RSA
RS Access, LLC

May 19, 2022

VIA ECFS

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
45 L Street, NE
Washington, DC 20554

Re: *Ex Parte* Presentation, *Expanding Flexible Use of the 12.2-12.7 GHz Band*, WT Docket No. 20-443

RS Access, LLC submits for the record a new study performed by leading radio engineering experts at RKF Engineering Solutions, LLC (RKF). RKF has considered comments addressing its May 2021 report and, in a study filed today, has again found that terrestrial 5G wireless broadband in the 12.2-12.7 GHz (12 GHz) band can readily coexist with non-geostationary orbit (NGSO) fixed-satellite service deployments, which use 10.7-12.7 GHz for downlink.[1] In the attached technical analysis, RKF documents in detail how 5G deployments would have no effect on 99.85% of NGSO operations in the 12 GHz band—*less* risk of harmful interference than the already *de minimis* impact demonstrated in last year's RKF study, even after incorporating technical feedback from various NGSO commenters. In other words, the probability of any harmful interference to NGSO operations is no greater than 0.15%, as discussed below, and the probability of any impact on actual users is likely to be substantially less.

RKF's May 2021 study simulated the interference environment of 5G-NGSO co-channel operations in the 12 GHz band based on performance characteristics of each system, using standard reference design parameters and publicly available data. RKF concluded that the Commission could introduce 5G into the 12 GHz band with a statistically negligible probability (less than 0.89%) of harmful interference to NGSO downlinks in the band.

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[1] RKF Engineering Solutions, LLC, *Assessment of Feasibility of Coexistence between NGSO FSS Earth Stations and 5G Operations in the 12.2–12.7 GHz Band* (May 7, 2021), https://bit.ly/3sJjU6w, *attached to* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021), https://bit.ly/3sGKDRq ("May 2021 Study"). This study demonstrates the feasibility of NGSO coexistence with terrestrial 5G regardless of whether the NGSO deployment remains closer to the small number of current users or reaches the 2.5 million hypothetical potential future subscribers in the continental United States generously assumed by RKF to inform its simulation.

In the year since RKF filed its initial report, satellite companies opposed to terrestrial 5G have failed to submit their own technical analyses into the record. They have, however, asserted that RKF should have used different satellite design parameters to model satellite operations that have the general effect of increasing the likelihood of interference.

To remove any doubt about the feasibility of 5G-NGSO coexistence, and despite serious questions about the claims made by opposing satellite companies, RKF's new analysis reflects two principal refinements to last year's study:

First, RKF uses technical assumptions put forward by Starlink about the nature and operation of NGSO terminals that inherently *increase* the likelihood of interference. Although the assumptions advanced by Starlink are contrary to what publicly available data show about how NGSO systems operate in the real world, RKF uses those assumptions and models Starlink terminals that: (i) more frequently use lower elevation angles close to the minimum elevation angle of 25 degrees; (ii) are deployed on rooftops more than half of the time, reflecting greater antenna heights; (iii) use an unusual antenna gain pattern that makes the terminals more vulnerable to interference. Despite numerous, well-documented reasons to doubt the merit of each of these assumptions, including contrary instructions in Starlink's own installation manual,[2] RKF uses each of Starlink's purported operating parameters for purposes of the updated simulation.

Second, RKF accounts for current-generation 5G equipment and technologies that terrestrial wireless operators use to reduce the potential for interference. For example, terrestrial wireless operators use 5G beamforming antennas to achieve sidelobe suppression and antenna nulling toward the horizon to mitigate emissions that might occur outside the intended path of the signal. Similarly, terrestrial wireless operators typically deploy 5G macro-cell base stations with an effective isotropic radiated power (EIRP) that is closer to 65 dBm, rather than base stations with the maximum permissible power assumed in the 2021 RKF study.

Despite the use of technical parameters advanced by Starlink that are uniformly weighted against coexistence, RKF's Monte Carlo simulation finds that 99.85% of NGSO terminals deployed over

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[2] *See, e.g.,* Letter from David Marshack, Managing Director and Chief Operating Officer, RKF Engineering Solutions, LLC to Marlene Dortch, Secretary, Federal Communications Commission, WT Docket No. 20-443 (Aug. 9, 2021), https://bit.ly/3yLRxs7 ("SpaceX's default installation is a ground deployment. The Starlink kit includes no mounting tools beyond a mounting tripod that 'is designed for ground level installation.' Any other type of deployment requires the purchase of additional equipment and, more likely than not, a professional installation to address the cabling and building penetration issues associated with rooftop mounting, including an 'acknowledg[ment of] the potential risks associated with [a roof mount] installation.'….And yet, without providing an affidavit, citation, or any data whatsoever, SpaceX claims that 'most current users install antennas as high as possible (typically rooftop).' Here, as throughout its filing, SpaceX makes vague assertions attacking the [May 2021 RKF] study's assumptions but does not provide even basic information to show how those assumptions should be changed. If SpaceX has valid data to use, we urge the Commission to require that data to be shared with us or, better yet, placed in the record.") (citations omitted).

the contiguous United States do not even experience a technical "exceedance event" in the 12 GHz part of the 2,000 megahertz of Ku-band downlink spectrum they can use.

As a general matter, an "exceedance event" occurs when an incumbent terminal receives a radio emission that surpasses a nominal threshold established by governing bodies in radio engineering. An "exceedance event" is not the same as "harmful interference"—exceedance probabilities simply represent the *upper-bound* of the likelihood of harmful interference. That is, when RKF says that 99.85% of Starlink terminals experience no exceedance from 5G operations in 12.2-12.7 GHz, it means that 99.85% of those terminals will not be subject to even a technical "exceedance event," let alone harmful interference from 5G. Further, even for the 0.15% of Starlink terminals identified as experiencing an exceedance event in the 12 GHz portion of the Ku-band downlink, service would not be affected unless the exceedance event both rose to a level of actual harmful interference *and* all other 250-megahertz channels assigned to NGSO licensees in the 10.7-12.7 GHz band were simultaneously unavailable. Therefore, even the exceedingly small number of users with NGSO terminals that might be subject to a technical exceedance event are unlikely to notice any impact on their service.

RKF's latest study reaffirms that terrestrial mobile broadband can readily share the 12 GHz band with NGSO services. The different target markets and network architectures of terrestrial and satellite services in the 12 GHz band limit the potential for harmful interference. NGSO service does not yet operate at scale, and its growth will be unaffected by 5G given the vanishingly small chance of any adverse impact in the 12.2-12.7 GHz portion of the 2,000 megahertz of Ku-band NGSO downlink spectrum accessible by Starlink and other potential Ku-band NGSO operators.

Sincerely,

/s/ V. Noah Campbell

V. Noah Campbell
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Attachment

The Effect of 5G Deployment on NGSO FSS Downlink Operations in the 12.2 – 12.7 GHz Band

May 19, 2022

Prepared by:

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Executive Summary

RKF Engineering Solutions, LLC (RKF) prepared this study to update and refine its assessment of the impact of deploying terrestrial 5G in the 12.2-12.7 GHz (12 GHz) band to emerging non-geostationary orbit fixed-satellite service (NGSO FSS or NGSO) deployments that are also co-primary in the band.

This study establishes the upper-bound probabilities that 5G might harmfully interfere with NGSO terminals in the 12 GHz band. To quantify 5G's effect on NGSO services, this study conducts a nationwide Monte Carlo simulation that models: (1) a robust 5G network consisting of nearly 50,000 macro-cell base stations, nearly 90,000 small-cell base stations, nearly 2 million simultaneously active mobile devices, and almost 7,000 point-to-point backhaul links; and (2) 2.5 million Starlink NGSO terminals throughout the contiguous United States (CONUS). These numbers provide a statistically robust sample to generalize the results below, no matter the number of devices or terminals actually deployed. To model antenna patterns and propagation characteristics, this study incorporates extremely detailed inputs that reflect real-world conditions; values based on Federal Communications Commission (FCC or Commission), International Telecommunication Union (ITU), and 3GPP reference materials; and, where public information is not available, algorithmically derived parameters based on commercially reasonable assumptions and the current state of the art. These inputs are generally chosen conservatively to err on the side of overestimating the likelihood of interference. Based on this nationwide, probabilistic modeling, this study finds:

- **No impact to 99.85% of NGSO terminals.** In particular, this study finds that only 0.15% of Starlink terminals that might hypothetically be deployed in the future throughout CONUS experience an exceedance of the ITU's interference-to-noise ratio (I/N) threshold from 5G operations in the 12.2-12.7 GHz portion of the NGSO downlink band. As explained below, "exceedance" is neither equivalent to harmful interference, nor does it mean there is any harmful effect on the subscriber.

In its May 2021 Study, RKF found that 5G would cause almost no interference to NGSO services, based on the performance characteristics of each system, standard reference design parameters, and publicly available data.[1] RKF has reviewed the technical comments submitted in the record following the May 2021 Study and considered the variables stakeholders identified as relevant to refining the analysis. This study presents a holistic perspective of the 12 GHz band's proposed

[1] RKF Engineering Solutions, LLC, *Assessment of Feasibility of Coexistence between NGSO FSS Earth Stations and 5G Operations in the 12.2–12.7 GHz Band* (May 7, 2021) *attached to* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("May 2021 Study").

operating environment, based on the best available inputs regarding NGSO and 5G system performance, including:

- **NGSO terminal assumptions that err on the side of overestimating the likelihood of interference.** This study incorporates several suggestions made by Starlink following the filing of the original May 2021 Study (even though RKF remains skeptical that they reflect actual NGSO deployments). *First*, this study now assumes Starlink terminals more frequently use lower elevation angles closer to the minimum elevation angle of 25°. Terminals that point closer to the horizon instead of the sky are more susceptible to interference because 5G devices operate closer to the ground. *Second*, this study now assumes that more than half of Starlink terminals would have a rooftop deployment. A rooftop NGSO terminal would not be shielded by clutter that might otherwise block 5G emissions. *Third*, this study assumes that NGSO terminals use an antenna gain pattern suggested by Starlink that would make such terminals more prone to interference.
- **5G technologies and inputs that are commercially available and proven to reduce interference.** 5G beamforming antennas can use sidelobe suppression and antenna nulling toward the horizon to mitigate inadvertent interference that might occur outside the intended path of the signal. This study also uses an effective isotropic radiated power (EIRP) of 65 dBm for 5G macro-cell base stations, which is more commercially reasonable than the value used in the May 2021 Study.

