Submission to Ofcom's consultation on Starlink NGSO Gateway License Applications

19 July 2022

I. Background to the consultation

On 27 May 2022, Ofcom received six applications from Starlink Internet Services Limited for Non-geostationary Earth Station Gateway licences (NGSO Gateway licences) operating in the Ka band frequencies.[1] SpaceX already operates three gateways in the UK. According to SpaceX, the proposed additional gateway sites are designed to help to meet user demand and provide weather diversity and network resiliency.

Stakeholders' comments on this application, including evidence on the co-existence of this system with current and future NGSO networks, and on any potential risks to competition, are invited by 19 July 2022.

This submission is structured as follows: (I) a general description of Viasat and its activities in the United Kingdom and Europe, (II) an overview of Ofcom's duties when assessing Starlink's applications, (III) a description of Viasat's main concerns with respect to Starlink's proposal, and (IV) Viasat's conclusions as to how Ofcom should act following Starlink's request for NGSO gateway earth station licences.

As a general matter, Viasat notes that SpaceX, in its license application, have not provided any information as to whether the authorisation sought for Starlink gateways concerns its Gen1 configuration of 4,408 operating satellites and/or its Gen2 configuration consisting of an additional 29,988 operating satellites. Viasat will therefore consider both configurations and their impact.

II. Introduction

Viasat UK thanks Ofcom for the opportunity to provide input on the issue of Starlink's applications for NGSO gateway licences. This public consultation is timely and important because we are witnessing an era of unprecedented activity and innovation in space, which requires all actors to have a particularly sharp focus on the efficient use and sharing of scarce orbital resources.

Viasat UK Limited (Viasat UK) is part of Viasat, a global provider of communication solutions that believes everyone and everything can be connected. The firm's 5,800 employees working out of more than 60 global locations deliver connectivity to consumers, business, governments, and militaries around the world, even in the hardest-to-reach places. Viasat is one of the world's leading providers of fixed

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1 Starlink Internet Services Limited's applications https://www.ofcom.org.uk/__data/assets/pdf_file/0017/239003/consultation-starlink-ngso-application.pdf.

broadband and in-flight connectivity services via satellite, with hundreds of thousands of fixed subscribers across the Americas, Europe, Middle East and North Africa and c.1,500 commercial aircraft in-service.

Viasat has decades of experience in both geosynchronous and low-earth orbit (respectively "GEO" and "LEO"): in GEO, the firm currently owns and operates, holds lifetime leases on, or is constructing, a total of 9 satellites including Ka-Sat. Viasat has also partnered with Avanti to boost Ka-Sat satellite network coverage across Western Europe[2] and more recently signed a long-term Ka band capacity lease agreement with Avanti targeting the energy sector.[3] Viasat has built LEO payloads, designed and manufactured ground networks and user terminals, and/or operated satellites, for the past 30 years.

In the UK, Viasat is teaming up with the Space Industry and contributing to the development of its national space strategy. Viasat UK provides deep security and communications expertise to rapidly deliver new sovereign technologies to the UK's civilian and defence markets - including the Royal Air Force's new F-35 stealth fighter and Royal Navy warships.

Moreover, in March 2021, Viasat opened a State-of-the Art Network Operations Centre & Cyber Security Operations Centre in Aldershot, UK.[4] The facility will support defence government and commercial organisations who rely on the guaranteed resilience of their networks and who are targeted by increasingly sophisticated cyberattacks. The project represents a major investment in UK, representing more than a £300m investment to support the launch and service roll-out of the impending ViaSat-3 constellation and creating over new jobs.

In March 2022, Viasat and Inmarsat reached agreement on a package of legally binding economic undertakings with the UK Government's Department for Business, Energy and Industrial Strategy.[5] As a result, this cooperation will contribute to create many highly skilled jobs in UK.

Viasat is also preparing to launch the ViaSat-3 network which is a global constellation of three Ka-band broadband communications satellites in GEO. The first two satellites will focus on the Americas and EMEA. A third satellite will provide service in the Asia-Pacific region, completing global service coverage. The ViaSat-3 constellation is currently in its final construction stage and scheduled for three launches commencing in the second half of 2022, including one that will serve UK and Europe. The ViaSat-3 satellite network architecture is taking another leap forward in performance, with capabilities of providing

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2 *Viasat Partners Avanti to Boost KA-SAT Satellite Coverage* (7 June 2021), https://www.nasdaq.com/articles/viasat-vsat-partners-avanti-to-boost-ka-sat-satellite-coverage-2021-06-07.

3 Viasat Press Release, *Avanti Communications and Viasat Energy Services sign long term Ka-band capacity lease agreement targeting the energy sector* (23 June 2022), https://investors.viasat.com/news-releases/news-release-details/avanti-communications-and-viasat-energy-services-sign-long-term.

4 Viasat Press Release, *Viasat Opens State-of-the-Art Network Operations Centre & Cyber Security Operations Centre in the UK* (30 March 2021), https://www.viasat.com/about/newsroom/press-releases/viasat-opens-state-art-network-operations-centre cyber-security/.

55 Viasat Press Release, *Viasat and Inmarsat reach agreement with UK government on a plan to increase highly-skilled jobs and R&D investment in UK Space sector* (21 March 2022), https://www.viasat.com/about/newsroom/press-releases/viasat-inmarsat-reach-agreement-uk-government-plan-increase/.

cost-effective high-speed broadband to customers featuring speeds of up to 1 Gbit/s and a total throughput above 1 Terabit per second (Tbit/s) per satellite. In addition, each of our next-generation Ultra High Throughput (UHT) ViaSat-4 satellites under development will offer 5-7 times that amount of throughput.

As a global industry leader, Viasat has been a strong promoter of responsible and equitable practices designed to ensure that the shared orbital environment remains available for all to use safely. This long-standing commitment is evidenced in Viasat's recent signature of the Paris Peace Forum's 'Net Zero Space' Initiative to tackle the growing space debris crisis. Viasat also stands for a responsible space industry that is committed to fostering public awareness of the risks associated with the proliferation of debris in near-Earth orbits. To this end, company representatives regularly take part in conferences, such as at the 4th edition of the Space Sustainability Summit co-sponsored by the UK Space Agency, which took place in London on 22 and 23 June.

We trust our suggestions below will help Ofcom ensure that any spectrum authorisations it chooses to award create a fair and level playing field for all actors, whether in GEO, LEO, or non-geostationary orbits (NGSO) other than LEO, and do not pose a threat to efficient spectrum use, UK's national interests, space safety, or the environment.

III. Ofcom's duties with respect to Starlink's request for six non-geostationary orbit earth station licences

Ofcom's competence to grant authorisations to use radio frequencies is defined by Article 8 of the Wireless Telegraphy Act 2006. Notably, this article provides that such authorisations can be refused, including for reasons pertaining to the production of interference (section 8-5.a), to the efficient use of radio spectrum (section 8-5.c), and to potential danger to safety or life (section 8-5.d).

Under section 8C-1.a of the Wireless Telegraphy Act 2006, Ofcom must propose a public consultation if it believes that the grant will have a significant impact on the market for the use of electromagnetic spectrum for wireless telegraphy.

Moreover, national regulatory authorities have a regulatory duty to structure the market to avoid a distortion of competition. Accordingly, Ofcom must carry out a thorough assessment, with a particular focus on the impact of Starlink's project in respect of the criteria provided for in the Wireless Telegraphy Act 2006, before deciding whether to issue the requested authorisation.

On this basis, Ofcom should, at the very least, carry out an independent assessment that would allow it to adopt an informed decision regarding the serious issues raised by Viasat in this submission. This should include the impact of the project on efficient and sustainable competition in the British market for the provision of broadband internet access from space and likely interferences with GSO and other NGSO systems.

In addition to these elements, it would be important for an independent assessment to study the impact of the proposed spectrum use, by the Starlink constellation, on astronomy, the night sky, the atmosphere, and the potential for collision risk and the creation of additional orbital debris.

If at the end of an independent and thorough assessment, Ofcom concludes that it can and should grant the authorisations requested by Starlink, Ofcom would have to determine the conditions governing this authorisation. It should be recalled that where Ofcom grants individual rights to use radio spectrum, it must ensure that such use is subject to appropriate conditions, including conditions pertaining to the nature and characteristics of the equipment, network, technologies, and services which may use the frequency band, as well as technical and operational conditions necessary to avoid harmful interference. In this regard, Ofcom should consider its principle duties and obligations, in particular the promotion of fair competition under the requirements of the Wireless Telegraphy Act of 2006 that Ofcom promote "competition in the provision of electronic communications services" (Section 3-2.d).

Taking appropriate action in this matter is the only way for Ofcom to address the harms to British interests presented by the Starlink system. Such action could include imposing suitable conditions to ameliorate the risks of those harms.

In light of the serious issues resulting from the deployment and operation of the Starlink system in terms of competition, efficient spectrum use, environmental protection, and national defense and security, it is Viasat UK's view that the conditions Ofcom must impose should it decide to issue an authorisation must (i) ensure non-interference into GSO and NGSO systems, (ii) ensure compliance by the entirety of the Starlink system with the interference limits that apply to each NGSO system, (iii) constrain the preclusive effect of the Starlink system on limited and shared NGSO orbital resources, and (iv) manage both the collision and orbital debris risks (and the resulting harms to others that operate in, or transit through, LEO) and other environmental harms, all as summarized below.

In this respect, the conditions imposed by Ofcom should be sufficiently specific to constitute an *ex-ante* safeguard against undesirable interferences, preclusive effects, and environmental harms. Otherwise, the harms that would result from grant of the proposed authorisations at issue will be extremely difficult to trace with specificity and certainty to Starlink and mitigate. Only conditions defined beforehand and tailored properly will be able to mitigate the expected detrimental effects of Starlink's project on competition, the efficient use of shared spectrum and orbital resources, and the environment.

For that matter, as a recent report by the EPFL International Risk Governance Center emphasizes, it is imperative that preventative action be taken now at the national level, because we just will not reach international consensus in the short term on a new framework for regulating large LEO constellations.[6] Therefore, preventative action taken by Ofcom would be an important, necessary, and critical first step toward managing risks in the short term and also providing "referenceable precedent as a foundation for building wider international agreements"[7].

Nor can Ofcom simply assume that these risks to British interests have been adequately addressed by Starlink's filing administrations. To the contrary, other nations have incentives to fully populate LEO before the UK and other countries. Moreover, the UK has substantial global GEO satellite interests to

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[6] Buchs, R., Policy Options to Address Collision Risk From Space Debris, Lausanne: EPFL International Risk Governance Center (25 November, 2021), https://infoscience.epfl.ch/record/290171.

[7] *Id.* at ii.

protect from interference, whether direct-to-home television (DTH) or broadband, and therefore Ofcom has a larger obligation to address the threats to British interests presented in this case.

For these reasons, Viasat UK urges Ofcom to exercise great care as it pursues these missions in light of (i) the unavoidable disruptive effects that both the first and second generation versions of the Starlink project would have on the market for the provision of DTH and broadband internet services in the UK and Europe, and the risks posed to other uses of LEO—including uses hundreds of kilometers away from the orbits that Starlink would use, such as space-based observations for weather forecasting, climate monitoring, and earth sciences, as well as positioning, navigation and timing (PNT), among others.

Indeed, the actions that Ofcom takes in this case to preserve and promote competition and equitable access to limited spectrum and orbital resources to serve British and European interests will serve as an important model for other national regulators – and a critical step toward sustaining a competitive environment for British and European satellite operators, manufacturers and launch providers alike around the globe.

IV. Viasat's concerns regarding the Starlink satellite constellation and the pending applications

This section and the associated Annexes A and B address Ofcom consultation questions 1, 2, 3 and 4 which have been identified in the applicable subsections below. Viasat responses to questions 1 and 2 are provided in subsection A, question 3 in subsection B, C, D, 2 and 3 and question 4 in subsection 4 and 5.

In the context of increases in proposals for mega-constellation projects, Viasat UK wishes to ensure that the expanded deployment and operation of the Starlink system, if permitted at all in the UK is conducted in a manner that respects the public interest and supports the long-term sustainability of the environment. Viasat UK believes firmly in open competition. Enabling competition requires that access to space be safe and available to more than a few LEO systems and nations. As such, sustainable space policies and industry competitiveness are complementary.

Therefore, Viasat UK submits the following contribution to focus on five key issues: (1) SpaceX precluding access to space and interfering with GSO and other NGSO systems, (2) significant adverse impacts on British and European space industry, (3) adverse consequences for end-users' and citizens' interests, (4) environmental effects on the atmosphere, sustainable space, optical astronomy, and radio astronomy, and (5) potential ramifications for national security. Viasat UK also suggests a non-exhaustive list of some precisely defined conditions for Ofcom's consideration (see V, "Conclusion").

1. Starlink's use of radio spectrum threatens to preclude equitable and safe access to space and interfere with GSO networks and other NGSO systems

Eventually, the goal of the Starlink project is to deploy approximately 42,000 operating satellites in LEO to provide internet service (plus an untold number of satellites undergoing orbit raising and deorbiting at any given time). This planned dramatic expansion of the Starlink system proposed by SpaceX would allow it to dominate critical, scarce, and shared spectrum and orbital resources, foreclosing the ability of other satellite operators to access and use spectrum (and LEO more generally) to provide innovative and competitive satellite offerings that would meet the needs of consumers and serve other vital needs.

This “resource-grabbing” approach by SpaceX thus presents very real risks, including:

A. Impermissible interference into GSO networks that interrupt their operations and reduce their capacity;
B. Blocking equitable access to shared NGSO frequency bands;
C. Precluding safe and reliable access to approximately 86 percent of the altitudes between 300 km and 700 km, regardless of frequency band; and
D. Consuming more than an equitable share of the aggregate amount of interference that all NGSO systems (combined together) may generate into GSO networks.

When issuing new licences, Ofcom’s main objectives are to ensure that there are no adverse impacts on competition and that all authorised systems are capable of coexisting (in bands they are using in common), such that they are all able to provide services to their users without experiencing harmful interference.

As Viasat demonstrated below, each of these risks entails serious threats to fair competition in the market for the provision of innovative (satellite) broadband internet solutions, with adverse consequences for consumers and efficient spectrum use and sharing.

Question 1: Do you anticipate one or more of the NGSO gateways in these applications will pose coexistence challenges to existing services?

Question 2: Do you consider that the measures to enable coexistence with future systems, as set out by the applicant, are reasonable? If not, what are your concerns and to which specific gateway sites do your concerns relate?

A. *Impermissibly interfering with GSO networks*

(i) Starlink should not be authorised to deploy additional gateways as there is no ex-ante evidence that a suitable avoidance angle will be used to mitigate interference into GSO networks

The movements of NGSO satellites across the sky create opportunities for time varying interference into GSO networks. Unless an NGSO operator, like Starlink, employs appropriate mitigation measures, in-line interference events with GSO networks will repeatedly degrade and disrupt services to end users of GSO networks.

Today’s GSO satellites are extremely efficient in how they use spectrum to provide innovative services with smaller user terminals than ever possible before. Taking advantage of advancements in technology, modern GSO satellites are capable of providing more than 1 Tbit/s of total capacity each, with even higher amounts of throughput expected in the next few years.

GSO networks achieve this unprecedented increase in capacity due in part to increased spectral efficiency which is facilitated by employing satellite receivers with low noise temperatures and high antenna gains (G/T). Today, even a single NGSO system, like Starlink, has the potential to cause interference into GSO networks. Multiple NGSO systems operating simultaneously on the same frequencies pose an even greater aggregate interference risk to those GSO networks.

Unless Starlink's communication links are angularly separated from the GSO arc by a sufficient amount, they could easily degrade service levels and cause capacity losses to the GSO networks with which Starlink seeks to compete, including those that serve UK and Europe. Angular separation is a relatively simple operational technique where the NGSO satellites avoid operating within a suitable angular separation around the GSO arc. If using one particular NGSO satellite to serve a given location would not maintain sufficient angular separation, then a different satellite would be used, and the other NGSO satellite would be used to serve a different location where it would be able to maintain the required angular separation. This concept is depicted in Figure 1.

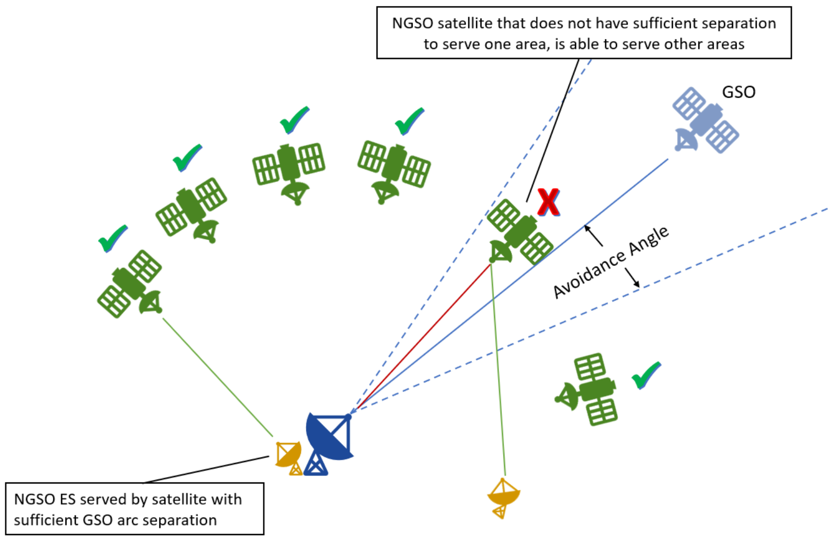

Figure 1 – NGSO System Employing GSO Avoidance Angle.

Notably, angular separation imposes virtually no constraint on NGSO system capacity as large NGSO systems like Starlink always have multiple options for assigning different satellites to serve different locations on the Earth. And they regularly hand off traffic from one NGSO satellite to another as the satellites move rapidly across the sky. Angular separation is routinely used by NGSO systems in ITU coordination agreements to protect GSO networks.

Although GSO arc avoidance has the potential to effectively mitigate some potential interference from NGSO systems into GSO operations, the effectiveness of this technique depends entirely on the avoidance angle that is specified. The sufficiency of that angle can be evaluated only in light of information about the radiofrequency design and EPFD performance of the relevant NGSO system.

This underscores the need to define appropriate up-front parameters that are shown through mathematical calculation to be reasonably likely to mitigate the potential for interference from Starlink into GSO network operations—*e.g.,* by specifying a precise and appropriate GSO arc avoidance angle on an *ex-ante* basis.

No such public information is available with respect to the Starlink operations in the UK proposed to be authorised under the consultation. As such, it is impossible to ensure that any avoidance angle Starlink may plan to employ would, in fact, be sufficient to protect GSO operations from interference.

For these reasons, and since, in the present case, the demonstration of the existence of adequate measures to avoid harmful interference should be provided *before* granting any authorisation (see below), Ofcom should not adopt its preliminary views subject to this public consultation.

If Ofcom were nonetheless to consider granting Starlink a spectrum authorisation, it should, at a minimum: (i) calculate the minimum GSO arc avoidance angle that would ensure that the Starlink system protects from interference GSO networks serving UK and Europe; (ii) allow interested parties to evaluate the efficacy of the proposed value; and (iii) require Starlink to maintain a suitable GSO arc avoidance angle as a condition of any authorisation that ultimately may be granted in this proceeding.

To assist in that analysis, Ofcom should require Starlink to provide the following information:

- Number of total beams on each satellite serving UK and Europe;
- Number of co-frequency beams on each such satellite;
- Number and size of frequency channels on each such satellite;
- The number of satellite beams used for transmissions on the same frequency in the same or overlapping areas at any given time; and
- How Starlink avoids interference to GSO networks created by earth station and satellite sidelobes, and earth station backlobes, particularly when phased array antennas are employed.

This information is relevant to assessing Starlink's potential interference impact on GSO networks, the potential for spectrum sharing with other NGSO systems discussed below, and thus Starlink's impact more broadly on the spectrum and competitive environments in UK and Europe.

In order to ensure that the bases on which Ofcom ultimately grants an authorisation (should it decide to do so) do not change by virtue of continuing iterations of the Starlink design, Ofcom should also (i) specify that Starlink not modify the radiofrequency characteristics of its satellite system without prior consent from Ofcom, and (ii) require that Starlink provide a bi-annual report on iterations of the Starlink design to ensure compliance with that condition.

(ii) Starlink fails to comply with ITU EPFD limits intended to constrain interference into GSO networks

The potential for disruption to GSO networks by co-frequency NGSO systems is well-known and is what led to the development of various ITU Radio Regulations (RR) that protect GSO networks from interference generated by NGSO systems, including in the frequency bands in which Starlink proposes to operate in the UK.

These provisions include:

- RR No. 22.2, which requires NGSO systems not to cause *unacceptable* interference to, or claim interference protection from, GSO networks;
- In certain frequency bands, equivalent power flux density (EPFD) limits that, ***if actually met during operation***, fulfils an NGSO system's RR No. 22.2 obligation; and
- In other frequency bands, a requirement that NGSO systems coordinate under RR No. 9.11A based on ITU network filing date priority.

As discussed above, a key operational requirement for complying with these non-interference requirements is for the NGSO system to greatly reduce the amount of unwanted energy it generates toward GSO networks, including by maintaining a suitable avoidance angle with respect to the GSO orbital arc.

In most portions of the 27.5 – 27.8185 GHz, 28.4545 – 28.8265 GHz and 29.4625 – 30 GHz frequency bands that specifically are the subject of this consultation, and the 14.0-14.5 GHz frequency band, which is included in Starlink's existing UK network license, Starlink is subject to limits on the uplink EPFD levels it may generate toward GSO satellites.[8] Furthermore, in its Space Spectrum Strategy consultation, Ofcom recently announced plans to introduce "*an explicit condition into NGSO earth station licences to require that the satellite downlinking to the earth station also complies with the limits in Article 22 downlink EPFD limits. [..], this would enable us to enforce directly against the UK licensee if this condition was not complied with*"[9]. For Starlink NGSO system operation in the UK, the downlink EPFD limits[10] apply in 10.7-12.75 GHz, 17.8-18.6 GHz and 19.7-20.2 GHz frequency bands.

