Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

REPLY COMMENTS OF APPLE INC., BROADCOM INC., CISCO SYSTEMS, INC., FACEBOOK, INC., GOOGLE LLC, HEWLETT PACKARD ENTERPRISE, INTEL CORPORATION, MARVELL SEMICONDUCTOR, INC., MICROSOFT CORPORATION, QUALCOMM INCORPORATED, AND RUCKUS NETWORKS, AN ARRIS COMPANY

March 18, 2019

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INTRODUCTION AND SUMMARY

Responses to the Commission's Notice of Proposed Rulemaking reflect widespread agreement that opening the entire 6 GHz band to unlicensed technologies is essential to meeting growing demand for wireless connectivity. By adopting its proposal to authorize unlicensed operations across the band, the Commission will empower a new generation of innovation in unlicensed services—including Wi-Fi 6 and 5G. As the NPRM suggests, by allowing unlicensed devices to share the band with existing services, the Commission will achieve this important goal without relocating large numbers of licensed incumbents, constraining their future growth, or dislocating federal users.

The Commission can achieve these goals by authorizing standard-power operations subject to Automated Frequency Coordination (AFC), in addition to low-power indoor (LPI) operations and very low-power operations indoors and outdoors. Each of these components is critical to the long-term success of the band. Band-wide authorization of LPI operations is of special importance to ensure the rapid availability of spectrum to American consumers, and to permit the use of large channel sizes.

Hard work by Commission staff and engineers in companies across the wireless sector has dramatically narrowed the open issues in this proceeding. Based on the strong record it has created, the Commission should adopt its proposal, with the important improvements detailed in our initial comments. In doing so, the Commission should reject efforts by CTIA and Ericsson to upend the Commission's proposed approach and instead displace federal users from the 7 GHz band, somehow relocate 6 GHz incumbents to these new frequencies, and auction a portion of the band. This scheme is unworkable, unnecessary, and unsupported by other commenters.

The Commission's less intrusive plan to promote coexistence between 6 GHz incumbents and RLAN operations, on the other hand, commands substantial support. Comments make it clear that in the vast majority of locations, times, and configurations, RLANs would not be positioned to even potentially cause harmful interference to incumbents. Some incumbents focus their advocacy on corner cases where they claim that 6 GHz RLAN operations could present a risk of harmful interference. However, with few exceptions, these commenters either provide no empirical support for these claims or repeat flawed arguments that have already been presented and addressed in prior phases of this proceeding. Nonetheless, these commenters continue to insist that the Commission should accept a series of unrealistic assumptions and accede to a severely distorted view of incumbent users' vulnerability to unlicensed transmissions. Below, we provide a more accurate picture of real-world interference risk that should form the foundation of an engineering-driven decision, and address demonstrably negligible, newly raised concerns about adjacent-channel interference.

Finally, some commenters ask the Commission to mandate the creation of a central database to track the locations and frequencies used by every consumer or business with an AFC-controlled device. The Commission should reject this unnecessarily restrictive approach. This proposal would be of little practical value in the 6 GHz band, both because harmful interference is extremely unlikely to occur, and because this database would be of little additional value even if it did. A central database would also make design of AFC systems significantly more complicated, limit flexibility of AFC operators and device manufacturers, and raise privacy questions.

I. The Record Supports the Commission's Proposal to Permit Unlicensed RLAN Use Throughout the 6 GHz Band.

Comments submitted by a wide range of parties in this proceeding demonstrate the unique importance of the 6 GHz band to supporting innovation and addressing the nation's unlicensed spectrum deficit. The record contains engineering analyses, commercial expertise, and policy perspectives from entities representing a wide range of perspectives on the Commission's proposals.[1] This deep record provides the Commission with a basis to proceed confidently in adopting a Report and Order to open the 6 GHz band to unlicensed use while protecting licensees in the band from harmful interference.

A. The Record Supports the Commission's Recognition That the Nation Needs More Unlicensed Spectrum.

Numerous commenters confirm the Commission's conclusion that the use of unlicensed technology has exploded, and that there is a current, and growing, need to open additional spectrum resources to unlicensed operations.[2] As Cisco explains, its most recent Virtual

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1 *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, 33 FCC Rcd. 10,496 (2018) ("NPRM"). Unless otherwise noted, all comments cited herein were filed in ET Docket No. 18-295 and GN Docket No. 17-183 on February 15, 2019.

2 *See* Comments of the Boeing Company at 3–4 ("Boeing Comments"); Comments of Broadcom Inc. at 25–26 ("Broadcom Comments"); Comments of Charter Communications, Inc. at 2 ("Charter Comments"); Comments of Cisco Systems, Inc. at 3–8 ("Cisco Comments"); Comments of the Computing Technology Industry Association (CompTIA) at 1 ("CompTIA Comments"); Comments of Facebook, Inc. at 1–2 ("Facebook Comments"); Comments of Federated Wireless, Inc. at 2 ("Federated Wireless Comments"); Comments of GE Healthcare at 1, 6 ("GEHC Comments"); Comments of the Hewlett Packard Enterprise Company at 3–7 ("HPE Comments"); Comments of IEEE 802 at 3 (filed Dec. 12, 2018) ("IEEE 802 Comments"); Comments of Microsoft Corporation at 2–4 ("Microsoft Comments"); Comments of NCTA – The Internet & Television Association at 2, 6–9 ("NCTA Comments"); Comments of Open Technology Institute at New America, American Library Association, Consumer Federation of America, COSN—Consortium for School Networking, Public Knowledge, and Access Humboldt at 5–14 ("PIOs Comments"); Comments of Qualcomm Incorporated at 6–7 ("Qualcomm Comments"); Comments of Quantenna Communications, Inc. at 2 (filed Feb. 14, 2019) ("Quantenna Comments");

Networking Index "reflects that Wi-Fi is 'the crucial link' to the Internet for numerous applications, and that the United States' reliance on Wi-Fi to carry enormous amounts of data will grow markedly over the coming years."[3] GE Healthcare states that "the healthcare industry drives innovation through the use of unlicensed spectrum," and that by "opening up the 6 GHz band for unlicensed use, the Commission can help ensure that these next-generation healthcare applications have the capacity and throughput necessary to reach their full potential."[4] NCTA predicts that "growing consumer demand, increased use of wide, high-bandwidth 'gigabit Wi-Fi' channels, the advent of 5G, and the growth of Internet-of-Things networks will strain the capacity of existing unlicensed bands." NCTA also notes that "between 788 megahertz and 1.6 gigahertz of new mid-band spectrum will be needed by 2025 to satisfy demand just for Wi-Fi."[5] Cisco cautions that "[u]nless the Commission opens new frequencies for unlicensed operations now, rising demand will increasingly result in congestion and adversely impact the user experience."[6]

B. Licensees, Unlicensed Spectrum Advocates, and Many Others Agree That an AFC System Can Protect Licensed Users While Enabling More Intensive Use of the Band.

The overwhelming majority of comments addressing the Commission's AFC proposal agree that a "properly designed system of automatic frequency control"[7] will protect licensees

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Comments of Wi-Fi Alliance at 2–5 ("Wi-Fi Alliance Comments"); Comments of the Wireless Internet Service Providers Association at 4–9 ("WISPA Comments").

3 Cisco Comments at 4.

4 GEHC Comments at 4, 6.

5 NCTA Comments at 2, 8 (citing Steve Methley & William Webb, Quotient Assocs. Ltd., *Wi-Fi Spectrum Needs Study* 26, 28 (2017)).

6 Cisco Comments at 4.

7 Comments of the Fixed Wireless Communications Coalition at 13 ("FWCC Comments").

while enabling unlicensed use of the band. This includes commenters representing or supporting fixed service licensees,[8] broadcast interests,[9] satellite providers,[10] mobile and fixed wireless providers,[11] scientific and public interest groups,[12] trade associations and advocacy groups,[13] and prospective unlicensed users and device makers.[14] The record confirms that AFC must reliably and successfully perform one central mission: ensure that no RLAN device causes harmful interference at the receiver for 6 GHz licensees. As FWCC explains, the potential for harmful interference to FS licensees that support critical public safety and infrastructure functions would only occur, if at all, due to a "single source at an unlikely location."[15] By contrast, the record

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8 *See* Comments of APCO International at 2–3, 5–6 ("APCO Comments"); Comments of the City of New York at 3 ("NYC Comments"); Comments of Comsearch at 7–8 ("Comsearch Comments"); Comments of Ericsson at 20; FWCC Comments at 13; City of LA Comments at 10–11, 13; Comments of Motorola Solutions Inc. at 2 ("Motorola Comments"); Comments of Nokia at 2 ("Nokia Comments").

9 *See* Comments of Alteros, Inc. at 13–14 ("Alteros Comments"); Comments of Teradek, LLC and Amimon, Inc. at 2 ("Teradek/Amimon Comments").

10 *See* Comments of Intelsat License LLC and SES Americom, Inc. at 12; Comments of Sirius XM Radio Inc. at 20 ("Sirius XM Comments").

11 *See* Comments of Cambium Networks, Ltd. at 2–3 ("Cambium Networks Comments"); Federated Wireless Comments at 1–2, 4–5; Comments of Starry, Inc. at 3 ("Starry Comments"); Comments of Verizon at 4–5 ("Verizon Comments"); WISPA Comments at 3, 11. *See also* Charter Comments at passim (discussing AFC implementation).

12 *See* Comments of the National Academy of Sciences' Committee on Radio Frequencies at 5–6 (filed Feb. 14, 2019); PIOs Comments at 25.

13 *See* CompTIA Comments at 2; Comments of CTIA at 17–18; Comments of Dynamic Spectrum Alliance at 9–10 ("DSA Comments"); Comments of the National Public Safety Telecommunications Council at 10 ("NPSTC Comments"); Comments of National Spectrum Management Association at 4–5 ("NSMA Comments"); NCTA Comments at 11–12; Wi-Fi Alliance Comments at 19; Comments of the Ultra Wide Band Alliance at 8 ("UWB Comments").

14 *See* Comments of Apple Inc. at 4–5 ("Apple Comments"); Boeing Comments at 12; Broadcom Comments at 4, 40; GEHC Comments at 8; HPE Comments at 22, 27–28; Microsoft Comments at 15–18; Qualcomm Comments at 11-12; Comments of Sony Electronics Inc. at 1–2 ("Sony Comments").

15 *See* FWCC Comments at 3.

supports the Commission's finding that RLAN operations do not pose an aggregate interference risk. Therefore, while the Commission should adopt rules governing AFC operation to prevent single-source interference, it need not develop a far more complex system for managing aggregate interference.[16]

Commenters emphasize that Commission rules will protect licensees and promote a well-functioning AFC system if they allow for flexibility in AFC implementation and operation.[17] As the Dynamic Spectrum Alliance notes, "[t]he best way for the Commission to ensure success in the 6 GHz band is to issue simple, flexible, ends-oriented rules, rather than adopting an over-regulatory approach."[18] Broadcom explains that the Commission should "give engineers as much freedom as possible to make engineering and design decisions regarding AFC systems—as long as they can provide the protection the FCC determines that FS systems require."[19]

In particular, commenters support geolocation requirements that will allow for accurate calculation of protection contours and will allow RLAN devices to maximize spectrum where doing so will not cause harmful interference to licensed services.[20] As FWCC explains, the

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16 *See* NPRM at 10,502 ¶ 62 & n.143; Facebook Comments at 9 ("There is no need for aggregate interference protection or any other need for data to be synchronized between operators."); FWCC Comments at 3, 12–13; HPE Comments at 25 ("The AFC must prevent each device under its control from operating within the zone where it could cause harmful interference to a licensed receiver on a certain frequency. But it does not need to know where devices under the control of another AFC are operating."); Wi-Fi Alliance Comments at 24, 36 ("[T]here is no need for AFCs to track aggregate interference, because there is no meaningful risk of increased aggregate interference from U-NII devices.").

17 *See* Broadcom Comments at 40–44; Microsoft Comments at 15–21; PIOs Comments at 26–27; HPE Comments at 24–25; Comments of the R Street Institute at 5 (filed Feb. 8, 2019) ("R Street Comments").