RKF's findings represent the upper-bound probabilities of 5G's potential impact on NGSO terminals. As noted above, RKF's simulations find that 99.85% of NGSO terminals do not experience an "exceedance event." As a general matter, an "exceedance event" occurs when an incumbent terminal receives an emission that surpasses a nominal threshold established by governing bodies in radio engineering. For NGSO systems, this study uses the ITU's exceedance threshold of -8.5 dB I/N. "Exceedance" values are heuristics intended to capture the possibility of disruption. It is important to understand that "exceedance" of the FCC or ITU thresholds does not imply that "harmful interference" has been experienced by any user. The Commission's rules define "harmful interference" qualitatively as an emission, radiation, or induction that "*seriously degrades, obstructs or repeatedly interrupts* a radiocommunications service."[2] Exceedance values, therefore, provide the upper-bound probabilities of potential harmful interference. A terminal for which the model predicts an exceedance event may not experience service degradation that is noticeable to a consumer in practice. But a terminal that does not experience an exceedance event will not encounter harmful interference. A 12 GHz exceedance event would also affect no more than two of the up to eight available 250-megahertz Ku-band NGSO FSS channels. Even in the unlikely, worst-case scenario where a 12 GHz exceedance event were to produce actual harmful interference on both channels in the 12.2-12.7 GHz portion of the NGSO FSS downlink

[2] *See* 47 C.F.R. §§ 2.1(c), 15.3(m) (emphasis added).

band, an NGSO FSS user would not necessarily experience any service degradation so long as one or more of the other six Ku-band downlink channels remain available.

Several factors explain why 5G's likely impact on NGSO terminals is so low. *First*, 5G base station antennas point downward below the horizon, whereas NGSO terminals point to the sky. *Second,* 5G macro-cell base stations will beamform toward the individual 5G user equipment and can simultaneously null in the direction of NGSO earth station locations. *Third*, 12 GHz 5G will have a relatively limited propagation distance at 12 GHz compared to lower frequency bands. *Finally*, 12 GHz 5G deployment and satellite terminals have limited geographic overlap due to their use-cases—12 GHz 5G services will be deployed most heavily in denser population centers, while satellite services are most useful in lower density population centers. These factors help explain why 5G is unlikely to cause harmful interference to NGSO services using the 12 GHz band.

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1. Introduction

1.1. Motivation and Objectives

The Federal Communications Commission (FCC or Commission) allocated the 12.2-12.7 GHz (12 GHz) band for Broadcasting Satellite Service (better known in the United States as DBS) in the early 1980s.[1] In 2000, the Commission added allocations for Fixed Service (FS) and non-geostationary satellite orbit (NGSO) fixed-satellite service (FSS) operations.[2] The resulting FS, terrestrial Multi-Channel Video and Data Distribution Service (MVDDS), and NGSO FSS are co-primary with each other but must operate on a non-interfering basis with Ku-band DBS.[3] The 12 GHz band also already has an international allocation for mobile except for aeronautical mobile.

To assist the Commission in a timely manner, RS Access, LLC submitted a study from RKF Engineering Solutions, LLC (RKF) that simulated the interference environment of 5G-NGSO co-channel operations in the 12 GHz band based on, among other things, performance characteristics of each system consistent with standard reference design parameters and publicly available data.[4] That study concluded that the Commission could introduce 5G into the 12 GHz band with a statistically negligible risk of harmful interference to NGSO FSS operations.

With the benefit of additional time, RKF has refined its 5G-NGSO analysis to reflect feedback from the record and incorporate additional observations about advances in real-world deployment conditions. For this report, RKF re-executes its 5G-NGSO model using updated assumptions based on new claims from Starlink about its system, including its purported operations at lower elevation angles and terminal antenna patterns. RKF also accounts for assertions that "the majority of [Starlink] users install their terminals as high as possible, and most frequently on rooftops."[5] These updated assumptions are summarized in Section 3.1.

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[1] *See Inquiry into the Development of Regulatory Policy in Regard to Direct Broadcast Satellites for the Period Following the 1983 Regional Administrative Radio Conference*, Report and Order, 90 FCC 2d 676 ¶ 7 (1982).

[2] *See Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range et al.*, First Report and Order and Further Notice of Proposed Rulemaking, 16 FCC Rcd 4096 ¶ 2 (2000).

[3] "Ku-band" spectrum is generally understood to include the bands allocated for satellite services between 11-14 GHz. "Ka-band" spectrum is generally understood to include the bands allocated for satellite services between 18-30 GHz. Satellite video services are delivered to homes using the 12.2-12.7 GHz band and Ka-band spectrum.

[4] RKF Engineering Solutions, LLC, *Assessment of Feasibility of Coexistence between NGSO FSS Earth Stations and 5G Operations in the 12.2–12.7 GHz Band* (May 7, 2021) *attached to* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183 (filed May 7, 2021) ("May 2021 Study").

[5] Reply Comments of Space Exploration Holdings LLC, WT Docket No. 20-443 and GN Docket No. 17-183, at 11 (filed July 7, 2021) ("SpaceX Reply Comments").

RKF also updates several parameters in the 5G deployment model to reflect commercially available technologies, including a macro-cell base station effective isotropic radiated power (EIRP) of 65 dBm per 100 MHz, horizon nulling for macro-cell base stations, optimized beamforming patterns for small-cell base stations, and other refinements. These updated assumptions are summarized in Section 2.1.

1.2. Methodology

This section provides a general description of the approach RKF uses to model the interference environment caused by terrestrial 5G to NGSO operations in the 12 GHz band. Sections 2.1 and 3.1 summarize methodological changes to the 5G and NGSO network models, respectively, since the May 2021 Study. Further details about the overall modeling framework are available in the sections below and, as relevant to the 5G and NGSO network models, in the May 2021 Study.

In simulating how 5G systems might interact with NGSO terminals, RKF has brought the latest computational resources to a big-data problem, conducting massive, geographically granular, nationwide simulations that require some 11.7 billion instructions and vastly improves on methodologies that rely on generalized models or highly localized samples. The tools available to handle the computational requirements of such big-data challenges have improved many times over since the Commission first adopted the existing 12 GHz band allocations in 2000. The quality of the current results provides a high level of confidence about the feasibility of solutions to challenges that were previously deemed too complex to solve.

To simulate Ku-band 5G-NGSO operations, RKF models a statistically significant population of nearly 2.1 million 5G devices, including approximately 2 million simultaneously active UEs, 90,000 fixed small-cell base stations, 50,000 fixed macro-cell base stations, and 7,000 point-to-point backhaul links. RKF also models 2.5 million NGSO terminals in CONUS using a Monte Carlo analysis—a computationally demanding, probabilistic technique that affords many advantages over simple, deterministic modeling. In recent years, the Commission has favored Monte Carlo simulations over worst-case analysis—a choice that federal courts have upheld as within the Commission's expertise as the nation's spectrum policymaker.[6] For this study, RKF's Monte Carlo modeling involves four steps:

<u>First</u>, RKF stochastically distributes a representative sample of 5G user equipment (UE), macro-cell and small-cell base stations, and fixed microwave backhaul sites in a computer-simulated terrain database of CONUS that includes the ground height at each specified latitude and longitude. In identifying where to position the terrestrial infrastructure, RKF uses an algorithm to generate a realistic network of terrestrial 5G base stations across CONUS by placing them randomly in the most densely populated areas comprising at least 10% of the population of each

[6] *See AT&T Servs., Inc. v. FCC*, No. 20-1190, 2021 WL 6122734, at *849 (D.C. Cir. 2021).

Partial Economic Area (PEA),[7] approximating the siting of a terrestrial 12 GHz network operator's macro-cell base stations. As a result, the 5G model covers population centers in very rural areas, which results in a 12 GHz deployment that includes smaller cities and towns, as well as the largest and most populous cities in CONUS. The algorithm then adds 12 GHz small-cell infrastructure in areas of high traffic density.

The study also incorporates mobile UEs in the service area of the macro-cell base stations and small-cells. Nearly 1.5 million UEs are "dropped" in locations that are randomly selected in proportion to the population density within the base station cell area. The model also simulates beamforming of 5G macro cells to the UEs and accounts for the assumed omnidirectional nature of 5G small-cell base stations. Finally, the study adds wireless point-to-point links for backhaul to macro- or small-cells based on known requirements for wireless backhaul in the United States. Each of these types of infrastructure equipment transmits in the 12 GHz band and is, therefore, a potential source of interference to satellite terminals. In sum, RKF places nearly 2.1 million 5G devices, comprising 1,499,910 simultaneously active macro-cell UEs, 49,997 fixed macro-cell base stations, 89,970 fixed small-cell base stations, 6,999 point-to-point backhaul links, and 449,850 simultaneously active small-cell UEs, capturing the diverse ways a nationwide 5G network could utilize the 12 GHz band.[8]

Second, RKF adds NGSO user terminals into the geographic simulation database. As with the 5G network model, NGSO user terminals are algorithmically distributed throughout CONUS. Inputs regarding the number, location, and technical specifications of NGSO user terminals are informed by the FCC authorizations and the public plans for the Starlink NGSO constellation, the largest and most developed system in operation today. Starlink is currently authorized to operate 4,408 satellites in orbit with a primary operational altitude in the 540-570km range.[9] The Starlink constellation will operate globally in the Ku- and Ka- bands, including—in some countries—the 12 GHz band segment assigned to MVDDS and DBS in the United States.[10]

For both the terrestrial and NGSO services, the model includes all areas within CONUS, *i.e.*, 5G macro-cell base stations, small cells, and point-to-point backhaul links appear in the more populous "rural" areas, and NGSO user terminals appear in "urban" areas.[11]

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[7] The methodology resulted in significantly higher population coverage in most large PEAs since population density was the primary criterion.

[8] *See* May 2021 Study at 48, Table 4-1.

[9] *See Space Exploration Holdings, LLC Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization and Order on Reconsideration, 36 FCC Rcd 7995 (2021) ("*SpaceX Mod2 Order*").

[10] *Space Exploration Holdings, LLC Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, Memorandum Opinion, Order, and Authorization, 33 FCC Rcd 3391 (2018).

[11] *See infra* Section 2.2.

This study models a generous hypothetical future deployment of 2.5 million fixed NGSO end-user terminals throughout CONUS (versus an estimated 250,000 that are currently deployed around the world) that use 10.7-12.7 GHz satellite downlink spectrum to receive signals from the thousands of NGSO space stations in the Starlink satellite system.[12] Simulating the effects of 5G on 2.5 million Starlink terminals provides a statistically significant sample size to generalize the results, no matter the actual number of NGSO terminals actually deployed.[13] RKF also assumes, based on recent assertions from Starlink, that 45% of NGSO terminals would have a HAGL of 1.5m, and 55% would have a HAGL of 4.5m. NGSO users are weighted toward: (1) areas where Starlink has committed to offering service under the Rural Digital Opportunity Fund (RDOF) program; and (2) areas where the fixed-satellite service value proposition relative to existing fixed broadband infrastructure is likely to result in the highest degree of market penetration.

The 5G transmissions are assumed to operate in time-division-duplex (TDD) mode with all the base stations coordinated such that uplink and downlink transmissions are synchronized. For this reason, uplink and downlink simulations are considered separately. RKF's preliminary analyses found that exceedance events were almost entirely caused by the downlink transmissions, whereas uplink exceedances were only a small fraction (< 1%) of downlink exceedances; accordingly, only 5G downlink simulation results are presented.- In calculating the aggregate interference-to-noise ratio (I/N), this study's results account for all active 5G transmitters within 50km of a Starlink terminal. The downlink calculations include transmissions from macro-cell and small-cell base stations and point-to-point links.

