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Via Electronic Filing

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Re: ***Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37, Amendment of Part 74 of the Commission's Rules for Low Power Auxiliary Stations in the Repurposed 600 MHz Band and 600 MHz Duplex Gap,*** **ET Docket 14-165;** ***Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*****, GN Docket No. 12-268**

Dear Ms. Dortch:

Since Reply Comments were filed in this proceeding, Google has conducted several analyses that further support the Commission's proposal to allow unlicensed operation in the duplex gap and guard bands. We have also conducted analysis and outreach regarding reasonable separation distances between unlicensed users and existing Channel 37 operations. Below, we summarize our results.

1. **Simulations, testing, and analysis conducted by Google continue to demonstrate that the Qualcomm's and CTIA's analyses rely on fundamentally flawed assumptions.**

If taken at face value, the analyses submitted by Qualcomm and CTIA would endanger meaningful unlicensed access to former TV broadcast spectrum that cannot be used for licensed mobile services. Yet those analyses are not reliable because they substantially overstate the risk of harmful interference to licensed services.[1] Several flawed assumptions and logical gaps in Qualcomm's and CTIA's analyses, all of which

[1] *See*, *e.g.*, Comments of Qualcomm Incorporated, ET Docket No. 14-165 and GN Docket No. 12-268, at 6-12 (filed Feb. 4, 2015) (Qualcomm Comments); Comments of CTIA—The Wireless Association, ET Docket No. 14-165, GN Docket Nos. 12-268 and 14-166, at 7-36 (filed Feb. 4, 2015) (CTIA Comments).

enable those parties to understate opportunities for coexistence between licensed and unlicensed services, are highlighted below.

LTE devices and white space devices are likely to be separated by at least two meters, and a variety of additional factors will further mitigate interference.

Both Qualcomm and CTIA assume a separation distance of one meter between an LTE handset and an unlicensed device.[2] But Commission precedents establish that a two-meter separation distance is more appropriate for calculating interference protection.[3] In fact, in the Commission's 2013 order establishing rules for the 1915-1920 MHz and 1995-2000 MHz band, the Commission specifically expressed concern that V-COMM Technical Engineering (the same company that prepared CTIA's technical analysis in this proceeding) had relied in that proceeding, too, on a one-meter separation distance between consumer devices.[4] As the Commission explained in rejecting V-COMM's approach, "a 1 meter separation distance represents an overly conservative value[,] and . . . it is a more realistic scenario to assume that the devices at issue are likely to be at least 2 meters apart."[5]

Common sense confirms this. Access points typically are mounted on walls and ceilings in enterprise settings; in residences, consumers tend to place them on the floor, on a shelf, in a cabinet, or in another unobtrusive location. It therefore is likely that an LTE handset and an unlicensed access point will be separated by substantially more than two meters.

Moreover, in many of these access point/handset configurations, there will be signal attenuation due to obstructions between the access point and the handset. For example, an access point placed on the floor or in a cabinet will often be separated from LTE handsets by furniture or walls. An access point placed in an enterprise setting might be obscured by cubicles, cabinets, or other fixtures. The unlicensed signal will exhibit signal loss as it travels over distances and through those obstructions, and, as a result, low-power transmissions from an access point are not a likely source of interference to LTE operations.

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[2] Qualcomm Comments at n. 6; CTIA Comments at 29-30, Appendix B at 76.

[3] *See, e.g.*, *In the Matter of Service Rules for Advanced Wireless Services H Block—Implementing Section 6401 of the Middle Class Tax Relief and Job Creation Act of 2012 Related to the 1915-1920 MHz and 1995-2000 MHz Bands*, Report and Order, 28 FCC Rcd. 9483, ¶ 142 (2013) (H Block Order) (reviewing Commission precedent and specifically citing two prior orders in which a two-meter separation distance was adopted).

[4] *See id.* at ¶ 112.

[5] *Id.* at ¶ 142.

It is also reasonable to assume that LTE handsets and personal/portable television white space (TVWS) devices will be separated by at least two meters and will have additional shadowing loss. In both home and enterprise situations, handsets almost invariably will be held on the body or placed on a radiation-blocking surface. We quantify these losses below. Even in dense urban settings, substantial additional shadowing losses will be present. In a bus, for example, passengers may be seated close together, but personal devices that are in use will likely be held in the hand, resulting in significant body loss. Similarly, large urban structures are likely to contain interior walls or fixtures, and people are likely to carry their phones on or very near their bodies when using them there.

In any event, most LTE-enabled personal devices in a home or office setting will default to an available Wi-Fi network rather than use an LTE network, while Wi-Fi often will be unavailable in congested urban settings like a bus. In such situations, two handsets in close proximity will either both be connected to Wi-Fi, or both be connected to LTE, and there will be no issue at all of interference between Wi-Fi and LTE.

Thus, Qualcomm's and CTIA's assumptions fail to account for real-world environments. Indeed, some of their positions border on absurdity. Qualcomm, for instance, suggests that the FCC should develop interference protection standards based on the assumption that an LTE device and an unlicensed device will commonly operate one meter apart from each other, suspended in air, with no obstructions in between them, and with perfect polarization matches between the two devices. CTIA proposes that shadowing losses should be ignored for all indoor use cases unless "the separation distances are much greater (*e.g.*, 20 meters)"[6]—an approach that is unsupported and contradicted by testing, as the next section of this letter shows.

In realistic operating environments, additional losses are substantial, and these losses dramatically affect interference protection requirements.

The conditions described above, along with other real-world losses described below, substantially mitigate the likelihood that unlicensed signals will harmfully interfere with LTE device operation at any distance. In this section, we quantify some of the most important of these signal losses.

Body Loss: Qualcomm's analysis assumes no body loss whatsoever,[7] while CTIA assumes 6 dB total of body loss.[8] Simulations described in the accompanying

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[6] *See* Letter from Krista L. Witanowski, AVP, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, FCC, ET Docket No. 14-165, GN Docket Nos. 12-268 and 14-166, Attach. at 8 (filed May 8, 2015).

[7] *See* Qualcomm Comments at 5 (arguing that the Commission should not take body loss into account).

[8] CTIA Comments at 9-10.

Declaration of Donald Breslin, however, reveal that holding an LTE handset and holding an unlicensed device adds *an extra 15 dB of loss over free space propagation*.[9] Thus, Qualcomm's and CTIA's assumptions are widely off the mark.

Tabletop Loss: Because devices generally will be sitting on a surface when they are not in the hand or on the body, Google measured losses associated with devices sitting on a table 2 meters apart from each other, without any obstructions in between. Just as body loss adds a substantial margin to the interference analysis, the mere placement of two phones on a table increases the loss between the two devices by 6-16 dB as compared to free space.[10]

Filter Attenuation: Qualcomm's and CTIA's analyses assume that an unlicensed signal will exhibit 0 dB of roll-off outside of a 6 MHz TVWS channel.[11] By contrast, Broadcom's calculations assume 10 dB attenuation.[12] To further investigate these rival assumptions, Google tested a TVWS device manufactured by 6Harmonics. It showed 10 dB of roll-off outside the 6 MHz passband, consistent with Broadcom's expectations.[13]

Polarization Mismatch: Finally, as CTIA acknowledges, polarization mismatch also contributes additional losses.[14] These losses can vary, but are often estimated to be approximately 3 dB.[15] In the real world, it is extremely unlikely that the antennas of two devices will be perfectly aligned so that there is zero loss due to polarization mismatch. Yet, Qualcomm assumes this situation.

CTIA's filings, as well as the Commission's own rules, corroborate the findings that LTE devices will not be harmed by interference from low-power unlicensed operations in the guard band(s) or duplex gap.

A recent CTIA submission explains why the vast majority of LTE devices are unlikely ever to experience conditions where their operation plausibly could be impeded

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[9] *See* Declaration of Donald Breslin, Appendix A, ¶¶ 4, 12 (Breslin Decl.).

[10] *Id.* ¶¶ 13, 16.

[11] Qualcomm Comments at A1; CTIA Comments, Appendix A at 6.

[12] Comments of Broadcom Corporation, ET Docket No. 14-165 and GN Docket No. 12-268, at 9 (filed Feb. 4, 2015) (Broadcom Comments).

[13] Breslin Decl. ¶¶ 19-20.

[14] CTIA Comments at 9-10.

[15] *See, e.g.*, CTIA Comments at 9-10; Broadcom Comments at 4-5.

by unlicensed signals.[16]

CTIA's recent filing confirms that most devices do not operate at the edge of range, where they might possibly be affected by TVWS device interference slightly above the thermal noise floor. LTE-to-LTE interference—whether from other base stations using the same band or from LTE signals in adjacent bands—is likely to dwarf any potential harmful interference from TVWS signals where LTE systems are optimized for capacity rather than range. In such dense deployments, a handset typically communicates with the closest tower, and switches towers as necessary as it moves, rarely reaching the edge of its thermal noise floor-limited range—where interference from low-power TVWS transmitters might become relevant.