There are two types of limits. "Aggregate" EPFD limits constrain the amount of interference that all NGSO systems (including Starlink) may generate in total, on a cumulative basis. These aggregate limits must be shared and apportioned among all NGSO systems using the overlapping frequencies. "Single-entry" EPFD limits constrain the amount of interference that the Starlink system itself may generate with respect to GSO networks. The single-entry limits were established based on the assumption that 3.5 NGSO systems would be operating at a given time and generating combined EPFD levels consistent with the applicable "aggregate" EPFD limits. Both "single-entry" and "aggregate" EPFD limits are specified as a series of different EPFD levels that are permitted for time-varying intervals and are reflected in the EPFD curves included in Annex A.[11] As also depicted in Annex A, one EPFD limit must be satisfied 100 percent of the time; and other EPFD limits must be satisfied for other, varying percentages of time.[12]

As illustrated in Annex A, the Starlink system would exceed both the "single-entry" and "aggregate" EPFD limits in various respects at locations in the UK, including all six proposed gateway locations. Exceeding the "single-entry" EPFD limits at any point on the curve is a violation of ITU Radio Regulations. Exceeding the "aggregate" EPFD limit at any point on the curve also is a violation. The instances described in Annex A in which Starlink would violate "single-entry" EPFD limits 1%, 10% and even 100% of the time are very concerning. Interference generated for these percentages of time could well degrade service levels and cause capacity losses to the broadband GSO networks with which Starlink seeks to

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[8] ITU Rad. Reg. Art. 22.

[9] Ofcom consultation on *Space Spectrum Strategy* (15 March 2022), https://www.ofcom.org.uk/__data/assets/pdf_file/0024/233853/consultation-space-spectrum-refresh.pdf, No. 6.47.

[10] ITU Rad. Reg. Art. 22; ITU Res. 76.

[11] ITU Res. 76.

[12] *See* Rad. Reg. Art. 22.

compete, including those that serve UK, as well as direct-to-home television (DTH) services used by many British citizens in the UK and globally.

SpaceX's violation of the "aggregate" EPFD limits also results from its attempt to ignore the way in which Starlink actually would operate and instead try to (1) artificially separate the Starlink system into constituent components, and (2) impermissibly evaluate each of those constituent components (instead of the Starlink system as a whole) against the "single entry" EPFD limits.[13]

Notably, the ITU has no way to effectively check the ability of a system operator to try to "game" the system in this manner, by contriving EPFD inputs in a way designed to "pass" the ITU's spot checks regarding EPFD without reflecting how the NGSO system actually would operate. The responsibility for checking NGSO system compliance falls on individual administrations and regulators, such as Ofcom, that consider authorising Starlink operations,[14] and it ultimately falls on the NGSO operator to conduct its operations in full compliance with all EPFD limits, regardless of any limited evaluation initially conducted by the ITU based merely on the data files provided by that operator and without regard to the actual operation of the NGSO system. Moreover, the ITU Radiocommunication Bureau itself has said that the SpaceX ITU filings STEAM-1, STEAM-2, STEAM-2B (representing SpaceX's Gen1 system) are currently undergoing assessment of a modification submitted by SpaceX and therefore, even the minimal EPFD compliance check has not yet been performed on the modified Gen 1 ITU filings.[15]

Furthermore, as explained in Annex A, the ITU's methodology and implementing software for assessing expected EPFD levels from NGSO operations rely on an algorithm that derives a "worst-case geometry" found at one particular location on the Earth's surface.[16] That is, the algorithm attempts to identify, for the specific NGSO satellites under the relevant filing and a representative GSO network, the single location that results in the highest single-entry NGSO EPFD level that can be expected. Again, this value is produced for a very short period of time, and thus lies at the bottom of the relevant EPFD results curve (*i.e.*, the alignment of the NGSO system with the GSO network that produces the highest instantaneous interference level---for a very small percentage of the time).

For this reason, an ITU evaluation would not be expected to reveal the exceedances detailed in Annex A regarding the six proposed gateway locations in the UK.

Therefore, Ofcom must perform this compliance analysis now. It would be practically impossible in the future to directly measure the Starlink-generated EPFD levels generated into GSO networks. Among other things, EPFD statistics include a percentage-of-time element, such that EPFD levels would need to be measured over and against time and then processed to check against the EPFD limits—a process that is computationally intensive and time-consuming for the same reasons that any up-front EPFD

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13 SpaceX plans to operate various elements of its integrated Starlink system under a variety of ITU filings made on its behalf by Norway, the United States and Germany.

14 Nevertheless, the U.S. Federal Communications Commission (FCC) has indicated that it did not conduct any such analysis of Starlink.

15 ITU Director, Radiocommunication Bureau, *Report to the 90th Meeting of the Radio Regulations Board* (27 May 2022), https://www.itu.int/dms_ties/itu-r/md/22/rrb22.2/c/R22-RRB22.2-C-0002!!PDF-E.pdf, section 7.

16 *See generally* ITU-R Rec. S.1503.

analysis is time-consuming. In addition, where multiple NGSO systems operate in the same band, it is not practical to differentiate between the contributions of each NGSO system given all the main-beam and sidelobe transmissions of numerous satellites of those multiple NGSO systems. As Ofcom is aware, multiple NGSO systems are now operating in the same frequency bands as Starlink. The way in which different NGSO systems contribute to the overall EPFD level received by a GSO earth station is illustrated by Figure 2, below. From the perspective of the GSO earth station, EPFD interference is EPFD interference — *i.e.,* the GSO earth station cannot isolate individual components of that interference or trace those components to their specific sources. This is why it is critical for Ofcom to evaluate Starlink's EPFD compliance (including the contributions of Starlink earth stations operating in the UK) before granting an authorisation for Starlink service in the UK.

Notably, SpaceX has already committed to limit to *one* the "number of co-frequency simultaneously transmitting satellites serving a given point on Earth"[17] in order to constrain EPFD levels to protect GSO networks. For this and other reasons, Ofcom should make any authorisation it may grant subject to the same condition that applies to Starlink's FCC-authorised earth stations operations, namely that "[o]perations are subject to the condition that SpaceX not use more than one satellite beam from any of its satellites in the same frequency in the same or overlapping areas at a time"[18].

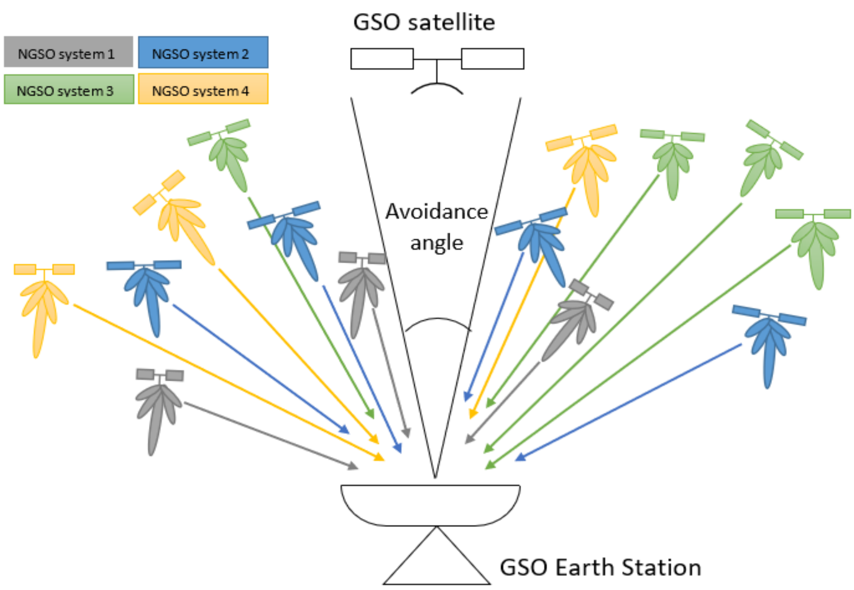

Figure 2 – Aggregate Mainlobe and Sidelobe Interference Contributions from Multiple NGSO Systems into GSO Earth Station.

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17 *See* Letter from SpaceX to FCC, IBFS File No. SAT-MOD-20200417-00037, at 1 & Att. at 3 (2 April 2021).

18 *See* FCC Authorisation, IBFS File No. SES-LIC-20210708-01019, Call Sign E210127, Condition 90676 (10 Nov. 2021).

Question 3: Could the granting of one or more of these licences prevent your service from operating in the UK or make it less attractive or more costly to enter the market?

B. Blocking equitable access to shared NGSO frequency bands

SpaceX proposes to operate 34,396 Starlink satellites in the Ku and Ka bands (4,408 satellites in its first-generation configuration, plus 29,988 additional satellites to be deployed in its second-generation configuration).[19]

The type of large LEO system that SpaceX proposes to use to serve UK can consume significant portions of the "look angles" toward space, and essential LEO orbits, preventing use of the sharing tools that have been employed successfully for decades among NGSO systems.

This threat to NGSO spectrum sharing arises because both the first- and second-generation configurations of the Starlink system would "blanket the sky" causing many in-line interference events limiting and sometimes completely blocking other NGSO systems from sharing the same spectrum. The Starlink system would rarely (if ever) experience this problem itself because it is composed of a far greater number of satellites than smaller NGSO constellations, which provides Starlink with alternative communications paths where the same spectrum remains available for its use. These impacts are depicted in Annex B.

SpaceX's application for six gateways, nine in total, in the UK with eight antennas at each of those nine gateway sites, would result in a high number of 'active' Starlink satellites operating over the UK and would increase the number of in-line events for other NGSO systems. The upshot is that SpaceX would have no incentive to avoid in-line interference events, and every incentive to maximize them; large numbers of in-line interference events would impede competition from smaller NGSO systems without materially impacting SpaceX's operations. As a result, SpaceX could effectively foreclose other satellite operators, including new entrants and other potential competitors, from accessing and using shared spectrum and orbital resources in the public interest. Even SpaceX acknowledged these kinds of risks when it objected to a proposal that it claimed would allow OneWeb to have access to twice the amount of spectrum as other Ku/Ka-band NGSO operators; as SpaceX noted, "*control of two systems in a band would reduce the incentives to invest in technologies that use spectrum efficiently and increase the incentives for obstructionism and gamesmanship in operator-to-operator coordination*"[20].

Moreover, this dynamic has the dangerous effect of incentivizing a "race to the bottom" in which LEO systems deploy many more satellites than actually needed, utilizing large numbers of spectrally-inefficient satellites and rejecting reasonable approaches that otherwise would enable spectrum sharing among all NGSO system types – even those operating at other altitudes.

In sum, Starlink's proposal to "blanket the sky" would have direct and harmful consequences for other NGSO systems and operators – and would foreclose competition and harm the broader public interest. This could easily leave only one or two NGSO systems with the ability to serve UK.

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[19] Approximately 7,000 additional V-band-only satellites are contemplated as well, making it a total of approximately 42,000 satellites.

[20] Petition to Deny or Defer of Space Exploration Holdings, LLC, US Federal Communications Commission IBFS File Nos. SAT-LOI-20170301-00031 and SAT-AMD-20180104-00004 at 13 (6 Aug. 2018) (emphasis added).

One solution would be to adopt a condition requiring “look angle” splitting, whereby Starlink and other NGSO systems serving UK in overlapping frequencies would divide the range of satellite azimuths as seen from a location on the Earth whenever the potential for interference exists at that location. For example, on such occasions one system would only operate with satellites to the West of that location while the other system would only operate with satellites to the East of that location. As long as each system has a satellite available in its assigned direction that is not within the minimum avoidance angle of a satellite in the other system, there would be no capacity reduction.

Notably, the same level of “look angle” splitting would occur regardless of the number of satellites in a given NGSO constellation. Each operator would bear the same burden by default, in the absence of some other coordinated outcome. This approach would allow multiple NGSO systems to access and use available spectrum resources on an equitable basis.

With this rule, NGSO systems would be on an equal footing, regardless of system size, incentivizing all NGSO systems to coordinate, preserving and promoting competition in UK and Europe, and also serving as a model for other national regulators – an important step toward sustaining a globally competitive environment for British satellite operators, manufacturers and launch providers alike.

C. *Precluding safe and reliable access to approximately 86 percent of the altitudes between 300 km and 700 km, regardless of frequency band*

A further threat to spectrum sharing exists because orbits in which LEO satellites must operate in order to use spectrum are limited, and as leading experts recognize[21] LEO mega-constellation operators are in a race to populate a wide swath of the “best” orbits (in the 300 km to 700 km range) with huge numbers of satellites. Orbits within this range are essential for the missions of earth observation[22] and PNT[23] satellites and also are very attractive for other purposes because of their associated passive decay times for failed satellites (which can deorbit much more quickly than from higher orbits).

LEO mega-constellation operators are engaging in a “land grab” of these prime orbital resources by planning to operate with unnecessarily wide orbital tolerances, and thus effectively filling up hundreds of kilometres of orbits to the exclusion of other NGSO systems that otherwise could operate safely in nearby orbits. This forecloses those other NGSO systems from using LEO to provide competitive and innovative services to the public and distorts the competitive balance in LEO—all of which is particularly critical to avoid at this very early stage of the New Space age.

The sheer number of Starlink satellites is problem enough, but the preclusive impact is magnified by the overly wide orbital tolerances within which Starlink proposes to operate (for the reasons discussed

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21 *See* The Verge, *Elon Musk’s shot at Amazon flares monthslong fight over billionaires’ orbital real estate* (27 January 2021), https://www.theverge.com/2021/1/27/22251127/elon-musk-bezos-amazon-billionaires-satellites-space.

22 *See, e.g.,* European Space Agency, *Earth observation satellites - Introduction* (16 July 2022), https://www.esa.int/SPECIALS/Eduspace_EN/SEM7YN6SXIG_0.html.

23 *See* Robyn Federman, Orolia Blog and Podcast, What Are LEO Satellites and Why Are They Good for PNT? https://www.orolia.com/what-are-leo-satellites-and-why-are-they-good-for-pnt/.

above). SpaceX proposes to operate across *hundreds of kilometres in LEO*—including in large shells that would spread from 290 km to 430 km and 475 km to 687 km. As depicted in Figure 3, this result would occur because SpaceX seeks to operate anywhere from 50 km below, to 70 km above, each of the nominal altitudes for its various orbital shells.[24]

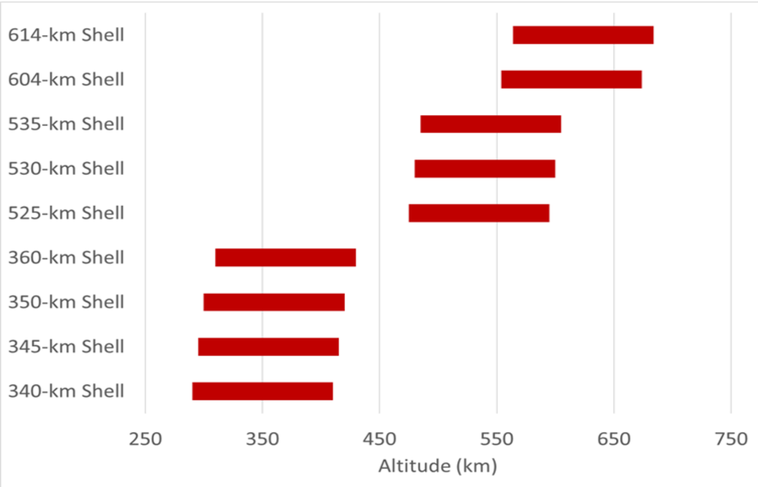

Figure 3 – Extent of Physical Orbits Proposed to be Consumed by Starlink.

The net effect would be to preclude other LEO systems from being able to safely and reliably access approximately 86 percent of the altitudes between 300 km and 700 km, regardless of frequency band (only 45 km of altitude between 430 km and 475 km might be available to other NGSO systems).

For the same reasons provided above with respect to in-line interference events, SpaceX would have every incentive not to consent to the operation of other LEO systems within the orbital ranges depicted in Figure 3. Particularly given that Starlink LEO already must operate within much narrower orbital tolerances to avoid collisions, there is no good reason to allow it to provide service to UK utilizing overlapping shells of satellites in very wide orbits that unduly consume what otherwise would be shared. Moreover, neither SpaceX's filing administration nor Starlink itself has identified what parameters would have to be satisfied to safely allow other LEO satellites or constellations to occupy, or overlap, the orbits Starlink plans to occupy. And other operators, (*e.g.*, Amazon/Kuiper and Iridium) have asserted to the contrary that other LEO constellations cannot safely share the same orbits.

Again, SpaceX would have both the ability and incentive to foreclose other satellite operators, including new entrants and other potential competitors, from accessing and using shared spectrum and orbital resources in the public interest. SpaceX already enjoys the ability to use LEO regardless of whether physical coordination with any other operator is concluded successfully. The same cannot be said with respect to new entrants, which may be deterred from even attempting to deploy systems that overlap with the Starlink system.

One mitigation would be to require Starlink to maintain an orbital tolerance of +/- 2.5 km for the apogee and perigee of each satellite, and a 0.5° tolerance for each orbital inclination it employs, in order to ensure other NGSO systems that seek to serve UK may access the shared LEO space, or alternatively

[24] *See* US FCC IBFS File No. SAT-AMD-20210818-00105 at 4 (18 Aug. 2021) ("Amendment Technical Narrative"). SpaceX plans to operate the first generation of its Starlink satellites with orbital tolerances that would spread from 510 km to 580 km.

to apply such orbital tolerance requirements as Ofcom deems appropriate to ensure the ability of other satellites and systems serving the UK to safely operate within, or overlap, orbits occupied by Starlink, and other large constellations.

D. *Consuming more than an equitable share of the aggregate EPFD limit for all NGSO systems*

As explained in Annex A, SpaceX's plans to operate Starlink under multiple ITU filings would result in Starlink exceeding the ITU's *aggregate* EPFD limits by a factor of as much as 6.4 dB. In addition to SpaceX causing far more interference into GSO networks than is permitted by ITU Radio Regulations, SpaceX would foreclose opportunities for other parties to operate their own NGSO systems, because Starlink would consume (and in fact exceed) all of the aggregate EPFD "budget" that must be apportioned among all NGSO systems using the same or overlapping frequencies.

And even if Starlink did not consume all of the aggregate EPFD budget, by virtue of claiming rights to operate under many different ITU system filings, SpaceX would have significant leverage against other NGSO systems in any negotiations that must occur over the allocation of the aggregate EPFD "budget" among NGSO systems.

2. Significant adverse impact on United Kingdom's space industry

A dominant position of SpaceX with respect to NGSO resources would not only prevent other satellite operators or constellation projects from competing effectively, it would also have a significant negative impact on the entire United Kingdom space and telecom industry, from satellite manufacturers (Surrey Satellite Technology Ltd, Clyde Space Ltd, etc.), satellite launchers (Skyrora, Orbex Space, etc.), and ground equipment / user terminal manufacturers (Goonhilly Satellite Earth Station, Milexia UK etc.) to telecommunication operators (OneWeb, Vodafone, British Sky Broadcasting, Telephonica UK Limited etc.). These effects are exacerbated by SpaceX's vertical integration strategy, *i.e.*, the fact that it has deliberately chosen to design and manufacture its satellites and user terminals in-house, to launch the Starlink constellation on its own rockets and to market its services directly to the end customers, thereby bypassing the entire existing ecosystem and keeping 100 percent of the value of the project for itself.

The loss in value for the British economy and the corresponding negative impact on jobs would be tremendous. By way of illustration, a report produced by London Economics on behalf of the UK Space Agency shows that United Kingdom's space industry has contributed £6.9 billion Gross Value-Added to the British economic output and employs nearly 47,000 workers over the year 2019/2020.[25]

In the long term, the combination of a dominant position of SpaceX with respect to NGSO resources and the company's full vertical integration would exclude the United Kingdom's space and telecom industry from a sizeable portion of the corresponding market for satellite-related equipment and services and significantly reduce the size, relevance and competitiveness of the United Kingdom's existing

25 UK Space Agency, Report "The Size and Health of the UK Space Industry 2021" surveyed in 2022 by London Economics on behalf of the UK Space Agency (updated 25 April 2022), https://www.gov.uk/government/publications/the-size-and-health-of-the-uk-space-industry-2021/size-and health-of-the-uk-space-industry-2021.

industrial base, as well as all British "new space" companies that depend on access to spectrum and orbital resources.

A growing recognition exists that there are constraints on the exploitation of LEO, which have been expressed alternatively as environmental limits,[26] "carrying capacity,"[27] and "time to Kessler Syndrome"[28]. Regardless of the terminology, the critical point is that LEO resources are *limited*. It therefore is incumbent on Ofcom to consider what portion of these resources – including spectrum resources – Starlink would consume, and what portion would remain available for the United Kingdom's participants in the space and telecom industry.

Moreover, with respect to the potential for SpaceX to interfere with services provided in the United Kingdom by GSO satellites, it bears emphasis that there are many millions of GSO satellite TV and/or broadband users in the United Kingdom, and more such users globally on satellites that are built or operated by companies that have substantial operations in the United Kingdom (including Airbus, OneWeb, Surrey Satellites, and Avanti plc.). Interference from Starlink into GSO networks thus would impair not only services in the United Kingdom, but also the global business prospects of those British enterprises. Ofcom has an opportunity to protect those interests globally through its actions in this matter.

3. Consequences on end-users and citizens interests

European economies and society are increasingly reliant on space services (such as radio communication, timing and/or positioning signals (*i.e.,* PNT) or Earth observation data). The growing reliance of GDP on space comes with the need to avoid and mitigate risks of disruption to space-based assets and infrastructure.

However, the increase in number of space objects – from 2,000 active satellites in late 2018 to approximately 4,000 today and likely 100,000 or more by the end of the decade – a growing amount of orbital debris, and the resulting growing congestion of LEO, increases the likelihood of collision events

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26 *See, e.g.*, European Space Policy Institute, ESPI Report 82 - Space Environment Capacity – Full Report (April 2022), *at* https://espi.or.at/news/espi-report-82-space-environment-capacityL. Miraux, *Environmental Limits to the Space Sector's Growth,* SCIENCE OF THE TOTAL ENVIRONMENT (February 2022), *at* https://www.sciencedirect.com/science/article/abs/pii/S0048969721059404?via%3Dihub. ("A common assumption is that limitations to the human enterprise in space are of a purely technical land economic nature. This paper challenges this assumption, by highlighting the existence of environmental limits to the currently planned development of space activities. Risks arising from these limits are explored, and the importance of ecodesign in the space sector is emphasized."); A. Boley & M. Byers, *Satellite Mega-Constellations Create Risks in Low Earth Orbit*, Sci Rep 11, 10642 (2021), at https://doi.org/10.1038/s41598-021-89909-7, at 1-3.