Finally, with 5G and NGSO terminals incorporated into the computer model, RKF's simulations identify "exceedance events" in 12.2-12.7 GHz. As a general matter, an "exceedance event" occurs when a satellite terminal experiences an event that surpasses a nominal emission threshold. For NGSO systems, this study uses the ITU threshold of -8.5 dB I/N.[14] It is critical to note that such exceedance events would, of course, not occur in any satellite operations utilizing frequencies outside the 12.2-12.7 GHz band. NGSO downlink operations in the 10.7-12.2 GHz band, the Ka-band, and the V-band would be completely unaffected.

Critical to an understanding of this study is a recognition that exceedance does not necessarily imply harmful interference. An "exceedance event" is not equivalent to harmful

[12] *See, e.g.,* Elon Musk (@elonmusk), Twitter (Feb. 14, 2022, 4:54 PM); Rachael Zisk, *SpaceX Increases Launch and Starlink Prices*, PAYLOAD SPACE (Mar. 24, 2022), https://bit.ly/3KcfA5W.

[13] The number of ordinary-course (non-beta) commercial U.S. subscribers to Starlink's service remains low. *See, e.g.,* Karl Bode, *Elon Musk's Starlink Gets Even More Expensive*, TECHDIRT (Mar. 29, 2022), https://bit.ly/3L4EiGo. Although Starlink may never achieve a subscriber base of 2.5 million, this figure provides a generous upper limit for service uptake by other NGSO FSS providers.

[14] *See infra* Section 3.3 and accompanying discussion. Although some commentators have suggested an exceedance threshold of -12.2 dB, that value would not materially affect this study's findings.

interference.[15] It occurs when an incumbent terminal receives an emission that surpasses a nominal threshold established by governing bodies in radio engineering. As noted above, this study uses the ITU's exceedance threshold of -8.5 dB I/N for NGSO systems. Whether an exceedance of -8.5 dB I/N is harmful depends on the desired signal strength and fading. Exceedance events may not result in actual service disruption or degradation.

"Exceedance" is intended to capture the possibility of disruption and does not mean that "harmful interference" will occur. The Commission's rules define "harmful interference" as an emission, radiation, or induction that "*seriously degrades, obstructs or repeatedly interrupts* a radiocommunications service."[16] Exceedance is a far lesser threshold that provides the upper-bound probabilities of the risk of harmful interference. A terminal that experiences an exceedance event may not suffer serious degradation, obstruction, or repeated interruption in practice. Thus, while an exceedance event does not necessarily imply harmful interference, the absence of exceedance, by definition, means no harmful interference will occur.

Any exceedance event that might occur in the 12 GHz band would also affect no more than two of the up to eight available 250-megahertz Ku-band NGSO FSS channels. Even in the worst-case scenario where a 12 GHz exceedance event were to rise to a level of actual harmful interference on both channels in the 12.2-12.7 GHz portion of the NGSO FSS downlink band, an NGSO FSS user would not necessarily experience any service degradation so long as one or more of the other Ku-band downlink channels remain available.

Figure 1-1 shows the assumed channel plan for the simulation. The figure shows the eight Starlink 250-MHz channels from 10.7-12.7 GHz and 5G use of the 12 GHz band.[17] Each macro-cell sector is assumed to have access to five 100 MHz channels from 12.2 to 12.7 GHz. Macro cells that do not have fiber access are assumed to use 12 GHz point-to-point backhaul. In this simulation, the backhaul has access to the same spectrum as the macro-cell base station, modeling the possibility that macro-cell beamforming will allow the same spectrum to be used for backhaul, which is the worst-case scenario from an interference perspective. To match the TDD four-to-one downlink-to-uplink ratio, the macro-cell backhaul connection operating in frequency division duplex (FDD) mode allocates 400 MHz (from 12.2 to 12.6 GHz) to the downlink and 100 MHz (from 12.6 to 12.7 GHz) to the uplink. Small-cell links are modeled to use ten 25 MHz channels for a total of 250 MHz (from 12.20 to 12.45 GHz). This enables separate spectrum for point-to-point small-cell backhaul links (from 12.45 to 12.70 GHz). Small cells are assumed not to have the same level of dynamic beamforming flexibility that macro cells will have

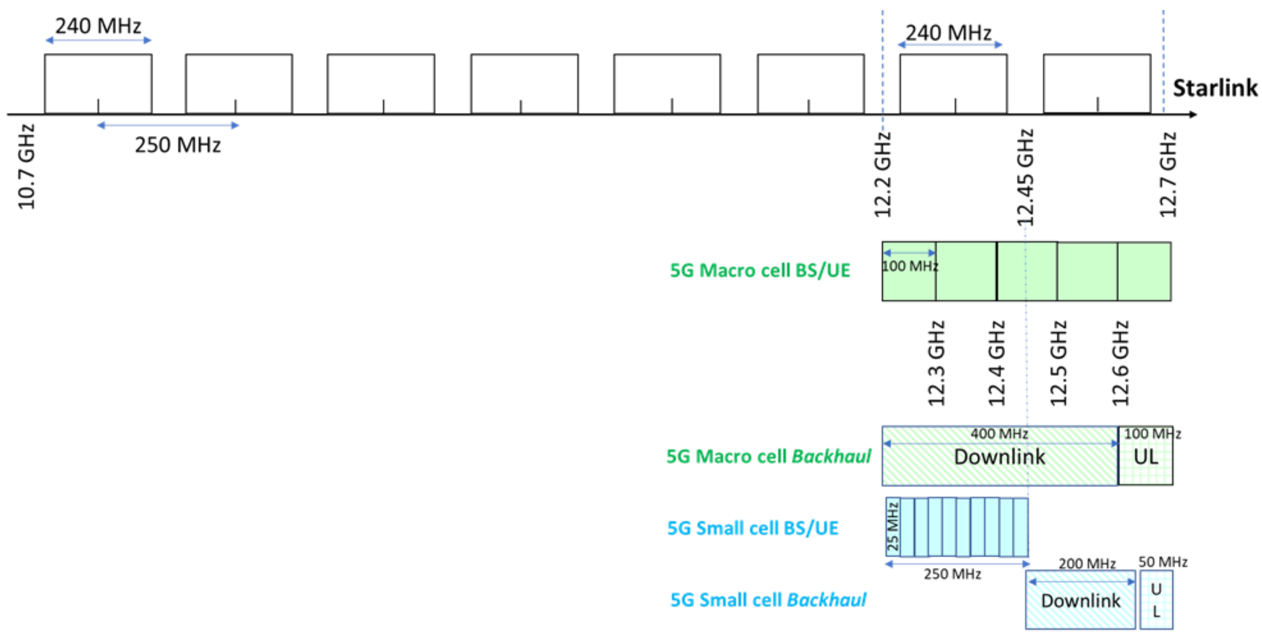
[15] *See, e.g.*, 47 C.F.R. § 2.1(c) (distinguishing between "Interference" and "Harmful Interference").

[16] *See* 47 C.F.R. §§ 2.1(c), 15.3(m) (emphasis added).

[17] Starlink is authorized for channels with an occupied bandwidth of 240 megahertz. For ease of reference, Starlink is described as having 250-megahertz channels because the eight channels occupy 2,000 megahertz of spectrum available for NGSO downlink use as depicted in Figure 1-1 (2000 MHz / 8 = 250 MHz).

and are therefore less likely to be able to operate with co-frequency backhaul. To match the TDD four-to-one downlink-to-uplink ratio, the small-cell backhaul connection allocates 200 MHz (from 12.45 to 12.65 GHz) to the downlink and 50 MHz (from 12.65 to 12.70 GHz) to the uplink.

Figure 1-1: 12 GHz Base Station/UE/Point-to-Point and Starlink (NGSO) Channel Plan



1.3. Summary of Results

The May 2021 Study's simulations found that only 0.89% of hypothetical Starlink terminals deployed over CONUS received emissions in excess of a nominal I/N value of -8.5 dB. Said another way, at least 99.11% of hypothetical Starlink terminals experienced no exceedance events.

This study strengthens RKF's level of confidence in the statistically negligible risk of harmful interference from 5G to NGSO. Taking into account current-day 5G operating parameters and interference-prone NGSO assumptions provided by Starlink, RKF's simulation finds that only 0.15% of Starlink terminals hypothetically deployed over CONUS experience an exceedance event in the 12.2-12.7 GHz portion of the NGSO downlink, affecting no more than two of the eight 250-megahertz Ku-band NGSO FSS channels. Thus, even if these rare exceedance events were somehow to rise to a level of harmful interference on both NGSO channels inside of the 12.2-12.7 GHz band, the NGSO system would still have up to six Ku-band downlink channels outside of the 12.2-12.7 band available to support the link, which would leave the user experience unaffected. In absolute terms, fewer than 4,000 NGSO terminals out of the hypothetical (and generous) future modeled base of 2.5 million experience any exceedance event in the simulation. **Put**

differently, at least 99.85% of Starlink terminals experience no harmful interference from 5G. Because not all exceedance events will cause harmful interference, this analysis yields an upper bound on the likelihood of harmful interference to NGSO terminals.

Several factors account for the highly favorable environment in the 12 GHz band for NGSO and 5G including the following:

- Large antenna discrimination resulting from NGSO antennas pointing with high elevation angle and the 5G base station downtilted;
- Interference mitigation achieved through 5G base station sidelobe suppression and antenna nulling toward the horizon; and
- Relatively localized 5G coverage due to the 12 GHz band's propagation characteristics.
- Complementary Ku-band use cases between 5G and NGSO due to market-driven geographic separation between terrestrial and satellite uses of the 12 GHz band;

2. The 5G Network

2.1. Overview

This study largely uses the same 5G network deployment and operation assumptions used in the May 2021 Study, with some improvements (shown in Table 2-1) to reflect more precisely commercially available technologies in network architecture that would be used in actual 12 GHz 5G deployments.

Table 2-1: Summary of Improvements to Assumptions between RKF's May 2021 Study and This Study

Parameter	May 2021 Study	April 2022 Study
Macro-Cell Horizon Nulling	No	Yes
Macro-Cell Base Station EIRP	75 dBm / 100 MHz	65 dBm / 100 MHz
Uplink-Downlink Duty Factor[18]	80% downlink 20% uplink	Simulations assume TDD operation of macro and small cells. Therefore, separate uplink

[18] TDD operation only applies to the macro cells and small cells. Point-to-point 5G backhaul links operate in FDD mode.

		and downlink simulations are performed. The TDD duty factor is not taken into account when calculating aggregate exceedance.
Small-Cell Base Station Peak Gain	15 dBi	18 dBi
Small-Cell Base Station EIRP	45 dBm / 100 MHz	48 dBm / 100 MHz
Small-Cell Antenna Pattern	ITU-R Rec. F.1336 *recommends* ¶ 2.2, average sidelobe pattern for stations with omnidirectional (in azimuth) antennas using the modifications in *recommends* ¶ 2.4 for operating with an electrical downtilt.	Omnidirectional azimuth and elevation pattern with nulling toward the horizon
Clutter Loss	UEs experience clutter loss when their heights are less than 1.5m HAGL.	Outdoor UEs (all at 1.5m HAGL) experience clutter loss. Indoor UEs experience clutter loss when their heights are less than 3m HAGL.[19] Small-cell base stations experience clutter loss from surrounding buildings.