The CTIA filing shows that the vast majority of users are operating at powers well below 23 dBm, the maximum power allowed for LTE user equipment transmissions.[17] Even for rural users, the CTIA probability curves show that 90% of users are operating at transmit powers of 16 dBm or below, with 7 dB or more of margin from cell edge transmit power of 23 dBm.[18] Devices transmit at maximum power when they are at the edge of range; when they are not at the edge of range, they use power control mechanisms to reduce power as appropriate.[19] Therefore, data showing that LTE devices are not maximizing power demonstrate that these same devices are not operating at the edge of their range and are therefore unlikely to hear any interference whatsoever from TVWS devices. Based on CTIA's own data, the "vast majority" of LTE users will not operate their handsets under conditions where TVWS interference can be observed because the devices will not be operating at the edge of range, at their lowest possible receive sensitivity.[20]

The Commission's out-of-band emission rules for LTE devices in the 700 MHz band also confirm that LTE-to-LTE interference causes far more significant risk to licensed operations in the 600 MHz band than any potential unlicensed operations. The Commission's rules limit out-of-band emissions from LTE in the 700 MHz band to -43 dBW / 100 kHz for a given transmit power P, or -13 dBm / 100 kHz for a given transmit power P (30 dBm is 0 dBW).[21] The TVWS out-of-band emissions levels contemplated by the NPRM are far lower. For a TVWS transmit power of 16 dBm (40 mW) in 6 MHz, the

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[16] *See* Letter from Krista L. Witanowski, AVP, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, FCC, ET Docket. No. 14-165; GN Docket. Nos. 14-166, 12-268, May 8, 2015 (CTIA Ex Parte).

[17] *Id.*, Attach. at 6, 7; 3GPP TS 36.101 V8.26.0, Table 6.2.2-1 (2015-2).

[18] CTIA Ex Parte, Attach. at 7.

[19] Breslin Decl. ¶¶ 30-32.

[20] CTIA Ex Parte at 6, Attach. at 5.

[21] Breslin Decl. ¶ 37.

equivalent transmit power in 100 kHz is -1 dBm.[22] Applying the emissions mask tested by Google and adjusting for a smaller distance between TVWS devices and LTE devices, as opposed to the large distance between LTE base stations and LTE devices, the maximum allowed out-of-band emissions from 700 MHz cellular transmissions into the repurposed portion of the 600 MHz band will exceed those proposed for TVWS devices by fully 14 dB.[23]

LTE-to-LTE interference therefore predominates in the vast majority of cases, rendering any interference from TVWS device operation irrelevant. Those very limited circumstances where LTE devices are operating at the edge of range are truly corner cases. But even in these rare events, the real-world impact on LTE operation is minimal. To estimate this impact, Google relied on Broadcom's and Qualcomm's assumptions regarding the receive sensitivity of LTE. Both Broadcom and Qualcomm have stated that -98.5 dBm is the maximum level of noise that could be transmitted into the LTE band by a TVWS device without causing harmful interference. Because uncorrelated noise sources add in power, this threshold represents an LTE user equipment receiver thermal noise floor of -98.5 dBm and an interference level of -98.5 dBm, both in 5 MHz, which add together in power to increase by 3 dB the effective noise floor seen by the LTE handset.[24]

To estimate the impact of a 3 dB loss in downlink budget for the minimal number of total LTE end users (1) operating in a thermal noise-limited scenario in the 600 MHz band (2) in very close proximity to a TVWS transmitter (3) that is capable of causing 3 dB of effective thermal noise floor rise, Google looked at published tables setting forth LTE SINR requirements for PHY rates.[25] These rates predict that for the very small percentage of LTE users that possibly could experience any impact from TVWS operation in a worst-case scenario, the expectation of a 3 dB loss of downlink link budget equates to no more than a 15% reduction in throughput.[26] To put this in context, a 15% reduction in throughput is substantially less than the variation in baseline throughput observed in the testing described above, and is likely to be overshadowed by ordinary variations in real-world operation.[27]

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[22] *Id.,*¶ 38.

[23] *Id.,* ¶ 39.

[24] The physical layer (PHY) rate defined by 3GPP for reference sensitivity power level (REFSENS) operates down to approximately -1 dB signal-to-noise-plus-interference (SINR), and thus the assumed sensitivity of the LTE handset for this threshold is approximately -99.5 dBm. Stefania Sesia et al., LTE - The UMTS Long Term Evolution 478*,* Table 21.7 (2011).

[25] *Id.,* ¶ 36 (citing Stefania Sesia et al., LTE - The UMTS Long Term Evolution 478*,* Table 21.7 (2011)*.*

[26] *Id.*

[27] *Id.*

Testing of actual devices confirms that unlicensed devices can operate in proximity to LTE receivers without degrading service.

Consistent with the points made above, handset testing detailed in the accompanying Declaration of Donald Breslin demonstrates that LTE devices in fact do not experience any discernible degradation in performance when operating in close physical and spectral proximity to unlicensed devices. Specifically, throughput measurements show that the LTE downlink remains robust even in the presence of interfering signals transmitting at powers as high as 20 dBm.[28] This is true even when spectral separation is as small as 2 MHz and devices are physically separated by as little as 1 meter in free space.[29] In these tests, the transmit powers for the interference source exceeded Qualcomm's and CTIA's proposed maximum power thresholds *by 20 to 30 dB*.[30] Qualcomm and CTIA demonstrably overstate the risk of harmful interference, and the Commission is justified in proposing TVWS operation in the duplex gap and guard band at powers of at least 40 mW (16 dBm).

There are, then, several reasons described in this letter why the Commission should disregard the Qualcomm and CTIA filings. First, Qualcomm and CTIA significantly underestimate the path loss contributions associated with body loss, shadowing, and polarization mismatch. Second, the Qualcomm and CTIA filings ignore the substantial sources of cellular interference that far outweigh the low levels of interference from TVWS that the proposed rules would allow. Qualcomm's and CTIA's interference claims focus on corner cases, and, even in those outlier situations LTE-to-LTE interference is likely to be far more significant than any interference from unlicensed systems. Finally, empirical testing conducted by Google shows that LTE devices do indeed operate without degradation in the presence of low-power unlicensed signals.

The Commission has held that "[t]o determine what interference is sufficient to be considered harmful, one should consider whether there is a reasonable probability that the conditions necessary to create that interference will occur."[31] The Qualcomm and CTIA analyses do not present "reasonab[ly] probabl[e]" conditions.

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[28] Breslin Decl. ¶¶ 21-29.

[29] *Id.*

[30] *See, e.g.,* Qualcomm Comments at 11 (proposing maximum EIRP of -14 dBm for TVWS devices separated from LTE by 3 MHz); CTIA Comments at 18, fig. 3 (claiming that a narrowband wireless microphone separated by 3 MHz from LTE would have to transmit at powers below -4.5 dBm to avoid sensitivity loss of LTE). Our tests measured the impact of transmit powers up to 20 dBm with 1 meter spacing in line of site conditions and found no meaningful impact.

[31] H Block Order ¶ 142.

2. **Relying primarily on GE Healthcare's own conservative assumptions regarding WMTS operations, Google conducted an analysis demonstrating that low-power unlicensed devices can operate well within 200 meters of a WMTS facility's perimeter, without harmful interference to WMTS equipment**.

The Commission has proposed a range of separation distances between unlicensed devices operating on Channel 37 and facilities that use WMTS radios.[32] In response, GE Healthcare submitted an interference analysis based on observations at the Inova Mount Vernon Hospital.[33] This analysis does not involve the impact of unlicensed devices on an actual WMTS implementation. Instead, GE Healthcare studied mock WMTS "victim transmitters" that it placed in a hospital that also contained a real WMTS system. The decision to test WMTS equipment that was not in actual use is understandable from the perspective of avoiding any impact on normal hospital operations. But in analyzing results, it is important to recognize that the reported siting, operational behavior, and interference do not necessarily reflect a real-world environment. Moreover, GE Healthcare's study contains design features that render it unreliable. Most important, by choosing a test site a substantial distance from any adjacent-channel television broadcaster, GE Healthcare was likely able to detect "interference" from signals that would not have been noticeable at WMTS sites operating on Channel 37 in noisier environments.[34]

As explained below, Google's recent analysis supplies additional evidence that separation distances smaller than those proposed in the Commission's NPRM can protect WMTS operations with a large margin of safety. Nevertheless, Google recognizes that building loss has a particularly significant effect on unlicensed signal propagation and suggests a compromise approach that would provide an even higher level of protection to WMTS facilities where justified by the building's construction type.

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[32] *In the Matter of Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37, and Amendment of Part 74 of the Commission's Rules for Low Power Auxiliary Stations in the Repurposed 600 MHz Band and 600 MHz Duplex Gap*; *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, 29 FCC Rcd. 12248, ¶ 112 (2014) (Part 15 NPRM).

[33] Comments of GE Healthcare, Appendix A, ET Docket No. 14-165 and GN Docket 12-268 (filed Feb. 5, 2015) (GE Healthcare Comments).

[34] *See* Reply Comments of Google Inc., ET Docket No. 14-165 and GN Docket 12-268 (filed Feb. 26, 2015) (Google Reply Comments).

