Bringing 5G to the 12 GHz Band

Accelerating Next-Generation Broadband Deployment with 500 MHz of Mid-Band Spectrum at 12.2-12.7 GHz

WT Docket No. 20-443

May 27, 2022

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Overview

- **Co-Primary Allocation.** In the 12 GHz band, the 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.
- **2021 RKF Study With Standard Reference Parameters.** In May 2021, 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.
- **2021 RKF Study: Coexistence Readily Feasible.** 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.
- **2022 RKF Study With NGSO-Preferred Parameters.** In May 2022, RKF refined its 5G-NGSO analysis to reflect feedback from the record and incorporate additional observations about advances in real-world deployment conditions.

2022 Results: Coexistence *More* Readily Feasible

- RKF's simulation finds that **at least 99.85% of Starlink terminals would experience no interference in 12.2-12.7 GHz.**
- Of the 2.5 million Starlink terminals modeled, only 3,825 terminals would experience a 12 GHz exceedance in the simulation.
- 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.
- And even if 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.

Why Such a Limited Effect?

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 toward the horizon.

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 different primary use-cases—12 GHz 5G services will be deployed most heavily in more densely populated areas, while satellite services will be most useful in lower population density areas.

How the Model Works

Objective

The objective of the "Monte Carlo" simulation is to model a large, statistically significant number of interference paths to evaluate the total cumulative risk of interference to the NGSO terminals.

Position.

An algorithm used in both the May 2021 and the current 2022 study to position 5G infrastructure and 5G UEs within a targeted 5G coverage area and to position Starlink UTs across areas with a variety of population densities.

Simulate.

The model then simulates 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.

Calculate.

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 backhaul transmissions.

Compute.

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 percentage that exceeds the threshold.

Updates Made Since May 2021

- Changes to address claims by Starlink
  - Lower elevation angles
  - ETSI antenna pattern for Starlink antenna
  - Majority of Starlink antennas on rooftops
- Changes to address 5G deployment realities and capabilities
  - 65 dBm/100 MHz EIRP
  - Horizon nulling to reduce interference from macro-cells
- Other significant assumptions were unchanged

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

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

RFK's 2022 results are even more promising than the 2021 results:

No impact to *at least* 99.85% of NGSO terminals

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Methodology: Baseline Model

Statistically significant Monte Carlo simulation throughout CONUS

- 50,000 fixed macro-cells
- 90,000 fixed small cells
- 2 million simultaneously active UEs
- 7,000 point-to-point backhaul links
- 2.5 million NGSO user terminals
- 11.7 billion calculations

5G coverage area based on 2010 Census tract population density (unchanged)

- All tracts with >7500 POPs/sq mi are included in 5G coverage area
- In PEAs with less than 10% POPs coverage, add the densest uncovered tracts to the 5G coverage area until each PEA has ~10% POPs covered
- Macro-cells and small cells are placed within the 5G coverage area in accordance with morphology-specific inter-site distances (ISDs)
- Macro-cell and small cell UEs are "dropped" in locations that are randomly selected in proportion to the population density within the base station cell area

2.5 million NGSO terminals are sited as described in the May 2021 report (unchanged)

- *Except*, 55% of terminals are assumed to be on rooftops at 4.5 meters AGL (vs. 20% in May 2021)
- 45% are assumed to be mounted at 1.5 meters AGL