18 DSA Comments at 10.

19 Broadcom Comments at 41.

20 *See* APCO Comments at 14; Comsearch Comments at 26–27; DSA Comments at 13–14; FWCC Comments at 29–30; HPE Comments at 24; Motorola Comments at 4; PIOs

Commission should allow the AFC to "ascertain the location accuracy for the particular environment, and coordinate the RLAN as though it were at the worst-case location within its region of uncertainty," rather than impose a strict "one-size-fits-all" location accuracy rule.[21] Allowing for flexibility in geolocation requirements will not increase the risk of harmful interference to licensees because an AFC "will produce larger protection contours to account for location uncertainty."[22] The FCC should allow AP manufacturers to prioritize location specificity for certain use cases or in higher-cost devices, or to accept more restricted channel availability that results from less location specificity for lower-cost devices. This will facilitate innovation and "encourage a diversity of use cases and service tiers," without compromising the AFC's interference protection function.[23]

This endorsement of flexible geolocation includes support for including height (i.e., z-axis coordinates) in AFC calculations, producing three-dimensional rather than two-dimensional protection contours.[24] Commenters note that considering an AP's "vertical location as well as horizontal location could lead to more accurate interference prediction

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Comments at 27; Qualcomm Comments at 17; Teradek/Amimon Comments at 8, 11; Wi-Fi Alliance Comments at 25–26.

21 FWCC Comments at 29. We agree with FWCC's recommendation that FCC rules allow the use of actual geographic positioning. We therefore disagree with FWCC that the Commission should take a strict one-size-fits-all approach to z-axis coordinates. We recommend that rules should allow AFCs to assign not only true x- and y-coordinates but also true z-axis coordinates.

22 HPE Comments at 24.

23 PIOs Comments at 27.

24 *See* NPRM at 10,515-16 ¶¶ 51–52; APCO Comments at 14; DSA Comments at 13; Comsearch Comments at Attachment A, tbl.3; FWCC Comments at 13, 29–30; HPE Comments at 24; Microsoft Comments at 19; Motorola Comments at 4; NCTA Comments at 12–13; NPSTC Comments at 11; NSMA Comments at 24; NYC Comments at 3; Sony Comments at 1; Comments of Southern Company Services, Inc. at 17; Starry Comments at 4; Wi-Fi Alliance Comments at 26; WISPA Comments at 17–18.

determinations,"[25] and that three-dimensional "modeling of antenna patterns and propagation paths (incorporating terrain and clutter effects) will also greatly improve the accuracy of the modeling performed in the AFC function."[26] The Commission should therefore adopt rules that allow AFC systems to produce three-dimensional protection contours around licensed receivers rather than relying on typical installation heights, or imposing height limits on APs, to produce two-dimensional exclusion zones.

Finally, the record provides strong support for the Commission's proposal to "designate multiple entities to operate AFC systems."[27] Numerous commenters note that, with access to an updated and accurate database of licensee receiver information, the FCC can test and certify multiple AFC operators to perform protection calculations and grant access to unlicensed APs.[28] For the 6 GHz band, "the Commission can adopt a more result-oriented and flexible framework that allows competing approaches."[29] The Commission can both maximize investment and protect licensees through a well-designed system of rules that set performance criteria for AFC implementations without unnecessarily regulating the technologies used to achieve them.

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[25] NPSTC Comments at 11.

[26] Motorola Comments at 4.

[27] NPRM at 10,507–08 ¶ 33.

[28] *See* APCO Comments at 10; Apple Comments at 11–13; Broadcom Comments at 43–44; Comsearch Comments at 25–26; DSA Comments at 12; Facebook Comments at 9; Federated Wireless Comments at 11–12; HPE at 25; Microsoft Comments at 20; Motorola Comments at 4–5; Comments of NETGEAR, Inc. at 2 (filed Feb. 13, 2019); PIOs Comments at 26; Quantenna Comments at 5; Sony Comments at 7–8; Teradek/Amimon Comments at 6; Wi-Fi Alliance Comments at 26–27; WISPA Comments at 19–20.

[29] PIOs Comments at 26.

C. Low-Power Indoor and Very-Low-Power Operating Restrictions Will Protect Incumbents in the 6 GHz Band, and the Commission Should Adopt Rules Authorizing Such Operations.

Numerous commenters also support the Commission's proposal to allow low-power indoor (LPI) operations in U-NII-6 and U-NII-8 without AFC control,[30] and agree that operation at those low power levels, indoors, will protect the licensees in those bands from harmful interference.[31] Notably, numerous commenters also support extending the Commission's proposal to authorize LPI operations to U-NII-5 and U-NII-7, thus allowing LPI operations throughout the entire 6 GHz band.[32] For example, Cisco explains that the Commission should permit LPI operations across the band because "the viability of that spectrum to support the high-traffic, fast-growing uses of unlicensed spectrum . . . would be threatened if the Commission were to limit low-power operations to less than half of the new spectrum in the 6 GHz band."[33] Likewise, Qualcomm highlights the fact that "to permit in alternating 6 GHz sub-bands standard-power unlicensed devices under AFC control and LPI devices would hinder investment in the 6 GHz band. It would prevent LPI devices from being able to access wider channel sizes that straddle multiple U-NII sub-bands to facilitate higher speeds and thus reduces the potential for global harmonization with other jurisdictions that permit LPI in U-NII-5."[34] As Boeing observes,

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30 NPRM at 10,518–19 ¶¶ 59–62.

31 *See* Motorola Comments at 6; Nokia Comments at 5; R Street Comments at 6; Sirius XM Comments at 11–12, 16.

32 *See* NPRM at 10,522 ¶ 73; Apple Comments at 3; Boeing Comments at 6–7; Broadcom Comments at 5–16; Cambium Networks Comments at 2; Charter Comments at 3; Cisco Comments at 10–13; CompTIA Comments at 2; Facebook Comments at 3–4; GEHC Comments at 7–8; HPE Comments at 7–17; Comments of HP Inc. at 3–4; Microsoft Comments at 5–11; NCTA Comments at 15–16; NETGEAR Comments at 2–3; Qualcomm Comments at 9–10; Quantenna Comments at 3–4; PIOs Comments at 17–20; Wi-Fi Alliance Comments at 10–17; WISPA Comments at 27–28.

33 Cisco Comments at 13.

34 Qualcomm Comments at 10.

"[g]iven the fact that the vast majority of unlicensed systems operate indoors, a decision to permit all 6 GHz U-NII devices to operate indoors without AFC control is warranted and can be implemented without resulting in harmful interference to incumbent services."[35]

Further, the record supports allowing a very-low-power (VLP) device class to operate at 14 dBm power limits without AFC control because devices operating at these power levels present no real-world risk of harmful interference.[36] As Apple highlights, this class of devices "would enable important applications at short ranges, including communications between devices and accessories such as headphones, hearing aids, watches, game controllers, and other peripherals."[37] Broadcom explains that VLP 14 dBm battery-operated devices would operate in geometries and at sufficiently low power levels that pose no actual risk of harmful interference to FS operations: "a portable device operating in a 160-megahertz channel at 14 dBm EIRP would have a transmitted PSD of only -8 dBm/MHz (157 µW/MHz)." Likewise, "[e]ven a 20-megahertz transmission would amount to a meager 1 dBm/MHz."[38] The Commission could, as Broadcom suggests, limit the maximum transmitted power spectral density to 1 dBm/MHz for this type of device.[39] The Commission can facilitate more rapid investment and innovation in the band by adopting rules to allow VLP use, without creating any additional risk of harmful interference to licensed incumbent services.[40]

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35 Boeing Comments at 6.

36 Apple Comments at 2–3, 7–9; Broadcom Comments at 27–31; Facebook Comments at 5–6; HPE Comments at 7, 16–17.

37 Apple Comments at 7–8.

38 Broadcom Comments at 29.

39 *Id.*

40 *See* Facebook Comments at 4.

D. The Record Supports Permitting Portable Unlicensed 6 GHz Devices Because They Present No Additional Harmful Interference Risk.

The NPRM asked whether Commission rules should permit portable operation of unlicensed APs under the control of an AFC system.[41] Numerous commenters demonstrated not only that such operation is feasible, but that it is important to meeting consumer expectations and delivering on the full value of the band.[42] As the Wi-Fi Alliance explained, "as technology evolves, mobile and transportable APs will constitute important use cases in the Wi-Fi ecosystem, addressing the growing demand for mobile connectivity."[43] Qualcomm explains that "[t]he same tools the AFC system uses to prevent interference to licensed incumbents can also cover portable devices and in-vehicle use."[44] DSA points out that Commission precedent strongly supports authorization of portable AFC-controlled devices, because "[t]he Commission has already concluded that it can protect licensees in other bands from interference from portable or mobile devices using a simple combination of re-check periods tied to motion as well as time."[45]

Commenters also explain that 6 GHz RLAN devices can operate in moving vehicles such as cars, trains, or aircraft without causing harmful interference.[46] Boeing encourages the Commission to treat the inside of aircraft cabins as indoor locations, as the Commission and

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[41] NPRM at 10,523 ¶ 76.

[42] *See, e.g.*, Apple Comments at 4–10; Broadcom Comments at 27–31, 45–46; DSA Comments at 14–15; HPE Comments at 25–26; NETGEAR Comments at 3; Qualcomm Comments at 15–16; Sony Comments at 9; Teradek/Amimon Comments at 8; UWB Comments at 9; Wi-Fi Alliance Comments at 34–35.

[43] Wi-Fi Alliance Comments at 34.

[44] Qualcomm Comments at 15.

[45] DSA Comments at 14.

[46] *See* Apple Comments at 7–11; Boeing Comments at 7–11; HPE Comments at 25–27.

other regulators have previously done in other bands.[47] Boeing explains that aircraft fuselages provide attenuation values between 20 dB and 45 dB, and that "the NPRM is incorrect in asserting that the signal attenuation from aircraft 'is likely to be significantly less than from a building.'"[48]

Several parties also explain that unlicensed operations inside automobiles and other terrestrial vehicles can protect incumbent services by operating at VLP levels,[49] or under the control of an AFC system.[50] The flexible geolocation parameters proposed by the Commission and supported by numerous commenters, as described above, will enable the operation of portable APs and devices inside vehicles.[51]

E. The Commission Should Adopt Technical Rules Allowing Effective Unlicensed Use Without Increased Risk of Harmful Interference, Including Higher PSD, and Higher Radiated Power Levels for Client Devices.

Many commenters emphasize that the proposed framework for the 6 GHz band will best facilitate deployment of unlicensed technologies if the Commission adopts technical rules allowing unlicensed devices to make efficient use of the frequencies, while still protecting licensees from harmful interference. Specifically, many parties support higher power spectral density limits than the Commission suggested in the NPRM.[52] The Commission should adopt power levels of 27 dBm/MHz for standard-power AFC-controlled equipment and 21 dBm/MHz

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[47] Boeing Comments at 8–10.

[48] *See id.* at 10 (citing NPRM at 10,526 ¶ 84); *see also* Apple Comments at 10–11.

[49] Apple Comments at 7–9.

[50] DSA Comments at 14; HPE Comments at 26; Qualcomm Comments at 15–16; Wi-Fi Alliance Comments at 34.

[51] *See* HPE Comments at 26.

[52] *Compare* NPRM at 10,523–24 ¶ 78 *with* Charter Comments at 3, Broadcom Comments at 34, NCTA Comments at 16–17, NETGEAR Comments at 2–3, Qualcomm Comments at 16–17, Wi-Fi Alliance Comments at 37–38, *and* WISPA Comments at 12–13.

for LPI operations to ensure that FCC rules keep pace with technological innovation and support the next generation of RLAN standards.[53]

Additionally, numerous commenters support higher power levels for client devices, allowing them to match the power levels of their associated APs.[54] The power levels for client devices specified in the NPRM would result in unbalanced links and create situations where the AP could communicate with the client, but not the other way around.[55] These commenters show that matching power levels will not increase the risk of harmful interference. For standard-power operation, the AFC will account for client devices in calculating protection contours. For LPI and VLP operations, restricted power levels and the LPI indoor-only requirement will protect licensees.

II. Proposals to Clear and License a Portion of the Band—Thereby Displacing Both Federal Users of the 7 GHz Band and Commercial Users of the 6 GHz Band—Are Patently Unworkable.

There is substantial support for the Commission's proposal to allow sharing between unlicensed devices and 6 GHz licensees. And while there are disagreements about the rules that should govern that sharing, the vast majority of commenters agree on the importance of preserving and protecting existing licensed use of the band. Nonetheless, CTIA and Ericsson propose that the Commission not only cap future FS growth in the 6 GHz band and forcibly relocate all incumbent users from the majority of it—but also that it should displace federal users

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[53] *See* Broadcom Comments at 34; Charter Comments at 4; NCTA Comments at 17; Qualcomm Comments at 16–17.

