SPACEX ANALYSIS OF THE EFFECT OF TERRESTRIAL MOBILE DEPLOYMENT ON NGSO FSS DOWNLINK OPERATIONS

SpaceX's study—even with very favorable assumptions that would reduce interference from mobile operations—shows harmful interference from terrestrial mobile service to SpaceX's Starlink broadband terminals operating in the 12.2-12.7 GHz band ***more than 77 percent of the time, resulting in full outages 74% of the time****.*

Critically, the study further shows the effect of this harmful interference will ***extend to a minimum of 21km (more than 13 miles)*** *from the macro base station even for best-case far-sidelobe to far-sidelobe coupling in unobstructed conditions.*

EXECUTIVE SUMMARY

The 12.2-12.7 GHz Band (the "12 GHz Band") has become one of the most important and intensively used spectrum bands for Americans who depend on satellite services. While the band lacks many of the positive physical characteristics of low- or mid-band spectrum, it nonetheless has some of the best frequencies allocated for satellite companies to share. As such, multiple thousands of satellites have been deployed that rely on the band to provide television services, close the homework gap, expand telehealth services, and connect those with no or few broadband options in both rural and urban areas. SpaceX, for example, depends on the 12 GHz Band as the workhorse frequencies to provide critical downlink services to Americans in every corner of the nation.

When the Commission unanimously rejected the pleas from MVDDS licensees to uproot these critical services from the band, it also set an extremely high bar for upsetting the Commission's carefully balanced regime for sharing in the band. Anyone hoping to add a new service in the band was required to make a proposal including specific technical parameters, as well as a showing that a service meeting those parameters would not cause harmful interference to the people that rely on this critical spectrum. [1] Yet, in the year-and-half since the Commission first made the request, no such proposal has been forthcoming, rendering it impossible to run any technical analysis on the service as proposed.

Instead, one of the MVDDS licensees—RS Access—paid RKF Engineering Solutions, LLC ("RKF") to file a technical report that purports to show a notional mobile service would harm

[1] *See Expanding Flexible Use of the 12.2-12.7 GHz Band*, 36 FCC Rcd. 606, ¶ 22 (2021) ("*12 GHz NPRM*").

only tens of thousands of Americans, which RS Access deems as negligible. Yet, as the vast majority of comments about this submission have noted, the analysis is riddled with errors and faulty assumptions. To respond to these criticisms, RKF made a supplement to that study a year later that partially addressed some of the errors, ignored the largest flaws, and introduced yet new inaccuracies.

Unfortunately, it has become clear that the MVDDS licensees do not intend to respond to the Commission's call for technical parameters, and RS Access does not intend to honestly correct its technical submission. SpaceX has therefore conducted its own study, using the same methodology as RKF but using assumptions that reflect reality and correcting several of the most glaring errors. Even still, SpaceX still left a number of RKF's assumptions that are unrealistically favorable for its MVDDS client, such as completely ignoring that the band is in fact shared among multiple satellite operators.

By using the same Monte Carlo methodology as RKF, but adjusting some the most egregious errors, SpaceX's study shows an impact from interference from terrestrial mobile service that will degrade service to SpaceX's Starlink broadband terminals operating in the 12 GHz Band ***more than 77 percent of the time, resulting in full outages 74% of the time***.[2]

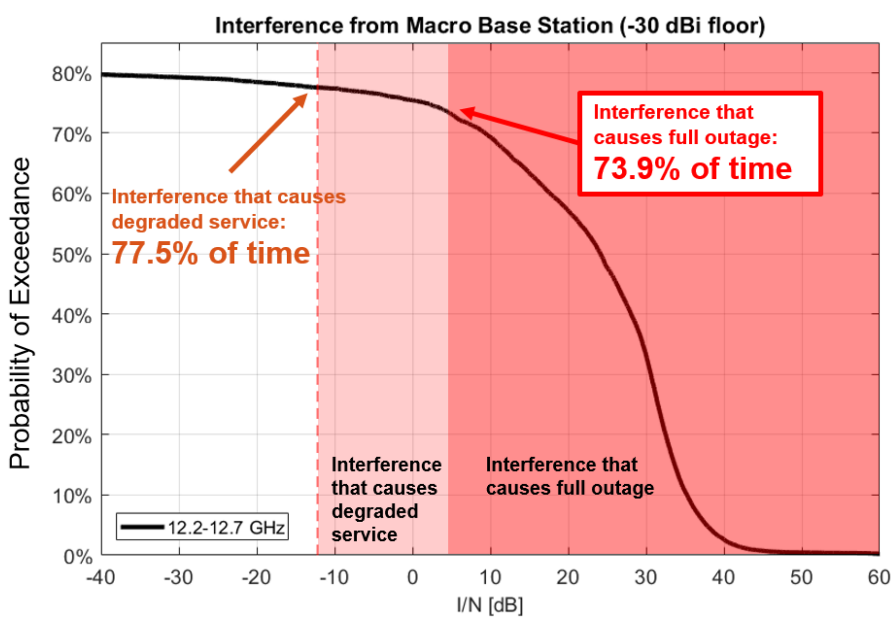

Figure 1. Cumulative Distribution Function of Interference-to-Noise Ratio into SpaceX User Terminals operating in the 12.2-12.7GHz band from Hypothetical Mobile System in Las Vegas, NV from Macro Base Station with a -30dBi Sidelobe Level floor

