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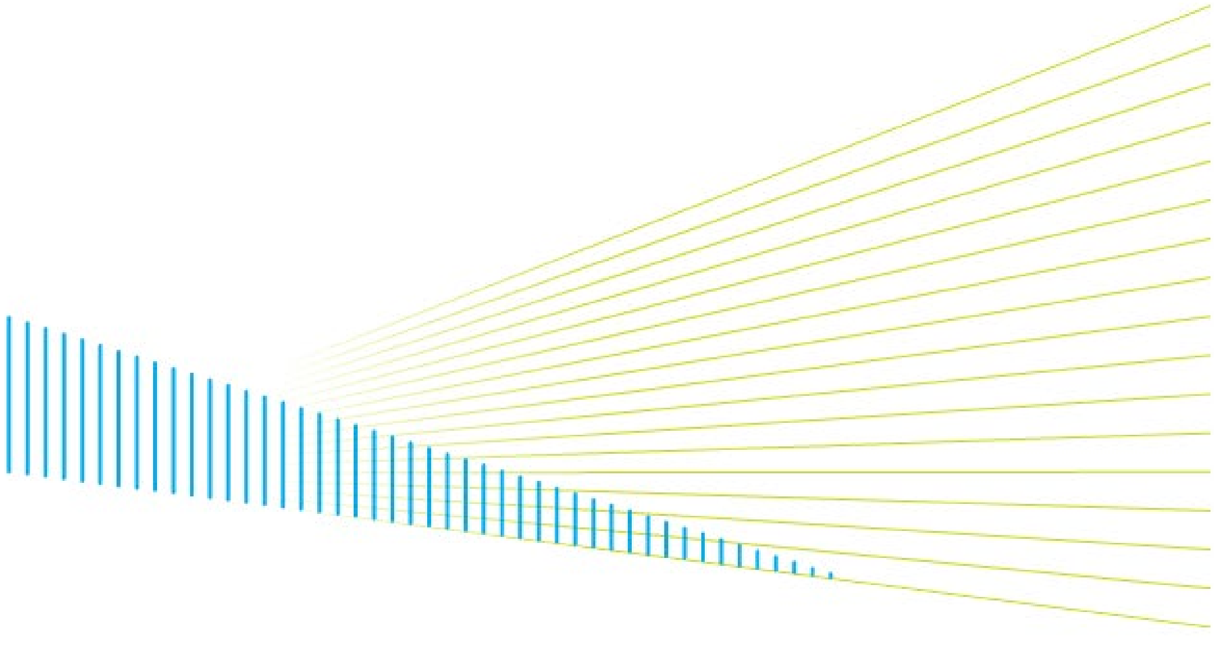
# Ensuring Innovation and Growth Opportunities in the New Space Age



Viasat

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## I. Introduction

This paper focuses on the pressing issues surrounding the race to populate the portion of space closest to Earth known as Low Earth Orbit (LEO). Unless the situation is suitably managed at the market access stage, the way LEO is being populated today poses a threat to innovation, growth opportunities, efficient spectrum use, national interests, space safety, and the environment.

These threats exist because a few large constellations consisting of many thousands of LEO satellites, so called "mega constellations," risk creating many harmful effects:

- Consuming an undue amount of spectrum and orbits in contravention of the International Telecommunication Union (ITU) Constitution, specifically Article 44, paragraph 2, which recognizes that radio frequencies and orbits are limited natural resources and must be used "rationally, efficiently, and economically;"
- Generating undue interference that reduces the reliability and capacity of other satellite systems, and constrains their ability to innovate and offer new services, including those offering direct to home (DTH) television, Broadcast Satellite Services (BSS), and broadband connectivity;
- Precluding equitable access to spectrum and orbits (both NGSO & GSO);
- Unduly raising the risks and costs associated with access to and use of space (regardless of orbit), including collisions and the creation of lethal orbital debris;
- Limiting consumer choice, adversely affecting national space industries, and threatening national security interests;
- Creating numerous environmental and other sustainability risks that may limit the deployment of additional NGSO systems:
    - Damaging the Earth's atmosphere and effecting climate change through radiative forcing and depletion of the ozone layer, thus increasing the risk of cancer and other negative health effects, because thousands of large LEO satellites reenter the atmosphere on a regular basis at the end of their short lives;
    - Impairing critical optical and radio astronomical research by disrupting the visible night sky and causing interference;
    - Creating light pollution, with the resulting negative impacts on the health and quality of life of humans and on plants and animals; and
    - Impairing the functioning of critical asteroid detection and defense capabilities.

The development of a stable global space economy requires that access to space be safely and reliably available to more than a few LEO systems from select nations. Indeed, the existence of "have nots" in the space economy could be a destabilizing force that we can and must avoid. Moreover, ensuring innovation and growth opportunities requires that we maintain a known interference environment that allows the certain deployment and operation of GSO and NGSO satellites by all nations in the limited resources that the entire world must share.

As leading experts and a leading legal institution emphasize, (i) it is imperative that preventative action be taken now at the national level because *we just won't reach international consensus in the short term* on a new framework for regulating large LEO constellations,[1] and (ii) it is critical to address the potential national harms *at the market access stage*, because that is "one of the rare decisions, if not the only one, taken by [a nation] which conditions the provision of [satellite] services" in its territory.[2]

The 2022 Plenipotentiary Conference of the ITU (ITU PP-22) also recognized the need to address as a matter of urgency concerns around the sustainable use of orbits and spectrum created by the "continued and expanded launch and operation of a large number of non-geostationary satellites in outer space."[3] ITU PP-22 called on member administrations to "take all necessary actions to avoid unacceptable interference to GSO and other non-GSO systems, as well as to other radio services, of other administrations and to ensure the efficient use of radio-frequency spectrum and associated orbits; to this effect, the necessary regulatory frameworks need to be developed for the operation of non-GSO systems."

The 2023 ITU Radiocommunication Assembly *resolved* (ITU-R Res 74), as a matter of urgency, that the ITU-R should act in support of the long-term sustainability of space "with a focus on the prevention of harmful interference, and ensuring the rational, equitable, efficient and economical use of the radio-frequency spectrum and associated orbit resources, with a focus on non-GSO systems . . . taking into account the special needs of the developing countries and the geographical situation of particular countries."[4]

*National regulators should consider these issues, discussed in further detail below, in relation to any requests they receive to license or grant market access to NGSO satellite systems.*

## II. Interference into GSO networks and threats to equitable and safe access to space

Reliable access to both sufficient spectrum and other orbital resources is a key driver in the ability of satellite services to meet evolving commercial, civic and military needs. Moreover, a growing recognition exists that *these resources are limited* and must be carefully managed to ensure that all needs for satellite-based services can be met—including new applications

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[1] R. Buchs, "Policy Options to Address Collision Risk from Space Debris," Lausanne: EPFL International Risk Governance Center (2021), at ii ("Given that the prospect of reaching consensus in the short term is very low, governments are advised to take unilateral but coordinated action by improving their national regulations.").

[2] Le Conseil d'État invalidation of Starlink market access, conclusions of rapporteur, Case No. 455321 (Apr. 5, 2022) (France).

[3] International Telecommunication Union, Final Acts of the Plenipotentiary Conference (Bucharest, 2022), Resolution 219, "Sustainability of the radio-frequency spectrum and associated satellite orbit resources used by space services" (Final Acts, p. 405-406), https://www.itu.int/dms_pub/itu-s/opb/conf/S-CONF-ACTF-2022-PDF-E.pdf.

[4] International Telecommunication Union, Resolutions, Radiocommunication Assembly (RA-23), Dubai, 13–17 November 2023, Res. ITU-R 74, Activities related to the sustainable use of radio-frequency spectrum and associated satellite-orbit resources used by space service (p. 148 – 151), https://www.itu.int/dms_pub/itu-r/opb/vadm/R-VADM-RES-2023-PDF-e.pdf.

for remote sensing/earth observation; science; defense; positioning, navigation and timing (PNT); and communications, alike.

At this early stage of the New Space Age, we are seeing a few actors in LEO staking claims to vast amounts of orbital resources in a manner that risks hindering innovation and growth opportunities in industry. These very real risks include:

- Creating impermissible interference into GSO networks that interrupts broadband and direct-to-home video (DTH) operations and reduces network capacity;
- Hindering equitable access by other NGSO systems to shared NGSO frequency bands;
- Hindering safe and reliable access to the lower portions of LEO that are needed so others can provide spectrum-based services; and
- Consuming more than an equitable share of the aggregate amount of interference that all NGSO systems (considered together) may generate into GSO networks.

By taking actions to manage these risks now, national regulators can ensure that their policies keep pace with changes and innovations in the space sector, and that opportunities continue to exist for growth in the provision of satellite-based services in their countries.

The critical issues discussed below should be addressed at a national level prior to granting a license or market access to an NGSO system. Doing so would mitigate the risk of interference between an NGSO system and GSO networks and ensure that limited spectrum and orbital resources are shared equitably among NGSO systems.

## A. Impermissible interference into GSO networks

### *1. NGSO system angular separation is needed to protect GSO networks from interference*

The movements of NGSO satellites across the sky create opportunities for time varying interference into GSO networks. Unless an NGSO operator 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 to smaller user terminals than ever possible before. Taking advantage of advancements in technology, GSO satellites now can provide more than 1 Tbit/s of total capacity each, with far greater levels of throughput coming 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 (high G/T). Today, even a single NGSO system 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 an NGSO system's communication links are angularly separated from the GSO arc by a sufficient degree, they could easily degrade service levels and cause capacity losses to GSO networks, including those that serve or plan to serve a given country.

Angular separation is a relatively simple operational technique whereby the NGSO satellites avoid operating within a suitable angular separation zone around the GSO arc. If using one specific NGSO satellite to serve a given location would not maintain sufficient angular separation, then a different satellite would be used, and the first 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 below in Figure 1.

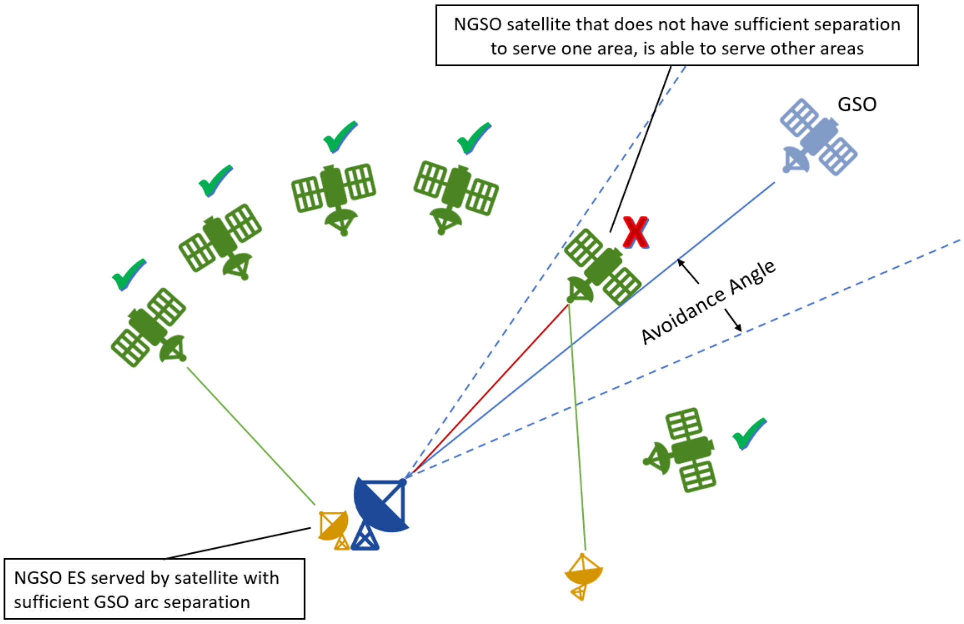

Figure 1: NGSO system employing GSO avoidance angle

Angular separation imposes virtually no constraint on NGSO system capacity because large NGSO systems always have multiple options for assigning different satellites to serve locations on the Earth. Further, 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.

Certain LEO constellations would not comply with various ITU Radio Regulation requirements designed to protect GSO networks from interference generated by NGSO systems. 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. Certain LEO operators have disavowed any responsibility to maintain any such avoidance angle, much less a suitable one. National regulators therefore should consider appropriate NGSO system conditions, like the requirement to meet a specific angular separation, to mitigate the risk of interference to GSO networks in the first place.[5]

The effectiveness of GSO arc avoidance as a potential way to mitigate interference from NGSO systems into GSO networks depends entirely on the avoidance angle that is specified. The sufficiency of that angle can be evaluated only (i) based on information about the radiofrequency design and equivalent power flux density performance of the relevant NGSO system, and (ii) by taking into account the actual characteristics of the GSO networks that would be affected (such as satellite receiver noise temperature and antenna gain, and sizes and characteristics of user terminals).

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

For these reasons, a suitable demonstration of the existence of adequate measures to avoid undue interference from an NGSO system should be provided *before* granting any authorization to serve a given country. In these cases, a national regulator should, at a minimum: (i) calculate the minimum GSO arc avoidance angle that would ensure that the NGSO system protects from interference those GSO networks serving its country; (ii) allow interested parties to evaluate the efficacy of the proposed value; and (iii) require the NGSO system to maintain a suitable GSO arc avoidance angle as a condition of any authorization that ultimately may be granted.

To assist in that analysis, national regulators should require all NGSO applicants to provide the following information:

- The number of satellite beams used for transmissions on the same frequency in the same or overlapping areas at any given time; and
- How the NGSO system avoids interference to GSO networks created by earth station and satellite antenna sidelobes, and earth station antenna backlobes, particularly when phased array antennas are employed.

This information is relevant to assessing an NGSO system's potential interference into GSO networks, the potential for spectrum sharing with other NGSO systems discussed below, and, more broadly, the impact of the NGSO system on the spectrum environment in a country and the satellite sector.

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[5] *See, e.g., In re Space Exploration Holdings, LLC, Request for Orbital Deployment and Operating Authority for the SpaceX Gen2 NGSO Satellite System*, FCC 22-91 (rel. Dec. 1, 2022), at ¶16 ("SpaceX must operate consistent with the technical specifications provided to the Commission as part of its application […]. *The relevant technical information includes* antenna beam patterns; *GSO avoidance angle*, physical characteristics; frequencies used for satellite communications, including outside the United States; and other technical information.") (emphasis added), https://www.fcc.gov/document/fcc-partially-grants-spacex-gen2-broadband-satellite-application.

In sum, a national regulator should require:

- An NGSO system to maintain a suitable GSO arc avoidance angle when serving its territory;
- An NGSO system not to cause unacceptable interference into GSO networks and not to claim interference protection from GSO networks;
- An NGSO system 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; and
- That if interference into a GSO network occurs, an NGSO system must cease operations and not recommence operations until it addresses the cause of such interference by, among other things, increasing angular separation, reducing power, and shaping antenna beams differently.

In order to ensure that the basis on which a national regulator grants an NGSO authorization does not change by virtue of continuing iterations of its NGSO system design, a national regulator should also: (i) specify that the NGSO operator not modify the radiofrequency characteristics of its satellite system without prior consent from the national regulator, and (ii) require that the NGSO operator provide a bi-annual report on iterations of its NGSO system design to ensure compliance with that condition.

### *2. Failures to comply with ITU EPFD limits that 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) intended to protect GSO networks from interference generated by NGSO systems and define the terms under which both GSO and NGSO systems are to coexist.

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, fulfill the RR No. 22.2 obligation with respect to an NGSO system; 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.

There are two types of EPFD interference limits.

- "Aggregate" EPFD limits constrain the amount of interference that all NGSO systems may generate in total, on a cumulative basis. These aggregate limits must be shared and apportioned among all NGSO systems using overlapping frequencies.

- "Single-entry" EPFD limits constrain the amount of interference that one NGSO 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 described and depicted in Annex A.[6] As further explained in Annex A, one EPFD limit must be satisfied 100 percent of the time; other EPFD limits must be satisfied for other, varying percentages of time.

Certain LEO operators propose to operate in a manner that would not comply with these limits. Unless prevented at the market access stage, such operations would generate excessive interference and could well:

- Degrade service levels and cause capacity losses to broadband GSO networks as well as direct-to-home video (DTH) services, and
- Forestall continued technological innovation by GSO networks.

In addition, such excessive operations would consume the entire EPFD budget that must be shared and apportioned among all NGSO systems using overlapping frequencies, making it difficult, if not impossible, for other NGSO systems to share the same spectrum.

As illustrated in Annex A, certain NGSO systems would exceed the "single-entry" EPFD limits and, in some cases, the "aggregate" EPFD limits as well. Exceeding the "single-entry" EPFD limits *at any point on the EPFD curve and at any location on Earth visible from the GSO orbit* is a violation of the ITU Radio Regulations.[7] Exceeding the "aggregate" EPFD limit at any point on the curve and at any location on Earth also is a violation.

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[6] Annex A, Examples of Violations of EPFD↓ Limits (Fuchsstadt, Germany).

[7] RR 22.5C provides in relevant part: "The equivalent power flux-density, epfd ↓, *at any point on the Earth's surface* *visible from the geostationary-satellite orbit*, produced by emissions from all the space stations of a non-geostationary-satellite system in the fixed-satellite service in the frequency bands listed in Tables 22-1A to 22-1E, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, shall not exceed the limits given in Tables 22-1A to 22-1E for the given percentages of time." (emphasis added; footnote omitted).

ITU-R Recommendation. S.1503-3 similarly explains the necessity of complying with all EPFD limits at all locations: "The epfd limits in Article 22 are applicable *for all GSO [earth station]s and all pointing angles towards that part of the GSO arc visible from that [earth stations.* [] *It remains necessary for the non-GSO operator to meet the epfd limits in Article 22 for all [] geometries* including the testing of specific GSO networks as noted in § A1.3.9." (emphasis added).

The instances described in Annex A in which an NGSO system would violate "single-entry" EPFD limits 1%, 10% and even 100% of the time are very concerning. Interference generated at those levels could well degrade service levels and cause capacity losses to GSO networks and constrain technological innovation. Annex A evaluates one specific interference case in Germany; similar analyses conducted for other locations around the world yield similar exceedances and violations of ITU limits.

These violations of EPFD limits can occur because geometry cases (geographic locations of GSO earth stations and satellites) within many nations are not tested by the limited examination conducted by the ITU, as explained in Annex A.

The violations also can occur because the so-called "worst-case geometry" used in that ITU spot check may be associated with only a single one of the many orbital shells in the ITU filing for the NGSO system (*i.e.*, a particular combination of orbital altitude and inclination(s)), *and may not represent the interference potential actually presented by the other orbital shells that are used to provide service.*

Moreover, these violations can occur because the EPFD software developed for the ITU has other known flaws that underestimate the level of interference expected to be generated into GSO networks.

As shown in Figure 2 below, the operation of many NGSO satellites can contribute to the EPFD levels received by a GSO network. These contributions include the main-beam and sidelobe transmissions of numerous satellites, from the same NGSO system, and from different NGSO systems as well.

Even though the *ITU Radio Regulations* expressly provide for the totality of *all these* contributions to EPFD[8] to be constrained to the levels specified in the Radio Regulations, *the EPFD software* developed for the ITU "counts" only some of these contributions. In other words, that EPFD software ignores many contributions to EPFD, including the sidelobes from the NGSO satellites depicted below with a red "X."

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[8] RR 22.5.C.1 provides an explicit formula to calculate EPFD. Downlink EPFD "is defined as the sum of the PFD produced at a GSO receive station on the Earth's surface … by all the transmit stations within a non-GSO system, taking into account the off-axis discrimination of a reference receiving antenna assumed to be pointing in is nominal direction" The summation is over the "number of transmit stations in the non-GSO system that are visible from the GSO receive station considered on the Earth's surface." Nevertheless, the EPFD software developed for the ITU does not factor in all those NGSO transmit stations.

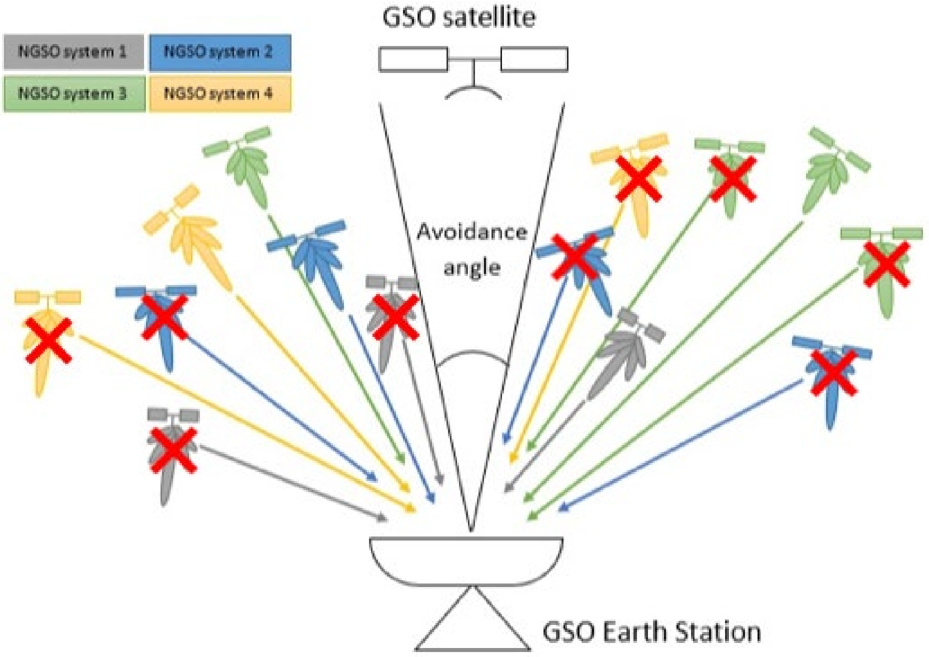

Figure 2: Multiple mainlobe and sidelobe interference contributions into a GSO earth station; contributions marked "X" not taken into account in ITU EPFD software

This failure to properly calculate EPFD exists despite the known potential for many NGSO sidelobes to contribute to overall NGSO interference into GSO operations. In the case of mega-constellations, hundreds of satellites potentially can cause this damaging interference, but the ITU software still does not account for it.