[54] *See* Broadcom Comments at 36–37; Cambium Networks Comments at 4; Charter Comments at 4; Facebook Comments at 5; GEHC Comments at 7; Microsoft Comments at 12–13; Motorola Comments at 6; NCTA Comments at 16–17; NETGEAR Comments at 3; Qualcomm Comments at 16; Quantenna Comments at 6–7; Starry Comments at 3–4; Wi-Fi Alliance Comments at 28; WISPA Comments at 13–14.

[55] *See* Microsoft Comments at 12.

from the 7 GHz band to make room for this relocation.[56] The Commission should reject this proposal.

Neither CTIA nor Ericsson provide a concrete explanation of their plan. How will their proposed relocation occur? They do not offer any insights. What frequencies will displaced government systems use? There is no roadmap. How long will this process take? Clarity on this delay is conspicuously absent. Because they have not even tried to address these basic questions, CTIA and Ericsson have not provided the Commission with any way to reasonably evaluate their proposal. For this reason alone, the Commission should not pursue it.

Furthermore, CTIA's proposal would have the Commission and NTIA displace federal users from the 7 GHz band to make room for 6 GHz incumbents. The 7 GHz band is currently allocated for exclusive federal use.[57] There is no evidence that existing federal users would be amenable to this arrangement. In fact, many of these agencies have just been relocated from 1.7 GHz to clear *another* band for licensed mobile services.[58]

Notably, the 6 GHz incumbents that CTIA plans to displace would include both fixed and mobile licensees, including TV pickup licensees that are protected by exclusion zones from new FS links.[59] CTIA's band-clearing proposal also would require users to purchase new equipment if 6 GHz incumbents are involuntarily relocated to the 7 GHz band. This would include FS radios and antennas as well as equipment used on broadcast trucks, news studios, camera-back transmitters, and other devices. As NAB points out, many BAS operations in U-NII-8 were

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[56] CTIA Comments at 13–16; Ericsson Comments at 13–16.

[57] *See* 47 C.F.R. § 2.106.

[58] *See* Urgent Communications, *AWS auction spawns spectrum shuffle* (Jan. 1, 2007), https://urgentcomm.com/2007/01/01/aws-auction-spawns-spectrum-shuffle/.

[59] 47 C.F.R. § 101.147(a) note 34.

recently relocated themselves from the UHF band.[60] The band-clearing proposal would burden these licensees with yet another forced transition, this time to an uncertain destination.

Perhaps CTIA intends for these licensees to share spectrum with government users. If so, the mere possibility of such an arrangement would be contingent on federal acquiescence to a proposal to share spectrum between government communications links and mobile broadcast operations that broadcast licensees themselves have described as incorrectly registered and unpredictable.[61] But because CTIA has made this proposal without providing a single study, much less a developed plan on how to establish that these operations can share with federal incumbents, the outcome of its proposed process is speculative at best.

Finally, the 6 GHz band also includes uplink and downlink operations for several satellite operators that likely cannot be moved without replacing existing satellite fleets. Although CTIA minimizes the sharing challenges, it has not offered any technical analysis to substantiate claims that high-power cellular radios can coexist with FSS systems without harmful interference. By contrast, this proposition has been documented extensively with respect to unlicensed operations.[62] It may be that CTIA also proposes to move satellite operations out of the 6 GHz band, but it fails to provide information about how this could occur.

CTIA's argument is largely premised upon a specious appeal to "balance." CTIA has it exactly backwards. Opening the 6 GHz band to unlicensed use is needed to maintain a balance with other Commission efforts to free new licensed spectrum for use by CTIA's carrier

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60 *See* Comments of the National Association of Broadcasters at 13 ("NAB Comments").

61 *See, e.g.*, *id.* at 12–14.

62 *See, e.g.*, RKF Engineering Services, *Frequency Sharing for Radio Local Area Networks in the 6 GHz Band* (Jan. 2018) ("RKF Study"), *as attached to* Letter from Paul Margie, Counsel, Apple Inc., Broadcom Inc., Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Jan. 26, 2018).

members.[63] But the critical fact is that the nation is facing a serious and growing unlicensed-spectrum deficit. Experts have estimated that, unless the Commission acts, current trends in data usage will cause the growth in demand for unlicensed spectrum to continue to outpace supply, with the deficit growing to as much as 1.5 gigahertz by 2025.[64] The most recent projections are that more than half of *all* IP traffic will run over Wi-Fi, with the number of Wi-Fi hotspots expected to quadruple. In fact, 54% of all mobile traffic already relies on Wi-Fi, with Wi-Fi's share expected to continue growing.[65] By contrast, CTIA ignores the vast amounts of exclusively licensed spectrum that the FCC has opened up for licensed mobile operations in recent years. Ericsson's own data highlights this disparity between growth in unlicensed and licensed spectrum use. For example, although Ericsson's comments highlight growing demand for licensed spectrum for IoT, Ericsson's own *Internet of Things Forecast* makes clear that the need for unlicensed spectrum will remain far greater for the foreseeable future.[66] Although cellular-based IoT is a growing segment, as the Ericsson report observes, that market remains only about one-tenth the size of the installed base of unlicensed IoT devices, and that disparity shows no sign of closing.[67]

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[63] CTIA ignores not only that there are several other ongoing proceedings to open new spectrum exclusively to licensed users, but also that band-clearing proponents actually seek to claim more than half of the 6 GHz band, that the unlicensed portion of 6 GHz would be shared while the top 6 GHz would be available to licensees exclusively, and that many of the licensed users of the lower 6 GHz band are themselves licensed mobile operators.

[64] Steve Methley & William Webb, Quotient Associates, *Wi-Fi Spectrum Needs Study* 26 (Feb. 2017).

[65] Cisco, *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017 – 2022 White Paper* 17 (Feb. 2019), https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.pdf ("Cisco VNI").

[66] *See* Ericsson, *Internet of Things Forecast*, https://www.ericsson.com/en/mobility-report/internet-of-things-forecast (last visited Mar. 18, 2019).

[67] *Id*.

The growing need for additional unlicensed spectrum is partially due to the fact that mobile networks, especially emerging 5G networks using the 3GPP 5G NR standard, themselves will use unlicensed spectrum, including unlicensed 6 GHz spectrum. In fact, without access to unlicensed spectrum, the transition to 5G would fail because of the enormous percentage of traffic that is offloaded from licensed onto unlicensed spectrum. More than half of all mobile traffic already uses unlicensed bands and, in 5G networks, more than twice as much mobile data is projected to travel over Wi-Fi as over licensed spectrum.[68] Therefore, making more spectrum available for unlicensed use would help to address any spectrum crunch that carriers may face in the future.

III. Interference Claims Submitted by FWCC and Other FS Incumbents Are Flawed and Unreliable.

The Commission has developed an extremely robust record that demonstrates how the AFC system can protect incumbents using a combination of licensee data from ULS, reported RLAN characteristics, and a version of the WINNER II propagation model. The record also demonstrates that devices without AFC control will protect incumbents through a combination of strict power limits and usage restrictions, enabling the critical LPI and VLP indoor/outdoor device classes.

By far the most careful, robust, and transparent analysis in the record is the RKF report, which used real FS-link data, highly conservative RLAN usage assumptions, and extensive Monte Carlo analysis of potential device placement.[69] This study produced a thorough documentation of the potential interference risk to FS links from standard-power RLAN operation without AFC control, including several probability distributions quantifying the

[68] Cisco VNI at 17–18.

[69] *See supra* note 62.

likelihood of various degrees of interference and the real-world effects of those levels of interference. The results showed that even standard-power RLAN operations not subject to any of the FCC's proposed interference-protection mechanisms would only exceed a highly conservative -6 dB I/N interference protection threshold 0.2% of the time. Importantly, -6 dB I/N is not a threshold for harmful interference; rather, it is a *protection* threshold with built-in margin. Thus, even in those 0.2% of cases, RKF's analysis demonstrated that interference would still not cause any change in the FS link's reliability. Links designed for 99.999% reliability, for example, would continue to meet that standard.[70]

RKF's analysis evaluated the interference risk of standard-power operations without AFC control. In our previous comments we provided additional analyses of the very low risk of interference posed by both LPI and VLP devices, focusing on the very narrow and unusual case of a device operating immediately in front of (i.e., aligned in azimuth with) an FS receiver both at ground level, in the case of a VLP device, and in a high-rise building, in the case of an LPI device. Thus, even though the overwhelming majority of configurations clearly pose no interference risk, we focused on unlikely situations where interference may have been thought to be possible. But even here, analysis showed no real-world risk of harmful interference.

Despite this, and notwithstanding the presence of an extraordinarily robust technical record, some commenters claim that our analysis and RKF's study represent only a crude "average of averages" analysis that ignores worst-case interference scenarios.[71] These complaints are misinformed. The RKF study does not consider merely "average" situations. As we have repeatedly emphasized, our companies are committed to protecting FS links from harmful

70 RKF Study at 43–53.

71 *See, e.g.*, Comments of El Paso Electric Company at 7; FWCC Comments at 4, 23–24.

interference. For that reason, our analyses have focused specifically on the very worst-case situations that FS incumbents claim we ignore. The RKF report took a wider view than limiting its study *only* to these unlikely scenarios, but any accusation that it evaluated only an "average" situation yielding a single numeric result is not credible. Although we have highlighted the 0.2% chance RKF identified of exceeding a -6 dB I/N threshold, this single number is only one value from a fully specified probability distribution included in RKF's report.[72] That probability distribution was then convolved—not averaged—with the distribution of fade margins for the entire population of FS receivers in the continental United States to predict the real-world effects of various interference levels on the availability of FS links, taking into account actual parameters for the full gamut of FS link configurations reflected in ULS.

Nonetheless, overlooking the numerous respects in which our analyses have focused almost exclusively on worst-case interference situations, FWCC focuses on two narrow parameters where they claim our assumptions have been too optimistic: propagation modeling and building entry loss. However, FWCC's arguments focus on isolated and hypothetical scenarios, without addressing the real-world relationships between these factors which make any significant interference extremely unlikely. FWCC also does not properly account for FS fade margin and other robustness features in determining the probability that this remote risk of measurable interference would translate into *harmful* interference.

Propagation modeling. FWCC unreasonably insists that the Commission must always assume free-space propagation conditions when evaluating the interference risk. Only this extreme assumption, they argue, will adequately protect FS receivers under worst-case propagation conditions. A Commission decision to do this would be a novel requirement. In

[72] *See* RKF Study at 47–48.

numerous prior proceedings, the Commission has decided to use conservative, but still realistic, propagation models for predicting harmful interference to incumbents. In the 600 MHz Incentive Auction proceeding, for example, the Commission decided to use a combination of Longley Rice and the Extended Hata model (with which WINNER II is generally consistent) to protect broadcast licensees from potentially interfering with licensed mobile wireless and unlicensed White Space transmissions.[73] Mobile wireless licensees including AT&T[74] and T-Mobile[75] supported the use of such terrain and clutter aware models in that context, and did not recommend that the Commission assume free-space propagation for all interference calculations. The same was true for protecting incumbent fixed broadband providers and other priority users in the 3.5 GHz CBRS proceeding. There, AT&T argued, for example, that "[e]ach SAS should include a collection of propagation models suitable for the diverse environments and deployment scenarios that will be present in the 3.5 GHz band."[76] AT&T did not argue that each SAS should use only free-space propagation.

This is for good reason: assuming free-space propagation would drastically over-protect licensees in virtually every instance and, correspondingly, would sharply reduce the spectrum available for productive uses. This is not to say that free-space conditions will never apply. In particular, we agree with FWCC and others that free-space conditions could apply between FS

73 *See Unlicensed Operation in the TV Broadcast Bands*, Third Memorandum Opinion and Order, 27 FCC Rcd. 3692, 3699 ¶ 17 & n.51 (2012); *Longley-Rice Methodology for Predicting Inter-Service Interference to Broadcast Television from Mobile Wireless Broadband Services in the UHF Band*, OET Bulletin, FCC/OET-74 (Oct. 26, 2015), https://transition.fcc.gov/bureaus/oet/info/documents/bulletins/oet74/OET74.pdf.

74 Comments of AT&T Inc. at 6, GN Docket No. 12-268 (filed June 14, 2013).

75 Letter from Trey Hanbury, Counsel to T-Mobile USA, Inc. to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 12-268, WT Docket No. 12-269, Attachment B at 8 (filed Sept. 24, 2013).