2.2. Modeling the 5G Network

The 5G network deployment and operational assumptions in this study follow those used in the May 2021 Study, with a few improvements summarized above and in the subsections below. Rather than repeat the unchanged assumptions in their entirety, key elements of the May 2021 5G network model are summarized below:

[19] *See* Section 2.2.4.

- This study models 49,997 5G macro base stations throughout CONUS.[20] These are distributed in the most densely populated areas of each PEA, comprising at least 10% of the population of the PEA.[21]
- This study models an outdoor small-cell deployment. The number of small cells is assumed to be 89,970—approximately double the number of urban macro cells.[22]
- This study models 1,499,910 macro-cell simultaneously active UEs and 449,850 small-cell simultaneously active UEs within the coverage area of macro-cell and outdoor small-cell 12 GHz base stations.[23]
- This study models 6,999 wireless point-to-point backhaul connections for macro- and small-cell base stations.[24]
- This study assumes 5G backhaul is provided by fiber or in-band point-to-point microwave links. If sites do not use fiber, they are assumed to use *only* the 12 GHz band for backhaul. This study assumes 5G backhaul operates in FDD mode, and both uplink and downlink paths transmit continuously.[25]
- This study assumes that 5G base stations and UEs operate in TDD mode; therefore, NGSO terminals potentially receive interference from both 5G base stations and mobile terminal UEs. However, base station transmissions are assumed to be synchronized so that the interference into NGSO terminals either comes from base stations or from UEs, but not both at the same time.[26]

An algorithm used in both the May 2021 and the current study positions UEs in the 5G model randomly within the coverage area of each terrestrial base station.[27] The model then calculates the emissions from the macro-cell base station as it beamforms a transmission path toward each UE within the coverage area of that base station. Small-cell emissions are also calculated; these emissions are not beamformed to specific UEs, but are instead transmitted omnidirectionally with fixed downtilt and nulling. Next, the model performs two separate aggregate interference power calculations: (1) from all simultaneously active macro base station beams, all small cells on the downlink, and all point-to-point backhaul transmissions, which continually transmit in FDD mode in both directions; and (2) from all active UEs on the uplink and all point-to-point

[20] *See* May 2021 Study at 13.

[21] *Id*.

[22] *Id.* at 34.

[23] *Id.* at 37-38.

[24] *Id.* at 40.

[25] *See id.* at 38-40.

[26] *See id.* at 33.

[27] *Id.* at 13.

backhaul transmissions. The aggregate interference power is computed with respect to each of the NGSO terminals from all 5G emitters within 50 km, and the result is compared to the I/N threshold to determine the percent that exceeds the threshold. The objective of the simulation is to model a large, statistically significant number of interference paths to evaluate the total cumulative risk of interference to the NGSO terminals.

The interference power, *I*, from each 5G transmitter is computed consistent with Equation 1 below, which corresponds to the macro-cell base station, the small-cell base station, the backhaul station, or the UE:[28]

Equation 1:

$$I = Tx\ Power + G_{5G\text{-}to\text{-}Rx} + L_{PathLoss} + L_{BodyLoss} + L_{BuildingLoss} + L_{SpectralOverlap} + G_{Rx\text{-}to\text{-}5G}$$

where,

- I (dBW) = Interference power from the 5G transmitter (Tx) at the NGSO terminal
- *Tx Power* (dBW) = 5G Tx Power at the antenna input within the 5G Tx channel bandwidth
- $G_{5G\text{-}to\text{-}Rx}$ (dBi) = Gain of the 5G Tx antenna toward the NGSO terminal (Rx) based on the azimuth and elevation angles relative to the boresight direction
- $L_{PathLoss}$ (dB) = Propagation path loss including clutter loss from the 5G transmitter to the NGSO terminal[29]
- $L_{BodyLoss}$ (dB) = User equipment body loss (=4 dB), not applied for base stations and point-to-point transmissions
- $L_{BuildingLoss}$ (dB) = Building penetration loss applied only to indoor UEs[30]
- $L_{SpectralOverlap}$ (dB) = $10*\log_{10}$ (spectrum overlap between the 5G Tx channel and the NGSO terminal occupied channel / 5G Tx channel bandwidth)
- $G_{Rx\text{-}to\text{-}5G}$ (dBi) = Gain of the NGSO Rx antenna toward the 5G Tx based on the angle off boresight

Differences from the May 2021 Study include the macro-cell and small-cell base station antenna patterns used and the peak EIRP. In addition, end-point clutter loss is applied at the UEs with an HAGL of less than 3m and at small-cell base stations (typically deployed on poles in the vicinity of buildings). These updated assumptions are summarized in Table 2-1and discussed in the subsections below.

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[28] *Id.* at 13-14 (Equation 2-1).

[29] *Id.* at 44.

[30] *See id.* (applying Recommendation ITU-R P.2109-1, *Prediction of building entry loss*, ITU (Aug. 2019)).

2.2.1. 5G Macro-Cell Base Stations

This study models 5G macro-cell base stations in a way that is similar to the May 2021 Study, with several updates noted below to more accurately reflect the operating characteristics of 5G macro-cell base stations.

The list below summarizes several key assumptions that have not changed:

- Each 5G macro-cell base station is assumed to be made up of three (120-degree) sectors.[31] Each sector is assumed to operate with five 100 MHz channels.[32]

- The 5G macro-cell base stations use beamforming. Because the base stations generate narrow beams to each user, the simulation assumes four simultaneous active users per 100-MHz channel and further assumes that each UE has access to 100 MHz of spectrum. In the frequency plan set forth in Figure 1-1, there are five 100-MHz channels for macrocells. Thus, a "fully loaded" 12 GHz sector can serve a maximum of 20 UEs simultaneously. The base stations are assumed to be 50% loaded in the simulation.[33]

- The base station antenna has 256 elements with a peak gain of 27.7 dBi.[34] The antenna beamforms toward each UE but is constrained by the minimum antenna downtilt levels in Table 2-4 of the May 2021 Study.[35] These downtilts are designed so that the gain directed toward a UE at 1.5m HAGL at the edge of coverage of the cell is 10 dB below the peak gain. The resulting gain is sufficient to serve UEs at the edge of coverage.[36]

- Base station transmissions are assumed to be synchronized. Thus, at any given instant, either all base stations are transmitting, or all the UEs are transmitting.[37]

- Macro-cell base stations use a four-to-one downlink-to-uplink ratio for the TDD transmission times.[38] That ratio means that the point-to-point macro-cell backhaul connections operating in FDD mode need four times the downlink spectrum compared to the uplink spectrum. This configuration is shown in Figure 1-1.

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[31] *Id.* at 33.

[32] *Id.* at 37.

[33] *Id.* at 33.

[34] *Id.*

[35] *Id.* at 32.

[36] *Id.*

[37] *Id.* at 33.

[38] *Id.* at 49 n.77.

Despite the continued assumption that macro-cell base stations use a four-to-one downlink-to-uplink TDD ratio, the aggregate interference calculations in this study do not take into account the TDD duty factor. Rather, the aggregate interference calculations unrealistically assume 100% downlink and 100% uplink duty cycle factors. Excluding the TDD duty factor represents a change from the May 2021 Study. That change likely overstates the probability of an exceedance event compared to real-world 5G operations because simulated base stations, the dominant source of exceedances, are assumed to be performing downlink transmissions 100% of the time, rather than at a more realistic 80% downlink, 20% uplink duty factor.

This study also updates the May 2021 Study by incorporating horizon nulling into the performance of 5G macro-cell base stations. 5G antennas can null the gain pattern at the horizon at all azimuth angles to mitigate ground-based interference to NGSO terminals. This study finds that, at elevation angles between -3° to +1°, 5G base stations can attenuate the sidelobe gain specified in 3GPP 38.820 by 20 dB in all azimuthal directions.[39] RKF's feasibility analysis, which tested various locations of the macro-cell UE throughout the coverage area, confirms that 20 dB of sidelobe suppression would minimally degrade the base station's gain toward the UE—that is, sidelobe suppression would not impair the 5G base station's ability to transmit a signal to the UE.

Equipment manufacturers like Nokia, Ericsson, and Samsung will use advanced antenna systems, which support interference mitigation technologies, including nulling beams and antenna downtilts that focus the beam toward the coverage area and reduce the impact of sidelobe interference.[40]

This study also updates the 5G network model to incorporate macro-cell base stations that will transmit with an EIRP of 65 dBm per 100 MHz. Although the May 2021 Study used an EIRP of 75 dBm per 100 MHz, a lower transmit power is much more likely for a national deployment as RKF has determined that a maximum sector EIRP of 65 dBm per 100 MHz would support UEs at the Edge of Coverage (EOC) at the defined macro-cell sector radius. With separate beamforming to four UEs per channel, the EIRP to each UE is calculated to be 61 dBm per 100MHz. The typical macro-cell sector today uses an EIRP consistent with that value. Indeed, according to ITU-R Report M.2292-0, the maximum base station output EIRP per sector (with a single beam per sector) is 61 dBm.[41]

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[39] *See also* 3GPP TR 38.820 V16.0.0 (2020-06).

[40] *See* Letter from Jeffrey Marks, Vice President, Nokia, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (filed Sept. 21, 2021); Letter from Mark Racek, Sr. Director of Spectrum Policy, Ericsson, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (filed Sept. 13, 2021); Letter from Robert Kubik, Sr. Director, Samsung, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (filed Sept. 20, 2021).

[41] Report ITU-R M.2292-0, *Characteristics of terrestrial IMT-Advanced systems for frequency sharing/ interference analyses*, ITU at 10, 12 (Dec. 2013).

2.2.2. 5G Small Cells

This study updates the May 2021 Study by modeling horizon nulling and optimized beamforming in small-cell base stations. This study finds that it is possible to do so in a way that minimizes the impact on small-cell performance while reducing the incidental interference they might generate.

The effect of incorporating horizon nulling and optimized beamforming appears in Table 2-2, which shows changes to the small-cell base station's antenna pattern, antenna peak gain, and hence the EIRP. The new small-cell beamformed antenna has 3 dB more gain than the omnidirectional antenna used in the May 2021 Study (18 dBi vs. 15 dBi), which increased the EIRP by 3 dB accordingly. Each small-cell base station occupies a single sector with omnidirectional azimuth coverage.

This study uses an antenna pattern that produces a null toward the horizon with an EOC gain 5 dB below the peak gain. The overall 5G network model, however, imposes two constraints on the siting of the small-cell base stations: (1) maintaining a certain number of macro-cell and small-cell base stations in each PEA and (2) maintaining minimum Inter-Site Distance (ISD) between the base stations. Conditions did not always permit the satisfaction of both objectives. Where ISD constraints prevented the siting of the desired number of base stations in a given PEA, this study reduced the ISD values in increments of 50m. The incremental reduction in ISD values by 50m resulted in two new ISD tiers. The three tiers are shown in Table 2-2 below.

