24 May 2022

Ofcom Space Spectrum Strategy Consultation: Viasat Comments

Introduction

Viasat welcomes the opportunity to comment on Ofcom's public consultation on space spectrum strategy ("consultation").[1] As a global industry leader, Viasat has been a strong promoter of responsible and equitable practices designed to ensure that the shared orbital environment remains available for all to use safely and equitably. This public consultation is timely and important because we are witnessing an era of unprecedented activity and innovation in space, which requires all actors to have a particularly sharp focus on the safe and efficient use and sharing of scarce spectrum and orbital resources.

Below, Viasat focuses on Section 6 of the consultation addressing "NGSO satellite communications," including "the wider and longer-term implications of NGSO systems, including the international framework for NGSO systems and coexistence between NGSO systems and other spectrum users" noted in Section 6.2. Our comments of this aspect of the consultation address questions 6-8 in Section 6, and are structured as follows:

1. Ensuring equitable and safe access to space and mitigating interference into geostationary (GSO) networks and other non-geostationary (NGSO) systems;
2. Potential significant adverse impacts on the British space industry;
3. Potential consequences on end-users and citizen interests;
4. Environmental effects on the atmosphere, sustainable space, optical astronomy, and radio astronomy;
5. Potential implications for national security;
6. Performance considerations with respect to NGSO systems; and
7. Other NGSO issues.

We also comment on question 3 with respect to Ofcom's proposal to: (i) release four guard bands in the Ka band for satellite earth station use, (ii) make more capacity available for earth stations in motion (ESIM),[2] and (iii) facilitate satellite-to-satellite links.[3]

Ofcom's stated goal of enabling competition requires that access to space be safe and available to more than a few low Earth orbit (LEO) systems and nations. As such, sustainable space policies and industry competitiveness are complementary.

As a recent report by the EPFL International Risk Governance Center emphasizes, it is imperative that preventative action be taken now at the national level, because we just will not reach international consensus in the short term on a new framework for regulating large

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1 Consultation: "Space Spectrum Strategy," (15 March 2022), https://www.ofcom.org.uk/consultations-and-statements/category-2/space-spectrum-strategy.

2 Consultation at section 5.16.

3 Consultation at sections 5.38 "[i]f feasible, such links would be operated under existing FSS allocations in the Ka band;" 5.51 (Table 2: Actions in work area 2: Earth observation and navigation).

LEO constellations.[4] Therefore, appropriate action taken by Ofcom now would be an important, necessary, and critical first step toward managing risks in the short term and also providing "referenceable precedent as a foundation for building wider international agreements."[5]

Ofcom should not assume that these risks to British interests have been adequately addressed by the licensing administrations of NGSO systems. To the contrary, other nations have incentives to fully populate LEO before the UK and other countries. Moreover, other nations have far less global GSO satellite business to protect from interference, whether direct-to-home television (DTH)[6] or broadband, and, therefore, have far less motivation to address the threats to British interests presented in this case.

We trust our suggestions below will help Ofcom ensure that any spectrum authorizations they choose to award will create a fair and level playing field for all actors, whether in GSO, LEO, or other NGSO orbits, and do not pose a threat to efficient spectrum use, British national interests, space safety, or the environment. Indeed, the actions that Ofcom takes to preserve and promote competition and equitable access to limited spectrum and orbital resources to serve British interests will serve as an important model for other national regulators – and a critical step toward sustaining a competitive environment for UK satellite operators, manufacturers and launch providers alike around the globe.

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

Background on Viasat

Viasat is a global communications company that connects homes, businesses, governments, and militaries with high-speed broadband services and secure networking systems. Viasat also provides in-flight connectivity services via satellite to about 1,500 commercial aircraft now in-service. Throughout the COVID-19 pandemic, Viasat's GSO satellites have supported critical broadband applications, such as telemedicine, distance learning, video streaming, video conferencing, voice, interactive applications, social networking, web (including online sales), messaging (including email), file transfer, security, cloud services, and internet of things applications.

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4 Buchs, R., "Policy Options to Address Collision Risk From Space Debris," Lausanne: EPFL International Risk Governance Center (2021).

5 *Id.* at ii.

6 Consultation at 3.25, "27.1% of homes in the UK have satellite pay TV."

As Ofcom identifies in section 3.4 of the consultation,[7] the development of a new generation of GSO Ultra High Throughput satellites (UHTS) has made it possible to provide cost-effective high-speed broadband to customers featuring speeds of up to 1 Gbit/s and beyond, dramatically increased capacity,[8] and smaller end-user terminals. These types of GSO satellites are able to extend critical broadband connectivity to the unserved and underserved at a much lower cost per bit than other technologies, quickly extending service to the hardest to reach locations (typically within a day) and providing consistently high-quality and reliable broadband services.

Viasat is completing construction of our UHTS ViaSat-3 satellites, each of which will be capable of delivering a total throughput of over 1 Tbit/s. Each of our next-generation UHTS ViaSat-4 satellites under development will offer 5-7 times that amount of throughput. At the same time, LEO has become more readily accessible due to lower launch costs and the ability to utilize mass-produced satellites and satellite components. LEO satellites can, among other things, augment other national telecommunications network resources such as GSO satellites, and support the types of civic and military applications noted above.

Viasat also has designed, built, and/or operated NGSO satellites, payloads and ground networks and terminals for the past 30 years. Viasat operates a LEO satellite for a U.S. Government customer at an orbit between 500 km and 600 km and is under contract to launch a high value LEO satellite into a similar range, which will demonstrate tactical data links from space. Many more such satellites are contemplated. In addition, Viasat holds authority to serve the U.S. market with an NGSO satellite system consisting of 20 satellites operating in MEO[9] and is seeking a modification to deploy 288 satellites in LEO.

Viasat welcomes Ofcom's and the Government's aim to support innovation as mentioned in section 2.32 of the consultation. Viasat, as a global industry leader, is at the forefront of innovation in design, development, deployment, operation, and maintenance of satellite systems, networking technologies, and wireless communication systems. We design and develop ground antennas for high-capacity broadband LEO, MEO and GSO satellite systems. Viasat's Real-Time Earth[10] service offers a network of antennas strategically located in areas, including Guildford, UK, that are secure, reliable, and reduce the time lag between data capture and data delivery. Viasat recently demonstrated its flat-panel phased array antenna technology,[11] on a flight over Europe, that can seamlessly connect to multi-orbit satellites, enabling end-terminals to communicate in a hybrid LEO/MEO/GSO environment.

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[7] Consultation at 3.4, "[t]echnologies adopted from the mobile sector such as small cell spectrum frequency reuse and higher frequency feeder links continue to increase the overall capacity of [GSO] satellites."

[8] Consultation at 5.10 "[the potential benefits for satellite services from greater access to [the 14.25-14.50 GHz] band would be a doubling of uplink capacity of Ku band user terminals. This could enable improved services for a range of applications provided by both GSO and NGSO systems, such as inflight broadband and consumer satellite broadband services."

[9] See, "Viasat, Inc. Petition for Declaratory Ruling Granting Access for a Non-U.S. Licensed Non-Geostationary Orbit Satellite Network," Order and Declaratory Ruling, 35 FCC Rcd. 4224 (23 April 2020).

[10] *See*, Viasat innovation in space and ground networks.

[11] *See*, Viasat phased array antenna technology.

Comments on Consultation

In this section, Viasat provides comments to address questions 6, 7 and 8 together.

Question 6: Are there other issues and actions specifically relating to NGSO communication systems that are likely to be important over the next 2 – 4 years?

Question 7: Do you have any evidence on whether specific actions relating to NGSO communication systems should be a high priority?

Question 8: Do you have any other comments relating to NGSO systems?

1. **Ensuring equitable and safe access to space and mitigating interference with GSO networks and other NGSO systems.**

Reliable access to both sufficient spectrum and other orbital resources are key drivers in the ability of satellite services, to meet the evolving commercial, civil 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 for remote sensing/earth observation, science, defence, position, navigation & timing, and communications, alike.

As Ofcom has appropriately recognised in section 6, the development of NGSO systems present new opportunities but also raise particular challenges. Significant opportunities for the UK presented by both GSO networks and NGSO systems can be realised only if the threats posed by certain large NGSO systems in LEO are appropriately managed.

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 freezing out competition from, and innovation by, others. 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;[12]
- Blocking equitable access by other NGSO systems to shared NGSO frequency bands;[13]
- Precluding 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 (combined together) may generate into GSO networks.

By taking actions to manage these risks now, Ofcom can ensure that its policies keep pace with changes and innovations in the space sector, and that opportunities continue to exist for robust competition in the provision of satellite-based services to the UK.

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12 Consultation sections 6.30-6.37 "[i]mproving the international framework for NGSO systems."

13 Consultation at section 6.30.

Viasat commends Ofcom's plans to build on the national licensing regime introduced recently for NGSO systems. In responses to sections 6.10-6.13 of the consultation, Viasat believes that additional actions are required on a national basis to mitigate the risks of interference between NGSO systems, and between NGSO systems and GSO networks, and to ensure that the spectrum and orbital resources are shared equally amongst all NGSO systems. Viasat outlines below critical issues, some already recognised by Ofcom, that are necessary to be addressed now (rather than in long term) and we urge Ofcom to take the proposed actions to allow both GSO networks and NGSO systems to realise their full potential.

A. Managing impermissible interference into GSO networks.

i. Maintaining angular separation by NGSO systems to protect GSO networks from unacceptable 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 are capable of providing more than 1 Tbit/s of total capacity each, with even higher amounts of throughput expected in the next few years.

GSO networks achieve this unprecedented increase in capacity due in part to increased spectral efficiency which is facilitated by employing satellite receivers with low noise temperatures and high antenna gains (G/T). Today, even a single NGSO system 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 amount, they could easily degrade service levels and cause capacity losses to the GSO networks with which the NGSO system seeks to compete, including those that serve the UK. Ofcom recognizes the importance of angular separation in A2.18 of the consultation.

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 particular NGSO satellite to serve a given location would not maintain sufficient angular separation, then a different satellite would be used, and the other NGSO satellite would be used to serve a different location where it would be able to maintain the required angular separation. This concept is depicted below in Figure 1.