27 *See* Toni Feder, *Q&A: Moriba Jah on the sustainability of near-Earth space*, PHYSICS TODAY (31 March 2022), https://physicstoday.scitation.org/do/10.1063/PT.6.4.20220331a/full/.

28 M. A. Sturza and G. Saura Carretero, Design Trades for Environmentally Friendly Broadband LEO Satellite Systems (2021), *2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)*, *at* https://amostech.com/TechnicalPapers/2021/Poster/Sturza.pdf ("AMOS Paper").

that can disable and even destroy satellites, and also generate more orbital debris.[29] Each collision will statistically lead to more collisions and ultimately can lead to a "belt of debris around the Earth"[30], leading to a series of self-sustaining collisions referred to as the Kessler syndrome, which could make certain orbits unusable for critical civil, military and commercial space services. One notable study commissioned by the U.S. National Science Foundation (NSF) indicates that it may not be feasible to sustain the deployment of Starlink over time as a result of these dynamics. That NSF study forecasts a dramatic increase in both space collisions and new debris, starting within just a few years; in the longer term, "satellites are destroyed [by collisions with debris] faster than they are launched"[31].

The collision risk is further exacerbated by the documented failure rates of Starlink satellites: indeed, satellites that cannot manoeuvre cannot avoid collisions, and Starlink's operational experience demonstrates that SpaceX has not been capable of maintaining a sufficiently low level of disposal reliability.[32] Moreover, all potential collisions cannot be predicted, and even where a satellite is maneuverable, all potential collisions cannot be avoided.

These points are particularly relevant in light of recent attention to the short-term and long-term consequences of a successful anti-satellite (ASAT) test that occurred in November 2021 with the Cosmos 1408 satellite. Another recent study shows that a similar result can be expected should two large Starlink satellites collide catastrophically.[33] Both types of events generate large numbers of lethal debris that spread into orbits hundreds of kilometres away from the point of impact and persist for decades,[34] including lethal, *non-trackable* debris, that (i) increase the risk of spacecraft collisions (and human casualties in space), (ii) cannot be seen and thus cannot be avoided, and the risks of which cannot otherwise be mitigated today, and (iii) can destroy or disable active satellites and thus disrupt vital satellite-based services in the UK and Europe.

Failures and collisions of this sort would affect far more than the Starlink constellation itself. Failed Starlink satellites, collisions involving Starlink, and the resulting debris fields, would affect all individual satellites and constellations that occupy, or transit orbits occupied by Starlink, potentially disrupting the operation of other critical satellite systems, including those in LEO. And both failed satellites and

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[29] The case for space environmentalism | Nature Astronomy.

[30] "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt", by Donald Kessler and Burton Cour-Palais.

[31] G. Long, The Impacts of Large Constellations of Satellites, JASON – The MITRE Corporation, JSR-20-2H, Nov. 2020, (Updated: 21 January 2021), https://www.nsf.gov/news/special_reports/jasonreportconstellations/JSR-20-2H_The_Impacts_of_Large_Constellations_of_Satellites_508.pdf.

[32] *See* https://planet4589.org/space/stats/star/starstats.html (detailing a variety of types of failures and anomalies involving Starlink satellites).

[33] *See Satellite Collisions Have the Same Consequences as ASAT Tests* (Nov. 2021), *available at* https://www.viasat.com/space-innovation/space-policy/space-debris/.

[34] *See Self-Cleaning Orbit Myth* (Dec. 2021), available at https://www.viasat.com/space-innovation/space-policy/space-debris/.

catastrophic collisions would make the orbital environment more crowded and dangerous, and make access to space more costly and risky for others — including satellites that provide broadband communications services, as well as those that provide critical space-based observations for weather forecasting, climate monitoring, and earth sciences, and PNT.

These harms would also include the costs and risks related to designing NGSO satellite and constellations to operate in a more crowded (and dangerous) environment, the risks and delays associated with launching satellites into and through those crowded environments (on the way to higher orbits, including GSO orbit), and the risks associated with deorbiting satellites through those crowded orbits at end of life.

Moreover, as observed by the CEO of one satellite launch provider,[35] the crowding of LEO from SpaceX's active satellites alone would reduce the number of viable launch windows available, and thus increase the costs and delay associated with launch activities of all types, for satellites in all orbits.

Furthermore, in a landmark report, the Organisation for Economic Cooperation and Development (OECD) points to the growing risk of an irreversible environmental and industrial disaster in space.[36] The deployment of mega-constellations such as Starlink outside a clear framework and regulation for the preservation of LEO therefore poses a potential direct threat to the function of key space-based systems, such as Galileo and Copernicus, which in turn "would have a direct impact upon the security, safety, economy and well-being of European citizens"[37].

Collision and orbital debris generation risks also are materially affected by the mass and cross-sectional area of LEO satellites, as well as just the number of satellites in a constellation and the particular orbits they employ. Ofcom therefore should (i) require Starlink to disclose those values so the aggregate risk presented by Starlink can be evaluated, and (ii) require that Starlink not make changes that increase the mass or cross-sectional area of its satellites, the number of its satellites, or the orbits it plans to use, without providing notice to and obtaining approval from Ofcom. This this information is essential to allow a calculation of, and management of, Starlink's total contribution to collision and orbital debris risk.

Finally, adverse effects on consumers and businesses are foreseeable due to the risk of market concentration and absence of competition. Indeed, an expanded Starlink system would place SpaceX in a quasi *de facto* monopoly in terms of LEO satellite broadband connectivity, squeezing out competition and considerably decreasing incentives to provide innovative and competitive offerings. As companies such as SpaceX further expand their grip over the space-based telecommunications sector, they will also have unprecedented control over vast amounts of its users' – and British citizens' – data, from web browser history to location tracking.

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[35] Jackie Wattles, Space is becoming too crowded, Rocket Lab CEO Warns, CNN (8 Oct. 2020), https://www.cnn.com/2020/10/07/ ("Satellite constellations can be particularly problematic, he said, because the satellites can fly fairly close together, forming a sort of blockade that can prevent rockets from squeezing through.").

[36] https://www.oecd.org/fr/environnement/space-sustainability-a339de43-en.htm.

[37] https://ec.europa.eu/info/sites/default/files/join_2022_4_1_en_act_part1_v6.pdf.

Question 4: Do you have any additional concerns or comments regarding this application?

4. Environmental effects on the atmosphere, sustainable space, optical astronomy, radio astronomy

The increased use of space is not without cost to the environment. The rapid development of mega-constellations such as Starlink risks multiple tragedies of the commons, including tragedies to ground-based astronomy, Earth orbit, and Earth's upper atmosphere.[38]

A growing number of scientific studies successively point to impediments to astronomy, increased risk of space debris, changes to the chemistry of Earth's upper atmosphere and increased dangers on Earth's surface from re-entered debris. NASA too has expressed concerns for "potential, additional impacts to science missions" in a recent filing to the United States Federal Communications Commission.[39]

The environmental consequences of the Starlink system—which is unprecedented in nature and would involve deploying approximately 90,000 (or more) satellites over 15 years, using a SpaceX launch every six days--would be grave.[40] Among other things, the impact of depositing an estimated 70,760 tons of alumina into the upper atmosphere when Starlink satellites deorbit[41] would certainly have deleterious effects. And the facts (including those provided by NASA) reflect that SpaceX is not protecting

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38 Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth | Scientific Reports (nature.com).

39 Letter from Kathy Smith, Chief Counsel, U.S. Department of Commerce, National Telecommunications and Information Administration to Ms. Marlene Dortch, U.S. Federal Communications Commission Secretary, *Re: Report No. SAT-01598 Space Station Applications Accepted for Filing, Space Exploration Holdings, LLC (SAT-AMD-202110818-00105)* (8 February 2022), https://cdn.arstechnica.net/wp-content/uploads/2022/02/NTIA-NASA-and-NSF-Fi.pdf.

40 Jeff Baumgartner, *Starlink's daunting deployment plan 'leaves no margin for error' – analyst*, BROADBAND WORLD NEWS (18 Jan. 2022), https://www.broadbandworldnews.com/author.asp?section_id=733&doc_id=774668, *citing Starlink: Go Big or Go Home*, MOFFETTNATHANSON (Jan. 18, 2022). "Even using Starship, at 100 satellites per launch, achieving a 30,000-bird constellation and sustaining it through, say, 2030, would require launching fifty thousand satellites, or five hundred rockets, between now and then," Moffett estimates. "That's a rocket launch roughly every six days... for nine years. Simply maintaining the constellation thereafter, if one assumes 20% annual attrition (de-orbiting), would require a new launch every six days. Forever."

41 Based on SpaceX's prior representation that 1st generation Starlink satellites "consist of approximately 230 pounds of aluminum" and that there is a "52% mass fraction aluminum" in alumina (Al_2O_3)., then 29,988 x 230 / 0.52 = 13,263,923 pounds. Factoring in replacements for those Gen2 satellites over a 15-year license term and that Gen2 satellites may be four times more massive, the proposed Starlink expansion could well result in SpaceX releasing over 78,000 tons of alumina into the upper atmosphere.

astronomy or preserving the night sky, and SpaceX has not shown how it would do so with an expanded Starlink system incorporating an additional 29,988 operating Gen2 satellites.[42]

Moreover, an increase in the number of failed Starlink satellites, catastrophic collisions involving Starlink (for any reason), and the resulting orbital debris fields, would make the orbital environment more crowded and dangerous, and risk the irreversible environmental disaster in space about which OECD warns (see section 3 above).

5. Potential implications for national security

Space is a vital component of any drive towards British strategic autonomy as it helps with situational awareness, decision-making and connectivity of technologies and systems, including with national security and defence applications.

The recent Anti-Satellite Test (ASAT) by the Russian Federation shows that hostile activities by sovereign actors in space represent a very significant threat to open and safe space. The same can be said of the risk that space activities carried out by private actors can represent to all space actors, in particular through the generation of a massive number of additional space objects and the corresponding risk of collisions leading to debris creation and possibly to a Kessler Syndrome (see section 3 above). As noted above, according to an evaluation of the debris generated by the Russian ASAT, a collision between two Starlink satellites would generate a similar dispersion of trackable and non-trackable debris in space.[43] Orbits made unusable by space debris would adversely affect defence and security applications the same way as civil and commercial use cases.

As a prime space power with significant existing and future assets in space to support its national security interests, the UK, through Ofcom, should be particularly mindful of the risk that ‘out-of-scale’ projects in LEO, like Starlink, could pose to its sovereign activities in and from space.

V. Conclusion

As the pace of space activities accelerates and societies become more reliant on space-based systems, the associated risks for the public interest and the British and European space industry deserve more attention. In light of the risks, outlined in the preceeding sections, posed by the Starlink system, Viasat UK urges Ofcom not to grant the authorisations requested by SpaceX in relation to Starlink.

Should Ofcom conclude that, at this stage, it does not hold sufficient information to allow it to reject Starlink’s applications, Viasat UK asks that Ofcom proceed with an independent assessment of the matters discussed above.

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42 Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth | Scientific Reports (nature.com).

43 *Satellite Collisions Have the Same Consequences as ASAT Tests* (Nov. 2021), available at https://www.viasat.com/space-innovation/space-policy/space-debris/.

Should Ofcom decide, after that assessment, to grant Starlink the requested authorisations to use radio spectrum, Ofcom should in any case subject such authorisations to the following conditions:

- Ensure non-interference into and mitigation of other adverse impacts on GSOs, including by requiring:
  - The Starlink system to maintain a suitable GSO arc avoidance angle when serving UK;
  - Starlink not to cause unacceptable interference into GSO networks and not to claim interference protection from GSO networks;
  - Starlink to have an operational feature that allows it to immediately interrupt radio frequency emissions to ensure satisfaction of this non-interference requirement, and to cease emissions upon notice of unacceptable interference;
  - If interference into a GSO network occurs, Starlink to cease operations and not recommence operations until it addresses the cause of such interference by, among other things, increasing angular separation, reducing power, shaping antenna beams differently;
  - That Starlink not use more than one satellite beam for satellite transmissions to user terminals operating on the same frequency in the same or overlapping areas at a time in the 10.7-12.75 GHz band or the 19.7-20.2 GHz band;
  - If aggregate interference to a GSO network from signals transmitted by multiple NGSO systems is detected, and it is not possible to identify the NGSO system generating the interference, that Starlink cooperate with the operators of such other NGSO systems, taking the technical measures necessary to eliminate the interference.

- Ensure non-interference into, and mitigation of other adverse impacts on, both GSOs and NGSOs, including by requiring:
  - Starlink to comply with single-entry EPFD limits across the entirety of the Starlink system, with Ofcom viewing all NGSO system filings under which the Starlink system operates as a collective;
  - The Starlink system operating such that it does not exceed the limits established for individual NGSO systems operating under a single ITU filing covering all system operations;
  - Starlink to constrain its preclusive effect on limited and shared NGSO orbital resources by:
    - Operating with only 1/n of the look angles in the UK, where *n* is the number of NGSO systems authorised to serve the UK in the same frequency band,
    - Coordinating in good faith and in advance with other NGSO systems so that all *n* look angles may be used to serve the UK by those different NGSO systems;
    - Maintaining an orbital tolerance of +/- 2.5 km for the apogee and perigee of each satellite, and a 0.5° tolerance for each orbital inclination it employs, in order to ensure other NGSO systems may access the shared LEO space (or complying with such other orbital tolerance requirements as Ofcom deems appropriate to ensure the ability of other satellites and

systems serving the UK to safely operate within the same or overlapping, orbits occupied by Starlink, or other large LEO constellations).

- Adopt suitable conditions to address the types of environmental harms discussed above.
- Require that Starlink not modify the characteristics of its LEO system (radio frequency, orbits used, number of satellites, or satellite cross-sectional area or mass) without prior consent from Ofcom (in order to maintain its authorisations in the UK).
- Require that Starlink provide, every 6 months, a report showing compliance with the obligations attached to the authorisations granted.

Finally, it bears note that these types of conditions could be equitably applied to all LEO constellations that seek to serve the UK. Plans exist for hundreds of thousands of LEO satellites from multiple large constellations and equitable conditions are essential for effective competition in the marketplace. The conditions should consider that to the extent LEO constellations are economically viable, there are likely to be many – not just a few. Moreover, consistent licensing conditions are likely to be an essential part of a global competitive market – since LEO satellites are intrinsically intended to operate globally. Thus, it would serve British and European interests if the UK worked with other administrations to adopt this type of approach on a coordinated basis to promote a pro-competitive environment that includes access for British and European industry globally.

Annex A: Starlink Interference Into GSO Networks

GSO networks are approaching a three-order-of-magnitude increase in capacity due in part to increased spectral efficiency which is facilitated by employing satellite receivers with low noise temperatures and high antenna gains (G/T). Today, even a single NGSO system has the potential to cause interference into GSO networks. Multiple NGSO systems operating simultaneously pose an even greater risk to those GSO networks.

In various frequency bands, Starlink is subject to limits on the EPFD it may generate toward GSO networks.[44] There are two types of these limits. "Aggregate" EPFD limits constrain the amount of interference that *all* NGSO systems in total (including Starlink) may cumulatively generate with respect to GSO networks. These aggregate limits must be shared among all NGSO systems using the same or overlapping frequencies.

"Single-entry" EPFD limits constrain the amount of interference that individual NGSO systems—including the Starlink system itself—may generate with respect to GSO networks. Those single-entry limits were established based on the assumption that 3.5 NGSO systems would be operating at a given time and generating combined EPFD levels consistent with the applicable "aggregate" EPFD limits.[45]

As detailed below, the Starlink system would exceed both the "single-entry" and "aggregate" EPFD limits in various respects in both the Ku and Ka bands. Exceeding the "single-entry" EPFD limit curve at any point is a violation of the ITU Radio Regulations. Exceeding the "aggregate" EPFD limit curve is also a violation.

Starlink Violations of Single Entry EPFD Limits

The single-entry EPFD limits that apply to Starlink are specified as a series of different levels that are permitted for time-varying intervals.[46] That is, one limit must be satisfied 100 percent of the time; and other limits must be satisfied for other percentages of time. Example limit curves are shown in Figures A-1 (Ku band) and A-2 (Ka band) below.

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[44] ITU Rad. Reg. Art. 22; ITU Res. 76.

[45] *See* ITU Res. 76.

[46] ITU Rad. Reg. Art. 22.

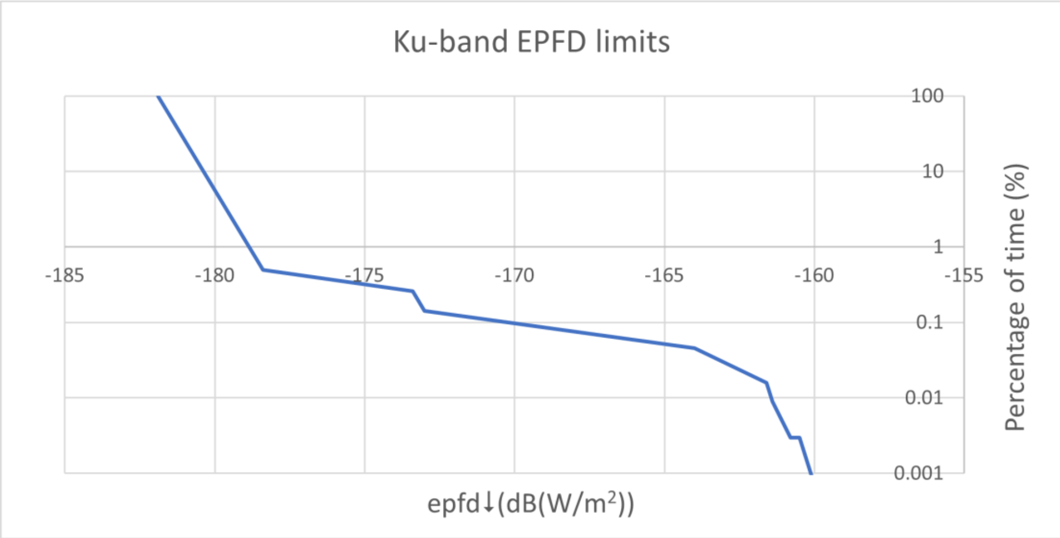

Figure A-1 – Ku-Band EPFD Limits Applicable to Starlink

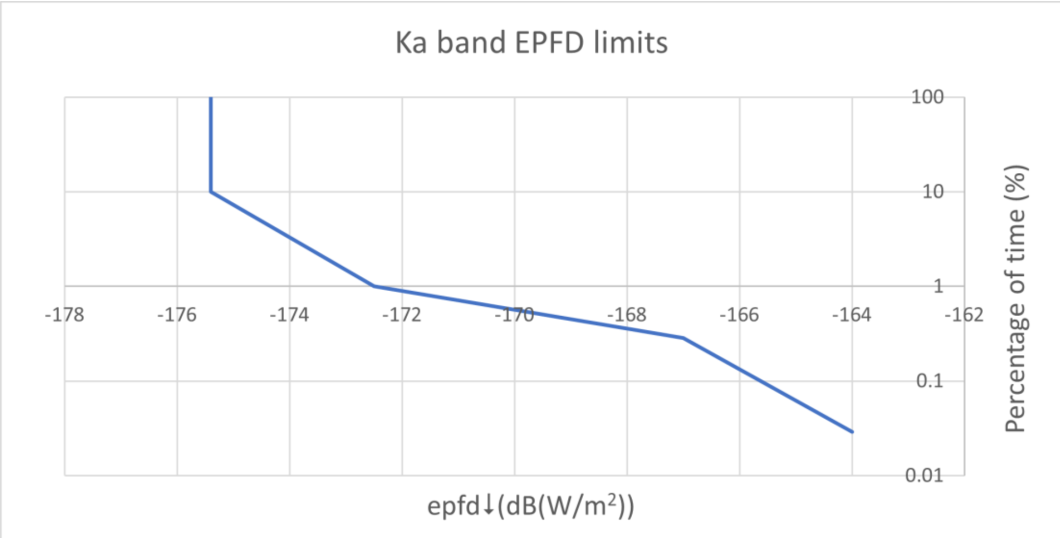

Figure A-2– Ka-Band EPFD Limits Applicable to Starlink

Any exceedances of those EPFD levels—whether of the "100%" value, the "1%" value, or of other values—has the potential to cause harmful interference into GSO networks.

The ITU's methodology and implementing software for assessing expected EPFD levels from NGSO operations rely on an algorithm that derives a "worst-case geometry" found at one particular location on the Earth's surface.[47] That is, the algorithm attempts to identify, for the specific NGSO satellites under the relevant filing and a representative GSO network, the single location that results in the highest single-entry NGSO EPFD level that can be expected. Again, this value is produced for a very short period of time, and thus lies at the bottom of the relevant EPFD results curve (*i.e.*, the alignment of the NGSO system with the GSO network that produces the highest instantaneous interference level---for a very small percentage of the time).

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47 *See generally* ITU-R Rec. S.1503.

Critically, EPFD level distributions predicted at locations other than the one identified by the algorithm can exceed the relevant EPFD limit curve even though the peak predicted EPFD at that location is lower than that at the so-called "worst-case" location. Such instances in which EPFD limits could be violated 1%, 10%, and even 100% of the time are most concerning. Interference generated for these percentages of time could well degrade service levels and cause capacity losses to GSO networks.