Violations of EPFD limits also can result from NGSO operators' attempts to ignore the way in which an NGSO system actually would operate and instead:

- Artificially separate an NGSO system into constituent components, and
- Impermissibly evaluate each of those constituent components (instead of the NGSO system as a whole) against the "single entry" EPFD limits.[9]

The Director of the ITU's Radiocommunication Bureau recently released a report which explains that the practice of splitting a non-geostationary satellite system into several filed systems, "may affect the effectiveness of single-entry epfd limits contained in Article 22 to protect geostationary systems or have an impact in the implementation of Resolution 76 (Rev.WRC-15)."[10] As that report details, this issue was first studied in 2003, and the conclusion reached then was: "the only reason for misapplication of these single entry epfd

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[9] One NGSO operator plans to operate various elements of its integrated system under a variety of ITU filings made on its behalf by at least three administrations.

[10] Director, ITU Radiocommunication Bureau, Preliminary Draft Report of the Director to WRC-23 on the Activities of the Radiocommunication Sector Experience in the Application of the Radio Regulatory Procedures and Other Related Matters, Addendum 2 to Document 4-3 (September 2023), at 28-29.

Resolution 76 is discussed below. It addresses compliance with limits on the entirety of the aggregate EPFD↓ created by all NGSO systems of all operators.

limits by artificially splitting or combining non-GSO FSS systems, will be to lower the epfd levels and therefore to get a favourable finding status as a result of this regulatory examination."[11]

The ITU alone cannot effectively check all of the ways an NGSO system operator may 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 and affect every nation. Notably, that responsibility falls on individual administrations and regulators that consider authorizing, or granting market access to, NGSO system operations.[12]

Moreover, it ultimately falls on the NGSO operator to conduct its operations in full compliance with all of the Radio Regulation's EPFD limits *at all locations around the world*, regardless of any limited evaluation initially conducted by the ITU for a limited set of locations and radiofrequency emitters (using software with known limitations), and based merely on the data files provided by that operator *and without regard to the actual operation of the NGSO system*. Notably, alternative software is available or is being developed that allows a more accurate assessment of the expected interference and that appropriately factors in all contributions to EPFD.

It would be practically impossible in the future to directly measure the NGSO-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 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. Multiple NGSO systems already operate in the same frequency bands.

The way in which different NGSO systems contribute to the overall EPFD level received by a GSO earth station is illustrated by Figure 2, above. 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.

Even when they are applied properly, the existing EPFD limits (developed over 20 years ago) are under-protective of today's GSO networks. The US Federal Communication Commission (FCC) has acknowledged that existing EPFD limits "were not developed with the most

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[11] *Id.* at 29, quoting 2003 CPM Report, Chapter 3, §3.1 (addressing WRC-03 agenda item 1.19 "to consider regulatory provisions to avoid misapplication of the non-GSO FSS single-entry limits in Article 22 based on the results of ITU-R studies carried out in accordance with Resolution 135 (WRC-2000)").

[12] Nevertheless, the U.S. Federal Communications Commission (FCC) has indicated that it did not and will not conduct any such analysis of an NGSO system, deferring instead to an ITU evaluation processes for the underlying filings, despite the known shortcomings as discussed both here and in Annex A.

advanced modern GSO networks in mind."[13] Indeed, those limits were designed to protect decades-old GSO network designs and do not adequately protect either (i) today's ultra-high-throughput GSO satellites, or (ii) the sub 1-meter antennas that GSO network (and NGSO systems alike) use to meet customer demands.

It is essential that NGSO systems satisfy all EPFD limits in each and every nation that they serve, and that a national regulator evaluate an NGSO system's EPFD compliance within its territories before granting market access.

For these reasons, a national regulator should:

- Conduct its own analyses to ensure that an NGSO system seeking to serve its territories can comply with *all* single-entry EPFD limits within those territories, with the national regulator viewing all NGSO system filings under which the NGSO system operates as a collective, and focusing in particular on:
    - Whether the actually-deployed portion of the system to be used to serve a nation's territories is able to meet the EPFD limits; and
    - The integrity of the NGSO system filings, for example, whether the avoidance angles are consistent with the masks and whether the masks for different orbital shells (*i.e.,* the particular combination of orbit altitudes and inclinations) are consistent;

  Inconsistencies in any of these can be used to game the current ITU EPFD software and produce false favorable results;
- Require that an NGSO system, during operations, comply with *all* single-entry EPFD limits across the entirety of the system, with the national regulator again viewing all NGSO system filings under which the NGSO system operates as a collective;
- In other words, require that an NGSO system operate such that it does not exceed any of the EPFD limits established for an individual NGSO system just as if it were relying on a single ITU filing for all co-frequency operations, and ensure the stated parameters in the filings are consistent within the filings and with the satellites to be used to serve the nation's territories;
- Conduct its own analyses of the aggregate EPFD levels from all NGSO systems seeking to serve its territories to ensure that the aggregate EPFD levels do not exceed any of the EPFD limits; and
- 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, require that the NGSO system operators cooperate with each other and take the technical measures necessary to eliminate the interference.

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[13] *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters,* 32 FCC Rcd 7809, ¶ 35 (2017).

### B. Hindering equitable access to shared NGSO frequency bands

Large NGSO systems with thousands of satellites, particularly when they employ small user terminals, can consume significant portions of the "look angles" toward space and LEO orbits as well, preventing use of the sharing tools that have been employed successfully for decades among certain NGSO systems. This threat to NGSO spectrum sharing occurs when large LEO constellations "blanket the sky," causing many in-line interference events limiting and sometimes completely blocking other NGSO systems from sharing the same spectrum. A large NGSO system would rarely (if ever) experience this problem itself because it has a far greater number of satellites than smaller NGSO constellations, which provides the large NGSO system with alternative communications paths in which the same spectrum remains available for its use. These impacts are depicted in Annex B.

The upshot is that a large NGSO system would have little incentive to avoid in-line interference events; large numbers of in-line interference events would harm smaller NGSO systems without materially impacting the large NGSO system's operations. As a result, the large NGSO system could hinder other satellite operators, including new entrants, from accessing and using shared spectrum and orbital resources in the public interest. One large NGSO operator acknowledged these kinds of risks when it objected to a proposal that it claimed would allow another NGSO operator to access twice the amount of spectrum compared to other Ku/Ka-band NGSO operators: "*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.*"[14]

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

In sum, efforts by some large NGSO operators to "blanket the sky" can have direct and harmful consequences for other NGSO systems and operators – and can harm innovation, industry growth, and the broader public interest.

To avoid this result, it is critical to adopt a condition requiring "look angle" splitting, whereby NGSO systems serving a country in overlapping frequencies would divide the range of satellite azimuths as seen from a location on the Earth whenever the potential for NGSO/NGSO interference exists at that location.[15] For example, on such occasions one

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

[15] In similar cases, the United States imposes spectrum-splitting constraints on "foreign" NGSO systems that seek U.S. market access. *See, e.g., In re Kinéis, Petition for Declaratory Ruling to Access the U.S. Market Using a Low-Earth Orbit Satellite System,* FCC 21-118 (rel. Dec. 19, 2021) at ¶¶ 2, 12 (French LEO system granted U.S. market access under the following condition: "Absent a coordination agreement, spectrum will be divided among licensees and grantees of U.S. market access pursuant to section 25.157 of the Commission's rules."), https://www.fcc.gov/document/fcc-grants-market-access-kineis-low-earth-orbit-

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 West or East direction from that location that is not within the minimum avoidance angle of a satellite in the other system in its assigned West or East direction from that location, 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 available spectrum resources on an equitable basis.

Specifically, national regulators should condition licenses for large NGSO constellations to ensure they do not hinder equitable access to shared and limited NGSO orbital resources by requiring NGSO systems authorized to serve their countries to:

- Operate with only 1/*n* of the look angles in a given country, where *n* is the number of NGSO systems authorized to serve that country in the same frequency band, and
- Coordinate in good faith and in advance with other NGSO systems so that all *n* look angles may be used to serve that country by those different NGSO systems.

With this approach, NGSO systems would be on an equal footing, regardless of system size, incentivizing all NGSO systems to coordinate, preserving and promoting new opportunities for industry growth in the country.

### C. Hindering safe and reliable access to shared LEO orbits

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[16] LEO mega-constellation operators are in a race to populate (with huge numbers of satellites) a wide swath of the orbits in the 300 km to 700 km range that are important for many strategic purposes, such as the missions of earth observation, remote sensing[17] and PNT[18] satellites. These altitudes are also attractive for other purposes because of their associated passive decay times for failed satellites (which can deorbit much more quickly than from higher orbits).[19]

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satellites-0. The US approach, however, disproportionately disadvantages smaller NGSO systems for the reasons explained in Annex B.

[16] *See, e.g.,* **"**Elon Musk's shot at Amazon flares monthslong fight over billionaires' orbital real estate" (Jan. 27, 2021), https:/www.theverge.com/2021/1/27/22251127/elon-musk-bezos-amazon-billionaires-satellites-space.

[17] *See*, *e.g.,* European Space Agency, eduspace, "Earth observation satellites – Introduction" https://www.esa.int/SPECIALS/Eduspace_EN/SEM7YN6SXIG_0.html.

[18] *See* "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/.

[19] Other current and forthcoming satellite broadband systems operate in different orbits.

LEO mega-constellation operators are engaging in a "land grab" of these orbital resources by planning to operate with unnecessarily wide orbital tolerances, effectively filling up hundreds of kilometers of orbits and hindering the ability of other LEO systems to operate safely in nearby orbits. This would impact the ability of other LEO systems to use these orbits to provide innovative services to the public and distort the existing 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 satellites proposed to populate these orbits (over 34,000 from one operator alone) is problem enough, but the harmful impact is magnified by the overly wide orbital tolerances within which they propose to operate. One LEO operator proposes to operate across *hundreds of kilometers in LEO*—including in large shells that would spread from 290 km to 430 km and 475 km to 687 km. As depicted below in Figure 3, this result would occur because it seeks to operate anywhere from 50 km below, to 70 km above, each of the nominal altitudes for its various orbital shells.[20]

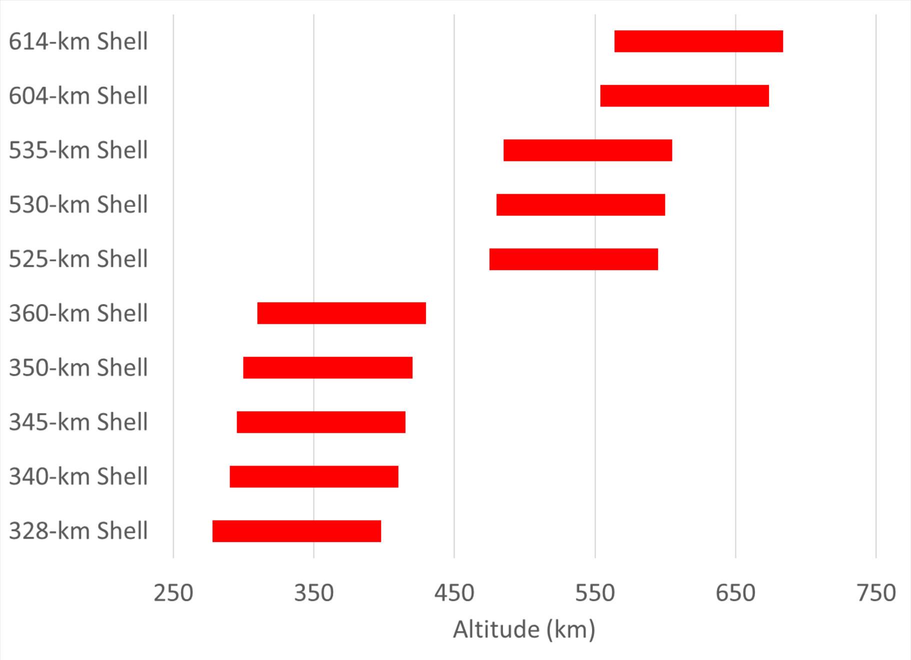

Figure 3: Extent of physical orbits proposed to be consumed by one large LEO system

The net effect would be to hinder 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).

The large LEO system would have limited incentive to allow other LEO systems to operate in the orbital ranges depicted in Figure 3. Particularly given that LEO systems already operate within much narrower orbital tolerances, there is no good reason to allow it to provide

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[20] *See* U.S. Federal Communications Commission, IBFS File No. SAT-AMD-20210818-00105, at 4 (Aug. 18, 2021). SpaceX plans to operate the first generation of its Starlink satellites with orbital tolerances that would spread from 510 km to 580 km.

service to a country utilizing overlapping shells of satellites in very wide orbits that unduly consume what otherwise would be shared.  Moreover, neither this LEO system's licensing administration nor the LEO operator itself has identified what parameters would have to be satisfied to safely allow other LEO satellites or constellations to occupy, or overlap, the orbits this LEO system plans to occupy.  And other LEO operators have asserted to the contrary that LEO systems cannot safely share the same orbits.

Again, this LEO operator could therefore hinder the ability of other satellite operators, including new entrants, to access and use the same shared spectrum and orbital resources in the public interest.  This operator already enjoys the ability to use LEO regardless of whether physical coordination with any other operator is concluded successfully but the same cannot be said with respect to new entrants (*i.e.*, beyond those already deploying LEO systems) which may be deterred from even attempting to deploy systems that overlap with this LEO system.

One mitigation would be to require any LEO operator serving a country 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, to ensure other LEO systems that seek to serve the country may access the shared LEO space, or alternatively to apply such orbital tolerance requirements as the national regulator deems appropriate to ensure the ability of other satellites and systems serving that country to safely operate within, or overlap, the orbits occupied by large LEO constellations.  Such an approach is depicted in Figure 4 below.

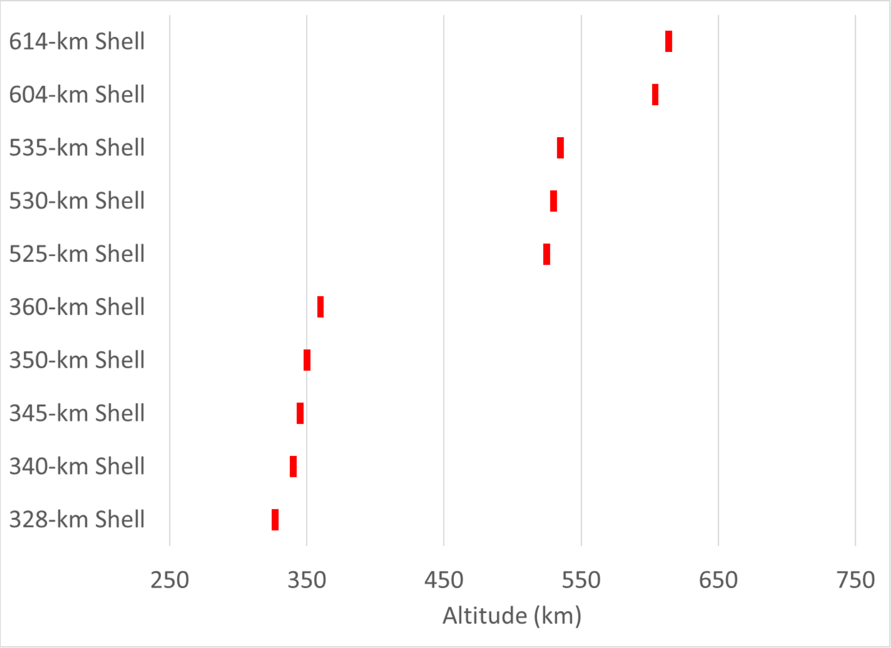

Figure 4:   Reasonable orbital tolerances leave room for many LEO systems

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

As explained in Annex A, one LEO operator plans to operate its system under multiple ITU filings that would result in its system significantly exceeding the ITU's *aggregate* EPFD limits.

In addition to that one system causing far more interference into GSO networks than is permitted by ITU Radio Regulations, it would hinder opportunities for other parties, including national operators, to operate their own NGSO systems, because that one system would consume (and in fact would exceed) the entire aggregate EPFD "budget" that must be apportioned among all NGSO systems using the same or overlapping frequencies.

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

## III. Adverse impact on national space industries

A leading position by one or two LEO operators with respect to NGSO resources could not only hinder the ability of other satellite operators or constellation projects to operate effectively, it also would represent a loss in value for national satellite communications infrastructures in both the public and the private sectors. This includes space industry players as diverse as manufacturers, launch operators, and national satellite programs for both communications and other LEO applications.

Particularly coupled with one NGSO operators' control over critical launch vehicles, the possibility of these harms is easy to envision.

The loss in value for national economies and the corresponding negative impact on jobs would be tremendous. National regulators should ensure the continued relevance of their existing national industrial bases, as well as all new domestic companies looking to take advantage of opportunities presented in the new space era 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,[21] "carrying capacity,"[22] and

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[21] *See, e.g.*, European Space Policy Institute, ESPI Report 82 - Space Environment Capacity – Full Report (Apr. 2022), https://espi.or.at/news/espi-report-82-space-environment-capacity; L. Miraux, "Environmental Limits to the Space Sector's Growth," SCIENCE OF THE TOTAL ENVIRONMENT (Feb. 2022), 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 eco-design 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 1-3, https://doi.org/10.1038/s41598-021-89909-7.

[22] *See* Physics Today, Toni Feder, "Q&A: Moriba Jah on sustainability of near-Earth space," (Mar. 31, 2022), https://physicstoday.scitation.org/do/10.1063/PT.6.4.20220331a/full/.

"time to Kessler Syndrome."[23] Regardless of the terminology, the critical point is that LEO (like all NGSO) orbital resources are *limited*. As one leading expert explains:

> I think we are going to lose the ability to use certain orbits because the carrying capacity is going to get saturated by objects and junk. Orbital capacity being saturated means "when our decisions and actions can no longer prevent undesired outcomes from occurring."[24]

It therefore is incumbent on national regulators to consider what portion of these resources – including spectral resources – NGSO systems that are permitted to serve their countries would consume, and what portion would remain available for domestic participants in the space and telecom industry.

## IV. Adverse consequences on end-users and citizens

National economies and societies are increasingly reliant on space services (such as location services, satellite-based media services, weather forecasting and emergency services). This growing reliance of national economic activities on space comes with the need to avoid and mitigate risks of disruption to space-based assets and infrastructure.

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 that can disable and even destroy satellites, and also generate more orbital debris.[25] Each collision will statistically lead to more collisions and ultimately can lead to a "belt of debris around the Earth,"[26] resulting in a series of self-sustaining collisions referred to as the Kessler syndrome, which could make certain orbits unusable for critical civic, 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 one large NGSO system over time because 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

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

[24] E. Berger, "Space debris expert: Orbits will be lost—and people will die—later this decade. Flexing geopolitical muscles in space to harm others has already happened," Ars Technica (Dec. 14, 2022) (quoting Moriba Jah), https://arstechnica.com/science/2022/12/space-debris-expert-orbits-will-be-lost-and-people-will-die-later-this-decade/.

[25] *See* A. Lawrence, M. L. Rawls, M. Jah, A. Boley, F. Di Vruno, S. Garrington, M. Kramer, S. Lawler, J. Lowenthal, J. McDowell, and M. McCaughrean, "The case for space environmentalism," NATURE ASTRONOMY (Apr. 22, 2022), https://www.nature.com/articles/s41550-022-01655-6.

[26] *See* D. J. Kessler and B. G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt" (1978).

destroyed [by collisions with debris] faster than they are launched."[27] Another study concludes that "Kessler Syndrome is expected to occur in low-Earth orbit around 2048 under recent historical sectoral growth trends, and may occur as early as 2035 if the space economy grows consistent with projections by major investment banks."[28]

Notably, the massive increase in LEO constellation sizes is driving an exponential increase in the number of conjunctions (*i.e.,* "close calls") that a given constellation can be expected to experience over time—dramatically increasing the likelihood of an in-orbit collision that would have devastating impacts on space sustainability and safety.[29] As one leading expert explains: "The law of very large numbers will tell you that very low probability events can happen if given enough opportunities."[30] However, no current rules or guidelines reflect the magnitude of these dangers.

The collision risk is further exacerbated by the documented failure rates of satellites in certain LEO constellations: indeed, satellites that cannot maneuver cannot avoid collisions, and experiential failure rates early in the life of one constellation demonstrates that it has not been capable of maintaining a sufficiently low level of disposal reliability.[31] Moreover, all potential collisions cannot be predicted, and even where a satellite is maneuverable, all potential collisions cannot be avoided.[32]

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 LEO satellites collide catastrophically.[33] Both types of events generate large numbers of lethal debris that spread into orbits hundreds of kilometers away

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[27] G. Long, "The Impacts of Large Constellations of Satellites," JASON – The MITRE Corporation, JSR-20-2H, Nov. 2020, (Updated: Jan. 21, 2021), at 97, https://www.nsf.gov/news/special_reports/jasonreportconstellations/JSR-20-2H_The_Impacts_of_Large_Constellations_of_Satellites_508.pdf.

[28] A. Rao and G. Rondina, "Open access to orbit and runaway space debris growth," arXiv:2202.07442 [econ.GN] (Feb. 16, 2022), at 1, https://arxiv.org/pdf/2202.07442.pdf.