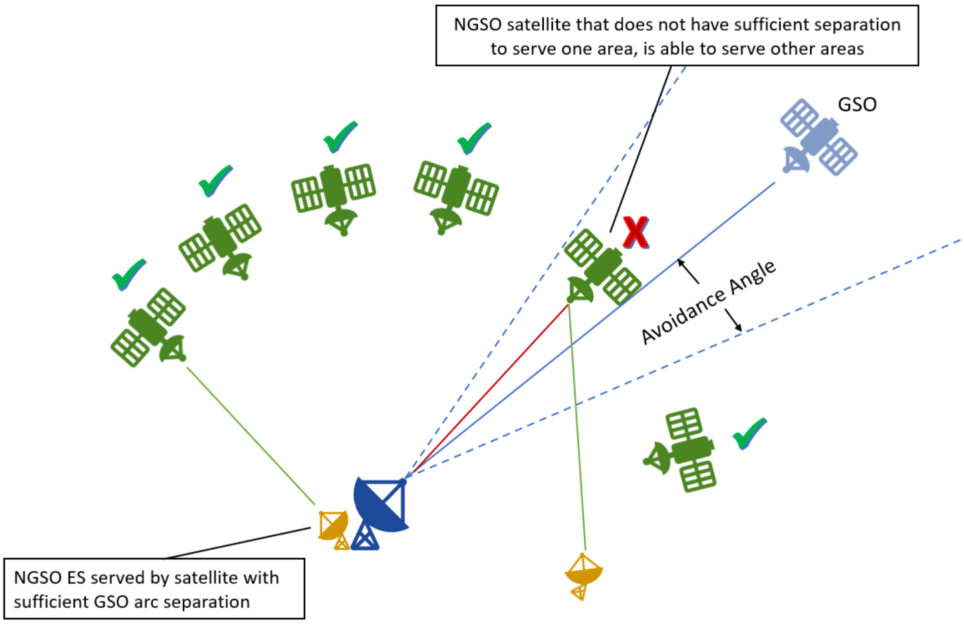

Figure 1: NGSO system employing GSO avoidance angle

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

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. Ofcom 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.

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

Moreover, the sufficiency of that angle should take into account the actual characteristics of the GSO networks that would be affected. Doing so would be consistent with Ofcom's spectrum management strategy published in July 2020,[14] according to which Ofcom

[14] Ofcom consultation, "Supporting the UK's wireless future: Our spectrum management strategy for the 2020s," (19 July 2021), https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf.

commits to "*use information regarding the real performance of equipment and services where this is available rather than particular equipment standard limits. This ensures that services and equipment performance are fairly taken account of in our coexistence analysis in a way that reflects their likely performance in practice.*"

Furthermore, such an approach would be consistent with the recognition in 6.52 of the consultation of the need to develop "improvements to the way NGSO systems are modelled when assessing their interference potential towards GSO systems."

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.

The relevant information regarding the NGSO system's characteristics is not readily available in the context of the application process at Ofcom. As such, it is impossible to ensure that any avoidance angle that an NGSO system may plan to employ would, in fact, be sufficient to protect GSO operations from interference.

For these reasons, the demonstration of the existence of adequate measures to avoid harmful interference should be provided *before* granting any authorization. Before granting any authorization for an NGSO system to serve the UK, Ofcom therefore should, at a minimum: (i) calculate the minimum GSO arc avoidance angle that would ensure that the NGSO system protects from interference GSO networks serving the UK; (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, and consistent with the recognition in Section 6.74 of the need for "improvements to the way NGSO systems are modelled when assessing their interference potential towards GSO systems," Ofcom should require NGSO applicants to provide the following information:

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

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

In sum, Ofcom should require:

- An NGSO system to maintain a suitable GSO arc avoidance angle when serving the UK;
- 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 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, shaping antenna beams differently.

In order to ensure that the bases on which Ofcom grants an NGSO authorization do not change by virtue of continuing iterations of its NGSO system design, Ofcom should also: (i) specify that the NGSO operator not modify the radiofrequency characteristics of its satellite system without prior consent from Ofcom, 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.

ii. Managing failures to comply with ITU epfd limits intended to constrain interference into GSO networks.

The potential for disruption to GSO networks by co-frequency NGSO systems is well-known and is what led to the development of various ITU Radio Regulations (RR) that protect GSO networks from interference generated by NGSO systems.

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, fulfil an NGSO system's RR No. 22.2 obligation; and
- In other frequency bands, a requirement that NGSO systems coordinate under RR No. 9.11A based on ITU network filing date priority.

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

There are two types of epfd 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 the same or overlapping frequencies. They are specified as a series of different epfd levels that are permitted for time-varying intervals, and are reflected in the epfd curves shown in Annex A. One aggregate epfd limit must be satisfied 100 percent of the time and other aggregate epfd limits must be satisfied for other, varying percentages of time.

"Single-entry" epfd limits constrain the amount of interference that a NGSO system itself may generate with respect to GSO networks. Those single-entry limits were established based on the assumption that 3.5 NGSO systems would be operating at a given time and generating combined epfd levels consistent with the applicable "aggregate" epfd limits. They are also specified as a series of different epfd levels that are permitted for time-varying intervals, and are reflected in the epfd curves shown in Annex A. One-single-entry epfd limit must be satisfied 100 percent of the time; and other single entry 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 interference and could well degrade service levels and cause capacity losses to broadband GSO networks as well as direct-to-home video (DTH) services. In addition, such operations would consume all of the epfd budget that must be shared and apportioned among all NGSO systems using overlapping frequencies.

As illustrated in Annex A, certain NGSO systems would exceed the "single-entry" epfd limits and, in some cases, the "aggregate" epfd limits. Exceeding the "single-entry" epfd limits at any point on the epfd curve is a violation of the ITU Radio Regulations. Exceeding the "aggregate" epfd limit at any point on the curve is also a violation. The instances described in Annex A in which NGSO systems 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 broadband GSO networks with which those NGSO systems seek to compete, including those that serve the UK, as well as to DTH services used by many millions of UK citizens.[15]

These violations of the "aggregate" epfd limits result from NGSO operators' attempts to ignore the way in which an NGSO system actually would operate and instead try to (1) artificially separate an NGSO system into constituent components, and (2) impermissibly evaluate each of those constituent components (instead of the NGSO system as a whole) against the "single entry" epfd limits.[16] They also occur because the violations occur at points in the epfd curves that are not examined in the ITU process.

Notably, the ITU has no way to effectively check the ability of a system operator to try to "game" the system in this manner, by contriving epfd inputs in a way designed to "pass" the ITU's spot checks regarding epfd without reflecting how the NGSO system actually would operate. Notably, that responsibility falls on individual administrations and regulators, such

[15] Consultation at section 3.25, "27.1% of homes in the UK have satellite pay TV."

[16] 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.

as Ofcom, that consider authorizing NGSO system operations.[17] Moreover, in other cases, an NGSO system's non-compliance with epfd limits may not be detected by an examination conducted by the ITU, as explained in Annex A. It ultimately falls on the NGSO operator to conduct its operations in full compliance with all epfd limits, regardless of any limited evaluation initially conducted by the ITU based merely on the data files provided by that operator and without regard to the actual operation of the NGSO system. Therefore, Ofcom must perform this compliance analysis now. Specifically, Ofcom should conduct single-entry epfd examination and verification of compliance against Article 22 epfd limits on the *entire NGSO system irrespective of the number of ITU filings* that makes up that system. And Ofcom also should conduct its own analysis of the aggregate epfd levels from all NGSO systems seeking to serve the UK to ensure that the aggregate epfd levels do not exceed any of the epfd limits.

Contrary to the suggestions on 6.48 and 6.49 of the consultation, 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. As Ofcom is aware, multiple NGSO systems are now operating 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, below. From the perspective of the GSO earth station, epfd interference is epfd interference—*i.e.,* the GSO earth station cannot isolate individual components of that interference or trace those components to their specific sources. This is why it is critical for Ofcom to evaluate an NGSO systems' epfd compliance (including the contributions of earth stations operating in the UK) before granting an authorization for service in the UK.

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

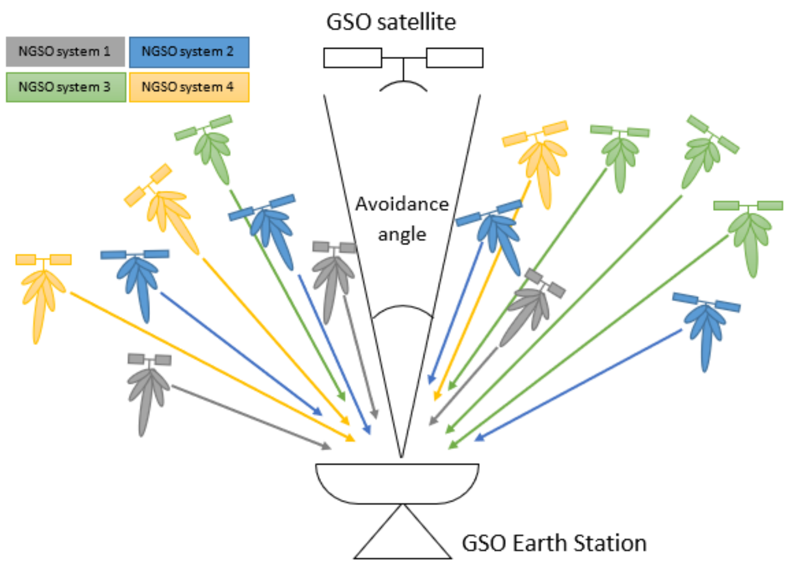

Figure 2: Aggregate mainlobe and sidelobe interference contributions from multiple NGSO systems into a GSO earth station

For these reasons, Ofcom should:

- Conduct its own analysis to ensure that an NGSO system seeking to serve the UK complies with *all* single-entry epfd limits, with Ofcom viewing all NGSO system filings under which the NGSO system operates as a collective;
- Conduct its own analysis of the aggregate epfd levels from all NGSO systems seeking to serve the UK to ensure that the aggregate epfd levels do not exceed any of the epfd limits;
- Require that an NGSO system comply with *all* single-entry epfd limits across the entirety of the system, with Ofcom again viewing all NGSO system filings under which the NGSO system operates as a collective;
- Require that an NGSO system operate such that it does not exceed any of the limits established for individual NGSO systems operating under a single ITU filing covering all system operations; 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 cooperate with the operators of such other NGSO systems, taking the technical measures necessary to eliminate the interference.