Analysis of Single-Entry EPFD Violations at Other Points on the EPFD Curve

Figures A-3 (Ku band) and A-4 (Ka band) below present the results of Ku and Ka band analysis at Goonhilly prepared by OneWeb for the Gen1 Starlink configuration.[48]

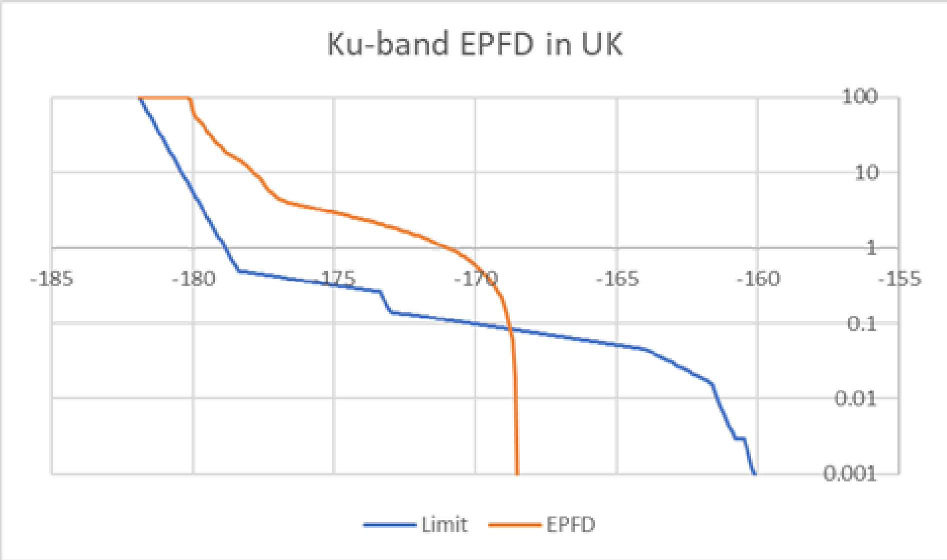

Figure A-3 – Starlink Ku-Band EPFD Levels at Goonhilly, England

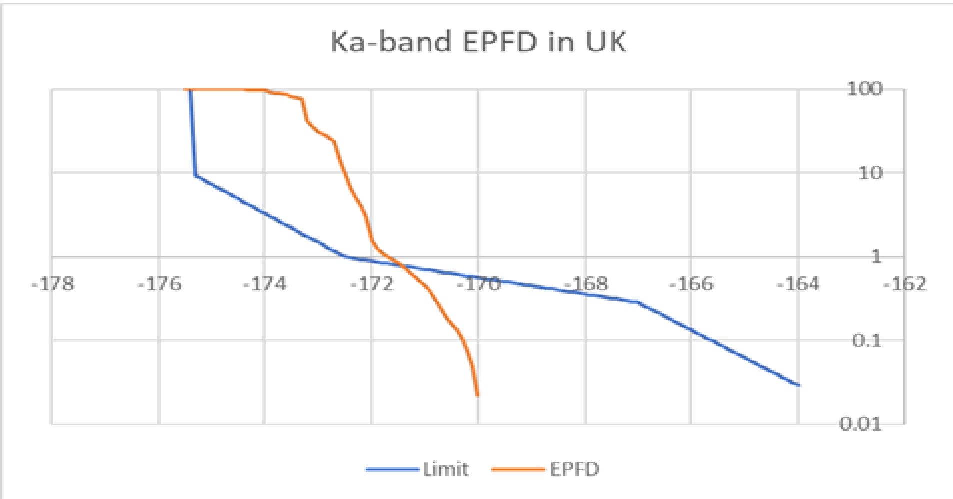

Figure A-4 – Starlink Ka-Band EPFD Levels at Goonhilly, England

48 "Need for a Procedure to Deal with Cases of EPFD Exceedance that are Not Detected by the Worst-Case Geometry Algorithm in Recommendation ITU-R S.1503", Document 4A/[OW-4] prepared by OneWeb and submitted to ITU-R WP4A, 19 June 2019.

Figures A-3 and A-4 show that even though the Starlink system may appear to be able to satisfy applicable EPFD↓ limits at the "worst-case" location tested pursuant to the ITU's algorithm, in reality there are other locations where the same system under the same input parameters and assumptions would exceed the EPFD↓ limits at other percentages of time. In fact, one exceedance reflected in Figure A-3 for Starlink alone is more than double the aggregate EPFD↓ limit that must be apportioned among all co-frequency NGSO systems.

Figures A-5 (Bristol), A-6 (Fawley), A-7 (Hoo), A-8 (Morn Hill), A-9 (Wherstead) and A-10 (Woodwalton) show that the Gen1 Starlink configuration exceeds the Art. 22 EPFD limits in Table 22-1B for the 17.8 – 18.6 GHz band at all the six proposed Starlink gateway locations. The peak exceedances with respect to the RR Table 22-1B EPFD limits are shown in Table A-1 below for all six proposed Starlink gateway locations.

Table A-1 - Peak Exceedances

Locations	Peak Exceedance
Bristol	2.2 dB
Fawley	2.5 dB
Hoo	1.9 dB
Morn Hill	2.3 dB
Wherstead	1.6 dB
Woodwalton	1. 4 dB

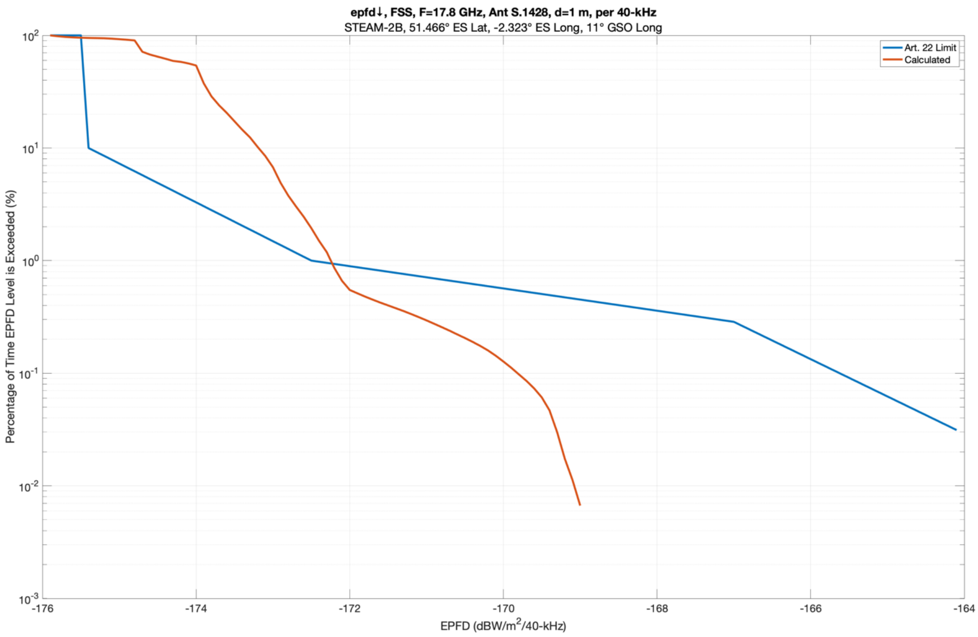

Figure A-5 - epfd↓,17.8 GHz, Bristol

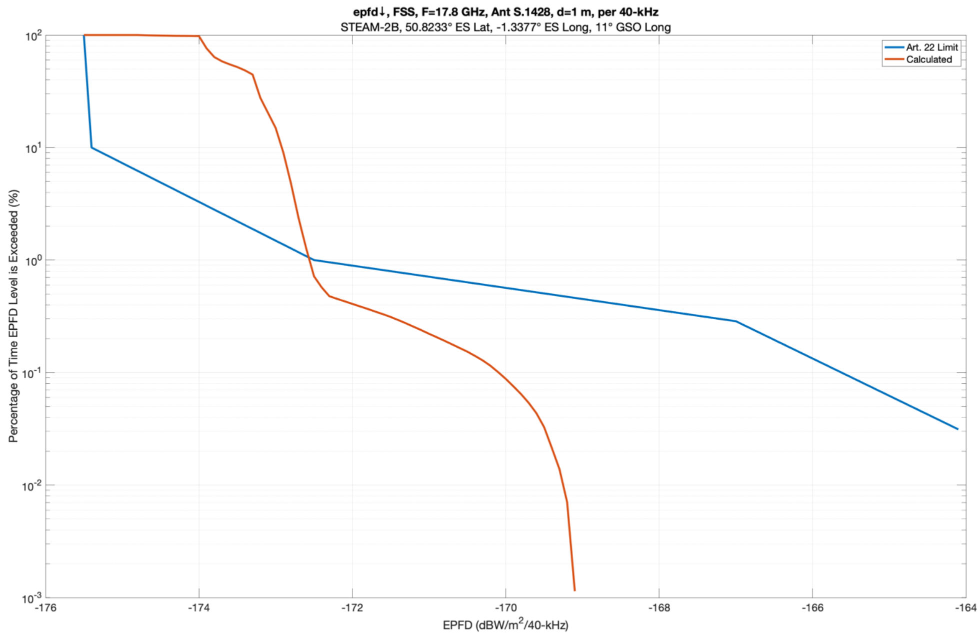

Figure A-6 - epfd↓,17.8 GHz, Fawley

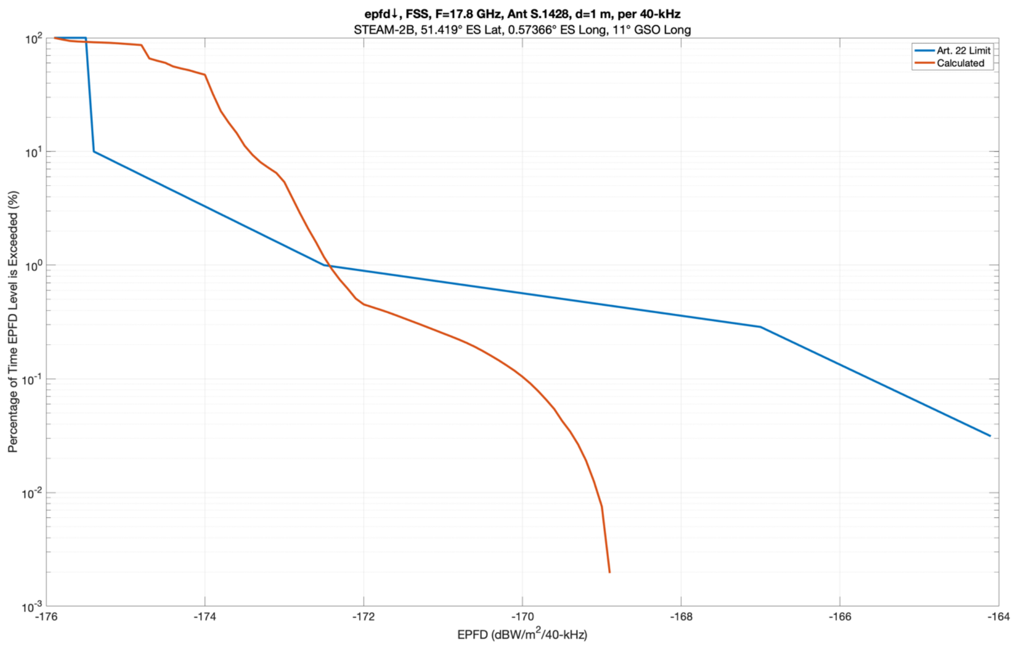

Figure A-7 - epfd↓,F17.8 GHz, Hoo

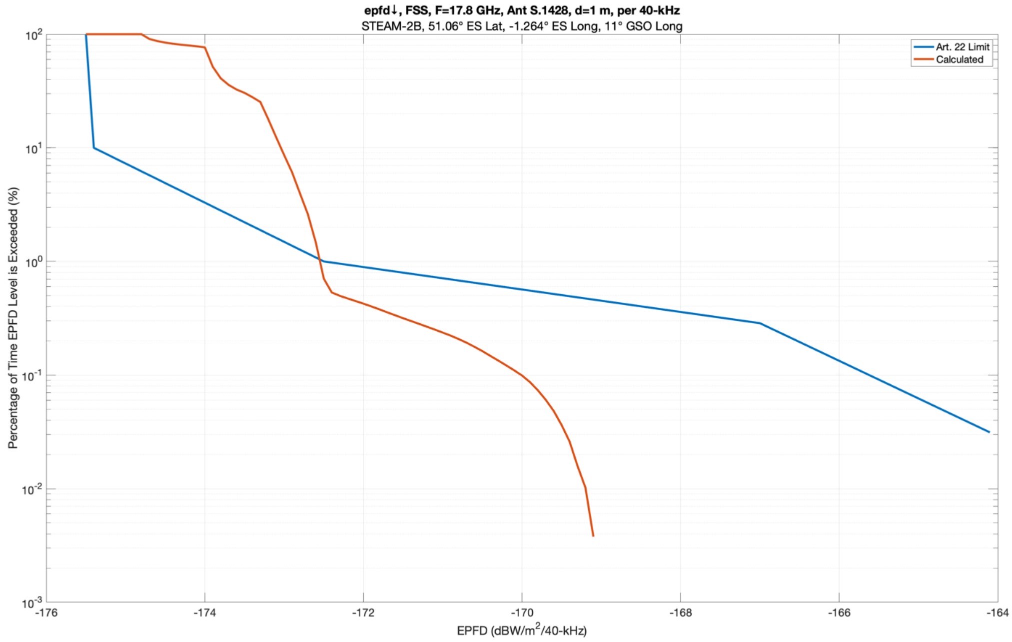

Figure A-8 - epfd↓,17.8 GHz, Morn Hill

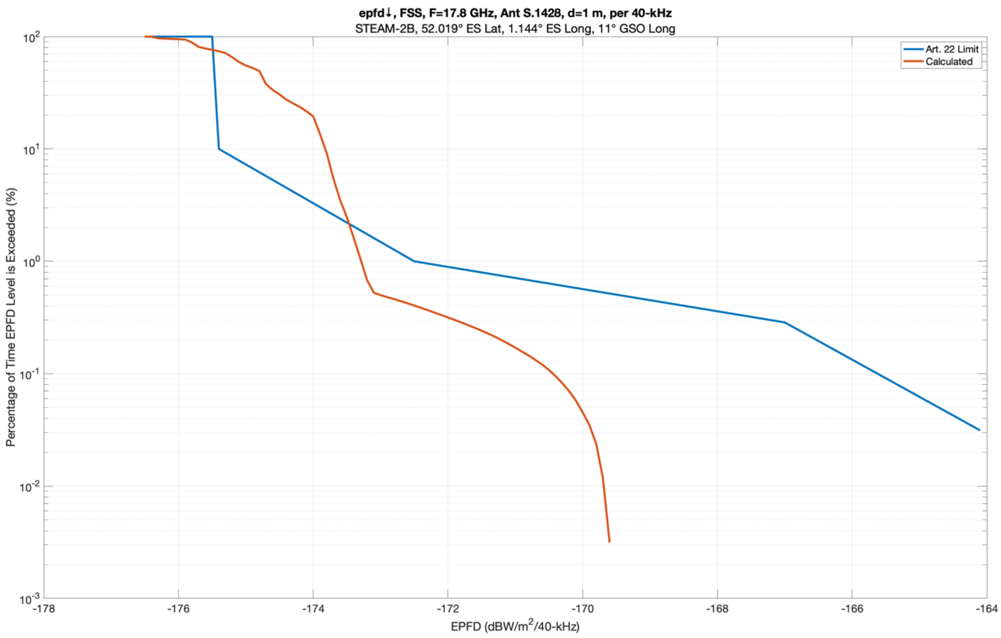

Figure A-9 - epfd↓,17.8 GHz, Wherstead

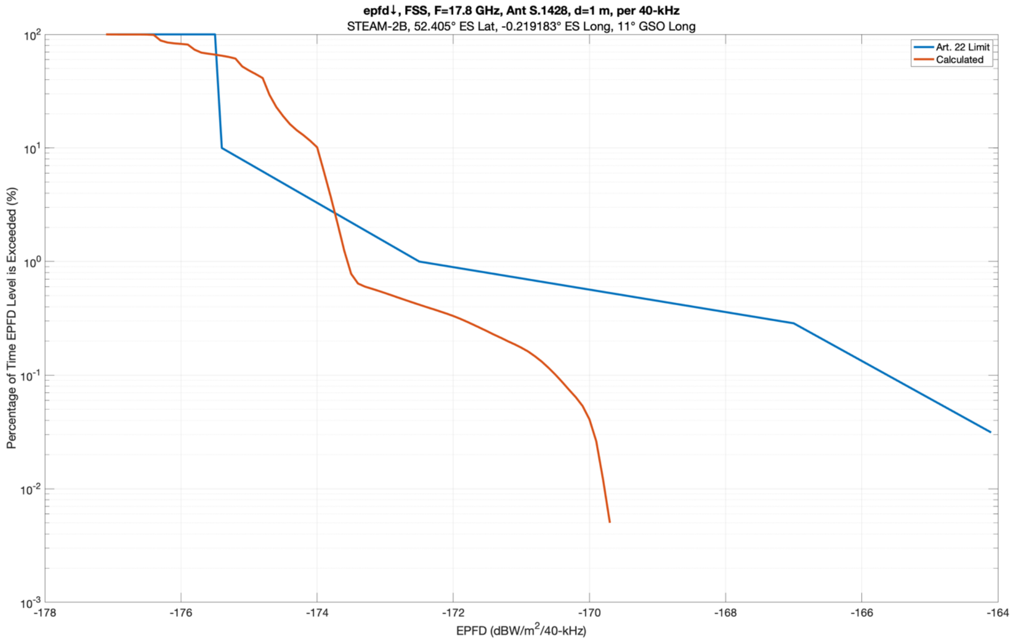

Figure A-10 - epfd↓,17.8 GHz, Woodwalton

In the Ku band, EPFD exceedances SpaceX's Gen1 Starlink configuration are not isolated to Goonhilly location. Figures A-11 to A-23, show that the Gen1 Starlink system exceeds the Art. 22 EPFD limits in Table 22-5C for the 10.7 – 11.7 GHz band at other locations as well like Portsmouth and Northampton. The peak exceedances are shown in Table A-2 and Table A-3 for the RR Table 22-5C GSO earth station antenna sizes.

Table A-2 – Peak Exceedances, Portsmouth

GSO ES Ant. Diam., m	Peak Exceedance
0.6 (FSS)	2.4 dB
1.2 (FSS)	8.0 dB
3.0 (FSS)	9.2 dB
10.0 (FSS)	1.4 dB

Table A-3 - Peak Exceedances, Northampton

GSO ES Ant. Diam., m	Peak Exceedance
0.6 (FSS)	1.3 dB
1.2 (FSS)	6.4 dB
3.0 (FSS)	6.4 dB
0.45 (BSS)	2.2 dB
0.6 (BSS)	2.2 dB
0.9 (BSS)	1.7 dB
1.8 (BSS)	0.8 dB
2.4 (BSS)	3 dB
3 (BSS)	5 dB

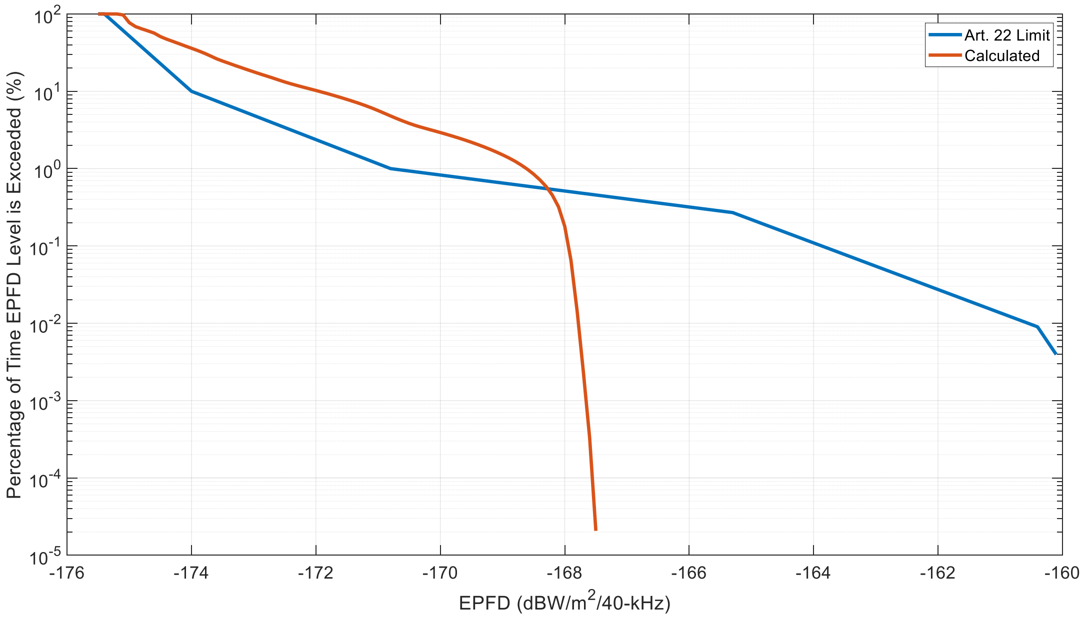

Figure A-11 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=.6 m, per 40 kHz (Portsmouth, UK)

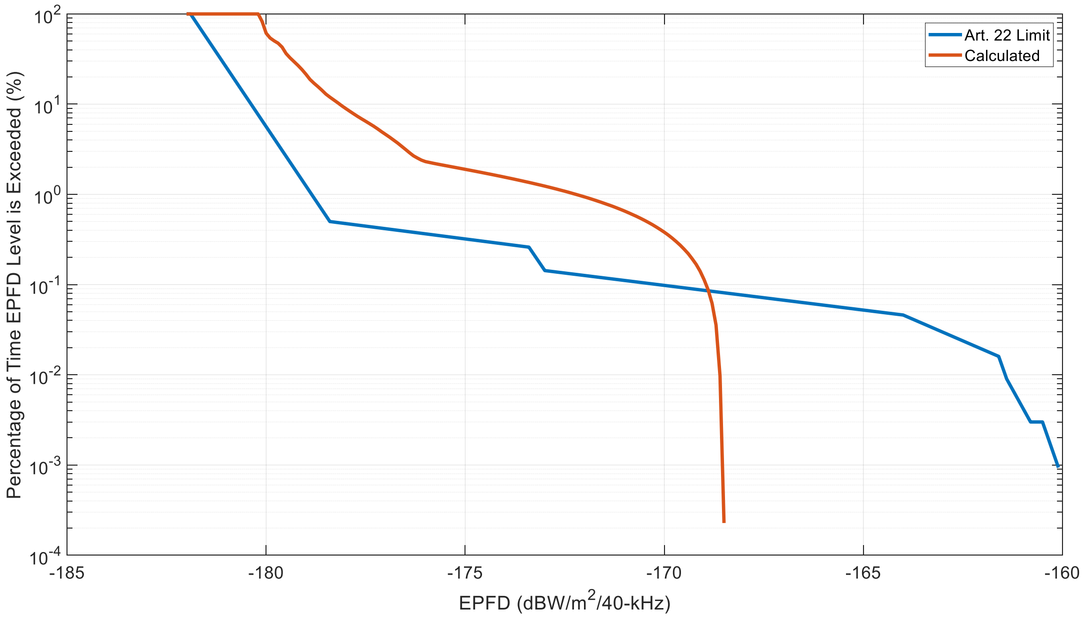

Figure A-12 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=1.2 m, per 40 kHz (Portsmouth, UK)

