# SMALL SATELLITE LICENSE

## Response to FCC's Request for Information

LYNK GLOBAL, INC.

August 27, 2021

Mr. Karl Kensinger
Chief, Satellite Division
International Bureau
Federal Communications Commission
45 L St. NE
Washington, DC 20554

Re: Lynk Global, Inc., IBFS File No. SAT-LOA-20210511-00064; Call Sign: S3087

Dear Mr. Kensinger:

Lynk Global, Inc. ("Lynk"), respectfully responds herein to your request for additional information to assist in the processing of the Lynk Smallsat System application.[1] Lynk provides the original questions with responses following each question.

1. **Please indicate when the required ITU materials (spacecap, GIMS database, compatibility analysis for operations under ITU Radio Regulation 4.4, etc.) will be provided to the FCC. Additionally, attached is a template for the ITU Cost Recovery letter, which should be completed and submitted in lieu of the letter previously submitted by Lynk.**

Lynk provided the ITU materials to the FCC on July 30, 2021. Lynk filed the ITU Cost Recovery letter in IBFS contemporaneously with this response per the template provided.

2. **Please indicate the GPS receiving frequencies for Lynk's satellites.**

Lynk's satellites utilize the GPS L1 frequency band centered at 1575.42 MHz.

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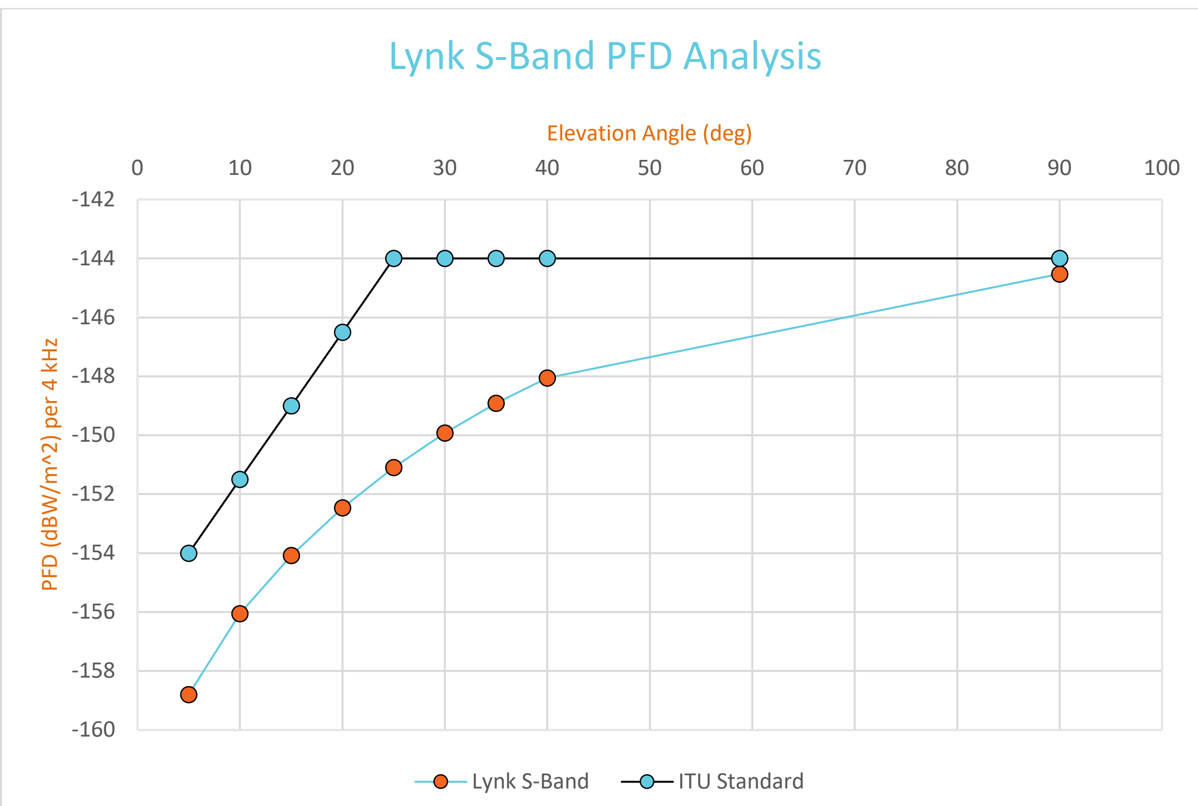
[1] Letter from Karl A. Kensinger, Chief, Satellite Division, International Bureau, FCC, to Shawn Marcum, Lynk Global, Inc., and Lynne Montgomery, Counsel to Lynk Global, Inc., IBFS File No. SAT-LOA-20210511-00064 (Aug. 2, 2021).

3. **In the Schedule S, the PFD provided for the 2200-2290 MHz downlink exceeds the ITU limits by ~30 dB. Please provide an explanation and/or justification.**

Table 21-4 of ITU Radio Regulation 21.16 includes the following PFD limits:

| Frequency Band | Service | Limit in dB(W/m$^2$) for angles of arrival (δ) above the horizontal plane | | | Reference Bandwidth |
|---|---|---|---|---|---|
| | | 0º – 5º | 5º – 25º | 25º – 90º | |
| 2200-2300 MHz | Space operation (space-to-Earth) | -154 | -154 + 0.5(δ – 5) | -144 | 4 kHz |

The values included in Schedule S of Lynk's application are based on a reference bandwidth of 1 MHz whereas the ITU Standard measures per 4 kHz of bandwidth. Considering the difference in the reference bandwidths, Lynk's transmissions in the 2200-2290 MHz band comply with the ITU PFD limits, as demonstrated in the following Table.[2]




[2] The Lynk Smallsat System's S-band operations are the same over any location on the Earth, so the following figure and table are applicable to any earth station location communicating with the Lynk Smallsat System in this band.

| Max PFD Parameters | 0º – 5º | 5º – 10º | 10º – 15º | 15º – 20º | 20º – 25º | 25º – 90º |
|---|---|---|---|---|---|---|
| ITU Standard (dBW/m$^2$/4kHz) | -154.0 | -151.5 | -149.0 | -146.5 | -144.0 | -144.0 |
| Lynk Schedule S (dBW/m$^2$/1MHz) | -134.8 | -132.0 | -130.1 | -128.4 | -127.1 | -120.5 |
| Lynk Schedule S (dBW/m$^2$/4kHz) | -158.79 | -156.05 | -154.07 | -152.45 | -151.08 | -144.52 |

**4. Please provide the EPFD for the 20.1-20.2 GHz downlink.**

Appendix B provides a detailed EPFD analysis for the Lynk Smallsat System.

**5. Starting on page 26 of the Orbital Debris Assessment Report (ODAR), the total time in orbit appears to vary between 6 and 13 years (5 years station-keeping, 1 to 8 years passive decay.) This would not be consistent with the eligibility rule for the streamlined small satellite process, 47 CFR 25.122(c)(2), which states the total in-orbit lifetime for any individual space station will be six years or less. Please clarify the total in-orbit lifetime for Lynk's satellites, including under worst-case scenarios, and address whether there are any circumstances in which the planned satellites would not meet this eligibility rule.**

The total in-orbit lifetime of Lynk's satellites accounts for the planned service mission duration plus the worst-case controlled deorbit times—i.e., the satellites with Attitude Determination and Control Systems (ADCS) but no propulsion capabilities—such that the total in-orbit lifetime of Lynk's satellites will not exceed 6 years. The service mission duration of any individual satellite is dependent on the controlled deorbit duration. Lynk's application provides the following table:[3]

[3] *See* Legal Narrative at 40; *see also* ODAR at 15.

| Deorbiting Situation | 550 km SSO | 500 km Mid-inclination Orbit |
|---|---|---|
| Uncontrolled Satellite (very unlikely event) | Demise $\leq$ 5.17 years | Demise $\leq$ 2.96 years |
| Controlled Satellite ADCS only | Demise $\leq$ 3.60 years | Demise $\leq$ 2.19 years |
| Controlled Satellite ADCS and Propulsion | Demise = days to weeks | Demise = days to weeks |

Consequently, to maintain a total in-orbit lifetime of 6 years or less, Lynk certifies that the service mission time of its satellites in SSO will be limited to 2.4 years or less before entering a controlled deorbit, and a satellite in mid-inclination orbit will be limited to a service mission duration of 3.81 years or less before entering a controlled deorbit.[4]

The current satellite design safeguards the satellites' health for controlled deorbits at the end-of-service times stated above. Lynk designed its satellites to operate long past their designed service mission time of 5 years. Lynk also included highly reliable and robust ADCS and propulsion systems, providing Lynk the capability to maintain its satellite's orbital altitude and ensure a controlled deorbit well beyond the designed operational lifetime of the satellites. Although Lynk has no plans to operate its satellites beyond the end-of-service times stated above, Lynk developed its satellites to include this capability to ensure the highest possibility of a controlled deorbit over the operational mission of the satellite. For instance, satellites equipped with propulsion could have the longest planned station-keeping depending on launch. Lynk could station-keep these satellites up to their designed 5-year service lifetime, and then by utilizing the ADCS and propulsion systems, Lynk can deorbit these satellites in a matter of days

[4] Lynk acknowledges that for satellites launched after the beginning of Lynk's license term, it may be necessary to reduce the service mission duration of these satellites to ensure compliance with the 6-year requirement.

or weeks, resulting in the on-orbit lifetime not exceeding 6 years. However, instead of extending service mission times, Lynk includes the propulsion systems to better mitigate collision risks, so Lynk will still deorbit its propulsive satellites at the same end-of service times as the non-propulsive satellites, with any remaining propulsive capabilities used to deorbit quickly. To be clear, Lynk does not seek to operate any satellites under the present application for the full 5-year service design life of the satellites; Lynk plans a controlled deorbit for all satellites at the end-of-service times stated above. Therefore, Lynk's operations will comply the 6-year requirement specified in Section 25.122(c)(2).

Lynk's satellites would have to enter a permanently uncontrolled state for it to even be possible for the total in-orbit time of its satellites to exceed 6 years. However, Lynk stresses that this situation is not a part of Lynk's planned operations and would be a highly unlikely event given the satellite design and the reliability of the maneuverability systems. As such, the total in-orbit duration of the satellites in the Lynk Smallsat System will be 6 years or less as required by Section 25.122(c)(2).

The Requirement 4.6 analysis provided in the DAS 3.1.0 Log of Lynk's Orbital Debris Analysis Report incorrectly suggested that Lynk's satellites could be in-orbit up to 13 years.[5] Lynk conducted the 4.6 analysis with incorrect assumptions regarding the station-keeping duration parameter. Lynk assumed that the satellites would station-keep for a duration of 5 years, which is consistent with the designed service lifetime of the satellites. However, that assumption is not consistent with Lynk's planned mission operations, which are compliant with

[5] *See* ODAR at 24-28.

the 6-year rule. As stated above, Lynk will limit its service lifetime of its satellites to 2.4 years or less in SSO and 3.81 years or less in mid-inclination orbit regardless of whether the satellites have propulsion capabilities. Accordingly, Lynk has corrected the station-keeping durations that are assumed in the 4.6 analysis, and Appendix A contains an updated Requirement 4.6 DAS 3.1.0 Log.

6. **Please provide any additional justification for consideration of the proposed MSS space stations as ones that do not "materially constrain" the operations of other systems. See 47 CFR 25.122(c)(9).**

Lynk purposefully chose the streamlined small satellite authorization process because it is synergistic with Lynk's commercial deployment strategy. The following analysis provides additional justification that the Lynk Smallsat will not materially constrain current and future operators from utilizing spectrum, including the use of cellular frequencies used for service links.[6]

First, Lynk does not currently seek to provide service in the United States with the Lynk Smallsat System. As such, Lynk's operations under this application will in no way constrain other operators from seeking to operate in cellular frequency bands in the United States.