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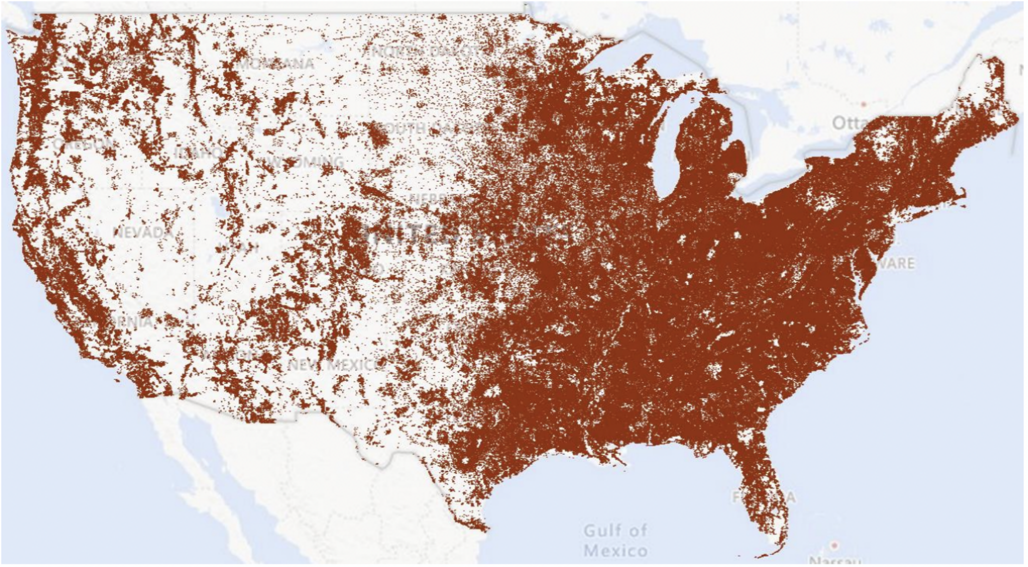
Methodology: NGSO Terminal Distribution

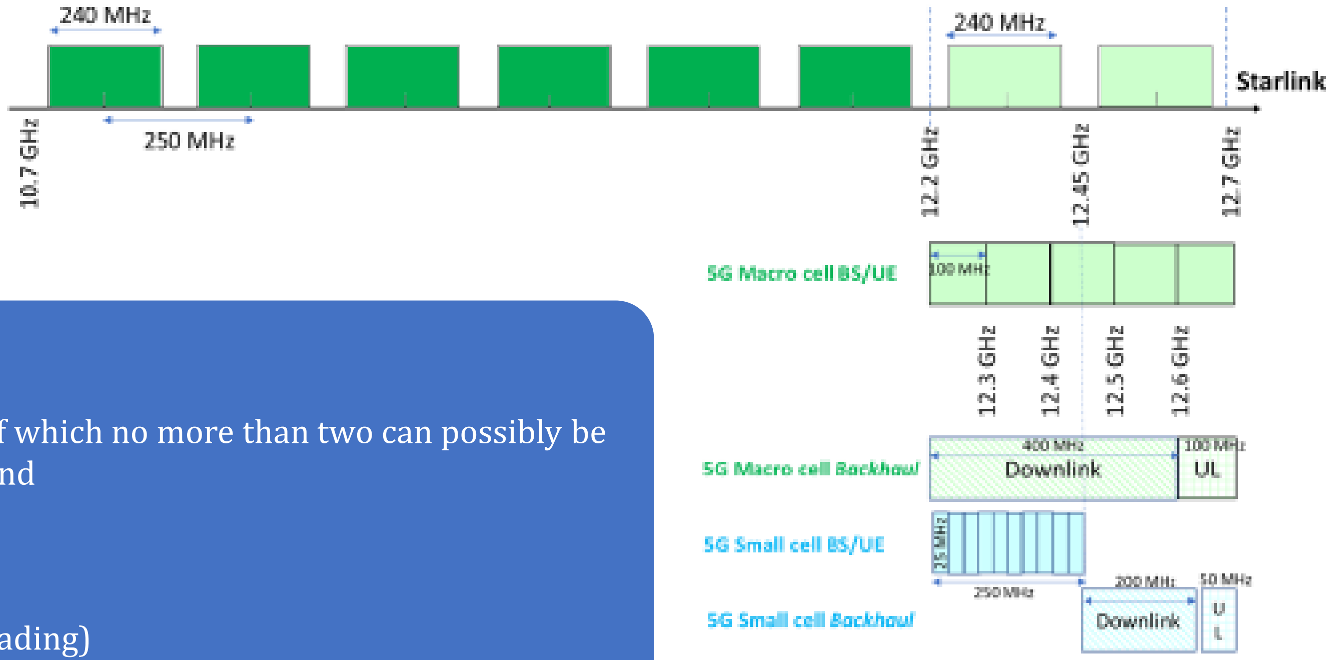
Although the absolute number of terminals that may experience an exceedance in the 12 GHz band would change if the actual number of terminals were lower than the 2.5 million Starlink terminals this study examines, the percentage would not.