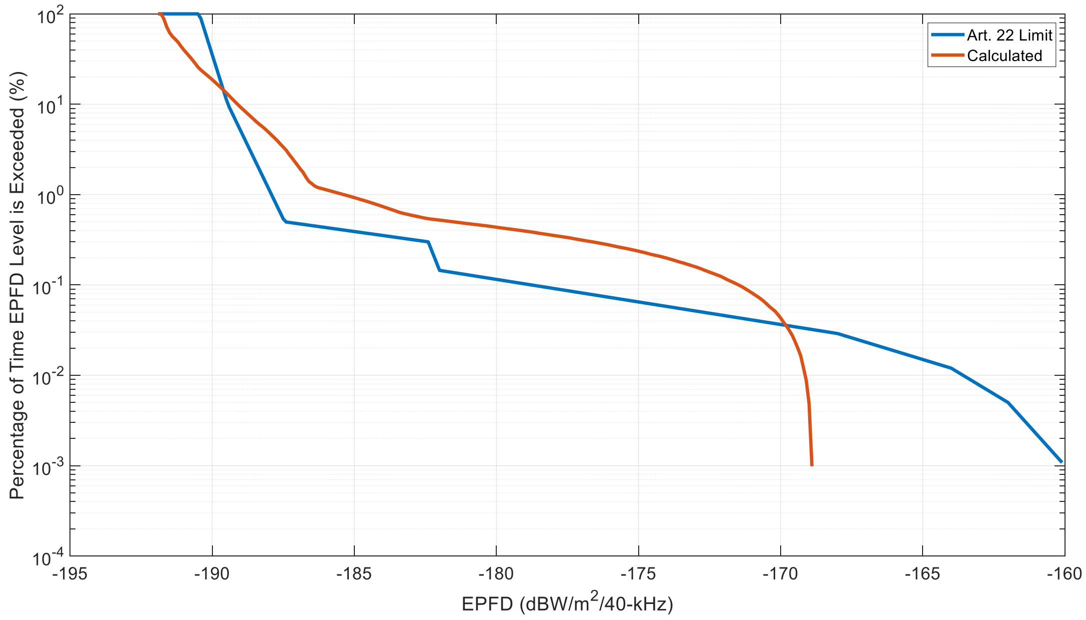

Figure A-13 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=3 m, per 40 kHz (Portsmouth, UK)

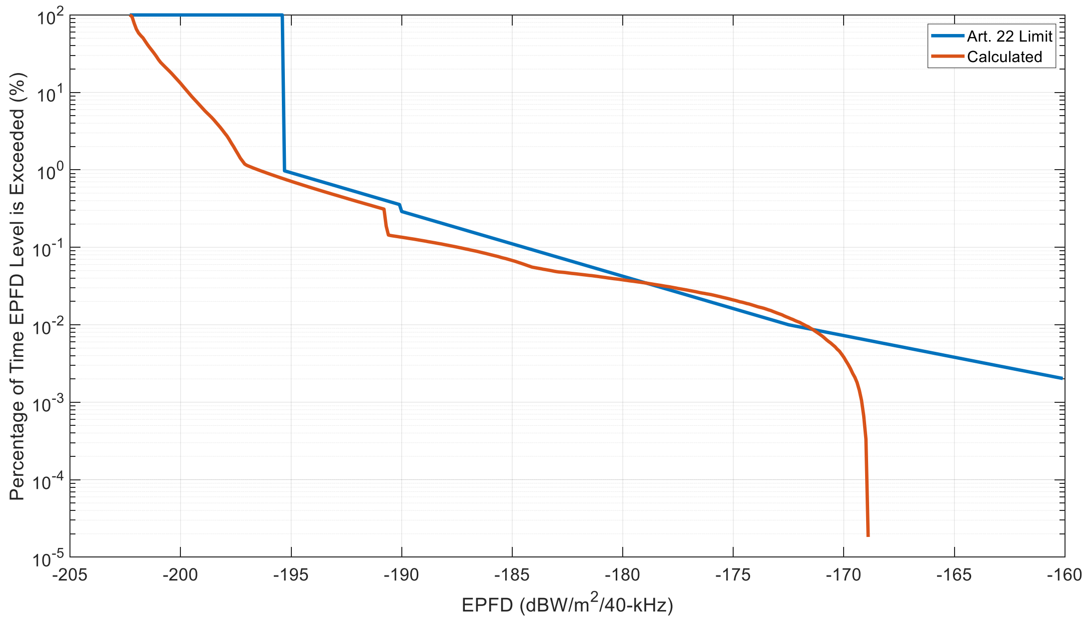

Figure A-14 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=10 m, per 40 kHz (Portsmouth, UK)

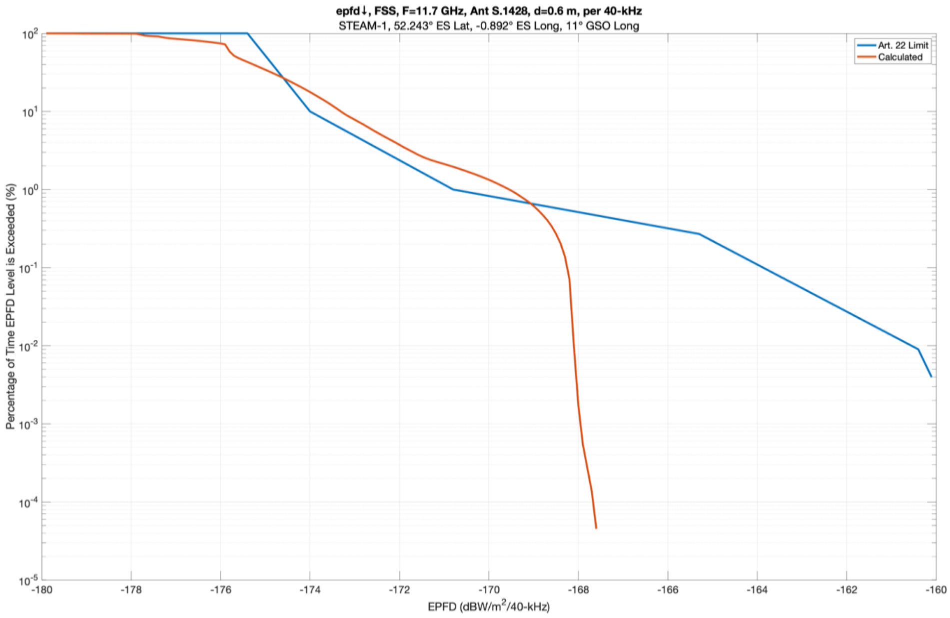

Figure A-15 - epfd↓, FSS, F=11.7 GHz, Ant S.1428, d=0.6 m, per 40 kHz (Northampton, UK)

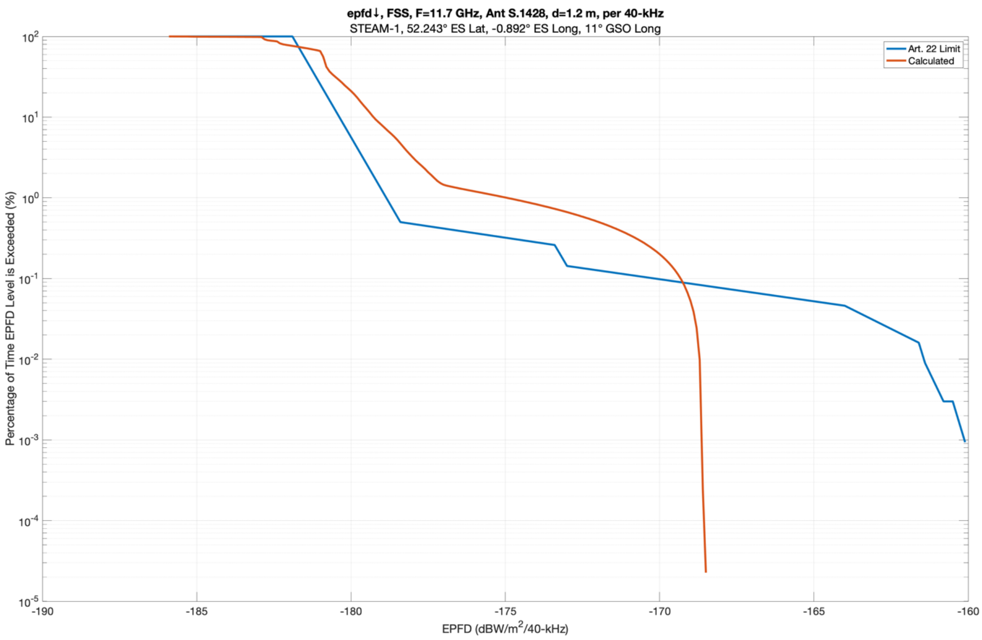

Figure A-16 - epfd↓, FSS, F=11.7 GHz, Ant S.1428, d=1.2 m, per 40 kHz (Northampton, UK)

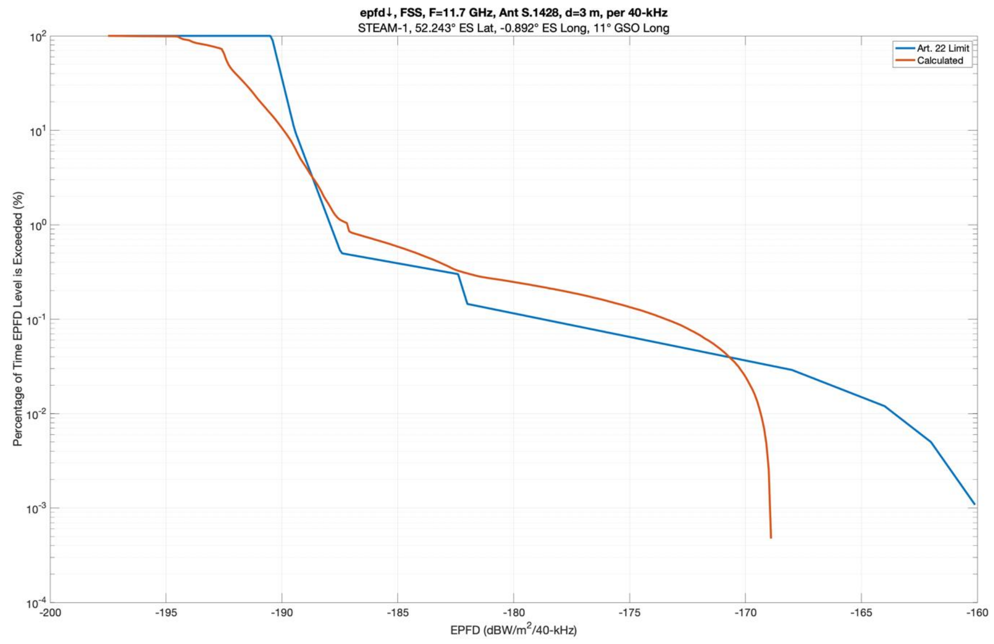

Figure A-17 - epfd↓, FSS, F=11.7 GHz, Ant S.1428, d= 3 m, per 40 kHz (Northampton, UK)

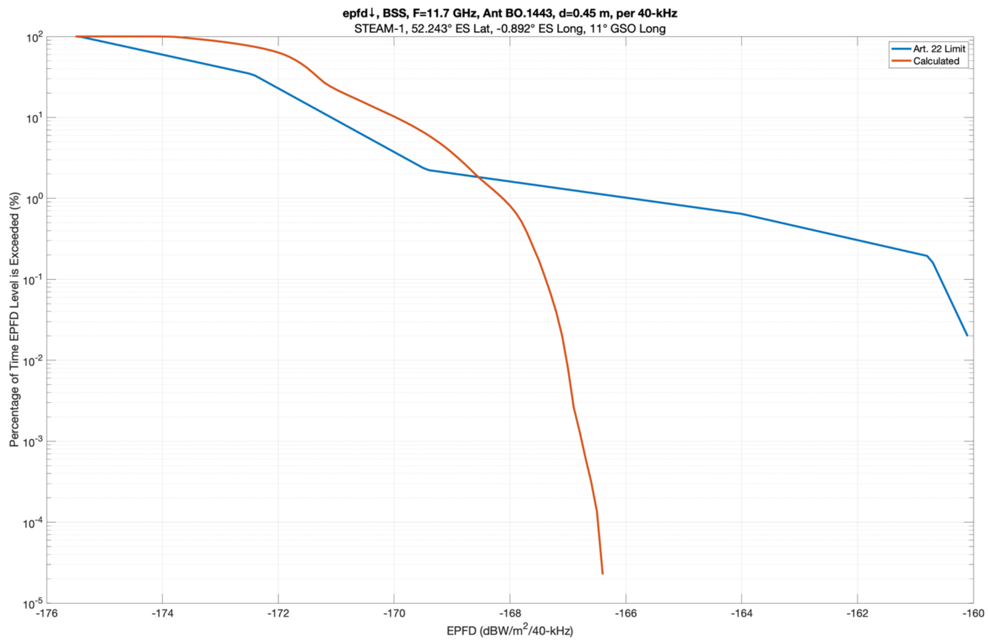

Figure A-18 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 0.45 m, per 40 kHz (Northampton, UK)

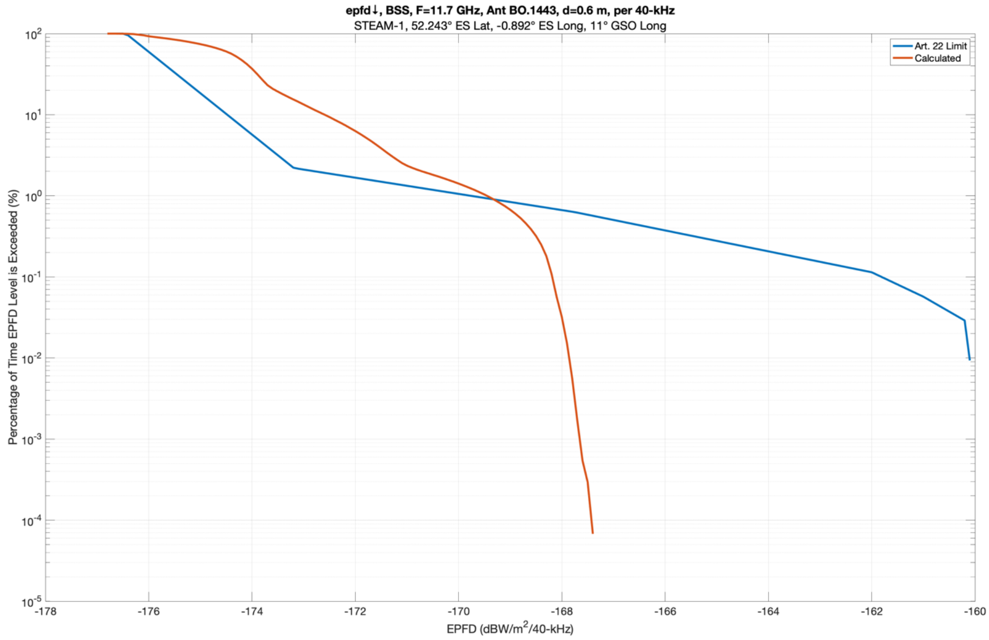

Figure A-19 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 0.6 m, per 40 kHz (Northampton, UK)

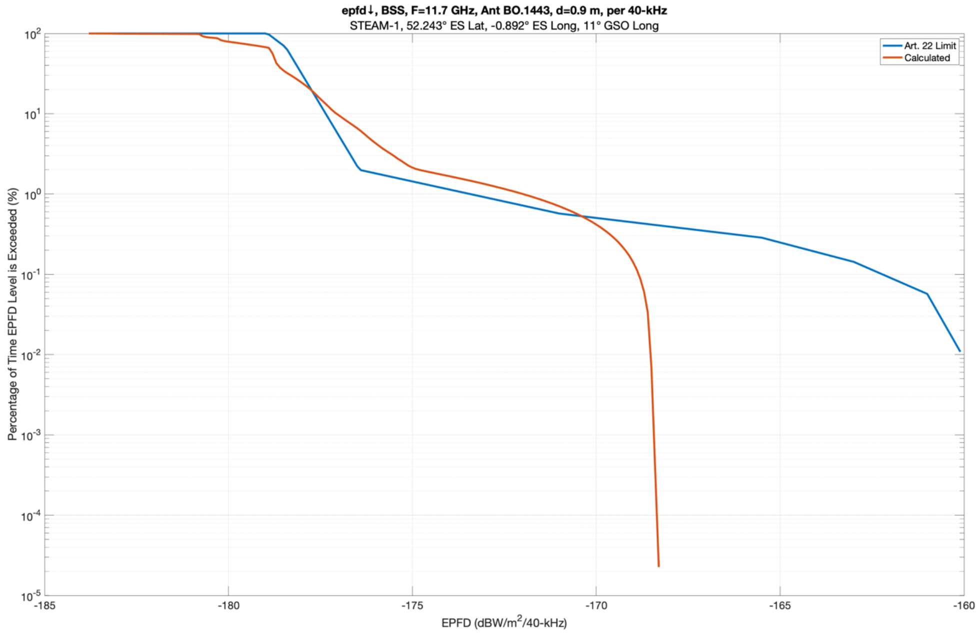

Figure A-20 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 0.9 m, per 40 kHz (Northampton, UK)

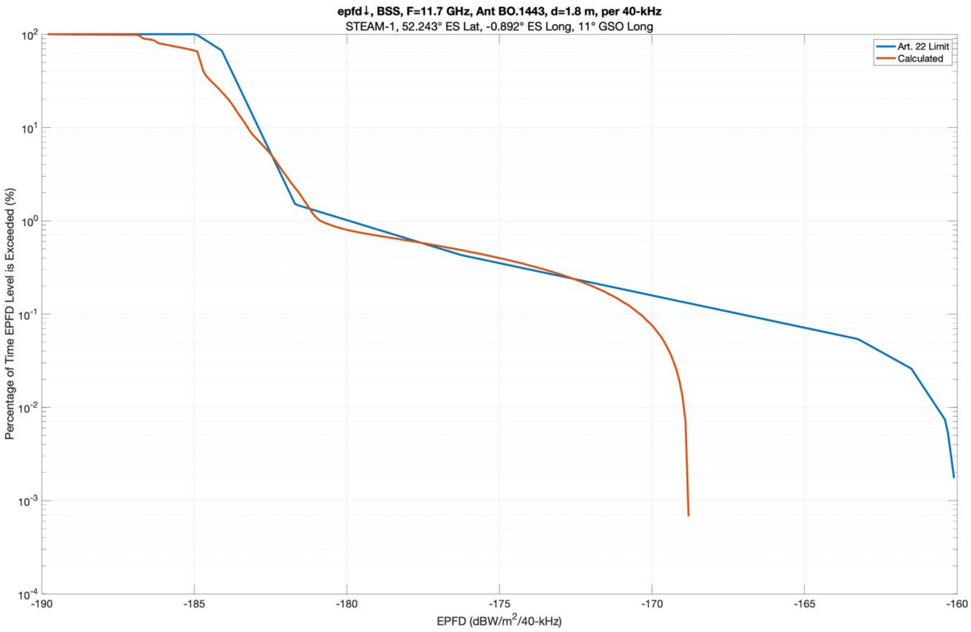

Figure A-21 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 1.8 m, per 40 kHz (Northampton, UK)

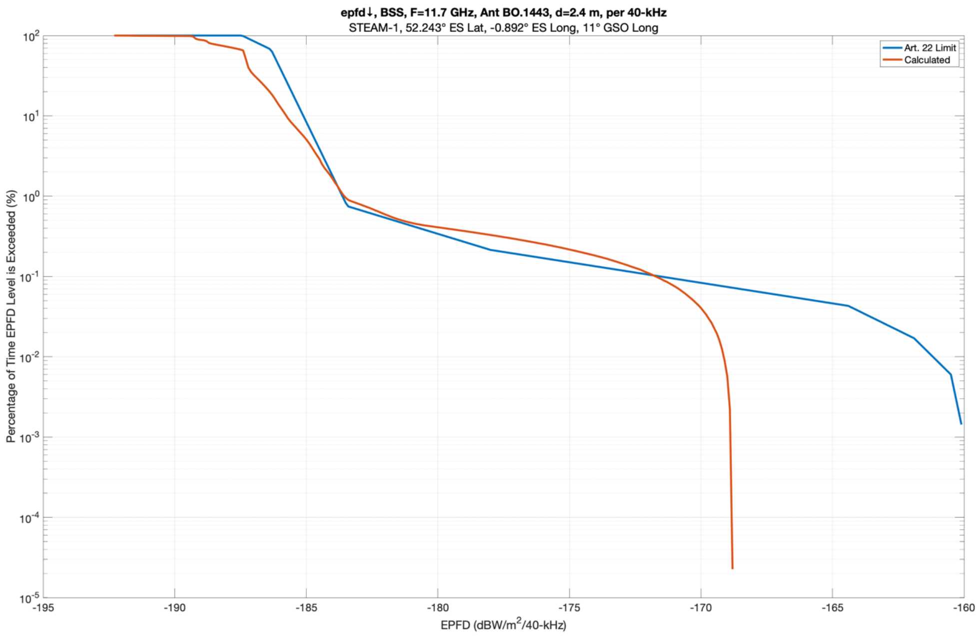

Figure A-22 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 2.4 m, per 40 kHz (Northampton, UK)

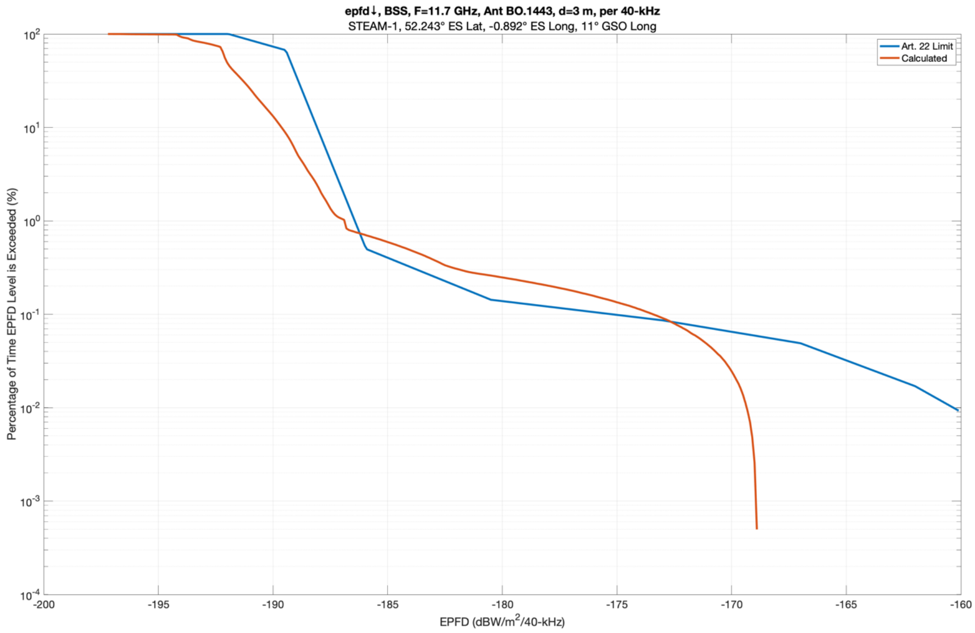

Figure A-23 - epfd↓, BSS, F=11.7 GHz, Ant BO.1443, d= 3 m, per 40 kHz (Northampton, UK)

Notably, ITU-R Rec. S.1503 explains the *necessity* of compliance with all EPFD limits *at all locations and for all geometries*. Specifically:

> The EPFD limits in Article 22 are applicable for all GSO ESs and all pointing angles towards that part of the GSO arc visible from that ES. It is, however, not feasible to model all such geometries within the verification software. The worst-case geometry (WCG) is a reference GSO satellite location and either an ES or boresight of the GSO satellite's beam which is used when examining a non-GSO system for compliance with the epfd limits in Article 22. *It remains necessary for the non-GSO operator to meet the epfd limits in Article 22 for all other geometries* including the testing of specific GSO networks as noted in § A1.3.[49]

Starlink Gen 2 Violations of EPFD Limits

The following figures show the interference impact on GSO networks where an NGSO system like Starlink operates under multiple ITU filings, as is the case for its Gen2 configuration. The following figures from A-24 to A-47 shows the interference levels that would be generated by SpaceX's proposed Gen2 operations considered as a whole—*i.e.,* the EPFD generated by all Gen2 satellites operating under SpaceX's 18 different ITU filings that comprise that configuration[50] — and compares those interference levels to applicable ITU Art. 22 single-entry EPFD down limits and ITU Res. 76 aggregate EPFD down limits.