This study assumes that small-cell base stations use beamformed pattern antennas optimized for each ISD tier. Because small cells do not beamform toward individual UEs, each UE must be allocated its own spectrum. The simulation assumes that UEs in small cells are allocated 25MHz channels. Figure 1-1 shows that there are ten 25-MHz channels available in each small cell and that each channel does not overlap with spectrum used for small-cell backhaul. Again, the small-cell backhaul spectrum is split into four-to-one downlink-to-uplink consistent with the four-to-one TDD operation in the small cell. Only outdoor small-cell base stations are simulated.

As with the 5G macro-cell base stations, the study applies nulling to small cells, reducing sidelobes that might generate incidental interference. And indeed, a fixed array optimization could maintain performance within the coverage area while reducing the first and second sidelobes as much as possible and increasing the slope of the peak to the first sidelobe. This type of configuration results in at least 20 dB gain suppression within more than 4.6° elevation angle, starting from a few degrees outside the EOC.

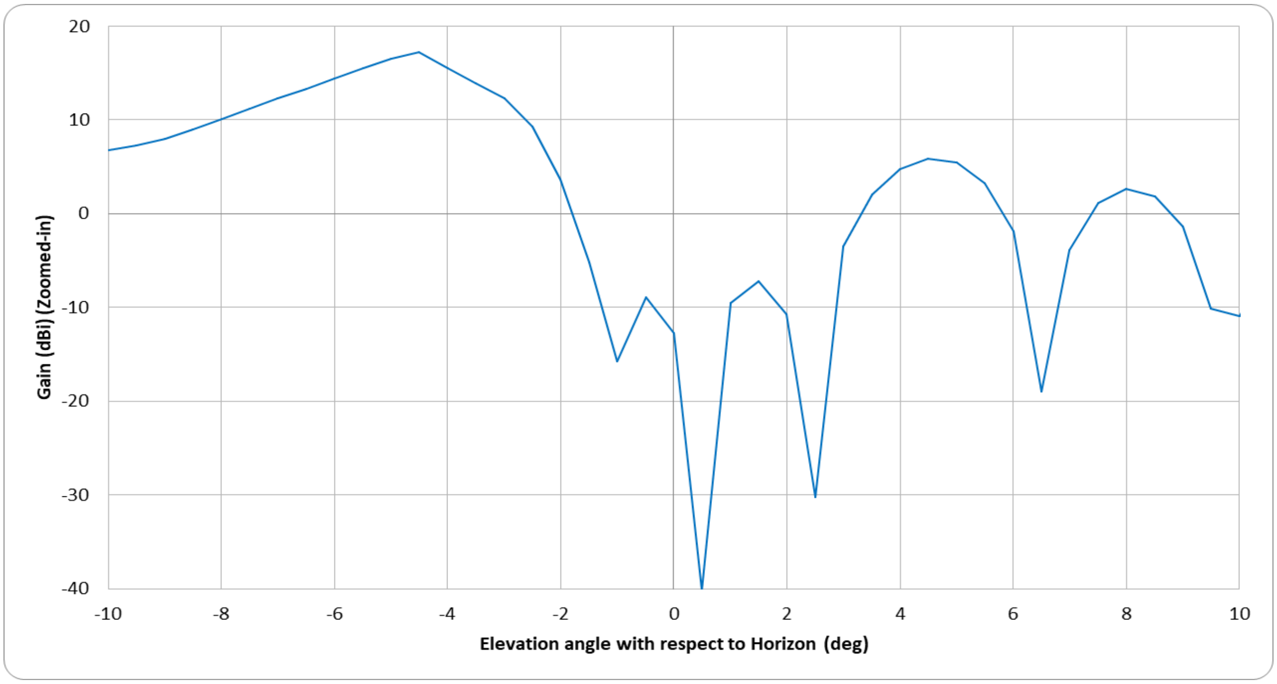
Table 2-2: 12 GHz Outdoor Small-Cell Base Station Operating Characteristics

Parameter	Value
Channel Plan and Bandwidth	Ten 25-MHz channels from 12.2-12.45 GHz
Height, AGL	6m (pole mount)
Antenna Pattern	Omnidirectional azimuth and elevation pattern with nulling toward the horizon
Antenna Peak Gain	18 dBi
EIRP	48 dBm / 100 MHz
ISD	150m (tier-1), 100m (tier-2), 50m (tier-3)
Downtilt[42]	5° (tier-1), 7° (tier-2), 11° (tier-3)

This study uses beam patterns for small cells that are optimized to the different tiers of small-cell spacing. Figure 2-1 depicts the antenna pattern for a small-cell antenna in the elevation plane for an ISD of 150m (which corresponds to an 86.6m cell radius). The large null at approximately 0° (that is, approximately 0° is toward the horizon) is placed at the optimal angle for each ISD tier such that the small cells would produce the least amount of power toward NGSO dishes. The elevation angles below -2.97° are within the coverage area for the 150m ISD, and with the peak at -4.5°, the UE at the edge of coverage will be 5 dB below the peak gain. This pattern achieves 20 dB suppression for elevation angles between -1.6° to 3°. For small-cell base stations with Tier-2 (100m) and Tier-3 (50m) ISDs, the designed beamformed patterns achieved 5 dB gain reduction at the edge of coverage and more than 20 dB suppression for elevation angles between -3.2° to 1.4° (for Tier-2) and -7.2° to 23.2° (for Tier-3).

[42] As a result of beam pattern optimization, downtilt angles varied slightly.

Figure 2-1: Small-Cell (150m ISD) Beamformed Antenna Pattern in the Elevation Plane



2.2.3. 5G Microwave Backhaul

As in the May 2021 Study, 5% of all base stations are assumed to use point-to-point in-band microwave backhaul.[43] Within each group, this study randomly assigns base stations that would hypothetically lack fiber access.

The backhaul links are designed to achieve higher throughput efficiency than the mobile links to ensure that the links can transport the full-cell capacity with an efficient amount of spectrum. The backhaul links operate in FDD rather than TDD mode; therefore, the backhaul links occupy separate uplink and downlink spectrum. The backhaul links are assumed to operate in FDD mode and use the spectrum simultaneously with the macro-cell base stations and UEs. Assuming that backhaul links operate in FDD mode results in overestimating the likelihood of exceedance because some reduction in base station spectrum or beam allocation might be needed to accommodate the backhaul in an actual deployment.

Table 2-3 shows the operating characteristics of the backhaul links. The "downlink" refers to the transmission from a base station with access to fiber to a base station with no access to fiber, and the "uplink" is defined as a transmission in the opposite direction. These parameters remain unchanged from the May 2021 Study.[44]

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[43] *See* May 2021 Study at 38-43.

[44] *See* May 2021 Study at 41 (Table 2-6).

Table 2-3: 12 GHz Point-to-Point Microwave Backhaul Link Operating Characteristics

Parameter	Value
Channel Plan and Bandwidth	Macro-cell downlink: 400 MHz (12.2-12.6 GHz) Macro-cell uplink: 100 MHz (12.6-12.7 GHz) Small-cell downlink: 200 MHz (12.45-12.65 GHz) Small-cell uplink: 50 MHz (12.65-12.7 GHz)
Tx/Rx Antenna Pattern	CommScope-HX6-13W[45]
Tx/Rx Antenna Diameter	1.8m (6 feet)
Tx/Rx Antenna Peak Gain	45 dBi
Tx/Rx Feeder Loss	0 dB
Rx Noise Figure	5 dB[46]
Duty Cycle	100% downlink and uplink

2.2.4. 5G User Equipment

As in the May 2021 Study, the UE antenna is assumed to have an isotropic gain of -3 dBi, a maximum conducted power of 23 dBm, and a body loss of 4 dB.[47] Each UE's EIRP is computed assuming open loop Transmit Power Control (TPC). The TPC parameters are set to typical parameters (P0=-90 dBm and alpha=0.8). The base station and UEs transmit with a downlink-to-uplink ratio of four-to-one. In other words, the base station transmits 80% of the time, and the UEs transmit 20% of the time. Again, this duty factor is not accounted for in the results; as noted above, disregarding the duty factor results in overestimating interference. Furthermore, 80% of the UEs are assigned as indoor and 20% as outdoor. Further details on UE parameters are available in the May 2021 Study.[48]

This study also updates the clutter loss assumptions for indoor UEs. The May 2021 Study assumed that indoor UEs with a HAGL less than 1.5m would experience clutter. The first floor of a building corresponds to a HAGL of approximately 3m, however. Because the model assumes that indoor UEs have a continuous height distribution, the May 2021 clutter loss assumption would have implied, unrealistically, that some UEs on the first floor of a building would not

[45] *See HX6-13W*, CommScope, https://bit.ly/33e49HE.

[46] *See* Recommendation ITU-R F.758-7, *System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference*, ITU, at Table 8 (Nov. 2019).

[47] *See* May 2021 Study at 38.

[48] *See id.* at 37.

experience clutter. This study updates this assumption to account for clutter loss when indoor UEs are between 1.5m and 3.0m HAGL. As in the May 2021 Study, this study assumes that outdoor UEs are at 1.5m HAGL and will experience clutter.

3. 5G and NGSO

3.1. Overview

To analyze the impacts of sharing between 5G terrestrial systems and NGSO operations in the 12 GHz band, RKF focuses on Starlink satellite terminals, which represent by far the largest planned deployment. RKF's Starlink user terminal deployment model is informed by the RDOF deployment areas Starlink has committed to serving and mirrors the deployment model that satellite operators and analysts anticipate will maximize the value proposition NGSO can offer consumers. RKF finds that at least 99.85% of Starlink terminals would experience no interference from 5G operations in 12.2-12.7 GHz.

RKF largely uses the same NGSO network deployment and operational assumptions as in its May 2021 Study, with three changes based on Starlink's subsequent comments, all of which increase the exceedance event probability. These changes are summarized in Table 3-1 and explained below.

Table 3-1: Summary of Changes to 5G-NGSO Assumptions

Parameter	May 2021 Study	April 2022 Study
Starlink Terminal Minimum Elevation Angle	Terminals prefer Starlink satellites with look angles of 55-85°	Terminals communicate with Starlink satellites with a high probability of low look angles according to the distribution Starlink provided (*see* Figure 3-1)
Starlink Terminal HAGL	80% 1.5m HAGL 20% 4.5m HAGL	45% 1.5m HAGL 55% 4.5m HAGL
Starlink Terminal Antenna Pattern	ITU-R Rec. S.1428[49]	ETSI Class B WBES

[49] Recommendation ITU-R S.1428-1, *Reference FSS earth-station radiation patterns for use in interference assessment involving non-GSO satellites in frequency bands between 10.7 GHz and 30 GHz*, ITU (Feb. 2001).

3.2. Modeling the NGSO Network

3.2.1. NGSO Terminal Elevation Angles

In this study, RKF assumes Starlink user terminals will more frequently employ a lower elevation angle closer to the minimum authorized angle of 25°, based on Starlink's comments in this proceeding.[50] By contrast, in the May 2021 Study, RKF simulated a hypothetical Starlink network consistent with then-authorized Starlink system parameters. In the May 2021 Study, RKF assumed the Starlink terminals would point at the satellite with the longest view time. This approach should produce a distribution of pointing directions at low elevation angles. However, even this methodology resulted in most of the elevation angles between 55° and 85°.