[29] *See* Comments of NASA, U.S. FCC IBFS File No. SAT-AMD-20210818-00105, at 1 (filed Feb. 8, 2022) ("NASA Letter") (With the increase in large constellation proposals to the FCC, NASA has *concerns with the potential for a significant increase in the frequency of conjunction events and possible impacts to NASA's science and human spaceflight missions*."); ("An increase of this magnitude into these confined altitude bands inherently brings *additional risk of debris-generating collision events based on the number of objects alone.*) (emphasis added).

[30] https://twitter.com/ProfHughLewis/status/1509903335251456045 (Apr. 1, 2022).

[31] *See* "Jonathan's Space Pages: Starlink Statistics," https://planet4589.org/space/con/star/stats.html (detailing a variety of types of failures and anomalies involving Starlink satellites).

[32] *See* NASA Letter at 3 ("[C]onsidering multiple independent constellations of tens of thousands of spacecrafts and the expected increase in the number of close encounters over time, the assumption of zero risk from a system-level standpoint lacks statistical substantiation.") (emphasis added).

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

from the point of impact and persist for decades,[34] including lethal, *non-trackable* debris (LNT), 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 fact, experts explain that LNT "dominates the risk profile of operational spacecraft."[35]

Failures and collisions of this sort would affect far more than the satellites in the LEO constellation itself. Failed LEO satellites, collisions involving LEO satellites, and the resulting debris fields, would affect all individual satellites and constellations that occupy, or transit, the same or overlapping orbits, potentially disrupting the operation of other critical satellite systems, including those in LEO and beyond. And both failed satellites and 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 DTH video and 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 also include the costs and risks related to designing NGSO satellites 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 (*i.e.,* 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 both the Chief Executive Officer of one satellite launch provider,[36] and NASA,[37] the crowding of LEO from the active satellites of one large LEO constellation 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 all satellites in all orbits.

Furthermore, in a landmark report, the Organization for Economic Cooperation and Development (OECD) points to the growing risk of an irreversible environmental and

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

[35] R. Buchs, "Collision risk from space debris: Current status, challenges and response strategies," Lausanne: EPFL International Risk Governance Center (2021), at 13, https://go.epfl.ch/irgc_space_debris_report ("LNT objects dominate the risk profile of operational spacecraft. As they are far more numerous than trackable objects and cannot be avoided, LNT objects make up more than 95% of the mission terminating collisional risk for a typical LEO satellite[.]").

[36] J. Wattles, "Space is becoming too crowded," Rocket Lab CEO Warns, CNN (Oct. 8, 2020), https://www.cnn.com/2020/10/07/business/rocket-lab-debris-launch-traffic-scn/index.html ("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.").

[37] NASA Letter at 4 ("NASA is also concerned with an increasing unavailability of safe launch windows, especially for missions requiring instantaneous or short launch windows, such as planetary missions like Europa Clipper, which would be significantly affected due to a lost launch opportunity.")

industrial disaster in space.[38] The deployment of large LEO constellations 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 that are coming online now and from which many countries may derive benefit in the future, such as GPS systems, which in turn "would have a direct impact upon the security, safety, economy and well-being" of citizens.[39]

Collision and orbital debris generation risks also are materially affected by the mass and cross-sectional area of LEO satellites, as well as by the number of satellites in a constellation and the particular orbits they employ.[40] In what is a disturbing trend, LEO spacecraft are becoming larger and more massive, with significant implications for the space sustainability and safety risks posed by individual satellites, even when viewed in isolation (*e.g.,* per-satellite collision risks), due to increased collision risk associated with greater cross-sectional area, and the larger resulting debris fields when these more massive satellites collide with other space objects.

The dramatic increase in satellite mass and cross-sectional area in LEO satellite designs is illustrated in Figure 5. *As discussed below, this trend has serious repercussions for others who seek to access and use space*.

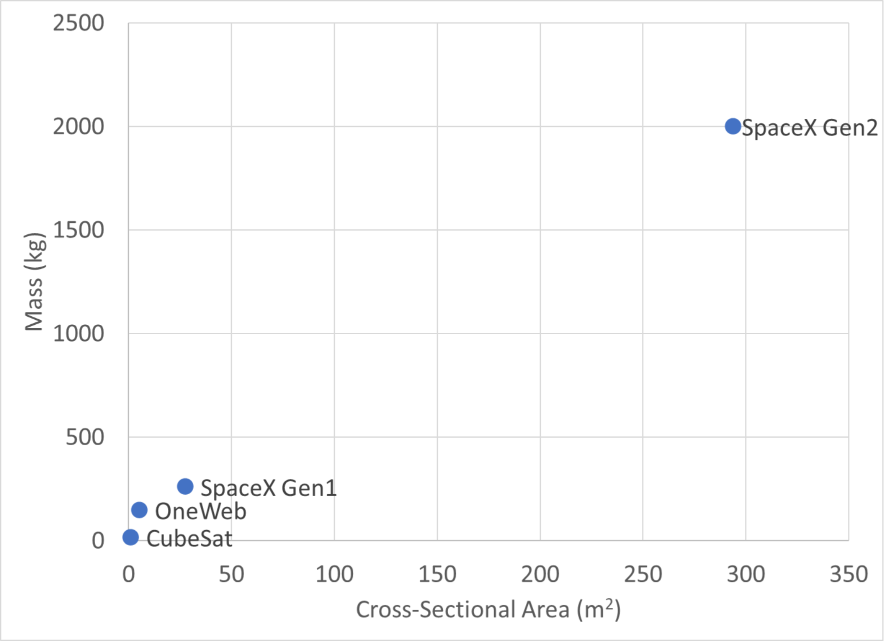

Figure 5: Trends in estimated LEO spacecraft mass and cross-sectional area

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[38] "Space Sustainability: The Economics of Space Debris in Perspective," OECD Science, Technology and Industry, Policy Papers, No. 87 (Apr. 2020), https://www.oecd.org/fr/environnement/space-sustainability-a339de43-en.htm.

[39] European Commission, Joint Communication to the European Parliament and the Council, "An EU Approach for Space traffic Management; An EU contribution addressing a global challenge" (Feb. 15, 2022), https://ec.europa.eu/info/sites/default/files/join_2022_4_1_en_act_part1_v6.pdf.

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

National regulators therefore should: (i) require LEO applicants to disclose the mass and cross-sectional area of proposed LEO satellites, in addition to the number of satellites in a constellation and the particular orbits they employ, so the aggregate risk presented by the constellation can be evaluated, and (ii) require that an applicant 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 the national regulator.  This information is essential to allow the calculation and management of a LEO constellation's total contribution to collision and orbital debris risk.

A very significant and positive development is reflected in the modeling (based on empirical measurement tools and quantitative analyses) that has been developed to help (i) understand the limits to LEO space exploitation and how we best can operate within those limits, and (ii) make more informed policy making and licensing decisions.

A recent study entitled "LEO Capacity Modeling for Sustainable Design"[41] estimates LEO "carrying capacity", that is, the sustainable satellite population distribution in LEO.  It estimates future debris propagation, considering both existing debris and the likelihood that non-debris objects become debris within a given time horizon.  It also accounts for the performances of various possible mitigations.  This methodology enables holistically comparing contributions to debris propagation as a function of specific system characteristics and deducing the incremental impact of individual systems and characteristics on LEO carrying capacity.

This study yields many significant results, including: (i) the proposed second-generation configurations of two particular mega-constellation would consume all, or nearly all, of the carrying capacity in LEO orbits neighboring those occupied by those constellations; (ii) less massive satellites with smaller cross-sectional area facilitate greater carrying capacity in LEO; and (iii) removing the existing population of derelict rocket bodies does not result in a material increase in LEO carrying capacity.

These results highlight the need to facilitate sustainable use of LEO by: (i) applying orbital admittance control and minimum satellite reliability requirements through license and market access conditions that limit the number of LEO satellites, mass, and cross-sectional area launched into various orbits, and ensure a certain probability of successful post-mission disposal; and (ii) developing suitable orbital regimes to support different types of LEO systems.  For example, (a) altitudes below 400 km may be suitable for non-propulsive satellites; (b) altitudes in the 400 km to 600 km range may be suitable for mega-constellations (provided that the number of satellites, mass, and cross-sectional area launched are managed); and (c) smaller constellations above 600 km are likely sustainable depending on mass and cross-sectional area.

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[41] M. Sturza, M. Dankberg, W. Blount, "LEO Capacity Modelling for Sustainable Design," Advanced Maui Optical and Space Surveillance Technologies Conference, Sept. 27-30, 2022, https://amostech.com/TechnicalPapers/2022/Space-Debris/Sturza.pdf.

Significantly, the model underlying this study is useful in: (i) assisting in the design of sustainable broadband LEO systems; (ii) assessing the impact of existing and planned LEO systems; and (iii) understanding the implications of multiple large LEO constellations occupying neighboring, interleaving, or overlapping orbits.

Moreover, using such a model can facilitate: (i) quantitatively measuring absolute and relative effectiveness of candidate regulations and policies governing space access and operations, and determining the effectiveness of remediations and mitigations such as debris removal strategies, Space Surveillance and Tracking (SST), Space Situational Awareness (SSA), and Space traffic Management (STM); (ii) considering interactions among all missions and constellations, instead of merely addressing each one individually and based on historical debris flux models; and (iii) fostering identification of quantitative system design characteristics that slow, halt, or reverse acceleration towards a point in time when access to space is intolerably impaired or even lost.

Thus, this type of model provides a quantitative alternative to intuitive heuristics and mitigations currently being contemplated to address the debris crisis and thus should provide for more informed policy making and licensing decisions.

## V. Adverse environmental effects on the atmosphere, astronomy, and the night sky

The increased use of space is not without cost to the environment.[42] The rapid development of large LEO constellations risks multiple tragedies of the commons, including tragedies to ground-based astronomy, life on Earth, and Earth's upper atmosphere.[43] Those costs include: (i) the potential for large quantities of satellites reentering the atmosphere to damage the Earth's atmosphere and effect climate change through, among other things, radiative forcing[44] and depletion of the ozone layer, increasing the risk of cancer and other

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[42] *See generally* S. Hall, The New Space Race Is Causing New Pollution Problems: Earth's stratosphere has never seen the amounts of emissions and waste from rockets and satellites that a booming space economy will leave behind, *New York Times* (updated Jan 22, 2024), https://www.nytimes.com/2024/01/09/science/rocket-pollution-spacex-satellites.html.

[43] *See* A. Lawrence, M. L. Rawls, M. Jah, A. Boley, F. Di Vruno, S. Garrington, M. Kramer, S. Lawler, J. Lowenthal, J. McDowell, and M. McCaughrean, "The case for space environmentalism," NATURE ASTRONOMY (Apr. 22, 2022), https://www.nature.com/articles/s41550-022-01655-6;

Letter from Natural Resources Defense Council and the International Dark-Sky Association to U.S. FCC, IBFS File Nos. SAT-LOA-20200526-00055 and SAT-AMD-20210818-00105 (Sep. 7, 2022) ("NRDC & IDA Letter");

A.C. Boley, and M. Byers, "Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth," SCIENTIFIC REPORTS, 11, Article number 10642 (May 20, 2021), https://www.nature.com/articles/s41598-021-89909-7.

[44] *See* L. Organski, C. Barber, S. Barkfelt, M. Hobbs, R. Nakagawa, Dr. M. Ross, Dr. W. Ailor, "Environmental Impacts of Satellites from Launch to Deorbit and the Green New Deal for the Space Enterprise," Aerospace Corporation (Dec. 2020);

D. Werner, "Aerospace Corp. Raises Questions about Pollutants Produced during Satellite and Rocket Reentry," *SpaceNews* (Dec. 15, 2020), https://spacenews.com/aerospace-agu-reentry-pollution/;

negative health effects;[45] (ii) impairing critical optical and radio astronomical research by disrupting the visible night sky;[46] (iii) creating light pollution, with the resulting negative impacts on the health and quality of life of humans and on plants and animals;[47] and (iv) as NASA has emphasized, impairing the functioning of critical asteroid detection and defense capabilities.[48]

In fact, certain choices made in LEO system design are the dominant factors affecting these additional impacts, such as satellite cross-sectional area, mass, orbit, and number of satellites, along with albedo (or reflectivity) and material composition.

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M. N. Ross & L. David, "An Underappreciated Danger of the New Space Age: Global Air Pollution*," Scientific American* (Feb. 2021), https://www.scientificamerican.com/article/an-underappreciated-danger-of-the-new-space-age-global-air-pollution/;

M. N. Ross and K. L. Jones, "Implications of a growing spaceflight industry: Climate change," *JOURNAL OF SPACE SAFETY ENGINEERING* (Jun. 6, 2022), https://www.sciencedirect.com/science/article/abs/pii/S2468896722000386;

U.S. Government Accountability Office, *Large Constellations of Satellites: Mitigating Environmental and Other Effects*, GAO-22-105166 (Sep. 29, 2022) ("First U.S. GAO Report"), https://www.gao.gov/products/gao-22-105166;

"NOAA scientists link exotic metal particles in the upper atmosphere to rockets, satellites" (Oct. 16, 2023), https://research.noaa.gov/2023/10/16/noaa-scientists-link-exotic-metal-particles-in-the-upper-atmosphere-to-rockets-satellites/#:~:text=NOAA%20scientists%20investigating%20the%20stratosphere,intense%20heat%20of%20re%2Dentry;

D. M. Murphy, M. Abou-Ghanem, D. J. Cziczo**, "**Metals from Spacecraft Reentry in Stratospheric Aerosol Particles," *Proceedings of the National Academy of Sciences* (Oct. 16, 2023), https://www.pnas.org/doi/10.1073/pnas.2313374120.

[45] *See* NRDC & IDA Letter at 3.

[46] *See* R. Boyle, "Satellite Constellations Are an Existential Threat for Astronomy," *Scientific American* (Nov. 7, 2022), https://www.scientificamerican.com/article/satellite-constellations-are-an-existential-threat-for-astronomy/;

A. Lawrence, M. L. Rawls, M. Jah, A. Boley, F. Di Vruno, S. Garrington, M. Kramer, S. Lawler, J. Lowenthal, J. McDowell, and M. McCaughrean, "The case for space environmentalism," *NATURE ASTRONOMY* (Apr. 22, 2022), https://www.nature.com/articles/s41550-022-01655-6;

C. Young, "The worst case Starlink scenario? We could be 'right on the edge' of Kessler syndrome," *INTERESTING ENGINEERING* (Aug. 11, 2022), https://interestingengineering.com/innovation/worst-case-starlink-scenario-kessler-syndrome;

First U.S. GAO Report at 1;

United Nations Office for Outer Space Affairs, International Astronomical Union, IAC, NOIR Lab, Dark and Quiet Skies for Science and Society: Report and Recommendations, (Dec. 29, 2020), available at https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf.

[47] NRDC & IDA letter at 3.

[48] *See* NASA Letter at 3 ("[T]here would be a Starlink in every single asteroid survey image taken for planetary defence against hazardous asteroid impacts, decreasing asteroid survey effectiveness by rendering portions of images unusable. This could … have a *detrimental effect on our planet's ability to detect and possibly redirect a potentially catastrophic impact.*") (emphasis added).

We are trending the wrong way in each of these respects as depicted in Figure 6, which shows the: (i) total number of satellites in LEO as of January 1, 2022,[49] as well as the associated mass and cross-sectional area of those satellites (in green); and (ii) the exponential increase in these values that would occur if merely one particular LEO system were allowed to deploy (in red).[50]

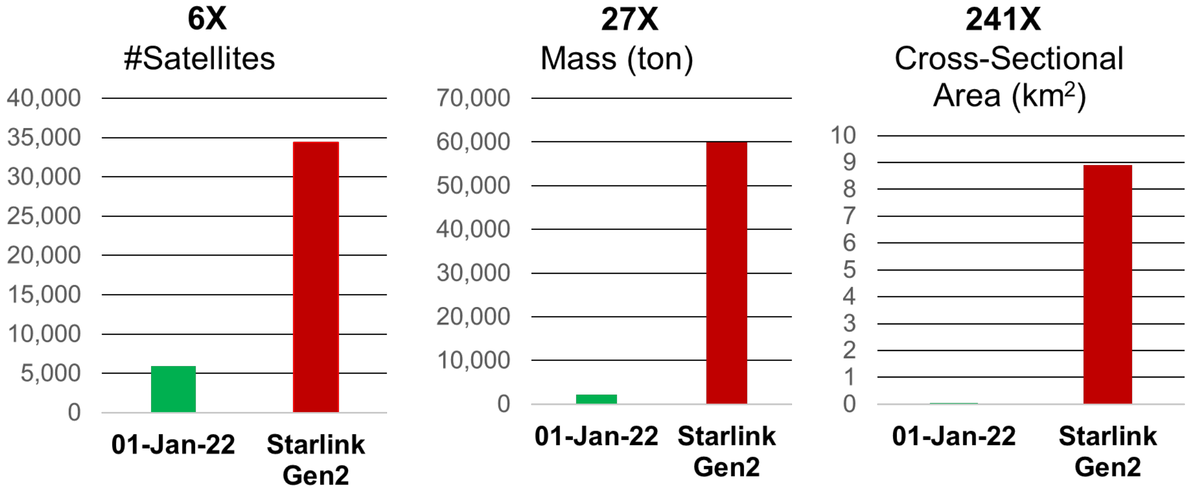

Figure 6: Trends in LEO constellation size, mass, and cross-sectional area

Expert review confirms that the decades-old approach being applied by some to the environmental effects of today’s mega-constellations must be revisited to account for the new information that is available about those never-before-contemplated effects.[51] It is essential that these effects be taken into consideration when evaluating what types of LEO constellations are authorized to serve a given country.

The environmental consequences of the proposed expansion of one large LEO system—which is unprecedented in nature and would involve deploying approximately 90,000 (or more) total satellites over 15 years, using a launch every six days—would be grave.[52] Among other things, the impact of depositing an estimated 150,000 tons of alumina into the

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[49] *See ESA’s Annual Space Environment Report*, at 52-54 (Apr. 22, 2022), https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf (providing data used for Jan. 1, 2022 “baseline”).

[50] Based on data SpaceX provided to the U.S. FCC in its proposal to expand its system.

[51] *See* U.S. Government Accountability Office, *FCC Should Reexamine Its Environmental Review Process for Large Constellations of Satellites,* GAO-23-105005 (Nov. 2022), at 28, https://www.gao.gov/products/gao-23-105005.

[52] *See* J. Baumgartner, “Starlink's daunting deployment plan 'leaves no margin for error' – analyst,” *Broadband World News* (Jan. 18, 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.”

upper atmosphere when its satellites deorbit[53] would certainly have deleterious effects. And the facts (including those provided by NASA) reflect that this operator is not protecting astronomy or preserving the night sky, and this operator has not shown how it would do so with an expanded system incorporating an additional 30,000 operating satellites.[54]

Moreover, an increase in the number of failed NGSO satellites, catastrophic collisions involving NGSO (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 IV above).

## VI. Implications for national security

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

The recent ASAT test shows that hostile activities by sovereign actors in space represent a very significant threat to open and safe space. Other counterspace capabilities — such as cyberattacks, electronic jamming or spoofing, and electromagnetic pulses (EMPs) — can affect all types of space assets. LEO operators that fall victim to these attacks may lose control over targeted satellites and be unable to maneuver to avoid collisions, if not cause one.

Satellite systems in LEO are susceptible to generate more in-orbit damage when targeted than other satellite systems. Constellations in LEO may have resilience when it comes to a failure of a single satellite, but they have a vulnerability because an attack or collision involving one satellite can generate a cascading series of collisions with all or many other spacecraft in a common orbital shell, and even shells in nearby orbital altitudes. Increasing densification in LEO combined with a heightened risks of counterspace attacks create LEO fragility.

The same can be said of the risk that space activities carried out by commercial actors represent to all space actors, including 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 IV above). As noted above, according to an evaluation of the debris generated by that ASAT test, a collision between two NGSO satellites would

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[53] Based on SpaceX's prior representation that 1st generation Starlink satellites "consist of approximately 230 pounds of aluminium" and that there is a "52% mass fraction aluminium" 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 almost eight times more massive, the proposed Starlink expansion could well result in SpaceX releasing about 150,000 tons of additional alumina beyond the Gen1 amounts into the upper atmosphere.

[54] *See* Scientific Reports, "Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth," Article number 10642 (May 20, 2021), https://www.nature.com/articles/s41598-021-89909-7.

generate a similar dispersion of lethal trackable and non-trackable debris in space.[55] Orbits made unusable by space debris would adversely affect defense and security applications the same way as they would affect civil and commercial use cases.

Moreover, the risk of business failure in this new environment is high, and business failures can leave an operator with neither the ability nor the incentive to promptly deorbit failed satellites, increasing the risk for everyone else.

*Countries, through their national regulators, should be particularly mindful of the risk that 'out-of-scale' projects in LEO like certain large NGSO constellations could pose to their sovereign activities in and from space. Overcrowding in space is 'fuel' for debris creation.*

## VII. Recommendations

As the pace of space activities accelerates and societies become even more reliant on space-based systems, the associated risks to the public interest and national and regional space industries deserve immediate attention, including in licensing and market access decisions.