2 SpaceX used the standard long-term interference threshold of -12.2 dB.

Critically, the study further shows ***the impact of this harmful interference will extend to a minimum of 21km (more than 13 miles) from the macro base station in unobstructed conditions even for best-case far-sidelobe-to-far-sidelobe coupling***. RS Access and RKF confirmed in a recent ex parte that the far sidelobe level corresponding to the 21 km best-case distance is correct after considering all sectors, bolstering this fundamental calculation.[3]

To reach these more accurate conclusions, SpaceX corrected a number of RKF's errors that had been highlighted by numerous stakeholders in the record, including:

- Focusing on a deployment in a market—Las Vegas, Nevada—that presents two key features making it the ideal study location. First, DISH has announced it will first launch its terrestrial mobile service in Las Vegas. And second, SpaceX has provided service to users in Las Vegas, meaning SpaceX is able to model a deployment of its own user terminals based on actual demand for the Starlink service.
- Correctly modeling placement of satellite user terminals based on actual user data, including placing them at the height they are most often installed in user homes. As most people know (although RKF strangely denies), satellite users almost always place satellite receivers, presumably including those used by DISH, on their roofs where they can get the best signal.
- Assuming a buildout of a terrestrial system based on Commission standards, correcting RKF's assumption of a mobile system with only 10 percent population coverage with a more typical Commission build out requirement for terrestrial mobile services of 70 percent of population.[4] Critically, even RS Access must expect to cover *at least* 70 percent of the population, as its "economic study" and members of the MVDDS coalition both tout that the public interest benefit of this deployment would be its ability to serve rural customers usually left behind by other 5G deployments.[5]

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[3] Letter from V. Noah Campbell to Marlene H. Dortch, WT Docket No. 20-443, Attachment at 16 (June 1, 2022) ("RS Access June 1 Ex Parte") (Plot B shows the typical sidelobe level with all sectors active exceeds -2.3 dBi).

[4] *See* 47 C.F.R. § 27.14(h), (p)-(w) (establishing coverage requirements for WCS (75%), 2.3 GHz (75%), AWS-4 (70%), AWS-H Block (75%), AWS-3 (75%), 600 MHz (75%), EBS (80%), C-band (80%), and 3.45 GHz (80%)).

[5] *See* The Brattle Group, *Valuing the 12 GHz Spectrum Band with Flexible Use Rights* 15 (May 7, 2021) (analysis "assume[s] the terrestrial mobile operations in the 12 GHz band will be available ubiquitously") ("MVDDS Valuation Study"), *as attached to* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, Appendix B (May 7, 2021); Comments of the MVDDS Licensees, WT Docket No. 20-443 and GN Docket No. 17-183, at 20 (May 7, 2021) (with a mobile allocation, "all MVDDS license holders, including the MVDDS Licensees, DISH and RS Access, will be able to provide new 5G broadband services, particularly in rural areas").

Yet, in the interest of providing a conservative analysis, the SpaceX simulation still understates interference by leaving many of RKF's overly-favorable assumption in place, including:

- Ignoring the deployment by any NGSO systems other than Starlink. Critically, the Commission requires all NGSO systems to share the band, meaning no NGSO will actually have unfettered access to the band as RKF and this study assume. As multiple NGSO operators continue to connect Americans, any individual NGSO's access will be further strained and the harm from terrestrial services will become more severe.
- Considering interference only due to transmission from macro base stations, while ignoring additional contribution from user handsets and point-to-point wireless backhaul systems transmitting in the band. Simulating multiple concurrent sources of interference, including mobile devices, is extremely complex, but would make the already bad interference environment even worse.
- Simulating macro base stations with the most generous assumptions for antennas with 256 antenna elements. Yet the MVDDS licensees are unlikely to actually use these more sophisticated antennas due to cost and complexity. For example, current designs in the C-band use only 96 elements.[6]
- Ignoring out-of-band emissions from the terrestrial mobile system. These out-of-band emissions extend interference beyond the 12 GHz Band so that all Ku-band satellite channels will be degraded, especially those close in frequency with the interferer.

Even with these favorable assumptions, the analysis clearly demonstrates that the introduction of a mobile service into the 12 GHz Band would interfere with the services already allocated and operating in the band and disrupt next-generation satellite service to Americans across the country.