B. Managing equitable access to shared NGSO frequency bands.

Large NGSO systems with thousands of satellites planning to use LEO orbits can consume significant portions of the "look angles" toward space, and essential LEO orbits, preventing use of the sharing tools that have been employed successfully for decades among NGSO systems. This threat to NGSO spectrum sharing 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 is composed of a far greater number of satellites than smaller NGSO constellations, which provides the large NGSO system with alternative communications paths where 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 no incentive to avoid in-line interference events, and every incentive to maximize them; large numbers of in-line interference events would impede competition from smaller NGSO systems without materially impacting the large NGSO system's operations. As a result, the large NGSO system could effectively foreclose other satellite operators, including new entrants and other potential competitors, from accessing and using shared spectrum and orbital resources in the public interest. 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 as 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.*"[18]

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

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

Beyond the measures the consultation suggests in 6.37, it is critical to adopt a condition requiring "look angle" splitting, whereby NGSO systems serving the UK in overlapping frequencies would divide the range of satellite azimuths as seen from a location on the Earth whenever the potential for interference exists at that location. For example, on such occasions one system would only operate with satellites to the West of that location while the other system would only operate with satellites to the East of that location. As long as each system has a satellite available in its assigned 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 and use available spectrum resources on an equitable basis.

[18] "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).

Specifically, Viasat recommends that Ofcom constrain the preclusive effect of large NGSO constellations on limited and shared NGSO orbital resources by requiring NGSO systems authorized to serve the UK to:

- Operate with only 1/n of the look angles in the UK, where *n* is the number of NGSO systems authorized to serve the UK 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 the UK 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 competition in the UK, and also serving as a model for other national regulators – an important step toward sustaining a globally competitive environment for UK satellite operators, manufacturers and launch providers alike.

C. Ensuring safe and reliable access to 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[19] LEO mega-constellation operators are in a race to populate a wide swath of the "best" orbits (in the 300 km to 700 km range) with huge numbers of satellites. Orbits within this range are essential for the missions of earth observation[20] and PNT[21] satellites and also are very attractive for other purposes because of their associated passive decay times for failed satellites (which can deorbit much more quickly than from higher orbits). LEO mega-constellation operators are engaging in a "land grab" of these prime orbital resources by planning to operate with unnecessarily wide orbital tolerances, and thus effectively filling up hundreds of kilometres of orbits to the exclusion of other NGSO systems that otherwise could operate safely in nearby orbits. This forecloses those other NGSO systems from using LEO to provide competitive and innovative services to the public and distorts the competitive balance in LEO—all of which is particularly critical to avoid at this very early stage of the New Space age.

The sheer number of satellites on some LEO constellations is problem enough, but the preclusive impact is magnified by the overly wide orbital tolerances within which they propose to operate (for the reasons discussed above). One LEO operator proposes to operate across *hundreds of kilometres in LEO*—including in large shells that would spread from 290 km to 430 km and 475 km to 687 km. As depicted below in Figure 3, this result

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

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

21 *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/.

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.[22]

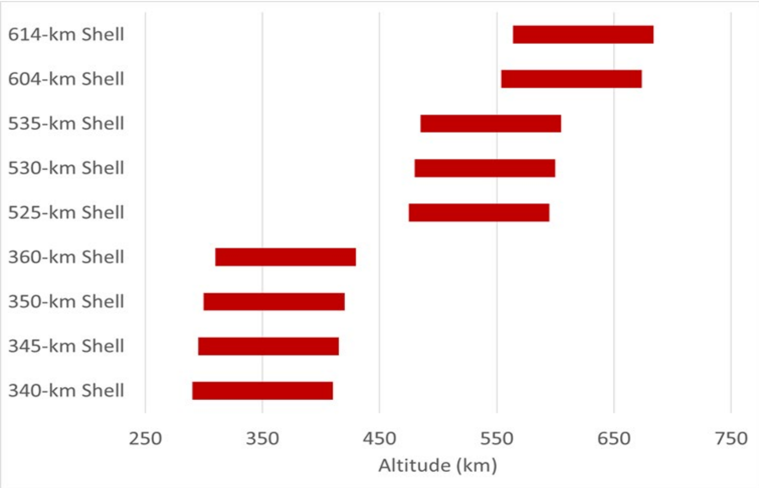

Figure 3: Extent of physical orbits proposed to be consumed by one large LEO system

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

For the same reasons provided above with respect to in-line interference events, the large LEO system would have every incentive not to consent to the operation of other LEO systems within the orbital ranges depicted in Figure 3. Particularly given that a LEO system already must operate within much narrower orbital tolerances to avoid collisions, there is no good reason to allow it to provide service to the UK 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 would have both the ability and incentive to foreclose other satellite operators, including new entrants and other potential competitors, from accessing and using shared spectrum and orbital resources in the public interest. It already enjoys the ability to use LEO regardless of whether physical coordination with any other operator is concluded successfully. The same cannot be said with respect to new entrants, which may be deterred from even attempting to deploy systems that overlap with this LEO system.

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

One mitigation would be to require any LEO operator serving the UK to maintain an orbital tolerance of +/- 2.5 km for the apogee and perigee of each satellite, and a 0.5° tolerance for each orbital inclination it employs, in order to ensure other NGSO systems that seek to serve the UK may access the shared LEO space, or alternatively to apply such orbital tolerance requirements as Ofcom deems appropriate to ensure the ability of other satellites and systems serving the UK to safely operate within, or overlap, orbits occupied by large LEO constellations. Such an approach is depicted in Figure 4 below.

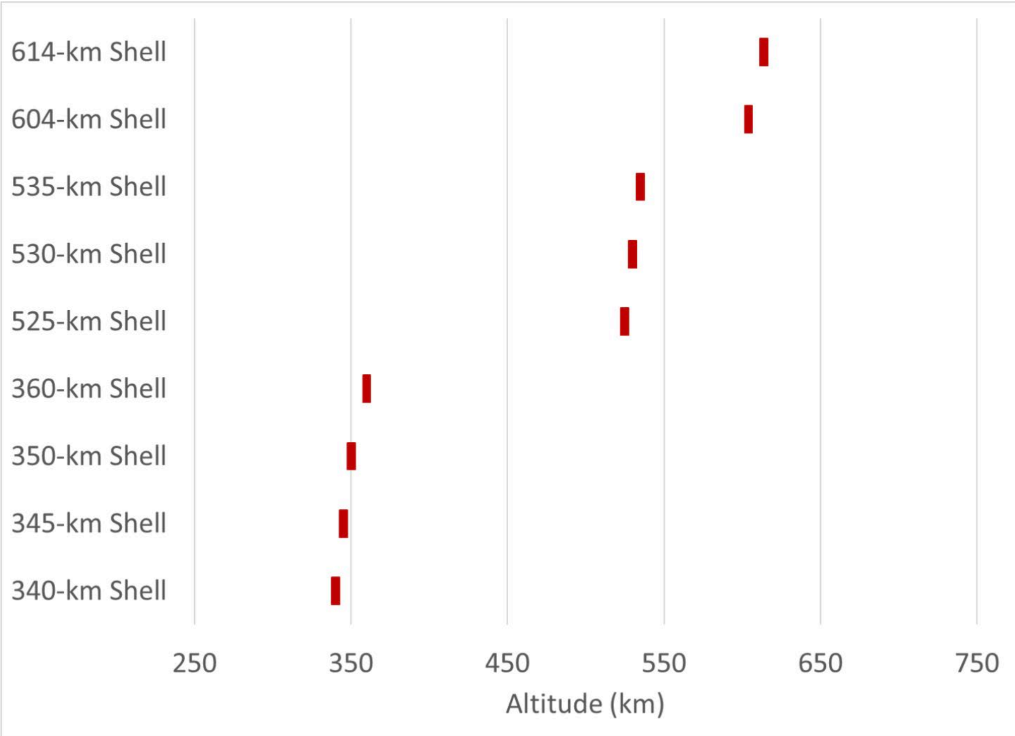

Figure 4: Reasonable orbital tolerances leave room for many LEO systems

2. Significant adverse impact on the British space industry.

An "ultra-dominant" position by one or two LEO operators with respect to NGSO resources would not only prevent other satellite operators or constellation projects from competing effectively, it would also have a significant negative impact on the entire United Kingdom's space and telecom industry, from satellite and satellite component manufacturers (Surrey Satellite Technology Ltd, Clyde Space Ltd, Oxford Space Systems, etc.), satellite launchers (Skyrora, Orbex Space, etc.), ground equipment/user terminal manufacturers, and operators (Goonhilly Satellite Earth Station, Milexia UK etc.), to telecommunication operators (Vodafone, British Sky Broadcasting, Telephonica UK Limited etc.).

These effects are exacerbated when a LEO operator employs a vertical integration strategy, *i.e.*, deliberately choosing to design and manufacture its satellites and user terminals in-house, to launch its satellites on its own rockets, and market its services directly to the end customers, thereby bypassing the entire existing ecosystem and keeping 100% of the value of the project for itself.

The loss in value for the British economy and the corresponding negative impact on jobs would be tremendous. By way of illustrative comparison, a report produced by London Economics on behalf of the UK Space Agency shows that the United Kingdom's space industry has contributed £6.9 billion Gross Value-Added to the British economic output and employs nearly 47,000 workers over the year 2019/2020.[23]

In the long term, the combination of an "ultra-dominant" position by a few companies with respect to NGSO resources, coupled with full vertical integration would exclude the British space and telecom industry from a sizeable portion of the corresponding market for satellite-related equipment and services and significantly reduce the size, relevance and competitiveness of the British existing industrial base, as well as all British "new space" companies that depend on access to spectrum and orbital resources.

A growing recognition exists that there are constraints on the exploitation of LEO, which have been expressed alternatively as environmental limits,[24] "carrying capacity,"[25] and "time to Kessler Syndrome."[26] Regardless of the terminology, the critical point is that *LEO resources are limited*. It therefore is incumbent on Ofcom to consider what portion of these resources – including spectral resources – NGSO systems that are permitted to serve the UK would consume, and what portion would remain available for British participants in the space and telecom industry.

Moreover, with respect to the potential for NGSO systems to interfere with services provided in the UK by GSO satellites, it bears emphasis that there are many millions of GSO satellite TV and/or broadband users in the UK.

3. Potential Consequences on end-users and citizens interests.

The British economy and society are increasingly reliant on space services (such as radio communication, timing and/or positioning signals (*i.e.,* PNT) or Earth observation data). For example, approximately 10% of the EU's GDP – more than €1,100 billion – is enabled by

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

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

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

[26] *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.

satellite navigation signals. [27] This growing reliance of GDP 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.[28] Each collision will statistically lead to more collisions and ultimately can lead to a "belt of debris around the Earth,"[29] leading to a series of self-sustaining collisions referred to as the Kessler syndrome, which could make certain orbits unusable for critical civil, military and commercial space services. One notable study commissioned by the U.S. National Science Foundation (NSF) indicates that it may not be feasible to sustain the deployment of one large NGSO system over time as a result of these dynamics. That NSF study forecasts a dramatic increase in both space collisions and new debris, starting within just a few years; in the longer term, "satellites are destroyed [by collisions with debris] faster than they are launched."[30]

The collision risk is further exacerbated by the documented failure rates of satellites in certain LEO constellations: indeed, satellites that cannot manoeuvre cannot avoid collisions, and experiential failure rates early in the life on 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 manoeuvrable, all potential collisions cannot be avoided.