To mitigate the risks and costs discussed above, national regulators should conduct an independent assessment of these matters and impose suitable conditions on ***both NGSO spectrum authorizations and grants of market access***, including the following:

### A. *Protect GSO networks from unacceptable interfence generated by NGSO systems, including by requiring*:

- An NGSO system to comply with single-entry EPFD limits across the entirety of the the system, with the national regulator viewing all NGSO system filings under which an NGSO system operates as a collective, and focusing in particular on:
    - Whether the actually-deployed portion of the system to be used to serve a nation's territories is able to meet the EPFD limits; and
    - The integrity of the NGSO system filings, for example, whether the avoidance angles are consistent with the masks and whether the masks for different orbital shells (*i.e.,* the particular combination of orbit altitudes and inclinations) are consistent;

  Inconsistencies in any of these can be used to game the current ITU EPFD software and produce false favorable results;
- In other words, require that an NGSO system operate such that it does not exceed any of the EPFD limits established for an individual NGSO system, just as if it were relying on a single ITU filing for all co-frequency operations, and ensure the stated parameters in the filings are consistent within the filings and with the satellites to be used to serve the nation's territories;

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

- An NGSO operator to provide, as part of the application process:
    - The number of satellite beams used for transmissions on the same frequency in the same or overlapping areas at any given time;
    - A demonstration how the NGSO system avoids interference to GSO networks created by earth station and satellite antenna sidelobes, and earth station antenna backlobes, particularly when phased array antennas are employed; and
    - An examinination of the interference cases within the national territories of the regulator that are not tested by the limited examination conducted by the ITU (with the regulator verifying that showing with its own analysis);
- An NGSO system to maintain a suitable GSO arc avoidance angle when serving its territory, taking into account the actual characteristics of affected GSO networks (such as satellite receiver noise temperature and antenna gain, and sizes and characteristics of user terminals);
- NGSO systems not to cause unacceptable interference into GSO networks and not to claim interference protection from GSO networks;
- NGSO systems to have an operational feature that allows them 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, NGSO systems to cease operations and not recommence operations until they address the cause of such interference by, among other things, increasing angular separation, reducing power, shaping antenna beams differently;
- All NGSO systems serving a given country, as a collective, not to exceed aggregate EPFD limits; and
- 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 NGSO system operators cooperate with each other and take the technical measures necessary to eliminate the interference.

**B.** ***Ensure NGSOs share frequencies and orbits with other NGSOs, including by requiring***:

- NGSO systems to constrain the ability to hinder use of limited and shared NGSO orbital resources by others by:
    - Operating with only 1/n of the look angles in a given country, where n is the number of NGSO systems authorised to serve that country in the same frequency band (whereby NGSO systems serving a country in overlapping frequencies would divide the range of satellite azimuths as seen from a location on the Earth whenever the potential for NGSO/NGSO interference exists at that location);
    - Coordinating in good faith and in advance with other NGSO systems so that all *n* look angles may be used to serve that country by different NGSO systems; and

    - Maintaining an orbital tolerance of +/- 2.5 km for the apogee and perigee of each NGSO satellite, and a 0.5° tolerance for each orbital inclination the NGSO system employs, in order to ensure other NGSO systems may access the shared LEO space (or comply with such other orbital tolerance requirements as the national regulator deems appropriate to ensure the ability of other satellites and systems serving its territory to operate in the same, or overlapping, orbits occupied by the NGSO system).

C. ***Ensure space safety and sustainability by managing the aggregate collision risk of the entirety of an NGSO system for the full orbital life of each satellite, and as system characteristics and the orbital environment may change, including by:***

- Evaluating the ***entirety of collision risk*** created by all of the satellites in a large NGSO system as a whole, taking into account:
    - Risks during the entire period each satellite in the constellation remains in orbit and at all orbits it may populate (injection, operational, and post mission disposal);
    - Increased risk of collisions due to changes in the orbital environment (such as satellites breaking up/exploding, debris colliding with other debris and breaking up further, and deployment of additional NGSO systems—not just the environment as it existed in the past);
    - Characteristics of the NGSO system—numbers of satellites, orbits used, total cross-sectional area and mass of all of the satellites, subsystem reliability, redundancy, shielding, and operational techniques to reduce risk of system failures—and any subsequent proposed changes to those parameters.

- Taking into account in an NGSO system's aggregate collision risk analysis:
    - Orbital tolerances employed, both altitude and inclination;
    - Risk of collisions with all sizes of space objects, whether trackable or not, including lethal non-trackable objects;
    - Continued reliability of critical command and propulsion capabilities needed to try to maneuver to avoid collisions—and probability that those critical systems may be damaged by untrackable debris too small to fragment the satellite (considering early life failure rates where available);
    - Numbers of satellites that have failed/lost maneuverability;
    - Means to coordinate collision avoidance with other satellite systems;
    - Risk of intra-system collisions within the NGSO constellation (due to all causes, including failed satellites, within that system);
    - Known risks with large numbers (potentially millions per year) of expected conjunctions between a large NGSO system and other space objects (*e.g.*, large numbers of maneuvers to avoid some collisions create other collision risks);
    - Interactions of all satellites in a large NGSO system with all other objects in their environment (including overlapping and intersecting orbits) during orbit raising

maneuvers for rising satellites, considering active and passive decay trajectories for satellites in the orbital disposal phase, as well as active in-service satellites.

- Avoiding the application of simplifying assumptions, such as:
  - Existence of purported “self-cleaning orbits”;
  - Efficacy of “autonomous” controls in avoiding collisions; and
  - Fallacy that maneuverable satellites have “zero risk” of collision.

***D. Adopt suitable conditions to address the types of environmental harms discussed above regarding the Earth’s atmosphere, a dark sky, and radio and optical astronomy.***

***E. Require that an NGSO operator not modify the characteristics of its LEO system (radio frequency, avoidance angle, orbital characteristics, number of satellites, or satellite cross-sectional area or mass) without prior consent from a national regulator (in order to maintain its authorizations in the country).***

***F. Require each NGSO system to provide, every six months, a report showing compliance with the obligations attached to the authorizations granted.***

# ANNEX A:

## Examples of Violations of EPFD↓ Limits (Fuchsstadt, Germany)

# Annex A: Examples of Violations of EPFD↓ Limits (Fuchsstadt, Germany)

This analysis calculates exceedances of ITU interference limits for the first and second generation Starlink configurations, based on the guidance provided in ITU-R Recommendation S.1503-3. It assesses the expected levels of interference generated by the Starlink system with respect to an earth station location at Fuchsstadt, Germany (50.118°N. 9.924°E) communicating with geostationary orbit (GSO) satellites serving Germany, located at 17.6°E longitude (H2M-17.6E) operating in both Ku and Ka-bands.

## A-I. Background

The ITU has established permissible levels of interference into GSO networks from non-GSO systems, like Starlink, in Article 22 of the ITU Radio Regulations. Exceeding these levels would violate the Radio Regulation 22.2 requirement that:

> *"Non-geostationary-satellite systems shall not cause unacceptable interference to [] geostationary-satellite networks in the fixed-satellite service and the broadcasting-satellite service operating in accordance with these Regulations."*

These interference limits are specified as single-entry equivalent power flux density downlink (EPFD↓) limits for individual non-GSO systems (in Tables 22-1A and 22-1B for the FSS and in Table 22-1D for the BSS), and EPFD↓ limits for all non-GSO systems of all operators considered together (in ITU Resolution 76).

The limits are specified as cumulative distribution function (cdf) curves. Each limit curve is defined, for a reference bandwidth and a reference antenna diameter, by a series of points, EPFD↓ (dBW/m$^2$) values and associated values for percentages of time during which EPFD↓ may not be exceeded. The complete limit curves are obtained by interpolating between those points.[56] Thus for any EPFD↓ value, there is a percentage of time that value may not be exceeded. Similarly, for each percentage of time from 0% to 100%, there is an EPFD↓ value that may not be exceeded.

Any exceedance of those EPFD↓ levels—whether for the 100% of time value, the 10% value, the 1% value, or for any other percentage of time value—is a violation of the ITU Radio Regulations and has the potential to result in interference into GSO networks that degrades service and causes capacity losses. This includes GSO direct-to-home television and BSS networks as well as broadband GSO FSS networks.

Based on the data provided in a given ITU EPFD input filing (consisting of SRS and Mask databases), the ITU's Radiocommunication Bureau (BR) does a limited assessment of the EPFD levels that may be generated by a non-GSO system *with respect to one particular*

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[56] RR 22.5C.5 For each reference antenna diameter, the limit consists of the complete curve on a plot which is linear (dB) for the epfd↓ levels and logarithmic for the time percentages, with straight lines joining the data points.

*combination of earth station location and GSO satellite location*. This “examination” uses a software package developed in collaboration with Transfinite to calculate expected EPFD levels that would be produced with respect to that particular non-GSO satellite filing in those limited circumstances. As explained below, ***those limited circumstances have little bearing on the interference that Starlink can be expected to produce in Germany*.**

The BR’s examination is actually a limited spot check, based on the “worst-case geometry” (WCG), one particular GSO earth station (ES) location and one particular GSO satellite location, which is identified as the geometry maximizing the instantaneous non-GSO EPFD↓ level for a specific case of the Table 22 limits (service, frequency, antenna diameter, and radiation pattern).[57] That maximum EPFD↓ value is typically produced for a very short period of time, and thus lies at the bottom-right corner of the relevant EPFD↓ cdf curve (*i.e.,* the alignment of the non-GSO system with the GSO orbital location that produces the highest instantaneous interference level—for a very small percentage of the time, typically on the order of 0.001%, or less). This examination does not consider the ability of a non-GSO system to satisfy EPFD↓ limits at any other GSO ES location or with respect to any other GSO orbital location.

Further, the ITU does not evaluate the ability of a non-GSO operator to actually operate in a manner consistent with the operator supplied EPFD input data, and concerns have been raised that some inputs in the data files provided to the ITU are inconsistent with the laws of physics. Critically, it ultimately falls on the non-GSO system operator to actually conduct its operations in full compliance with all EPFD↓ limits, regardless of any limited evaluation initially conducted by the ITU. Moreover, it is difficult to attribute interference to a particular non-GSO system once it is in operation, particularly when more than one non-GSO system operates in the same or overlapping frequencies. Some of these factors are why the French space agency, CNES, has recommended that frequency regulators require applicants to provide more detailed information that allows an analysis of foreseeable interference with other systems, existing or future.[58]

Critically, EPFD↓ levels calculated for geometries other than the one identified by the WGC algorithm in ITU-R Recommendation S.1503 that is implemented in the Transfinite software can exceed the relevant EPFD↓ limit cdf curve at any point. Specifically, this can occur at different GSO ES locations on Earth, and with different GSO satellite locations, than those identified by the S.1503 WCG algorithm. An analysis at those other geometries can be conducted with Transfinite’s commercially available Visualyse EPFD software, which uses the same algorithm and EPFD calculation engine as in the software it developed for the ITU, with an added feature that allows the geometry (GSO ES location and GSO satellite location) to be set manually, so that compliance with *all EPFD limits, at all GSO ES locations* and *for all GSO satellite locations* can be evaluated. This is particularly valuable when an examination is desired of the expected interference into GSO services in a given country, or into one of its GSO satellite networks.

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[57] *See generally* ITU-R Rec. S.1503.

[58] Letter from CNES to ARCEP regarding Starlink’s request for a radio frequency use authorization, Ref. DS/DAI/D-2022-0006202 (May 9, 2022).

ITU-R Recommendation. S.1503-3 explains the necessity of complying 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 remains necessary for the non-GSO operator to meet the epfd limits in Article 22 for all [] geometries including the testing of specific GSO networks as noted in § A1.3.*[59]

The Transfinite Visualyse EPFD software used in this analysis allows precisely that type of evaluation called for by S.1503-3. It assesses the expected impact of the Starlink system for a GSO ES located at Fuchsstadt, Germany (50.118°N. 9.924°E) with a GSO satellite located at 17.6°E longitude serving Germany.

This analysis uses (i) the constellations defined by SpaceX's EPFD input files for the particular ITU filings that it has specified as relevant (which data vary in some respects from the data initially provided in ITU notifications), and (ii) the particular orbital deployment configuration that SpaceX specified, all during the licensing process at the United States Federal Communications Commission (FCC).

Notably, this analysis does not suggest that Starlink *could not be* operated in a manner compliant with the ITU Radio Regulations.

This analysis shows that SpaceX *does not plan* to operate Starlink in a manner compliant with the EPFD↓ limits in the ITU Radio Regulations.

To comply with those EPFD↓ limits, Starlink could employ various combinations of its own choosing of (i) numbers of satellites, (ii) specific orbit parameters, (iii) power flux density (PFD) emissions masks, (iv) effective isotropic radiated power (EIRP) emissions masks, (v) GSO network avoidance angles, and (vi) frequency reuse parameters.

## A-II. Analysis of EPFD↓ Violations by 4,408 Satellites in Starlink's First Generation Configuration

The following are examples of EPFD↓ exceedances for the first generation Starlink configuration of 4,408 satellites, which, when tested only with the WCG combination of GSO ES location and GSO satellite longitude, has received a favorable finding under the ITU's "spot check" process[60] described above. By way of example, the WCG for the 10.7 GHz, 1.2 m, FSS limit is a GSO ES in the ocean approximately 200 km off the coast of West Africa with a GSO satellite at about 1.5°E longitude.

This analysis is for a GSO ES located in Fuchsstadt, Germany (50.118°N. 9.924°E) with a Ku-band GSO satellite located at 17.6°E longitude. The instances depicted below in which EPFD↓ limits are violated 1%, 10%, and even 100% of the time are most concerning and

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[59] ITU-R Rec. S.1503-3, § D3.

[60] 319520108_STEAM-1_ResultsSummary.pdf (itu.int) and 319520109_STEAM-2B_ResultsSummary.pdf (itu.int).

violate ITU Radio Regulations. Interference generated at those levels could well degrade service levels and cause capacity losses to GSO networks.

The following figures show that the Starlink STEAM-1 and STEAM-2 filings exceed the Article 22 EPFD↓ limits in Tables 22-1A, 22-1B, and 22-1D in the Ku and Ka bands for a GSO ES located in Fuchsstadt, Germany (50.118°N. 9.924°E) with a GSO satellite located at 17.6°E longitude, even though it does not exceed the limits at the so-called WCG[61]. The peak exceedances are shown in Table A-1. Combinations of other earth stations and satellite locations serving Germany could result in larger violations of ITU limits than these examples.

Table A-1: Example peak STEAM-1 and STEAM-2 exceedances in Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

| System | Service | Freq | Antenna Diameter | Radiation Pattern | Peak Exceedance | Percent of Time | Figure |
|---|---|---|---|---|---|---|---|
| STEAM-1 | FSS | 10.7 GHz | 1.2 | S.1428 | 6.3 dB | 0.50% | A-1 |
| STEAM-1 | FSS | 11.7 GHz | 1.2 | S.1428 | 5.5 dB | 0.50% | A-2 |
| STEAM-1 | BSS | 11.7 GHz | 0.45 | BO.1443 | 5.3 dB | 93.58% | A-3 |
| STEAM-1 | BSS | 11.7 GHz | 0.6 | BO.1443 | 4.1 dB | 59.58% | A-4 |
| STEAM-1 | FSS | 12.2 GHz | 1.2 | S.1428 | 5.1 dB | 0.50% | A-5 |
| STEAM-1 | BSS | 12.2 GHz | 0.45 | BO.1443 | 4.9 dB | 91.48% | A-6 |
| STEAM-1 | BSS | 12.2 GHz | 0.6 | BO.1443 | 3.7 dB | 59.58% | A-7 |
| STEAM-1 | FSS | 12.5 GHz | 1.2 | S.1428 | 4.8 dB | 0.50% | A-8 |
| STEAM-1 | BSS | 12.5 GHz | 0.45 | BO.1443 | 4.7 dB | 90.89% | A-9 |
| STEAM-1 | BSS | 12.5 GHz | 0.6 | BO.1443 | 3.5 dB | 60.10% | A-10 |
| STEAM-2B | FSS | 17.8 GHz | 1 | S.1428 | 3.3 dB | 10.00% | A-11 |

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[61] The EPFD data underlying the WCG plots was generated with the ITU's EPFD software using the STEAM EPFD input databases available from the ITU at EPFD data and EPFD examination results (itu.int).

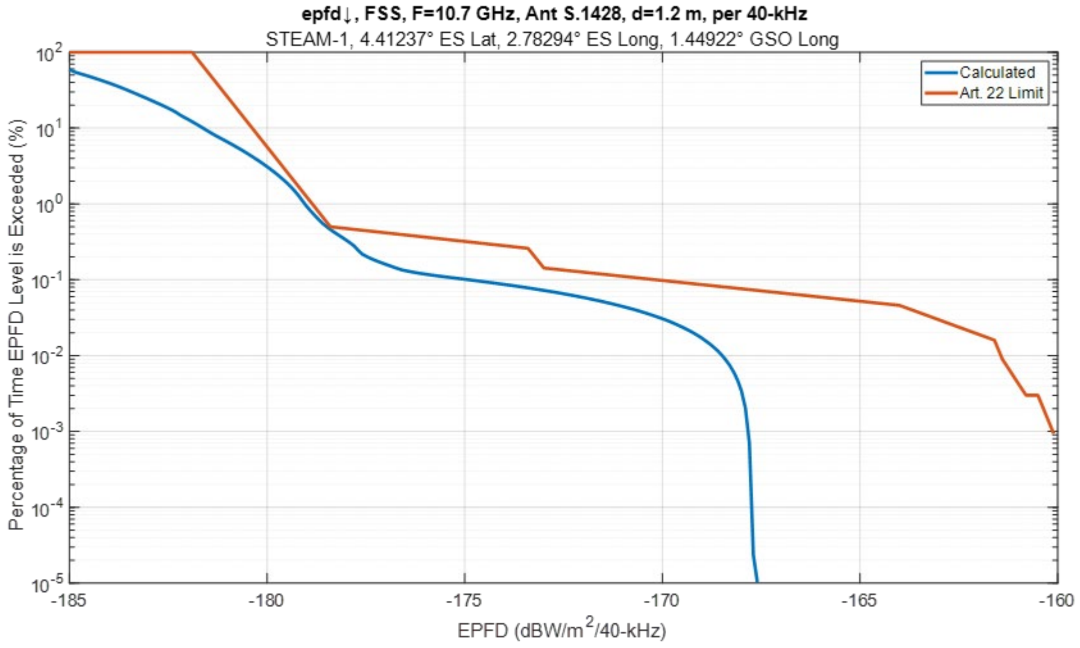
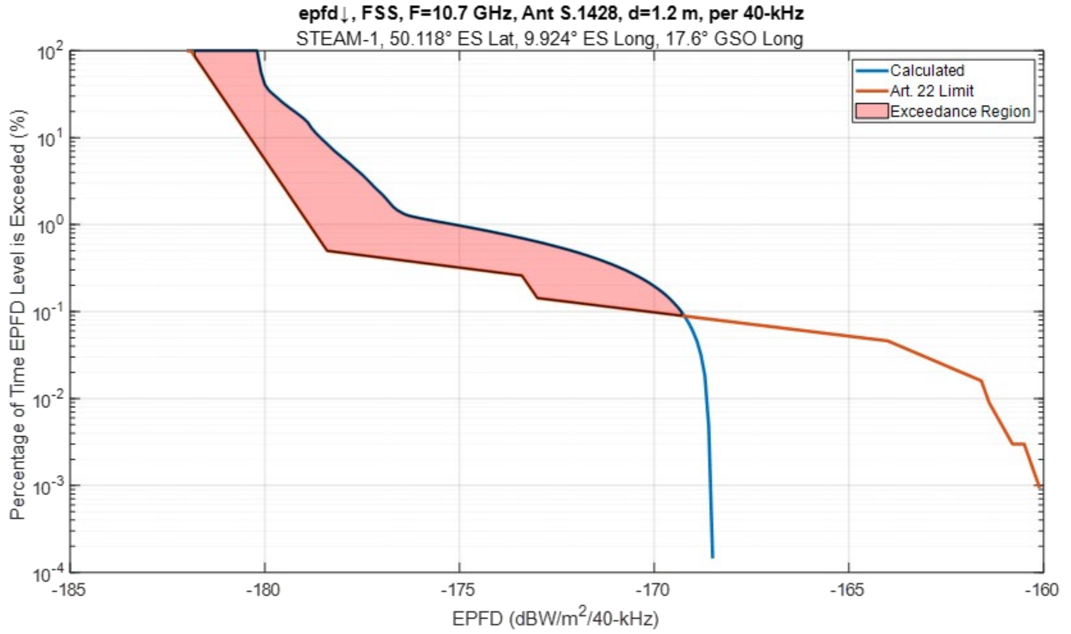
| | |
|---|---|
| WCG (ES: 4.41°N, 2.78°E, GSO: 1.45°E) |  |
| Fuchsstadt, Germany |  |

Figure A-1: Comparison of STEAM-1 EPFD↓ at 10.7 GHz with 1.2 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