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



Methodology: Operations and Channels

- 5G base station transmissions are assumed to operate in time-division-duplex (TDD) mode
  - All base stations are coordinated such that uplink and downlink transmissions are synchronized
  - Therefore, uplink and downlink simulations are considered separately
  - Exceedance events caused primarily by downlink transmissions

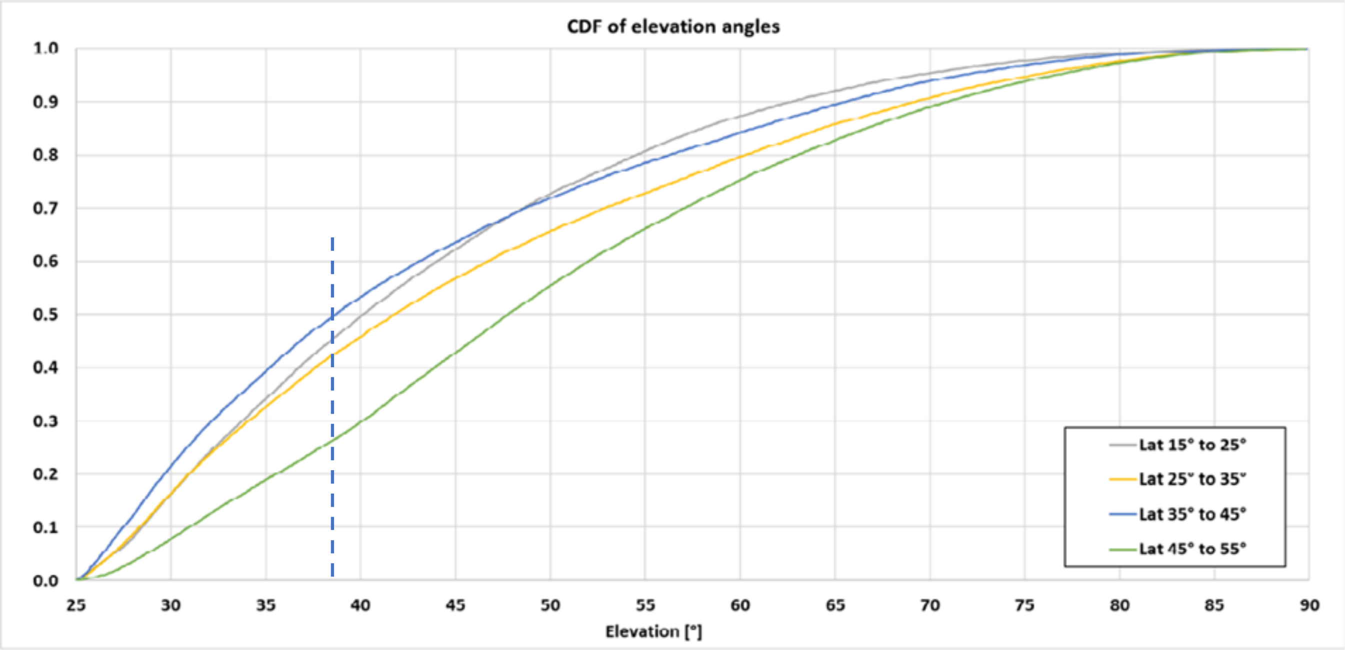


- Channel layout of NGSO and 5G is as shown
  - NGSO has *eight* downlink channels to choose from, of which no more than two can possibly be affected by the introduction of 5G into the 12 GHz band
  - Five 100 MHz 5G channels
  - Four beams per sector, three sectors per site
  - 20 UEs per sector, ten simultaneously active (50% loading)
  - Integrated Access and Backhaul for macro-cells assumed to be without fiber
  - Split frequency access and backhaul at small cells without fiber
  - Point-to-point links are FDD and always transmitting in both directions

Methodology: Elevation Angle Distribution

Elevation angle of NGSO terminals follows the distribution provided by Starlink in July 2021

- Ex.: For Starlink terminals between latitudes 35°N (e.g., Memphis, Albuquerque) and 45°N (Minneapolis, Vermont-Quebec border), the elevation angle will be below ~38° *fifty percent* of the time