Second, the Lynk Smallsat System is a limited commercial deployment consisting of only 10 satellites and will only be capable of intermittent coverage. The Lynk Smallsat System will provide service to at most 6% of the world and for no more than 90 minutes non-consecutively

[6] Lynk's Technical Narrative explains in detail how Lynk will not materially constrain the use of other frequency bands requested in Lynk's application, including the Ka-band, S-band, and inter-satellite links with the Globalstar system.

per day in any particular location.[7] These coverage limitations make the Lynk Smallsat System different from other "always-on" MSS systems and mean that there are many opportunities for sharing spectrum with other operators through geographic or temporal separation.[8]

Third, Lynk's operations in these cellular frequencies are limited by the need to coordinate with, and obtain the consent of, the Mobile Network Operators (MNOs) in each country where Lynk seeks to operate. In areas where Lynk has not reached an agreement with an MNO, Lynk will not operate and therefore will have no impact on the ability of other operators to use spectrum licensed to that MNO. Even in areas where Lynk has reached agreements with MNOs, Lynk's access will be directed by the MNO partners, and who will have the ability to contract with multiple satellite operators to utilize the spectrum for which the MNOs hold terrestrial licenses.

Lastly, an MNO that has agreed to allow satellite operators to use its terrestrially licensed spectrum can manage spectrum access by such satellite operators using the same techniques that are used to manage spectrum within the MNO's own terrestrial network. When an MNO seeks to extend its coverage with a new tower, it levies a requirement on itself to analyze the frequency, bandwidth, and signal power of the coverage extension such that it does not interfere with the existing terrestrial network. A beam from a Lynk satellite can be

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[7] *See* UHF Interference Mitigation Analysis at 29.

[8] The limited nature of the operations of Lynk's Smallsat System are consistent with the Commission's view that "requesting operations in [MSS] bands . . . can . . . be accomplished because of the limited nature of the small satellite operations." *Streamlining Licensing Procedures for Small Satellites*, Report and Order, 34 FCC Rcd 13077, 13122 ¶ 113 (2019). The limited nature of the Lynk Smallsat System's operations meets the Commission's criteria for streamlined small satellite operations.

thought of as another very large terrestrial macro cell. As a result, Lynk's MNO partners will impose the same requirement on Lynk so that the coverage extension using Lynk's network will not interfere with the existing terrestrial network.[9] The same techniques would be used by MNOs to enable use of their terrestrially licensed spectrum by multiple different satellite operators. As demonstrated in Lynk's Interference Mitigation Analysis, it is common for MNOs to have licenses across a plurality of bands, often more than 100 MHz of bandwidth.[10] This offers ample spectrum for deployment of heterogenous networks utilizing both terrestrial and satellite-based cell towers. The MNO, as the holder of the terrestrial spectrum rights, will dictate where, when, and how any satellite operator will deploy that spectrum on the ground. Thus, the ability of other satellite operators to utilize an MNO's terrestrial spectrum is fundamentally constrained by the MNO's willingness to enter agreements with additional satellite operators and any limitations imposed by the MNO in those agreements.

Lynk's commercial deployment strategy is to deploy intermittent commercial operations with the Lynk Smallsat System to provide crucial services overseas and revenue for the company. For instance, the intermittent service of the Lynk Smallsat System will support among many other things: emergency cellular broadcast warnings overseas, disaster relief field staff check-in and situational awareness updates, civilian distress calls via SMS text, and last mile connectivity. These operations will also provide regulators an opportunity to monitor a preliminary deployment of satellite-direct-to-handset service. The streamlined licensing

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[9] A more detailed explanation of these techniques is included in the UHF Interference Mitigation Analysis submitted with Lynk's application.

[10] *See* UHF Interference Mitigation Analysis at 10.

process for small satellites is a low-risk way of authorizing this revolutionary technology that has significant public benefits.

7. **Please provide written confirmation from the operator of the Globalstar constellation that it is aware of and plans to operate with the frequencies specified (or a corrected range of frequencies) for operation with that system. (On page 12 of the narrative, Lynk lists the transmit frequency to the Globalstar constellation as 2483.5-2500 MHz and the receive from the constellation as 1613.75-1616.88 MHz, which is inconsistent with the capabilities of the Globalstar system. The frequency ranges specified are also outside the ranges typically specified for inter-satellite link operations with the Globalstar system.).**

In the time since the Commission requested additional information on the Lynk Smallsat System application, Lynk received notice that Globalstar will not support Lynk's proposed use of its spectrum in a commercial application but will continue to support Lynk's experimental endeavors. Therefore, Lynk withdraws the portion of its application requesting authority to operate with the Globalstar constellation.

8. **In the ODAR, two area-to-mass (A-to-M) values are provided: 0.017 $m^2$/kg and 0.028 $m^2$/kg. Please describe what flight profiles these two A-to-M values represent, and indicate whether these two profiles are the only intended configurations in which the spacecraft will be flown during the course of orbital lifetime.**

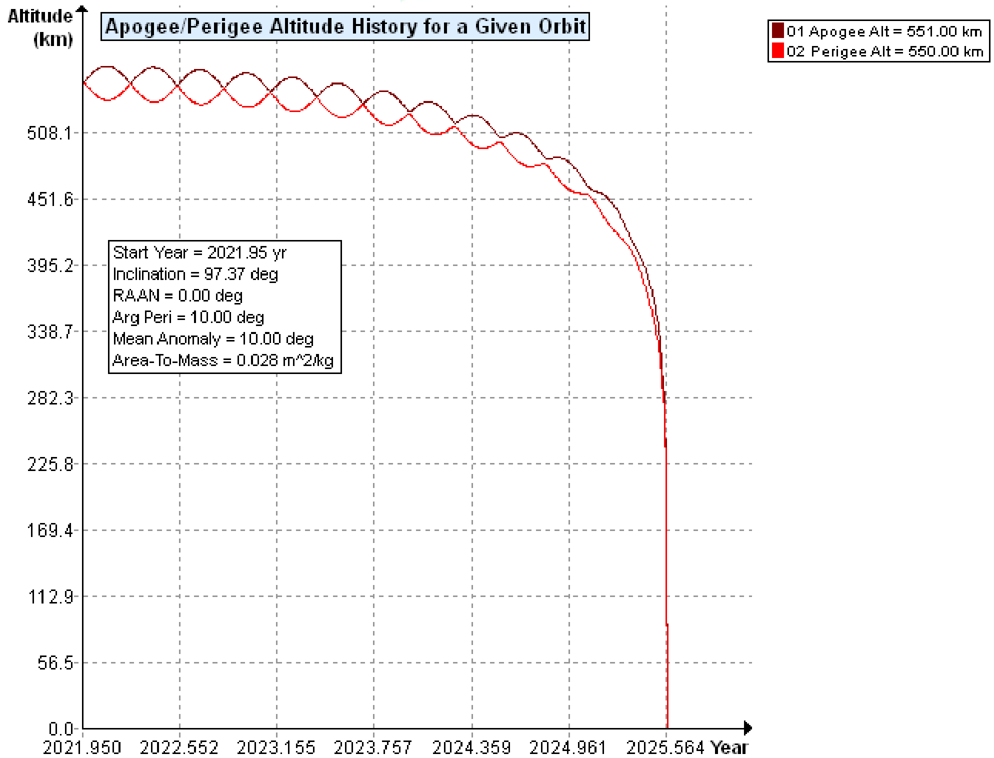
As noted in the ODAR, the two area-to-mass (A-to-M) ratios provided are the A-to-M ratios for the Lynk satellites that are relevant to the demise analysis. One of these A-to-M ratios (0.028 $m^2$/kg) describes the "high drag" orientation of the spacecraft, which is the attitude that Lynk places its satellites into for increasing drag at the end-of-service to deorbit. This orientation requires active control and presents a 2.25 $m^2$ face toward the velocity direction, which gives an 80 kg satellite an A-to-M ratio of 0.028 $m^2$/kg. The other A-to-M ratio (0.017 $m^2$/kg) describes the "uncontrolled" orientation of the spacecraft. This is the resulting spacecraft attitude when active control is lost; an uncontrolled Lynk satellite will tumble randomly. Through numerous simulations, Lynk estimates that a tumbling satellite with Lynk's planned geometry will present an effective windward surface area about 60% of the high-drag case. Consequently, Lynk used an A-to-M value of 0.017 $m^2$/kg = 0.60 * 0.028 $m^2$/kg to model the demise of a tumbling satellite at end-of-service.

The two A-to-M profiles described above are not the only intended configurations in which the spacecraft will be flown during the course of orbital lifetime. While the "high drag" and "uncontrolled" flight profiles are the only ones that are relevant to the demise analysis, the Lynk satellites will operate in a third flight profile when conducting normal mission operations. The flight profile during normal mission operations will have the large faces of the satellite point in the nadir and zenith directions, respectively. A qualitative description of this flight profile could be "flying thin edge on." This flight profile represents 0.225 $m^2$ of surface area in the velocity direction given an A-to-M value of 0.0028 $m^2$/kg. This attitude also requires active control of the satellite.

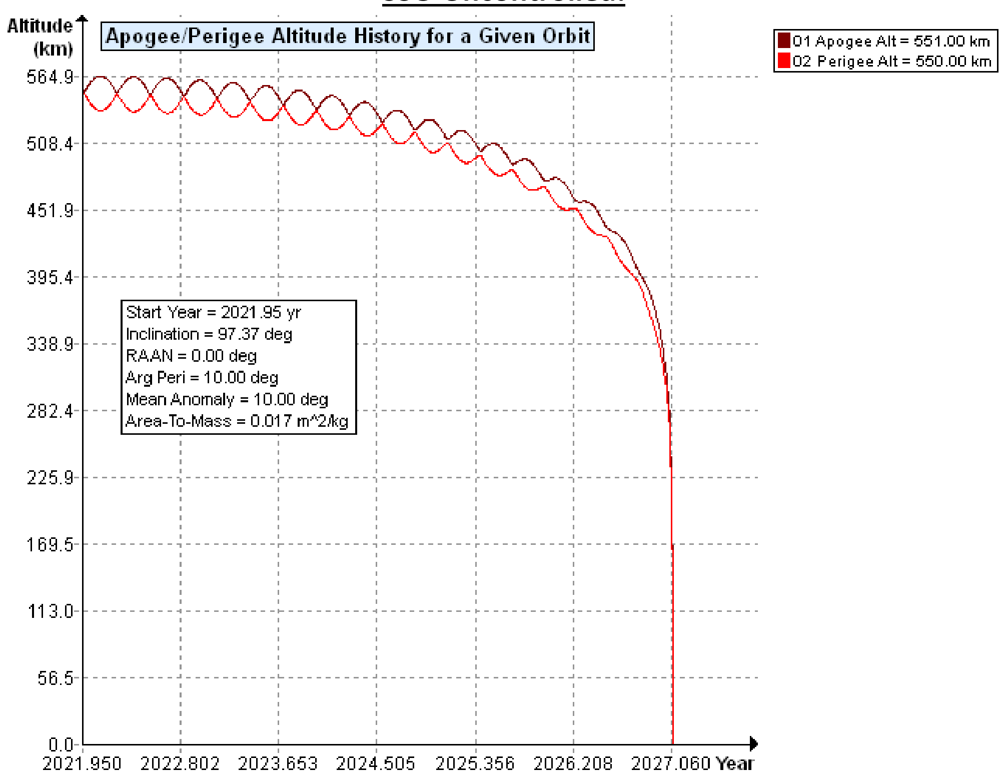
9. **On page 17 of the ODAR, the graphs are labeled as "SSO" while the inclination is listed as 53 degrees. Please explain or correct the discrepancy.**

The referenced graphs produced in the ODAR were produced using the wrong input for orbit inclination. The analysis for the SSO orbits was re-run with the correct orbital inclination. The results do not measurably differ from what was previously provided. Please find the corrected versions below.