BACKGROUND

In 2016, a group of Multichannel Video and Data Distribution Service ("MVDDS") licensees filed a petition for rulemaking seeking new rights to deploy high-power, two-way mobile services in the 12.2-12.7 GHz band, spectrum that is also used by NGSO satellite

[6] *See* Letter from David Goldman to Marlene H. Dortch, WT Docket No. 20-443 and GN Docket No. 17-183, at 5 (June 3, 2022).

systems.[7] In support of that petition, the MVDDS coalition submitted expert technical analyses concluding that "coexistence between MVDDS 5G operations and NGSO FSS operations is not possible"[8] and "prospects for sharing appear to remain poor regardless of the deployment assumptions we use or the operating environment we model."[9] In recognition of the technical impossibility of giving MVDDS operators new rights without harming consumers of next-generation satellite services, the MVDDS petition proposed that "[t]he Commission should eliminate or render secondary the unused NGSO FSS allocation at 12.2-12.7 GHz."[10]

The Commission unanimously rejected the MVDDS request in 2020, instead initiating a rulemaking saying it would consider adding a new or expanded terrestrial mobile allocation in the 12 GHz Band only if doing so would not harm people who depend on next-generation satellite systems or satellite television services.[11] Among other things, the Commission specifically asked commenters to submit proposals for "the appropriate technical criteria that would be necessary to protect NGSO FSS from harmful interference from higher-power, two-way mobile operations"[12] and to discuss "the maximum power levels and the most flexibility that could be granted to new terrestrial operations with simple service-rule sharing while still protecting incumbents from harmful interference."[13]

To date, the MVDDS licensees and their supporters have failed to respond to the Commission's request that they propose technical rules that would govern the new mobile service they envision. As a result, neither the Commission nor stakeholders can fully evaluate the effect such a service would have on NGSO systems that use the 12 GHz Band to deliver advanced satellite services to American customers. The studies submitted by the MVDDS licensees in 2016 clearly indicate that such a service would cause devastating interference on NGSO systems, making band sharing impossible. But the MVDDS licensees reversed course after the Commission rejected their initial proposal, submitting a new study by RKF of the effect on NGSO operations of a hypothetical high-power mobile system operating in the 12 GHz Band and also later submitting a supplement to that study.[14] Despite several requests by SpaceX to

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7 MVDDS 5G Coalition Petition for Rulemaking to Permit MVDDS Use of the 12.2-12.7 GHz Band for Two-Way Mobile Broadband Service, Docket No. RM-11768, at 22 (Apr. 26, 2016) ("MVDDS Petition").

8 Tom Peters, *MVDDS 12.2-12.7 GHz Co-Primary Service Coexistence* 35 (June 8, 2016) ("First Peters Study"), *as attached to* Comments of MVDDS 5G Coalition, Docket No. RM-11768, Attachment I (June 8, 2016).

9 Tom Peters, *MVDDS 12.2-12.7 GHz Co-Primary Service Coexistence II* 2 (June 23, 2016), *as attached to* Reply Comments of the MVDDS 5G Coalition, Docket No. RM-11768, Appendix A (June 23, 2016).

10 MVDDS Petition at 22-24.

11 *See 12 GHz NPRM* ¶ 2.

12 *Id.* ¶ 30.

13 *Id.* ¶ 42.

14 *See* 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 2021) ("RKF Report"), *as attached to* Comments of RS Access, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, Appendix A (May 7, 2021); RKF Engineering Solutions, LLC, *The Effect of 5G Deployment on NGSO FSS Downlink Operations in the 12.2-12.7*

work together, RS Access hid RKF's original submission from SpaceX until it filed it with the Commission and thus did not consult with SpaceX regarding the existing operating parameters of Starlink. Accordingly, RKF made a number of incorrect assumptions about the operating parameters of the single NGSO service considered in the analysis—the NGSO system operated by SpaceX. Interestingly, RKF also made inaccurate and inappropriate assumptions about their proposed mobile service (yielding far more favorable results for the system RKF chose to model). Notably, RKF explicitly denied that the assumptions in its submissions should be considered a proposal.

DISCUSSION

A. The RKF Report and Supplement

In its analysis,[15] RKF employs a probabilistic technique known as Monte Carlo analysis to quantify the risk of interference from a nationwide mobile deployment of 12 GHz spectrum into SpaceX user terminals receiving NGSO signals in the 12 GHz band by modeling terrestrial and NGSO networks. For this purpose, RKF's model assumes that terrestrial mobile licenses will be issued on a Partial Economic Area ("PEA") basis and calls for the 12 GHz mobile network to cover 10 percent of the population in each PEA. The modeled mobile network is composed of terrestrial macro-cell and small-cell base stations, mobile user devices, and point-to-point backhaul links, placed using an algorithm that RKF claims would approximate real-world siting. RKF sited satellite user terminal locations with a different algorithm that it claims to be consistent with the most likely satellite broadband use cases, and in particular used areas identified as unserved for purposes of the Rural Digital Opportunity Fund ("RDOF") auction as a proxy for areas most likely to benefit from satellite broadband and exhibit a greater propensity for satellite terminal deployment in the model.