Starlink has declined to reveal the source of the "actual" distribution shown above

- It likely does not represent elevation angles for the fully mature 4,408 satellite constellation, which is what RKF is simulating
- Since the only part of CONUS that is below 25°N latitude is the Florida Keys, the data may also not be representative of elevation angles in CONUS

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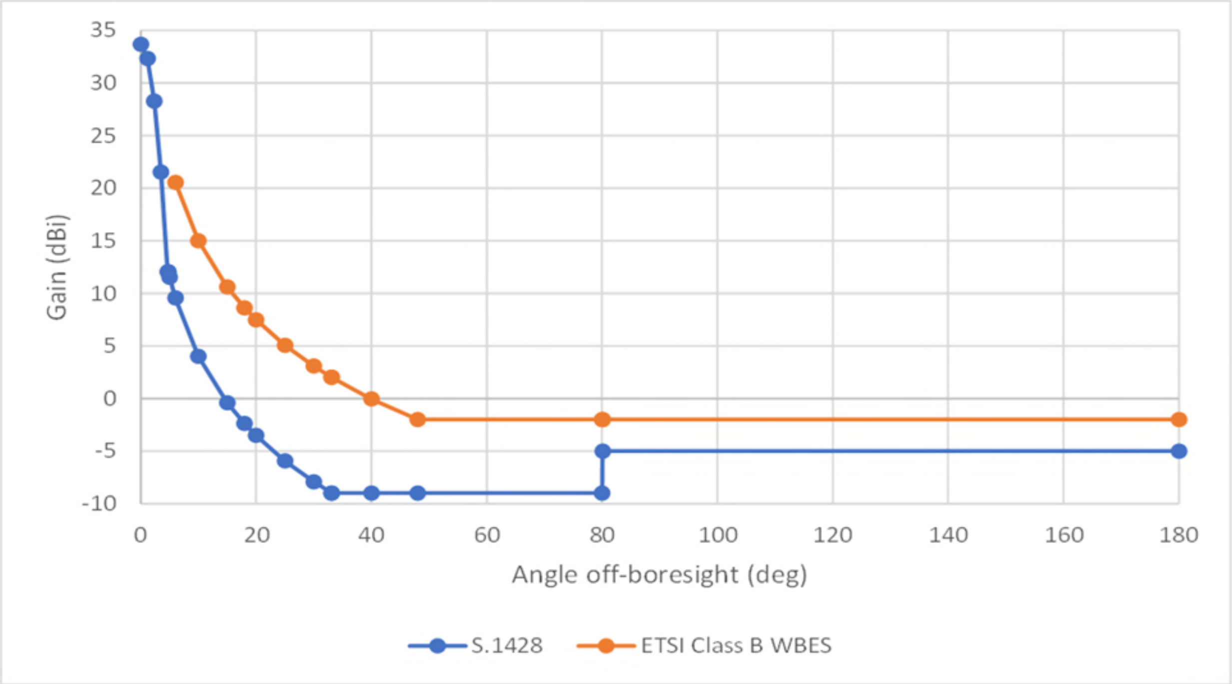
Methodology: Antenna Pattern

- The Starlink antenna was modeled using the ETSI Class B Wideband Earth Station mask
  - Starlink provided this mask after RKF's initial study.
  - Starlink has declined to provide its actual antenna mask.
  - Using an actual pattern would yield more accurate—and very likely more favorable results—than using industry reference parameters.
  - The ETSI pattern gives 3 to 11 dB more gain at off-axis elevation above 25° than the S.1428 mask used in the 2021 RKF study