Additional analysis confirms that separation distances of 200 meters will protect WMTS operations from low-power unlicensed operations.

Google recently conducted an analysis using very conservative assumptions regarding both WMTS and unlicensed device operations and concluded that unlicensed devices can operate with 200 meters of a WMTS facility's perimeter without causing harmful interference to WMTS receivers. In conducting this analysis, we aimed to determine what separation distances effectively protect WMTS devices as they currently operate. Below, we set forth our assumptions and results.

Assumptions regarding WMTS systems and unlicensed device signal propagation

- *Unlicensed Device Transmit Power:* Consistent with the FCC's proposal, we calculated separation distances for devices operating between 16 dBm and 36 dBm (40 mW-4 W EIRP).[35]
- *WMTS Receiver Sensitivity:* Consistent with GE Healthcare's most recent presentation, we assumed a receive sensitivity of -95 dBm for WMTS devices.[36] Based on publicly available product manuals, it appears that actual devices in GE Healthcare's product line are designed to meet this level of sensitivity.[37] In practice, though, there are many situations where receivers would be unable to receive signals at -95 dBm because adjacent channel TV broadcast operations would impair reception at such a low level. For example, New York, Los Angeles, Chicago, and Washington, DC, each have full power TV broadcasts on channel 36, 38, or both, limiting the effective receiver sensitivity in those markets. Protecting devices at the -95 dBm level is conservative because there are many markets in which such signals would rarely if ever be heard.
- *Additional Margin:* Consistent with GE Healthcare's presentation in the Commission's broadcast incentive auction proceeding, we assumed an additional 6 dB of margin to protect WMTS receivers from potential harmful interference.[38] In other words, we assumed a potential interferer's power at the potential victim receiver should be at least 6 dB below the

[35] Part 15 NPRM at ¶ 112.

[36] GE Healthcare Comments, Appendix A at 5.

[37] GE Medical Systems, *ApexPro Receiver SystemService Manual* 2-8 (2002), *available at* http://www.frankshospitalworkshop.com/equipment/documents/ecg/service_manuals/GE_ApexPro_Telemetry_Receiver_-_Service_manual.pdf; *see also* GE ApexPro Telemetry System 3, http://www.somatechnology.com/pdffiles/ge_apex_pro_telemetry_telemetry_systems.pdf.

[38] Comments of GE Healthcare, GN Docket 12-268, Technical Appendix at 40 (filed Jan. 25, 2013) (GE Healthcare Incentive Auction Comments).

receiver's sensitivity level. Using a margin this large is extremely conservative, as it targets sensitivity loss of no more than 1 dB. (1 dB of desensitization corresponds to a 6 dB reduction in power.) For comparison, in the context of LTE interference scenarios, 3GPP metrics allow as much as a 6 dB loss of sensitivity due to in-band blocking, and 14 dB loss of sensitivity for adjacent channel scenarios.[39] Nevertheless, we recognize that WMTS facilities support critical operations, so we allowed 6 dB of additional margin for the purposes of our analysis.

- *Building Loss:* Based on GE Healthcare's testing at Inova Mount Vernon Hospital, we assumed building loss of 16 dB.[40] This assumption is substantially more conservative than the building attenuation GE Healthcare assumed in the context of the broadcast incentive auction proceeding.[41] In that proceeding, GE Healthcare recognized that building walls often cause losses of 20 dB or more. Because building construction can vary substantially, below we outline a simple approach that accounts for this variation and allows hospitals to request additional protection for sites that feature lighter construction. Nevertheless, even our baseline analysis relies on a conservative default value of 16 dB.
- *Additional Link Margin for Aggregate Interference:* GE Healthcare asserts that its systems must be accorded additional margin to account for the possibility that multiple TVWS devices might transmit into a WMTS distributed antenna system at the same time.[42] In making this argument, GE Healthcare assumes that ten different WMTS receive antennas would all

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[39] *See* 3GPP TS 36.101 v8.26.0 § 7.6.1.1 (In-band blocking); *id.* § 7.5.1 (adjacent channel selectivity). The Commission has also recognized that a 1.0 dB desensitization level, as GE Healthcare advocates, is inappropriate in the LTE context. H Block Order ¶ 144 (noting that LTE systems "are designed to perform in a strong interference environment, much of which is often self-generated, coming from other network elements (*e.g.*, other nearby base stations in the same or adjacent bands)").

[40] GE Healthcare Comments, Appendix A at 10, Table 2 (showing six out of eight sites tested exhibiting more than 15 dB of building loss). In Google's initial comments in this proceeding, we noted that commercial construction at Google's main campus exhibited a range of building losses between 13 dB and 20 dB, consistent with the 16 dB assumption proposed here. In that filing, we suggested the Commission adopt a conservative building loss of 10 dB but calculated separation distances based on a 20 dB loss in non-line-of-sight conditions. *See* Comments of Google Inc., ET Docket No. 14-165 and GN Docket 12-268, Appendix A, ¶¶ 6-10 (filed Feb. 4, 2015) (Google Comments). The approach proposed here is largely consistent, but simplifies site-specific protection by relying on the easily identified characteristic of building construction.

[41] GE Healthcare Incentive Auction Comments, Appendix A at 41.

[42] *See, e.g.*, *id.,* Appendix A at 51, Table 5.

receive a TVWS signal delivered at maximum power, at exactly the same time.[43] This circumstance is extremely unlikely to occur. Multiple TVWS devices would have to operate within line-of-sight of *ten* WMTS receivers and transmit in unison at the maximum power allowed. This scenario would require near-perfect alignment across of variety of devices and receivers and perfectly harmonized transmissions from TVWS devices across ten device/receiver pairs. It would also require all unlicensed devices to operate without the use of polite protocols, even though polite protocols are a component of two common industry standards developed for this band.[44] Nevertheless, because there may be some risk associated with aggregate interference, our analysis included an additional 3 dB of link margin to account for this possibility.

- *Additional Path Loss*: A variety of factors beyond simple free-space path loss are likely to cause additional losses between a TVWS device and a WMTS receiver, including ground clutter (such as trees, sidewalks, and roofs, even in line-of-sight conditions) and antenna polarization and pattern mismatch. As an extremely conservative estimate of these losses, we estimated 3 dB of additional loss.[45]

Using these assumptions, we calculated the following range of separation distances between unlicensed devices and WMTS facility perimeters.

Unlicensed device transmit power	**16 dBm (40 mW)**	**20 dBm (100 mW)**	**24 dBm (250 mW)**	**28 dBm (625 mW)**	**32 dBm (1600 mW)**	**36 dBm (4 W)**
Required co-channel separation distance (meters)	187	296	469	744	1,179	1,868

These distances represent the separation required to protect actual WMTS systems against interference from TVWS devices operating in Channel 37, with a wide margin of

[43] *See id.*

[44] *See* Completed Standards, IEEE 802.22 Working Group on Wireless Regional Area Networks, http://www.ieee802.org/22/; IEEE Standards Association, IEEE Standard 802.11af-2013, https://standards.ieee.org/findstds/standard/802.11af-2013.html.

[45] Again, we make an extremely conservative estimate here on account of the critical nature of WMTS uses, especially as compared to more realistic losses we recognize in the case of unlicensed-to-LTE interference. *Cf., e.g.*, Google Comments at 7-9; Google Reply Comments at 7-11.

safety.

If the FCC wishes to provide still more protection to WMTS, it could adopt variable separation distances to account for differences in building construction.

As noted above, 16 dB loss represents a contextually reasonable, albeit conservative, default assumption for building loss in commercial-grade buildings. Google thus recommends that the Commission establish default separation distances—from the actual perimeters of WMTS facilities, as described in Google's prior filings[46]—that are based on a 16 dB assumed building loss, as well as the other very conservative assumptions set forth in this analysis.

Building construction can vary, however. Google supports providing a margin of assurance at all WMTS facilities, regardless of their construction. In order to allow departures from the default presumption of commercial-grade construction in appropriate cases, therefore, the FCC could establish a process by which managers of WMTS facilities can request that a particular building be classified as light construction or very light construction, and thus receive additional interference protection where warranted. Buildings qualifying as light construction would include those constructed primarily of wood or non-tinted glass. Very light construction would include buildings that are residential grade. The Commission could appropriately ascribe separation distances for light construction using an assumed building loss attenuation of 13 dB, and separation distances for very light construction using an assumed attenuation of 10 dB.

In the typical case of commercial-grade construction, a WMTS facility operator would not need to take any action to receive full protection, beyond registering in a TVWS database. In the rarer cases of lighter construction, a WMTS operator's assertion that a medical building qualifies as light or very light construction could be substantiated on the basis of a verified statement providing detailed construction information such as materials used and interior and exterior photographs that clearly establish the building's eligibility for increased protection. A party seeking to dispute a claim of light or very light construction could bring a complaint to the Commission. Such disputes should be rare, however, because the general characteristics of a building's construction are readily apparent to any visitor, or from online resources such as Google Street View[47] and Google Earth.[48] To avoid controversy in cases where a single building exhibits both standard commercial construction and lighter construction, protection could be based on the lighter construction. Google is prepared to work with the WMTS community to develop clear eligibility standards for the light and very light construction categories.