76 Comments of AT&T at 7–8, GN Docket No. 12-354 (filed July 15, 2015).

receivers and RLAN devices operating in some high-rise buildings in some situations—but in these cases significant building entry loss would apply, greatly reducing any risk of harmful interference.[77]

Building entry loss. Although FWCC claims that 30 dB building attenuation is excessive, the record provides a great deal of evidence that this assumption holds for high-rise buildings that might be located in the path of an FS link. We agree that other types of buildings, such as single-family homes in temperate environments, may exhibit less attenuation. But, transmissions originating from within this type of building will not be subject to line-of-sight propagation conditions. In the infrequent case that such a building is located near the FS receiver, it will be located well below the FS main beam or it will be far away from the FS receiver. Therefore, the building entry loss associated with these buildings is of far less significance.

Even in high-rise buildings, however, FWCC claims that devices located just inside of building windows will exhibit far less than 30 dB building loss. In fact, it goes so far as to make the extraordinary claim that such devices are effectively "outside."[78] This is incorrect. Although modern energy-efficient windows used in high-rise buildings are transparent to visible light, the record clearly establishes that these windows attenuate 6 GHz signals very significantly. This is because, as the Leading Builders of America explain, modern windows are typically multi-paned, have metal coatings, or both.[79] While attenuation associated with such a window may be less than that of a concrete and steel wall, it remains very significant. In fact, the attached results

[77] Free-space conditions may also occur in situations where an RLAN device is very close to an FS receiver. However, an RLAN device at ground level sufficiently close to the FS antenna would be far from its boresight and likely be subject to significant sidelobe rejection.

[78] FWCC Comments at 21–22.

[79] Comments of the Leading Builders of America at 13–14.

from measurements performed by Qualcomm in a Qualcomm office building in San Diego, CA show that its windows attenuate 6 GHz signals by about 25 dB—hardly equivalent to being located "outside."[80] The measurements also indicate that the overall attenuation due to building loss was as great as 70 dB.[81]

This narrow focus on the building entry loss of various construction materials also overlooks real-world usage, adding another unrealistically conservative assumption. In actual deployments—whether consumer or enterprise—access points are not positioned such that they transmit directly out the window towards a nearby FS receiver. In the real-world, access points typically transmit either down towards the floor (as in enterprise installations),[82] or mostly towards ceilings, walls, and furniture. Thus, building entry loss, properly understood, applies *in addition to* significant losses caused by reflecting off of or passing through interior surfaces, either of which would absorb significant radiofrequency energy. FWCC does not account for this in its analysis.

Fade margin. It is also critical to remember that a momentary increase in the noise received by an FS transmitter would almost certainly not constitute harmful interference, even if an outlandishly unlikely situation were to occur. As two experts on FS link design explained in the opening comment round, virtually all FS transmitters have tens of dB in fade margin, so that the link can continue operating at its intended speed during periods when multipath fading

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80 Measured Attenuation from a Large Building Wall at 6.0, 6.5 and 7 GHz at A-12, attached hereto as Appendix A.

81 *Id.* at A-11–A-12, A-14.

82 Comments of Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Semiconductor, Inc., Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company at Appendix D, Characteristics of Enterprise Deployments Using IEEE 802.11 Equipment ¶¶ 7–11 (filed Feb. 15, 2019) ("RLAN Group Comments").

temporarily increases, reducing received signal strength at the FS receiver.[83] In fact, links used for public safety and links with receivers located near urban areas tend to be designed with even greater available fade margin due to the critical nature of the link, or because the shorter path length makes greater margin readily achievable—and often both.[84] They also tend to use space diversity and other techniques to increase robustness. Therefore, for the two types of links for which this analysis is most important, the data show that they will be especially robust in the event of any worst-case RLAN interference.

Importantly, unless the already-unlikely interference event coincides with a period of maximum fading, there will be no effect on the FS receiver because the signal-to-noise ratio at that receiver will already be far above what is necessary to maintain link performance. For the sake of comparison, exceeding a noise level of 0 dB I/N, 6 dB above the widely agreed AFC protection threshold of -6 dB I/N, would only increase the noise floor of the FS receiver by 3 dB. But most links are designed to achieve signal-to-noise ratios 25-40 dB, or more, beyond what is necessary to account for environmental concerns completely unrelated to RLAN activity.[85] Moreover, the consequence of briefly exceeding a link's available fade margin is typically not an outage. Although FWCC, the Utilities Technology Council and several other utility interests (UTC/EEI), and others imply that momentarily exceeding the available fade margin will result in a complete outage of the link, the reality is that for any modern radio employing adaptive modulation, the link would temporarily employ a lower order modulation that is able to tolerate a

[83] *See* RLAN Group Comments at Appendix B, Declaration of Fred Goldstein Regarding Fixed Service Operations ¶ 33 ("Goldstein FS Declaration"); HPE Comments at Appendix 2, Declaration of Ira Wiesenfeld at 11 ("Wiesenfeld Declaration").

[84] *See* Reply Comments of Broadcom Inc. at 10, 12, 14–15 (filed Mar. 18, 2019).

[85] FWCC Comments at 16.

lower signal-to-noise ratio for the duration of the interference event.[86] We do not propose that the Commission should craft its rules specifically to allow this miniscule amount of noise to FS receivers. Instead, the point is that even if an extreme outlier event did occur, the very small amount of interference to FS receivers would not be harmful.

FWCC highlights a single, unnamed system that it claims would be taken offline for 15 minutes while it "resynchronizes" if it received even momentary interference.[87] We are not aware of any such radio system and ask that FWCC identify it on the record. Unless FWCC identifies this system, it would be inappropriate for the Commission to consider this assertion because neither the Commission nor other parties can evaluate FWCC's claim. It may be possible that a system requiring a 15-minute resynchronization period whenever *any* network connectivity is interrupted could be incorporated as part of a network involving one or more FS links. But as FS experts Fred Goldstein and Ira Wiesenfeld both explained,[88] it would be exceptionally poor engineering practice to design such a network in a way that would be susceptible to outages of single FS paths. In fact, UTC/EEI concede that a system with such extreme reliability requirements "is accomplished through the use of redundant ring pathways."[89] Typically, such a network would use redundant paths or other techniques, and if nothing else, certainly could be expected to be designed with significant excess fade margin to ensure robustness.

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86 *See* Goldstein FS Declaration ¶ 34; Wiesenfeld Declaration at 16.

87 FWCC Comments at 2.

88 *See* Goldstein FS Declaration ¶¶ 35–40; Wiesenfeld Declaration at 15–16.

89 *Spectrum and Utility Communications Networks: How Interference Threatens Reliability* (2019), *as attached to* Comments of Utilities Technology Council, Edison Electric Institute, National Rural Electric Cooperative Association, American Public Power Association, American Petroleum Institute, and American Water Works Association.

In fact, UTC/EEI's detailed explanation of Tier 1 utility networks highlights the fact that such extreme reliability requirements are generally not met through the use of single links designed for similarly extreme reliability. According to UTC/EEI, each link is only designed to achieve a reliability of 99.97%, and these links are integrated into a broader architecture that achieves five nines for the system as a whole. But there is no way a system that requires a 15-minute resynchronization period after an outage could possibly achieve these reliability goals without using other robustness features such as redundant paths. Link reliability of 99.97% represents 26 seconds of outage *per day*, or over 13 minutes per month. But if each of these disruptions triggered a 15-minute system outage due to resynchronization, there would be no way for the system as a whole to achieve even 99.97% link availability, let alone 99.999%. Regardless, there is no reason to anticipate that RLAN interference would cause any such outage. In the very unlikely event that an FS link experiences sufficient interference to affect its operations, the consequence would be reduction in speed, not outage of the link.[90]

Finally, a small number of commenters provided studies that raise even more unlikely interference concerns, including aggregate interference.[91] Each of these studies, however, suffers from a common flaw: greatly exaggerated RLAN duty cycle assumptions. A small number of commenters continue to assume activity levels ranging from 10% to *100%*, without any reasoned explanation. In each case, this mistaken assumption leads them to conclude that the possibility of RLAN interference is far greater than it is and underlies their incorrect assertions that FS and

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90 *See* Goldstein FS Declaration ¶ 34; Wiesenfeld Declaration at 16.

91 *See* Comsearch Comments at Appendix A, *Sharing in the 6 GHz Band by Unlicensed Low-power Indoor Devices*; Lauri Sormunen et al., Nokia Bell Labs, *Coexistence of Unlicensed National Information Infrastructure (U-NII) Devices with Fixed Links at 6 GHz* (2018), *as attached to* Nokia Comments; Roberson and Associates, LLC, *Technical Analysis of Impact of Unlicensed Operations in U-NII-8 on Globalstar Mobile Satellite Service* (2018) ("Globalstar Study") *as attached to* Comments of Globalstar, Inc. ("Globalstar Comments").

FSS licensees could experience aggregate RLAN interference. Nokia, for example, bases its study on a highly unrealistic assumption of "full buffer" RLAN traffic, i.e. 100% duty cycle. Assuming gigabit speeds, this level of utilization would correspond to an implausible 450 gigabytes per hour, equivalent to approximately 200 HD streaming movies. Similarly, Globalstar assumes a lower, but still incorrect, 10% duty cycle. This would likewise translate into an implausible 45 gigabytes per hour. Correcting these and, in some cases, other erroneous assumptions, accounts for the implausible results of these studies.

IV. The Commission Should Affirm Its Proposal Not to Require Special Adjacent-Channel Restrictions and Should Reject Calls to Establish Massive Guard Bands to Protect FS Licensees.

The Commission rightly proposed not to establish unnecessary adjacent-channel restrictions that would limit RLAN devices' abilities to operate on channels close to, but not overlapping, those used by nearby FS receivers. As the NPRM recognizes, the out-of-channel emissions characteristics of RLAN devices themselves can prevent any such interference.[92] This is true of standard-power devices under AFC control as well as LPI and VLP devices.

Nonetheless, some FS interests raise concerns about potential adjacent-channel interference.[93] FWCC presents these concerns in the greatest detail. FWCC does not appear to disagree that RLAN devices' adjacent-channel emissions characteristics can protect FS receivers from any potential interference due to out-of-channel emissions by RLAN devices into the channel being used by the FS receiver.[94] However, FWCC claims that FS receivers will experience harmful interference because the filters used in FS receivers do not adequately

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92 NPRM at 10,511 ¶ 44.

93 *See, e.g.*, Comments of the Association of American Railroads at 10–11; Comsearch Comments at 22–23; NSMA Comments at 17–23.

94 FWCC Comments at 25.

distinguish between energy within their channel and energy present in other nearby channels. These would not be out-of-band (or, more accurately, out-of-channel) emissions from the RLAN device, but rather transmissions within the RLAN device's channel of operation (but outside the FS channel of operation) that are erroneously received by an FS receiver operating on an adjacent channel. This, FWCC claims, means that no matter how stringently RLAN devices limit their out-of-band emissions, they will still need to use huge guard bands in order to accommodate the supposedly poor adjacent-channel filtering performance of FS receivers.[95] FWCC suggests that these guard bands may be as wide as 50% of the FS channel width, meaning that they could be up to 30 megahertz wide for a 60-megahertz FS channel. Considering that FWCC claims these guard bands would be needed both above and below each and every FS channel, this would leave a huge amount of spectrum unused—by either FS or RLAN operations—in order to accommodate certain FS receivers with low-performance filters.

Rather than basing its claims on a typical FS system, FWCC appears to assume that all receivers will have the same receiver performance of an older FS radio that is likely near the end of its useful life. Given the spectrum constraints on FS links in certain high-value areas and the significant cost of deploying an FS link, it does not appear realistic that the typical receiver could exhibit the poor adjacent-channel rejection FWCC asks the Commission to use as the basis of its analysis. In addition, in a modern radio, the performance of the receiver filter itself is only one part of the complete receiver system that works together to nearly eliminate adjacent-channel interference from all but the strongest sources. In addition to the front-end receiver filter that FWCC describes, the baseband radio of a modern receiver should be capable of eliminating virtually all adjacent-channel noise through digital processing. In addition, as FWCC's diagram

[95] *Id.* at 27.

illustrates,[96] FS radios also observe an internal guard band, presumably to minimize adjacent-channel interference between FS systems. RLAN operations should be authorized consistent with these receiver characteristics.