## SSO High Drag:




## SSO Uncontrolled:



**10. Page 15 of the ODAR states that for station-kept satellites at end-of-life, remaining fuel can be used to lower the altitude of the satellites over the course of days or weeks. What apogee/perigee will the spacecraft be lowered to in order to achieve this timeframe? Additionally, please indicate the fuel reserve that will be budgeted for this operation, and address whether it is sufficient.**

Lynk's propulsive satellites will launch with up to 5 kg of reaction mass. The amount of delta-V provided by this amount of fuel is 128 m/s for the 85 kg wet mass satellites and 200 m/s for the 55 kg wet mass satellites. When the satellites are at their operating altitude, propulsion will only be used sparingly to correct satellite trajectories as they degrade in altitude. In other words, the satellites will intentionally drift lower in orbit altitude during operations. Lynk anticipates using no more than 2 m/s of delta-V per year, used mostly for collision avoidance and small trajectory corrections.

At the end-of-service when a satellite is scheduled for deorbit, it will use the remaining fuel in its tank to lower the altitude over the course of 1 week. Once its fuel tanks are exhausted, the satellite will then be placed into a high drag orientation in which it will continue to deorbit and then demise within approximately 4 weeks. The planned propulsive deorbit maneuver will lower the satellites to approximately 350 km at the end-of-service. The delta-V for this maneuver is 112 m/s or 84.4 m/s for initial operating altitudes of 550 km and 500 km respectively, although the actual delta-V will be less than this since the altitudes will have already degraded over the service lifetime of the satellites. As such, the budgeted fuel should be sufficient and conservative for a controlled, propulsive deorbit of Lynk's satellite.

Through spacecraft telemetry, Lynk will have up-to-date information on remaining fuel reserves during normal operations. Thus, even if Lynk expends more fuel for collision avoidance and trajectory correction than planned and fuel reserves for deorbit are less than needed to lower to 350 km, Lynk will know this well before end-of-service and will utilize the ADCS to place the satellite in the high drag attitude to ensure that the satellite demises within the 6-year timeframe in Section 25.122(c)(2).

**11. How much time will be required from receipt of a Conjunction Data Message to determine if a maneuver is required?**

Lynk can determine whether a maneuver is required within 8 hours of receiving a conjunction data message. Lynk satellites are registered with the United States Space Force 18th Space Control Squadron (18 SPCS) at Vandenberg Air Force Base. When a conjunction data message is generated by 18 SPCS, an email alert is sent to Lynk's primary registered representative with an identifier for the object, a time for potential impact, distance separating the objects, the probability of a collision, and the contact information for the other responsible party, if applicable. Lynk's representative reviews the information to determine the appropriate course of action. Potential objects are either debris, non-propulsive space stations, or propulsive space stations. After the data is reviewed, Lynk determines the best course of action in coordination with the other party involved in the conjunction, if any. This coordination is done prior to the predicted conjunction time and within the operating constraints of both space stations to ensure sufficient time for any required maneuver. Historically, Lynk receives notice at least 72 hours prior to conjunction and all conjunction alerts are reviewed within 8 hours of receipt.

**12. Are the propulsive Lynk satellites able to effect a 10 km change within 48 hours? If not, please provide the time required to achieve a level of risk reduction of one-and-a-half orders of magnitude below the mitigation action threshold. If Lynk has not adopted a mitigation action threshold, please use a 1E-5 threshold.**

Yes, Lynk's satellites are capable of a 10 km change within 48 hours. Within 8 hours, the Lynk's propulsion system can cause a 12 km in-track relative position change by burning prograde or retrograde, consuming approximately 40 grams of reaction mass.

**13. Can Lynk confirm whether it will comply with Section 9.18 of the Commission's rules?**

Section 9.18 of the Commission's rules requires an MSS operator to provide Emergency Call Center service" when that MSS operator is providing "two way switched voice service that is interconnected with the public switched network and use an in-network switching facility which enables the provider to reuse frequencies and/or accomplish seamless hand-offs of subscriber calls."[11] Lynk's application seeks Commission authority to launch and operate ten small satellites *outside* the United States to provide "intermittent coverage to off-the-shelf mobile devices"[12] that will not be interconnected with the public switched network. Lynk's initial satellite network will enable text message communications only in countries in which Lynk has obtained agreements with MNOs and requisite regulatory authority to provide service. Given the intermittent, non-voice nature of the planned service outside the United States, Lynk does not believe the requirements of Section 9.18 of the Commission's rules apply to its initial operations. However, when Lynk does obtain agreement with a U.S.-based MNO and files an

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[11] 47 C.F.R. § 9.18.

[12] *See* Legal Narrative at 4.

application to provide service to the United States, Lynk will ensure that the two-way switched voice service that it does offer complies with Section 9.18 of the Commission's rules and will demonstrate that compliance in such future application materials.

For the reasons set forth in Lynk's application and in the accompanying materials herein, Lynk respectfully requests the Commission expeditiously grant Lynk the authority to launch and operate the Lynk Smallsat System.

Respectfully submitted,

**LYNK GLOBAL, INC.**

/s/ Shawn Marcum

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## APPENDIX A: Updated DAS 3.1.0 Log - Requirement 4.6

08 25 2021; 18:55:44PM Activity Log Started
08 25 2021; 18:55:44PM Opened Project C:\Users\lab\Desktop\DAS Projects\LynkCommercialV4\
08 25 2021; 18:56:26PM Processing Requirement 4.6 Return Status: Passed

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Project Data
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**INPUT**

Space Structure Name = LynkComm-sso-wide
Space Structure Type = Payload

Perigee Altitude = 550.000000 (km)
Apogee Altitude = 551.000000 (km)
Inclination = 97.370000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.028000 (m^2/kg)
Start Year = 2021.500000 (yr)
Initial Mass = 80.000000 (kg)
Final Mass = 80.000000 (kg)
Duration = 2.400000 (yr)
Station Kept = True
Abandoned = True
PMD Perigee Altitude = 550.000000 (km)
PMD Apogee Altitude = 551.000000 (km)
PMD Inclination = 97.370000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

Suggested Perigee Altitude = 550.000000 (km)
Suggested Apogee Altitude = 551.000000 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2026 (yr)
Requirement = 61

Compliance Status = Pass

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**INPUT**

Space Structure Name = LynkComm-sso-tumble
Space Structure Type = Payload

Perigee Altitude = 550.000000 (km)
Apogee Altitude = 551.000000 (km)
Inclination = 97.370000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.016681 (m^2/kg)
Start Year = 2021.500000 (yr)
Initial Mass = 80.000000 (kg)
Final Mass = 80.000000 (kg)
Duration = 2.400000 (yr)
Station Kept = True
Abandoned = True
PMD Perigee Altitude = 550.000000 (km)
PMD Apogee Altitude = 551.000000 (km)
PMD Inclination = 97.370000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

Suggested Perigee Altitude = 550.000000 (km)
Suggested Apogee Altitude = 551.000000 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2028 (yr)
Requirement = 61
Compliance Status = Pass

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**INPUT**

Space Structure Name = LynkComm-midinc-wide

Space Structure Type = Payload

Perigee Altitude = 500.000000 (km)
Apogee Altitude = 501.000000 (km)
Inclination = 53.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.028000 (m^2/kg)
Start Year = 2021.500000 (yr)
Initial Mass = 80.000000 (kg)
Final Mass = 80.000000 (kg)
Duration = 3.810000 (yr)
Station Kept = True
Abandoned = True
PMD Perigee Altitude = 500.000000 (km)
PMD Apogee Altitude = 501.000000 (km)
PMD Inclination = 53.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

Suggested Perigee Altitude = 500.000000 (km)
Suggested Apogee Altitude = 501.000000 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2026 (yr)
Requirement = 61
Compliance Status = Pass

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**INPUT**

Space Structure Name = LynkComm-midinc-tumble
Space Structure Type = Payload

Perigee Altitude = 500.000000 (km)
Apogee Altitude = 501.000000 (km)
Inclination = 53.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.016681 (m^2/kg)
Start Year = 2021.500000 (yr)
Initial Mass = 80.000000 (kg)
Final Mass = 80.000000 (kg)
Duration = 3.810000 (yr)
Station Kept = True
Abandoned = True
PMD Perigee Altitude = 500.000000 (km)
PMD Apogee Altitude = 501.000000 (km)
PMD Inclination = 53.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

Suggested Perigee Altitude = 500.000000 (km)
Suggested Apogee Altitude = 501.000000 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2027 (yr)
Requirement = 61
Compliance Status = Pass

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=============== End of Requirement 4.6 ===============

**APPENDIX B: EPFD Analysis**

This document provides a detailed explanation of the EPFD levels produced by the Lynk Smallsat System in the Ka-band, and how they comply with the single-entry EPFD validation limits in No. 22.5C, 22.5D and 22.5F of the ITU Radio Regulations. While these EPFD limits apply to NGSO FSS systems, they have been applied here for the proposed MSS frequency assignments for the 10-satellite constellation to demonstrate how the Lynk Satellite System will protect GSO FSS networks. The main thrust of this Appendix is to provide the Commission with a detailed explanation of the derivation of PFD/EIRP masks for the 10-satellite configuration, a combination of inclined-orbit and quasi-polar sun synchronous orbit (SSO) satellites, operating in the 29.9-30.0 GHz and 20.1-20.2 GHz bands, which are identical to the masks supplied for the larger Lynk the World NGSO satellite system.[13]

## $EPFD_{down}$ Analysis

In order to demonstrate compliance with the single-entry validation equivalent power flux-density limits in Ka-band, in the space-to-Earth direction ($EPFD_{down}$), Lynk provides the Commission, with this submission, the computer files that contain the set of Ka-band power flux-density (PFD) masks, on the surface of the Earth, for each space station in the Lynk Smallsat System. These masks have been generated in accordance with the specification stipulated in

[13] Lynk recently provided the Commission with AP4 data in the form of an ITU SRS database, complete with a Mask database which contains the PFD/EIRP masks for the 5110-satellite filing (LynktheWorld). That filing covers a broader frequency range, namely 27.5-28.6 GHz, 29.5-30.0 GHz, 17.8-18.6 GHz and 19.7-20.2 GHz for feeder links.

the ITU-R Recommendation S.1503-2 issued in December 2013.[14] The PFD masks are one of the data inputs to the EPFD validation software program required to calculate the $EPFD_{down}$ levels in Ka-band.

The PFD masks define the maximum satellite downlink PFD in Ka-band over the surface of the Earth that is visible to the satellite and may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the sub-satellite latitude. The PFD masks can be expressed in one of two ways. The first is as a function of the azimuth ("Az") and elevation ("El") angles as viewed from the satellite towards the Earth. Azimuth is in the east-west direction and elevation is in the north-south direction, relative to the sub-satellite point. The second is as a function of two different variables: the $\alpha$ angle, which is defined in the recommendation as the separation angle, measured at the surface of the Earth—i.e., at a potential victim GSO earth station, between the line to the NGSO satellite and the nearest point on the GSO orbit, and the $\Delta L$ angle which is the difference in longitude between the NGSO sub-satellite point and the point on the GSO arc where the $\alpha$ angle is minimized.