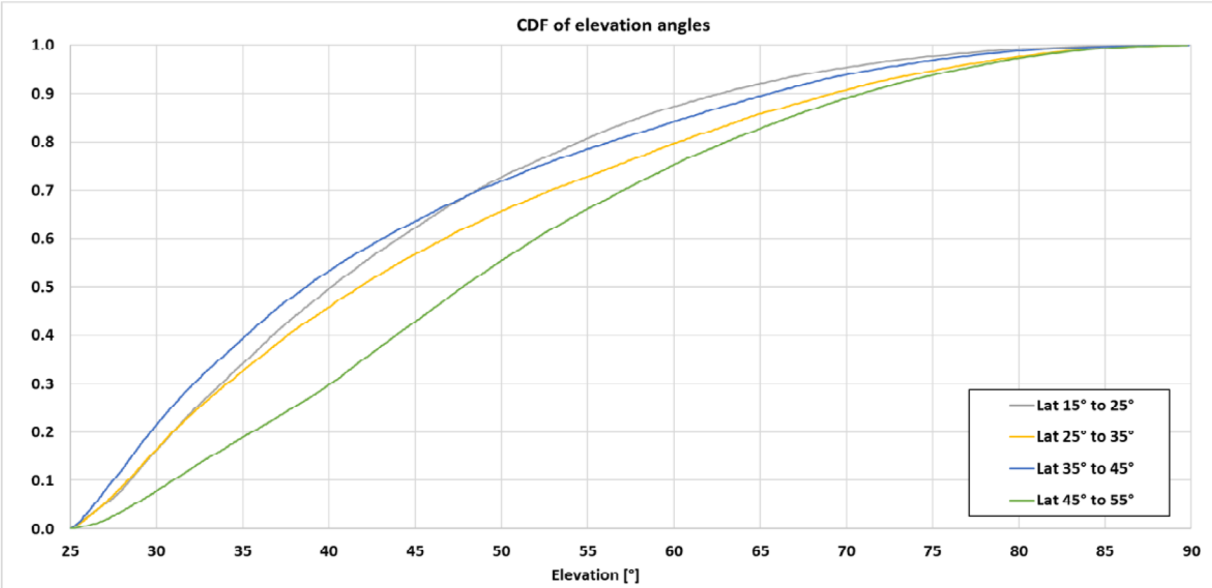
The performance requirements of large NGSO satellite constellations—particularly Starlink, which is obliged to satisfy RDOF speed benchmarks—require a user terminal operation that is typically limited to comparatively high elevation angles.[51] Lower elevation angles imply more obstructions, more latency, lower link margins, higher rain fade, lower data rates, or more power from the satellites and larger beam footprints. Despite the numerous limitations associated with operating at lower elevation angles, Starlink has insisted that its terminals will be deployed in this manner based on the chart it has presented to the Commission (*see* Figure 3-1 below).[52] When the full Starlink constellation is deployed and operational, it remains doubtful whether Starlink terminals would actually use lower elevation angles with any degree of frequency due to the meaningful performance and capacity constraints that those operations will entail for the Starlink system. Nevertheless, this study incorporates Starlink's claimed distribution of elevation angles into its updated analysis.

[50] *SpaceX Mod2 Order* at n.3.

[51] RKF previously explained why the use of higher elevation angles improves Starlink system capacity and increases the number of users that can be served simultaneously. *See* Letter from David Marshack, Managing Director and Chief Operating Officer, RKF Engineering Solutions, LLC, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443, at 6 (filed Aug. 9, 2021) ("Lower elevation angles also mean each SpaceX spot beam is covering a much larger area. To maintain an Nco value of 1 (*i.e.*, no overlapping co-frequency beams), a larger spot beam due to a sharper satellite-to-earth angle will result in lower system capacity.").

[52] SpaceX Reply Comments at 9. Interestingly, while RKF's model is based on Starlink's full 4,408 satellite Gen1 constellation, which is not fully launched, Starlink did not use the future tense when providing its "correction" to the elevation angle distribution used by RKF, and instead used the present tense. The cumulative distribution function chart that Starlink provided was preceded by the words, "In reality, however, the distribution of Starlink user terminal elevation angles *is* as follows:". *Id.* (emphasis added). This suggests that the elevation angle data is based on the operational constellation as it existed in the summer of 2021, for which the elevation angle distribution would be much more heavily weighted toward lower angles due to fewer satellites. Even so, RKF used the Starlink-provided elevation angle distribution.

Figure 3-1: Starlink's Claimed Distribution of Elevation Angles of Starlink Terminals[53]



3.2.2. NGSO Terminal Heights

The May 2021 Study assumed a distribution of NGSO terminals more heavily weighted toward ground installations—80% of Starlink terminals would have an HAGL at 1.5m, and 20% would have an HAGL of 4.5m. This study now assumes, in response to recent assertions, that 45% of Starlink terminals would be installed near ground level with an HAGL of 1.5m, and 55% of Starlink terminals would be installed on rooftops with an HAGL of 4.5m.

The May 2021 Study's assumptions are consistent with Starlink's blanket earth station license application, which used an HAGL of 0.0m.[54] Indeed, Starlink's default installation is a ground deployment, and the Starlink kit includes no mounting tools beyond a mounting tripod that "is designed for ground-level installation."[55] Any other type of deployment requires the purchase of additional equipment and, more likely than not, a professional installation to address the cabling

[53] RKF digitized the four curves manually, based on the CDF value (approximated to the nearest value with 2 decimal points) for every 5° from 25° to 90°.

[54] Application of SpaceX Services, Inc., IBFS File No. SES-LIC-20190211-00151, Form 312, Schedule B (filed Feb. 1, 2019); Application of SpaceX Services, Inc., IBFS File No. SES-MOD-20200731-00807 (withdrawn Feb. 6, 2022).

[55] *General FAQ*, Starlink, https://bit.ly/3tqYD12 (last visited Mar. 1, 2022) ("What comes in my Starlink kit? Your Starlink Kit includes everything you need to connect to the internet including your Starlink, WiFi router/power supply, cables, and base. The Starlink base is designed for ground level installation, or to support a quick start setup to test your internet connection. Many customers find that a permanent mount provides the best installation and service. Additional mounts and accessories are available for purchase on the Starlink Shop once your Starlink Kit is ready to ship.").

and building penetration issues associated with rooftop mounting.[56] As Starlink's CEO noted, the "[i]nstructions are simply: plug in socket, point at sky."[57]

Nevertheless, the company has claimed that "most current users install antennas as high as possible (typically rooftop)."[58] Although RKF finds these assertions to be unsupported and inconsistent with publicly available information about Starlink terminal deployment practices by consumers, RKF now assumes, out of an abundance of caution, that a majority (55%) of terminals will have a 4.5m HAGL consistent with rooftop installation.

3.2.3. NGSO Terminal Gain Patterns

This study assumes, again in response to recent assertions from Starlink, a maximum off-axis antenna gain pattern from an ETSI standard for user terminals.[59]

Equation 2: ETSI Standard for User Terminals

> For Class B WBES, the maximum antenna gain of each of the co-polarized components in any direction ϕ degrees from the antenna main beam axis shall not exceed the following limits:
>
> $G = 40 - 25 \log \phi$ dBi for $6° \le \phi < 48°$
>
> $G = -2$ dBi for $48° \le \phi \le 180°$

Although no party expressly claims that Starlink terminals perform at this standard, Starlink belatedly asserts that the ETSI values should have been used.[60] In the May 2021 Study, RKF relied on an off-axis gain pattern based on Recommendation ITU-R S.1428.

Using the ETSI formulas results in a larger assumed off-axis gain, which in turn makes Starlink terminals more prone to exceedance events. For the revised analysis, RKF implemented the ETSI

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[56] Starlink Pre-Order Agreement, Starlink, https://bit.ly/3isXZMf (last visited Jan. 30, 2022) ("If you require a permanent roof mount installation, you acknowledge the potential risks associated with this type of installation, including, without limitation, with respect to any warranty that applies to your roof or penetration of your roof membrane. Follow the Install Guide. If you cannot safely install the Starlink Kit, do not install it.").

[57] Elon Musk (@elonmusk), Twitter (Jan. 7, 2020, 9:06 AM), https://bit.ly/3Asv1SK.

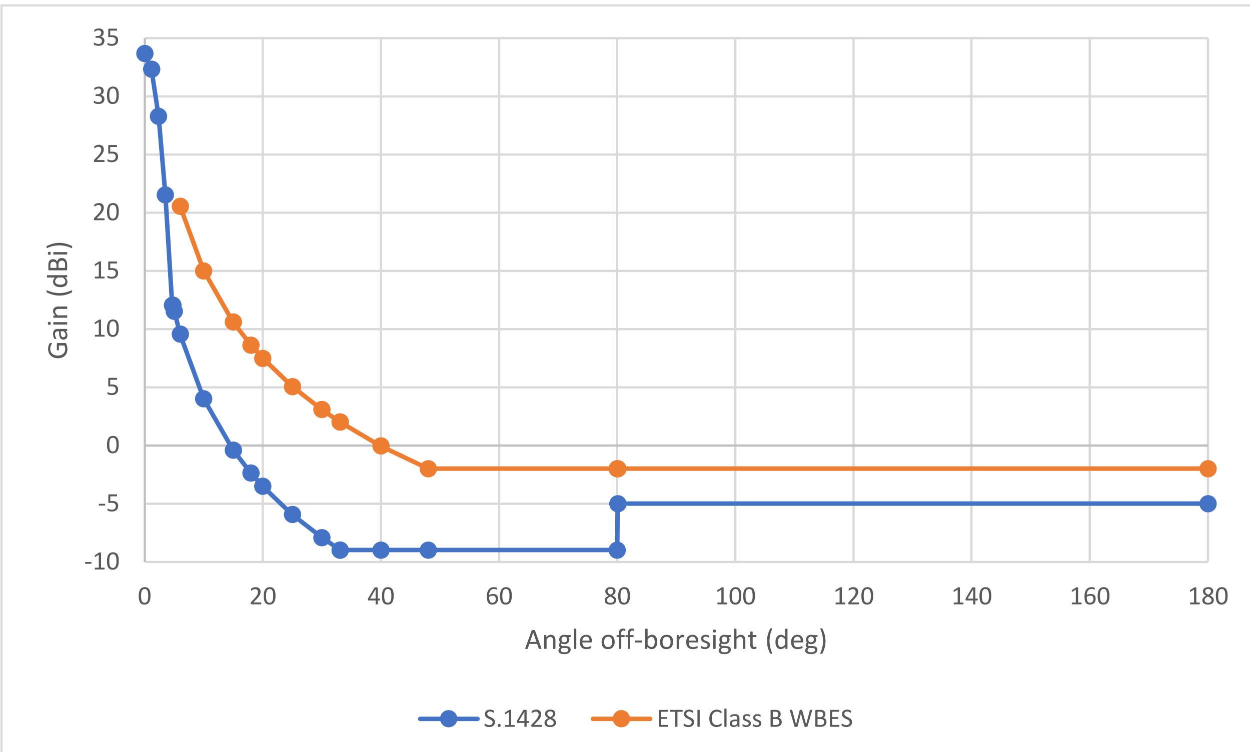
[58] Letter from Letter from David Goldman Director, Satellite Policy, Space Exploration Technologies Corp., to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443 and GN Docket No. 17-183, Attachment, at 8 (filed Aug. 2, 2021).