These points are particularly relevant in light of recent attention to the short-term and long-term consequences of a successful anti-satellite (ASAT) test that occurred in November 2021 with the Cosmos 1408 satellite. Another recent study shows that a similar result can be expected should two large LEO satellites collide catastrophically.[32] Both types of events generate large numbers of lethal debris that spread into orbits hundreds of kilometres away

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[27] *See*, European Commission, « Commission Staff Working Document, Impact Assessment, Proposal for a Regulation of the European Parliament and of the Council, « establishing the space programme of the Union and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013, (EU) No 377/2014 and Decision 541/2014/EU (6 June 2018), EUR-Lex - 52018SC0327 - EN - EUR-Lex (europa.eu).

[28] *See*, "The case for space environmentalism," (22 April 2022), https://www.nature.com/articles/s41550-022-01655-6.

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

[30] *See*, 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.

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

[32] *See*, "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,[33] including lethal, *non-trackable* debris, that (i) increase the risk of spacecraft collisions (and human casualties in space), (ii) cannot be seen and thus cannot be avoided, and the risks of which cannot otherwise be mitigated today, and (iii) can destroy or disable active satellites and thus disrupt vital satellite-based services in the UK.

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

Moreover, as observed by the Chief Executive Officer of one satellite launch provider,[34] 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 satellites in all orbits.

Furthermore in a landmark report, the Organisation for Economic Cooperation and Development (OECD) points to the growing risk of an irreversible environmental and industrial disaster in space.[35] 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, such as Galileo and Copernicus, which in turn "would have a direct impact upon the security, safety, economy and well-being" of citizens of the UK and Europe as well.[36]

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33 *See*, "Self-Cleaning Orbit Myth," (December 2021), https://www.viasat.com/space-innovation/space-policy/space-debris/.

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

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

36 *See*, 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," (15 February 2022), https://ec.europa.eu/info/sites/default/files/join_2022_4_1_en_act_part1_v6.pdf.

Viasat welcomes Ofcom's recognition that physical risks to satellites from space debris could ultimately impact the provision of space-based communication services and that Ofcom would increase its engagement with other relevant UK organisation (CAA and UKSA) to work together on this critical issue.

As mentioned earlier, it is vitally important that the relevant UK organisations including Ofcom take tangible steps and measures now to ensure safety sustainability in the space environment near Earth. In this respect, it bears emphasis that collision and orbital debris generation risks also are materially affected by the mass and cross-sectional area of LEO satellites, as well as just the number of satellites in a constellation and the particular orbits they employ.[37] Ofcom therefore should: (i) require LEO applicants to disclose those values so the aggregate risk presented by a 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 Ofcom. This information is essential to allow calculation and management of a LEO constellation's total contribution to collision and orbital debris risk.

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

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

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

The environmental consequences of one large LEO system—which is unprecedented in nature and would involve deploying approximately 90,000 (or more) satellites over 15 years, using a launch every six days--would be grave.[40] Among other things, the impact of

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[37] *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.

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

[39] *See*, 20220208-NASA-NSF-letter-to-FCC-regarding-Starlink-Gen-2 (005).pdf, (8 February 2022).

[40] Jeff 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."

depositing an estimated 70,760 tons of alumina into the upper atmosphere when its satellites deorbit[41] 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 satellites.[42]

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 3 above).

5. Potential 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 defence applications.

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

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

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[41] 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 four times more massive, the proposed Starlink expansion could well result in SpaceX releasing over 78,000 tons of alumina into the upper atmosphere.

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

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

6. Performance considerations with respect to NGSO systems.

Section 6.6 of the consultation addresses two comparisons of NGSO constellations vis-à-vis GSO networks: latency[44] and capacity and discusses them as comparative advantages. Viasat respectfully submits that discussion is both incomplete and incorrect.

As to capacity, GSO networks are scalable in the same manner as LEO constellations: more satellites yield more capacity. What is not discussed in Section 6.6 is that because LEO constellations are always moving in low orbits, LEO constellations distribute their capacity essentially uniformly across the globe, while GEO satellites operate from a fixed orbit and deliver capacity through targeted spot beams. LEO systems have lower useful bandwidth because their capacity is evenly distributed, but global populations are not. An estimated 95% of the world's population lives on 10% of the land and land represents ~30% of the Earth's surface. Those facts limit the sellable capacity of a large LEO system, and render LEO systems relatively inefficient, as depicted in Figure 5 below. And considering the capital-intensive nature of LEO systems and the short useful lives of the many satellites (especially when the entire fleet must be replaced every five years, if not sooner), it is apparent that those assets are not as productive from an economic perspective either.

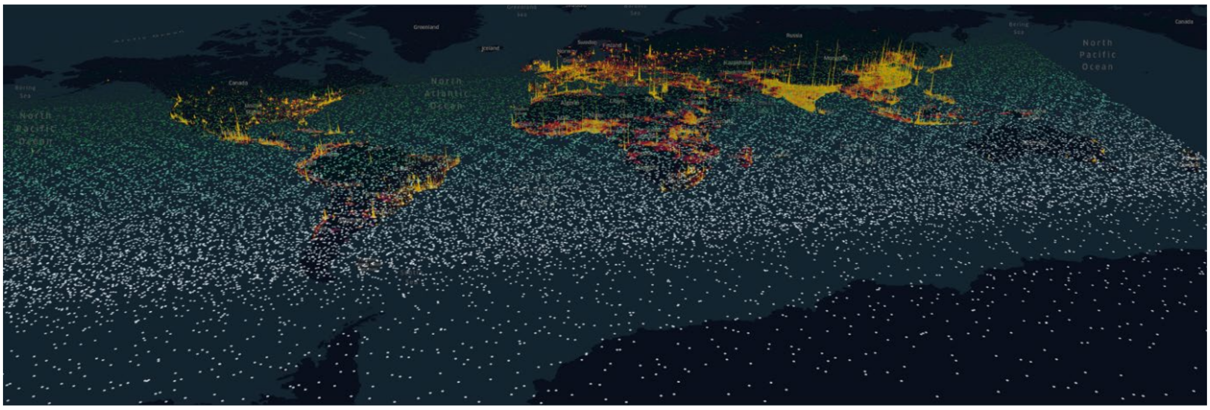

Figure 5: Large LEO Constellation Covers Mostly Unpopulated Areas
(37,272 LEO satellites in 20 orbital shells)

As to latency, Section 6.6 fails to discuss other broadband performance characteristics that affect a consumer's experience, and incorrectly focuses on "link" latency and not the entirety of the communications path. The user experience is affected by performance characteristics that include, among other things, speed, service availability and reliability, service interruptions, packet loss, jitter and (in the case of the limited class of applications that are latency-sensitive) end-to-end latency. A few of these elements warrant particular note:

Packet loss: Low rates of packet loss ensure the integrity of data that is sent and received over a broadband connection and are essential to ensuring the reliability of broadband services. Packet loss of no more than 0.1 percent is critical for real-time

44 *See also*, consultation sections 3.5, 6.8 (Table 5: Commercial NGSO systems, latency column) at 44; footnote 53.

applications (other than VoIP, for which quality is measured differently). Notably, unacceptable levels of packet loss can result from efforts to reduce latency—even though packet loss has a more significant impact on service quality and reliability than latency.

Service Interruptions: For obvious reasons, unplanned service interruptions can have a significant and adverse impact on the quality of the end-user experience. On the other hand, high levels of service availability are the *sine qua non* of a reliable service offering, such as when service interruptions are held to no more than a cumulative one second as measured over any continuous 12-hour period.

Jitter: Jitter (or the variation in latency/delay over time) is an important metric for understanding the quality of interactive, real-time applications. Notably, low rates of jitter can mitigate any impact that may result from latency/delay in the first instance. For such applications (other than VoIP, for which quality is measured differently), average one-way jitter greater than 25 milliseconds will result in a poor-quality experience for consumers.

Modern GSO satellites meet all these performance requirements. Critically, GSO technology also exceeds the gold standard for consumer applications for key latency requirements.[45] This includes transmission time, queueing delay, processing time at the source, destination and intermediate switches, buffering delay at nodes, and packet retransmission - both at the link level and end-to-end.[46] In other words, GSO broadband access technology solutions meet the gold standard for latency criteria in every critical user application when properly analysing latency within the full context of the entire network path. The key requirement is that an access technology meets the application requirement when *all* delay elements are considered. Focusing on one limited element of latency, such as link or propagation delay over one discrete element of the network, does not reflect a broadband users' experience.

LEO solutions, of course, suffer from limits on actual usable capacity, frequency reuse limitations, constraints on density of coverage, and inconsistency in quality, availability and reliability of service. Both mean service interruption frequency and mean service interruption duration on LEO systems can have an adverse impact on an end-user's broadband experience due to handovers from one satellite to another and line of sight issues at low terminal elevation angles.

The critical points are:

- No single satellite technology solution uniformly dominates the rest along various relevant performance metrics.
- There is no one size fits all solution for broadband deployment.
- Proven GSO technology is a reliable way to expand broadband connectivity.

[45] Consultation at 15.

[46] *Id.*

8. Other NGSO Issues.

As discussed above, Viasat supports the conclusion in 6.52 of the consultation that improvements are needed "to the way NGSO systems are modelled when assessing their interference potential towards GSO systems." But we respectfully disagree that the methodology used by the ITU-R contained in Recommendation ITU-R S.1503 "results in unnecessary constraints to NGSO systems." To the contrary, as detailed in Annex A, the ITU process entirely fails to evaluate expected epfd compliance of an NGSO system with respect to *all* single-entry epfd limits, and it is not clear how the ITU process prevents an NGSO operator from artificially separating an NGSO system into constituent components, and then impermissibly seeking to have the constituent components separately evaluated against the single-entry epfd limits.

Moreover, contrary to the stated desire of Ofcom to "use information regarding the real performance of equipment and services where this is available rather than particular equipment standard limits,"[47] the ITU process for examining interference into GSO networks from NGSO systems is based on GSO network characteristics from over 20 years ago with a limited range of antenna sizes, and does not consider that today's very high throughput GSO, employ much lower total satellite receiver noise temperatures and much higher satellite receive antenna gains, to provide innovative services with smaller user terminals than ever possible before.