Spectrum in the 12 GHz Band is unpaired, so RKF assumed that terrestrial mobile systems in the band would operate on a time-division duplex ("TDD") basis and further assumed that synchronized TDD operations would have a four-to-one downlink-to-uplink ratio, such that 80% of the time base stations are transmitting (and potentially causing interference) and 20% of the time mobile user devices are transmitting (and potentially causing interference). RKF then calculated the interference-to-noise ratio ("I/N") at each SpaceX user terminal from active 12 GHz mobile transmitters within 50 kilometers. The model calculates aggregate interference to SpaceX terminals sufficient to arrive at a statistically significant output, resulting in a cumulative distribution function to assess the probability of interference *to* the simulated

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GHz Band (May 19, 2022) ("RKF Supplemental Report"), *as attached to* Letter from V. Noah Campbell to Marlene H. Dortch, WT Docket No. 20-443 (May 19, 2022).

15 *See* RKF Report at i-ii (summarizing methodology). Except as noted, the RKF Supplemental Report used this same assumptions and methodology for its analysis.

deployment of SpaceX user terminals *from* the simulated deployment of terrestrial 12 GHz transmitters, including macro-cell base stations, small-cell base stations, point-to-point backhaul links, and mobile devices.

B. Revised Assumptions

In its analyses, RKF makes a large number of assumptions about the characteristics of 12 GHz systems and the propagation environment in which they will operate. For purposes of its own analysis, SpaceX has used many of those assumptions. However, RKF has no particular knowledge of how SpaceX operates its system. As a result, many of its assumptions related to SpaceX's user terminals are false and must be adjusted to better reflect real-world conditions. In addition, SpaceX has revised several RKF deployment assumptions to better reflect real-world conditions. As the following section demonstrates, RKF made a number of flawed assumptions that result in the understatement of actual interference to satellite antennas.

1. Assumptions about SpaceX

Antenna Height. The height at which users mount their SpaceX user terminals has a dramatic effect on the interference to which they are subject. Users typically mount their antennas on rooftops with a clear and unobstructed view of the sky so they can better receive signals from the SpaceX satellites where placing them at lower heights could limit the view of the sky and harm users' service. However, this higher placement also means that they are more likely to receive more direct interference from mobile system base stations and UEs. RKF assumed a low number of roof mounts, so its interference results skewed significantly lower and do not reflect reality. Tellingly, in its initial report, RKF falsely assumed that the vast majority of Starlink user terminals would be at ground level, and subtly manipulated the propagation model to assign substantial clutter loss to *any* ground level Starlink user antenna beyond 30m away.

RKF initially assumed that the majority of SpaceX user terminals would be located at ground level—specifically, that 80% would be deployed at a height of 1.5 meters and 20% would be deployed at a height of 4.5 meters, representing a rooftop installation.[16] Subsequently RKF revised this to 55% on rooftops (4.5m height) and 45% at ground level (1.5m height). However, as even DISH has recognized, SpaceX terminals are typically installed on rooftops to get above ground clutter and afford a less obstructed view to satellites in the sky. DISH noted that "Starlink's installation guide shows the importance SpaceX attaches to avoiding obstructions, as shown by the following diagram, reproduced from the Starlink setup instructions."[17]

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[16] *See id.* at 22.

[17] Letter from Pantelis Michalopoulos to Marlene Dortch, WT Docket No. 20-443 and GN Docket No. 17-183, at 8-9 (Jan. 13, 2022).

Similarly, SpaceX's website states that "[m]any customers find that a permanent mount in an elevated location, like a roof, pole, or wall, provides the best installation and service."[18] These materials clearly evidence the expectation that most SpaceX antennas will be installed on users' rooftops or other elevated locations. In its own informal customer surveys, SpaceX has found most consumers do mount their antennas on a roof. Accordingly, for purposes of this analysis and consistent with consumer surveys, SpaceX corrected RKF's ratio and assumed that 10% of its user terminals would be deployed at a height of 1.5 meters and 90% would be deployed at a height of 4.5 meters.

Antenna receive pattern. RKF used an optimistic receive antenna pattern that understates receive interference. RKF claimed it did not know the actual SpaceX user terminal antenna pattern, and thus used what it called "the standard ITU pattern for NGSO earth stations as described in [ITU-R Rec.] S.1428."[19] However, SpaceX has previously disclosed and confirmed "the applicable ETSI standard for user terminals such as those employed in the Starlink system,"[20] which is an inherently global system that deploys user terminals in Europe as well as the United States. That standard is ETSI_EN_303_981 Class B WBES, which relates specifically to operations in the Ku-band (including 12 GHz).[21] Accordingly, SpaceX has used this ETSI pattern for purposes of its analysis rather than the generic ITU pattern. In its most recent update, RKF updated this assumption to use the ETSI_EN_303_981 Class B WBES pattern as well.