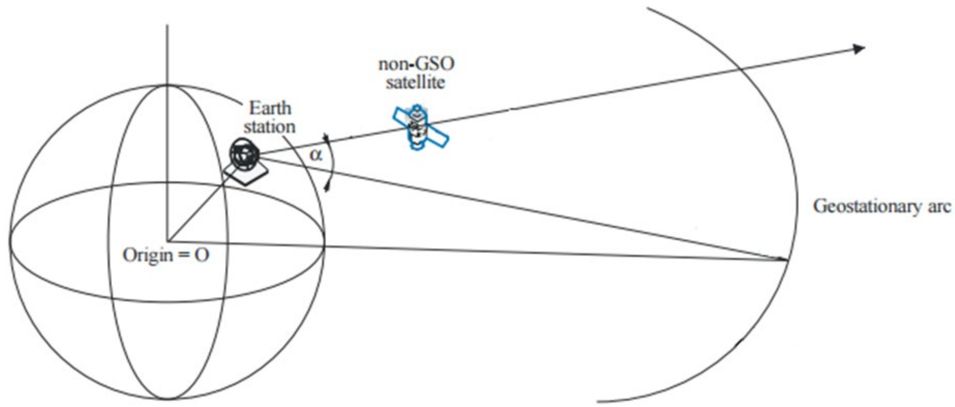
The Lynk Smallsat System satellite Ka-band antennas are relatively narrow beamwidth,[15] steerable antennas that point towards the gateway earth stations, and there is only one such transmit antenna on each Lynk Smallsat System satellite. For the definition of its satellite Ka-

[14] While the ITU-R has recently adopted version 3 of this Recommendation, the software is not yet available for validation using this revision.

[15] The Technical Narrative and Schedule S indicate two spacecraft antenna specifications: a 1.5m by 1.5m antenna with 23.2 dBi gain (LK15 and RK15) and a 1m by 1m antenna with 19.1 dBi gain (LK10 and RK10). The larger antenna was used for this analysis to represent the maximum PFD possible in the derivation of the PFD masks.

band PFD masks that are provided with this submission, Lynk uses the option described above where the PFD masks are defined as a function of the $\alpha$ angle. The definition of the $\alpha$ angle is shown in Figure 1 below.

**Figure 1: Definition of the $\alpha$ angle**



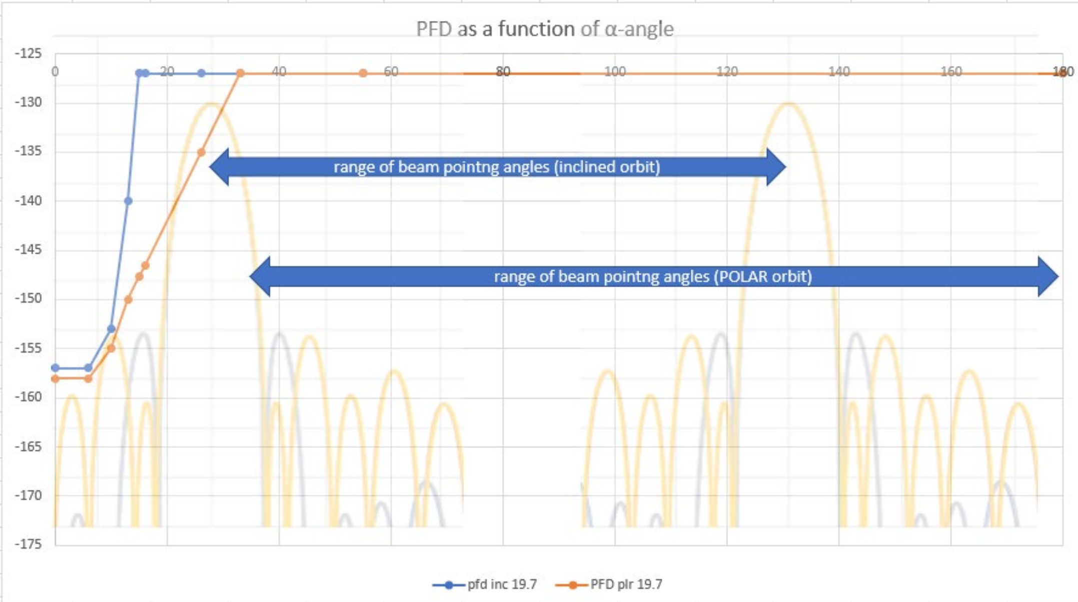

The PFD masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the Lynk Smallsat NGSO system:

(a) The starting point is the generation of an off-axis EIRP density mask (i.e., EIRP density per 40 kHz versus off-axis angle) based on the actual performance of the Lynk Smallsat System Ka-band satellite transmit beam at the maximum operational transmit EIRP level. The maximum EIRP density is calculated using the peak transmit power spectral density of -71 dBW/Hz combined with a maximum transmit antenna gain of 23.2 dBi, which yields -1.8 dBW/40 kHz EIRP using the bandwidth scaling factor. The maximum PFD is thus -127 dBW/m$^2$ per 40 kHz, for areas on Earth's surface outside the GSO arc avoidance.[16]

[16] The maximum PFD in Schedule S is -115.7 dBW/m$^2$ per MHz. So scaling to 40-kHz yields -129.7 dBW/m$^2$, which is about 3 dB lower than assumed in the PFD masks, to account for both polarizations.

(b) In the Ka-band, the Lynk Smallsat System will maintain a GSO arc avoidance angle ($\alpha$) of 4°. For the Ka-band downlink this means the angle, as viewed from any GSO earth station, between its boresight pointed to the GSO arc and the location of any Lynk Smallsat System satellite that is transmitting towards that GSO earth station, will never be less than 4°. When the NGSO satellite is directly in-line between the GSO earth station and the GSO arc, or within 4° of this line, the NGSO satellite can only transmit minimum sidelobe energy towards that location and Lynk computed a value of -157 dBW/m$^2$ per 40 kHz PFD level, so it requires 30 dB antenna discrimination. In between the GSO avoidance angle and the peak PFD level, the PFD mask rolls off gently as shown in Figure 2. The blue curve represents the PFD mask for the satellites in inclined orbit, whereas the orange line represents the polar orbit satellites, which require a roll-off at larger alpha angles. The figure also provides the antenna patten overlaid on the masks, showing the shape of the antenna off-axis gain characteristic. The Lynk Smallsat System satellite PFD mask is typically independent of the $\Delta$L variable provided in the ITU-R Recommendation S.1503-2, except within the GSO exclusion zone (arc avoidance area), where for $\Delta$L values between 10° and 35°, a further reduction of 8 dB (PFD equal to of -165 dBW/m$^2$ per 40 kHz) was assumed.

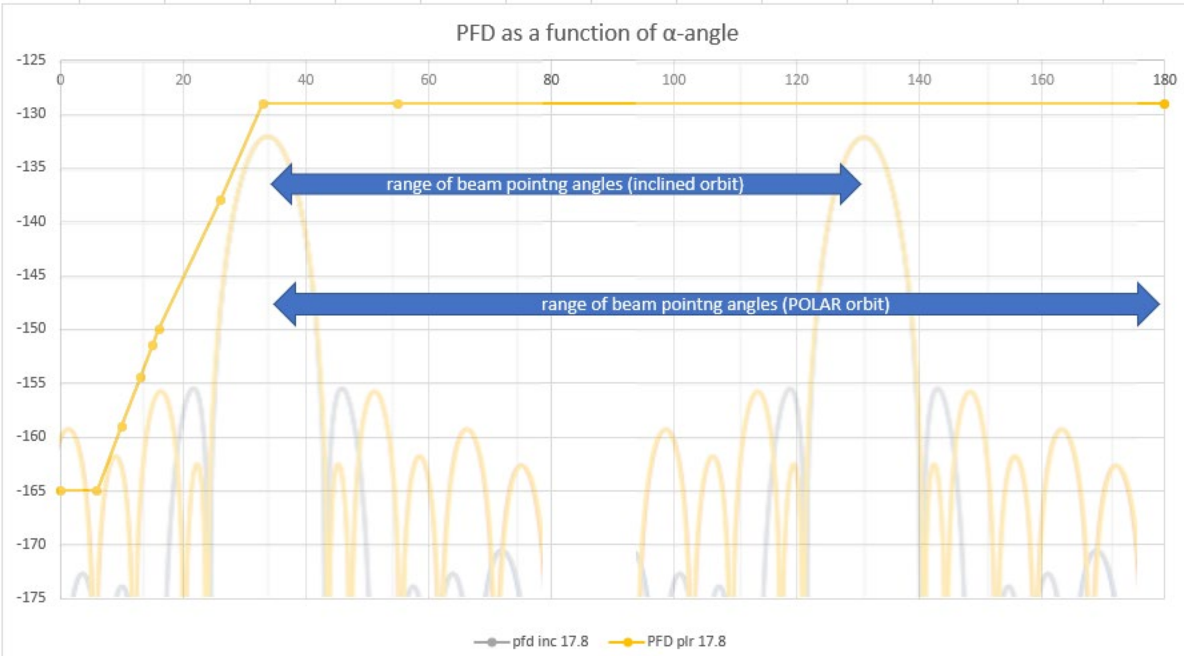
**Figure 2: PFD mask for 19.7-20.2 GHz Ka-band downlink (10-satellite configuration)**




(c) For a configuration, whereby Lynk would deploy all or some of these satellites in a polar orbit, there is a need for a further reduction of the PFD masks at high latitudes, which indicates that such satellites would not communicate with earth stations located above 70 degrees North or South.

(d) While this application only covers the frequency range 20.1-20.2 GHz, the ITU filing (AP4 for CR/C coordination request) included PFD masks for a much larger system, called Lynk the World. The lower band subject to Table 22-1b of the ITU Radio Regulations requires a different PFD mask, as shown in Figure 3. The main difference is the use of lower far sidelobes which would require some tapering of the antenna and operation at a lower maximum PFD level. In the figure below, the maximum PFD was assumed to be -132 dBW/m$^2$ per 40 kHz per polarization. The PFD mask is the same for both orbits: inclined and polar.

**Figure 3: PFD mask for 17.8- 18.6 GHz Ka-band downlink (10-satellite configuration)**




Lynk is also providing to the Commission, with this application, the necessary input data files needed to run the ITU EPFD validation program to validate the $EPFD_{down}$ levels. This replicates part of the ITU's SRS database file and contains the orbital parameters and other data concerning the Lynk Smallsat System constellation necessary to run the EPFD validation software. The data contained in the SRS file[17] is as follows:

(a) The orbital parameters of the Lynk Smallsat System constellation, consistent with the associated Schedule S submission, Lynk's Technical Narrative, and the larger ITU filing;[18]

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[17] There are two SRS data files: one for a 10-satellite inclined orbit constellation and the other for a 10-satellite polar constellation, which are identical except for the inclination angle, and the associated masks.

[18] Lynk recently submitted to the Commission a much larger constellation consisting of 5110 satellites for its ITU filing (LynktheWorld).

(b) The parameter entitled "nbr_op_sat" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.6.a). This is defined as "the maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location in various latitude ranges." The value of this parameter is set to two (the maximum number of satellites visible anywhere) to ensure a worst-case analysis.