Question 3: Are there other issues and actions that are likely to be important over the next 2 – 4 years?

- Release of four guard bands in Ka band for satellite earth station use.

Viasat appreciates the opportunity to address the release for satellite earth station use of four guard bands interspersed within the 27.5-29.5 GHz uplink portion of the Ka band.[48] Guard bands are an inefficient use of the critical spectrum resource in cases where other effective spectrum usage and interference mitigation arrangements are being applied. A direct relationship exists between: (i) the spectrum available for satellite broadband networks; (ii) the number of consumers who can be served with a given satellite; and (iii) the cost of the service to end-users. As mentioned earlier, the ViaSat-3 satellites are designed to yield an unprecedented 1+ Tbit/s of total throughput and our next generation ViaSat-4 satellites will produce 5 to 7 times that capacity, yielding further significant cost-efficiency gains.

To provide such capacity that enables provision of reliable and affordable satellite broadband connectivity to hundreds of millions of end users and even more devices requires access to contiguous spectrum in the Ka band, including the guard bands. Notably, Viasat satellite network designs are able to use the same part of the spectrum for user

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[47] Ofcom consultation, "Supporting the UK's wireless future: Our spectrum management strategy for the 2020s," at p. 23 (19 July 2021), https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf.

[48] Consultation, Sec. 5.8, 5.16, 5.23, Table 1 (Actions in work area 1: Communications).

terminals and gateways, employ highly intensive frequency reuse with a significant number of spot beams, all contributing towards high overall spectrum reuse and efficiency of the network.

Furthermore, todays sophisticated satellite modems are capable of producing sharp filter roll-offs allowing the satellite traffic carriers to transmit right up to the adjacent band edge with at least 25-30 dB (for 80 megabaud carrier) reduction in the in-band power at the band edge. For narrower bandwidth carriers, the roll-off is even steeper in terms of dB/MHz, allowing closer spacing of those carriers with respect to the band edge. Together with the satellite earth station antenna off-axis gain reduction, due to the elevation angle towards the GSO satellite, and selectivity of the adjacent band receive filter, the adjacent band interference can be managed adequately without the need for guard bands.

As per Ofcom's spectrum strategy,[49] Viasat notes Ofcom's vision to promote spectrum sharing by ensuring that wireless systems are resilient to interference from their neighbours. Better adjacent band receiver selectivity avoids the need for guard bands and facilitates efficient use and sharing of spectrum between different services.

- Provide access to the entire 27.5-30 GHz band for Aeronautical and Maritime ESIM.

Viasat also supports Ofcom's plan to review the existing arrangement for ESIM in the 27.5-29.5 GHz band with a view to extending the authorisation to a larger range of frequencies within the band. Ofcom's leadership and support at an international level was instrumental in the success of WRC-19 Agenda Item 1.5 that validated use of the bands 27.5-29.5 GHz and 17.7-19.7 GHz for the operation of GSO ESIM globally and it is only appropriate that Ofcom now take the necessary steps to allow operation of GSO ESIM across these bands nationally.

Broadband services on flights and ships are no longer considered a luxury. From Viasat's experiences, we know first-hand that airline passengers not only expect broadband services when they board the plane at the gate, they expect it to work as well in the air as it does on the ground demonstrating the need for full access to 27.5-29.5 GHz spectrum. Recent changes in online behaviour, as people have adapted to working, schooling, and consuming entertainment content at home, are expected to accelerate what was already strong demand for high-speed broadband access in the air. With the end of the pandemic in sight the travel sector has already started seeing a surge in demand. This growth in turn is increasing demand for broadband services on flights and ships and will also assist in speedy recovery of the global economy. As per an Allianz report,[50] aviation trends post Covid-19 show a steep increase in travel activities which is already back to pre-Covid levels in some regions of the world.

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[49] Ofcom consultation, "Supporting the UK's wireless future: Our spectrum management strategy for the 2020s," at 24 (19 July 2021), https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf.

[50] *See*, Allianz Global Corporate & Speciality, "Aviation trends post Covid-19: Nine issues to watch as the industry prepares for takeoff," "https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/agcs-aviation-trends-post-covid-19.pdf.

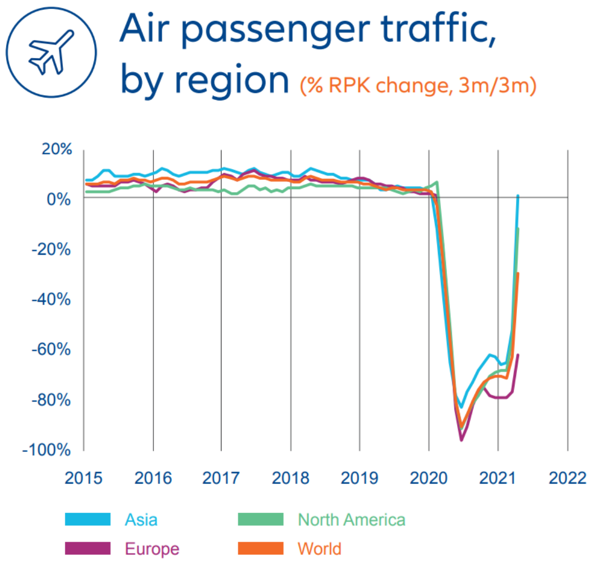

Figure 6: Aviation trends pre and post Covid-19

The above plot clearly indicates the urgency and necessity, as was the case before the pandemic, of allowing GSO operators to access the full 27.5-29.5 GHz (28 GHz) band to provide the much needed and expected capacity for broadband services in flight and on ships.

Viasat acknowledges that Ofcom has awarded portions of the 28 GHz band for national use on a technology neutral basis and in order to protect any terrestrial services that may be operating in those portions of the band, Viasat urges Ofcom to adopt and implement the latest revision of ECC Decision (13)01[51] that is based on the core principle of Radio Regulations Footnote 5.517A and Resolution 169 (WRC-19) - provisions to ensure that maritime and aeronautical ESIMs do not cause unacceptable interference and that only apply when ESIM operate in frequencies overlapping with allocated and authorized frequencies for terrestrial services. The technical conditions included in ECC Decision (13)01, (*i.e.*, PFD limits for aeronautical ESIM and in particular for maritime ESIM) are fully consistent with Ofcom's spectrum strategy published in July 2021.[52] In accordance with provision 2.2 of Annex 3 of Resolution 169 (WRC-19), an administration can agree to allow operation of maritime ESIM within 70 km. A blanket 70 km distance limit from the shore of the UK not only results in inefficient use of spectrum resources but also overprotects terrestrial services.

As an example, the scenario where a GSO maritime ESIM is operating in the English Channel would not be required to maintain a minimum distance of 70 km from the UK shore to

[51] *See*, Electronic Communications Committee (ECC), Decision (13)01, "The harmonized use, free circulation and exemption from individual licensing of Earth Stations On Mobile Platforms (ESOMPs) within the frequency bands 17.3-20.2 GHz and 27.5-30.0 GHz," (approved 8 March 2013; latest amended 2 July 2021), https://docdb.cept.org/download/3452.

[52] Ofcom consultation, "Supporting the UK's wireless future: Our spectrum management strategy for the 2020s," (19 July 2021), https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf.

adequately protect terrestrial stations. This is because the main beam of a GSO maritime ESIM operating in the English Channel would be pointed in the 'south direction' towards the GSO arc. Hence, any radio frequency (RF) energy radiated towards mainland UK would be through the ESIM antenna sidelobes and backlobes. This scenario was studied in the contribution[53] submitted by Viasat to FM44#61 (Nov. 2020) and the results showed that for a maritime ESIM located around the Strait of Dover, the minimum distance necessary to meet the PFD limit is approximately 7 km.

Furthermore, as explained in the contribution, Viasat employs sophisticated network control and management systems that continuously monitor the location of an ESIM with respect to a pre-defined 'Automatic Transmit Inhibit' (ATI) zone. The network automatically inhibits ESIM transmissions if it crosses the ATI zone. Such functionalities, which Viasat has been using since the early-2000s, provide the assurance that GSO ESIM will not cause unacceptable interference to other services based on a PFD limit requirement as per ECC/DEC/(13)01 and at the same time, that the GSO ESIM meets Ofcom's spectrum management vision of 'sustained improvements in the efficiency of spectrum use.'

- Facilitate Satellite-to-Satellite links.

In addition to the above matters, there is growing interest for utilising satellite-to-satellite links for a variety of applications including, but not limited to, relaying Earth observation and science mission data from NGSO satellites to Earth using a GSO satellite. Viasat welcomes Ofcom's plan to engage on WRC-23 Agenda Item 1.17 and encourages more active participation at CEPT and ITU meetings. We believe that operation of such satellite-to-satellite links, if within the "cone of coverage"[54] or "slightly extended cone of coverage," could be carried out under FSS allocations and does not require a new intersatellite service allocation. Viasat supports operation of satellite-to-satellite links within the cone of coverage and slightly extended cone of coverage. The slightly extended cone of coverage concept would allow a GSO service provider to communicate with a LEO satellite for a longer duration and at the same time not alter the interference geometry significantly. By way of example, for a LEO satellite operating at an altitude of 1,000 km, the slightly extended cone of coverage concept would just increase the maximum 'off-nadir' angle from a GSO satellite from 8.7° to 10°.

53 *See*, European Communications Committee (ECC), PT-FM44 (Doc. FM44(20)069), Viasat contribution to FM44#61 on maritime ESOMPs compliance with pfd limit (11 November 2020).

54 Cone of coverage - the conical volume of space defined by a cone whose apex is at the service provider space station and whose base does not extend beyond the edge of coverage of the Earth as viewed by the service provider space station.

Annex A: NGSO Interference into GSO Networks

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

In various frequency bands, NGSO systems are subject to limits on the epfd they may generate toward GSO networks.[55] There are two types of these limits. "Aggregate" epfd limits constrain the amount of interference that ***all*** NGSO systems in total may cumulatively generate with respect to GSO networks. These aggregate limits must be shared among all NGSO systems using the same or overlapping frequencies.

"Single-entry" epfd limits constrain the amount of interference that individual NGSO systems may generate with respect to GSO networks. Those single-entry limits were established based on the assumption that 3.5 NGSO systems would be operating at a given time and generating combined epfd levels consistent with the applicable "aggregate" epfd limits.[56]

As detailed below, today's NGSO systems could exceed both the "single-entry" and "aggregate" epfd limits in various respects in both the Ku and Ka bands. Exceeding the "single-entry" epfd limit curve at any point is a violation of the ITU Radio Regulations. Exceeding the "aggregate" epfd limit curve is also a violation.