Channel plan. RKF's study understated the effect of interference in the 12 GHz Band by averaging the results across the entire 10.7-12.7 GHz downlink band, thus watering down the

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18 *Why do I need a clear "field of view" to use Starlink?*, Starlink, https://support.starlink.com/?topic=4badc520-cf8e-b3aa-dd49-b731686d5bf1 (last visited June 17, 2022).

19 RKF Report at 23. *See also* ITU Radiocommunication Assembly, *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 (2000-2001), https://bit.ly/3b3jhvH.

20 *See* Reply Comments of Space Exploration Holdings, LLC, WT Docket No. 20-443 and GN Docket No. 17-183, at 10 (July 7, 2021); Letter from David Goldman to Marlene H. Dortch, WT Docket No. 20-443 and GN Docket No. 17-183, at 6 (Sept. 27, 2021).

21 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 (2020-10), https://www.etsi.org/deliver/etsi_en/303900_303999/303981/01.01.00_20/en_303981v010100a.pdf.

results. To water it down further, RKF even included spectrum that SpaceX does not have the ability to use because of adjacent-band protections, required by Commission and international rules. RKF assumed that the SpaceX NGSO system would operate its Ku-band user downlinks with eight 240 MHz channels with 250 MHz spacing, covering the entire 10.7-12.7 GHz downlink band.[22] However, as SpaceX has previously demonstrated,[23] its system currently does not use the 10.7-10.95 GHz portion of the band due to regulatory constraints imposed to protect Radio Astronomy activity in the adjacent 10.6-10.7 GHz band.[24] Accordingly, the SpaceX analysis is based on seven 240 MHz channels with 250 MHz spacing from 10.95-12.7 GHz.

User terminal deployment. RKF's study downplayed the effect of interference by assuming that there was little overlap of service areas—i.e., that mobile service users would be urban and satellite users would be rural. As mentioned above, RKF based its assumptions about deployment of SpaceX user terminals on the areas identified as unserved for purposes of the Commission RDOF program.[25] Despite SpaceX repeatedly pointing out in the record that this assumption dramatically undercounts SpaceX users in other areas, RKF insisted on assuming only 1.07 percent of SpaceX user terminals would be deployed in urban areas, significantly underestimating the effect of the proposed system on the existing Starlink customers.[26]

For its analysis, SpaceX used a distribution based on actual demand in the Las Vegas market to deploy a representative 1,000 Starlink user terminals within the Las Vegas PEA. This distribution is based on actual user data and thus more appropriately matches real customer use of the service. While SpaceX's Starlink service is uniquely positioned to offer high-speed broadband service to those who are unserved or underserved anywhere in the continental United States, it has existing demand (customers) in rural, suburban and urban areas. The distribution places 17% in urban areas, 37% in suburban areas and 46% in rural areas. SpaceX used the same population density thresholds as RKF to define urban, suburban and rural areas.

Signal propagation and ground clutter. RKF further lessened the effect of interference in its assumptions about clutter (obstructions that reduce or interrupt radio signals, thereby reducing the extent of interference). To consider the potential effects of obstructions such as buildings, foliage, and terrain in attenuating radio transmissions, the model includes assumptions about signal propagation and ground clutter.

Both the RKF and SpaceX analyses model path loss using 3GPP Specification 38.901, applying the Urban Macro-Cell ("UMa") model for both urban and suburban macro-cells at 30

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22 *See* RKF Report at 23.
23 *See* Letter from David Goldman to Marlene H. Dortch, WT Docket No. 20-443 and GN Docket No. 17-183, at 2-4 (Feb. 3, 2022).
24 *See* 47 C.F.R. § 2.106 n.US131; *Space Exploration Holdings, LLC*, 36 FCC Rcd. 7995, ¶ 97c (2021).
25 RKF Report at i.
26 *See id*. at 21 (Table 2-1).

meters to 1 km distance, the Rural Macro-Cell ("RMa") model for rural macro-cells at 30 meters to 5 km, and the Micro-Cell ("UMi") model for small-cells at 30 meter to 1 km distance.[27]

However, RKF subtly understates the high interference line of sight cases in the 3GPP 38.901 model by using a single weighted average between NLOS (non-line of sight) and LOS (line of sight) path loss to represent both cases:

$PL_{38.901}(dB) = PL_{LOS}(dB) \times Prob_{LOS} + PL_{NLOS}(dB) \times \{1 - Prob_{LOS}\}$

RKF's approach of employing a weighted average to represent two distinctly different cases dramatically understates the line of sight cases that would actually occur under the 3GPP 38.901 model. In fact, the LOS and NLOS events are distinct and have considerably different results that shouldn't be averaged, even if weighted, but each should be represented in the cumulative distribution of interference, occurring with the appropriate probability predicted in the model.