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[46] Google Comments at 22.

[47] *See* https://www.google.com/maps/views/u/0/streetview?gl=us.

[48] *See* https://www.google.com/earth/.

This approach would provide WMTS facilities both the certainty of a high level of default protection and the opportunity to request tailored protection through a straightforward, standard process.[49] In the table below, we show separation distances for the three classes of construction, based on the methodology and assumptions described above.

Class of construction	**Required co-channel separation distance (meters)**					
	16 dBm (40 mW)	**20 dBm (100 mW)**	**24 dBm (250 mW)**	**28 dBm (625 mW)**	**32 dBm (1600 mW)**	**36 dBm (4 W)**
Commercial Grade/ Default (16 dB loss)	187	296	469	744	1,179	1,868
Light (13 dB loss)	264	418	663	1,051	1,665	2,639
Very Light (10 dB loss)	332	527	834	1,323	2,096	3,322

By using the conservative assumptions described above and tailoring separation distances to variations in building construction, the FCC can allow meaningful unlicensed use of Channel 37 while also protecting WMTS facilities from harmful interference with a wide margin of safety in all cases.

3. Reasonable separation distances can protect radio astronomy observations.

Based on informal discussions with consultants to the National Academy of Sciences' Committee on Radio Frequencies (CORF), Google proposes that the Commission adopt the following approach to protecting radio astronomy observations:

- The Commission should exclude unlicensed device operations on Channel 37 within the National Radio Quiet Zone (NRQZ) and the Puerto Rico Coordination Zone (PRCZ).
- The Commission should adopt bearing-dependent separation distances for Channel 37 unlicensed device operations, tailored to each individual Very Long Base Array (VLBA) site using the Longley-Rice propagation model, as presented in Google's comments in this proceeding.

[49] In earlier filings, Google advocated differentiating between line-of-sight and non-line-of-sight conditions. *See* Google Comments at 22-25. The approach proposed here provides an alternative method that also allows for tailored protection, while assuming close to pure line-of-sight conditions for all sites.

- No unlicensed device operations should be allowed in any guard bands adjacent to Channel 37 in the NRQZ or the PRCZ, or within 16 km of any VLBA site.
- The prohibition against TVWS operations within 2.4 km of radio astronomy sites should be maintained.[50]

We continue to believe that time-based coordination for the use of Channel 37 in exclusion areas surrounding radio astronomy sites would improve spectrum efficiency without risk of harmful interference, by protecting radio astronomy observatories only when those observatories are actually utilizing Channel 37. Nevertheless, we appreciate CORF's concerns regarding the readiness of the observatories to implement such a solution at this time.

Google appreciated the opportunity to speak with CORF's consultants. The discussions allowed Google to understand better the concerns of the radio astronomy community, and we believe the solutions described above are responsive to CORF's concerns.

Respectfully submitted,

Aparna Sridhar
Counsel
Google Inc.

[50] *See* 47 C.F.R. § 15.712(h).

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

In the Matter of	)	
	)	
Amendment of Part 15 of the Commission's Rules for Unlicensed Operations in the Television Bands, Repurposed 600 MHz Band, 600 MHz Guard Bands and Duplex Gap, and Channel 37	)	ET Docket No. 14-165
	)	
Amendment of Part 74 of the Commission's Rules for Low Power Auxiliary Stations in the Repurposed 600 MHz Band and 600 MHz Duplex Gap	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	GN Docket No. 12-268

DECLARATION OF DONALD BRESLIN

1. My name is Donald Breslin. I am a wireless systems engineer at Google Inc. (Google). Before joining Google, I was a principal systems engineer at Qualcomm Atheros. At Qualcomm Atheros, I spent 10 years managing systems integration teams within the Wi-Fi hardware development group covering both mobile and access point platforms, and developed deep experience with Wi-Fi technologies. Before joining Qualcomm Atheros, I worked at Arraycomm managing wireless systems teams for macro-cellular data products. I also gained experience in propagation measurements and modeling at Bell Communications Research and in the Mobile and Portable Radio Research group at the Virginia Polytechnic Institute and State University. I hold four patents, and my work has been published in the IEEE International Solid-State Circuits

Conference proceedings, as well as in Bell Communications Research Reports. I received an M.S. and a B.A. in electrical engineering from Virginia Polytechnic Institute and State University.

2. I have reviewed the Notice of Proposed Rulemaking (NPRM) in the above-captioned proceeding. I have also reviewed the responses of Qualcomm Incorporated (Qualcomm) and CTIA—The Wireless Association (CTIA) to the NPRM.[1]

3. In this proceeding, Google has argued that unlicensed TV white space devices can operate at powers of 40 milliwatts in the guard bands and duplex gap established in the 600 MHz band plan, as well as in Channel 37. To further verify this, we recently conducted several simulations and tests related to our earlier analyses. Specifically, we performed the following investigations. (1) We validated that body loss associated with both LTE and white space devices is substantial. (2) We measured loss associated with two phones sitting on a tabletop approximately 2 meters apart, without any obstructions between them, and confirmed that even in these ideal, line-of-sight conditions, substantial losses occur as compared to free space propagation. (3) We measured the transmit emissions mask of a sample white space device currently in production, and confirmed that it exhibits additional roll-off outside of a 6 MHz operating channel. (4) We confirmed through empirical testing that operating a white space device

[1] Comments of Qualcomm Incorporated, ET Docket No. 14-165 and GN Docket No. 12-268 (filed Feb. 4, 2015) (Qualcomm Comments); Comments of CTIA—The Wireless Association at 7-36, ET Docket No. 14-165, GN Docket Nos. 12-268 and 14-166 (filed Feb. 4, 2015) (CTIA Comments); Reply Comments of Qualcomm Incorporated, ET Docket No. 14-165 and GN Docket No. 12-268 (filed Feb. 25, 2015) (Qualcomm Reply Comments); Reply Comments of CTIA—The Wireless Association, ET Docket No. 14-165, GN Docket Nos. 12-268 and 14-166 (filed Feb. 25, 2015) (CTIA Reply Comments); Letter from Krista L. Witanowski, AVP, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, FCC, ET Docket. No. 14-165; GN Docket. Nos. 14-166, 12-268, May 8, 2015, (CTIA Ex Parte).

at 40 milliwatts, with 4 MHz separation from LTE, does not impact LTE transmission speeds or packet loss. (5) Finally, relying on CTIA's filings and published data regarding LTE performance, we performed a mathematical analysis that further corroborates our tested observations regarding the minimal impact of TVWS operation on LTE performance.

Body Loss Simulation

4. In both its Comments and Reply Comments in this proceeding, Google observed that body loss can account for significant attenuation of the signal from unlicensed white space devices.[2] Qualcomm's analysis, however, assumed no body loss whatsoever,[3] and CTIA assumed only 6 dB total of body loss.[4] To further investigate these varying assumptions, Google conducted simulations to compare propagation losses when both an LTE device and an unlicensed device are held in the hand with free space propagation. These simulations reveal that holding an LTE handset and holding an unlicensed device adds approximately 15 dB of excess path loss over what free space propagation would predict.

5. A simulation tool from Remcom, XFdtd,[5] was used for collecting the mutual coupling results for the handheld scenario. This tool uses an electromagnetic simulation based on the Finite Difference Time Domain numerical analysis approach to solving

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[2] Comments of Google Inc. ET Docket No. 14-165 and GN Docket No. 12-268, at 6-9 (filed Feb. 4, 2015); Reply Comments of Google Inc. ET Docket No. 14-165 and GN Docket No. 12-268, at 6-10 (filed Feb. 25, 2015).

[3] *See* Qualcomm Comments at 5 (arguing that the Commission should not take body loss into account).

[4] CTIA Comments at 9-10.

[5] *See* Remcom, XFdtd EM Simulation Software, http://www.remcom.com/xf7.

Maxwell's equations.

6. The dimensions for the mobile device used for the simulation were 86 mm x 156 mm x 7 mm, representative of a typical smartphone device like the Nexus 6 and iPhone6+. The antenna system modeled was a monopole design, including a metal frame typical of smartphones, with the antenna located at the bottom of the device. An Inverted F, or IFA antenna, was also simulated and provided similar results to those described below.