Violations of Single Entry epfd Limits

The single-entry epfd limits that apply to NGSO systems are specified as a series of different levels that are permitted for time-varying intervals.[57] That is, one limit must be satisfied 100 percent of the time; and other limits must be satisfied for other percentages of time. Any exceedances of those epfd levels—whether of the "100%" value, the "10%" value, the "1%" value, or of other values—has the potential to cause harmful interference into GSO networks.

The ITU's methodology and implementing software for assessing expected epfd levels from NGSO operations rely on an algorithm that derives a "worst-case geometry" found at one particular location on the Earth's surface.[58] That is, the algorithm attempts to identify, for the specific NGSO satellites under the relevant filing and a representative GSO network, the single location that results in the highest single-entry NGSO epfd level that can be expected. As such, this value is produced for a very short period of time, and thus lies at the bottom-right of the relevant epfd results curve (*i.e.*, the alignment of the NGSO system with the GSO

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[55] ITU-R, Radio Regulations, Article 22; ITU-R, Radio Regulations, Resolution 76.

[56] *See,* ITU-R, Radio Regulations, Resolution 76.

[57] ITU-R, Radio Regulations, Article 22.

[58] *See generally,* ITU-R Recommendation S.1503.

network that produces the highest instantaneous interference level---for a very small percentage of the time).

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

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

Figures A-1 (Ku band) and A-2 (Ka band) below present the results of Ku and Ka band analysis prepared by OneWeb for the STEAM-1 and STEAM-2 NGSO filings.[59]

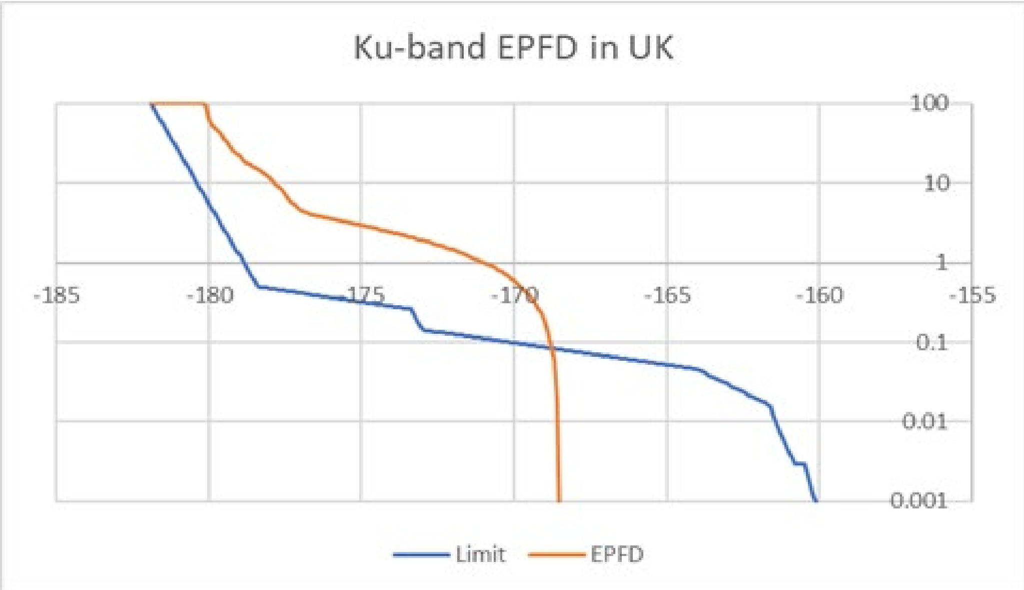

Figure A-1 –STEAM-1 Ku-Band epfd Levels at Goonhilly, UK

[59] "Need for a Procedure to Deal with Cases of epfd Exceedance that are Not Detected by the Worst-Case Geometry Algorithm in Recommendation ITU-R S.1503," (Doc. 4A/[OW-4]) prepared by OneWeb and submitted to ITU-R Working Party 4A (19 June 2019); *see also*, Viasat contribution formally submitting excerpts of OneWeb contribution to ITU-R Working Party 4A (Doc. 604) (5 May 2022), https://www.itu.int/md/R19-WP4A-C-0604/en.

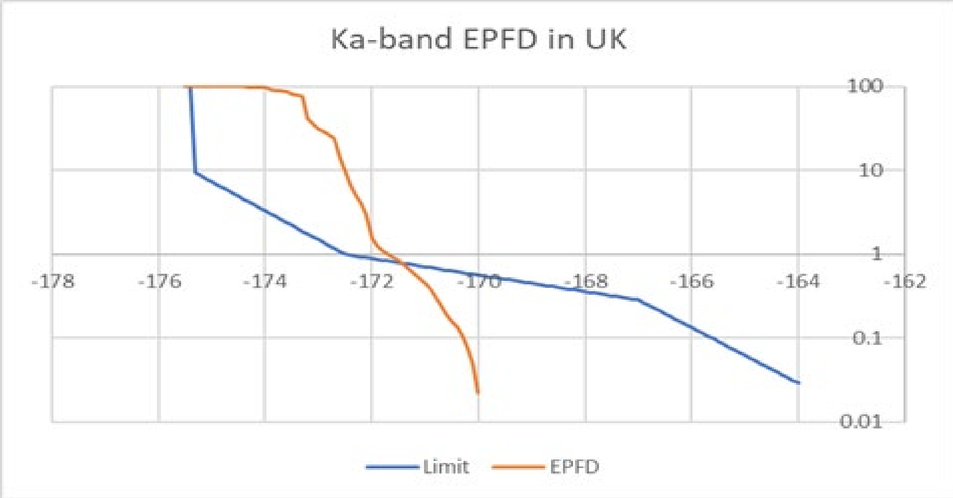

Figure A-2 –STEAM-2 Ka-Band epfd Levels at Goonhilly, UK

Figures A-1 and A-2 show that even though the STEAM-1 and STEAM-2 filings may appear to satisfy applicable epfd↓ limits with the “worst-case” geometry tested pursuant to the ITU’s algorithm, in reality there are other geometries where the same system under the same input parameters and assumptions would exceed the epfd↓ limits at other percentages of time. In fact, one exceedance reflected in Figure A-1 for STEAM-1 alone is more than double the aggregate epfd↓ limit that must be apportioned among all co-frequency NGSO systems.

Exceedances of the Art. 22 epfd↓ limits by NGSO systems are not limited to Goonhilly or to STEAM filings. The following figures demonstrate exceedances from several NGSO filings at different UK locations - Portsmouth, Bath, Oxford and Cullompton. The maximum exceedances for these examples are shown Table A-1. It is expected that additional examples of EPFD exceedances exist at locations throughout the UK for these and other NGSO filings that have received favourable finding from the ITU for Art. 22 EPFD limits.

Table A-1. Exceedance Examples for Several Systems in Different UK Cities

Filing	Admin	ES Lat	ES Lon	GSO Lon	Freq.	Ant. Diam.	Max Exceed.	Figure
STEAM-1	NOR	50.81	-1.09	35.00	10.7 GHz	0.6 m	2.4 dB	A-3
						1.2 m	8.0 dB	A-4
						3 m	9.2 dB	A-5
						10 m	1.4 dB	A-6
STEAM-2B	NOR	51.38	-2.36	39.65	17.8 GHz	1 m	3.2 dB	A-7
USASAT-NGSO-3B-R	USA	51.75	-1.26	-31.10	17,8 GHz	1 m	4.0 dB	A-8
EMPYREAL-A	G	50.86	-3.39	-35.07	19.7 GHz	0.9 m	0.05 dB	A-9

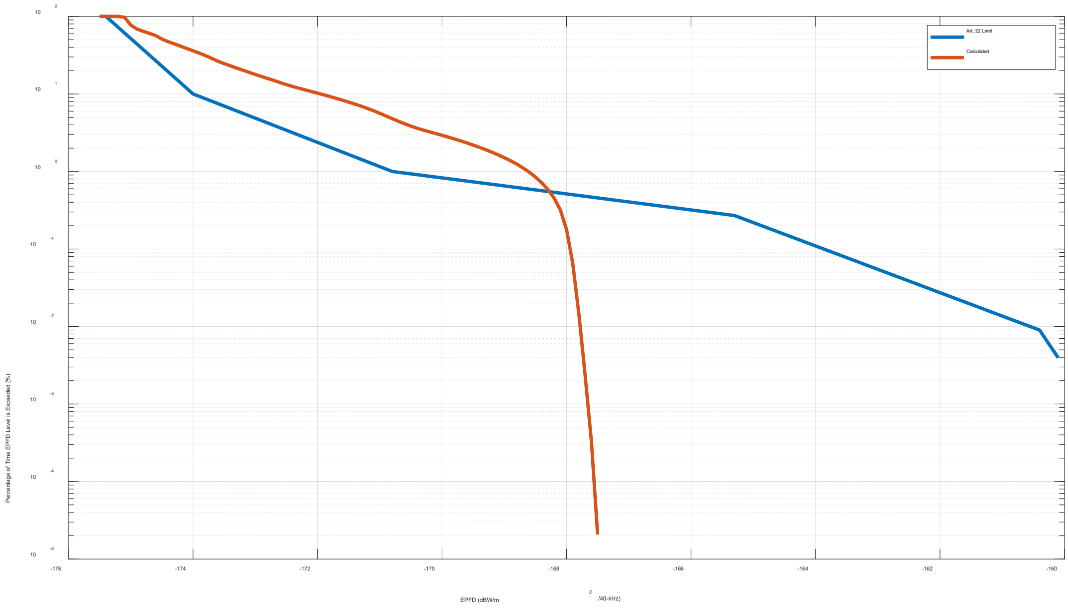

Figure A-3 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=.6 m, per 40 kHz (Portsmouth, UK)