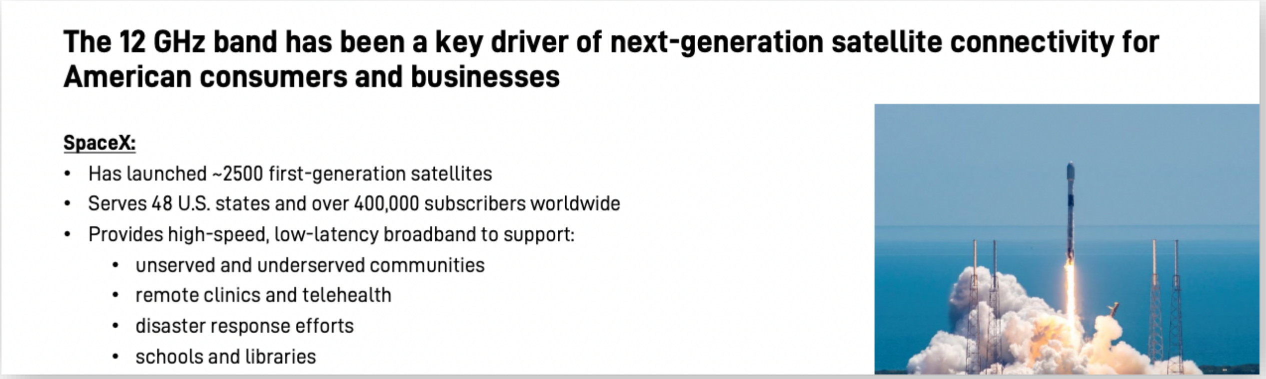
As Starlink recently observed, the off-axis gain of a Starlink UT at elevation angles above 48° (i.e., -2 dBi) is greater than the gain of a typical handheld 5G mobile device with head and body loss

- Thus, Starlink terminals within the 5G coverage area typically suffered an exceedance
- For more distant terminals, horizon nulling helped to mitigate the unwanted 5G signal

Starlink versus Starlink: Installation Height

- Starlink May 19: the "claim that users of satellite services place their equipment on the ground…is contrary to both common sense and the actual data"
- In 2021, RKF assumed 80% of Starlink antennas operate at 1.5m AGL and 20% at 4.5m AGL
- In 2022 despite ample reason for doubt, RKF assumes 55% of Starlink antennas operate on rooftops at 4.5m AGL and 45% at 1.5m AGL

Starlink May 19, 2022 Presentation to the FCC Legal Advisors show most installations at ground level.


The 12 GHz band has been a key driver of next-generation satellite connectivity for American consumers and businesses

SpaceX:
- Has launched ~2500 first-generation satellites
- Serves 48 U.S. states and over 400,000 subscribers worldwide
- Provides high-speed, low-latency broadband to support:
  - unserved and underserved communities
  - remote clinics and telehealth
  - disaster response efforts
  - schools and libraries

Starlink's 2021/2022 user install guide identifies the default installation at ground level: "If you could not find a clear field of view from the ground level, consider installing in an elevated location, like a roof, pole, or wall. Additional mounts and accessories are available for purchase on the Starlink Shop"