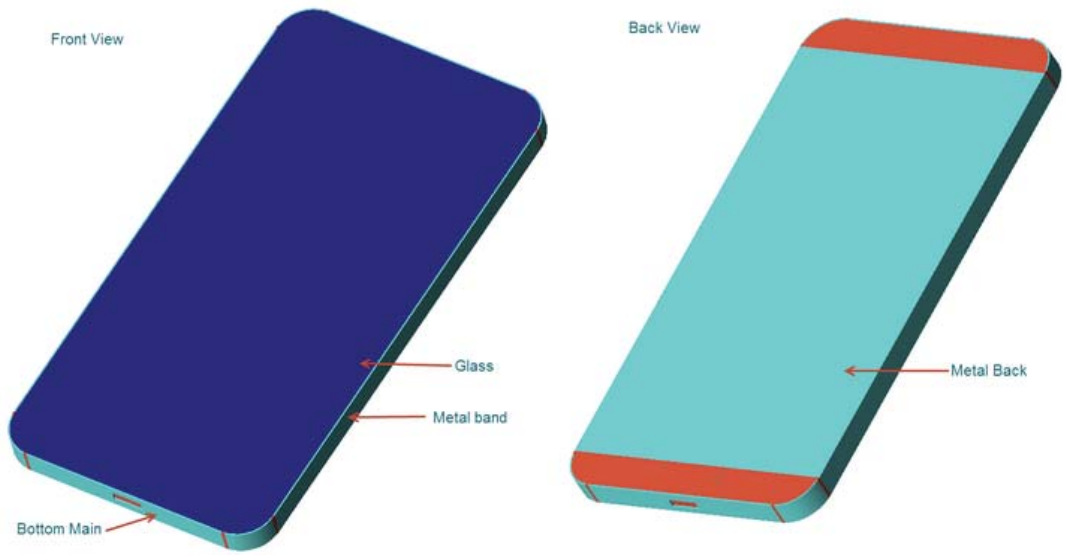


Figure 1: Diagram of handsets used in simulations and testing

7. The return loss of the antenna simulated was better than 10 dB in the passband, showing it was well matched, and the peak antenna gain was approximately 2 dBi, as shown in the polar plot in Figure 2 below. Simulating an antenna gain of 2 dBi represents an idealized, conservative scenario because inefficiencies and losses were minimized by measuring the signal directly at the RF port of the antenna. A real

smartphone antenna would also be required to cover multiple bands, whereas our test antenna had a simple design that covers a single band. Adaptive matching to tune antenna center frequencies and multi-resonant structures are commonly used, which provide improved frequency coverage at the expense of efficiency. Typical inefficiencies and losses, including those from connectors, diplexers, and other material in the phone, provide for overall antenna gains in the range of -6 dBi in real world operation. Still, the relative impact of holding a device in the hand or laying it on a table can be quantified from our antenna benchmark by measuring the difference between propagation losses in free space as compared to losses shown when both devices are both held in the hand or placed on a table.

8. The radiation pattern below shows a peak gain at 0 degrees and 180 degrees, broadside to the phone. This direction was used to measure the impact of the human hand.

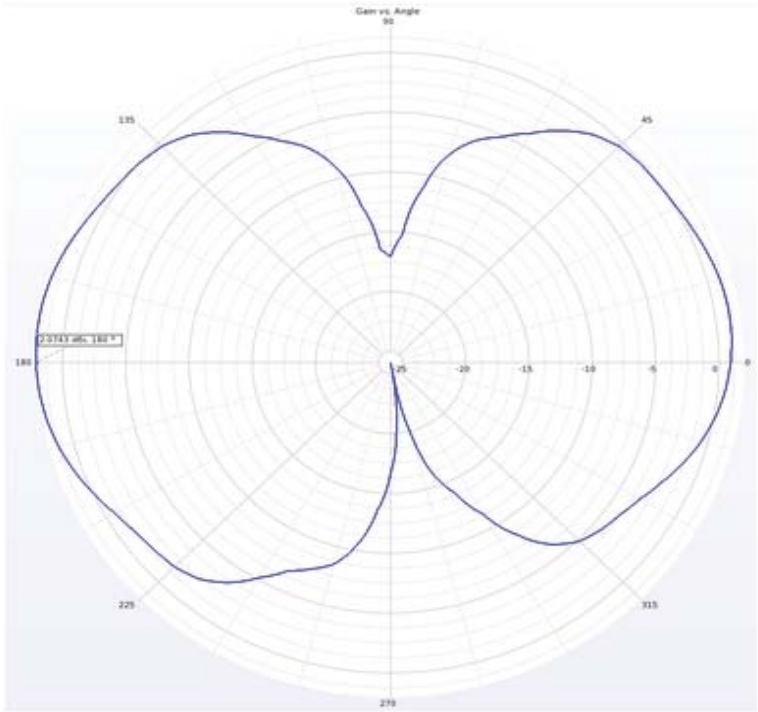


Figure 2: Antenna radiation pattern

9. A stylized diagram of the handheld use case at 2 meters spacing appears in Figure 3 below.

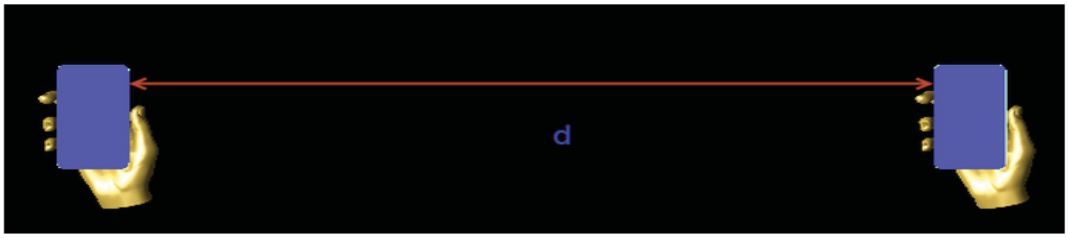


Figure 3: Diagram of handheld scenario simulation

10. Figure 4 below shows mutual coupling, labeled |S21|, for the phones in free space at 2 meters. As shown in the figure, the simulation demonstrated mutual coupling of approximately -31 dB in free space for this idealized antenna reference.

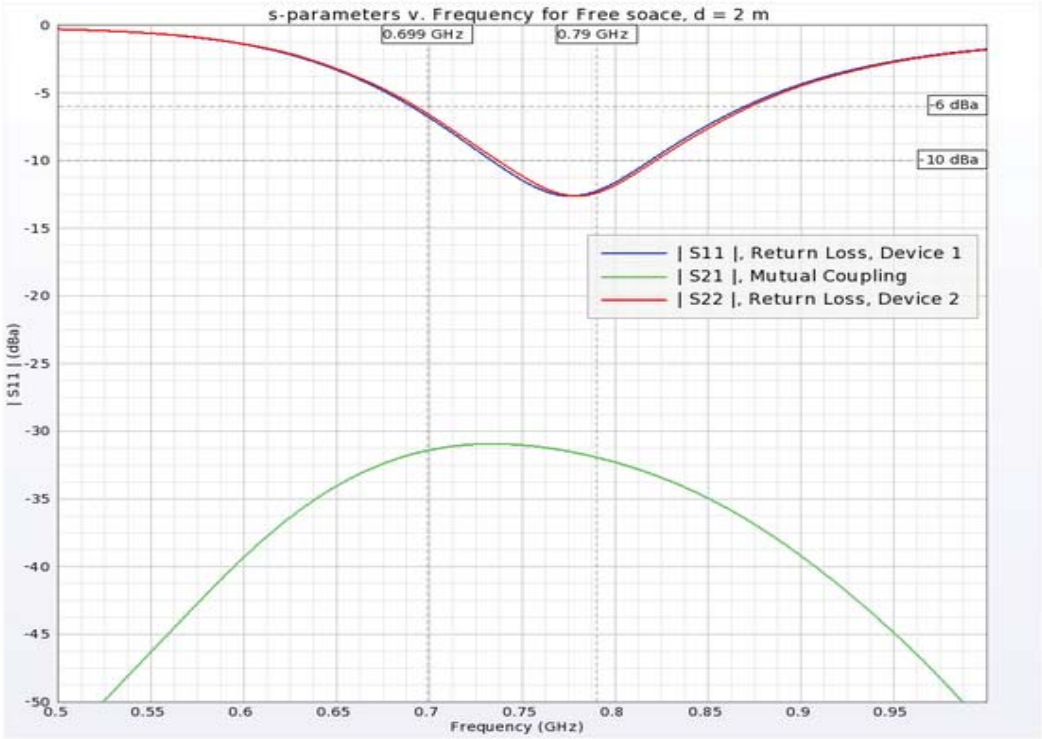


Figure 4: Simulation of mutual coupling: two handsets in free space

11. Figure 5 below shows the mutual coupling, labeled |S21|, for the phones held in the hand and separated by 2 meters. As shown in the figure, the simulation demonstrated mutual coupling of -46 dB in free space with the presence of a hand.