To correct this, for each interference path SpaceX randomly selects either the LOS or NLOS path loss with the appropriate probability distribution predicted by 3GPP 38.901.[28]

SpaceX uses the ITU-R P.452 model for longer distances beyond 1 km (for urban/suburban macro cells) and beyond 5 km (for rural macro cells). SpaceX assumed clutter categories of "Urban" and "Suburban" within the ITU-R P.452 model for areas with population densities classified as Urban and Suburban Rural respectively. RKF overstated clutter attenuation in rural areas by assuming the "Village Center" clutter category in rural areas which overstates the size and distribution of buildings in rural areas. To correct for this error, SpaceX instead used the "Sparse Houses" category in rural areas.

As in the RKF model, SpaceX applied clutter at TX only when the transmitter is a UE with height 1.5 m, and clutter at RX only when the Starlink terminal height is 1.5 m.[29]

2. Assumptions about Terrestrial Mobile

Deployment density. As it did with satellite user terminals, RKF also used assumptions about the deployment of a notional terrestrial mobile system designed to minimize the overlap of users of the two services, thereby disguising the true interference that would result using more accurate distributions. In its analysis, RKF inexplicably assumed a hypothetical terrestrial

[27] *See* RKF Report at 44-45.
[28] *See 3GPP TR 38.901 V17.0.0,* 3GPP (Mar. 2022), https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3173.
[29] *See* RKF Report at 45.

mobile service that covers just 10% of the population in each license area.[30] That falls far below the 70% to 80% population coverage requirement the Commission has routinely applied to other recently allocated flexible use spectrum (including the AWS-4 band licensed solely to DISH).[31] RKF's assumption of such limited deployment is also inconsistent with the economic study submitted by terrestrial mobile proponents, which "assume[d] the terrestrial mobile operations in the 12 GHz band will be available ubiquitously."[32] This 10 percent assumption is also inconsistent with the public interests claimed by members of its coalition that mobile services in 12 GHz band be required to serve rural customers, left behind by other 5G deployments. SpaceX therefore used a 70 percent terrestrial coverage assumption in its analysis, to more closely mirror the real-world deployment requirements typically applied to terrestrial operators.

ANALYSIS

A. Baseline analysis

As an initial baseline for its analysis, SpaceX first examined the distance at which a mobile base station could be expected to cause interference to a SpaceX user terminal in unobstructed conditions. For this purpose, SpaceX used RKF's assumption that the macro base station has an input power of 41.3 dBm per 100 MHz per user[33] and that the SpaceX user terminal has a -2 dBi far sidelobe gain and 200 K system noise temperature. SpaceX also assumed that the far sidelobe level of the macro base station is -2.3 dBi. Note RKF assumed a -30 dBi sidelobe performance for macro base stations.[34] (To be clear, in its later Monte Carlo simulation, SpaceX used the same -30 dBi sidelobe floor for an individual sector antenna pattern, although this value is highly optimistic.[35])

This analysis shows that ***even for best-case far-sidelobe-to-far-sidelobe coupling, the effect of harmful interference (I/N > -12.2dB) will extend up to 21.4 km (more than 13 miles) from the macro base station in unobstructed conditions***. RS Access and RKF themselves confirmed in their recent ex parte that the far sidelobe level is in fact -2.3dBi or higher after

30 *See id.* at 27.

31 *See* 47 C.F.R. § 27.14(h), (p)-(w) (establishing coverage requirements for WCS (75%), 2.3 GHz (75%), AWS-4 (70%), AWS-H Block (75%), AWS-3 (75%), 600 MHz (75%), EBS (80%), C-band (80%), and 3.45 GHz (80%)).

32 MVDDS Valuation Study at 15.

33 *See* RKF Report at 34.

34 *See id.* at 33-34.

35 That assumption corresponds to 57.7 dB of peak-to-far-sidelobe discrimination from the 27.7 dBi peak gain—a value grossly out of line with international consensus that 30 dB of peak-to-far-sidelobe discrimination is typical for mobile base station antennas. Indeed, a report filed in this proceeding by RS Access indicates that only 25-30 dB of sidelobe discrimination is achievable in practice.

considering all sectors, as shown in the figure reproduced below.[36] Importantly, this conclusion is consistent with the more reliable technical study the MVDDS licensees submitted in this docket (i.e., the First Peters Study).

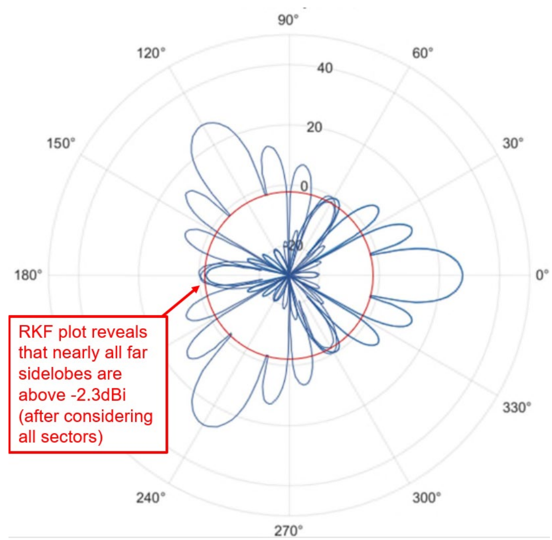

Figure 2. RKF and RS Access Plot B showing Macro Base Station antenna pattern with all sectors active, illustrating that nearly all far sidelobes are above -2.3dBi after considering all sectors

Thus, a SpaceX user terminal (or any satellite earth station operating in the band) would be subjected to significant interference whenever located in the line of sight of a macro base station like the ones anticipated in the RKF Report.