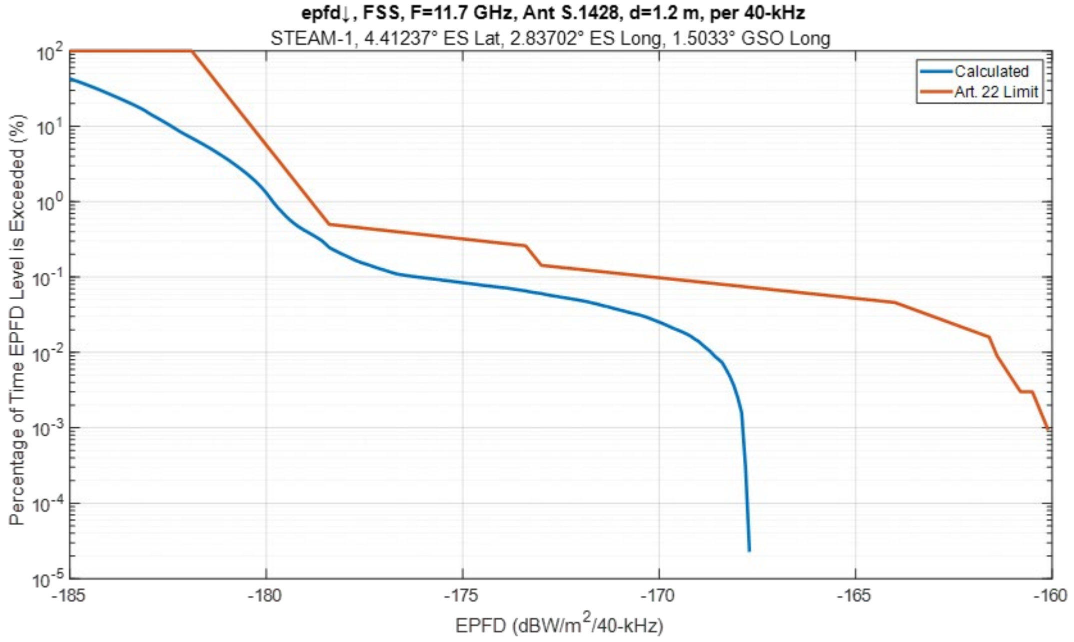
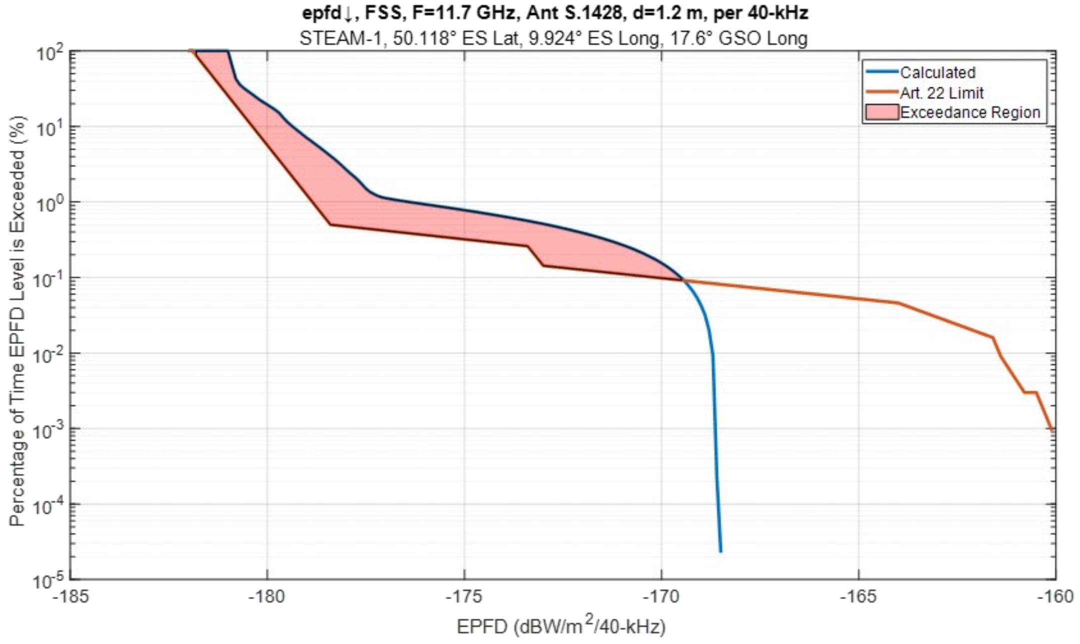
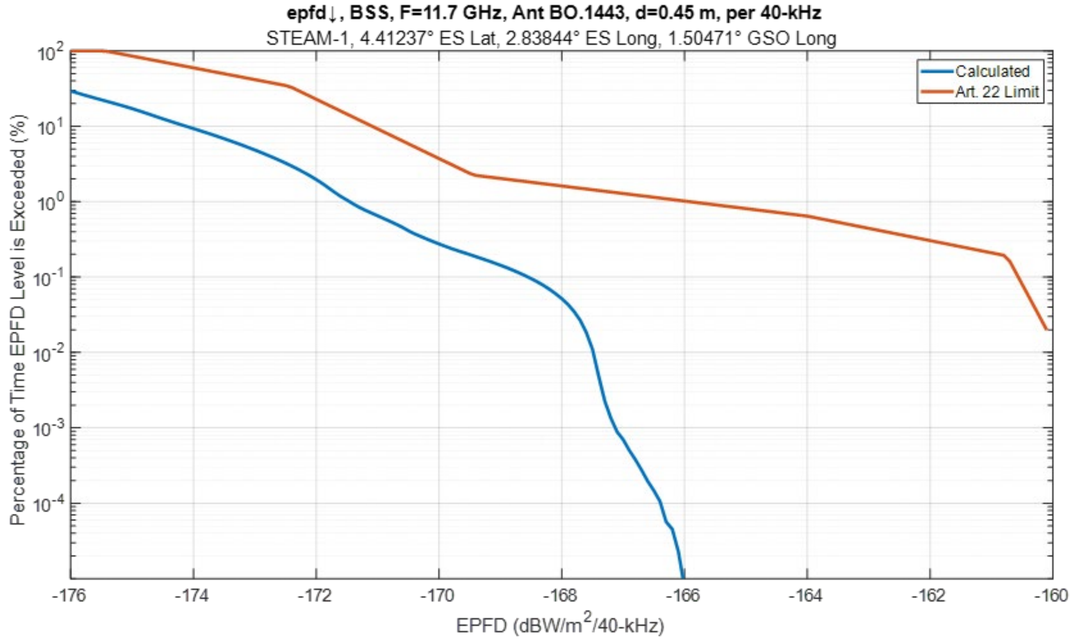
| | |
|---|---|
| WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E) |  |
| Fuchsstadt, Germany |  |

Figure A-2: Comparison of STEAM-1 EPFD↓ at 11.7 GHz with 1.2 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E)



Fuchsstadt, Germany

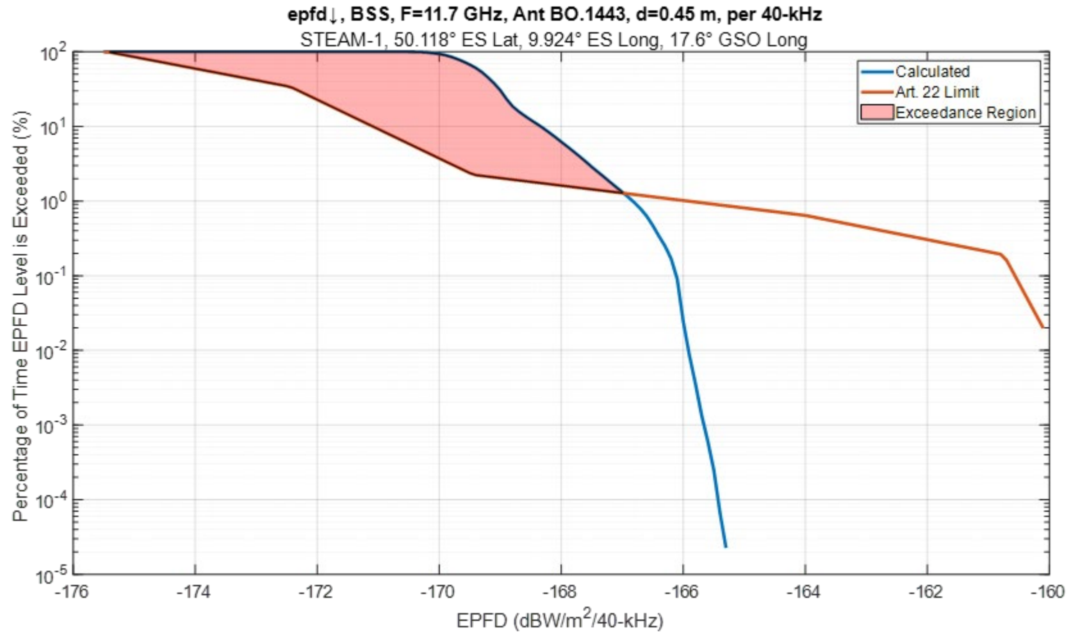


Figure A-3: Comparison of STEAM-1 EPFD↓ at 11.7 GHz with 0.45 cm GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

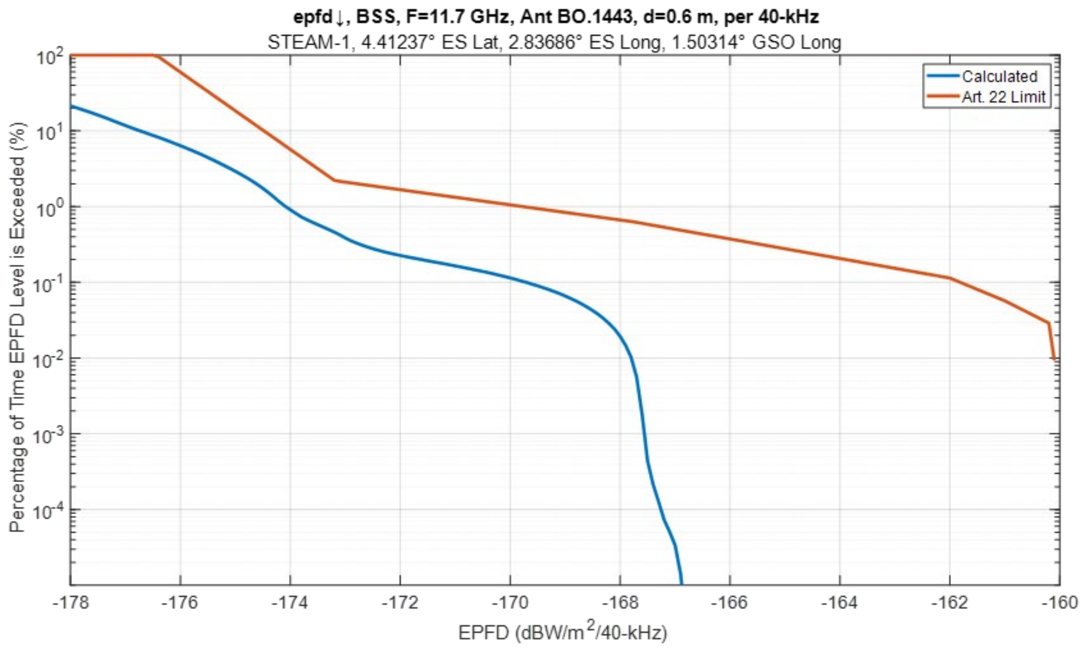
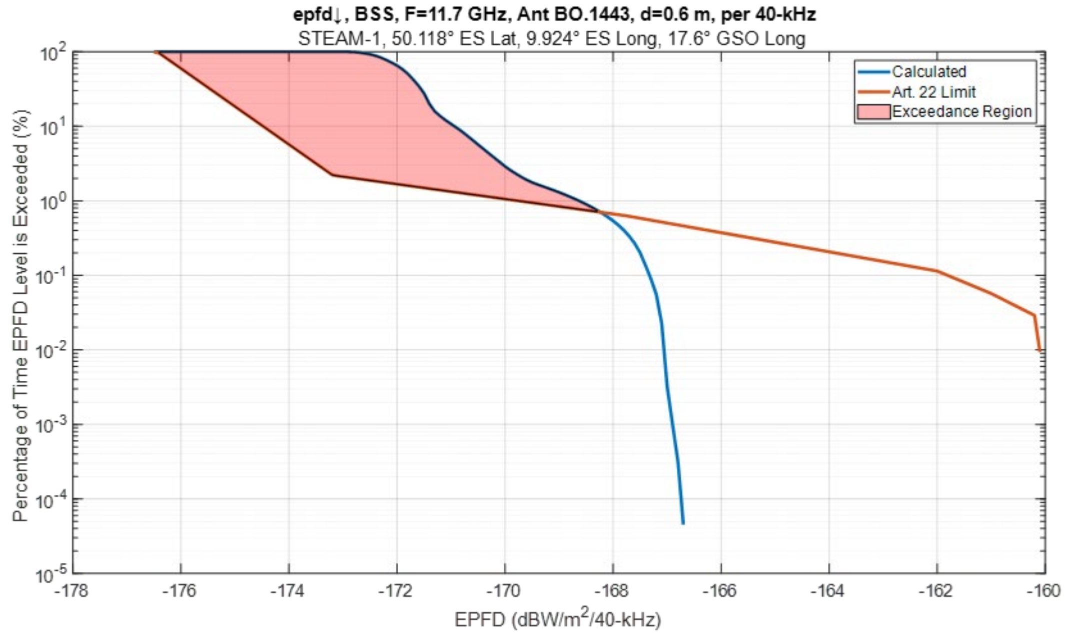
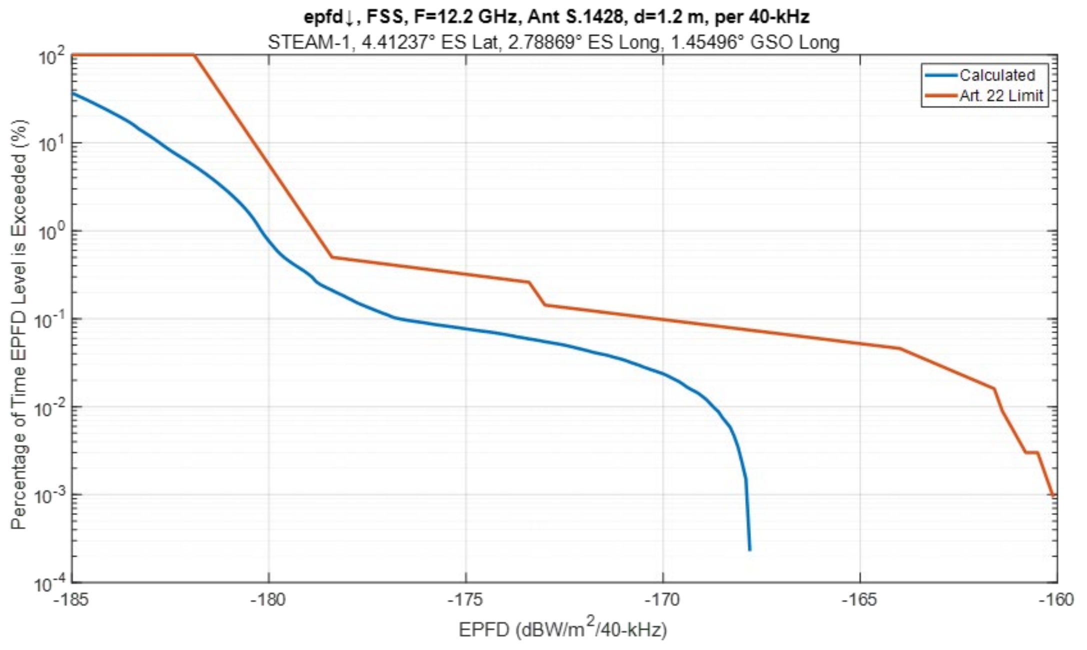
| | |
|---|---|
| WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E) |  |
| Fuchsstadt, Germany |  |

Figure A-4: Comparison of STEAM-1 EPFD↓ at 11.7 GHz with 0.6 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E)



Fuchsstadt, Germany

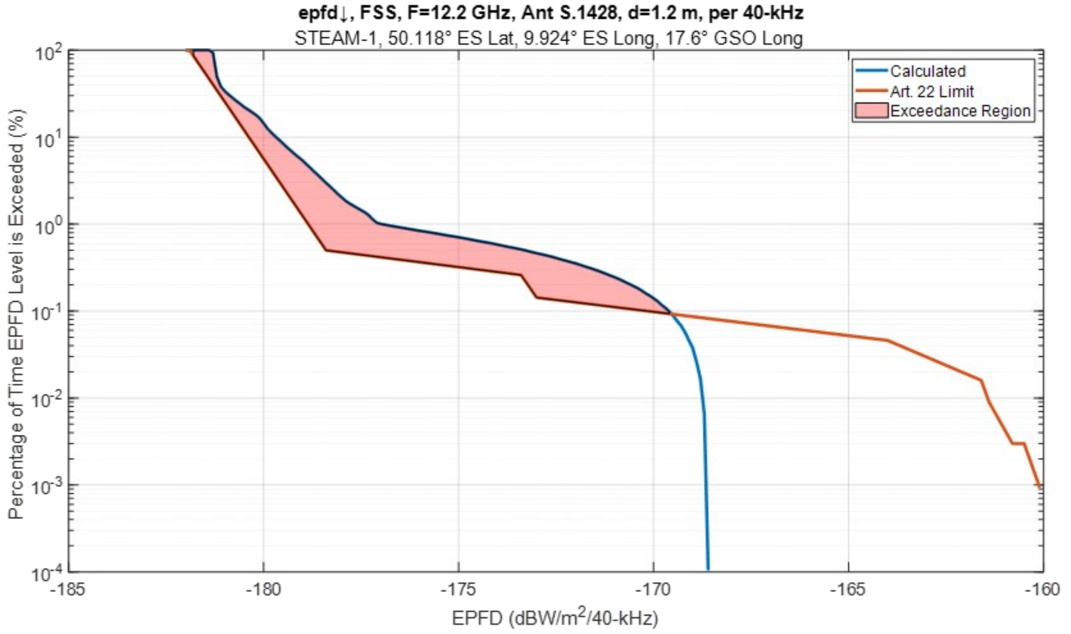


Figure A-5: Comparison of STEAM-1 EPFD↓ at 12.2 GHz with 1.2 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO Satellite at 17.6°E

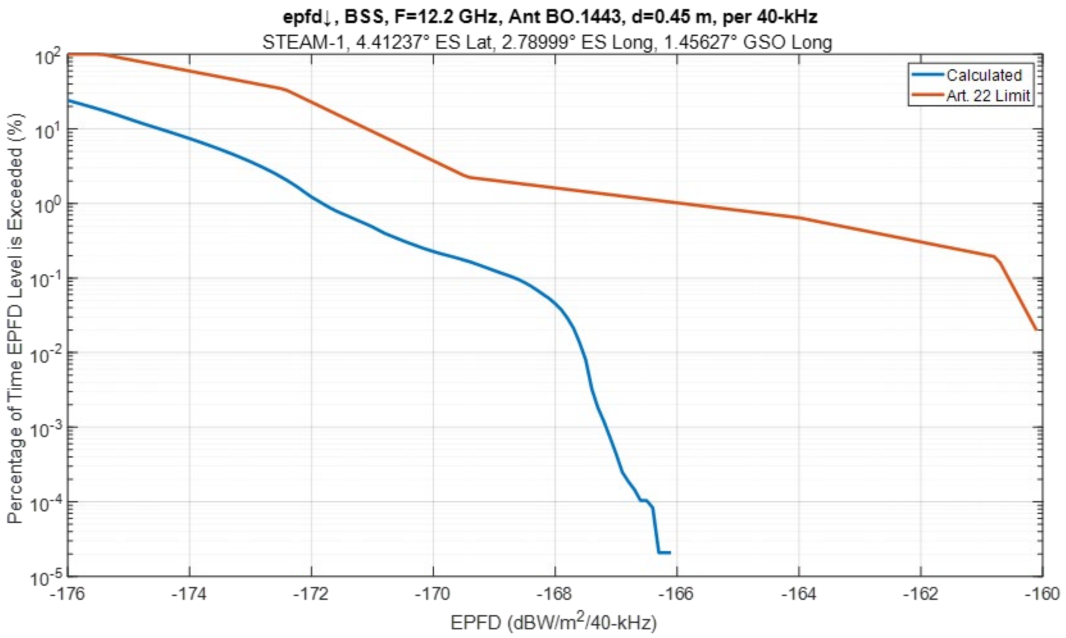
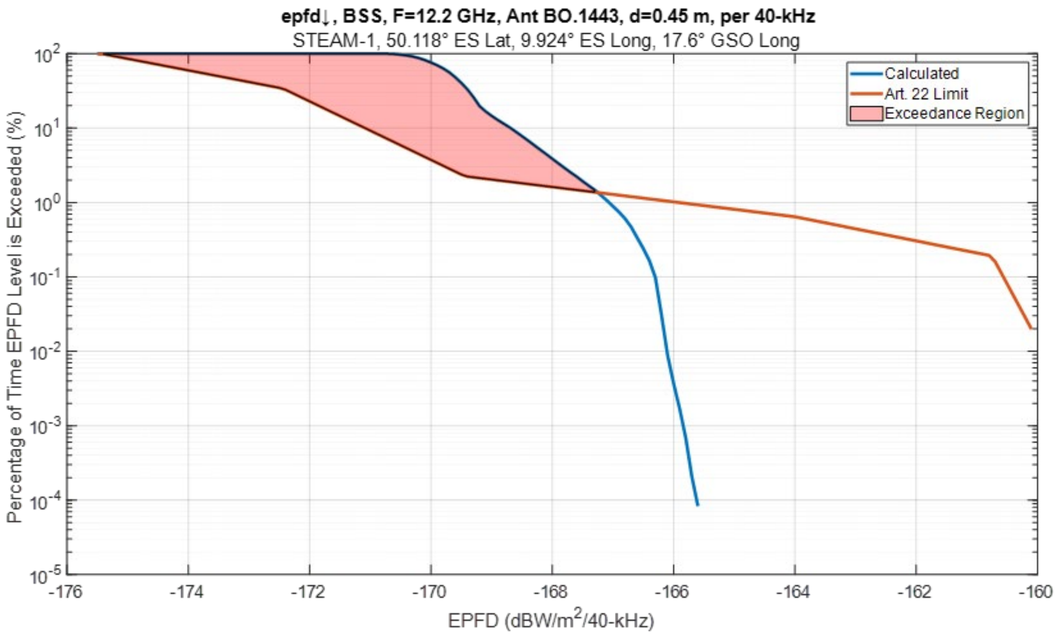
| | |
|---|---|
| WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E) |  |
| Fuchsstadt, Germany |  |

Figure A-6: Comparison of STEAM-1 EPFD↓ at 12.2 GHz with 0.45 cm GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO Satellite at 17.6°E