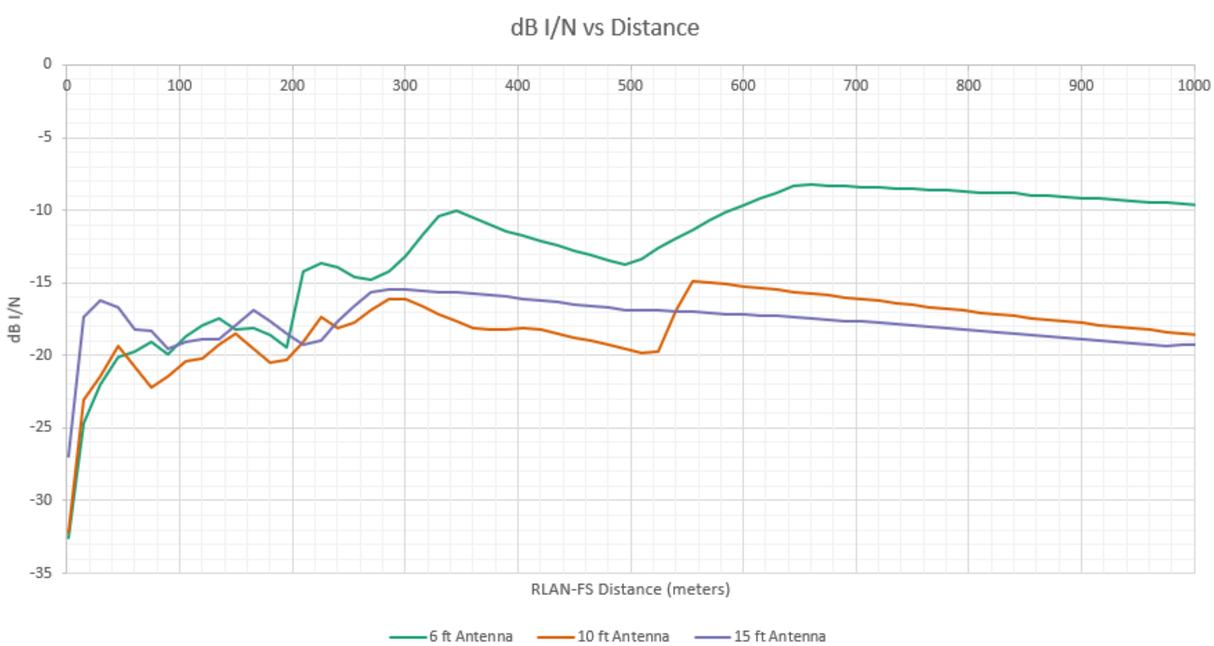
Critically, however, there is no need for the huge guard bands that FWCC proposes, even to protect the vulnerable FS receivers that FWCC describes. Like all other aspects of RLAN-to-FS interference risk analysis, the probability of interference from an RLAN device to an FS receiver is a function of the probable interference geometry and propagation conditions, in addition to FS receive filter performance—factors that FWCC's analysis does not properly consider.

As RKF illustrated, the interference risk from standard-power devices to even *co-channel* FS receivers is very limited. Taking into account the adjacent-channel rejection of FS receivers, which remains significant even in the most vulnerable FS receivers, this probability becomes insignificant. For example, for a 160-megahertz RLAN signal, the FS receive filter would attenuate an adjacent-channel RLAN signal with zero guard band by approximately 25 dB. Although RKF found a probability of exceeding a -6 dB I/N protection threshold only 0.2% of the time (in the absence of any of the Commission's interference-control mechanisms), the results would clearly have shown even more resoundingly that there is no meaningful interference risk if it had assumed an additional 25 dB attenuation (equivalent to assuming a maximum RLAN transmit power of only 11 dBm EIRP rather than 36 dBm).

As we demonstrated in our opening comments, there is no need for AFC control of LPI or VLP devices, due to proposed low power levels and usage restrictions. An analogous analysis can be applied for standard-power RLAN devices operating on an adjacent channel to an FS

[96] FWCC Comments at 25 & fig.6.

receiver, with attenuation provided by the FS receive filter serving to reduce received power in place of power reduction and (assuming outdoor operations) building entry loss. And, as with those classes of devices, interference will remain below -6 dB I/N for virtually all interference geometries. For example, as depicted below, with only 2 MHz frequency separation, an outdoor standard-power access point would not cause interference to exceed -6 dB I/N at any distance, even assuming line-of-sight propagation conditions, considering only FS receive filter performance.



This analysis assumes a typical 3 dB polarization mismatch loss, 3 dB feeder and other system loss, and -2 dB antenna gain, consistent with typical gain at the elevation angle corresponding to the 700-meter worst-case distance depicted above.[97]

[97] *See* RKF Study at 20–22.

In all events, the Commission should not accept proposals to address adjacent-channel claims with guard bands that effectively double the size of each FS channel. Such large guard bands, indiscriminately applied regardless of device location and actual interference risk, could effectively and needlessly bar AFC-controlled RLAN devices from urban areas. Although no adjacent-channel protections are needed to protect FS licensees from adjacent-channel interference in real-world operational scenarios, such protections could be implemented far more efficiently and effectively by the AFC system itself, using analyses similar to those used for co-channel protections.

V. The Record Confirms That Unlicensed Operations Will Not Cause Harmful Interference to Other Incumbents, Including BAS and Satellite.

The record demonstrates that, in addition to being compatible with FS receivers, 6 GHz RLAN devices will not cause harmful interference to other categories of 6 GHz licensees, such as BAS, LPAS, and FSS systems. Although some BAS and satellite licensees submitted comments attempting to raise interference concerns, many of these comments focused on potential interference from outdoor operations in U-NII-8. These concerns should be fully addressed by our proposal to adopt an indoor-only restriction for RLAN operations throughout all but the lowest 100 megahertz of U-NII-8. In particular, although Sirius XM is incorrect in its claims that outdoor RLAN operations could present a risk of harmful interference to its operations, limiting outdoor operations to the bottom 100 megahertz of U-NII-8 should fully resolve Sirius XM's arguments[98] regarding potential interference to their feeder links in the upper portion of that band. It should also address broadcast licensees' concerns that they will have no alternative spectrum in which to operate if they experience harmful interference.

[98] Sirius XM Comments at 11.

Although RLAN devices will not cause such interference, the absence of outdoor operations in the top portion of U-NII-8 provides yet another layer of protection.

Beyond this, BAS and LPAS operators have provided little new analysis to show that there is a substantial risk of harmful interference, and what analysis they did provide is deeply flawed. NAB, for example, submitted an analysis that purports to show a significant risk of harmful interference. But NAB assumes perfect alignment of RLAN transmitter and the BAS receive antenna without any shielding due to buildings or terrain, assumes free-space propagation conditions, ignores all sources of real-world attenuation, and generally lacks any useful detail to assist the Commission in determining the probability of this artificially constructed scenario. Moreover, NAB confirms that ENG crews today are already accustomed to positioning news trucks in locations that maximize signal quality.[99] This same process would naturally address any potential interference from RLAN transmissions, in the unlikely event that NAB's hypothetical situation were actually to occur.[100]

Finally, as NAB's comments highlight, LPAS operations typically occur in closed venues with managed information technology and wireless communications systems.[101] These operations can also be protected though spectrum coordination by the venue operator, who can choose to deploy access points that give them control of which RLAN channels to use and thereby not authorize RLAN devices on the same frequencies as LPAS operations within the venue. Again, this highlights the significance of flexible rules that allow different device

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[99] NAB Comments at 6.

[100] NAB's other arguments regarding RLAN duty cycle, clutter, and propagation model assumptions generally mirror those raised by FS licensees and are addressed in that context above. *See supra* Section III.

[101] *See* NAB Comments at 2–3 (highlighting LPAS use in the U.S. Capitol building and in a stadium).

capabilities and price points. These venue operators will have an even greater degree of control in the top portion of U-NII-8 where we propose to restrict operations to LPI only.

Likewise, FSS operators provided little additional analysis, and much of what they did provide has already been addressed in previous filings.[102] One exception, however, is Globalstar, which claims that its *downlinks* are vulnerable to aggregate interference from LPI operations in U-NII-8 close to the associated earth stations.[103] This is because although most operators locate their earth stations far from areas with large numbers of people, at least one of Globalstar's earth stations is located near potential interferers—a racetrack and a large hotel.

Nonetheless, Globalstar's predictions are inaccurate, due to a number of significant flaws in its analysis. Most conspicuously, as discussed above,[104] Globalstar assumes a wholly unrealistic RLAN duty cycle of 10%, meaning that Globalstar asks the Commission to believe that every Wi-Fi access point in the country transmits the equivalent 45 gigabytes per hour (more data than twenty simultaneously streamed HD movies). In addition, the analysis assumes that all RLAN activity is concentrated at a small number of sites, and that the earth station antenna is pointed directly at each, resulting in a highly unrealistic assumption that RLAN transmissions will always be subject to 7 dBi of antenna gain.[105] In addition, the analysis assumes that all RLAN devices operate at maximum permitted radiated power, with peak antenna gain implausibly directed toward the Globalstar earth station. Due to these defects, Globalstar's study is fatally flawed and should be disregarded.

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[102] Letter from Paul Margie, Counsel to Apple Inc., Broadcom Inc., Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Apr. 10, 2018).

[103] Globalstar Comments at 7–9.

[104] *See supra* p. 25.

[105] Globalstar Study at 22.

It should also be noted that, although Globalstar claims that the interference it predicts would render its earth stations "unusable," its studies only *attempt* to substantiate its harmful interference predictions at a single extreme angle. For each analysis, Globalstar assumes that its antenna would be oriented in its lowest usable elevation—10 degrees from the horizon—at a brief period of time when Globalstar's satellites are most likely to actually be within view of multiple earth stations.

VI. Proposals to Require a Central Database of 6 GHz RLAN Users Are Unnecessary, Will Dramatically Increase AFC Complexity, and Could Raise Questions About Privacy.

As we have detailed, the ability to use robust but straightforward AFC implementations is critical to promoting intensive use of the band and reducing costs for consumers. However, some commenters continue to argue that AFC implementations must maintain unnecessary logs of the locations and frequencies of all AFC devices and that all of these records must be compiled in a single searchable location.

Proponents of this extraordinarily regulatory proposal have yet to provide a cogent explanation of its value, or address the serious complexity, cost, and potential privacy questions that it raises. Although they speak in broad terms about how this centralized repository would allow FS licensees to identify and address interference concerns, this claim falls apart under scrutiny.

Most fundamentally, as the record shows, the AFC will protect licensees from harmful interference, so logging the use of every access point would only be relevant in the unlikely case that an individual user operated a device in violation of the FCC's rules. Proponents of this proposal confirm this, raising the possibility that users or manufacturers might illegally modify their devices in ways that could cause harmful interference. However, they do not provide any reason that users would have an incentive to do so in the 6 GHz band. There is no reason for users to undertake the trouble, expense, and risk of illegally modifying their device to gain access to a single 6 GHz channel. Historical examples of aftermarket modifications to RLAN devices raising interference concerns generally arose from earlier stages of the development of the RLAN market, when a far narrower range of devices was available and prices were significantly higher.[106] They also predate the U-NII device security requirements in Section 15.407(i), and the detailed guidance that OET now provides to manufacturers and certifying bodies to ensure that devices will remain compliant with the Commission's technical rules. Moreover, there is little reason to expect that these hypothetical bad apples would register themselves in the database in any event, resulting in a system that raises costs and reduces options for law-abiding consumers, while doing nothing to address interference.

Even in cases where the database might work as intended, simply recording the fact that a certain device used a given frequency at a particular time does not establish that this device was the cause of any interference that an FS receiver may have experienced. In urban areas, there are likely to be a large number of RLAN devices using a given channel under AFC control. Determining which device among them was the actual source of interference would be possible using conventional techniques for physically locating radio sources, but these same techniques would be just as effective *without* a database of candidate interferers, rendering the database superfluous. Moreover, some commenters describe using this database to identify *past* interferers, but fail to explain how a licensee or the Commission could responsibly associate a device and RLAN user in the database with particular interference events.

[106] *See, e.g.*, HPE Comments at 20–21; RLAN Group Comments at 30–31.

A small number of satellite interests also suggest the creation of a centralized system for tracking and authorizing AFC devices in order to prevent aggregate interference to FSS systems. However, the record clearly shows that 6 GHz RLAN devices pose no risk of harmful aggregate interference to FSS systems, rendering such a burdensome approach unnecessary.