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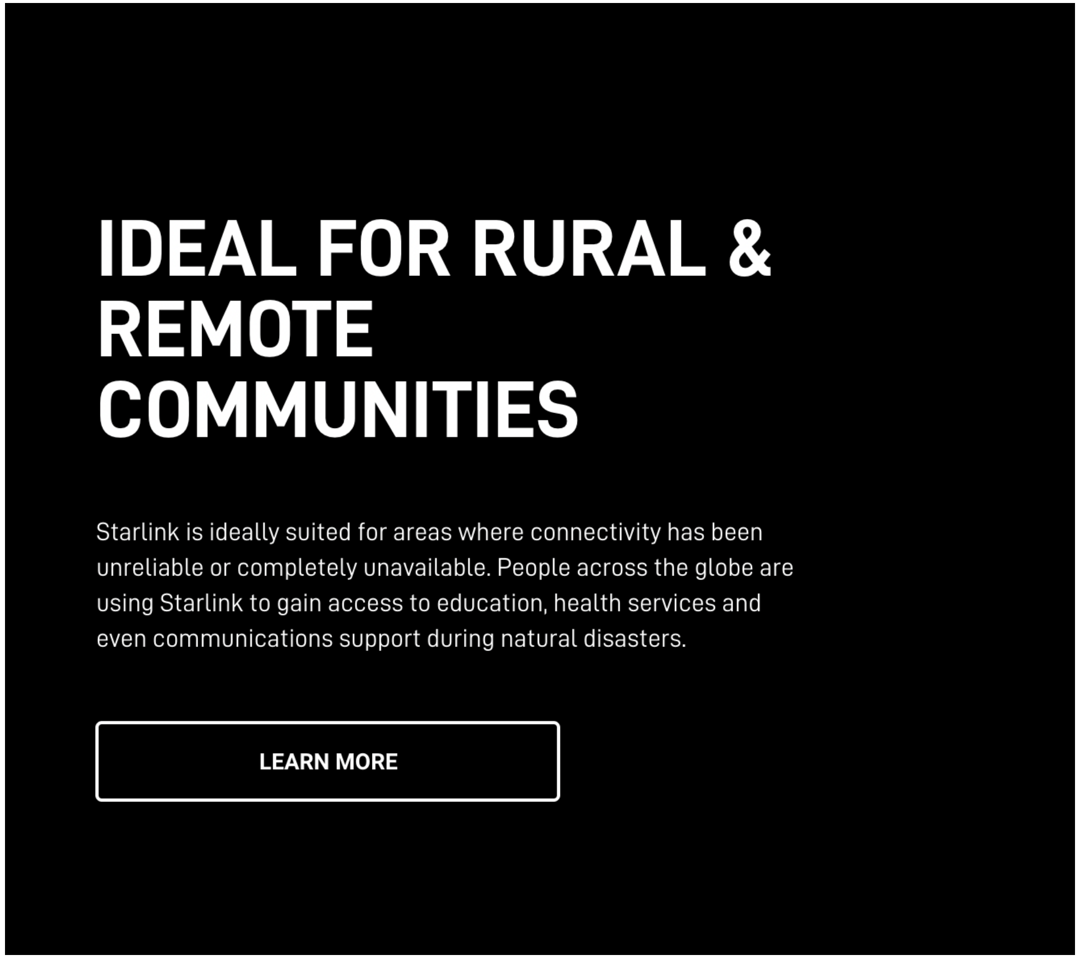
Starlink versus Starlink: Terminal Distribution

Starlink May 19 Letter to the FCC: “false assumptions… about user locations”

- Starlink’s Musk: “It’s really meant for sparsely populated regions. In high-density areas, we will be able to serve a limited number of customers.”
- Starlink’s FCC Authorization: “Operations are subject to the condition that SpaceX not use more than one satellite beam from any of its satellites in the same frequency in the same or overlapping areas at a time.”



Order Starlink, www.Starlink.com (May 26, 2022)