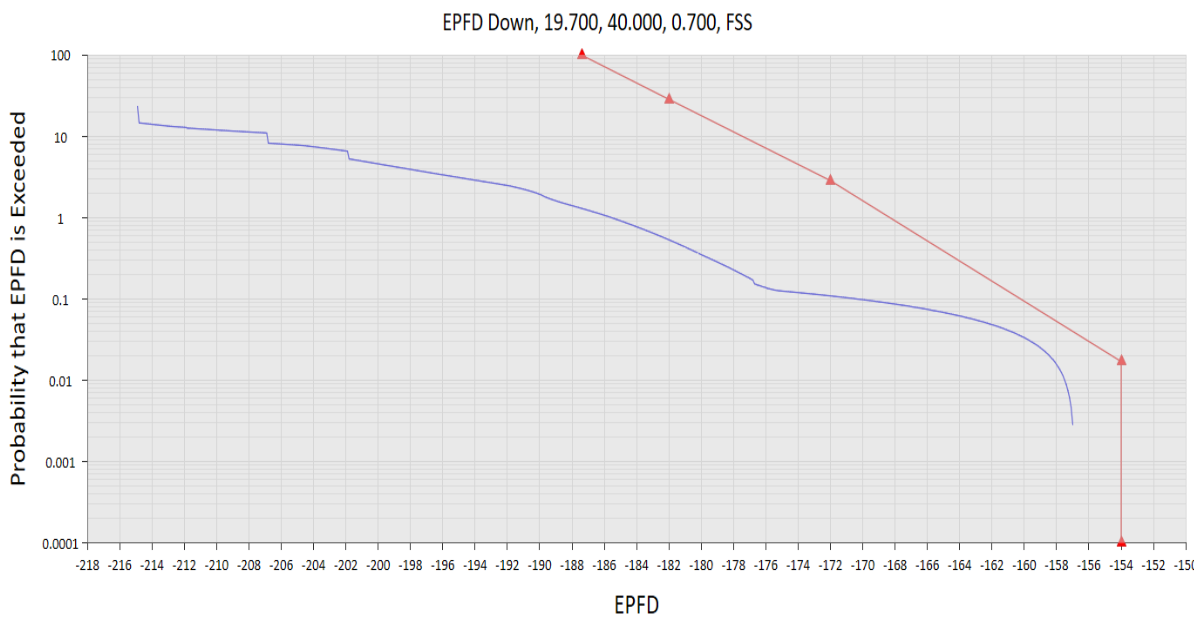
(c) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite." The minimum elevation angle of 5° used for the gateway links is used for this parameter.

The Ka-band $EPFD_{down}$ results from the ITU EPFD validation computer program using the input data explained above are shown below. Each plot shows one of the GSO reference earth station cases from the EPFD limits. The labeling of each diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the size of the GSO reference earth station antenna (in meters), and the fact that this is a FSS EPFD limit.[19] The EPFD results are for the worst-case geometry defined by the latitude of the GSO reference receiving earth station location and the $\Delta_{long}$ (difference in longitude between the GSO reference receiving earth station location and its corresponding GSO satellite) determined by the software. This worst-case geometry has been

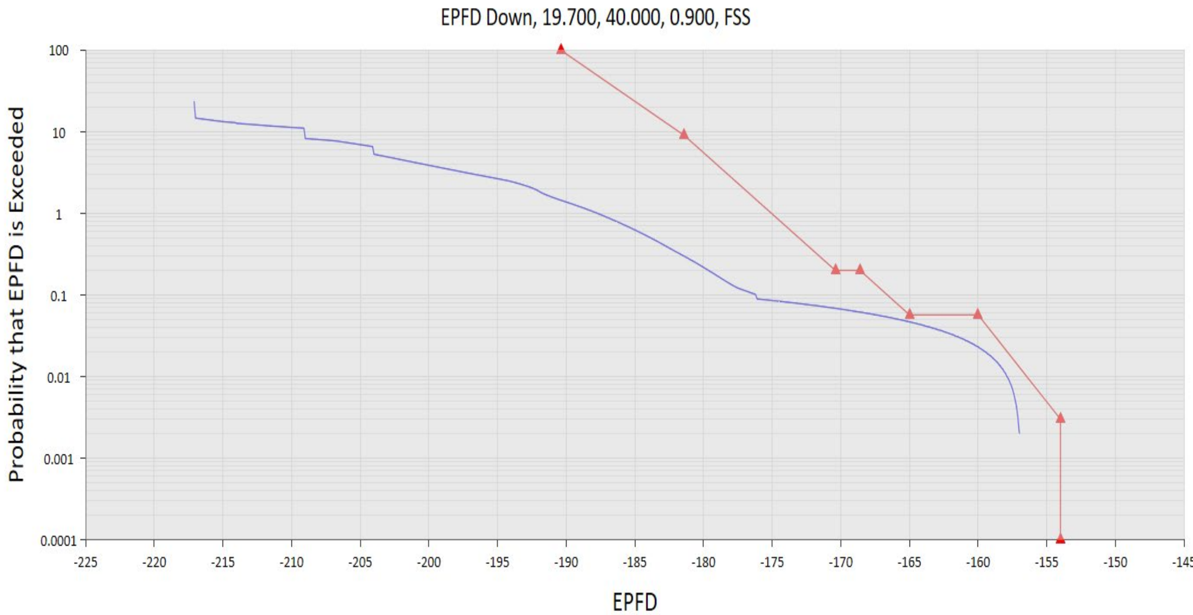
[19] The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular GSO allocation. For example, the frequency is 17.8 GHz for the frequency range 17.8-18.6 GHz as per Table 22-1B of the ITU RR, and 19.7 GHz for the frequency range 19.7-20.2 GHz subject to Table 22-1C.

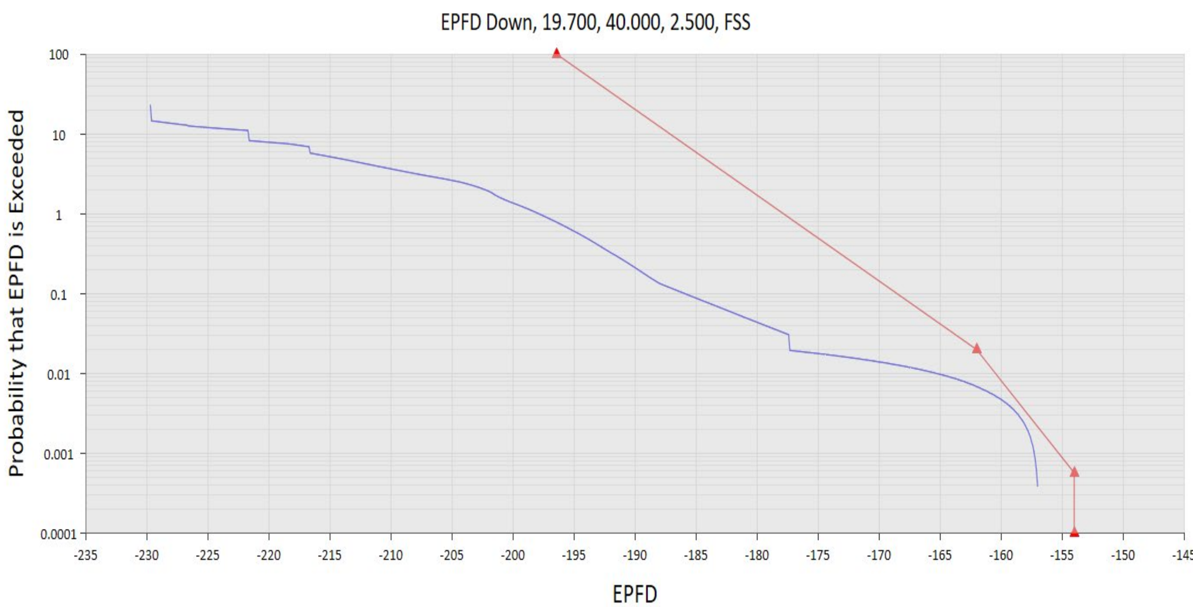
determined by the EPFD validation software to be the worst case (i.e., highest EPFD levels) according to the Recommendation ITU-R S.1503-2. On each diagram, the resulting EPFD level is shown by the blue curve and the EPFD mask that applies is shown by the red lines.

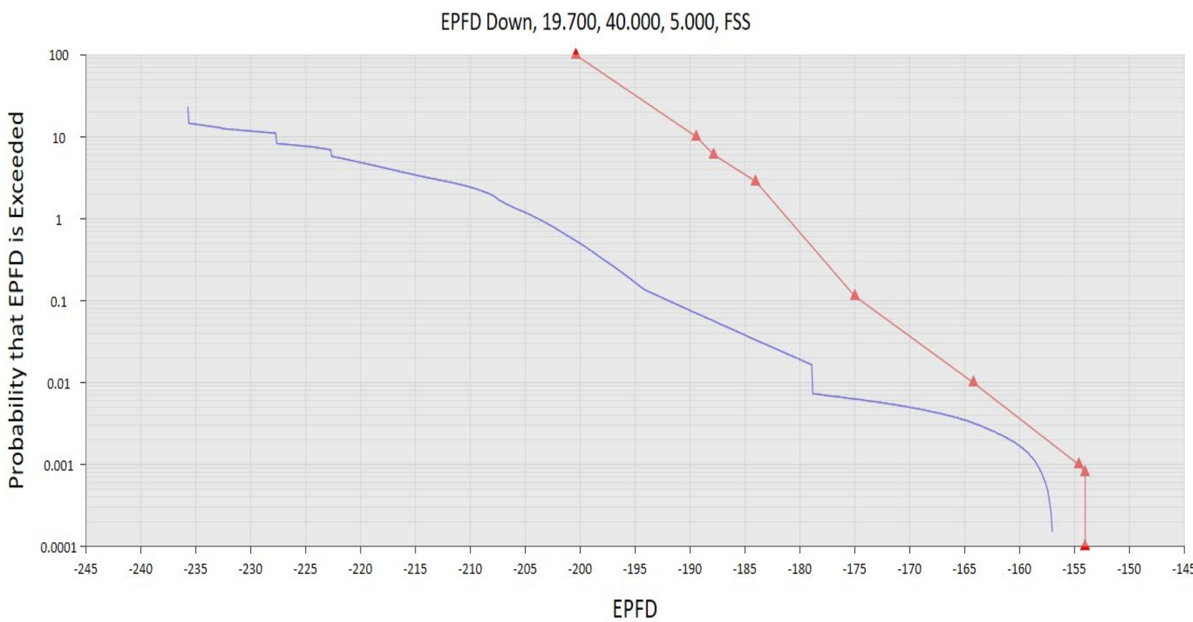
The first set of results is for the limits in Table 22-1B of the ITU Radio Regulations, applicable to the band 19.7-20.2 GHz, which encompasses the frequency range proposed in this application in the case of 10 inclined satellites.[20] For all four reference GSO receive earth station antenna sizes, the EPFD limits are met.



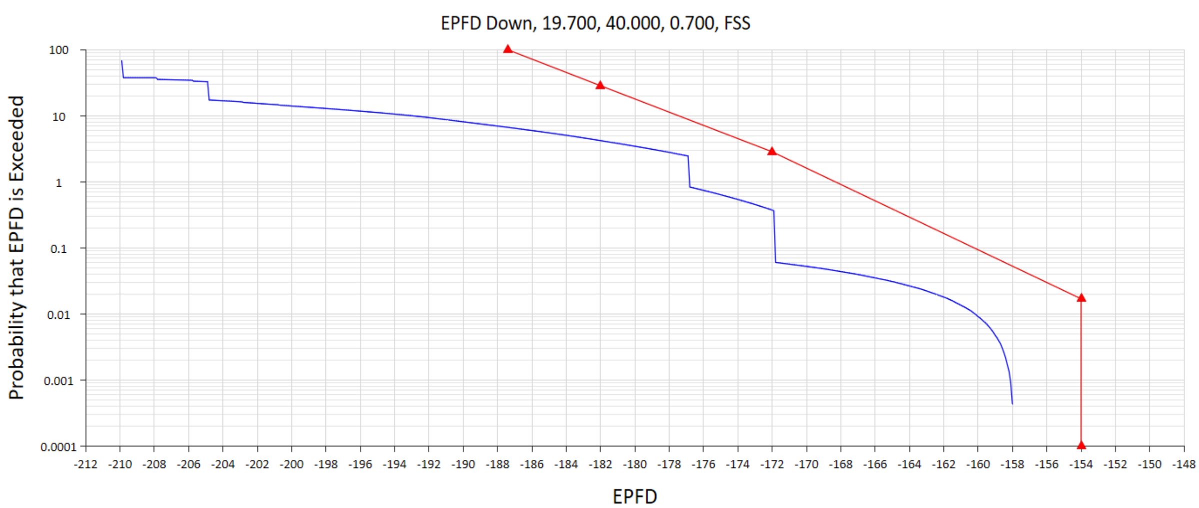

[20] The Lynk Smallsat application has a mix of inclined and polar satellites, so the EPFD analysis was conducted for 10 inclined satellites, then 10 polar satellites, which is representative of any combination of inclined and polar satellites.

