled Orbit Life	3.2	9.7	26.8

- d. The deployed solar panels are designed and developed by a third-party provider. This provider has previously flight tested their system, which employs several redundancy measures to increase reliability of the deployment, including:
- i. Redundant power channels (x2) are used on each deploy side in order to increase the reliability of power supplied to the release mechanisms.
 - ii. Redundant thermal-knife architecture in the deployment mechanism to increase reliability as above. This is currently under discussion.
 - iii. Deployment hinges employ use of dissimilar metals (pins) and surface coatings to reduce the possibility of induced surface adhesion through vibration and vacuum.

The deployment mechanisms used have significant flight heritage and have no reported failed deploys on-orbit.

- e. The brake configuration, as shown below in Figure 4, has the same drag parameters for both orientations a. and b. and can be used during normal operation for differential drag spacing, however only orientation b. demonstrates passive dynamic stability.

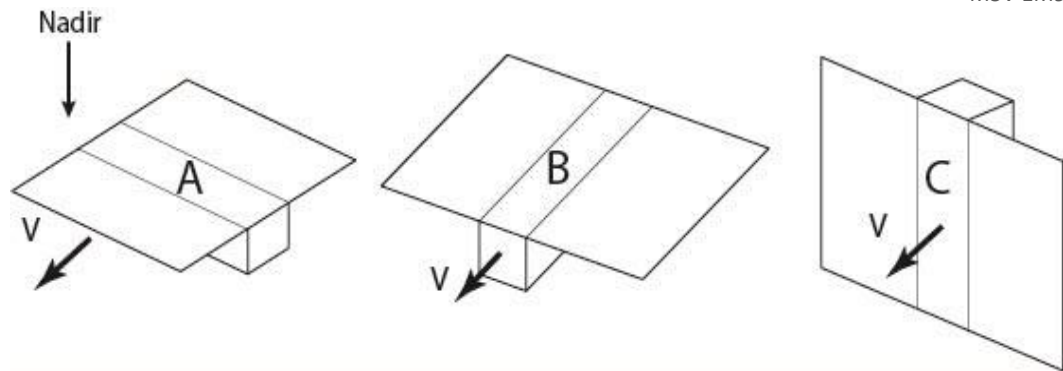


Figure 4: High Drag "Brake" Configurations

Passive dynamic stability in roll about the spacecraft Z-axis is maintained at orbit altitudes through separation of the Deployed Center-of-Mass (CoM) and the Center of Aerodynamic Pressure. When the X-axis is aligned with the velocity vector for the stable brake configuration, the positive separation of the CoM and Cp is 0.0257m resulting in a positive static margin necessary for static stability and a stabilizing moment. With the predicted positive margin, preliminary analysis suggests this configuration has a stiffness that results in a steady state error of $\pm 30^\circ$ with varying disturbances.

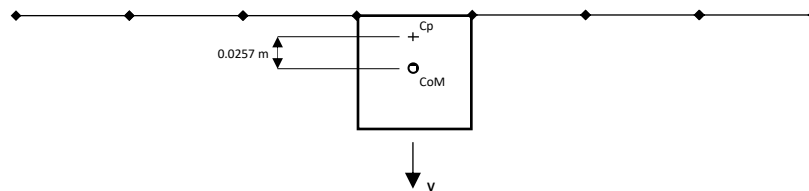


Figure 5: Passive Stability Configuration Details

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Collision Risk with large objects:

A probability of collision analysis was performed using NASA's DAS 2.0.2 software. This analysis was done for a single satellite over a mission duration of 25 years at an altitude of 600 km. The mission duration of 25 years is used as this is maximum lifetime prior to re-entry should the solar arrays fail to deploy.

Note that for each phase the maximum conservative estimate of the sum of individual spacecraft collision probabilities was used for constellation phases.