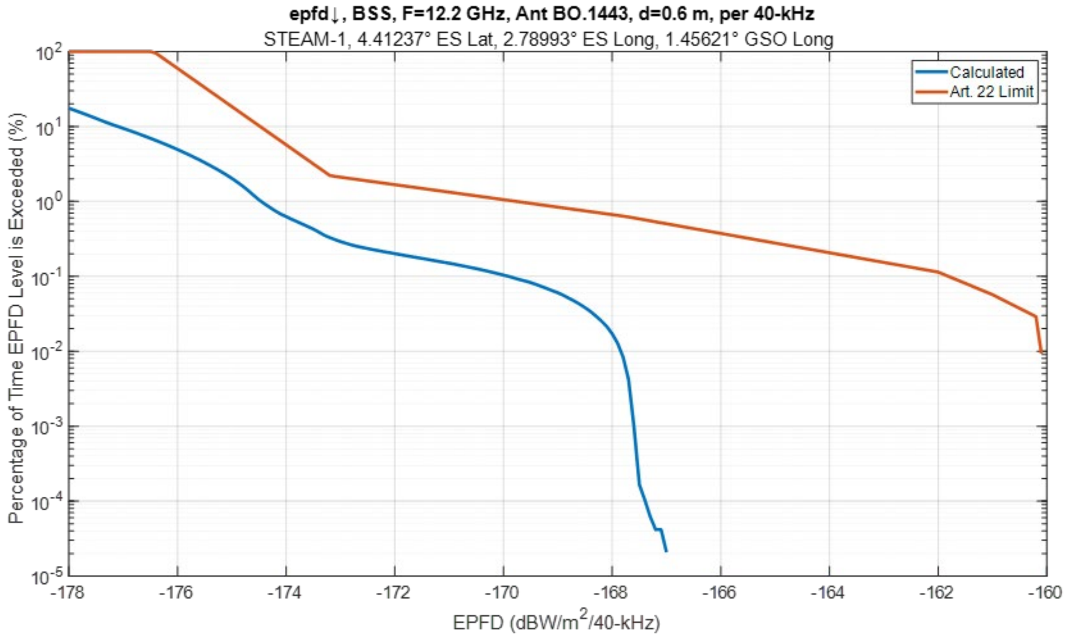
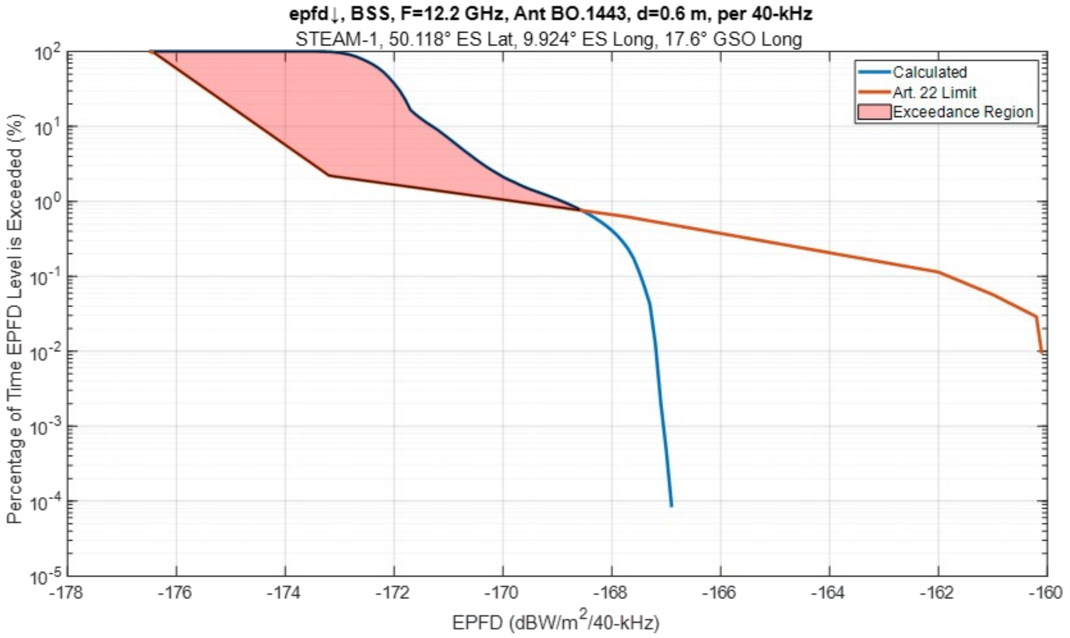
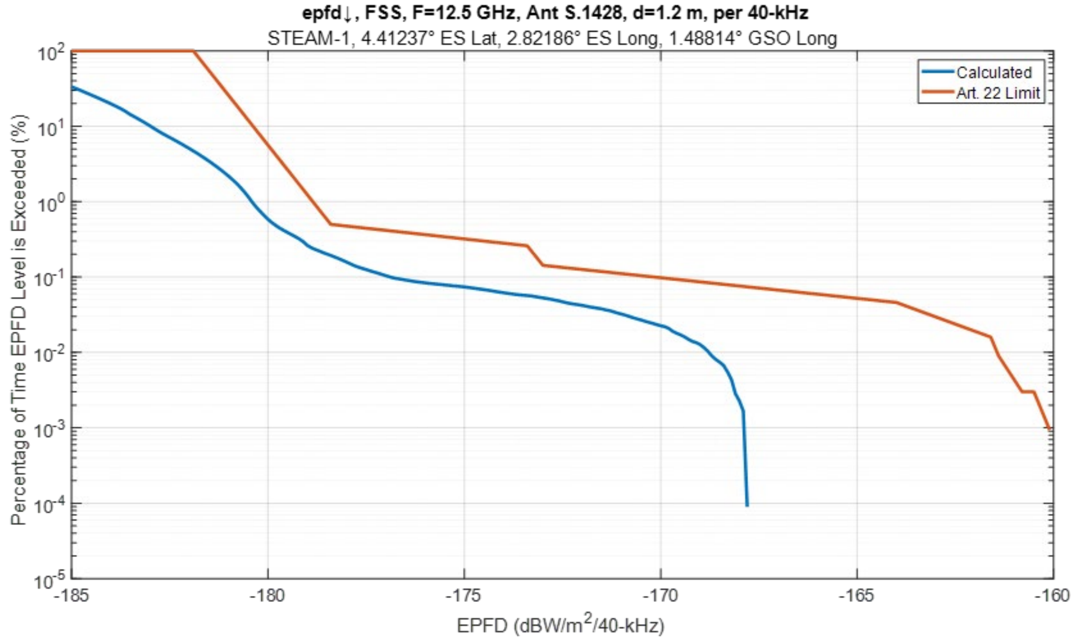
| | |
|---|---|
| WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E) |  |
| Fuchsstadt, Germany |  |

Figure A-7: Comparison of STEAM-1 EPFD↓ at 12.2 GHz with 0.6 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E)



Fuchsstadt, Germany

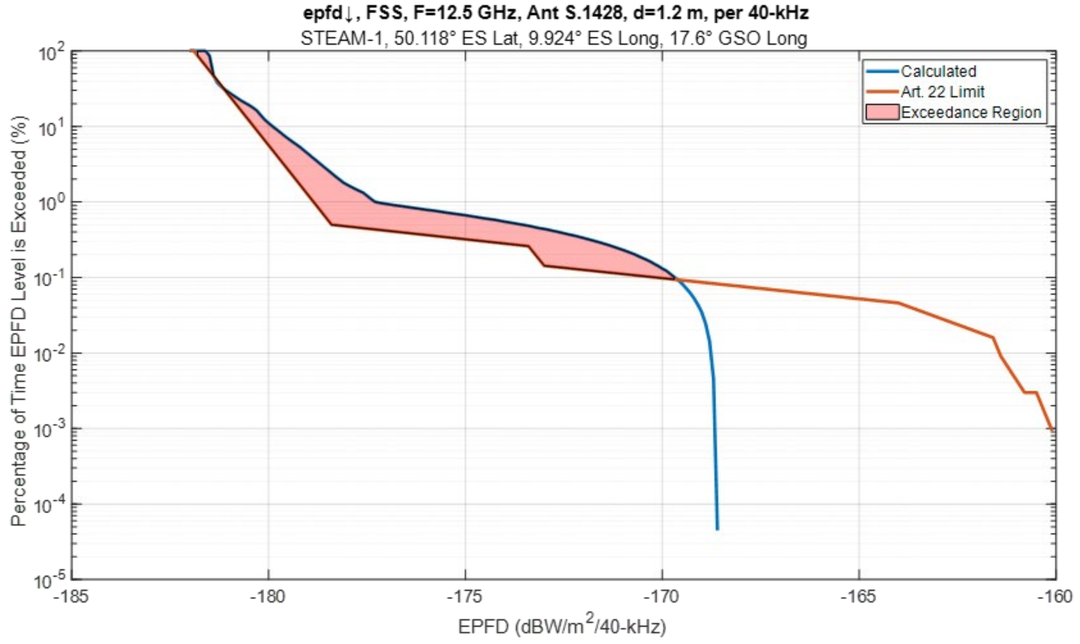


Figure A-8: Comparison of STEAM-1 EPFD↓ at 12.5 GHz with 1.2 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

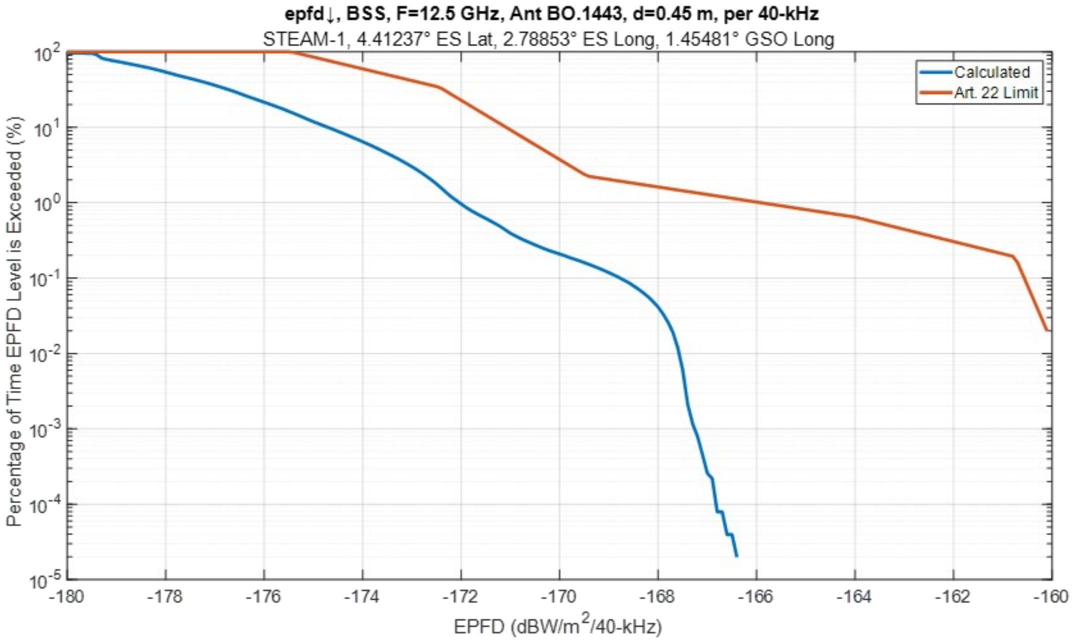
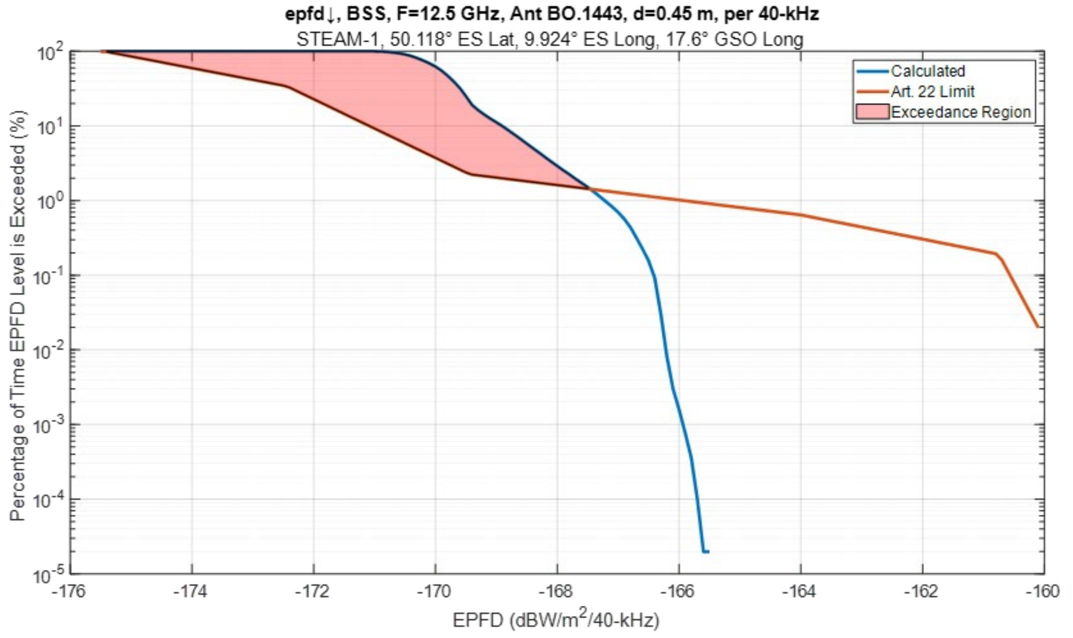
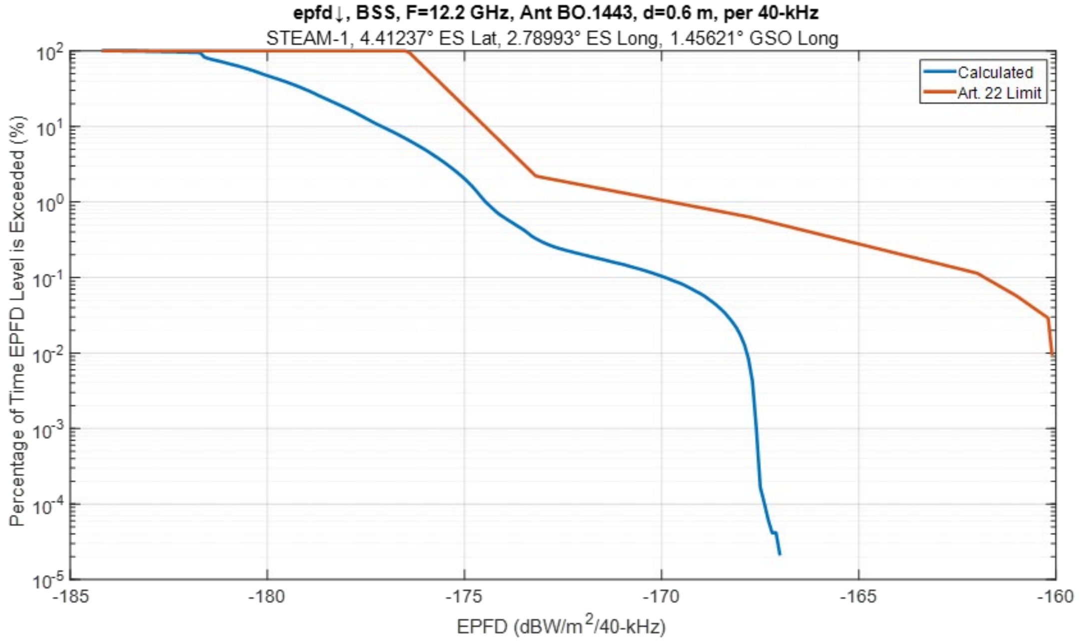
| | |
|---|---|
| WCG (ES: 4.41°N, 2.79°E, GSO: 1.45°E) |  |
| Fuchsstadt, Germany |  |

Figure A-9: Comparison of STEAM-1 EPFD↓ at 12.5 GHz with 0.45 GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

WCG (ES: 4.41°N, 2.79°E, GSO: 1.45°E)



Fuchsstadt, Germany

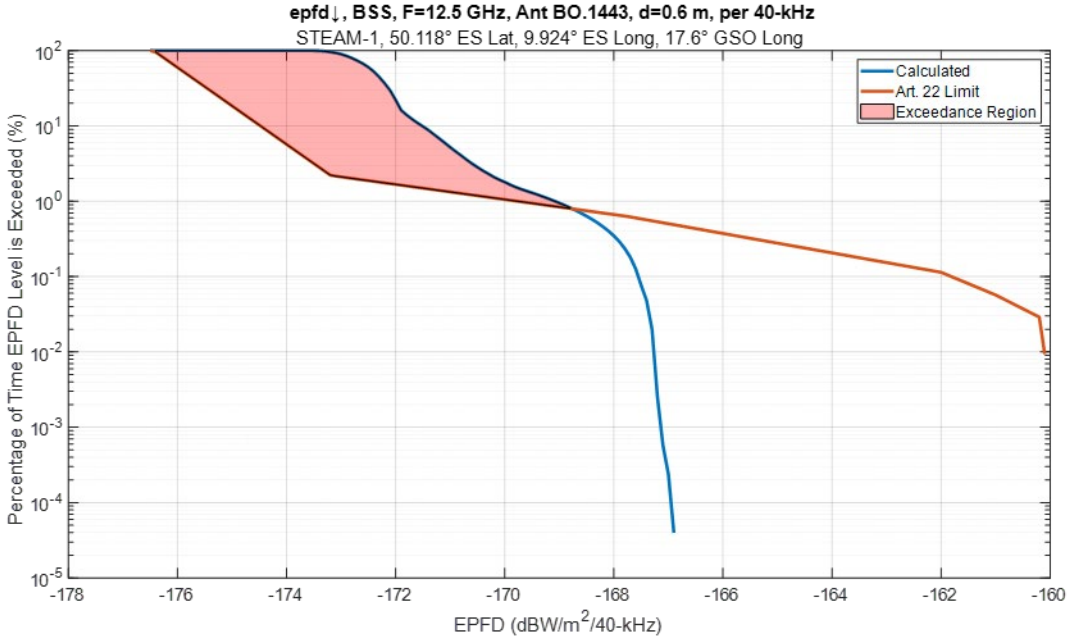
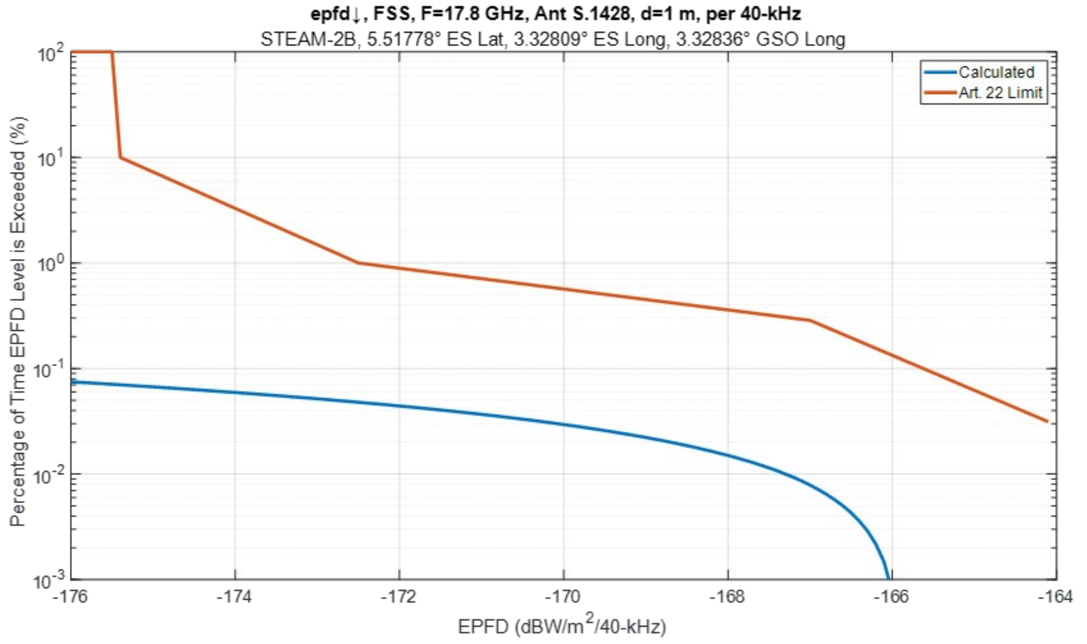
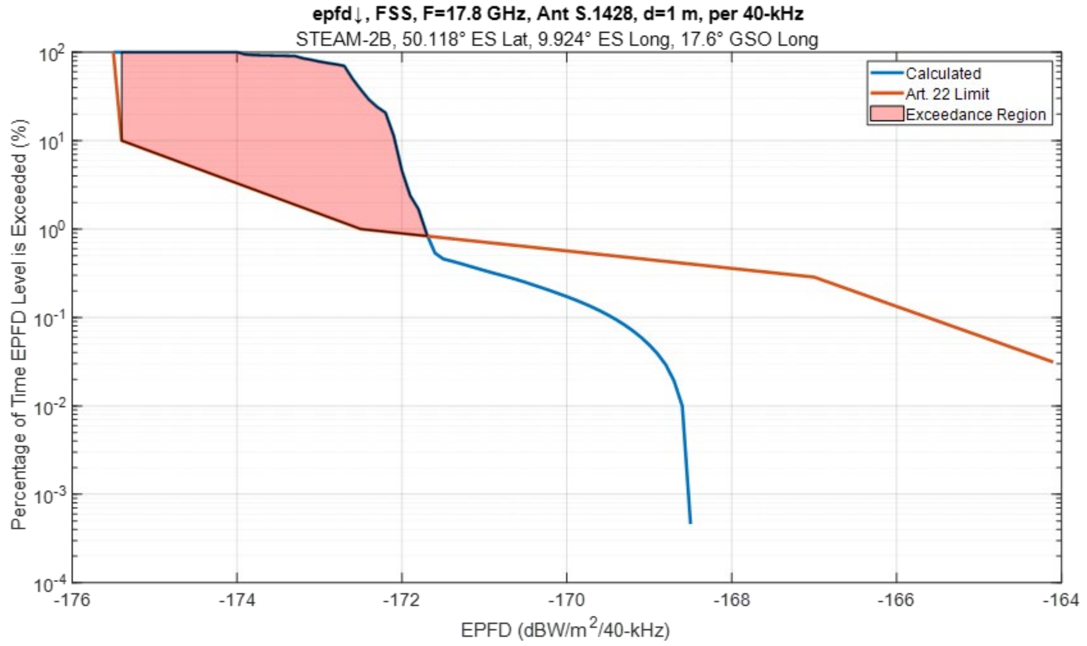


Figure A-10: Comparison of STEAM-1 EPFD↓ at 12.5 GHz with 0.6 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

<table>
<tr>
<td>WCG (ES: 4.41°N, 2.84°E, GSO: 1.50°E)</td>
<td>


</td>
</tr>
<tr>
<td>Fuchsstadt, Germany</td>
<td>


</td>
</tr>
</table>

Figure A-11: Comparison of STEAM-2 EPFD↓ at 17.8 GHz with1 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

## A-III. Analysis of EPFD↓ Violations by Additional 29,988 Satellites in Starlink's Second Generation Configuration

The following are examples of EPFD↓ exceedances for the additional 29,988 satellites in the second generation Starlink configuration, which has not yet been evaluated by the ITU. SpaceX proposes to operate those additional satellites under 18 different ITU filings.[62] As shown below, Starlink exceeds the Article 22 EPFD↓ limits in Table 22-1B for the 17.8 – 18.6 GHz band with several of these filings even when they are evaluated individually. Moreover, when all 18 ITU filings are considered together, the EPFD↓ exceedances are substantially greater.