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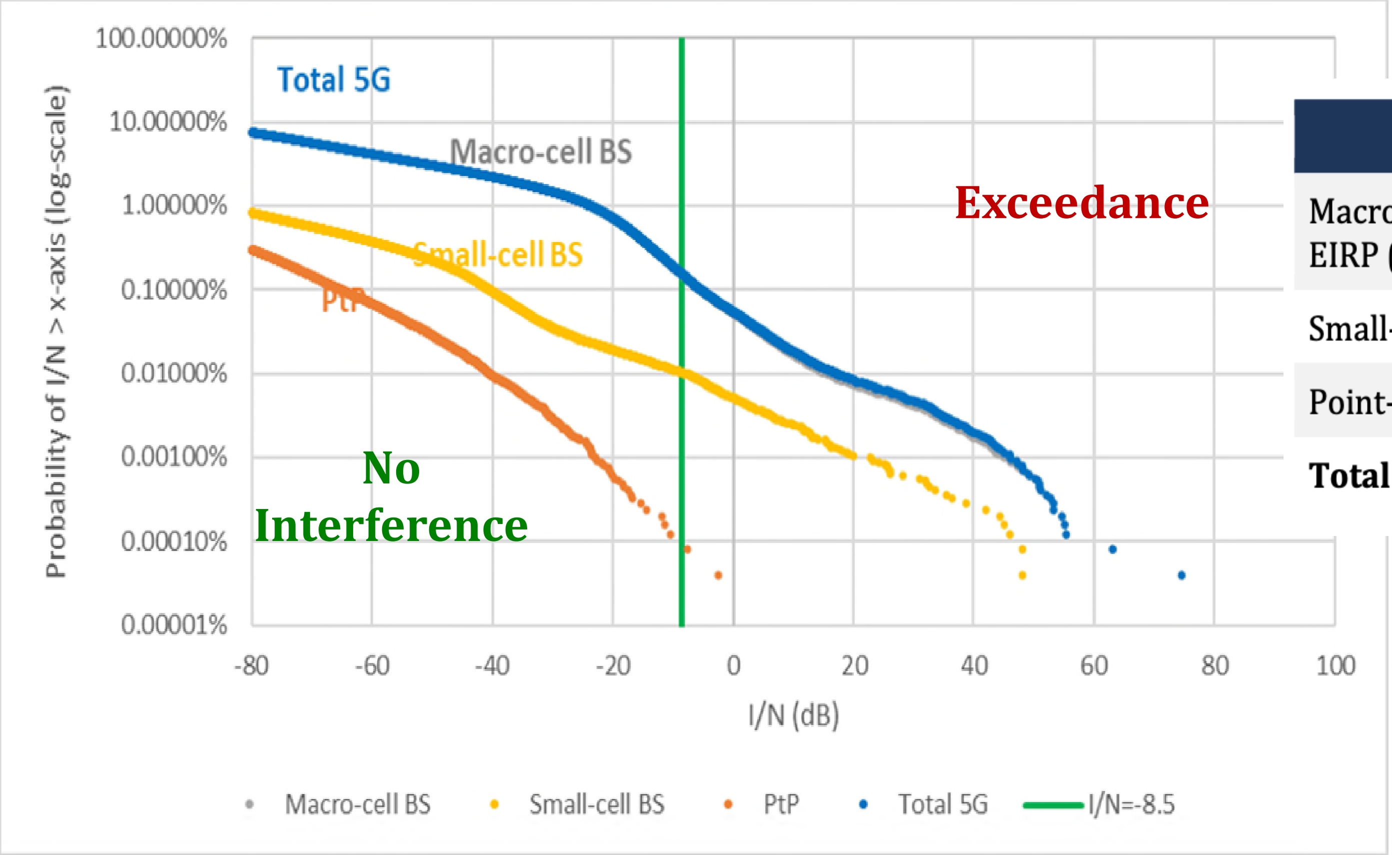
Methodology: Exceedance Threshold

- Exceedance events occur when a satellite terminal receives signals that exceed an acceptable performance threshold.
- An exceedance event does not mean harmful interference, only that there is a possibility that harmful interference may occur. But the absence of an exceedance event means that harmful interference will not occur.
- An I/N of -8.5 dB is the most recent ITU standard for terrestrial interference into FSS earth stations.
- Although Starlink has suggested using an exceedance threshold of -12.2 dB rather than -8.5 dB I/N, using a -12.2 dB value increases the noise level by just 0.3 dB, so changing the exceedance threshold would not materially affect RKF's findings.

Results: Very Low Cumulative Probability



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]

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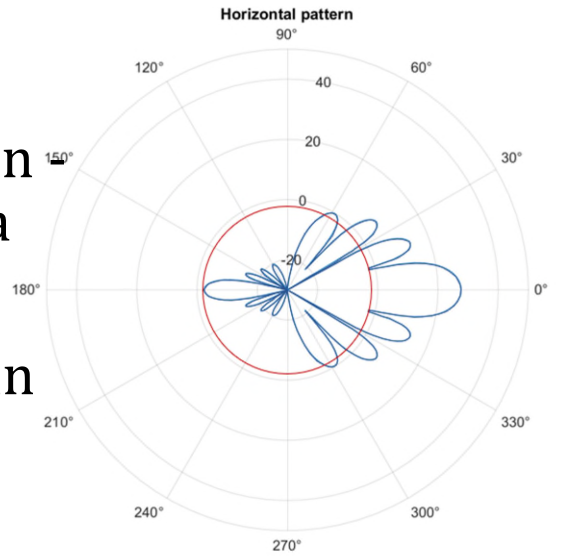
Starlink's Phantom -30 dBi