[59] ETSI, *Satellite Earth Stations and Systems (SES); Fixed and in-motion Wide Band Earth Stations communication with non-geostationary satellite systems (WBES) in the 11 GHz to 14 GHz frequency bands; Harmonised Standard for access to radio spectrum*, ETSI EN 303 981 V1.1.0, at 27 (2020-10).

[60] SpaceX Reply Comments at 10. RKF notes that Starlink still has not provided the actual antenna pattern for Starlink. Starlink could better advance the FCC's analysis by providing this information rather than industry reference parameters.

off-axis receive gain pattern described above for all Starlink terminals in the simulation. As Figure 3-2 shows, the revised ETSI pattern implies (1) an increase in gain of 11 dB between 6° and 33.1°; (2) the increase in gain dropping from 11 dB to 7 dB between 33.1° and 48°; (3) an increase in gain of 7 dB between 48° and 80°; and (4) an increase in gain of 3 dB for elevation angles greater than 80°.

Figure 3-2: Gain Patterns Using ETSI Class B Wideband Earth Station (WBES) Formula Versus S.1428



3.2.4. NGSO Interference Propagation Model

The propagation models for this study are largely the same as those used in the May 2021 Study. Rather than repeating that discussion in its entirety, a summary of the propagation model, along with adjustments made to the May 2021 Study, are discussed below.

Table 3-2 summarizes the propagation models used in calculating interference to NGSO terminals from the 12 GHz 5G network. The application of the models depends on the interference source, the cell-site morphology, and the length of the interference path.

Table 3-2: Summary of Propagation Models

Slant Range (12 GHz Transmitter to NGSO Terminal)	Morphology	Propagation Model
Up to 30m	Any	Free Space Path Loss FSPL[61]
30m to 1km	Urban/Suburban Macro-cell BS to UE or NGSO terminal	38.901 UMa
	Urban/Suburban Macro-cell UE to NGSO terminal	38.901 UMi
	Small-cell BS and UE	38.901 UMi
30m to 5km	Rural Macro-cell BS and UE	38.901 RMa
> 1km	Urban/Suburban Macro-cell BS and UE Small-cell BS and UE	ITM + Clutter at Tx + Clutter at Rx[62] Clutter at Tx or Rx: ● urban/suburban: P.2108 ● rural: P.452 village center clutter Clutter at Tx is applied when Tx is a UE with height < 3m, or a Small-Cell BS
> 5km	Rural Macro-cell BS and UE	

[61] Free Space Path Loss (dB) = 92.45 + 20*log10 (center frequency in GHz) + 20*log10 (Tx-Rx distance in km).

[62] Recommendation ITU-R P.2108-1, *Prediction of clutter loss*, ITU, Table 1 (Sept. 2021).

		Clutter at Rx is applied to the 1.5m-height Starlink terminals and not applied to 4.5m-height Starlink terminals

3.2.5. NGSO Terminal Quantity and Distribution

The large number of simulated NGSO terminals—2.5 million in total—implies that the study's results are statistically valid for any large number of NGSO user terminals. Put differently, although the absolute number of terminals that may experience an exceedance in the 12 GHz band would change if the actual number of terminals were higher or lower than the 2.5 million Starlink terminals this study examines, the percentage will not. The deployment distribution of 2.5 million Starlink terminals is summarized in Table 3-2.[63]

Table 3-3: Derivation of Number of Starlink Terminals over CONUS

Case	Percentage of Locations Served	Total Locations in RDOF	Total Assumed Starlink Terminals
Starlink RDOF Wins: Non-Metropolitan	60%	545,851	327,511
Starlink RDOF Wins: Metropolitan	15%	97,474	14,621
Other Bidder RDOF Wins: Non-Metropolitan	30%	4,334,999	1,300,500
Other Bidder RDOF Wins: Metropolitan	5%	243,885	12,194
Total within RDOF Funded Areas in CONUS			1,654,826
Total Spread in Non-RDOF Rural Areas in CONUS			845,174
Total within CONUS			2,500,000

[63] *See* May 2021 Study at 21. A full description of the model can be found in this study.

As described extensively in the May 2021 Study, this study continues to use the Census Bureau's definition of "urban" areas to weight satellite terminals to "rural" areas.[64] Modeling a rural-deployment weighting for Ku-band satellite user terminal sites is well supported by the operational characteristics of satellite systems. Elon Musk has explained that Starlink is not well suited to urban areas: "The challenge for anything that is space-based is that the size of the cell is gigantic … it's not good for high-density situations. We'll have some small number of customers in LA. But we can't do a lot of customers in LA because the bandwidth per cell is simply not high enough."[65] In May 2021, Musk tweeted that Starlink would "most likely" fulfill Starlink orders, but the company would face "[m]ore of a challenge when we get into the several million user range" and a "limitation" based on a "high density of users in urban areas."[66]

3.3. Results and Discussion

RKF's simulation finds that only 0.15% of Starlink terminals receive emissions in excess of a nominal I/N value of -8.5 dB. **Stated differently, at least 99.85% of Starlink terminals experience no interference in 12.2-12.7 GHz.** To put this probability of exceedance into context, of the 2.5 million Starlink terminals modeled, only 3,825 terminals would experience a 12 GHz exceedance in the simulation. And even this small number of 12 GHz exceedance events would affect no more than two of the up to eight available 250-megahertz Ku-band NGSO FSS channels. Thus, even in the unlikely, worst-case scenario where a 12 GHz exceedance event were to produce actual harmful interference on both channels in the 12.2-12.7 GHz portion of the NGSO FSS downlink band, an NGSO FSS user would not necessarily experience any service degradation so long as one or more of the other Ku-band downlink channels remained available.

RKF's analysis produces a cumulative distribution function (CDF) to assess the probability of potential interference to Starlink earth terminals from a robust national deployment of terrestrial 5G in the 12 GHz band, including base stations, small cells, backhaul, and user equipment. RKF is only presenting the results for the downlink simulation because the downlink simulation bounds the worst-case interference. The downlink simulation assumes that all Starlink terminals would receive downlink emissions from 5G base stations and that the 12 GHz FDD point-to-point links are continuously active. These results confirm the May 2021 Study's findings: 5G terrestrial broadband operations do not cause harmful interference to Starlink operations. Once the 5G deployment model is better aligned with real-world 5G base station

[64] *See* May 2021 Study at 8-9.

[65] Jon Brodkin, *Elon Musk: Starlink latency will be good enough for competitive gaming*, ARS TECHNICA (Mar. 10, 2020), https://bit.ly/3dUrbbu; *see also* Sascha Segan, *Who Needs Starlink Internet? These Rural US Counties Top the List*, PC MAGAZINE (Mar. 31, 2021), https://bit.ly/3a5z9gW; *see also* Anshu Goel, *Intelligence Brief: Is direct-to-consumer satellite broadband now viable?*, MOBILE WORLD LIVE (Mar. 10, 2021), https://bit.ly/3dVmTke ("Given the current prices for satellite broadband, it looks likely consumer uptake will probably be highest amongst rural households in developed countries.").

[66] Elon Musk (@elonmusk), Twitter (May 4, 2021, 5:22 PM), https://bit.ly/34pNd52.

power levels and incorporates current-generation 5G horizon-nulling technologies, even with Starlink's weighted distribution of terminals with lower elevation angles, higher off-axis antenna gain, and other conservative assumptions, there is no significant probability of exceedance.

To measure exceedance, this study compares aggregate interference against an I/N of -8.5 dB, which is the ITU's criteria for potential interference between FSS earth stations and FS operations.[67] This criterion was chosen because it is the most recent standard for terrestrial interference into FSS earth stations. Although some commentators have suggested an exceedance threshold of -12.2 dB I/N,[68] that value would not materially affect this study's findings: A -12.2 dB I/N increases the noise level by 0.3 dB relative to -8.5 dB I/N, and therefore only marginally increases the percentage of additional Starlink terminal exceedances.

Figure 3-3 shows the individual I/N statistics generated using the assumptions in this report resulting from the 49,997 fixed macro-cell base stations (gray curve), 89,970 fixed small-cell base stations (yellow), 6,999 point-to-point backhaul links (orange), and the combined 5G transmissions (blue). The figure shows the y-axis in log-scale to make visible the points above the -8.5 dB I/N threshold. Note that due to the dominance of total interference by the macro-cell base stations, the gray curve (from macro-cell base stations) is under the blue curve (from total 5G interferers).

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[67] Recommendation ITU-R SF.1006, *Determination of the Interference Potential Between Earth Stations of the Fixed-Satellite Service and Stations in the Fixed Service*, ITU, Table 1 (Apr. 1993).

[68] *See* Letter from David Goldman, Director of Satellite Policy, Space Exploration Technologies Corp., to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443 and GN Docket No. 17-183, at 6 (filed Feb. 3, 2022) ("Feb. 3, 2022 SpaceX Letter).

Figure 3-3: Probability of Aggregate I/N Due to Macro-Cell BS, Small-Cell BS, Point-To-Point Links and the Combined 5G Transmissions Exceeding X-Axis Value at Starlink Terminal Locations over CONUS