This analysis is for a GSO ES located in Fuchsstadt, Germany (50.118°N. 9.924°E) with a Ka-band GSO satellite located at 17.6°E longitude. The instances depicted below in which EPFD↓ limits are expected to be violated 1%, 10%, and even 100% of the time are most concerning and violate the ITU Radio Regulations. Interference generated at those levels could well degrade service levels and cause capacity losses to GSO networks.

Notably, this analysis does not factor in the aggregate effect of the Starlink satellites operated under ITU filings other than those listed in the footnote below, such as the 4,408 first generation satellites discussed above.

### A. Starlink Second Generation EPFD↓ Exceedances under Individual ITU Filings

Table A-2 shows examples of EPFD↓ exceedances that exist for the second generation Starlink configuration when the various 18 underlying ITU filings are examined in isolation. Combinations of other earth stations and satellite locations serving Germany could result in larger violations of ITU limits than these examples.

Table A-2: Example peak SpaceX Gen2 exceedances in Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E for the 17.8 – 18.6 GHz band with 1-m GSO ES antenna diameter

| System | Peak Exceedance | Percent of Time | Figure |
|---|---:|---:|---:|
| USASAT-NGSO-3V-2 | 3.2 dB | 10% | A-12 |
| USASAT-NGSO-3W-1 | 3.2 dB | 10% | A-13 |
| USASAT-NGSO-3W-2 | 3.2 dB | 10% | A-14 |

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[62] The relevant ITU system filings are: USASAT-NGSO-3N, USASATNGSO-3O, USASAT-NGSO-3P, USASAT-NGSO-3Q, USASAT-NGSO-3R1, USASATNGSO-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.

The following figures contrast these EPFD↓ violations in Germany with the WCG results. By way of example, the WCG[63] for the 17.8 GHz, 1.0 m, FSS limit, calculated for the USASAT-NGSO-3V-2 system, is a GSO ES in Tathlith, Saudi Arabia with a GSO satellite located near 5°E longitude.

As can be seen, the second generation Starlink configuration is clearly non-compliant with the ITU Radio Regulations.

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[63] The EPFD data underlying the WCG plots was generated with the ITU’s EPFD software using the STEAM EPFD input databases provided by SpaceX for each of the 18 Gen2 ITU filings.

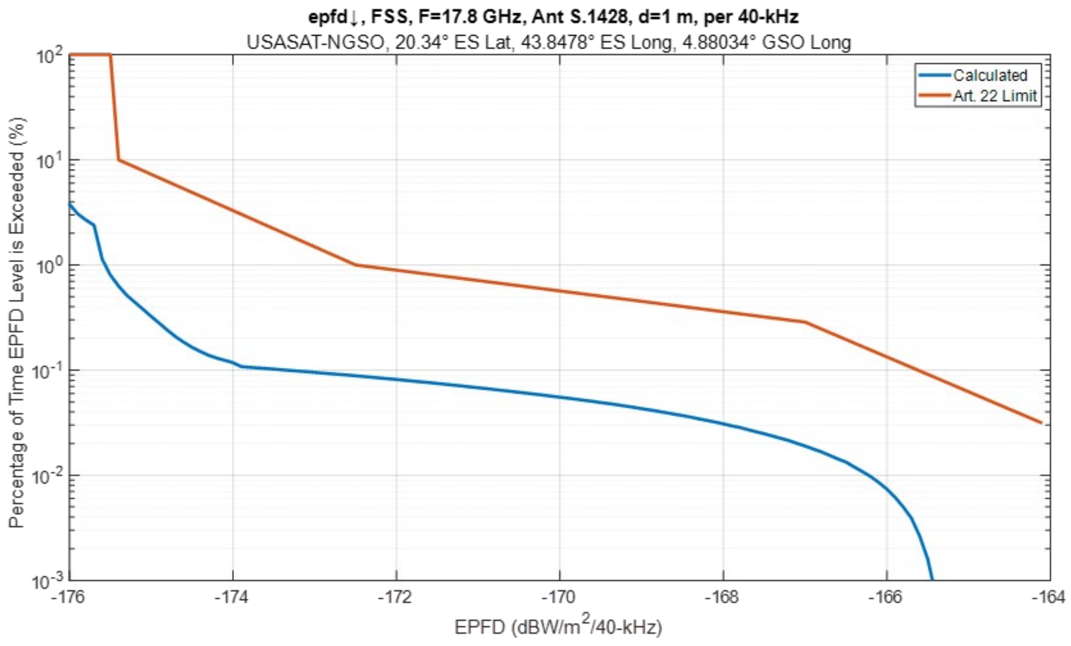
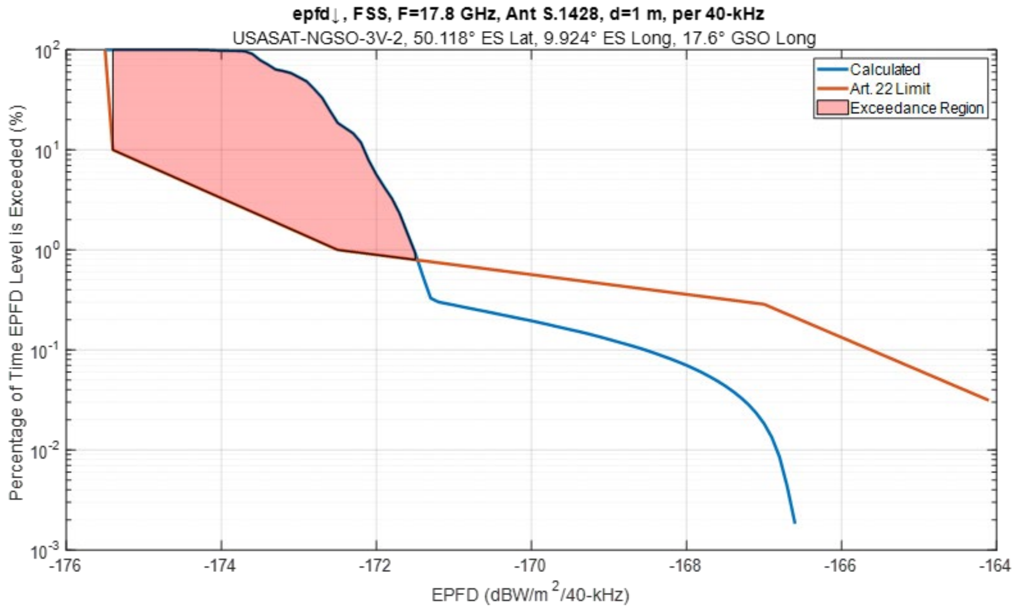
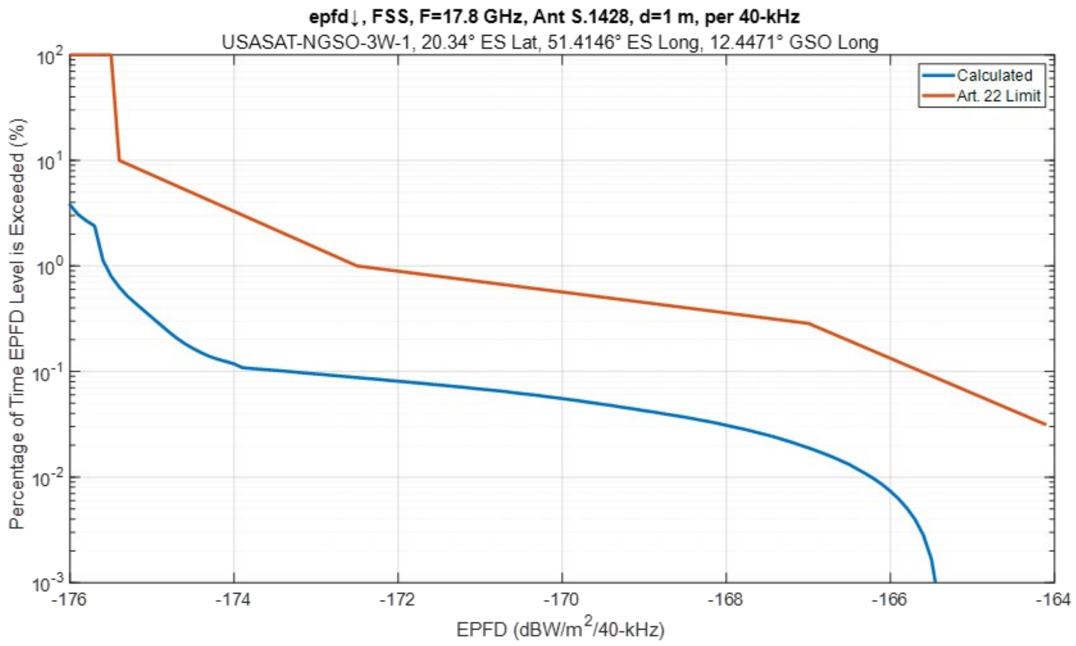
| | |
|---|---|
| WCG (ES: 12.23°N, 65.08°W, GSO: 112.54°W) |  |
| Fuchsstadt, Germany |  |

Figure A-12: Comparison of USASAT-NGSO-3V-2 EPFD↓ in 17.8 – 18.6 GHz Band with 1-m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

WCG (ES: 6.59°N, 93.77°W, GSO: 98.84°W)



Fuchsstadt, Germany

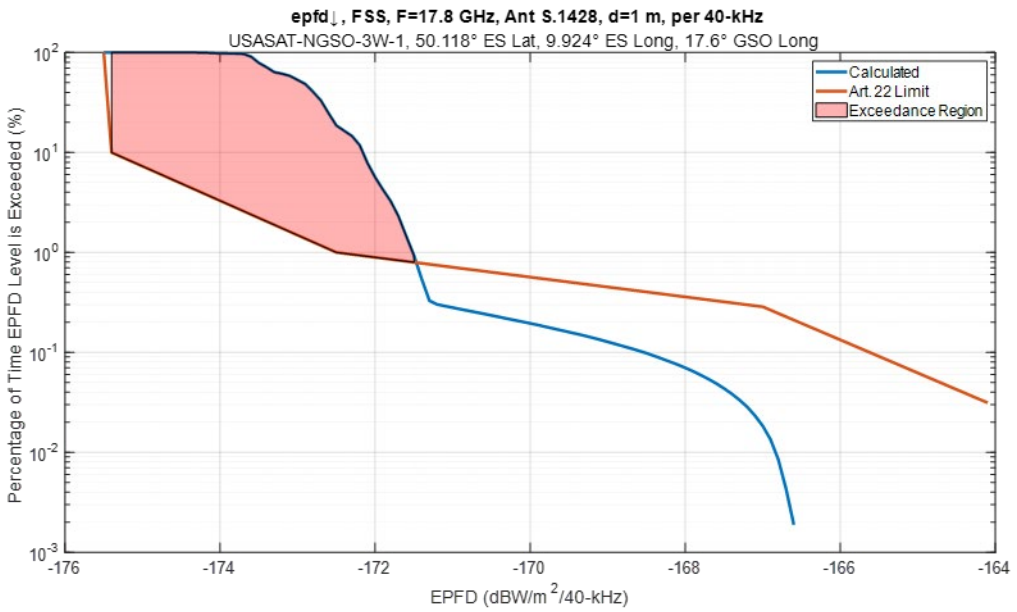


Figure A-13: Comparison of USASAT-NGSO-3W-1 EPFD↓ in 17.8 – 18.6 GHz Band with 1-m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

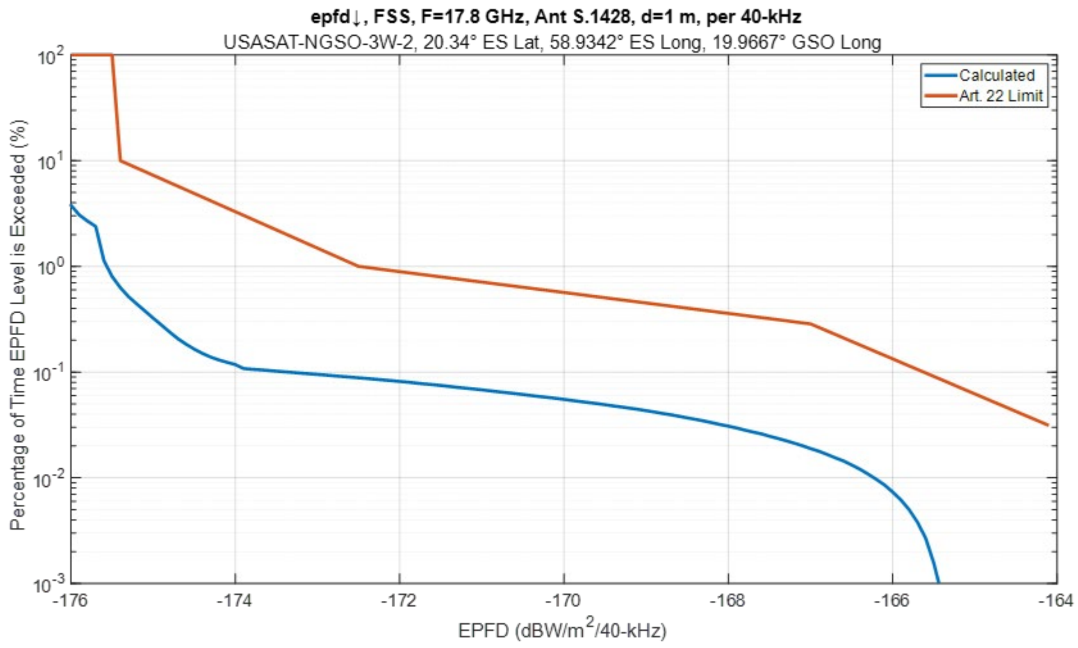
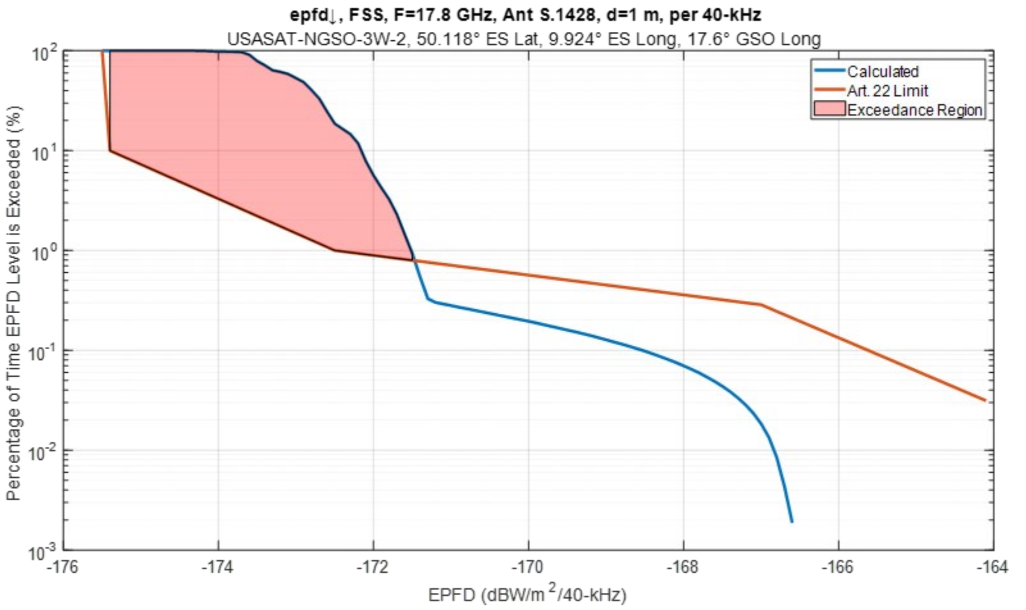
| | |
|---|---|
| WCG (ES: 6.59°N, 80.89°W, GSO: 85.95°W) |  |
| Fuchsstadt, Germany |  |

Figure A-14: Comparison of USASAT-NGSO-3W-2 EPFD↓ in 17.8 – 18.6 GHz Band with 1-m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

### B. Starlink Second Generation EPFD↓ Exceedances under Combined ITU Filings

This section evaluates the interference levels that would be generated by the additional 29,988 second generation Starlink satellites operating under SpaceX's 18 new ITU filings—and compares those interference levels to applicable ITU Article 22 single-entry EPFD↓ limits and ITU Resolution 76 aggregate EPFD↓ limits. Notably, SpaceX *has* made clear that its 29,988 additional satellites would operate as a single non-GSO system.[64]

Combined EPFD↓ curves were generated for all 29,988 satellites operating under these 18 filings with a 1-m GSO ES in the 17.8 – 18.6 GHz band, using the EPFD input files provided by SpaceX for each of those 18 ITU filings. The GSO ES is located in Fuchsstadt, Germany (50.118°N. 9.924°E) with the GSO satellite at 17.6°E longitude. The resulting 18 EPFD↓ probability density functions (pdf's) for each of the cases identified in the Article 22 and Resolution 76 EPFD↓ limits were combined, using standard techniques for the sum of independent random variables,[65] to generate the combined EPFD↓ cdf curves.

Figure A-15 shows the results of this analysis and depicts: (i) the Article 22 single-entry limit cdf curve; (ii) the Resolution 76 aggregate limit cdf curve; and (iii) the combined EPFD cdf curve for 29,988 Starlink satellites generated using the methodology described above. **The analysis shows that Starlink would exceed both the Article 22 single-entry limits and the Resolution 76 aggregate limits for all percentages of time and all EPFD levels. The peak exceedances are 9.4 dB above the Article 22 limit and 4.0 dB above the Resolution 76 limit, each at 10% of the time.[66]**

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[64] *See, e.g.,* Consolidated Opposition to Petitions and Response to Comments of Space Exploration Holdings, U.S. Federal Communications Commission IBFS File Nos. SAT-LOA-20200526-00055 and SAT-AMD-20210818- 00105, at 3, (confirming that SpaceX intends to operate a single "Gen2 system").

[65] The relevant techniques used are discussed in most textbooks on probability theory. *See, e.g.,* Marco Taboga, *Sums of independent random variables*, STATLECT, available at https://www.statlect.com/fundamentals-of-probability/sums-of-independent-random-variables (last visited Aug. 24, 2022); Alex Tsun, *Convolution*, available at https://courses.cs.washington.edu/courses/cse312/20su/files/student_drive/5.5.pdf (last visited Aug. 24, 2022).

[66] Does not factor in the aggregate effect of the 4,408 first generation satellites discussed above.

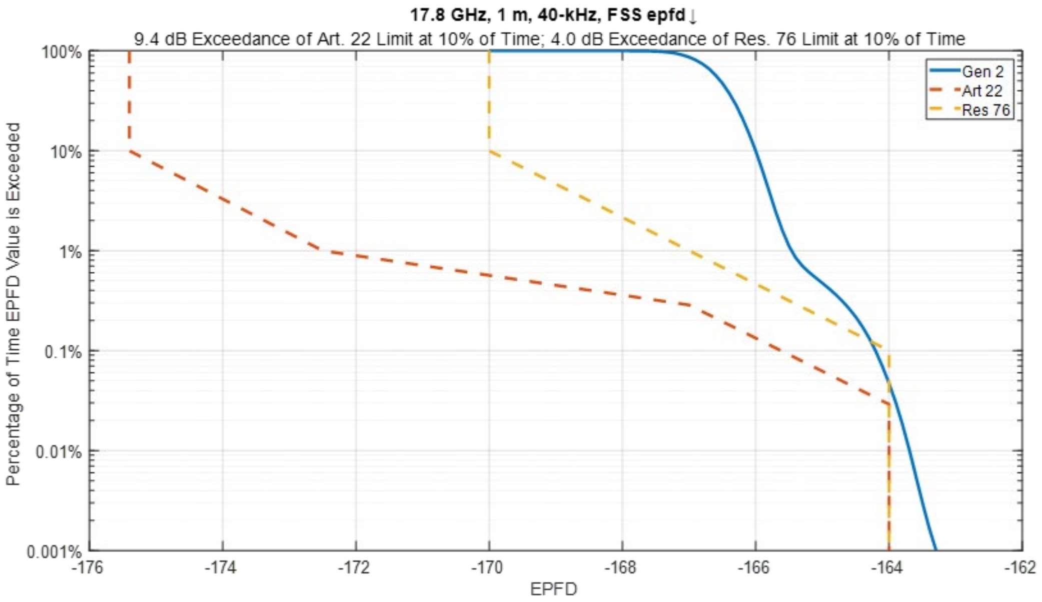

Figure A-15: Combined EPFD↓ for 29,988 Gen2 Starlink satellites in 17.8 – 18.6 GHz band with 1-m GSO ES for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

Again, ITU-R Recommendation S.1503 is instructive. It is based on the premise that the parameters specified in relevant EPFD input files reflect the way that a non-GSO 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, that Recommendation 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*.[67]

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[67] ITU-R Rec. S.1503-3, § 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 . . .").