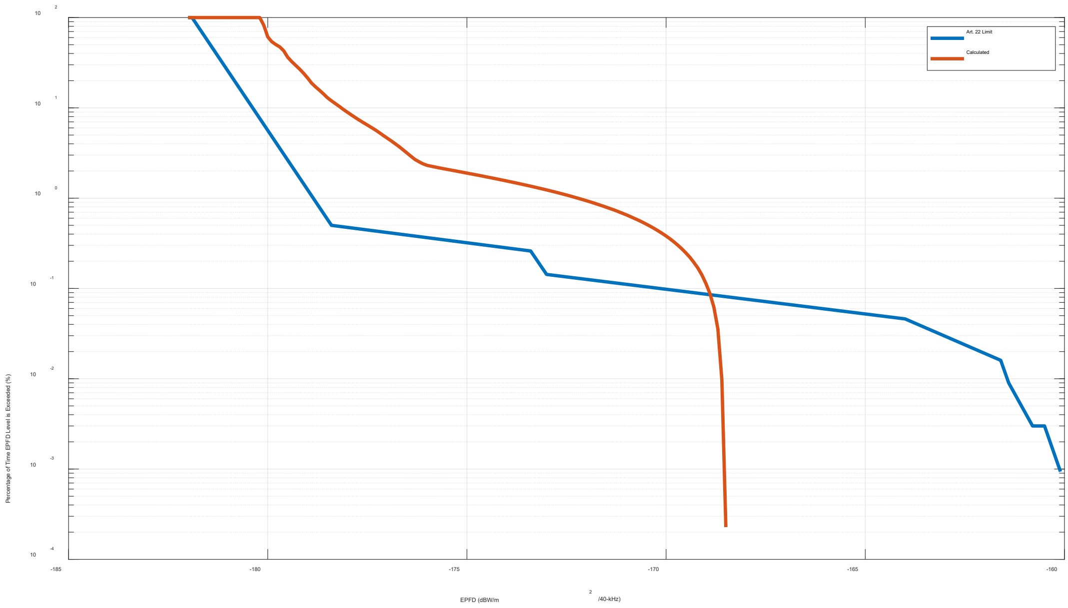

Figure A-4 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=1.2 m, per 40 kHz (Portsmouth, UK)

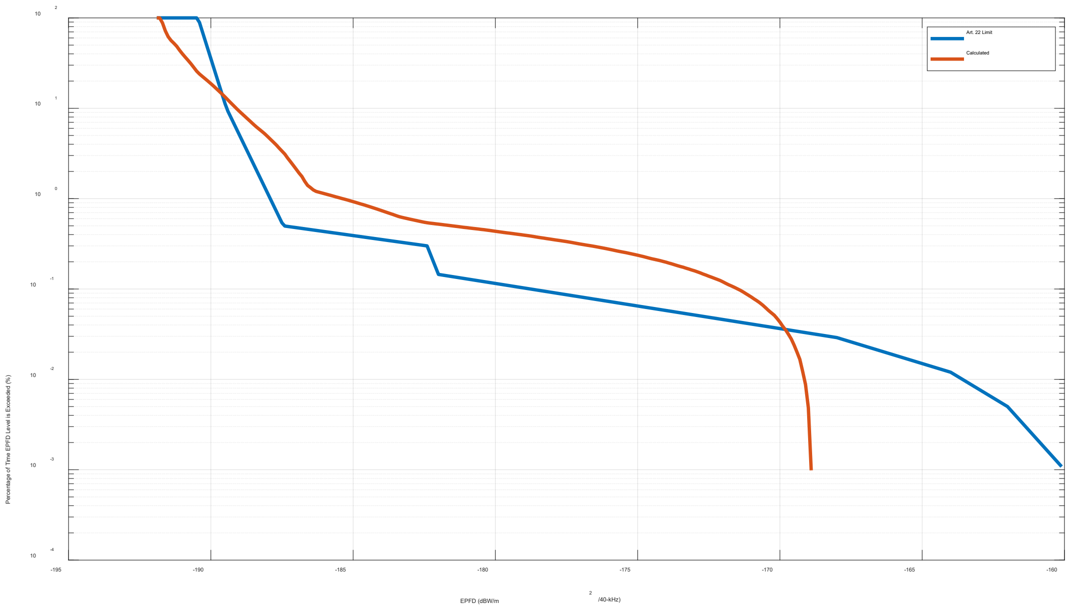

Figure A-5 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=3 m, per 40 kHz (Portsmouth, UK)

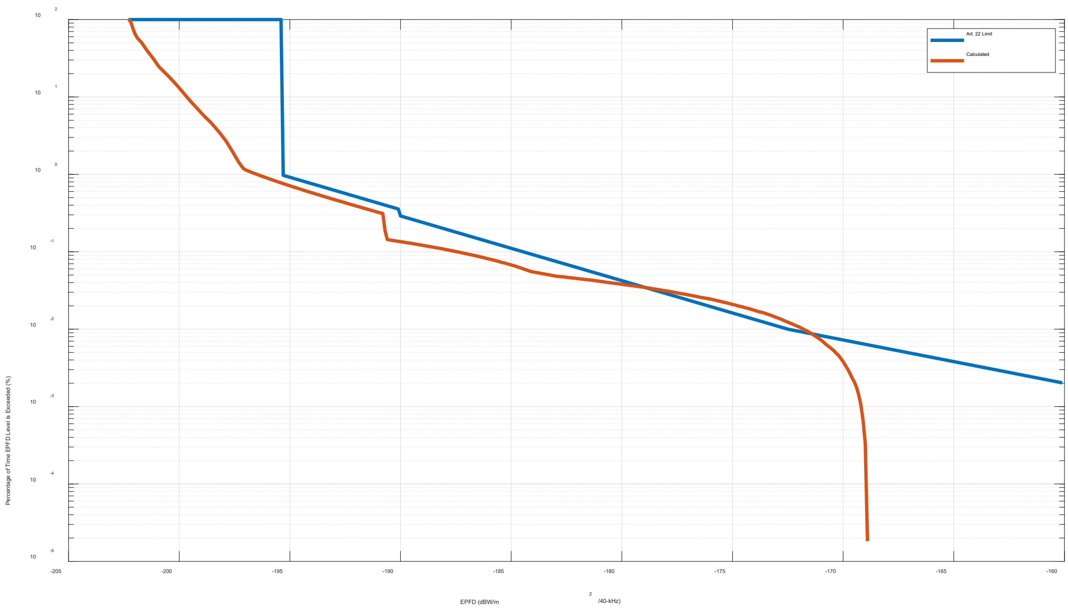

Figure A-6 - epfd↓, FSS, F=10.7 GHz, Ant S.1428, d=10 m, per 40 kHz (Portsmouth, UK)

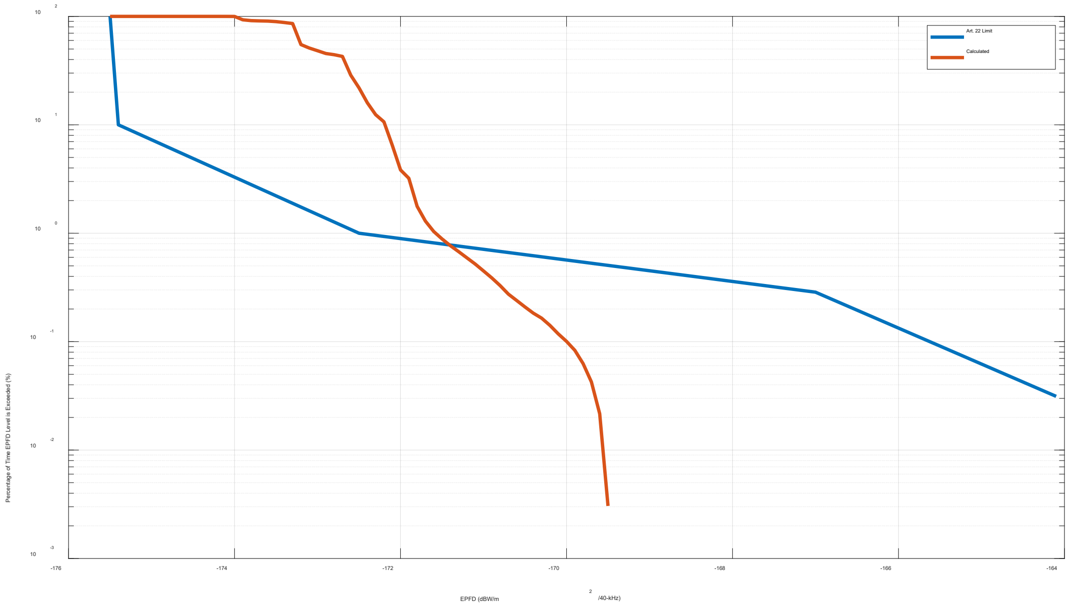

Figure A-7 - epfd↓, FSS, F=17.8 GHz, Ant S.1428, d=1 m, per 40 kHz (Bath, UK)

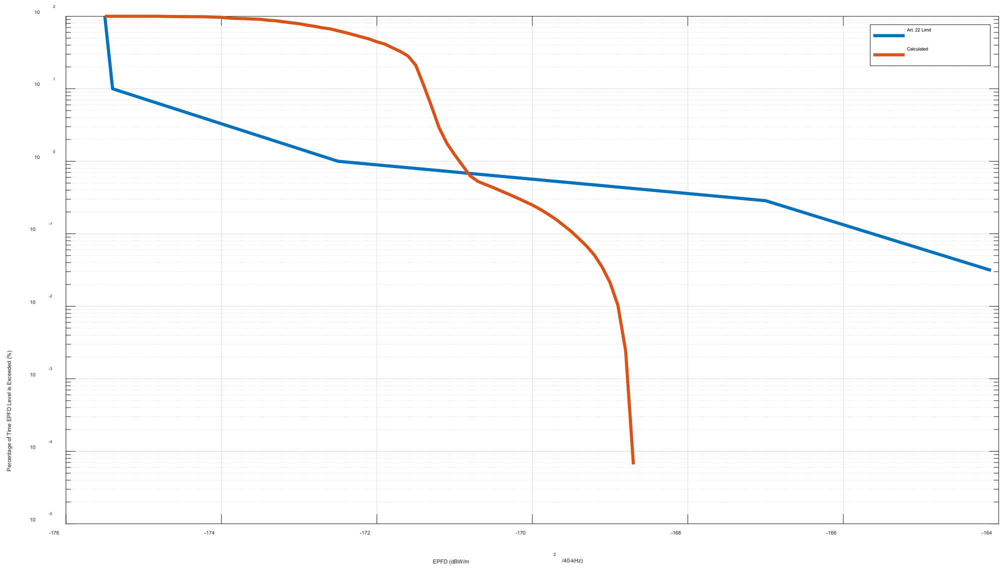

Figure A-8 - epfd↓, FSS, F=17.8 GHz, Ant S.1428, d=1 m, per 40 kHz (Oxford, UK)