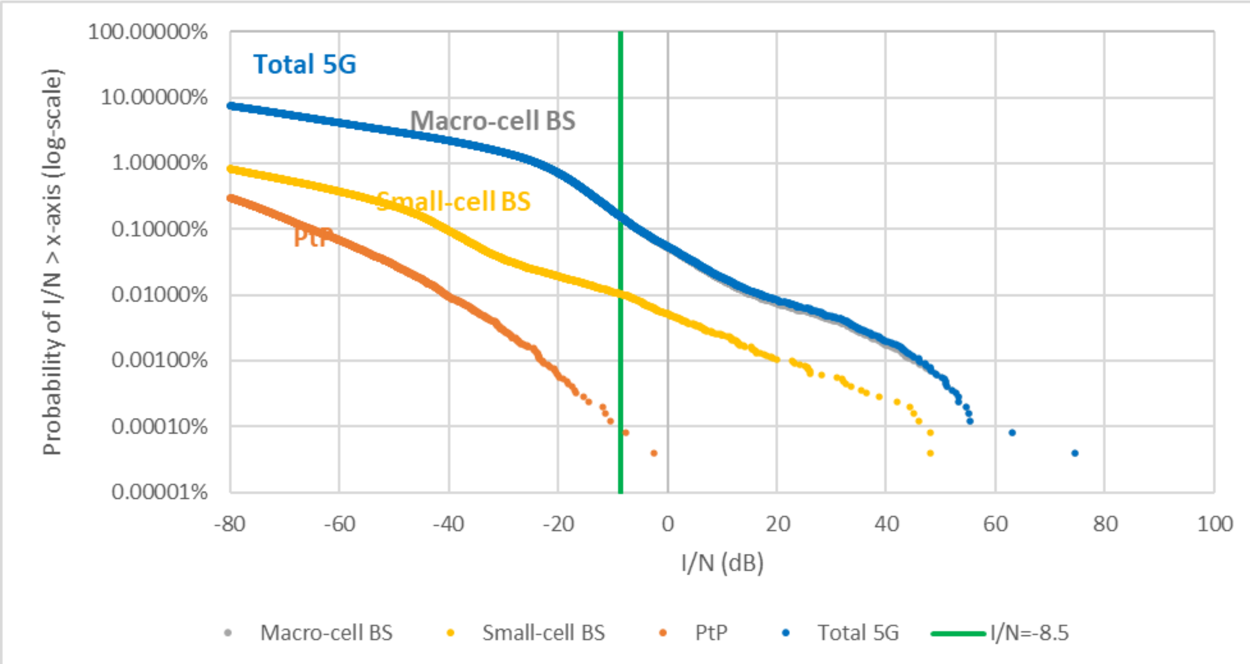

Table 3-4 shows the exceedance probabilities from each of the curves in Figure 3-3.[69] As indicated, the transmissions from 49,997 macro-cell base stations over CONUS result in 0.152% of all 2.5 million Starlink terminals having an aggregate I/N greater than -8.5 dB. Similarly, the transmissions from 89,970 small-cell base stations over CONUS results in 0.010% of all the Starlink terminals having an I/N exceeding -8.5 dB. Finally, the transmissions from 6,999 point-to-point backhaul links result in 0.00008% of all the Starlink terminals having an exceedance. Considering the aggregate I/N statistics from all the 5G macro- and small-cell base station transmissions as well as the point-to-point links, -8.5 dB I/N exceedance occurs for 0.153% of Starlink terminals.

[69] Note that the total exceedance probabilities in the table are not equal to the sum of individual exceedance probabilities because the total statistics includes Starlink terminals experiencing exceedances from more than one 5G transmitter type.

Table 3-4: I/N Exceedance Probabilities from Each Category of 5G Downlink Transmitter and the Total

Exceedance Source	% of Starlink Terminals
Macro-Cell Base Station 65 dBm/100 MHz EIRP (DL) or UE (UL)	0.152%
Small-Cell Base Stations	0.010%
Point-to-Point Microwave Backhaul	0.00008%
Total	0.153%[70]

If anything, the finding that 0.15% of NGSO terminals could experience an exceedance of -8.5 dB I/N overstates the interference potential of 5G networks. RKF's study errs toward overestimating exceedances in ways that would not be likely to materialize in the real world. For example, this study assumes that the Starlink terminals use lower elevation angles and a greater proportion of rooftop installations than seems likely.

Additionally, for the small percentage of terminals that may experience exceedances, the degradation will generally be a reduction in the link margin that will have no or only a very small impact on their throughput if they point toward satellites with high elevation angles.

Starlink also has other user downlink spectrum available to support its hypothetical future customers, including the 10.7-11.7 GHz band. These issues are discussed below.

3.3.1. Fixed Service Operations (10.7-11.7 GHz)

Some responses to the May 2021 Study argued that FS operations in the 10.7-11.7 GHz band meant that NGSO operators had limited ability to use that band for user downlinks.[71] RKF previously addressed those concerns in a detailed analysis of the NGSO-FS environment in the 10.7-11.7 GHz band.[72] RKF developed a robust model of FS operations in the 10.7-11.7 GHz band

[70] This figure is computed for the 2.5 million Starlink terminals that were subject to 5G base station downlink transmissions, by adding the I/N from the individual 5G sources (*i.e.*, macro- and small-cell base stations and point-to-point backhaul) linearly, then taking the 10*log10 of the total to convert to dB, and finally computing the percentage of those Starlink terminals that had total I/N greater than -8.5 dB. The same methodology was used to calculate the values for each type of exceedance source (i.e., 0.152%, 0.010%, and 0.00008%).

[71] *See* Reply Comments of OneWeb, WT Docket No. 20-443 and GN Docket No. 17-183, at 8 (filed July 7, 2021) ("[The 10.7-11.7 GHz band] is likely to be limited to satellite user terminals located on board aircraft, ships at sea, and in lesser-developed countries where there are significantly fewer terrestrial stations.").

[72] *See* Letter from David Marshack, Managing Director and Chief Operating Officer, RKF Engineering Solutions, LLC, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443 (filed Dec. 9, 2021). Starlink replied to RKF in a heated submission that not only questioned RKF's engineering credentials, but also alleged misrepresentation and lack of

to assess claims about the Starlink system, extracting and assembling data for each of the roughly 162,000 frequency transmit paths from the FCC's ULS database, including each transmitter's precise latitude/longitude coordinates, maximum EIRP, and antenna height above ground level. RKF assumed the same Starlink performance characteristics as those used in this study. RKF found that 3% of Starlink terminals may be affected by FS frequency transmit paths in the 10.7-11.7 GHz band, and such an attenuated effect represents a situation that good-faith coordination can resolve.[73]

These points carry two implications for this study. First, the small effect of FS operations in the 10.7-11.7 GHz band for co-frequency NGSO operations confirms that NGSO operators can reliably use downlink channels outside the 12 GHz band to mitigate the effects of a 5G exceedance. Second, however small FS interference might be for NGSO operators in the 10.7-11.7 GHz band (3%), the incremental effects of 5G are much smaller.

3.3.2. Radio Astronomy Service (10.6-10.7 GHz)

Some NGSO licensees claimed a limited ability to use the lower channels of the 10.7-11.7 GHz band due to RAS operations in the 10.6-10.7 GHz band.[74] But they have never said the band is unusable.[75] In fact, Starlink sought and received an authorization to use that band[76] and represented to the FCC that it could use the spectrum for user downlinks, as recently as October 2020.[77] And while Starlink *suggests* it cannot use the 10.7-10.95 GHz channel based on a European Conference of Postal and Telecommunications Administrations (CEPT) report, Starlink never actually says it has committed not to transmit on those bands and retains its authorizations for use.[78] Instead, Starlink hides behind CEPT's pronouncement and downplays

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candor. *See* Letter from David Goldman, Director Satellite Policy, Space Technologies Exploration Corp., to Marlene H. Dortch, Secretary, FCC, WT Docket No. 20-443 (Feb. 3, 2022). RKF categorically rejects Starlink's claims as empty rhetoric that has no place in this proceeding. Rather than match Starlink's baseless and inflammatory allegations, RKF will focus on the facts, such as they are, that Starlink has submitted on the record.

[73] *Id.* at 8.

[74] SpaceX Reply Comments at 10, 20.

[75] *Cf.* Matt Daneman, *LEO Boom Increasingly Concerns Radio Astronomy*, COMMUNICATIONS DAILY (June 17, 2021), https://bit.ly/3fuYT9g ("[OneWeb] will protect the radioastronomy sites in 10.6-10.7 GHz primary allocation by not transmitting in the adjacent frequency channel when a OneWeb satellite *is in the visibility* of the radioastronomy receiver.") (emphasis added).

[76] *See supra* note 54.

[77] Short-form Application of Space Exploration Technologies Corp., ULS File No. 0009149922, Spectrum Access Attachment at 2 (filed Oct. 23, 2020) ("The following chart details the link, transmission direction, and frequency ranges that SpaceX will use for supported services . . . User Downlink Satellite-to-User Terminal . . . 10.7 – 12.7 GHz[.]").

[78] *See* Feb. 3, 2022 Starlink Letter at 2-4 (citing ECC Report 271, *Compatibility and sharing studies related to NGSO satellite systems operating in the FSS bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space)*, CEPT Electronic Communications Committee (updated Apr. 23, 2021) ("ECC Report 271")).

the possibility of any sharing solution that could allow for NGSO FSS operations at 10.7-10.95 across much of the globe. Indeed, Starlink has acknowledged that it "continues to work with the RAS community to optimize spectrum sharing strategies."[79]

[79] *Compare id.* at 4 ("[T]he CEPT report's rigorous analysis confirms that the lowest 250 MHz of the 10 GHz band are essentially unusable for NGSO operations.") *with* ECC Report 271 at 24 ("These unwanted emission e.i.r.p. levels can be met by the NGSO FSS constellation through a careful design of the satellite payload using appropriate modulation shaping, IF and RF filtering, constraints on the SSPA design.").

4. Conclusion

This study reports the results of a nationwide Monte Carlo analysis modeling the interaction of:

- A robust terrestrial 5G network deployment consisting of nearly 50,000 macro-cell base stations, nearly 90,000 small-cell base stations, nearly 2 million simultaneously active mobile devices, and almost 7,000 point-to-point backhaul links across CONUS; and
- 2.5 million Starlink terminals that operate according to the reference parameters that were disclosed in filings to the Commission and, where applicable, have been adjusted to accommodate more conservative assumptions that Starlink has provided during the course of this proceeding.

RKF then simulated the interaction among this large population, set of services, equipment, and devices to assess the likely real-world effects of 5G deployments on NGSO terminals on an aggregated, nationwide basis. RKF examined how each of the 2.5 million Starlink terminals respond to the presence of a robust 5G deployment that RKF simulated using siting algorithms carefully attuned to the design considerations terrestrial network operators would use in optimizing a 12 GHz network.

RKF's simulations find that 99.85% of Starlink terminals deployed over CONUS experience no exceedance events from 5G operations at 12 GHz and thus have no possibility of experiencing harmful interference from 5G. That is, only 0.15% of Starlink terminals deployed over CONUS experience an exceedance event. And even users of the 0.15% of Starlink terminals that experience an exceedance event in the 12.2-12.7 GHz band would not experience a service disruption unless the exceedance event rose to a level of actual interference *and* all other 250-megahertz Ku-band NGSO FSS channels were simultaneously unavailable.

The exceedance values that RKF calculated do not necessarily result in service disruption or degradation of NGSO terminals. Exceedance thresholds are heuristics that are intended to capture the possibility that some percentage of subscribers might be affected. That an NGSO subscriber experiences exceedance at a particular moment in time does not mean the subscriber will suffer "harmful interference" as the Commission defines that term, much less that a consumer would experience any service interruption or degradation. Rather, the exceedance probabilities in this study represent an upper bound on the likelihood of potentially harmful interference.

Several qualitative factors account for the highly favorable environment in the 12 GHz band:

- NGSO satellite constellations that are designed to provide mass-market broadband internet access often include thousands of satellites; therefore, user terminal operation is typically limited to comparatively high elevation angles.

- 5G base stations utilize horizon nulling, advanced beamforming, and antenna downtilt to avoid self-interference, which also further limits the risk of interference to NGSO user terminals. Using these technologies, 5G macro-cell base stations can focus their radiated energy on the UEs being served, instead of NGSO terminals.
- Propagation distances at 12 GHz are limited compared to lower frequency bands, which in turn limits the likelihood that 5G transmissions will interfere with NGSO terminals.
- The primary markets for NGSO user terminals are in less densely populated areas, whereas terrestrial 12 GHz systems will be primarily deployed in areas of greater population density.