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49 ITU-R Rec. S.1503 § D3 (emphasis added).

50 The relevant ITU filings are: USASAT-NGSO-3N, USASAT-NGSO-3O, USASAT-NGSO-3P, USASAT-NGSO 3Q, USASAT-NGSO-3R1, USASAT-NGSO-3R2, USASAT-NGSO-3S1, USASAT-NGSO-3S2, USASAT-NGSO-3S3, USASAT-NGSO-3T1, USASAT-NGSO-3T2, USASAT-NGSO-3T3, USASAT-NGSO-3U1, USASAT-NGSO-U2, USASAT-NGSO-3V1, USASAT-NGSO-3V2, USASAT-NGSO-3W1, and USASAT-NGSO-3W2.

Combined EPFD curves were generated for all proposed Gen2 satellites using the EPFD input files provided by SpaceX for each of its 18 ITU system filings. The ITU's EPFD validation software (based on ITU-R Rec. S.1503-2) was run for each of the filings. The resulting 18 EPFD probability density functions ("PDFs") for each of the cases identified in the Art. 22 and Res. 76 EPFD limits were combined, using standard techniques for the sum of independent random variables,[51] to generate the combined EPFD curves.

This analysis was conducted for different portions of the Ku and Ka band covering both FSS and BSS allocations and various GSO earth station antenna sizes ranging from 0.3 m to 10 m. The Article 22 limits are exceeded by as much as 7.6 dB to 11.8 dB, depending on the case. The Resolution 76 limits are exceeded by 1.5 dB to 6.4 dB.

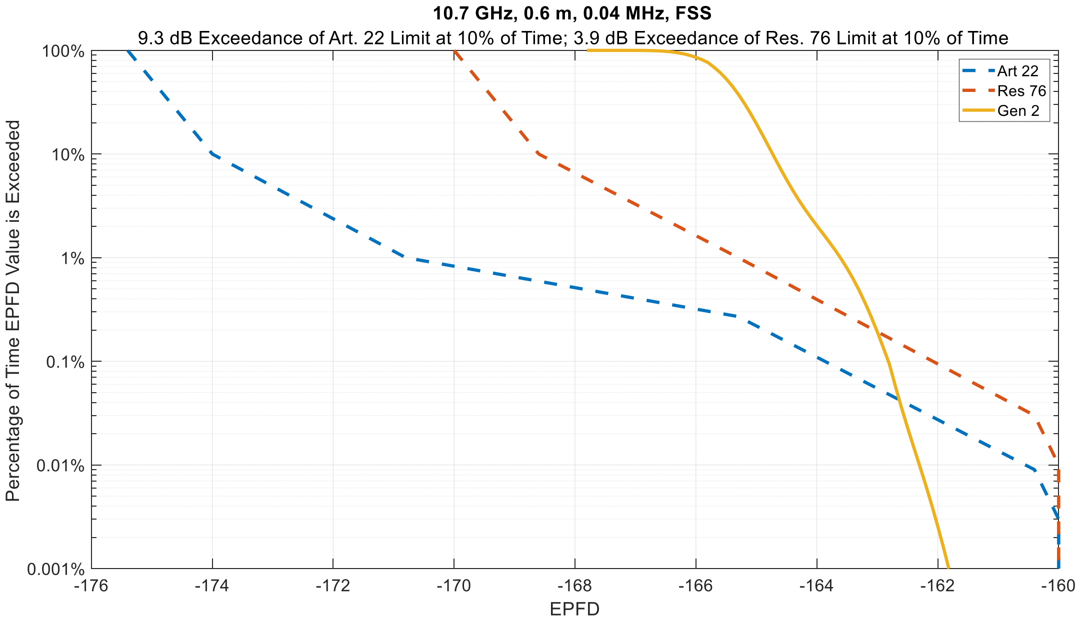

Figure A-24 - epfd↓, FSS, F=10.7 GHz, d=0.6 m, per 40 kHz

51 The relevant techniques are discussed in most textbooks. See any textbook on probability theory. See also, *e.g.*, Marco Taboga, Sums of independent random variables, StatLect, at, or for example: https://www.statlect.com/fundamentals-of-probability/sums-of-independent-random-variables (last visited 14 July 2022); Alex Tsun, Convolution (last visited 14 July 2022), https://courses.cs.washington.edu/courses/cse312/20su/files/student_drive/5.5.pdf.