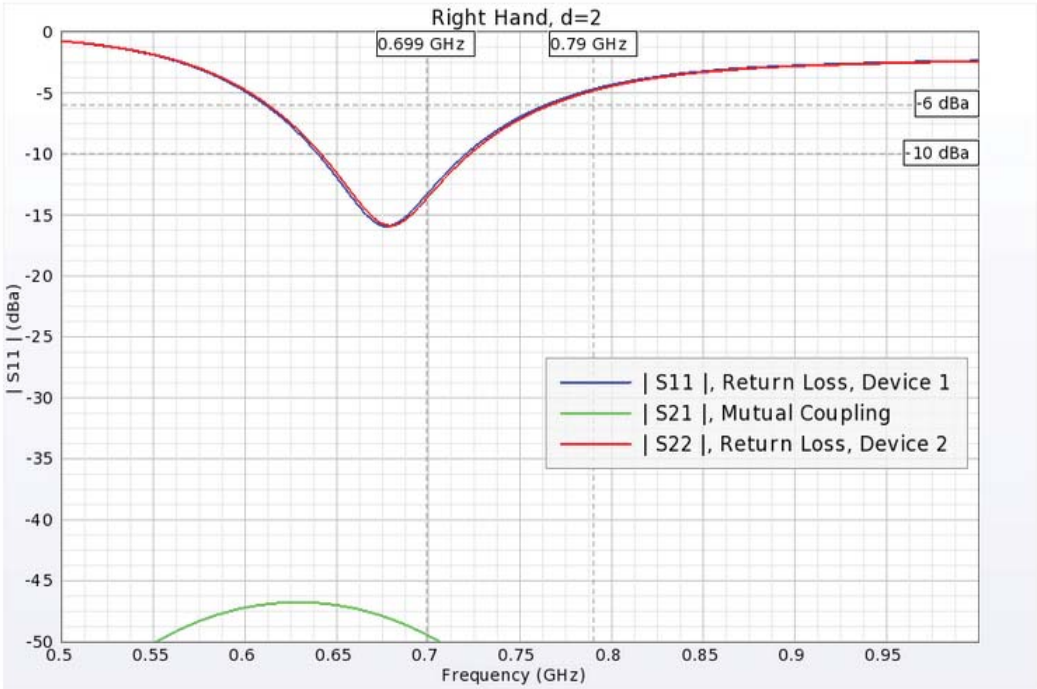


Figure 5: Simulation of mutual coupling: two handsets held in the hand

12. The difference between the initial free space condition and the handheld use case is approximately 15 dB, after discounting the center frequency shift due the hand. Thus, we can attribute 15 dB loss to the presence of the hand holding each phone.

<u>Short Range, Line-of-Sight Testing</u>

13. Google also measured losses associated with devices sitting on a table two meters apart from each other, without any obstructions between the phones. This spatial configuration eliminates body loss and other potential sources of path loss and thus represents a very conservative scenario for testing interference potential. In most cases, one or both users would hold the handset if actually using the device. And in many cases, even if handsets are not held close to the body, they will not be operating directly within the line-of-sight of another handset. Even in this corner case, however,

there is substantial loss not accounted for in the Qualcomm and CTIA analyses. Indeed, the mere placement of two phones on a table increased the loss between the two devices by 6-16 dB as compared to free space.

14. For the table top scenario, the presence of a ground plane below the table and the specifics of the supporting structure of the table were difficult to simulate. For this reason, a measurement approach was used. An antenna test fixture with a monopole design, similar to the one used in the simulations above, was fabricated, and measurement of the mutual coupling separately in free space and on a table was conducted. The tested measurement of antenna-to-antenna mutual coupling in free space was close to the results simulated: tested results showed 32 to 33 dB of loss, as compared to approximately 31 dB in simulation.[6] Again, as with the simulated measurements, these results represent a conservative scenario when compared to real-world operation, because we took measurements at the RF port of the antenna itself. The -32 dB of measured mutual coupling correlates well to predicted free space path loss of 35 dB at 2 meters (assumes 0 dBi antenna), after accounting for the 2 dBi antenna gain included in the mutual coupling measurement.

15. As with our analysis of body loss, we used the radiation pattern described in paragraph 8 and Figure 2 when measuring the impact of placing the handset on a tabletop.

16. The loss associated with the test fixtures when placed 2 meters apart on a typical wood table was approximately 38 dB and 48 dB for the favorable broadside angles (main lobes pointing to each other). This is equal to a 6 to 16 dB loss attributable

[6] *See* ¶ 10, *supra*.

to the presence of the table alone. (We used 32 dB as the benchmark for free space loss to ensure apples-to-apples comparison between the two measured scenarios—free space operation and operation on a tabletop.)

17. The antenna test fixtures and measurement scenarios for free space and tabletop are shown in Figures 6 and 7 below.

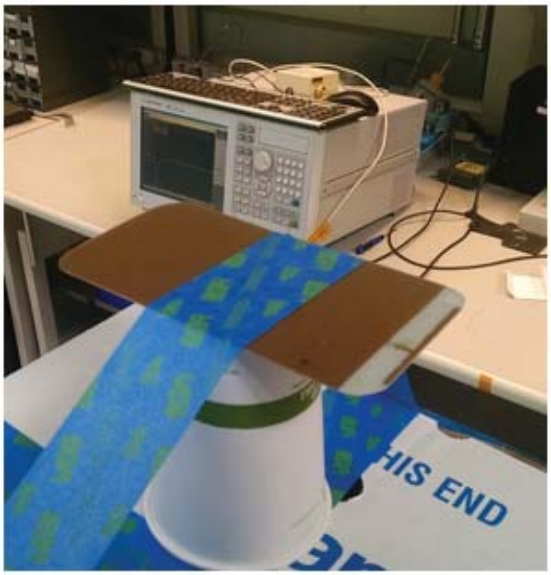
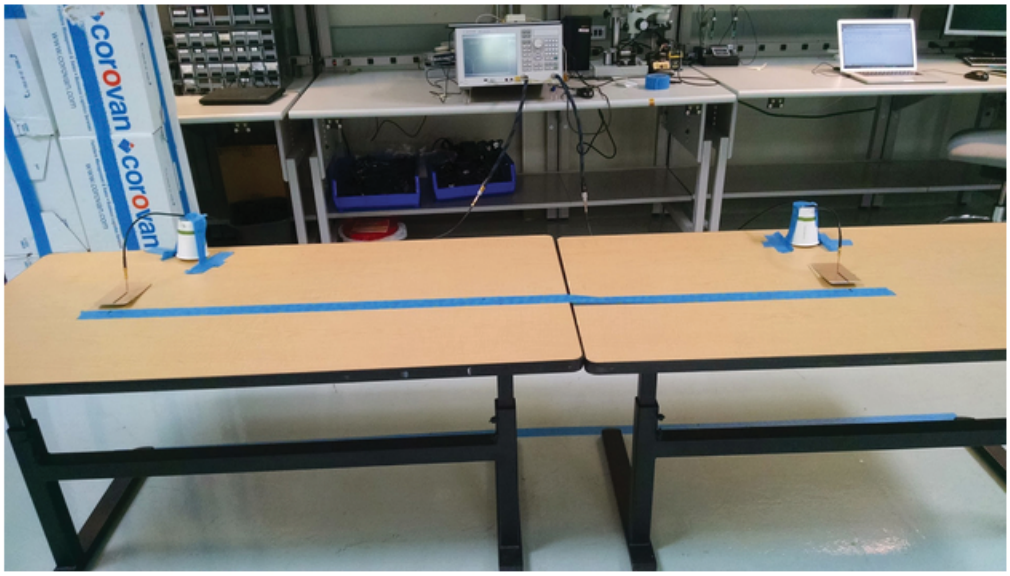


Figure 6: Test environment for free space measurement



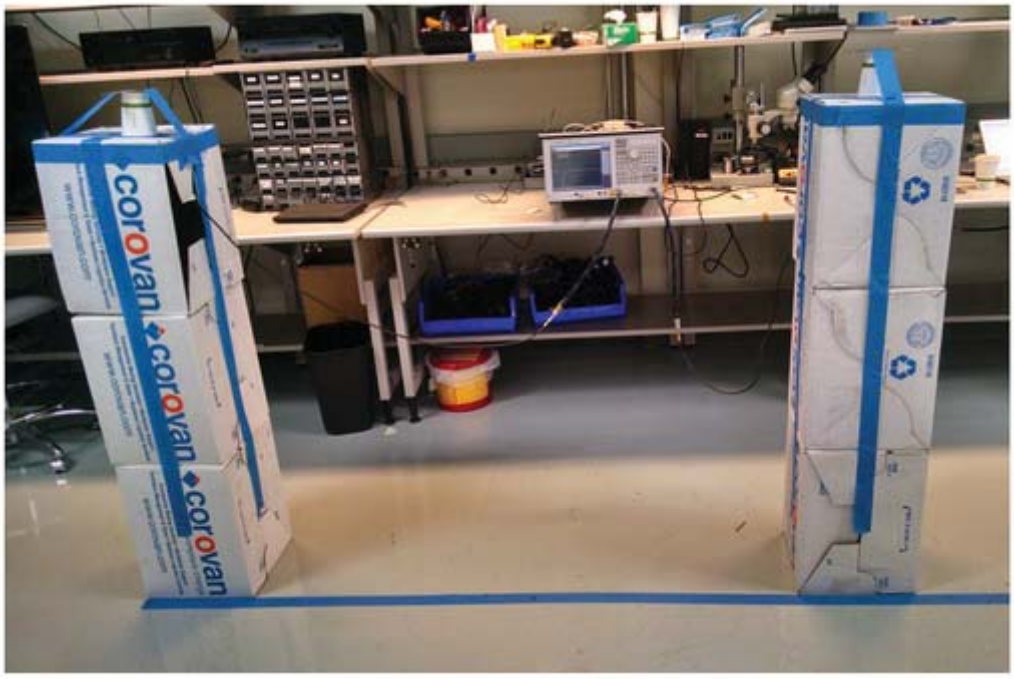


Figure 7: Comparison of test environment for free space and tabletop measurements

TV White Space Device Emissions Characteristics

18. In their submissions, Qualcomm and CTIA both assumed that an unlicensed device would not exhibit additional signal roll-off outside of the 6 MHz channel in which it is designed to operate.[7] The amount of roll-off assumed is a significant factor in determining how much power the out-of-band-emissions of the TVWS device will have in the nearest LTE downlink channel for duplex gap and guard band operation. By contrast, Broadcom's calculations assumed 10 dB of additional decrease in TVWS emission power from the TVWS channel edge to the nearest LTE channel edge.[8] By assuming no further roll-off, Qualcomm and CTIA estimate significantly higher TVWS signal power at the LTE band edge than Broadcom.