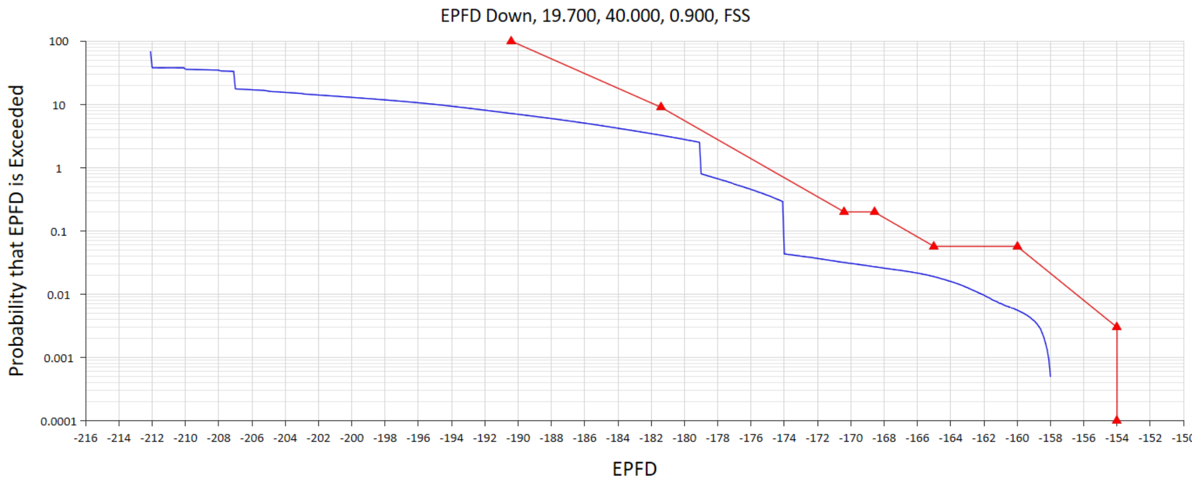

EPFD Down, 19.700, 40.000, 0.900, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-225
-220
-215
-210
-205
-200
-195
-190
-185
-180
-175
-170
-165
-160
-155
-150
-145
EPFD

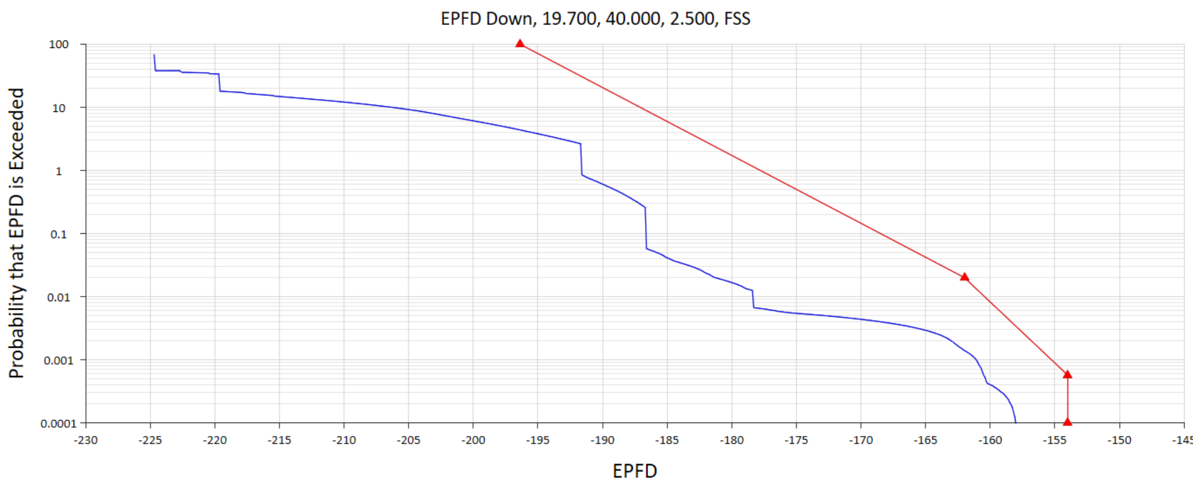

EPFD Down, 19.700, 40.000, 2.500, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-235
-230
-225
-220
-215
-210
-205
-200
-195
-190
-185
-180
-175
-170
-165
-160
-155
-150
-145
EPFD

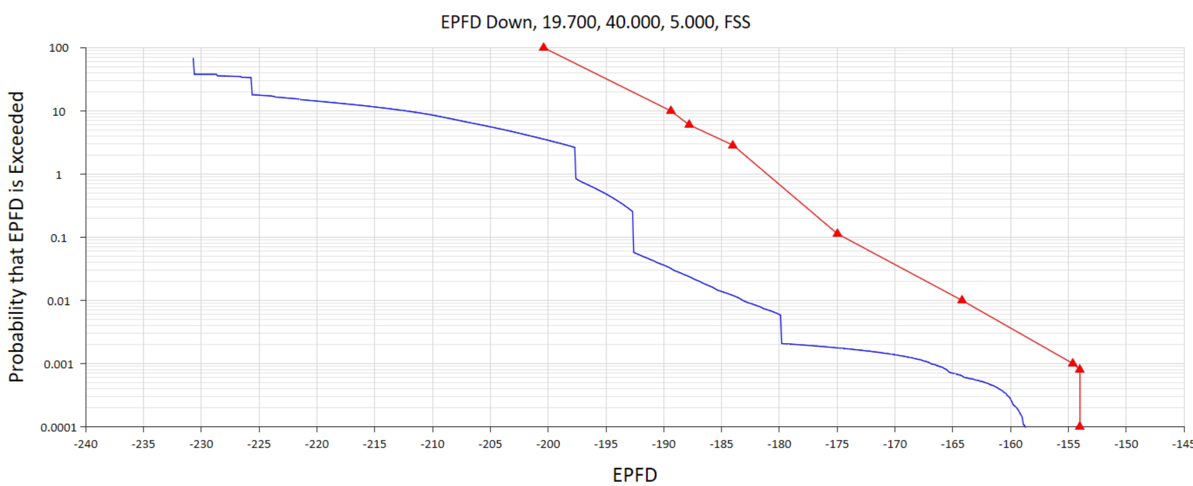



The next set of results are for a 10 polar satellite configuration, for the same 19.7-20.2 GHz frequency range.