## A-IV. STEAM-1 ID Number 121520025 Exceedance

BR International Frequency Information Circular (Space Services) (BR IFIC) Number 2981 (4 October 2022) promulgated a “favorable” finding for STEAM-1 ID 121520025. This modified version of the STEAM-1 notice corresponds to the current 4,408 satellite configuration in four shells (540 km, 550 km, 560 km, and 570 km).

As with the prior STEAM-1 favorable finding (ID 114520273), reported upon above, even though this new filing received a favorable finding from the BR it exceeds the Art. 22 EPFD↓ limits in Tables 22-1A and 22-1D for a GSO ES located in Fuchsstadt, Germany (50.118°N. 9.924°E) with a GSO satellite located at 17.6°E longitude[68]. Exemplary peak exceedances are shown in Table A-3. Combinations of other earth stations and satellite locations serving Germany could result in larger violations of ITU limits than these examples.

Table A-3: Example peak STEAM-1 (ID 121520025) exceedances in Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

| System | Service | Freq | Antenna Diameter | Radiation Pattern | Peak Exceedance | Percent of Time | Figure |
|---|---|---|---|---|---|---|---|
| STEAM-1 | FSS | 10.7 GHz | 1.2 m | S.1428 | 0.6 dB | 0.79% | A-16 |
| STEAM-1 | BSS | 12.7 GHz | 0.45 m | BO.1443 | 4.2 dB | 89.75% | A-17 |
| STEAM-1 | BSS | 12.7 GHz | 0.6 m | BO.1443 | 3.1 dB | 71.6% | A-18 |

---

[68] The EPFD data underlying the WCG plots was generated with the ITU’s EPFD software using the STEAM EPFD input databases available from the ITU at EPFD data and EPFD examination results (itu.int).

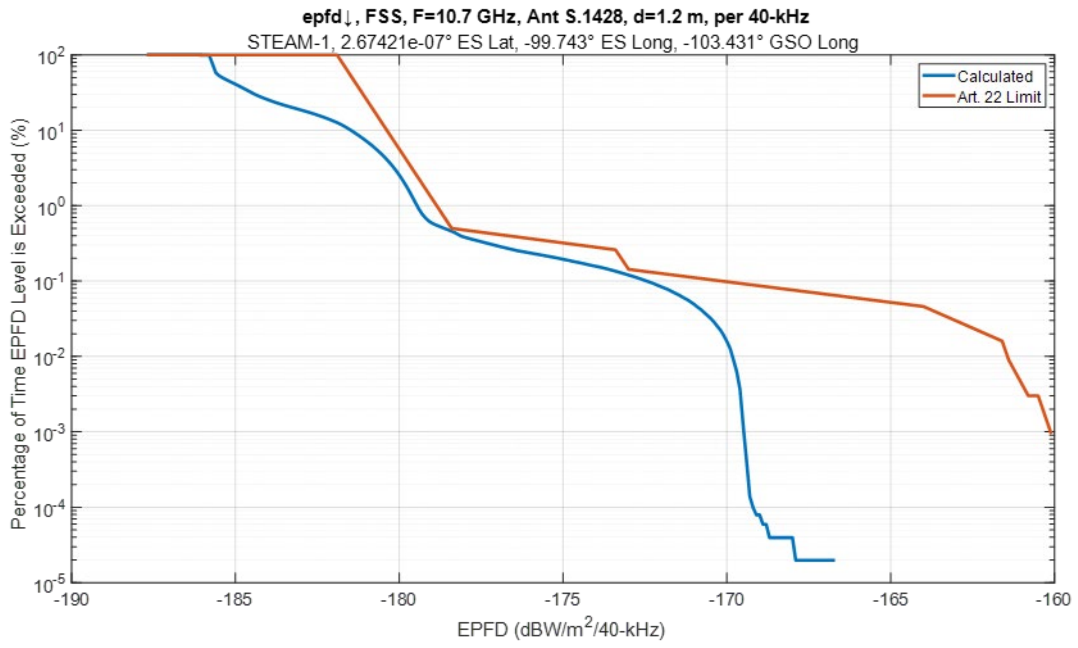
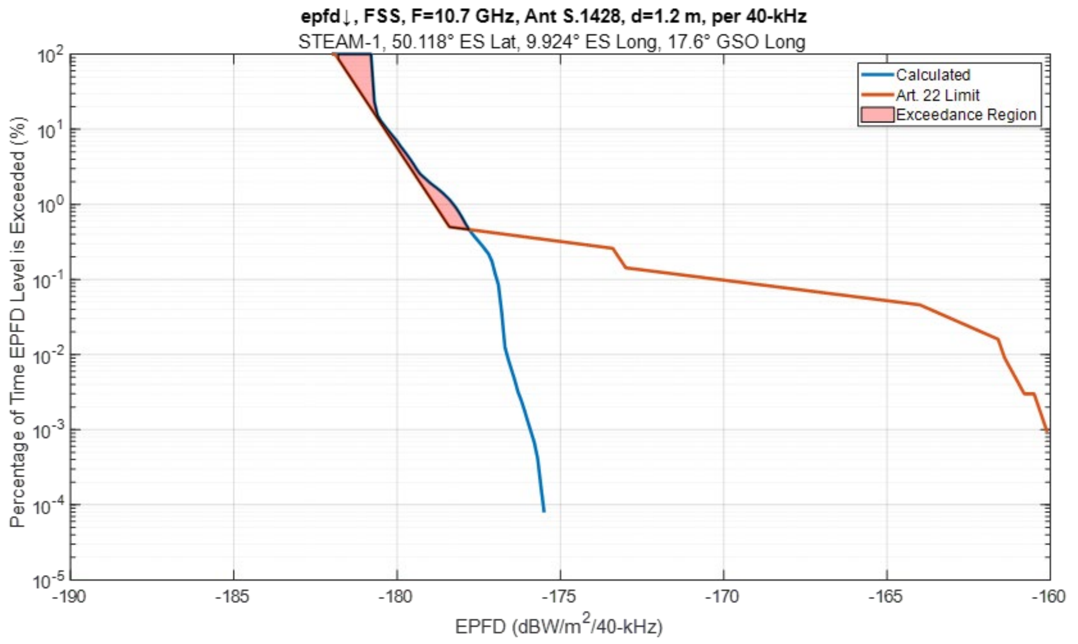
| | |
|---|---|
| WCG (ES: 6.59°N, 93.77°W, GSO: 98.84°W) |  |
| Fuchsstadt, Germany |  |

Figure A-16: Comparison of STEAM-1 (ID 121520025) EPFD↓ at 10.7 GHz with 1.2 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

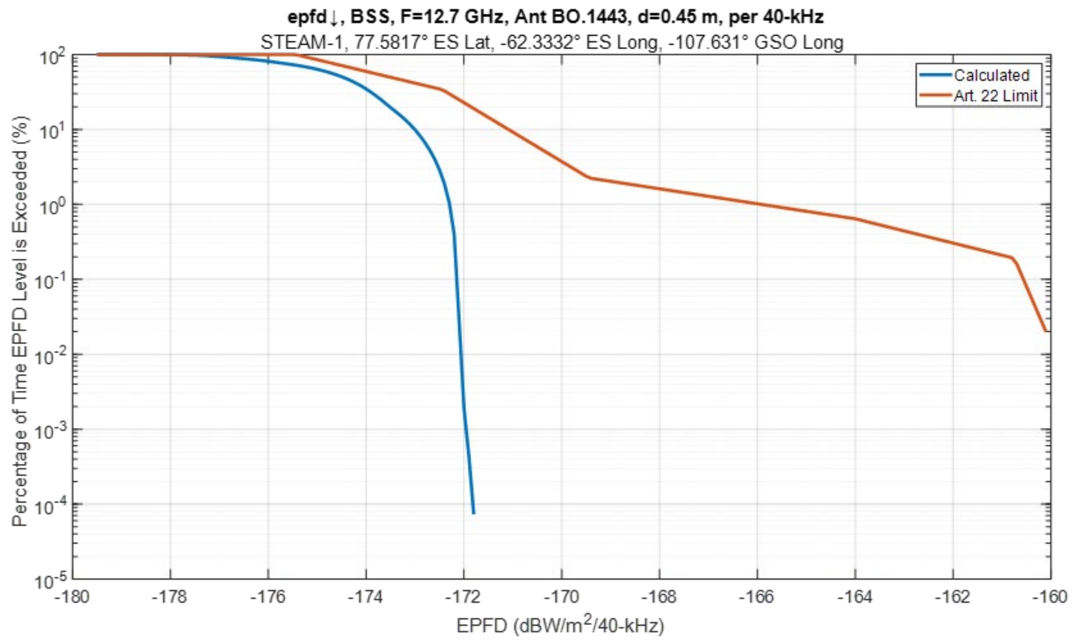
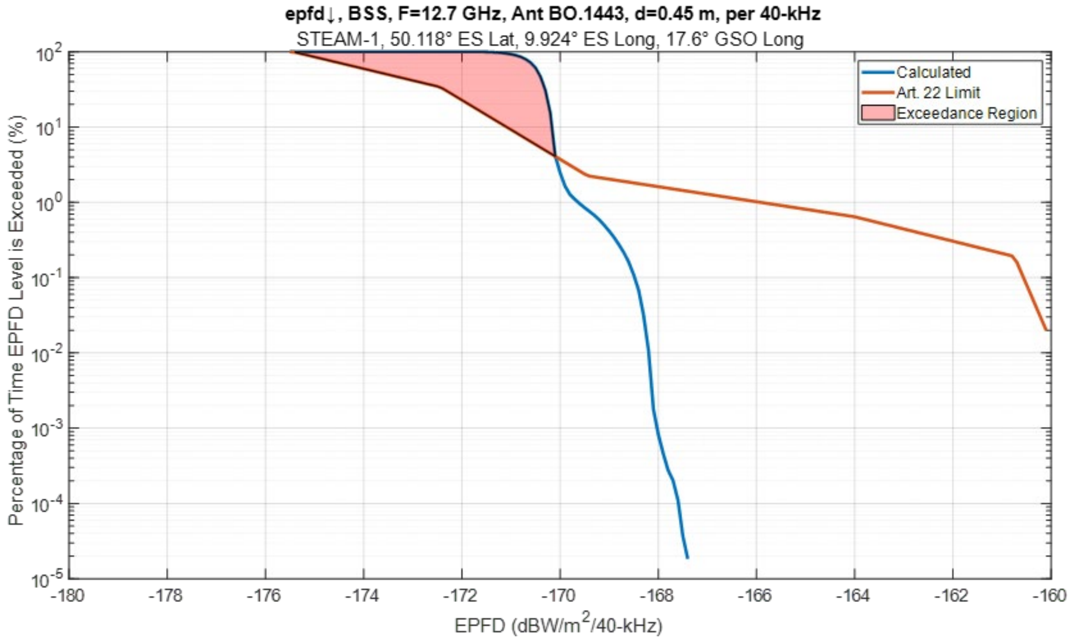
| | |
|---|---|
| WCG (ES: 6.59°N, 93.77°W, GSO: 98.84°W) |  |
| Fuchsstadt, Germany |  |

Figure A-17: Comparison of STEAM-1 (ID 121520025) EPFD↓ at 12.7 GHz with 0.45 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

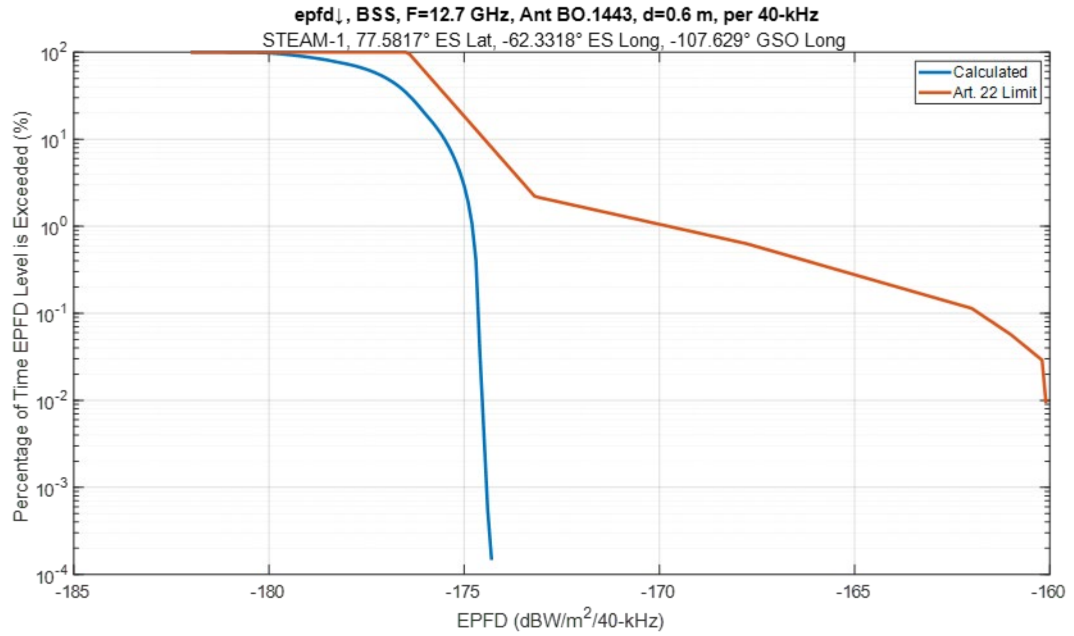
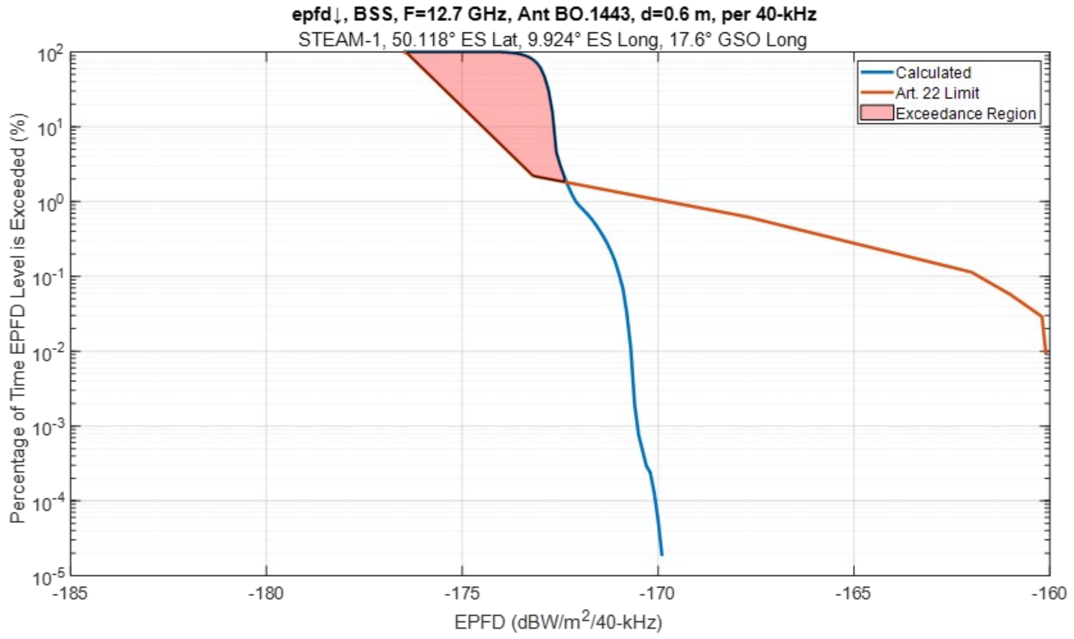
| | |
|---|---|
| WCG (ES: 6.59°N, 93.77°W, GSO: 98.84°W) |  |
| Fuchsstadt, Germany |  |

Figure A-18: Comparison of STEAM-1 (ID 121520025) EPFD↓ at 12.7 GHz with 0.6 m GSO ES for WCG and for Fuchsstadt, Germany (50.118°N. 9.924°E) with GSO satellite at 17.6°E

# ANNEX B:

# Hindering Equitable Access to NGSO Frequency Bands

# Annex B: Hindering Equitable Access to NGSO Frequency Bands

The adverse effect of large NGSO systems on smaller NGSO systems is illustrated by Table B-1 below, which shows the probability that a NGSO system of one size blocks another NGSO system of a different size. Representative NGSO systems were modelled with 100, 300, 1,000, 3,000, and 10,000 satellites. The probability of blocking (the system being blocked not being able to find one of its satellites with sufficient angular separation from a satellite of the blocking system to avoid interference) was computed by Monte Carlo simulation. The percentages reflect the amount of time near in-line interference events can be expected.

| | | **Blocking System Number of Satellites** | | | | |
|---|---|---|---|---|---|---|
| | | **300** | **1,000** | **3,000** | **10,000** | **30,000** |
| **Blocked System Satellites** | **300** | - | 9.4% | 36.3% | 96.9% | 100.0% |
| | **1,000** | 0.0% | - | 9.5% | 92.4% | 100.0% |
| | **3,000** | 0.0% | 0.0% | - | 89.0% | 100.0% |
| | **10,000** | 0.0% | 0.0% | 0.0% | - | 100.0% |
| | **30,000** | 0.0% | 0.0% | 0.0% | 50.7% | - |

**Table B-1: Percentage of Time Large NGSO System Hinders Smaller NGSO Systems**

As reflected in Table B-1, the larger constellations would have a significant impact on smaller NGSO systems with the smaller systems experiencing blocking virtually all of the time. The adverse impact of the large system can also be illustrated by examining the “look angles” that would be blocked as a function of NGSO constellation size. Figure B-1 below depicts the percentage of available look angles that would be consumed by the NGSO systems as a function of the number of satellites they incorporate. As Figure B-1 shows, a 10,000-satellite NGSO constellation would block about 79 percent of the look angles available from an earth station location, and a 30,000 satellite NGSO constellation would block ***virtually all of the look angles available from that same location.***

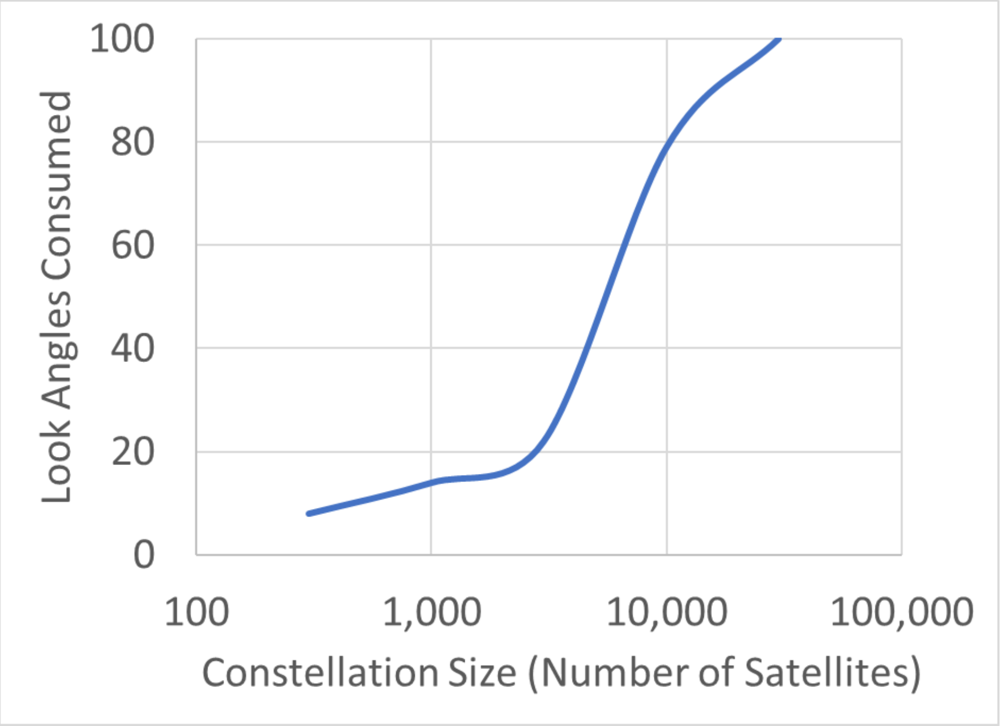


**Figure B-1: Percent of Look Angles Used as a Function of NGSO Constellation Size**

Large NGSO constellation's ability to "block" smaller NGSO systems would effectively reduce the capacity available to those smaller systems.

Critically, the large NGSO system itself would never be "blocked," or suffer any reduction in available capacity, as a result of the operation of smaller NGSO systems. This is because it would be able to leverage the satellite diversity afforded by the extremely large number of satellites in the system; in the event of an in-line interference event involving one satellite, it could simply reroute through another of its satellite.

Notably, and as discussed in Section II.B above, one solution would be to adopt a license condition requiring "look angle" splitting, whereby NGSO systems serving the country 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. 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.