19. To investigate these competing assumptions, Google tested a white space device manufactured by 6Harmonics. The radio performed consistent with Broadcom's expectations, showing 10 dB of roll-off outside the 6 MHz passband.

20. A graph of the transmit emissions mask for the GWS4006-17/20 model from 6Harmonics, is shown in Figure 8 below. The edge of the 6-MHz channel assignment is marked by the red vertical bars, +/- 3 MHz from center. Consistent with Broadcom's assumption, the roll-off beyond the channel edge is approximately 10 dB over the next 4 MHz.

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[7] Qualcomm Comments at A1; CTIA Comments, Appendix A at 6.

[8] Comments of Broadcom Corporation, ET Docket No. 14-165 and GN Docket No. 12-268, at 9, Fig. 1 (filed Feb. 4, 2015).

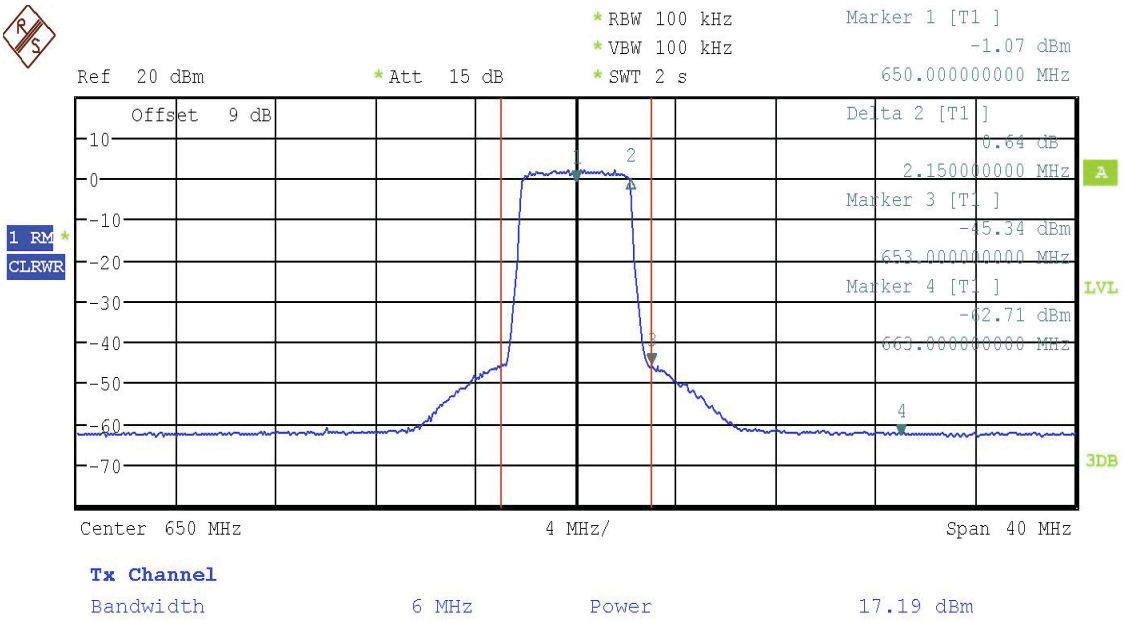

Figure 8: TVWS transmit emissions mask

Radiated Measurement of Impact on LTE Performance

21. Each of the analyses set forth above probes a particular assumption or set of assumptions regarding the transmission or propagation of white space device signals into an adjacent LTE band. After conducting these analyses, Google also investigated the overall impact of unlicensed device transmissions on LTE. To do this, Google asked Dr. Paul Kolodzy of Kolodzy Consulting, LLC, to conduct the radiated tests and measurements described below.

22. To evaluate the real world impact of a signal source operating in close proximity to an LTE handset near the edge of range, radiated tests were conducted on a Samsung Galaxy S4, a popular LTE handset. The Galaxy S4 was taken to the interior of the basement of a suburban residence to generate edge of LTE coverage conditions, and the “FCC Speed Test” Android application was run to quantify the impact of an

interference source placed one meter away from the handset. The LTE device was found to be very robust to interference, with no significant degradation in measured user throughput and packet loss rates at frequency offsets from 2 MHz to 6 MHz, interference transmit powers as high as 20 dBm, and short range conditions with minimal isolation. The tested transmit powers for the interference source exceed CTIA's and Qualcomm's proposed maximum power thresholds by 20 to 30 dB.[9] Because no meaningful degradation was measured even at these higher powers, these results show that CTIA and Qualcomm overstate the risk of harmful interference to licensed operation.

23. During the tests, the Samsung Galaxy S4 was operating in the Verizon C-Block band on a channel centered at 751 MHz (746 to 756 MHz), as shown in Figure 9 below. In the geographic area where the tests were conducted, Verizon has deployed a 10 MHz bandwidth LTE network in this band. The interfering signal used to simulate white space device transmissions, operating under FCC authorization, was a continuous waveform tone operating at transmit powers between -20 dBm to 20 dBm at a spacing of 1m from the handset. Downlink throughput and error rate were measured using the FCC "Speed Test" application, with and without interference, in multiple iterations, to quantify the impact of a nearby signal source on an LTE link. The edge of coverage for the LTE network in this location was found to be approximately -80 dBm. The measured throughputs at this point were low (around 2 Mbps), and the LTE network was found to switch to 3G at user equipment receive powers below approximately -81 dBm. For the

[9] *See, e.g.,* CTIA Comments at 18, fig. 3 (claiming that a narrowband wireless microphone separated by 3 MHz from LTE would have to transmit at powers below -4.5 dBm to avoid sensitivity loss of LTE); Qualcomm Comments at 11 (proposing maximum EIRP of -14 dBm for white space devices separated from LTE by 3 MHz). Our tests measured the impact of transmit powers up to 20 dBm with 1 meter spacing in line of site conditions and found no meaningful impact.

tests, the user equipment's receive power was maintained at approximately -79 to -80 dBm to remain in the LTE mode for the duration of the test.[10]

24. A spectrum analysis tool was used to collect the data on received power versus frequency spectrum that is shown below, indicating the LTE signal power in the vicinity of the handset, and the frequency spacing relative to the interfering signal source. The LTE signal occupies the bandwidth from 746 MHz to 756 MHz. The interfering signal source is shown at 760 MHz in the spectrum capture. In the throughput and packet error rate charts below, the interfering signal was tested at 762 MHz, 760 MHz, and 758 MHz center frequencies, which represent 6 MHz, 4 MHz, and 2 MHz spacing from LTE channel edge, respectively.

[10] These receive powers were in fact higher than 3GPP's specified REFSENS for this band, which is -94 dBm for 10 MHz. However, our tests were designed conservatively across a variety of other measures. Transmit powers were higher by 4 dB than the limits proposed in the NPRM. Separation distance was limited to 1 meter as urged by Qualcomm and CTIA, rather than the 2 meters that Google believes is an appropriate assumption. Polarization mismatch, body loss, and shadowing were eliminated through idealized placement of the two devices. Taken together, these factors resulted in at least 20 dB less isolation than one would expect in ordinary, real-world operation.

Figure 9: Spectrum capture showing LTE signal and spectral positioning of simulated interferor

25. As noted above, the interfering signal source was spaced one meter from the LTE handset. This configuration was used to create a very conservative minimum isolation scenario between the LTE user equipment and transmissions from the external interference source. Cable loss and antenna gains for the interference source totaled -4 dB of gain (4 dB of loss from conducted to radiated power). The total radiated power as seen at the LTE handset antenna was approximately 33 dB less than the listed interference transmit powers, after accounting for 29 dB of free space path loss at one meter and 4 dB of additional cable and antenna gain losses. For example, under this experimental configuration, a 20 dBm transmit power from the interferer translates to -13 dBm power at the LTE handset antenna.

26. In addition to limiting separation to 1 meter, a number of other measures were also taken to establish minimum, simplistic, and conservative path loss channel conditions between these devices: The LTE handset was placed in a plastic structure and suspended in a vertical orientation, and the interfering signal antenna was placed directly in its line of sight, with matching vertical polarization. Real-world operation between an LTE handset and TVWS transmitter would incur much higher losses, after accounting for greater distance between the two devices, hand and body losses, and other sources of shadowing and polarization mismatches between these devices.