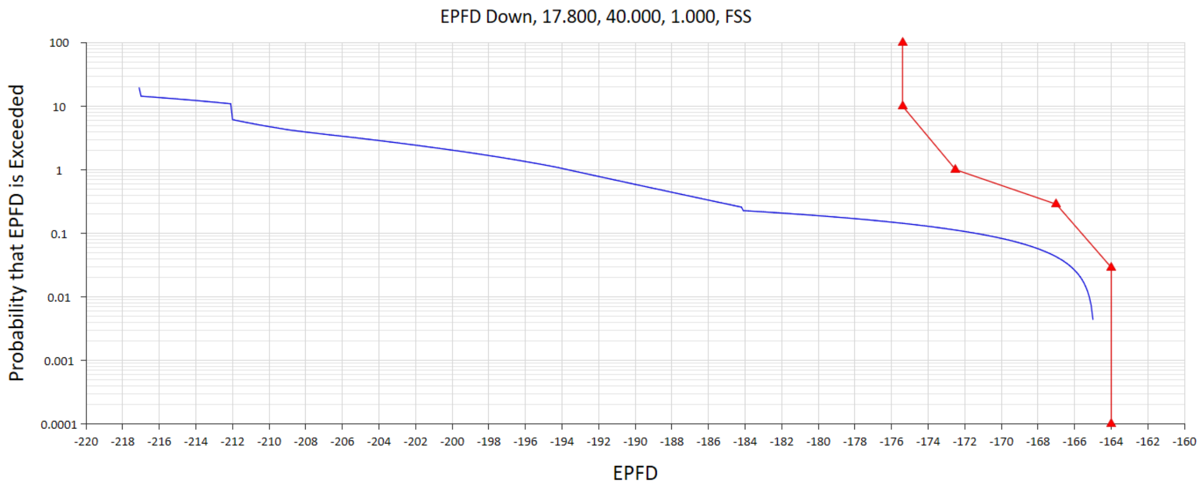


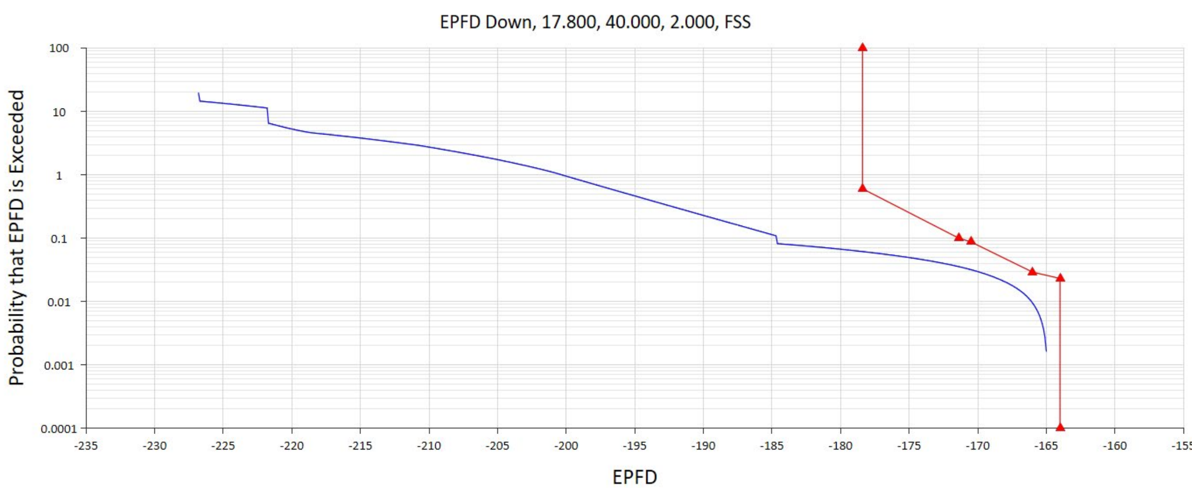


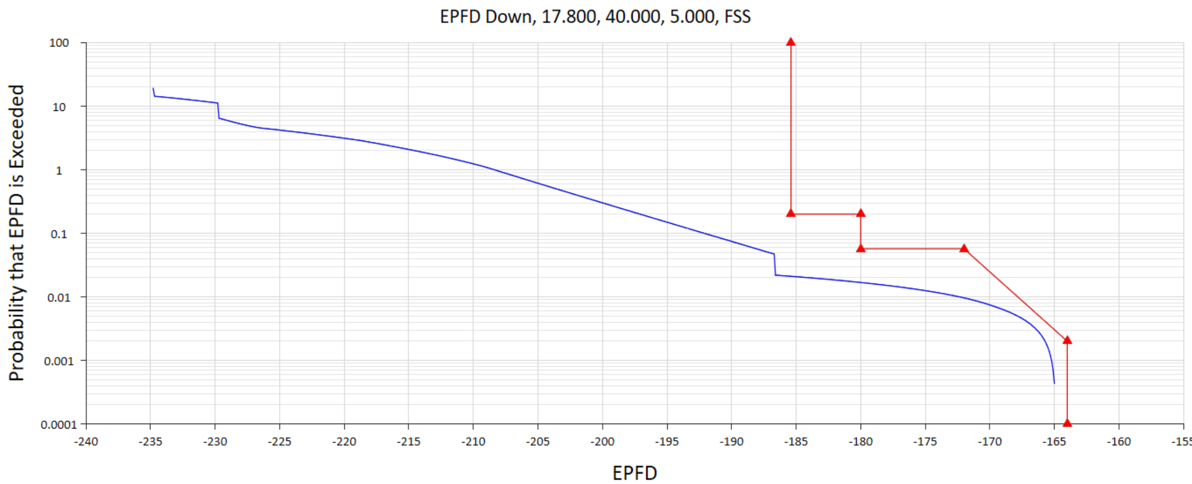



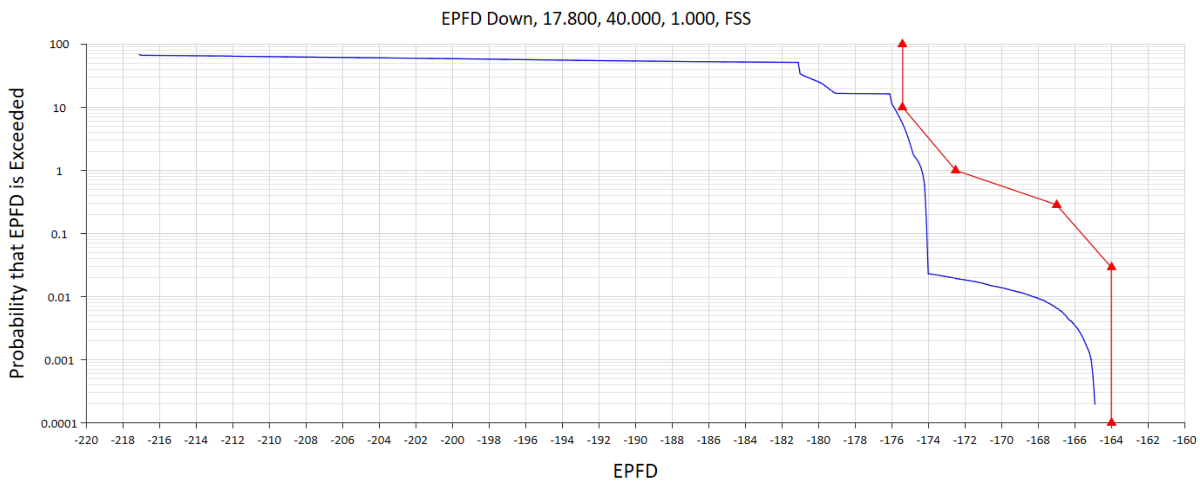



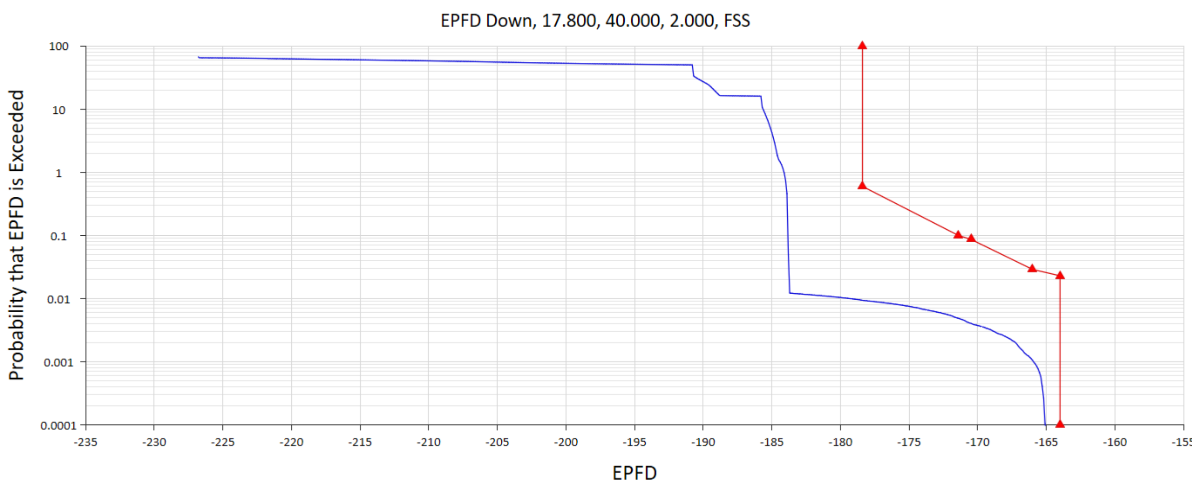

While this application does not include frequencies below 18.6 GHz, the ITU filings do include frequencies below 18.6 GHz. Lynk has therefore also assessed the Table 22-1B limits, as shown below for 10-inclined satellite configuration (first 3 plots) and next the 10-polar (SSO) satellites (second 3 plots).

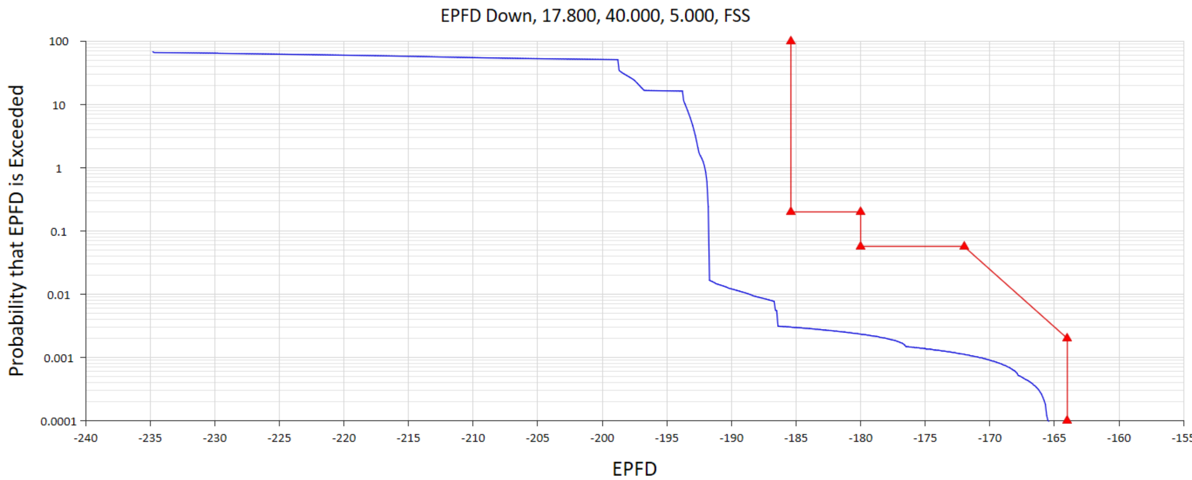



EPFD Down, 17.800, 40.000, 5.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-240
-235
-230
-225
-220
-215
-210
-205
-200
-195
-190
-185
-180
-175
-170
-165
-160
-155
EPFD


EPFD Down, 17.800, 40.000, 1.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-220
-218
-216
-214
-212
-210
-208
-206
-204
-202
-200
-198
-196
-194
-192
-190
-188
-186
-184
-182
-180
-178
-176
-174
-172
-170
-168
-166
-164
-162
-160
EPFD


EPFD Down, 17.800, 40.000, 2.000, FSS
Probability that EPFD is Exceeded
100
10
1
0.1
0.01
0.001
0.0001
-235
-230
-225
-220
-215
-210
-205
-200
-195
-190
-185
-180
-175
-170
-165
-160
-155
EPFD




The above results show that the two possible satellite configurations; inclined and polar SSO orbits, both meet the EPFD limits in the two portions of the Ka-band. These results above demonstrate that the Lynk Smallsat System complies with the ITU's $EPFD_{dn}$ limits and therefore will not cause unacceptable interference to GSO satellite networks in the space-to-Earth direction.

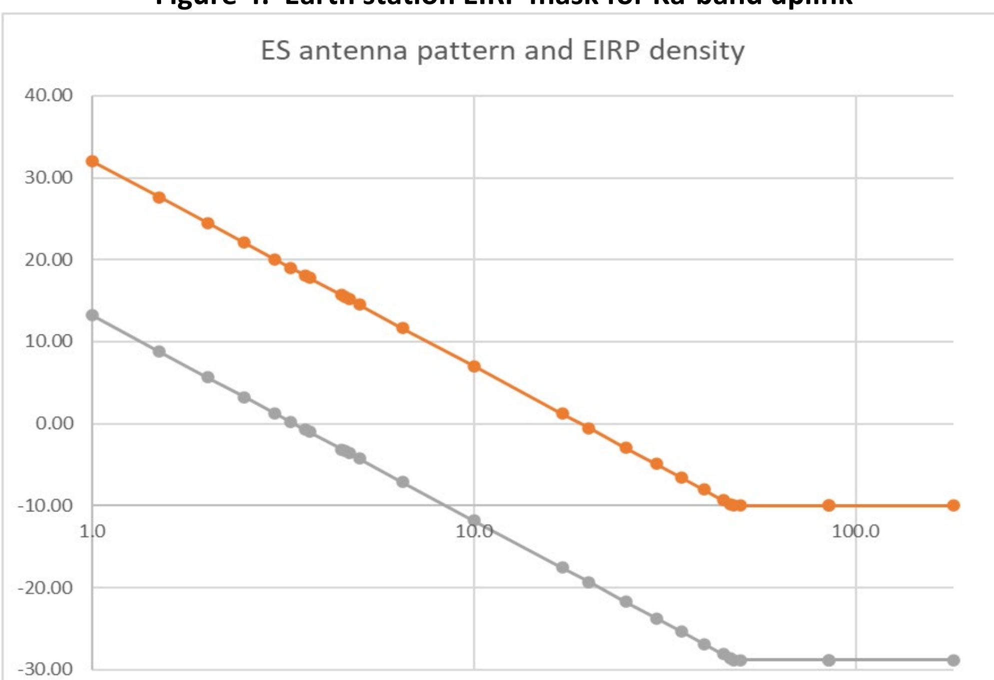
## $EPFD_{up}$ Analysis

To demonstrate compliance with the single-entry validation equivalent power flux-density ($EPFD_{up}$) limits, in the Earth-to-space direction, Lynk Global is providing the Commission, with this application, the computer files that contain the set of Ka-band earth station maximum off-axis EIRP masks, for the earth stations in the Lynk Smallsat System. These masks have been generated in accordance with the specification stipulated in Recommendation ITU-R S.1503-2 issued in December 2013. The EIRP masks are one of the inputs to the EPFD validation software program required to calculate the $EPFD_{up}$ levels in Ka-band.

The EIRP masks define the off-axis EIRP density of the Ka-band transmitting earth stations as a function of off-axis angle. They assume the off-axis gain is rotationally symmetric around the boresight of the antenna. They may, according to ITU-R Recommendation S.1503-2, be constant or variable as a function of the sub-satellite latitude. There are several antenna sizes filed for this NGSO system, however, all are sufficiently large as to have a similar antenna pattern, according to Recommendation ITU-R S.465 (32 – 25 log (angle) pattern), beyond their main beams. Since the GSO arc avoidance angle is 4° which exceeds the main beam to sidelobe transition even for the smallest gateway antenna, the use of a single EIRP mask is justified.

These masks have been generated using the following methodology and assumptions related to the actual design and real-world operation of the Lynk Smallsat System. A single EIRP mask is provided that represents the highest on-axis and off-axis EIRP density levels (per 40 kHz) for the Ka-band transmitting gateway earth stations, shown in Figure 4.