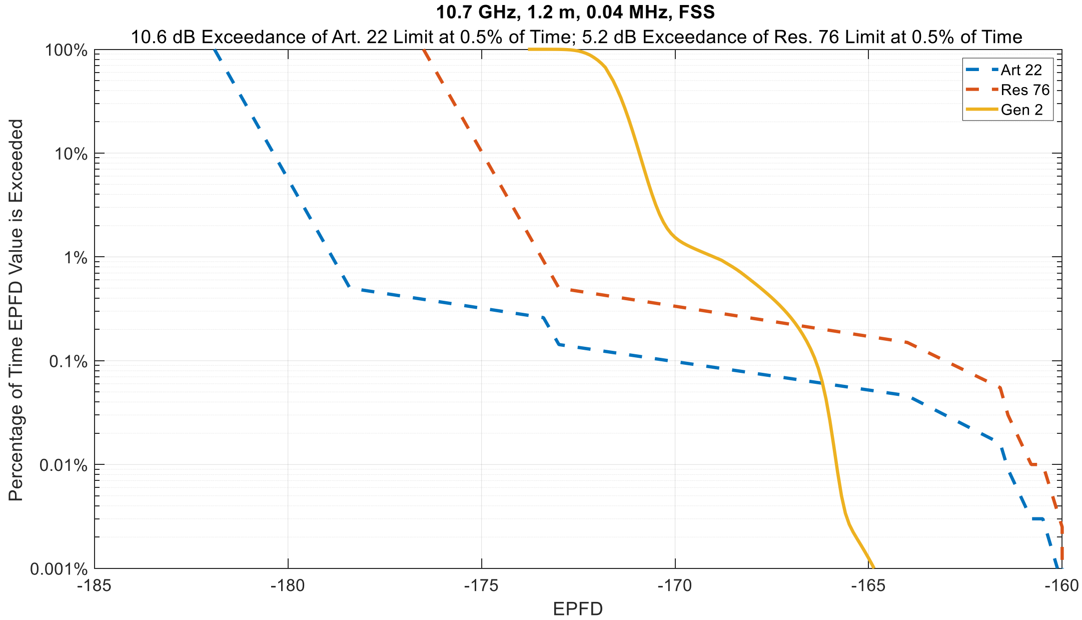

Figure A-25 - epfd↓, FSS, F=10.7 GHz, d=1.2 m, per 40 kHz

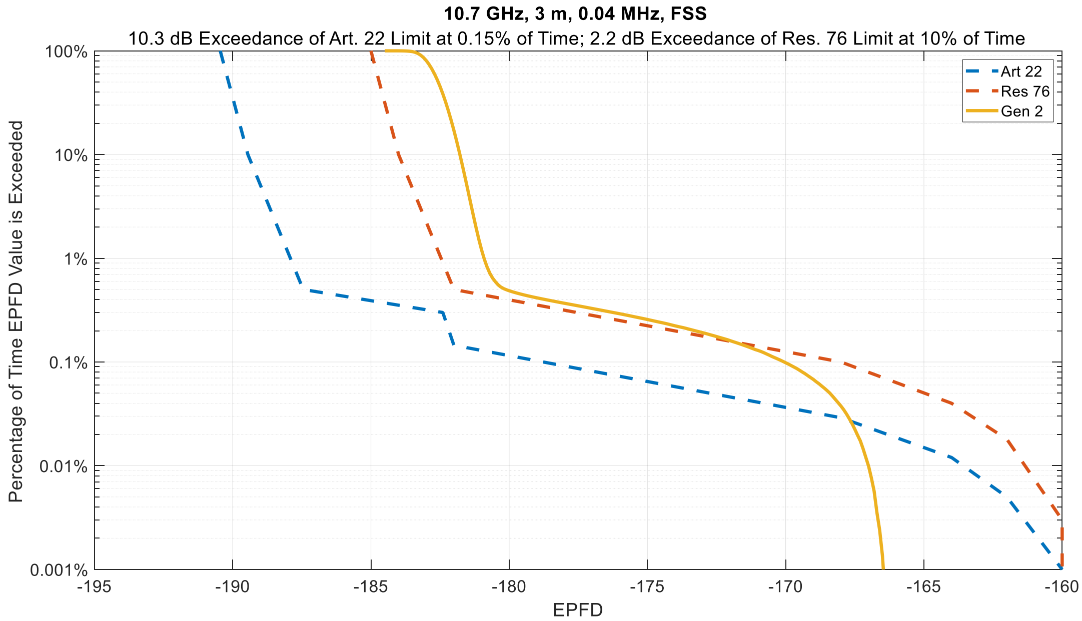

Figure A-26 - epfd↓, FSS, F=10.7 GHz, d=3 m, per 40 kHz

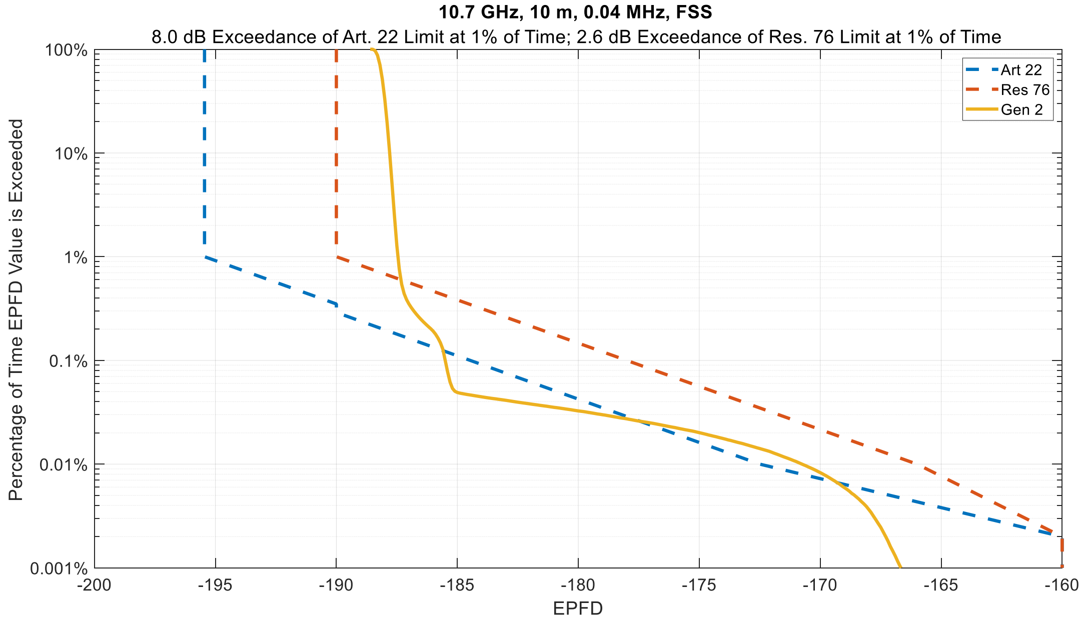

Figure A-27 - epfd↓, FSS, F=10.7 GHz, d=10 m, per 40 kHz

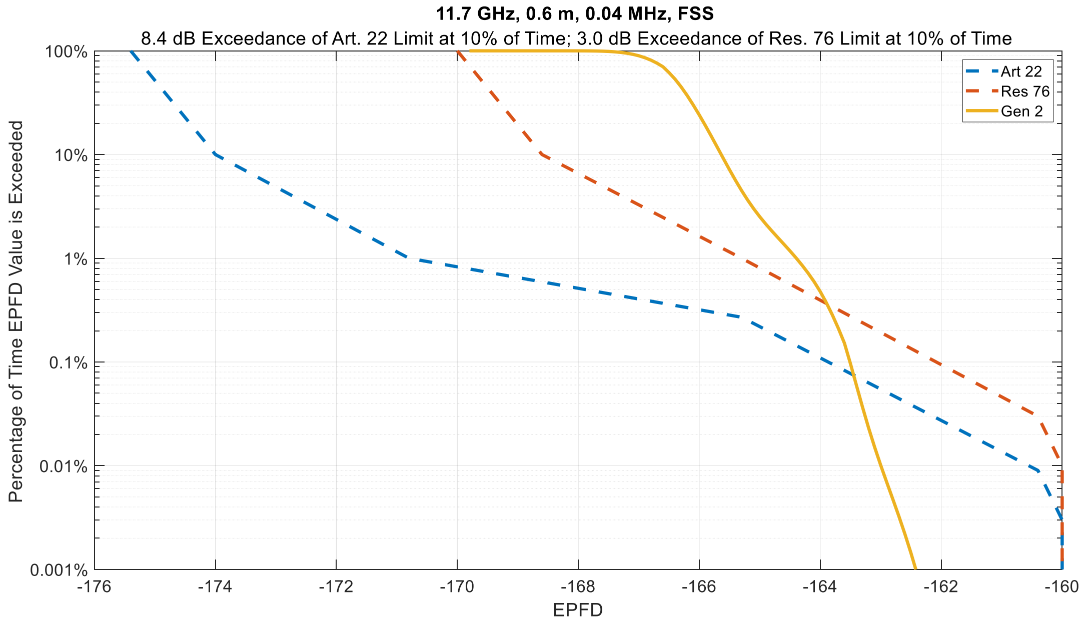

Figure A-28 - epfd↓, FSS, F=11.7 GHz, d=0.6 m, per 40 kHz

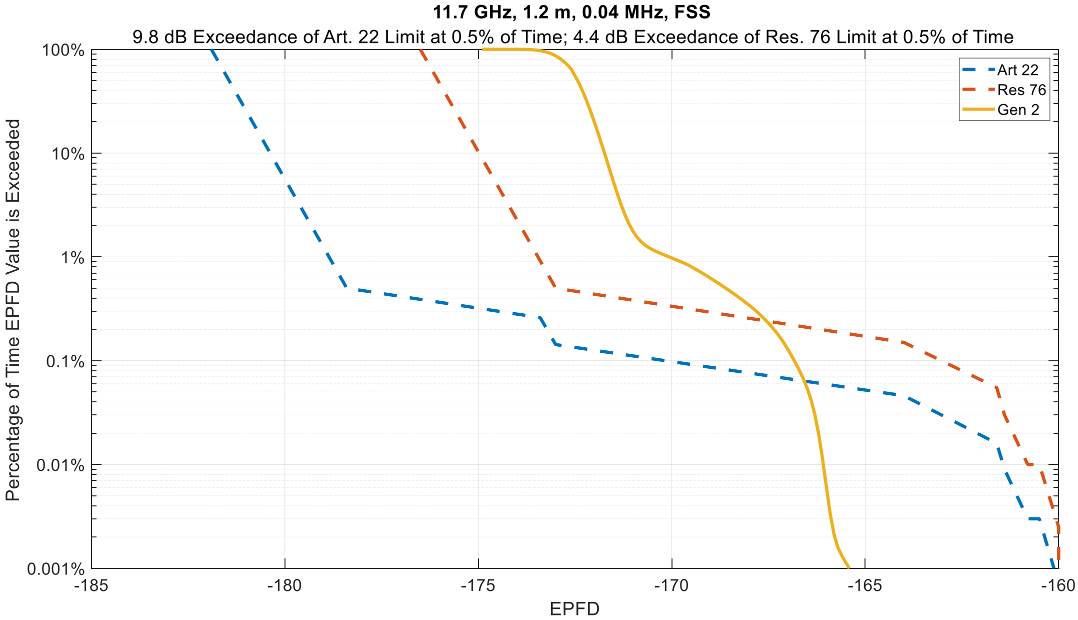

Figure A-29 - epfd↓, FSS, F=11.7 GHz, d=1.2 m, per 40 kHz

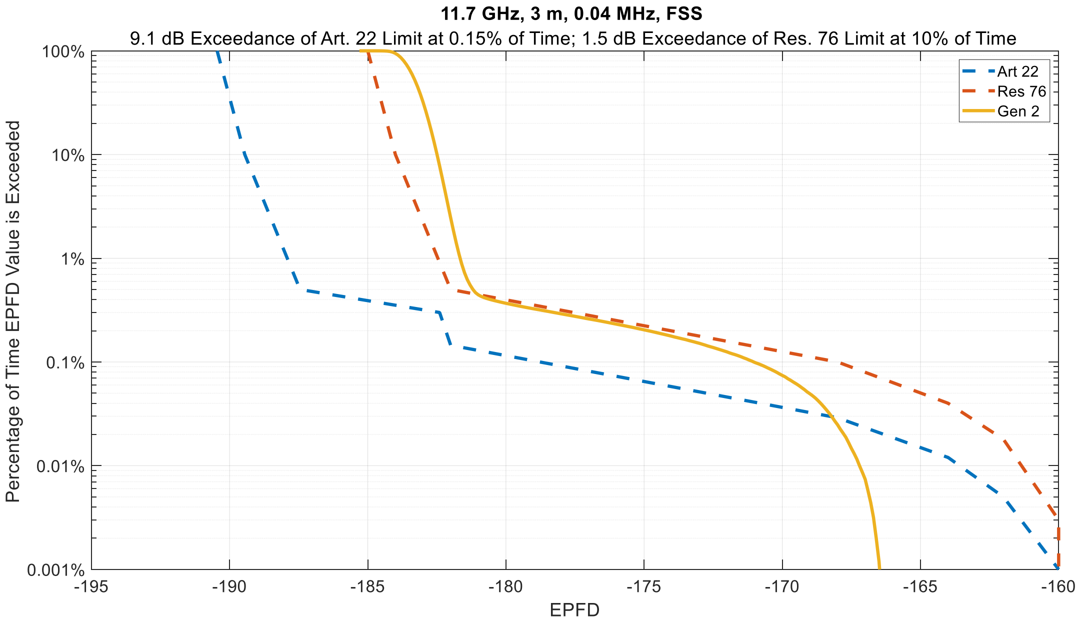

Figure A-30 - epfd↓, FSS, F=11.7 GHz, d=3 m, per 40 kHz

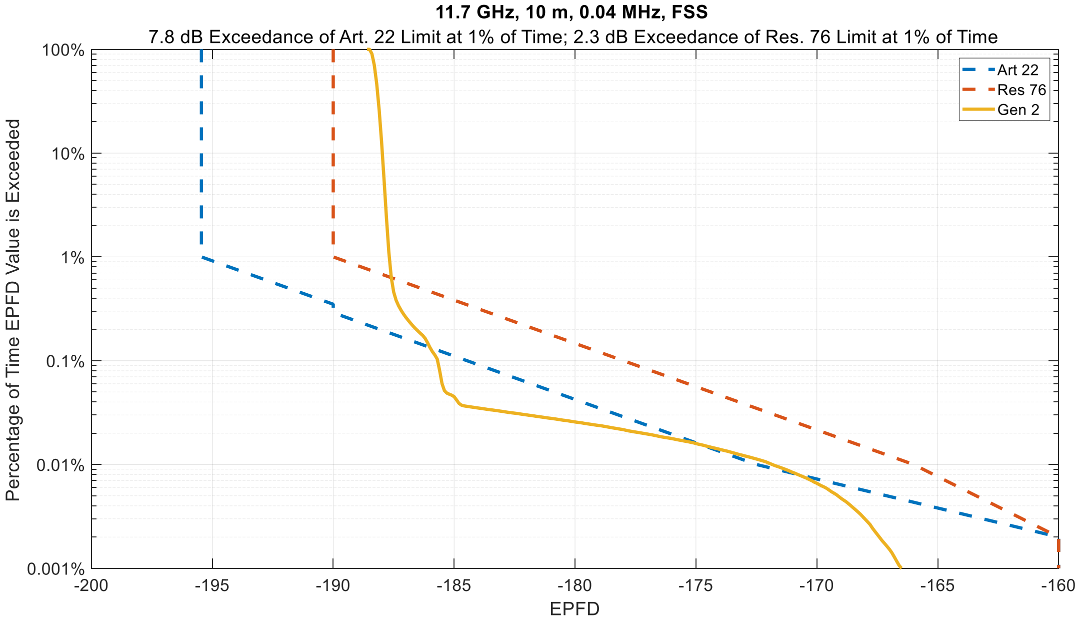

Figure A-31 - epfd↓, FSS, F=11.7 GHz, d=10 m, per 40 kHz

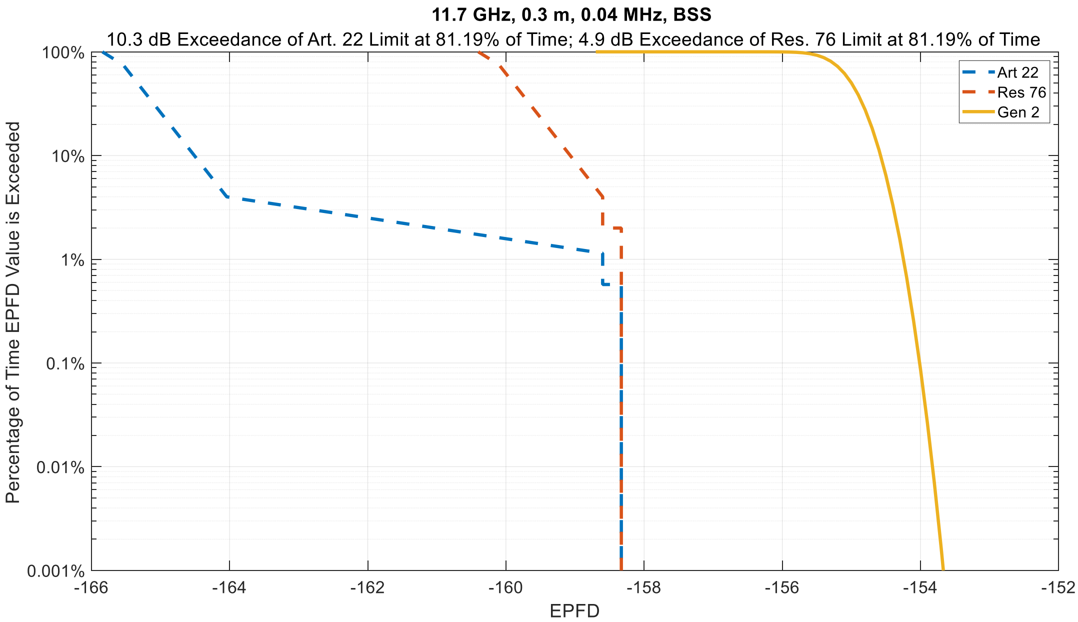

Figure A-32 - epfd↓, BSS, F=11.7 GHz, d=0.3 m, per 40 kHz

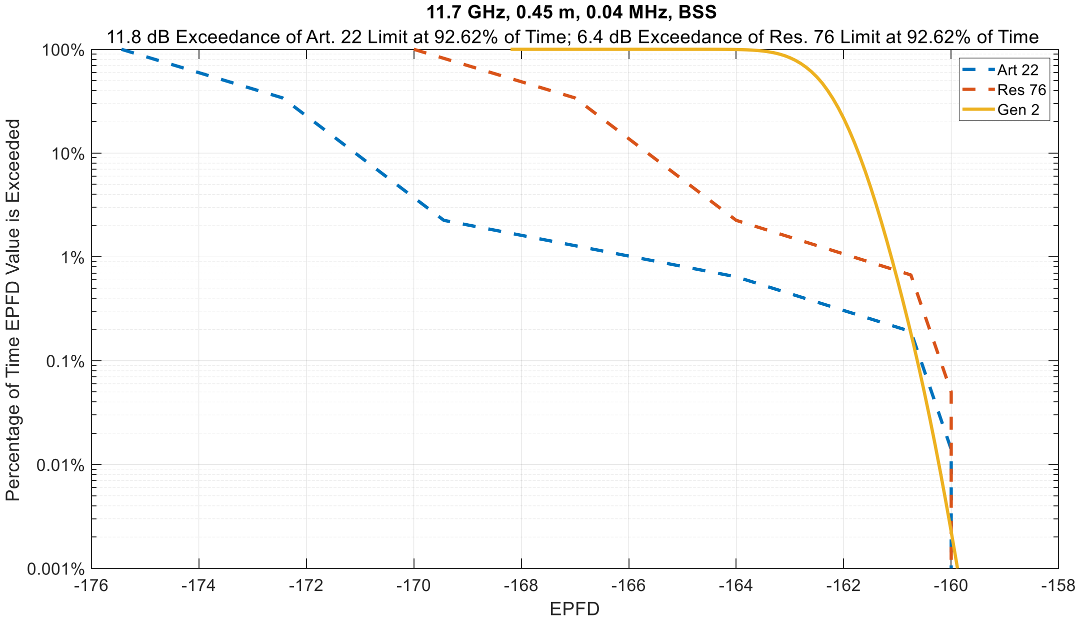

Figure A-33 - epfd↓, BSS, F=11.7 GHz, d=0.45 m, per 40 kHz

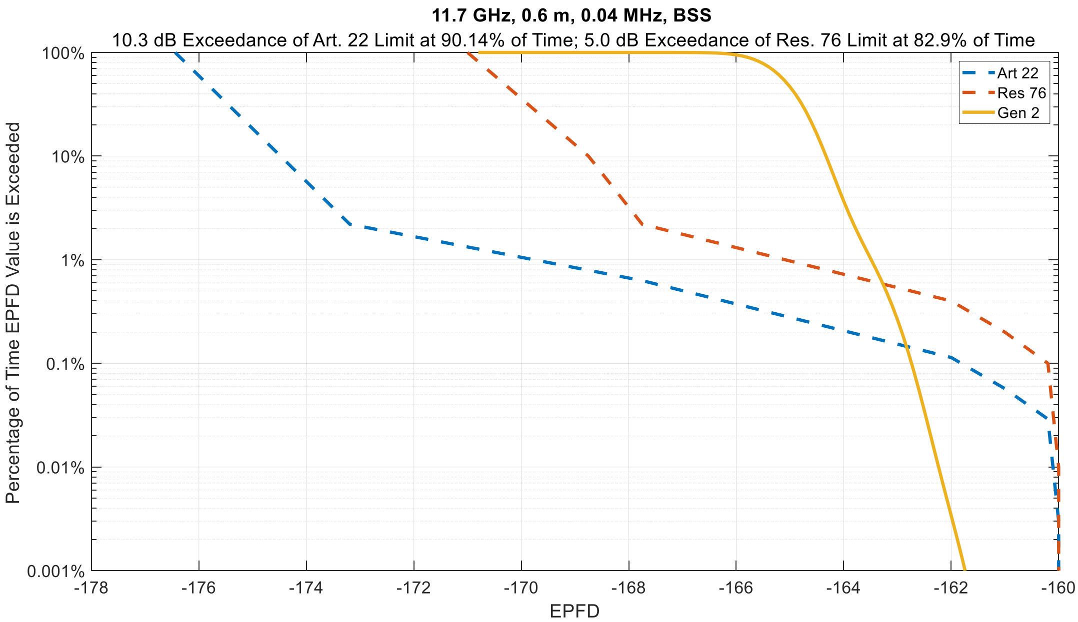

Figure A-34 - epfd↓, BSS, F=11.7 GHz, d=0.6 m, per 40 kHz

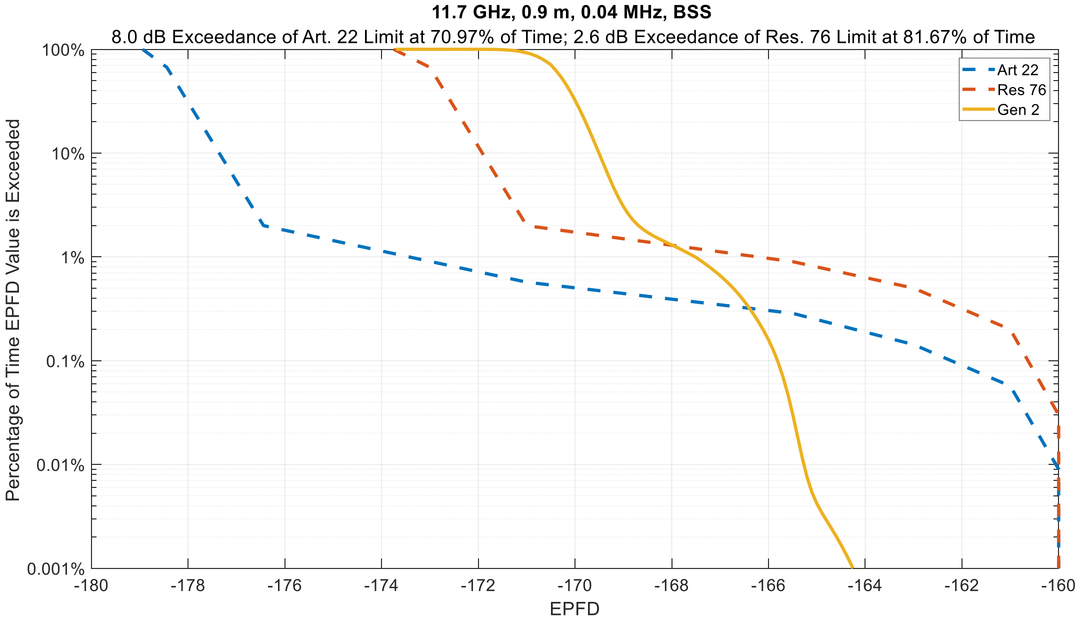

Figure A-35 - epfd↓, BSS, F=11.7 GHz, d=0.9 m, per 40 kHz

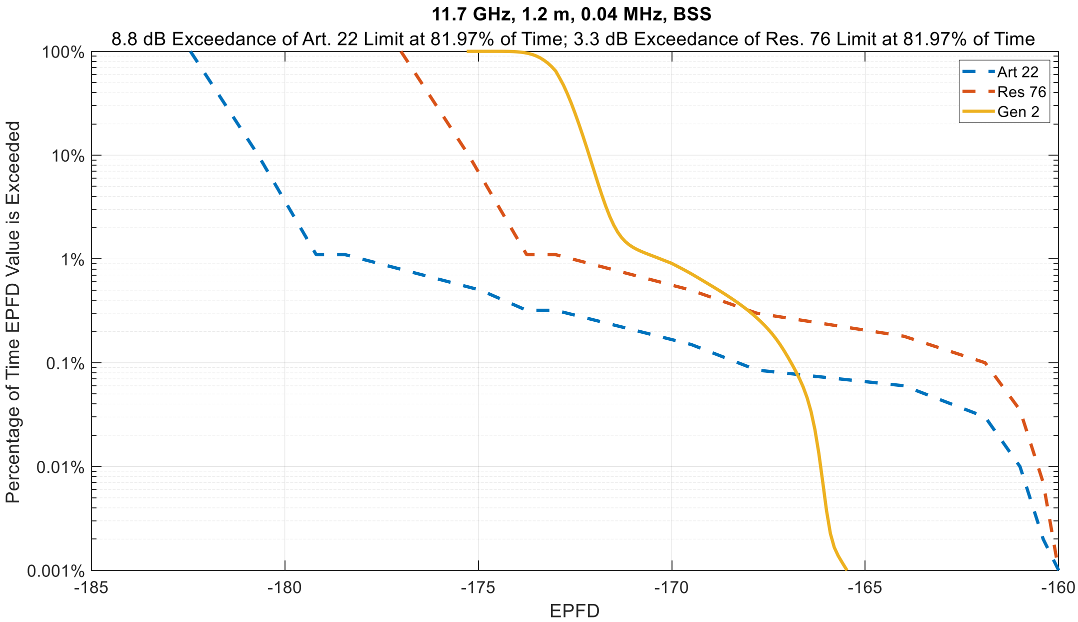

Figure A-36 - epfd↓, BSS, F=11.7 GHz, d=1.2 m, per 40 kHz

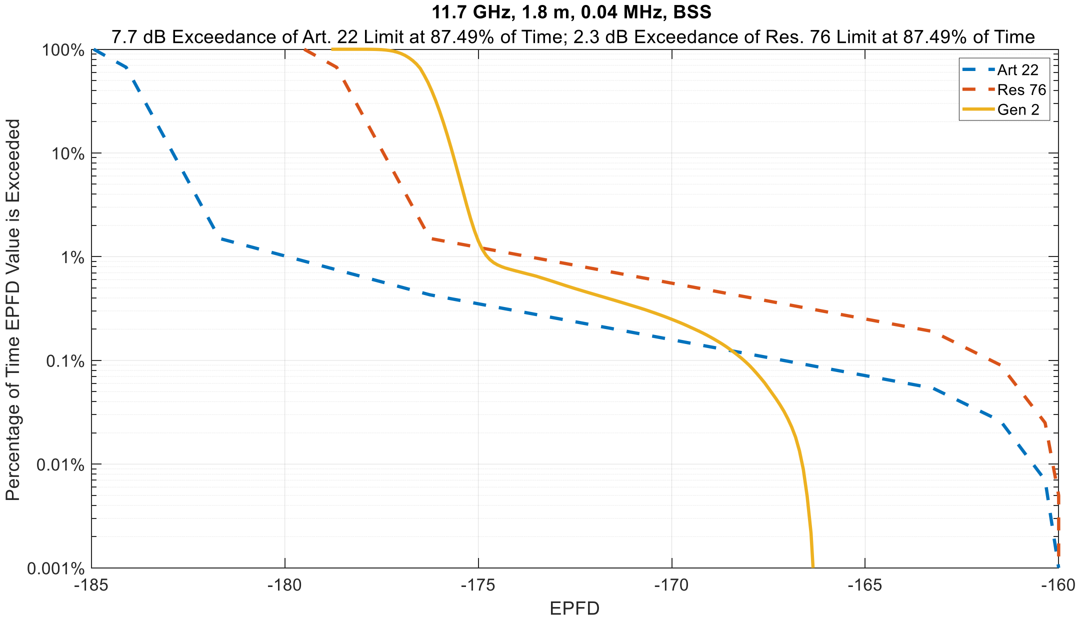

Figure A-37 - epfd↓, BSS, F=11.7 GHz, d=1.8 m, per 40 kHz

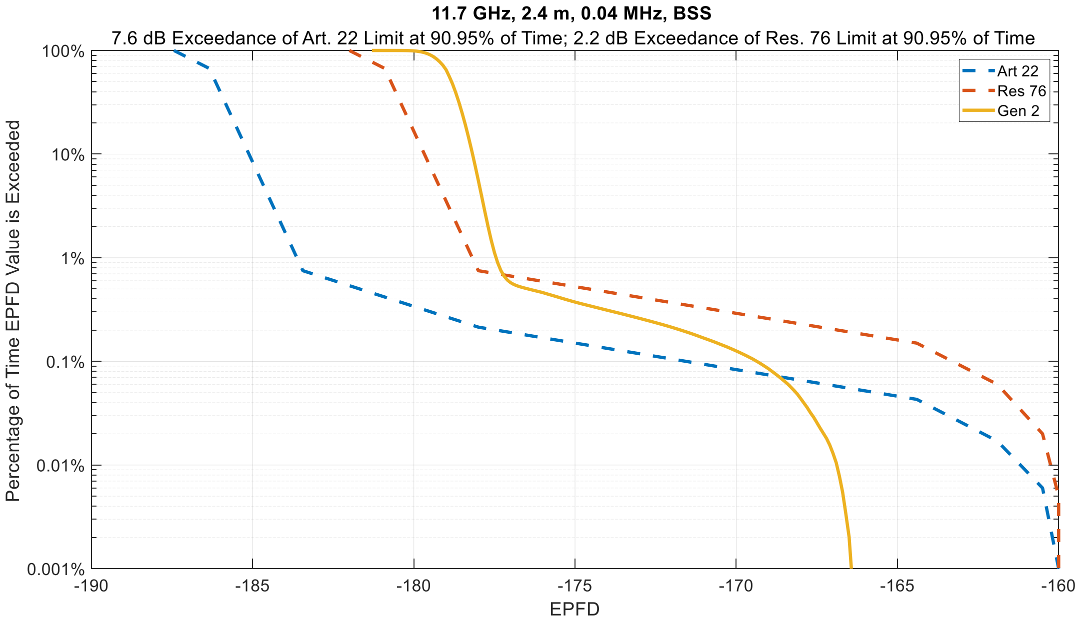

Figure A-38 - epfd↓, BSS, F=11.7 GHz, d=2.4 m, per 40 kHz

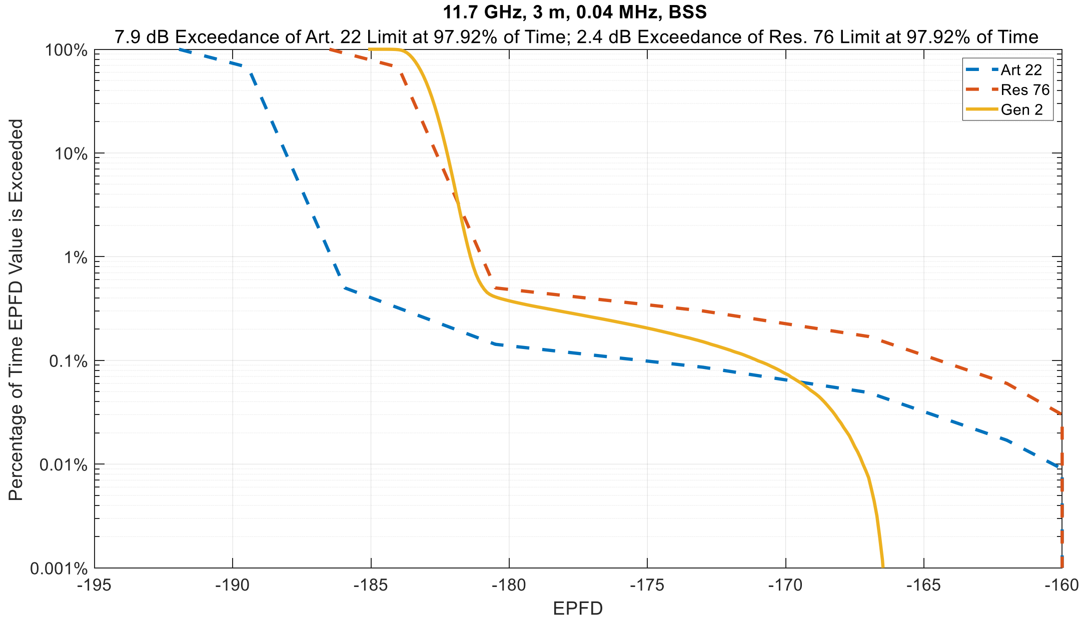

Figure A-39 - epfd↓, BSS, F=11.7 GHz, d=3 m, per 40 kHz

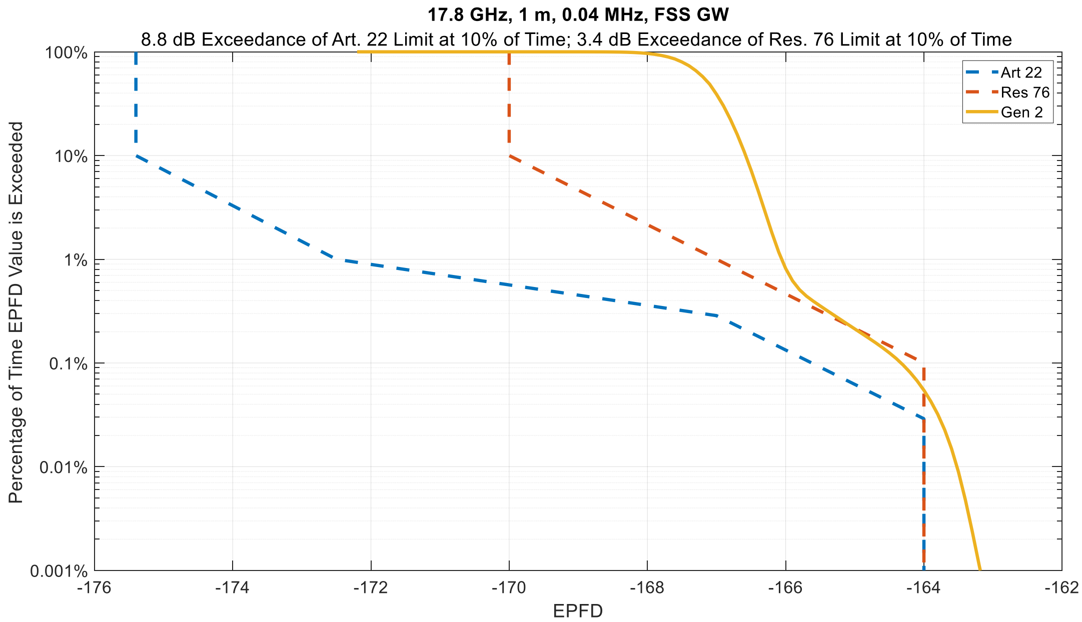

Figure A-40 - epfd↓, FSS, F=17.8 GHz, d=1 m, per 40 kHz

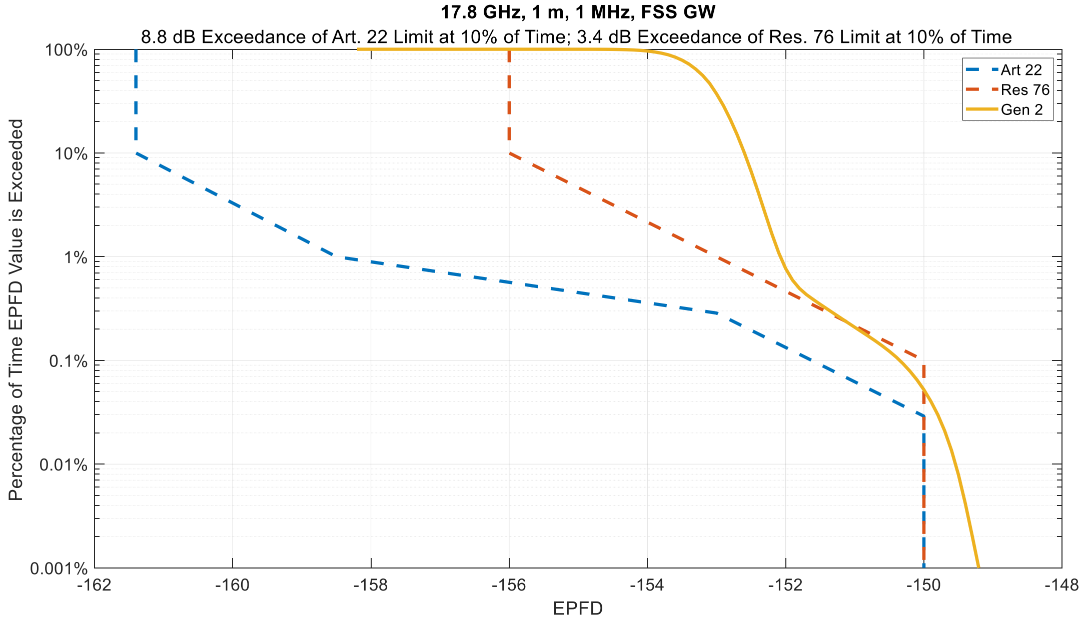

Figure A-41 - epfd↓, FSS, F=17.8 GHz, d=1 m, per 1MHz

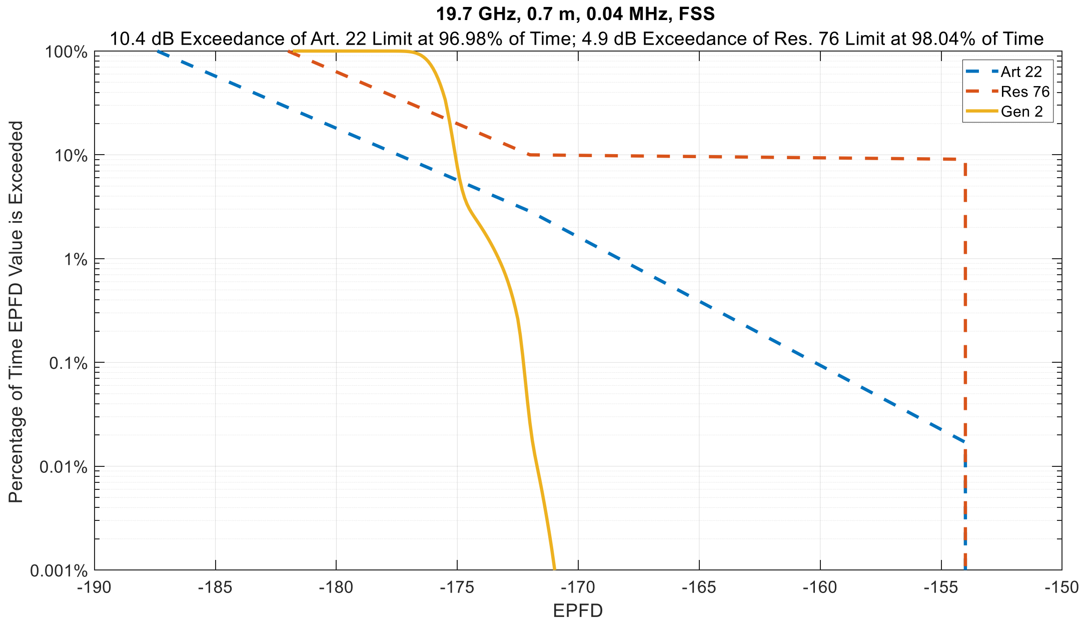

Figure A-42 - epfd↓, FSS, F=19.7 GHz, d=0.7 m, per 40 kHz

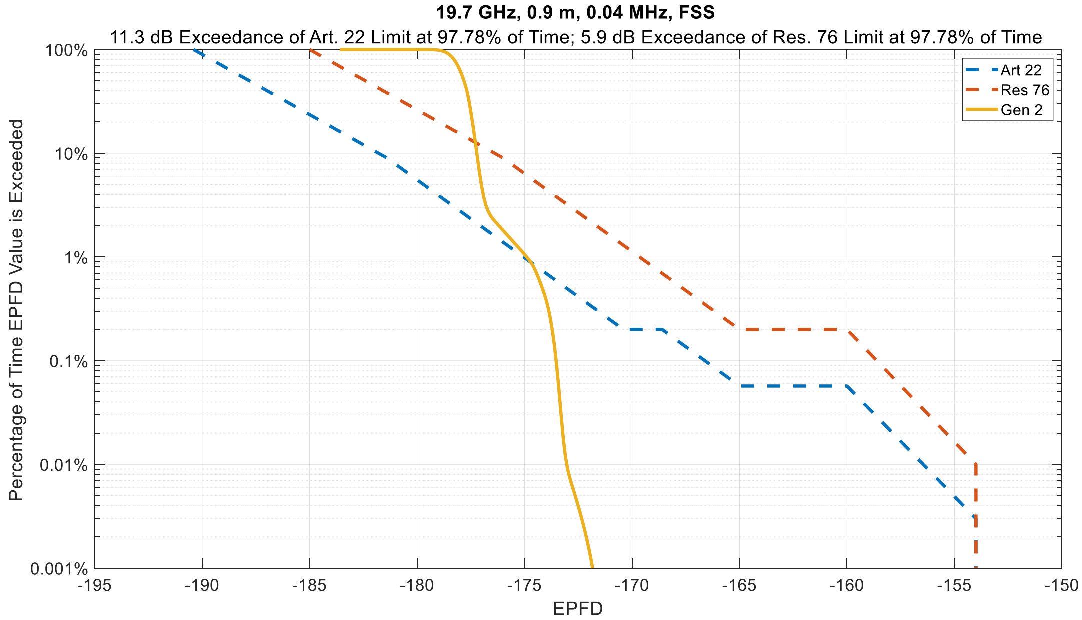

Figure A-43 - epfd↓, FSS, F=19.7 GHz, d=0.9 m, per 40 kHz

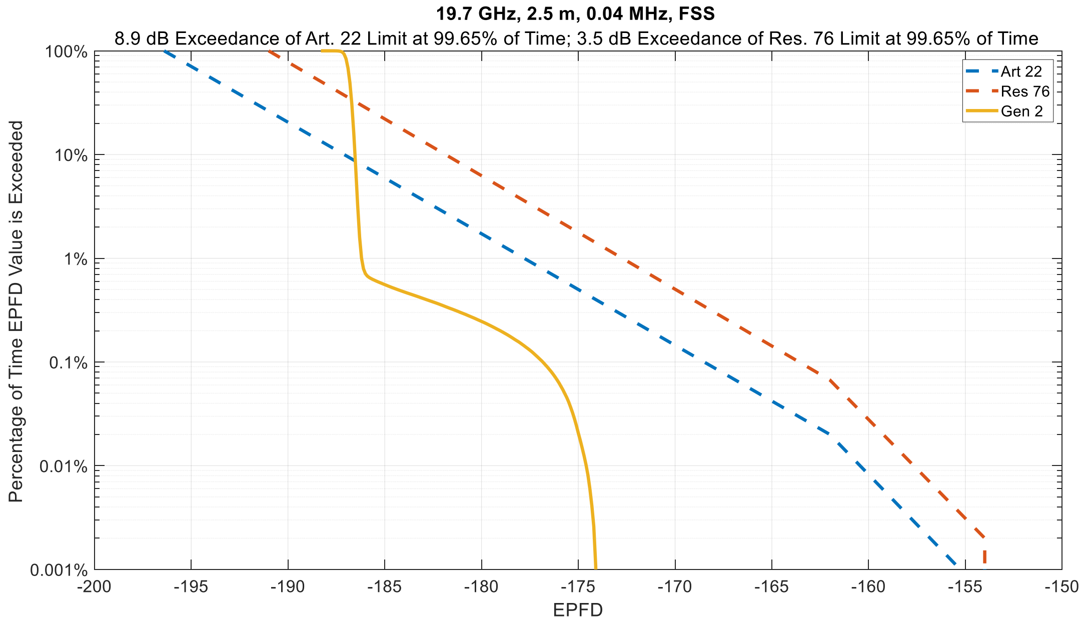

Figure A-44 - epfd↓, FSS, F=19.7 GHz, d=2.5 m, per 40 kHz

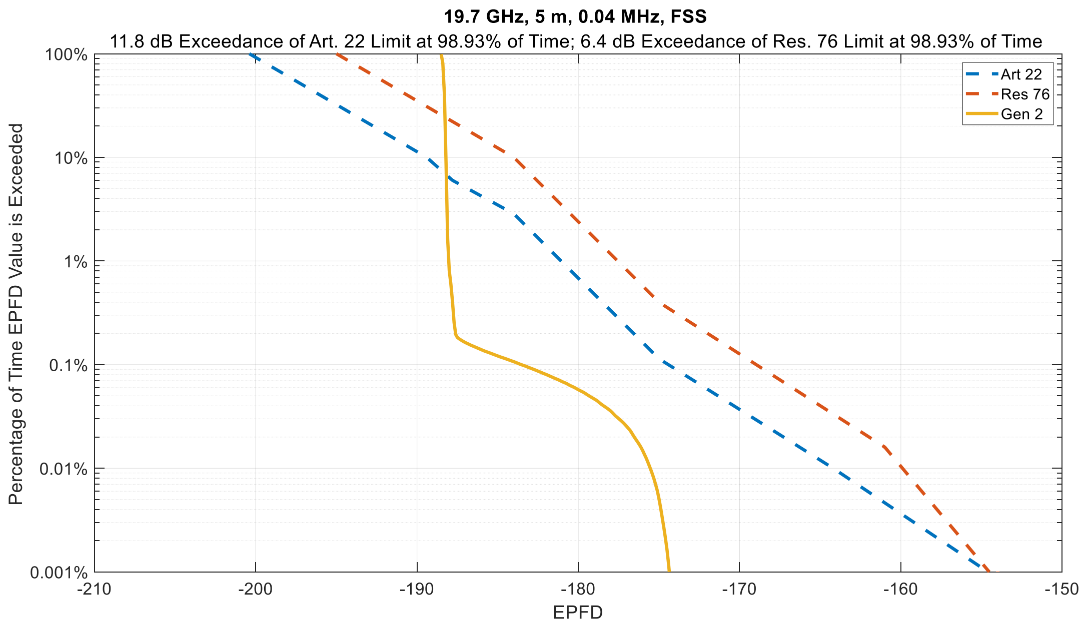

Figure A-45 - epfd↓, FSS, F=19.7 GHz, d=5 m, per 40 kHz

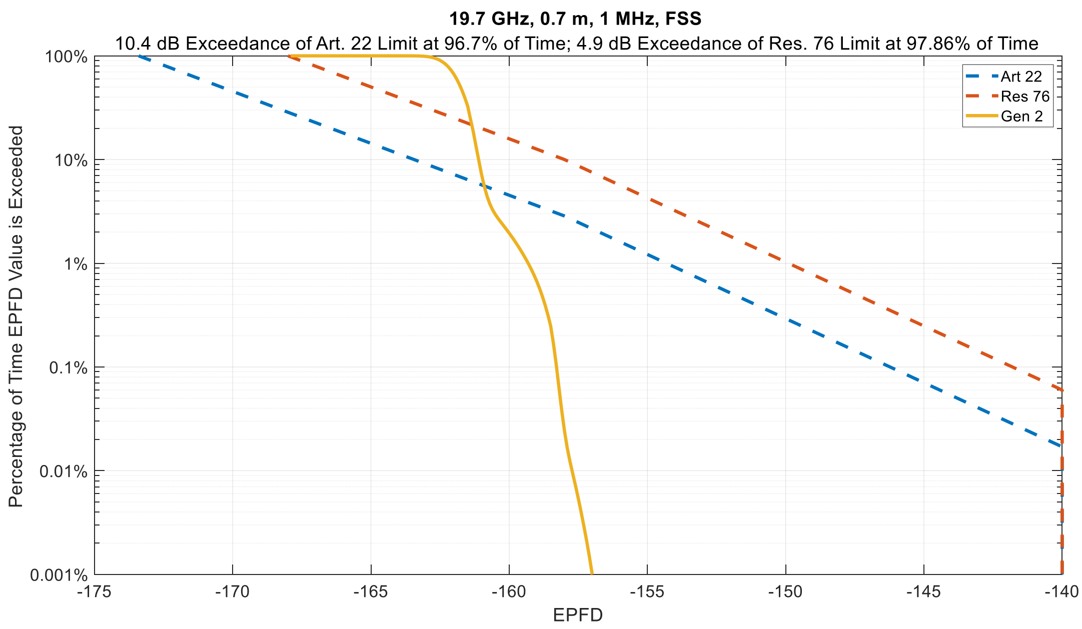

Figure A-46 - epfd↓, FSS, F=19.7 GHz, d=0.7 m, per 1 MHz

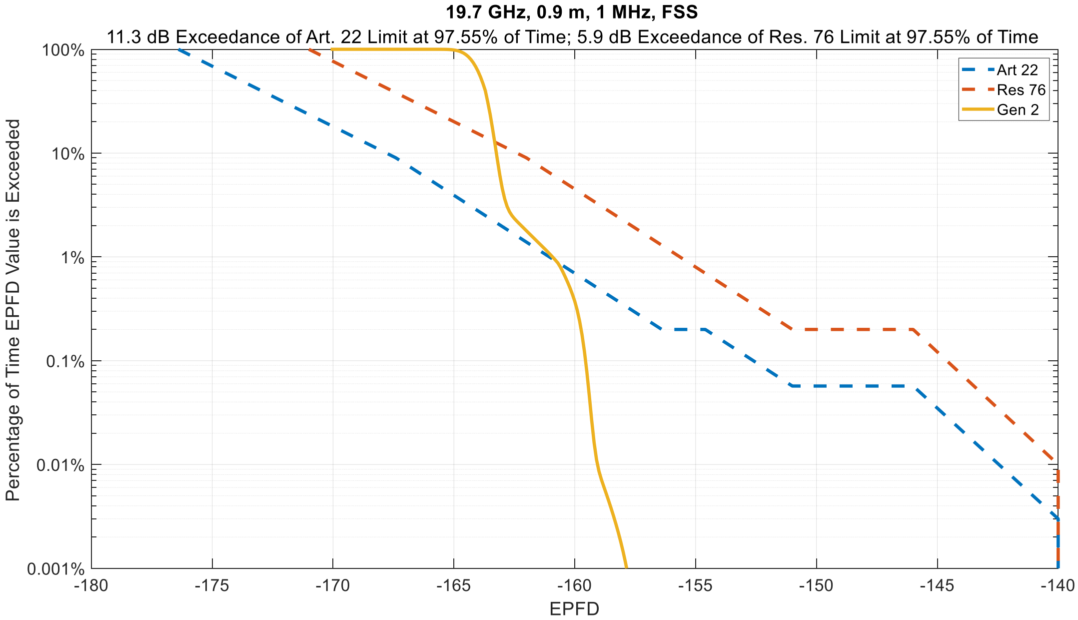

Figure A-47 - epfd↓, FSS, F=19.7 GHz, d=0.9 m, per 1 MHz

Exceeding an Art. 22 EPFD limit curve at any point is a violation of that limit and would result in an unfavourable finding from the ITU. Exceeding a Res. 76 aggregate EPFD limit curve is also a violation.

Res. 76[52] provides that:

1. administrations operating or planning to operate non-GSO FSS systems … shall take all possible steps, including, if necessary, by means of appropriate modifications to their systems, to ensure that the aggregate interference into GSO FSS and GSO BSS networks caused by such systems operating co-frequency in these frequency bands does not cause the aggregate power levels given in Tables 1A to 1D to be exceeded (see No. 22.5K);

2. in the event that the aggregate interference levels in Tables 1A to 1D are exceeded, administrations operating non-GSO FSS systems in these frequency bands shall take all necessary measures expeditiously to reduce the aggregate epfd levels to those given in Tables 1A to 1D, or to higher levels where those levels are acceptable to the affected GSO administration (see No. 22.5K).

The exceedances of the aggregate EPFD limits results from SpaceX's attempt to ignore the way in which Starlink actually would operate, artificially separate the Starlink system into constituent components, and then impermissibly evaluate constituent components against the single entry EPFD limits.[53]

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52 RESOLUTION 76 (REV.WRC-15) Protection of geostationary fixed-satellite service and geostationary broadcasting-satellite service networks from the maximum aggregate equivalent power flux-density produced by multiple non-geostationary fixed-satellite service systems in frequency bands where equivalent power flux-density limits have been adopted The World Radiocommunication Conference (Geneva, 2015).

53 SpaceX plans to operate various elements of its integrated Starlink system under a variety of ITU filings made on its behalf by Norway, the United States and Germany.