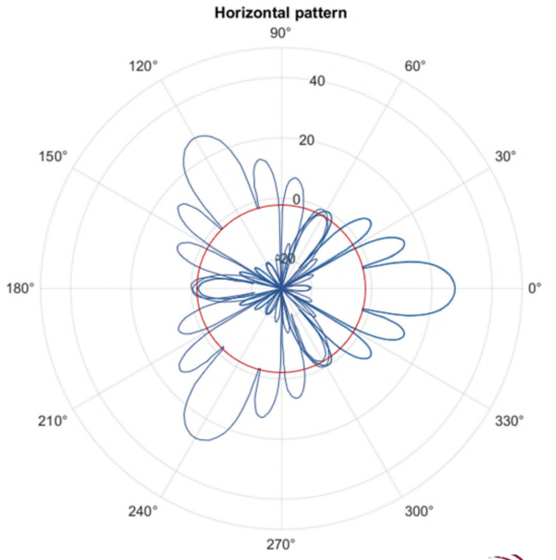
Starlink May 19 Letter : a -30 dBi minimum gain combined with a 27.7 dBi maximum gain produces a ratio of 57.7 dB which, when adjusted to 30 dB, would produce interference

- RKF relied on the 256-element array antenna in 3GPP TR 38.820 and identified a -30 dBi minimum gain as a practical necessity to depict the antenna pattern, as shown in plot A below
- Accounting for three-sector base stations shows why the minimum -30 dBi is never seen in practice: the other sectors overtake it, as shown in plot B below

- Seeing a null where the gain is less than -2.3 dBi (red circle) is only possible at a few, very narrow azimuth angles
- And of course, the actual minimum gain value of the composite three-sector pattern is typically much greater than the -30 dBi assumption



Plot A



Plot B

Starlink's Heated Objections to….What Exactly?

RKF used the values SpaceX identified in its May 19 letter and, despite revelatory rhetoric, many of SpaceX's truthful observations are unremarkable and irrelevant to the RKF analysis

SpaceX complains about the use of the word "reject."

SpaceX reproduces a standard I/N formula.

SpaceX says satellite receivers can be more sensitive than terrestrial receivers.

Marlene H. Dortch
May 19, 2022
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antenna discrimination would not provide adequate mitigation," DISH argues that "what SpaceX does not say is this: the RKF Report's use of 25° minimum elevation angles resulted in NGSO antenna discrimination far better than 30 dB—about 34-36 dB."[13] While this is true, it does not mean that SpaceX UTs will reject 30 dB or more of an interfering signal.

A high gain antenna (such as the SpaceX UT) is designed with sufficient sensitivity to receive very weak signals coming from a desired transmitter. Such antennas do not, however, "reject" interference coming from other directions. On the contrary, they can be significantly more sensitive to an interfering signal from a base station than a mobile receiver with an omni antenna is to that same signal. This can be seen in the formula for calculating I/N:

$$I/N = EIRP - 10\log(4\pi d^2) - 10\log(4\pi/\lambda^2) + G/T - 10\log(k)$$

where d is the distance, λ is the wavelength, k is Boltzmann's constant, G is the gain of the victim antenna in the direction of the interference, and T is the receiver temperature (dependent on noise figure and antenna temperature). The gain of the victim antenna at beam peak and the antenna discrimination are nowhere to be found in this calculation. They are totally irrelevant.

In this particular case, a relatively small phased array antenna such as the SpaceX UT has a gain of approximately 33 dBi at beam peak and a gain of approximately -2 dBi at large off-axis angles. Note this off-axis value is the lowest gain for the victim antenna, and hence the best-case scenario for interference. The antenna discrimination is 35 dB—i.e., the difference between the beam peak and lowest off-axis values (or 33-(-2)). For its simulation, RKF assumed a mobile UE with an omnidirectional antenna with a gain of -3 dBi, and further assumed that gain would be reduced by operation in close proximity to the human body (4 dB loss), for an effective gain of -7 dBi.[14] *Note that this is less gain than the SpaceX UT has even at far off-axis angles.* The SpaceX UT has a very good noise figure of 2 dB, and hence a clear sky G/T of approximately 10 dB/K. By comparison, the noise figure for a mobile UE is about 9-10 dB.[15] Given the differences in gain, noise figures, and antenna temperature, the SpaceX UT is about 16 dB more sensitive to the interfering signal coming into its sidelobes than the mobile UE is for its desired signal. In other words, ***the SpaceX UT (even when doing its best to minimize interference) is a much better receiver for the mobile signal than is the mobile UE.***

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Thank you

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