**Figure 4: Earth station EIRP mask for Ka-band uplink**




**Orange is gain (dBi) and Grey is EIRP density (dBW per 40 kHz)**

Lynk is also providing to the Commission, with this application, the other necessary input data file needed to run the ITU EPFD validation program to validate the $EPFD_{up}$ levels.

This replicates part of the ITU SRS database file and contains the orbital parameters and other data concerning the Lynk Smallsat System NGSO constellation necessary to run the EPFD validation software. The data contained in this file is as follows:

(a) The orbital parameters of the Lynk Smallsat System constellation, consistent with the associated Schedule S submission and Lynk's Technical Narrative;

(b) The parameter entitled "nbr_sat_td" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.a). This is defined as "the maximum number of non-geostationary satellites receiving simultaneously with overlapping frequencies from the associated earth stations within a given cell." The value of this parameter is set to 2 (the maximum number of satellites visible anywhere) to ensure a worst-case analysis.

(c) The parameter entitled "density" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.b). This is defined as "the average number of associated earth stations with overlapping frequencies per square kilometer within a cell." The value of this parameter is the inverse of the square of the average distance between sites, and this gives a value of 0.000004.

(d) The parameter entitled "avg_dist" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.4.b.7.c). This is defined as "the average distance, in kilometers, between co-frequency cells." The value of this parameter is determined by the average geographic density of the gateways, which has been set as a minimum of 500 km.

(e) The parameter entitled "elev_min" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations this is referred to as A.14.b.4). This is defined as "the minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite. For the gateway earth stations this parameter is set to 5°.

(f) The parameter entitled "x_zone" in ITU-R Recommendation S.1503-2 (in Appendix 4 of the ITU Radio Regulations, this is referred to as A.4.b.7.d.2). This is the minimum GSO avoidance angle measured at the surface of the Earth. For the Lynk Smallsat System Ka-band gateway earth stations, this parameter is set to 4°.

The Ka-band $EPFD_{up}$ results from the EPFD validation computer program using the input data explained above are shown below. The labeling of the diagram indicates the frequency (in GHz), the reference bandwidth (40 kHz), the beamwidth of the reference GSO satellite receiving antenna beam (1.55 degrees) and the fact that this is an FSS EPFD limit.[21] Also the worst-case geometry defined by the latitude of the pointing direction of the reference GSO satellite receiving beam and the $\Delta_{long}$ (difference in longitude between this pointing direction and the corresponding GSO satellite) was assumed. 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. The resulting EPFD level is shown by the blue curve and the EPFD mask is shown by the red line.

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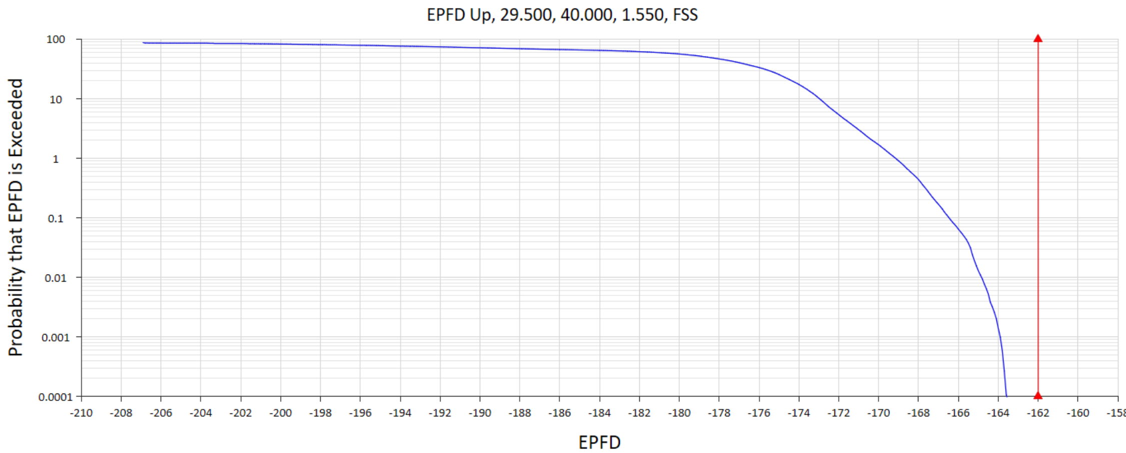
[21] The frequency used for the analysis is determined by the EPFD validation software and is the lower end of the range of frequencies for the particular analysis which was conducted for the FSS frequency ranges of 29.5-30 GHz, but which would also be equally applicable to the range 27.5-28.6 GHz.



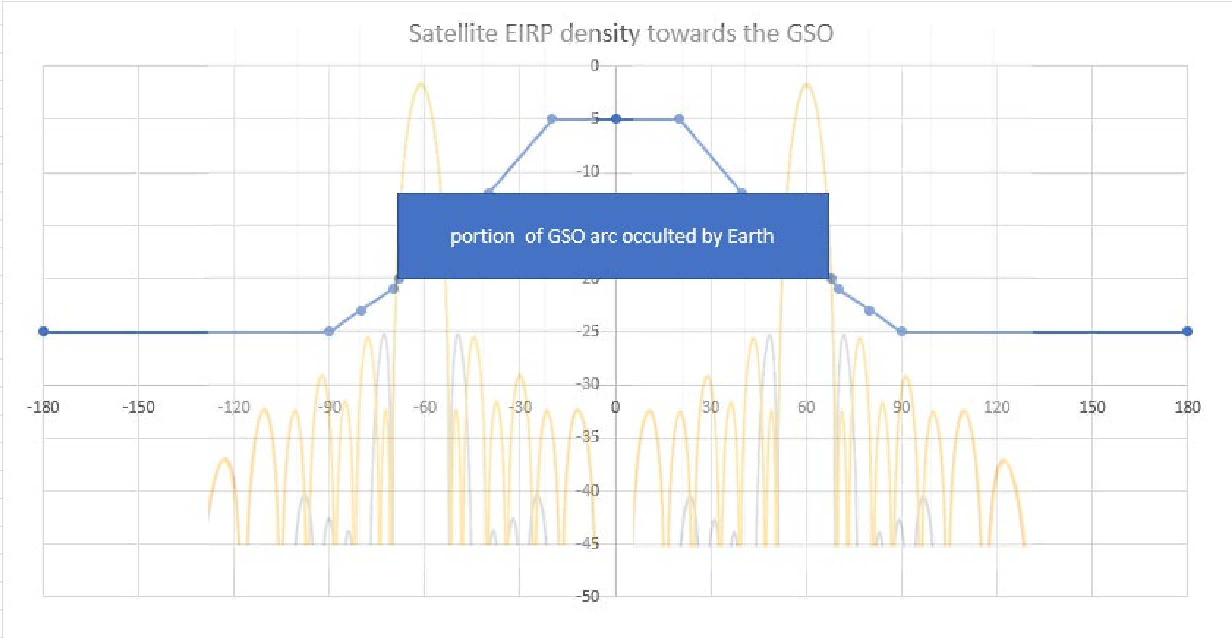

The above results apply equally to the two possible satellite configurations: inclined and polar SSO orbits. These results above demonstrate that the Lynk Smallsat System complies with the ITU's $EPFD_{up}$ limits and therefore will not cause unacceptable interference to GSO satellite networks in the Earth-to-space direction.

## $EPFD_{is}$ Analysis

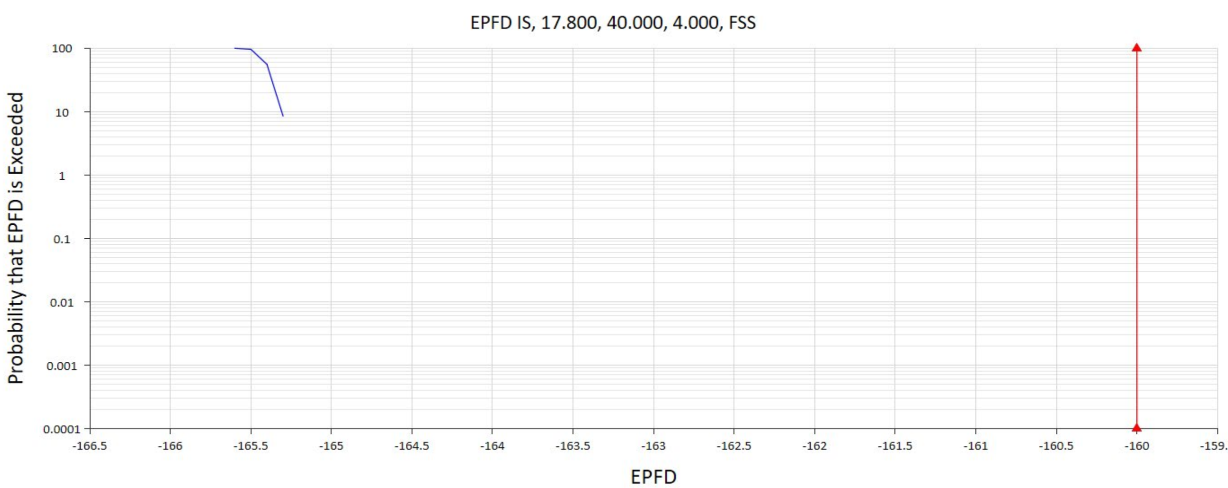
The $EPFD_{is}$ limits in the ITU Radio Regulations are intended to protect frequency ranges that are allocated bi-directionally (i.e., simultaneously for both uplinks and downlinks). They essentially protect receiving GSO satellites from interference from the unintended emissions of an NGSO transmitting satellite. In Ka-band, the bidirectional allocations exist in the 17.8-18.4 GHz band in all ITU Regions, which is beyond the frequency range of this application.

Nevertheless, for completeness and considering that the ITU filing includes an expanded frequency range, the $EPFD_{is}$ was computed. For Ka-band, the peak Lynk Smallsat System satellite transmit EIRP density is -1.8 dBW/40kHz, as provided above for the $EPFD_{down}$ analysis. At a 500 km orbit, the cone of visibility, with apex at the satellite and the circular base representing the edge of the Earth as viewed from the satellite position is 68 degrees wide relative to the sub-satellite point. At 10 degrees elevation, which would correspond to the lowest beam center, the angle as seen from a satellite at 500 km orbit would be about 61.2° off nadir. So, if a satellite beam is placed at that exact location, the Earth's limb would be at an off-axis angle of 6.8 degrees. In this direction, just above the Earth's surface, the antenna discrimination would be at last 23 dB, as per Figure 5, but to remain conservative Lynk assumes 20 dB reduction to account for both polarizations. The EIRP for the combined polarizations just above the Earth's surface is thus -21.8 dBW/40 kHz at an angle, relative to nadir, of 68 degrees. Lynk further assumes that the gain, and EIRP density, are further reduced by another 5 dB, for larger angles, exceeding 90 degrees from sub-satellite point. The resulting satellite EIRP density mask, referenced at the sub-satellite point is provided in Figure A-6 with the satellite antenna gain pattern overlayed at both extreme pointing angles (+/- 61.2° off nadir). Ignoring the portion of the satellite EIRP mask between -68° and 68° off nadir, which is obstructed by the Earth, it can be seen that the assumed mask more than adequately covers the proposed operation.

**Figure 5: NGSO satellite beam for $EPFD_{is}$ calculation**




The results of the $EPFD_{is}$ analysis are provided in the following plot, where even with the very conservative assumptions, there is at least 5 dB margin.



**APPENDIX D: Engineering Certification**

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 and belief.

Respectfully submitted,

/s/ Tyghe Speidel

Tyghe Speidel
CTO
Lynk Global, Inc.