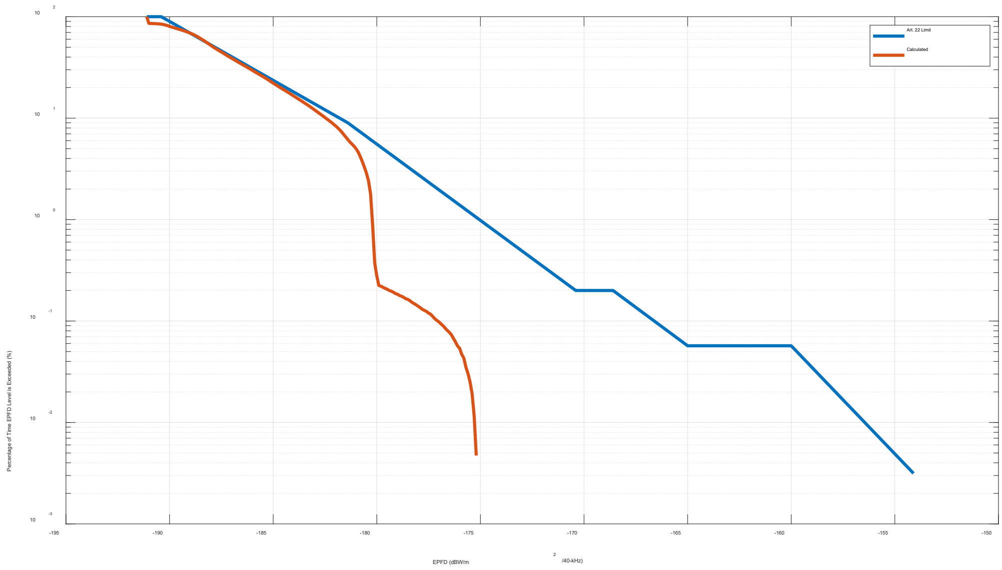

Figure A-9 - epfd↓, FSS, F=19.7 GHz, Ant S.1428, d=0.9 m, per 40 kHz (Cullompton, UK)

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

> The epfd limits in Article 22 are applicable for all GSO ESs [earth stations] and all pointing angles towards that part of the GSO arc visible from that ES. It is, however, not feasible to model all such geometries within the verification software. The worst case geometry (WCG) is a reference GSO satellite location and either an ES or boresight of the GSO satellite's beam which is used when examining a non-GSO system for compliance with the epfd limits in Article 22. *It remains necessary for the non-GSO operator to meet the epfd limits in Article 22 for all other geometries* including the testing of specific GSO networks as noted in § A1.3.[60]

NGSO System Violations of Aggregate epfd Limits

The following figures show the interference impact on GSO networks in a case where an NGSO system operates under multiple ITU filings. Figure A-10 shows the Art. 22 single entry limits, the Res. 76 aggregate limits, and the resulting epfd levels associated with: (i) a single filing and (ii) 18 instances of that filing aggregated to show cumulative epfd impact of (impermissibly) operating a single NGSO system under multiple ITU filings and thereby evading the single-entry epfd limits.

Figure A-10 shows the epfd down ("epfd↓") case in the 10.7 to 11.7 GHz band for a 1.2-meter GSO Earth Station ("ES"). The epfd↓ for the original single filing appears to comply with the Art. 22 limit, *i.e.*, the "1 Filing" curve is to the left of the Art. 22 limit curve in all places. But it does not reflect the actual operation of an NGSO system under multiple filings. The "18 Filings" curve exceeds the Res. 76 aggregate limit for all values below -165 dBW/m^2/40-kHz.

[60] ITU-R Recommendation S.1503 § D3 (emphasis added).

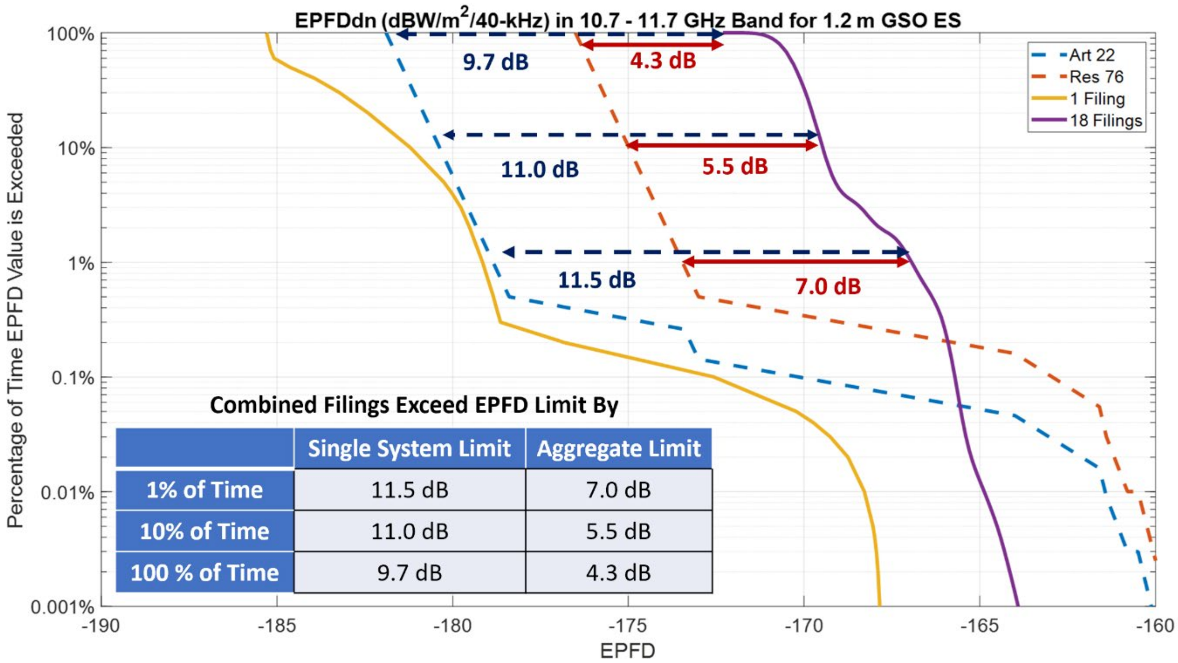

Figure A-108 – Aggregate epfd↓ for NGSO System Operating Under Multiple Filings (10.7 – 11.7 GHz, 1.2 m GSO ES)

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

Res. 76[61] provides that:

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

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

The exceedances of the aggregate epfd limits results from an NGSO system's attempt to ignore the way in which they would actually operate, artificially separate their system into

[61] ITU-R, Radio Regulations, Resolution 76, "Protection of geostationary fixed-satellite service and geostationary broadcasting-satellite service networks from the maximum aggregate equivalent power flux-density produced by multiple non-geostationary fixed-satellite service systems in frequency bands where equivalent power flux-density limits have been adopted."

constituent components, and then impermissibly evaluating constituent components against the single entry epfd limits.[62]

Again, ITU-R Rec. S.1503 is instructive. It is based on the premise that the parameters specified in relevant input files reflect the way that an NGSO system would actually operate once implemented. Among other things, the methodology is based on *all satellites that could contribute to the epfd levels generated by the entire system being considered together*. Thus, for example, ITU-R S.1503 explicitly anticipates that where a large constellation is divisible into separate "sub-constellations," *epfd compliance will still be evaluated across the constellation as a whole*.[63]

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

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

Annex B: Blocking Equitable Access to NGSO Frequency Bands

The preclusive effect of 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.

System Blocked #Satelites	Blocking System #Satellites				
	300	1,000	3,000	10,000	30,000
300	-	10%	37%	96%	100%
1,000	0%	-	9%	93%	100%
3,000	0%	0%	-	91%	100%
10,000	0%	0%	0%	-	100%
30,000	0%	0%	0%	49%	-

Table B-1 – Percentage of Time Large NGSO System Block 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 preclusive 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.***

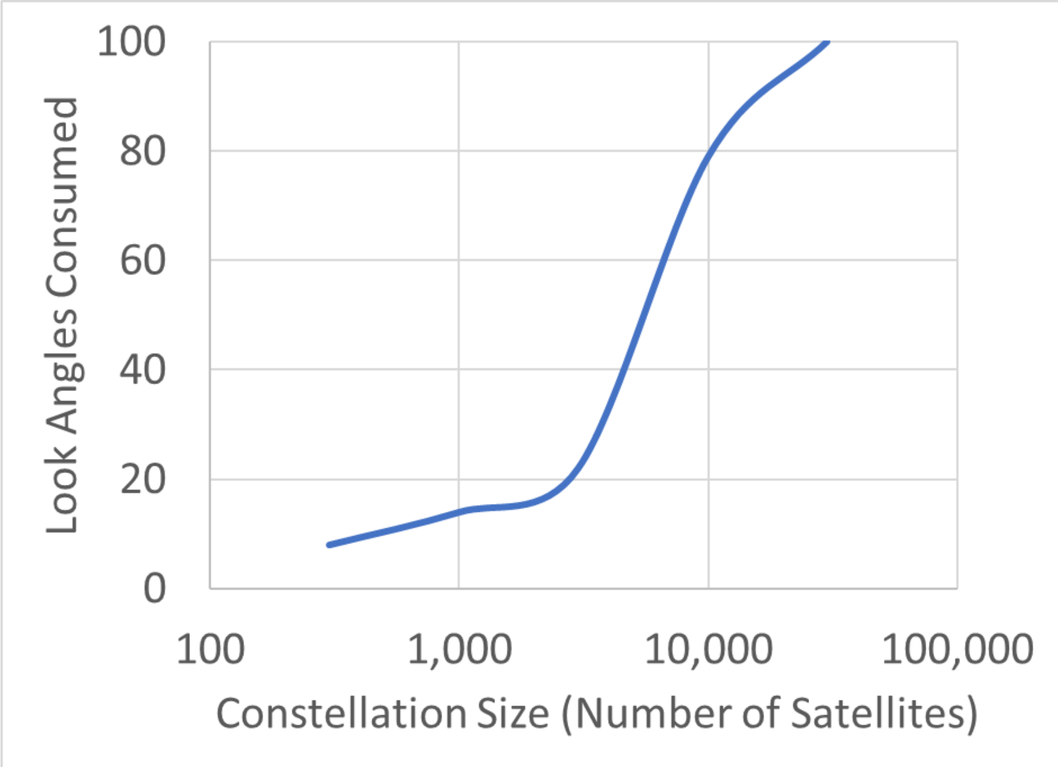

Figure B-1 – Percent of Look Angles Used as a Function of NGSO Constellation Size

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.