The alleged benefits of the centralized database approach for 6 GHz unlicensed devices are far outweighed by significant costs. Such a database would require all AFC-controlled devices to be registered, meaning that consumers would be required to go through some type of registration process before using their devices, a step entirely inconsistent with consumer expectations for these types of devices. The database would also dramatically increase the complexity of AFC implementations, requiring each AFC implementation to be able to identify and synchronize data with one or more central repositories of AFC user data. This would eliminate, for example, any potential "standalone" AFC implementations and the associated benefits to the market.[107]

Even more burdensome than a requirement to synchronize all AFC usage data with a central repository would be a requirement for all AFC implementations to synchronize data with each other. Such an approach incorrectly assumes a small number of AFC implementations that are all able to identify and communicate with one another, akin to White Spaces databases or CBRS spectrum access systems. In fact, however, a successful AFC framework should allow a large number of AFC implementations of varying complexities, ranging from standalone AFC systems that fully operate within an AFC access point itself, to carrier-grade implementations managing large wide-area RLAN networks.[108] Requiring each of these independent

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[107] *See* RLAN Group Comments at 60–61.
[108] *See* RLAN Group Comments at 59–64.

implementations to somehow identify and communicate with one another while keeping any sensitive non-public information secure would likely preclude many important AFC implementations and drive up the cost of all implementations, because the amount of communications required for mutual synchronization would increase geometrically with the number of separate implementations.

CONCLUSION

The 6 GHz band presents an ideal opportunity for the Commission to meaningfully address the growing shortfall in unlicensed spectrum. Unlicensed frequencies carry more than half of all mobile internet traffic and are projected to soon carry the majority of *all* internet activity. But multiple studies demonstrate that unless the Commission opens new unlicensed bands soon, existing bands will not be able to accommodate expected growth. Fortunately, the

Commission now has the record it needs to act: extensive technical analyses demonstrate that the framework the FCC has proposed will protect licensees, and support critical modifications to expand LPI and standard-power operations and to authorize portable use of VLP devices and standard-power devices under AFC control. Consequently, the Commission should adopt an order implementing its proposed framework, improved by permitting LPI and VLP operations in all four sub-bands, while allowing portable RLAN operation and rejecting calls to impose burdensome and unnecessary new restrictions.

Respectfully submitted,

Apple Inc.
Broadcom Inc.
Cisco Systems, Inc.
Facebook, Inc.
Google LLC
Hewlett Packard Enterprise
Intel Corporation
Marvell Semiconductor, Inc.
Microsoft Corporation
Qualcomm Incorporated
Ruckus Networks, an ARRIS Company

March 18, 2019

Appendix A

Measured Attenuation from a Large Building Wall at 6.0, 6.5 and 7 GHz

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March 7, 2019

Abstract

In the context of the FCC's ongoing proceeding dealing with unlicensed use of the 6 GHz band, Fixed Service operators of microwave line of sight radio systems expressed concerns that in the absence of frequency coordination, co-frequency, unlicensed devices operating in high-rise buildings may degrade their link performance, due to poor building shielding combined with un-obstructed paths to their victim receivers. To address these concerns, building attenuation measurements were made using continuous wave signals at 6.0, 6.5 and 7 GHz on an upper floor of an energy efficient high-rise building, built in 2007. The corresponding leakage signals were measured with a directional horn antenna on a high-rise building 1/2 mile away with its bore-sight pointed at the building wall to provide a constant range, illumination gain and incidence angles of 6° to mimic realistic conditions seen by a microwave radio receiver. Measured attenuation, which is frequency dependent, was in a range: 25-70 dB, with 25 dB (at 6 GHz) of that attributed to low emissivity, metal coated windows used for solar gain control.

1 Introduction

In the ongoing FCC proceeding addressing unlicensed use of the 6 GHz band [1], Fixed Service operators expressed concerns that, in the absence of frequency coordination, co-frequency signals from low power unlicensed 6 GHz devices located in high-rise buildings and close to, or in direct line of sight of their radio receiver paths could create harmful interference. The concerns are:

- A building may not provide much attenuation.
- In tall buildings, radio waves can propagate freely because there is no ground clutter to attenuate them.
- In some cities, a microwave receiver may be located on a building roof, making it susceptible from devices on all the building floors.

Figure 1 depicts the scenarios.

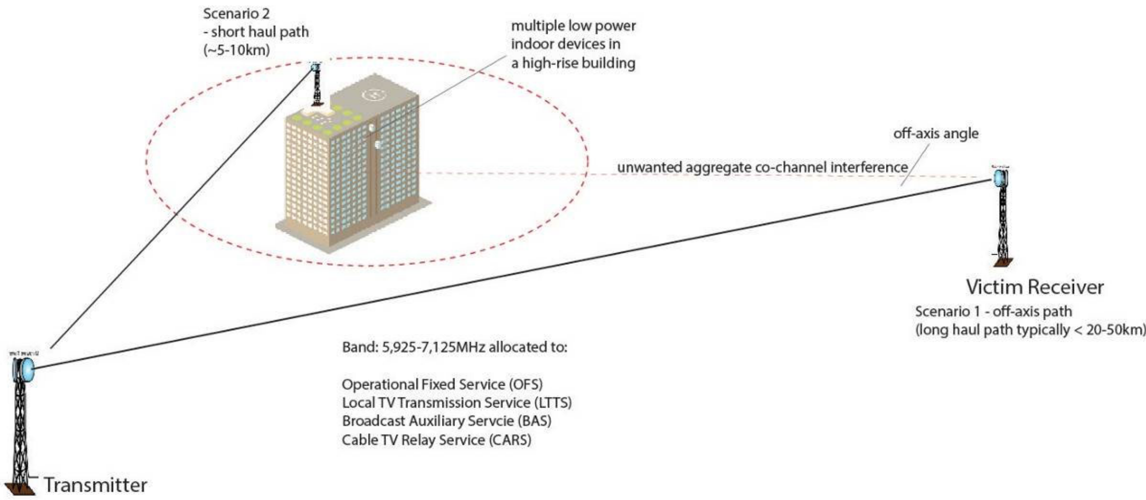


Figure 1: Fixed Service receiver interference scenarios

We report the results from attenuation measurements made on a high-rise building using a distant microwave receiver test method that mimics scenario 1. The direct path, scenario 2, has not been addressed.

2 Building Attenuation Principles

In figure 2, a carrier wave of power, P_{in} is applied to an antenna and is radiated as a transverse wave, but undergoes absorption, reflection, diffraction and scattering from the walls, ceiling and furniture before exiting the building surfaces from multiple places with different phases and departure times. A probe placed outside the building at a point P_r, at distance r, θ, φ will measure the vector sum of these carrier wave components. The waves will have dissipated some energy in the Ohmic losses as they travel through the lossy building but will exit with random phases (due to path differences and reflections) so wave cancellation and re-enforcement will also occur. The net result is interpreted as: “attenuation” when observed at a large distance from the building.

By integrating all measurement points over a hemisphere, the resultant power leaving the building, P_b can be found:

$$P_b(\theta, \phi) = \frac{1}{2\pi}\int_0^{\pi/2}\int_0^{\pi} P_r . sin(\theta) d(\theta) d(\phi)$$

The attenuation, A_b of the building is then: $A_b = P_b/P_{in}$

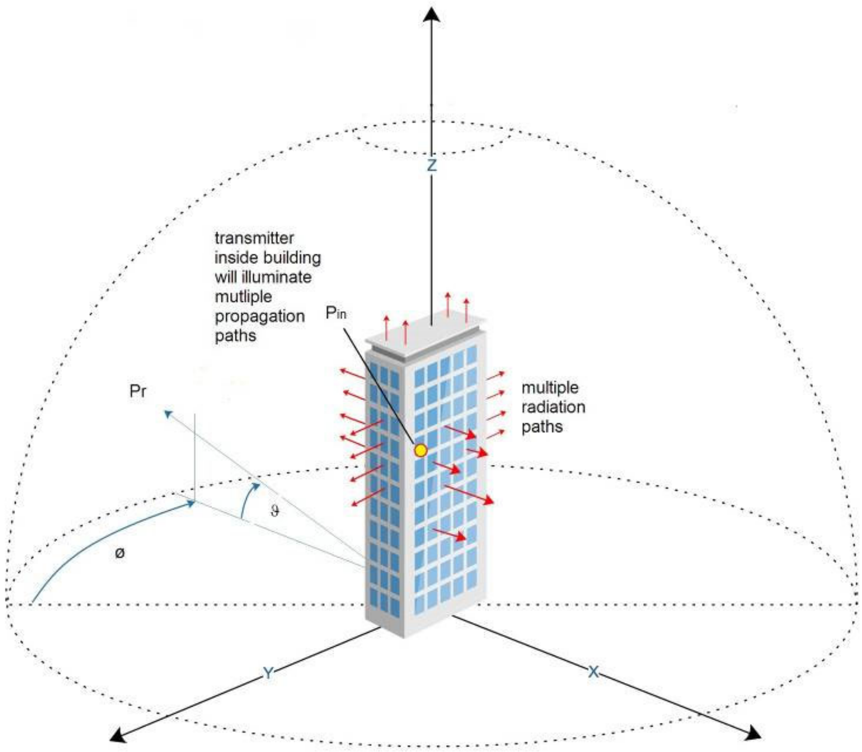


Figure 2: Building emissions and attenuation.

However, a spherical measurement is impractical since it would require an aircraft to make and the results would suffer large scintillation due to vehicle motion. The Ohmic losses also depend upon the antenna directivity and the propagation paths taken as the signal passes through the non-homogeneous, dispersive and dissipative medium of the building floors and walls which change with transmitter location – thus the effective attenuation is not only a property of the building structure but also the antenna directivity pattern used – it is not possible to separate the two effects.

Instead, attenuation is referenced to a vertical plane Y-Z of the front surface of each building wall rather than a hemisphere since this resembles the interference geometry that is of concern to FS operators. This is referred to in the report as ***wall attenuation*.**

Street level measurements (which are commonly made in many studies) close to the building were ruled out, because variations in transmitter-receiver distance, angle of incidence, receiver gain variation, multi-path effects outside the building and oblique propagation paths through multiple floors would have introduced large and unknown errors and victim receivers are not located there in practice.

3 Objectives

Because practical data is helpful to quantify the interference threat from unlicensed devices to distant microwave receivers, the objective is to seek answers to the following questions:

Q1. What range of attenuation can a building provide to a single transmitter located inside?

Q2. How does the attenuation depend upon the transmitter location? and its frequency?

Q3. Does the attenuation depend upon building construction factors?

The measurement objectives are finding answers to these questions.

4 Building Selection

Building WT, a Qualcomm building located in San Diego, California was selected for the following reasons:

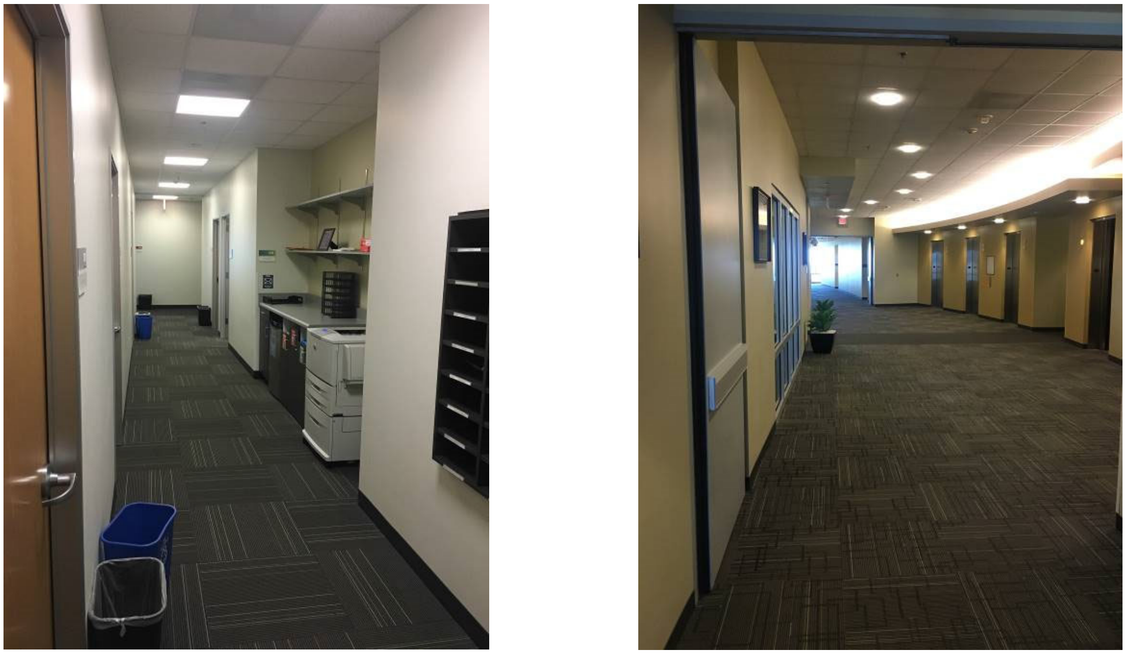
- It is approximately 200 feet tall, offers access to the upper office floors and to the roof for "0 dB loss" reference measurements.
- It can be "observed at a distance" approximately 0.5 mile away from building N receiving station, with near-normal constant angles of incidence, near-uniform gain illumination and practically constant and un-obstructed path.
- It was built in 2007 using energy efficiency technologies and construction methods that are believed to influence radio wave attenuation.