Again, ITU-R S.1503 is instructive. It is based on the premise that the parameters specified in relevant input files reflect the way that an NGSO system would actually operate once implemented. Among other things, the methodology is based on *all satellites that could contribute to the EPFD levels generated by the entire system being considered together*. Thus, for example, ITU-R S.1503 explicitly anticipates that where a large constellation is divisible into separate "sub-constellations," *EPFD compliance will still be evaluated across the constellation as a whole*.[54]

[54] *See, e.g.,* ITU-R S.1503 § A2.4 (specifying constellation types that can be evaluated using specified procedures and explicitly noting that "[c]onstellations can contain sub-constellations with different orbit parameters and shape . . .").

Annex B: Blocking Equitable Access to NGSO Frequency Bands

The preclusive effect of Starlink on smaller NGSO systems is illustrated by Table B-1 below, which shows the probability that other NGSO systems of various sizes would be completely "blocked" from reasonable spectrum access by the proposed Starlink configuration due to in-line interference events. Representative NGSO systems were modelled with 300, 1,000, and 3,000 satellites. The probability of blocking (the system being blocked not being able to find one of its satellites with sufficient angular separated from a Starlink satellite to avoid interference) was computed by Monte Carlo simulation. The percentages reflect the amount of time near in-line interference events can be expected.

	Starlink	
Other NGSO System	**4,408 Satellites**	**34,396 Satellites**
300 Satellites	26%	99%
1,000 Satellites	5%	99%
3,000 Satellites	3%	99%

Table B-1 – Percentage of Time Starlink Constellation Blocks Smaller NGSO Systems

As reflected in Table B-1, Starlink would have a significant impact on other NGSO systems with the smaller systems experiencing inline events virtually all of the time with the larger Starlink constellation.

The preclusive impact of the expanded Starlink system can also be illustrated by examining the additional "look angles" that would be blocked as a result. Figure B-1 below depicts the percentage of available look angles that would be consumed by the Starlink system as a function of the number of satellites it incorporates. As Figure B-1 shows, a 4,408-satellite Starlink constellation would block about 57 percent of the look angles available from the ES location. An expanded 34,396-satellite Starlink constellation would block *over 98 percent of the look angles available from that same location.*

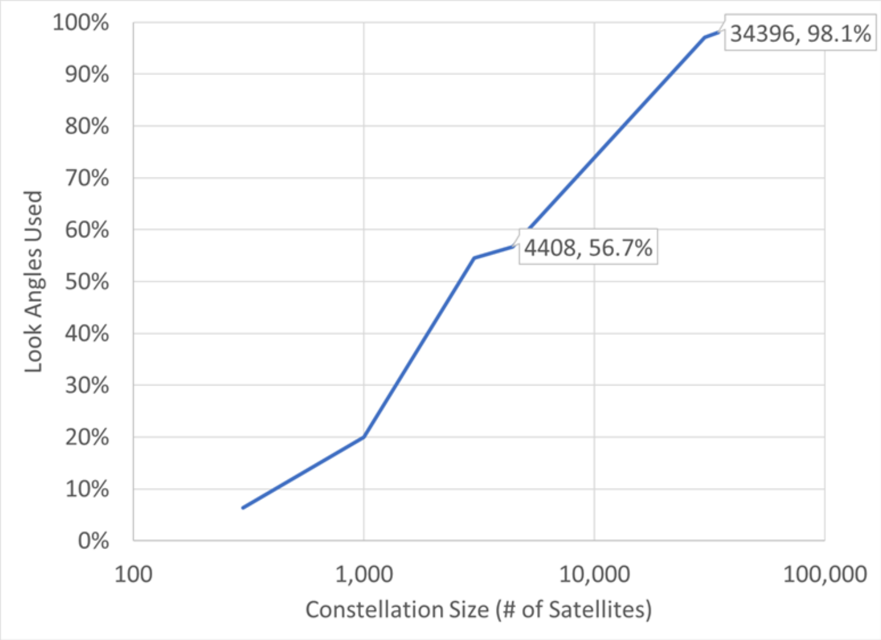

Figure B-1 – Percent of Look Angles Used as a Function of Starlink Constellation Size

Starlink's ability to "block" smaller NGSO systems would effectively reduce the capacity available to those NGSO systems (because those other systems would have their available spectrum reduced during in-line events while Starlink with its Nco=1 commitment would always be able to provide service through a satellite not subject to an in-line interference event).[55]

Critically, the Starlink system itself would not be "blocked," or suffer any reduction in available capacity, as a result of the operation of smaller NGSO systems. This is because SpaceX would be able to leverage the satellite diversity afforded by the extremely large number of satellites in the Starlink system; in the event of an in-line interference event involving one Starlink satellite, SpaceX could simply reroute through another Starlink satellite. And because Starlink user links are based on "Nco=1"— *i.e.*, no more than one satellite could be used to serve subscribers in a given area and frequency band at the same time—this would not result in any reduction in Starlink system capacity.[56]

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55 SpaceX has committed to limit to one the number of co-frequencies simultaneously transmitting satellites serving a given point on Earth in the 10.5-12.75 GHz and 29.5-30 GHz frequency bands order to constrain its EPFD levels to protect GSO networks. In ITU parlance, this is reflected as Nco=1 in SpaceX's ITU filings.

56 At latitudes between 60°S and 60°N, each Starlink earth station would be able to "see" over 100 satellites in a 34,396-satellite Starlink system above the 25° elevation mask. With the Nco=1 commitment, SpaceX would need only one of those satellites to remain unaffected by an in-line interference event and be able to use 100% of otherwise available spectrum.