The MVDDS licensees also promoted the fallacy that high-gain antennas are immune to interference because interference coming into their sidelobes is "rejected." For example, in response to SpaceX's citation to the First Peters Study noting "that even '30 dB' of antenna discrimination would not provide adequate mitigation," DISH argues that "what SpaceX does not say is this: the RKF Report's use of 25⁰ minimum elevation angles resulted in NGSO antenna discrimination far better than 30 dB—about 34-36 dB."[37] But this does not mean that SpaceX user terminals will reject 30 dB or more of an interfering signal.

A high-gain antenna (such as the SpaceX user terminal) 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

36 RS Access June 1 Ex Parte, Attachment at 16. Plot B shows the typical sidelobe level with all sectors active exceeds -2.3dBi. Note that the separate SpaceX Monte Carlo simulation still uses a -30dBi floor for an individual sector.

37 Letter from Pantelis Michalopoulos to Marlene Dortch, WT Docket No. 20-443 and GN Docket No. 17-183, at 8 (Apr. 21, 2022).

significantly more sensitive to interfering signals 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 both totally irrelevant.

In this particular case, a relatively small phased array antenna such as the SpaceX user terminal has a gain of approximately 33 dBi at beam peak and a gain of approximately -2 dBi at large off-axis angles (far sidelobes). Note -2dBi 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.[38] *Note that this is less gain than the SpaceX user terminal has even at far off-axis angles.* The SpaceX user terminal 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.[39] Given the differences in gain, noise figures, and antenna temperature, the SpaceX user terminal is about 16 dB more sensitive to the interfering signal coming into its far sidelobes than the mobile UE is for its desired signal. In other words, ***the SpaceX user terminal (even when doing its best to minimize interference) is a much better receiver for the mobile signal than is the mobile UE***.

As a result, if a SpaceX user terminal is located in an area where a mobile UE can receive a signal from the base station, the interfering signal it receives will be much stronger than the desired signal received by the UE. For example, assume a mobile UE with a very modest signal-to-noise ratio of only 0 dB (i.e., at the UE noise floor). For the SpaceX user terminal, this mobile signal becomes an interferer that is 16 dB above the noise floor of the user terminal (I/N = 16 dB) and completely wipes out the desired signal. SpaceX's high-gain user terminal is designed to amplify a very weak satellite signal received in its boresight, but it is still more sensitive to incoming signals at its lowest off-angle gain than the mobile UE is. Thus, no matter how good the satellite antenna is—and even if pointing only at high elevation angles so that terrestrial mobile signals are only received at large off-axis angles—interference will be overwhelming

[38] *See* RKF Report at 38.

[39] *See 3GPP TR 38.820 v. 16.1.0*, 3GPP at Table 5.5.1.1-1 (Mar. 2021), https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3599 (typical noise figure for 10 and 15 GHz example frequencies).

within the coverage area of a terrestrial base station. Indeed, RKF seems to recognize this fact, as it freely admits that "Starlink terminals within the 5G coverage area typically suffered an exceedance."[40]

B. Simulation of mobile service interference into NGSO user terminals

Having established a baseline for interference to SpaceX user terminals in the absence of obstructions, SpaceX then proceeded to a more sophisticated analysis based on a simulation of the operations of a hypothetical terrestrial mobile system and its effect on SpaceX user terminals. For this purpose, SpaceX used the Las Vegas PEA, the market that DISH—one of the main proponents of terrestrial mobile services in the 12 GHz Band—has targeted for its first mobile operations.

1. SpaceX user terminal deployment

SpaceX is currently authorized to deploy an unlimited number of its second-generation user terminals within the United States.[41] That authorization was issued several months after RKF filed its first report but months before RKF filed its updated supplemental report, both of which relied in part on the authorization for one million first-generation user terminals to set a limit of 2,500,000 SpaceX user terminals for its simulation.[42] For purposes of its simulation, as noted above, SpaceX placed its user terminals in the Las Vegas PEA based on actual user demand distribution of urban/suburban/rural areas. As discussed below, SpaceX also ran the model using the same distribution pattern as RKF to evaluate the effect of this parameter.

Even if SpaceX uses the RKF's faulty assumption for Starlink user terminal deployment that places the vast majority of them in rural areas,[43] interference remains unacceptably high. The probability of detrimental interference that seriously degrades service still occurs more than 64% of the time in the 12 GHz Band, while even more intense interference causing full Starlink user terminal outage will occur more than 53% of the time.