4.1 Building Description

The building is 12 stories high (197 ft), steel-framed building clad with a glass and steel unitized glazing system. The glass is tinted and comprised of insulated, dual-panned units comprising $^1/_4$ inch Visteon Versalux Blue 2000T, and airspace of $^1/_2$ inch and inboard pane $^1/_4$ inch PPG Solarban 60 (Low-E). The Tower is designed to perform with 15.4 percent greater efficiency than California's current Title 24 requirements and was awarded LEED Gold certification for energy efficiency in 2007. The structure is skinned with a custom unitized curtain wall system incorporating combinations of limestone, metal panels and glass. The building houses over 1200 engineers in labs, offices and amenity spaces like a gym and cafe and has 420,000 square feet with floor dimensions 164 x 210 feet.

4.2 Building Interior

The internal construction is depicted in Figure 3. It uses floor-ceiling partitions and corridors to divide the floor space into closed-plan offices.



(a) Typical corridor　　(b) Main corridor and elevator shafts

Figure 3: Closed-plan internal construction

4.3 Measurement Paths

Table 1 and figure 4 show the geometry and the path between the building N receiving station and the south wall being measured.

	Height of station above ground	Range to receiver station	Angle of incidence (degrees)		Angle subtended by building	Illumination gain flatness
	(m)	(m)	elevation	azimuth	(degrees)	(7GHz)
WT transmitter	48	820	0.2	6	<3	0.0, -0.3dB
N receiver	51	-	-	-	-	-

Table 1: Path geometry values

Figure 4: View from the receiving horn

5 Measurement Method

Figure 5 depicts the test configuration.

It relies on a difference measurement of power when the transmitter is located on the roof, measurement A, and when it is shielded in the building – measurement B. The configuration comprises:

- A transmitter that radiates 3 continuous wave, fixed-frequency, fixed-power signals at 6.0, 6.5 and 7.0 GHz from each floor location and from the roof during a reference measurement.
- A directional horn antenna (with pre-amplifier to receive the signals). Its bore-sight has been pointed at the building wall to capture leakage radiations emitted from the wall.
- The received signal powers are measured by a spectrum analyzer which continuously measures and records each carrier power in sequence, appending a time stamp to each measurement.

The test is conducted as follows:

1. A technician moves the transmitter between offices, parks it at each one for 2 minutes, after noting the office number, arrival and departure times. The technician also monitors and trims the transmitter power if needed. This is all that is needed.

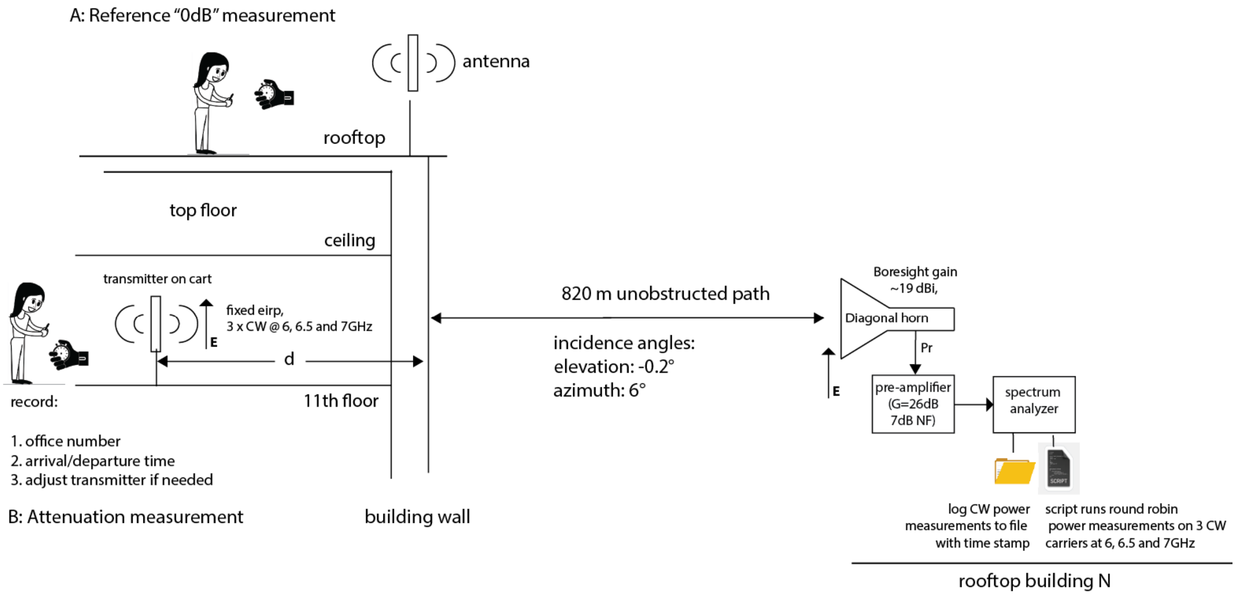


Figure 5: Test configuration

Measurements are not made if persons are in the corridor to avoid possible body attenuation effects, also the technician stands outside of the direct path to the receiver a few meters away. The technician makes a measurement on the roof where there is no building attenuation.

2. The following post processing is needed to get attenuation for each floor location:

   - By matching-up the time that the transmitter was parked with the spectrum analyzer time records, the power when the transmitter was operating at each location is found.
   - These power measurements are subtracted from the roof reference to obtain the attenuation values in dB.
   - The distance to each office from the outer wall surface is read from a scale drawing of the floor plan where each office is identified. See 6.1.2.

Since the spectrum analyzer makes 20 measurements of each carrier signal, at the rate of 1/second in a 6, 6.5 and 7 GHz automatic repeating sequence, all 3 carrier signals are measured in a minute.

The average power and standard deviation are calculated from each 1-minute set and this value is subtracted from the "0 dB reference measurements" to obtain the attenuation at each frequency.

5.1 Precautions Taken:

1. Any bias in the reference signal shifts all the attenuation results, so careful selection and test was needed.
2. Any bias in direction of transmission will favor one exit path to the outside wall over others, so an antenna with a uniform horizontal radiation pattern was used.

3. Variation in the wall illumination gain will be counted as attenuation unless compensated for. Compensation was not needed as the antenna gain variation was < 0.5dB. See appendix A.

4. Variation in the transmitter to receiver distance between front and back of the building introduces additional path loss unless compensated for. Compensation was not needed as the increase in range is insignificant.

5. A low incidence angle of 6° was used without any oblique paths through floors which provides the lowest, worst-case attenuation with respect to the victim.

6. Verification that the receiver system was linear and free of interfering signals near to the frequencies used in the test.

6 Results

6.1 Range of Attenuation

Figure 6 shows the attenuation measured at 44 points throughout the 11th floor which correspond to the attenuation map shown in figure 7. Note that the median values are: 46 dB (6 GHz), 44 dB (6.5 GHz) and 36 dB (7 GHz).

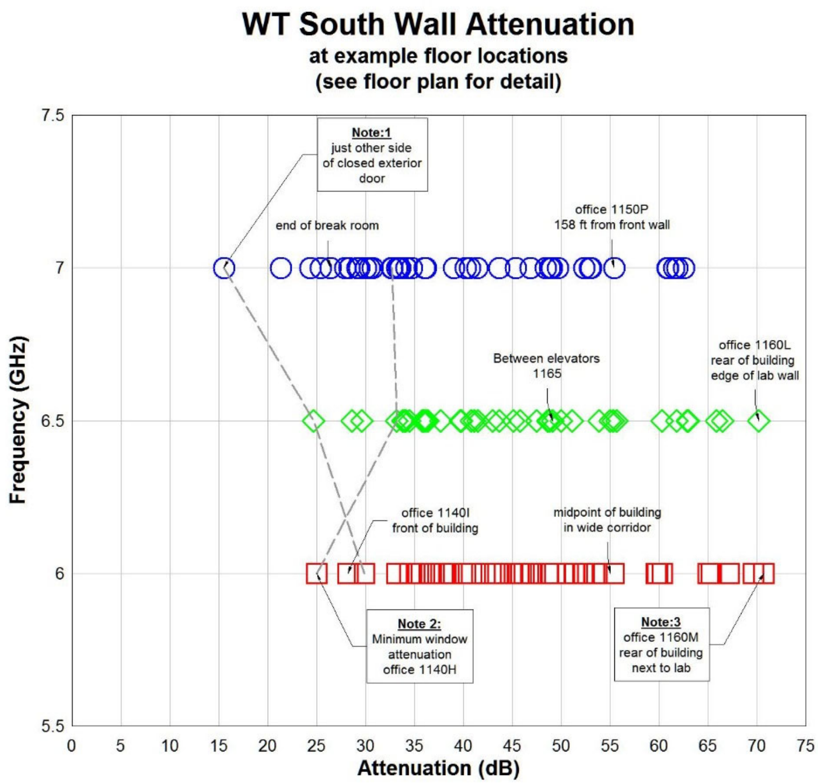


Figure 6: Range of attenuation measured at known office locations

Notes:

1. Measurements were made just the other side of closed exterior door. Leakage though the door gaps was expected and was measured. The floor plan attenuation map shows how this leakage occurs only in the immediate proximity of the door and at 7 GHz in particular. Note that at 6 and 6.5 GHz attenuation is 25 dB and 30 dB respectively.

2. The transmitting antenna was placed in office 1140H window to assess directly the attenuation provided by the glass window.

3. There is a 50 dB range of attenuation between the front and back of the building and minimum of 20 dB at 7 GHz.

6.1.2 Floor Plan Attenuation Map

Figure 7, below, shows where each measurement was made on the floor and the attenuation values for each frequency. Each value is the average of 20 successive measurements. At nearly all floor locations, the loss at 7 GHz is consistently less than at 6 GHz, which is believed to be a property of this particular building.

Figure 7: Floor locations and associated attenuation values

6.1.3 Attenuation vs. Distance

Figure 8 shows that the attenuation increases from the front of the building to the rear for all three frequencies.

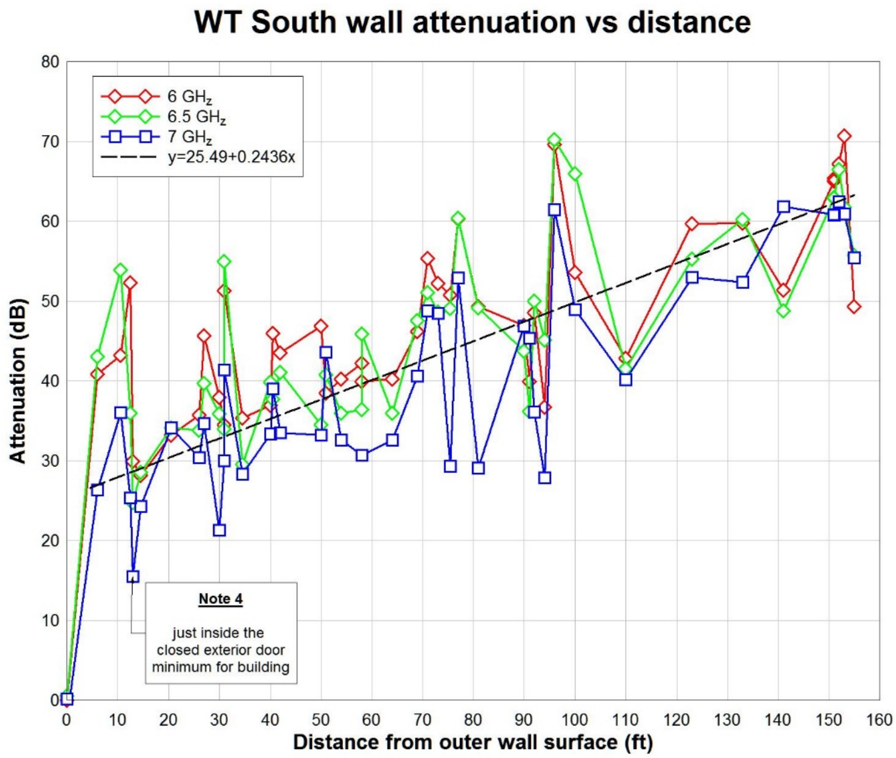


Figure 8: Attenuation vs. distance from the outer wall

A first-order polynomial curve fitted to all data indicates that 25 dB on the average can be relied immediately the other side of the wall due to the attenuation provided in the first few feet by the windows. This is more evident by examining the attenuation values on the floor plan in figure 7.