Table 2: DAS Collision Probability for Kepler Constellation Phases

	Collision Probability with Large Objects	Collision Probability with debris	Total Probability of single Spacecraft loss
Single Spacecraft	0.000003	0.000673	0.000676
Phase I (5 SC)	0.000015	0.0034	0.003415
Phase II (20 SC)	0.000060	0.01346	0.01352
Phase III (140 SC)	0.00042	0.094	0.09442

Small Object Impact and Collision Risk

The probability of collision and impact with debris and small objects was calculated using NASA's DAS 2.0.2 software. Conservatively, a fixed orientation was used for the entire mission duration, with a damaging impact on any face of the spacecraft counted as debilitating the entire spacecraft. The sum total of probability of impact with each face is shown in Table 2. Here, the total probability of spacecraft loss from external impacts is 0.000676 per spacecraft.

Deterministic Model of Collision Risk

For redundancy, a deterministic model was used to predict the number of conjunctions, and probability of collision per spacecraft for both the minimum and maximum modeled life. The STK Conjunction Analysis Tool (AdvCAT) was used for the prediction. A Kepler satellite was given a threat ellipsoid measuring 10 km in the tangential direction and 2 km in both the Crosstrack and normal directions. The model compared the propagated orbits against all TLEs in the STK database in addition to the 140 Kepler spacecraft in a complete Phase III constellation, all beginning at a 600 km orbit altitude. The TLEs were allocated threat volume based on their orbit class.

Table 3: STK AdvCAT probability of conjunctions with known TLEs

	Number of Close Approaches	Number of Conjunctions	Maximum Analytic Probability of Collision	Maximum Probability of Collision
Single Spacecraft	191501	123288	2.15×10^{-9}	0.000236

Collision Risk and continuity of service:

The initial Phase III constellation will be deployed in the 7 orbital planes, with spacecraft strategically spaced in argument of perigee to avoid collisions at plane crossings. During Operational life, the Mission Planning and Scheduling Software (MPS) will track the orbit for each Kepler spacecraft and additional threat TLEs with high-precision orbit propagators to predict conjunctions in the following 1-3 days. Predicted conjunctions can be avoided through application of variable-drag maneuvers. An argument of perigee adjustment of $\sim 6^\circ$ per day can be accomplished with these maneuvers resulting in a significant reduction of impact risk. Due to the low collision probability and low risk of a single spacecraft loss, the continuation of full constellation service will be up kept through planned renewal launches and reactionary replacements if necessary. No pre-defined continuation efforts are necessary

- g. Kepler spacecraft will be operating in altitudes in LEO above that of the ISS, but will fully and partially cohabitate station altitude bands during the decaying orbit operations of each spacecraft. While precise tracking and reporting will be maintained by Kepler throughout these phases, both statistical and deterministic models have been used to predict the number of conjunctions between Kepler spacecraft and the ISS.

The statistical analysis assumes a spatial distribution of the spacecraft in its orbit of equal probability. The ISS and Kepler Spacecraft are given assumed tangential threat dimensions of 10 km and 2 km respectively to account for size and velocity uncertainty. For the worst-case model of Kepler time spent in ISS altitudes, the resulting probability of a conjunction is 0.00025.

The deterministic model was used to predict the number of conjunctions, and probability of collision per spacecraft for both the minimum and maximum modeled life. The STK Conjunction Analysis Tool (AdvCAT) was used for the prediction.

Table 4: Probability of Kepler Conjunction with ISS

	Number of Close Approaches	Number of Conjunctions/ Maneuvers	Analytic Probability of Collision	Maximum Probability of Collision
Deployed Solar Array (0.083 m2, HPOP, 4.6 year life)	1	1	0.0000028	0.000098
Undeployed Solar Array (0.03 m2, HPOP, 25 year life)	16	2	0.00034	0.0015

Should any of the above not provide adequate detail or provide reason for concern, Kepler welcomes further questioning by the Commission. As demonstrated above, Kepler has every intent to be transparent and forthcoming in its responses. Kepler notes that any data presented here within may change as a result of ITU findings. If changes are required to the system, the Commission will be notified.

Respectfully submitted,

Kepler Communications Inc.

- April 20, 2017

By: /s/ Nickolas G. Spina

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Kepler Communications Inc.