2. Terrestrial mobile deployment

SpaceX followed a similar procedure as RKF for deploying mobile base stations, starting with urban areas, then suburban, then rural and accounting for minimum inter-site distance ("ISD") between base stations. In determining the number of base stations to deploy in the Las Vegas PEA, SpaceX proceeded from RKF's assumptions that (1) to obtain 10% population coverage 49,997 macro base stations would be deployed throughout CONUS, (2) these macro

[40] RS Access June 1 Ex Parte, Attachment at 11.
[41] *See* Radio Station Authorization, Call Sign E210127 (issued Nov. 10, 2021).
[42] *See* RKF Report at 16.
[43] *See id.* at 21 (parameters in Table 2-1).

base stations would be distributed in the most populated areas including at least 10% of population density areas in each PEA, and (3) the number of small-cells will be double the number of macro-cells.[44] The number of base stations was scaled from RKF's 10% assumption to obtain 70% population coverage, resulting in the figures shown in Table 5.

Deployment	Number
Macro Base Stations **Minimum inter-site distance described in RKF Table 2-4**	3,215
Mobile Handsets	96,450 (50% network loading)

Table 5. Mobile Network Simulation in Las Vegas PEA

Like RKF, SpaceX's simulation assigned 80% of mobile handsets as indoor and 20% as outdoor. Outdoor handsets are assumed to have a height above ground level of 1.5m. For indoor UEs, the height above ground is uniformly distributed between 1.5 meters and the height at which base station's downtilt is the minimum value in Table 2-4 (for macro cell) and Table 2-5 (for small cell) of the RKF Report. SpaceX also followed RKF's methodology by restricting handset heights to six floors (16.5 meters) in urban macro-cells and two floors (4.5 meters) in suburban and rural macro- and small-cells. Like RKF, SpaceX assumed a 50% network loading factor.[45]

Following RKF's approach,[46] the handsets are placed randomly within each terrestrial base station coverage area. The base station forms a narrow beam toward each handset. The SpaceX user terminal selects a random pointing direction from the distribution of simulated pointing directions. Then the aggregate interference from all simultaneously active macro base station beams on the downlink to each of the SpaceX user terminal receivers within 50 kilometers is computed. The objective of the simulation is to model a large number of statistically significant interference paths to evaluate the risk of interference to the SpaceX user terminals.

SpaceX used the same equation used by RKF[47] to compute the interference power from each terrestrial mobile transmitter. However, as noted above, SpaceX's simulation assumes that SpaceX user terminals have seven 240 MHz channels to choose from (rather than eight as

44 *Id.* at 13.
45 *See id.* at 37.
46 *See id.* at 13.
47 *See id.* at 14.

RKF assumed), only two of which fall in the 12 GHz Band and can receive interference from the mobile network. Like RKF's model,[48] the simulation assigns channels randomly to SpaceX user terminals. The macro-cell base stations are assumed to operate with 100-MHz channels; the simulation assumes four simultaneous active users per 100-MHz channel and that each user has access to 100 MHz of spectrum. There is an assumed four-to-one downlink-to-uplink ratio for the mobile TDD transmission times. Beamforming is not used on small-cells, so for small-cells the four mobile handsets are assumed to split the channel, each being allocated 25 MHz.

CONCLUSION

The Commission asked MVDDS licensees and its supporters to submit a proposal with specific technical parameters that show how it would not harm people who depend on next-generation satellite services. The lack of any specific proposals or technical parameters by MVDDS licensees or their supporters has made it impossible for others to perform an independent analysis of the harm caused by any new terrestrial deployment in the 12.2-12.7 GHz band. RKF has also specifically stated that its assumptions should not be seen as representative of an actual terrestrial deployment, further complicating matters. And while RKF has made claims about its conclusions, most observers have noted RKF's reports are deeply flawed.

Nonetheless, SpaceX has been able to replicate RKF's methodology, but adjust some the most serious errors. Even with leaving many assumptions that are unrealistically favorable to RKF's clients, RKF's methodology still demonstrates that terrestrial mobile service will degrade service to SpaceX's Starlink broadband terminals operating in the 12 GHz Band *more than 77 percent of the time, resulting in full outages 74% of the time*. The effect of this harmful interference will extend to a minimum of 21 kilometers from the macro base station even for best-case far-sidelobe to far-sidelobe coupling in unobstructed conditions. This conclusion is consistent with the conclusion of the 2016 Peters Study that concluded a 5G mobile device operating would need to be located approximately 32 kilometers from the NGSO terrestrial mobile receiver to avoid generating an MVDDS signal that is equal to or greater than the power the NGSO equipment would receive from the space station. In other words, by correcting some of the erroneous assumptions in RKF's report, all technical analysis of the 12 GHz band confirm that "coexistence between MVDDS 5G operations and NGSO FSS operations is not possible without severe operational constraints on MVDDS, NGSO FSS or both services."[49]

[48] *See id.* at 14-15.
[49] First Peters Study at 35.