Note 4 refers to a leaky door at 7 GHz previously mentioned.

6.1.4 Attenuation vs. Frequency

Figure 9 indicates that the attenuation is frequency dependent with a stronger trend towards lower attenuation at 7 GHz.

Frequency (GHz)	Median attenuation (dB)	Average difference wrt 6 GHz
6	43	-
6.5	41	-0.9
7	36	-6.3

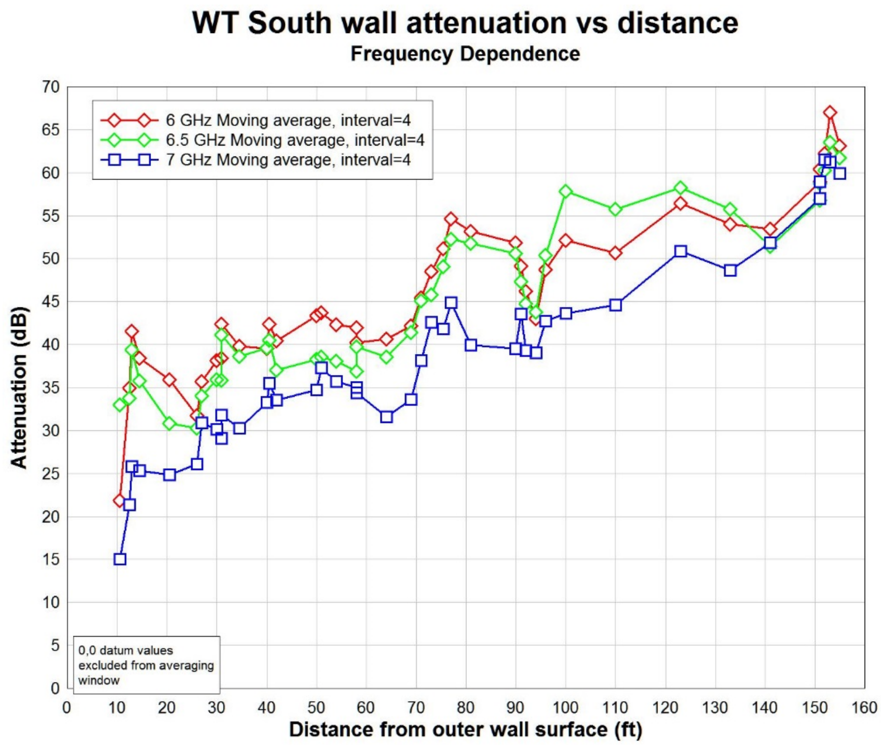


Figure 9: Frequency dependence

No further experiments have been conducted to ascertain why this building shows lower attenuation at the higher frequency.

6.1.5 Window Measurements

Figure 10 shows the transmitter radiating in office 1140H facing the distant receiver. A comparison of these signal levels with un-attenuated roof signal levels demonstrate that this window attenuates 6-7 GHz radio waves by at least 25 dB and is frequency dependent.

(a) room 1140H

Attenuation

	Room 1140H (FSL+ window)	WT Roof (FSL)	Glass attenuation
	dBm	dBm	dB
6 GHz	-51.5	-26.4	25
6.5 GHz	-60.2	-27.1	33.2
7 GHz	-68.9	-36.2	32.7

WT Low-Emissivity Glass with conductive silver coatings

	Product	NFRC U value	SHGC
Outer pane (Viracom)	¼" Visteon Versalux Blue 2000T	0.28	0.39
Airspace	½" dry air		
Inner pane (PPG)	¼" PPG Solarban 60 (Low-E)	0.29	0.28

(b) attenuation and specification

Figure 10: Window measurements

This double-pane glass has conductive silver coatings on both panes, causing reflection back into the room from the indoor pane, followed by (after refraction and reflection) a heavily attenuated reflection from the outer pane. The same behavior occurs on the outer side of the glass. It is plausible that the double-pane window with metal coating on each may cause a cancellation effect, when the incident wave strikes the second pane with phase reversal and re-emerged out of phase with the incident wave. Refer to [2] for a more details on the modes of reflection and transmission.

This has not been analyzed further, but the measurements clearly show a frequency dependent attenuation of the building. Also, the windows are acting as strong RF reflecting surfaces producing a reverberant RF environment inside the building and a huge reflective mirror-like one on the outside. Some buildings may intentionally use glass such as: "Viracom Cybershield" which is designed to attenuate radio waves by 45 dB.

6.2 Low-E Coating Properties

In our study, we wanted to know if low-emissivity windows are necessarily coated with an electrically-conductive film. From research done by Hagen and Rubens, reference [3] explains that:

> *"Around the 1900s, the German physicist Paul Drude explained the optical behavior of free electrons in a solid based on the kinetic theory of free electrons in a metal. This theory is still widely used in literature today. In the early twentieth century, physicists Hagen and Rubens found that the heat emission from bulk metals described by their emissivity, ε, correlates strongly with their conductivity, σ, i.e., with the concentration of free-electrons. Based on the Drude model, they derived a formula to connect conductivity and emissivity:*

$$\varepsilon = \sqrt{\frac{8\varepsilon_0 \omega}{\sigma}}$$

> *Thus, the higher the conductivity, the lower the emissivity."*

This important physical property means that all low-emissivity windows, which are in growing usage due to their energy efficiency, will use electrically-conductive coatings, which in turn means that these windows will also attenuate radio waves.

7 Conclusions

1. 25-70 dB of attenuation at 6, 6.5 and 7 GHz has been measured from the front window to the back of the building.

2. The attenuation increases quickly as the transmitter on the floor being measured is moved away from the wall being measured.

3. The window construction and glazing material plays a large role in the shielding effectiveness of the building overall, with double-pane, low-emissivity windows creating a very effective RF shield at these frequencies.

References

[1] Federal Communications Commision, "Unlicensed Use of the 6 GHz Band, Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz," ET Docket No. 18-295, GN Docket No, 17-183, 2018.

[2] P. O'Leary, H. Doelecke, N. Knauer, "Wireless Attenuation by Energy Efficient Windows in the 8-12.5 GHz region."

[3] G. Ding & C. Clavero, "Silver-Based Low-Emissivity Coating Technology for Energy-Saving Window Applications."

A Building N Receiving Station

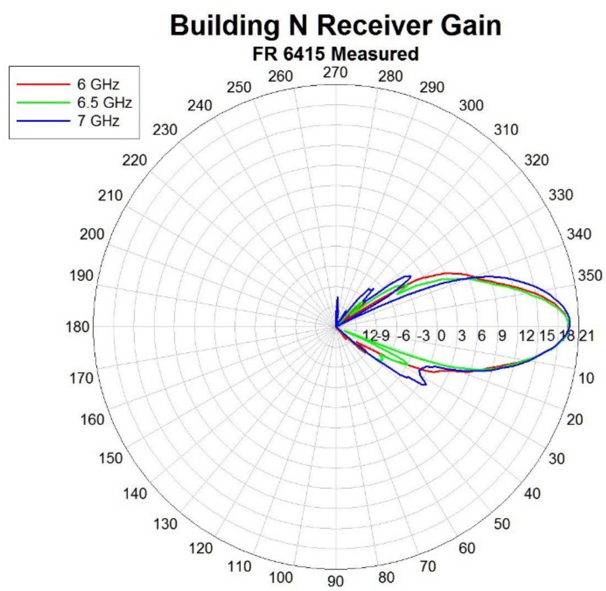
The receiver comprises a diagonal horn antenna (Fram and Russel model 6415) with 19 dBi of gain, vertically polarized, mounted on a tripod allowing fine adjustment of azimuth and elevation. A pre-amplifier is needed to raise the signal level about the noise floor of the spectrum analyzer. It has 26 dB of gain and a 7 dB noise figure and connected to the antenna output by 4 inches of loss loss-coax. A high-performance spectrum analyzer (Rhode and Schwarz Model FSQ) is connected to the pre-amplifier output via low-loss cable. A Windows PC running a Python script controls the spectrum analyzer settings and records the instrument data using a direct Ethernet cable and TCP/IP protocol. All equipment has been calibrated.

The horn is pictured in figure 11(a) and its corresponding pattern in 11(b).

The spectrum analyzer settings are:

- center frequencies: 6.0 GHz, 6.5 GHz, 7.0 GHz
- frequency span: 50 kHz
- video and resolution bandwidths: 1 kHz
- detector type: rms with peak search

(a) Horn and Tripod



(b) Gain pattern

Figure 11: Building N receiving horn

B Mobile Transmitting Station

The transmitter comprises a vector signal generator (Rhode and Schwartz SWM 200A) configured to operate in multi-carrier mode to create 3 frequency-coherent CW signals at 6.0, 6.5 and 7.0 GHz with uniform power. This multi-carrier signal drives a wide-band, 20W TWT power amplifier to raise the levels sufficiently to enable detection at the spectrum analyzer and overcome cable and antenna losses. The output back-off is approximately 10 dB. The amplifier drives a toroidal antenna mounted on a tripod that has the gain patterns shown in figure 12 and 13 respectively. A Windows PC is used with an Excel spreadsheet with a time-tagging macro to avoid possible human error when recording the time. A polarization check was made by rotating the toroidal antenna through 90 and noting that maximum cross polarization isolation was observed at this rotation angle.

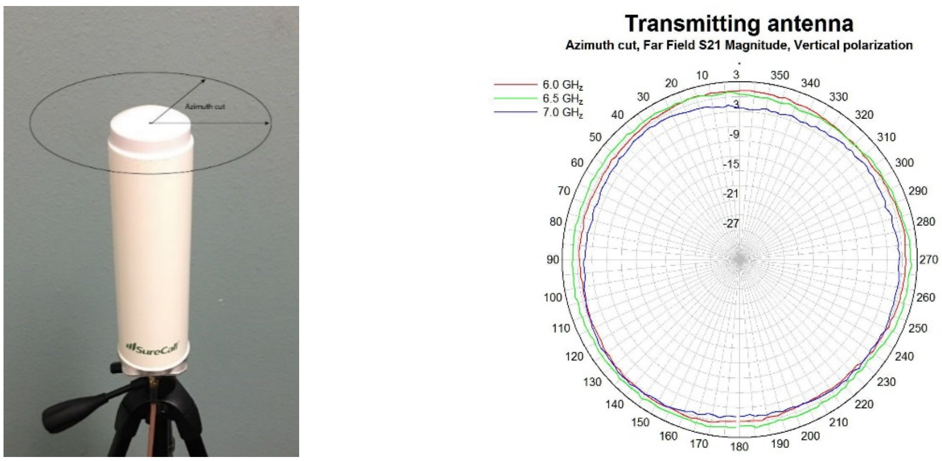


Figure 12: Azimuth pattern

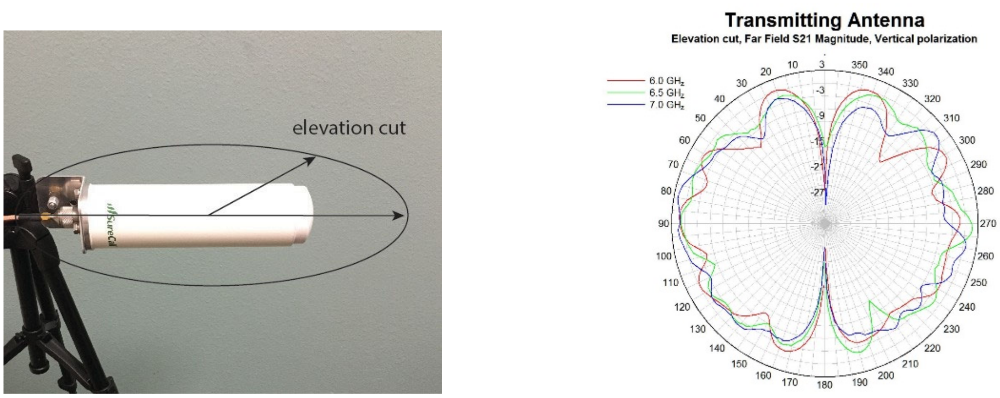


Figure 13: Elevation pattern