27. Figures 10 through 15 below show the impact of the simulated interference signal on LTE operation. The baseline measurement, without the interference signal generator output enabled, is captured in the charts at -50 dBm for presentation purposes. This measurement shows download speed and packet loss in normal conditions. The baseline measurements with no external interference from the signal generator show relatively low user throughputs, 2 Mbps on average, suggesting a near edge-of-range condition. The results also show a relatively high variance in both throughputs and packet error rates, even though the user equipment was receiving relatively strong signals (-80 dBm RSSI).

28. As seen in Figures 10, 12, and 14, the baseline throughputs ranged from approximately 1 Mbps to 3 Mbps. As shown in Figures 11, 13, and 15, the packet error rates ranged from approximately 5% to 15%. This suggests the LTE system is operating in the presence of background cellular interference levels, which have raised the combined interference and thermal noise floor substantially. Comparing the -80 dBm user equipment received power at the edge of LTE coverage to the -97 dBm 3GPP

REFSENS for edge-of-range conditions, we estimate the interference floor at approximately 17 dB above the user equipment's thermal noise floor. By the same comparison, these LTE receive powers were also 20-25 dB higher than the LTE handset sensitivity levels cited by CTIA and Qualcomm, which were based on idealized bench tests.[11]

29. The delivered throughput and packet error rates did not show a significant dependence on interfering transmit power for frequency spacings of 2 MHz, 4 MHz, or 6 MHz from the LTE channel edge to the interference signal, even at interfering signal powers as high as 20 dBm.[12] Throughputs ranged between 1 to 6 Mbps, equal to or better than baseline measurements, even in the presence of an interfering signal.[13] Packet error rates were similarly unaffected, ranging from 0 to 20%.[14]

[11] CTIA Ex Parte, Attach. at 5 n.19; Qualcomm Comments at A2.

[12] *See* figs. 10-15 *infra*.

[13] *See* figs. 10, 12, 14 *infra.*

[14] *See* figs. 11, 13, 15 *infra.*

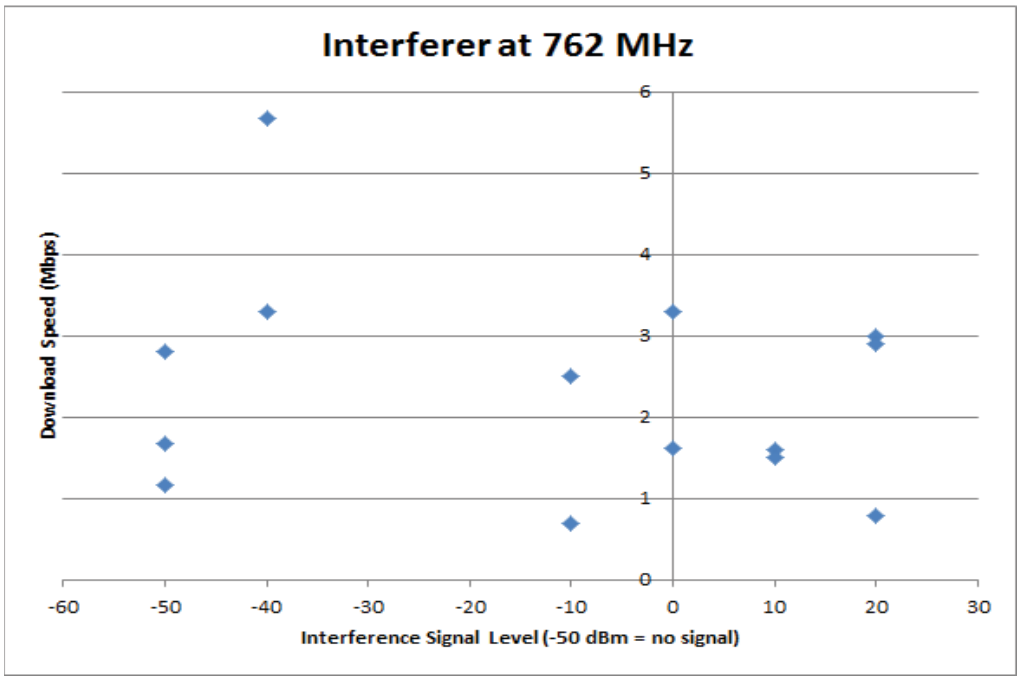

Figure 10: Download speeds - 6 MHz separation between LTE and interfering signal

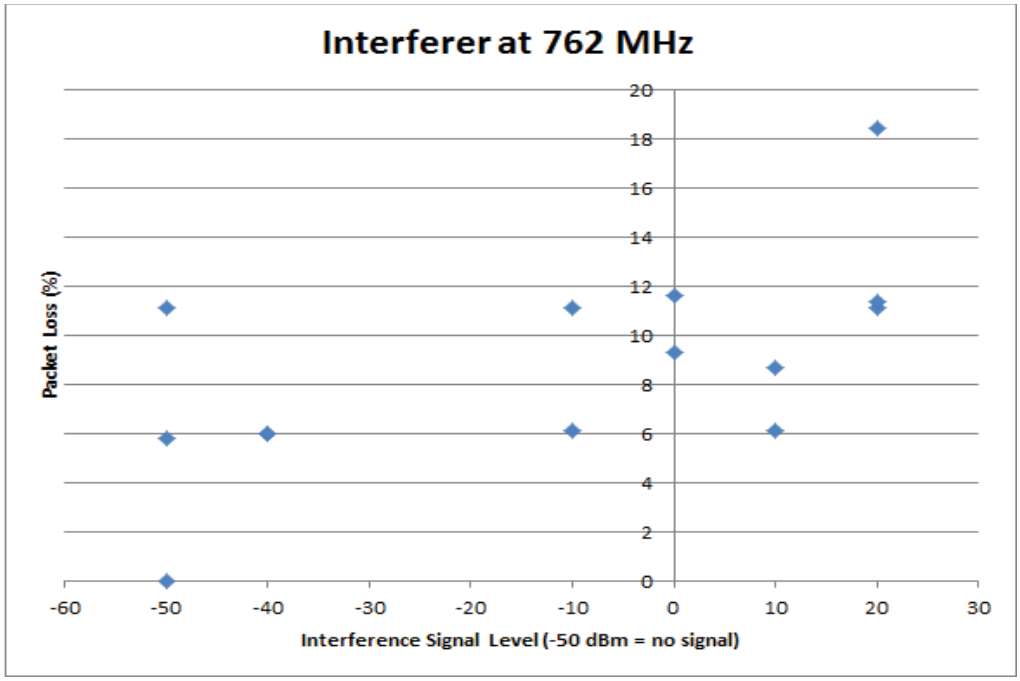

Figure 11: Packet loss - 6 MHz separation between LTE and interfering signal

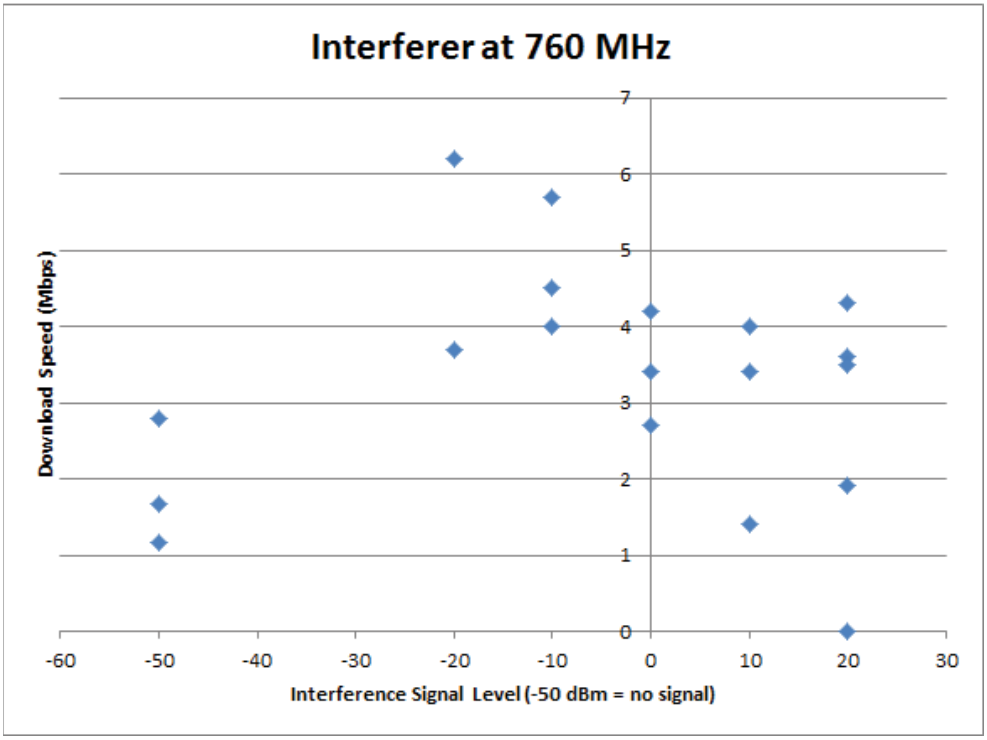

Figure 12: Download speed - 4 MHz separation between LTE and interfering signal

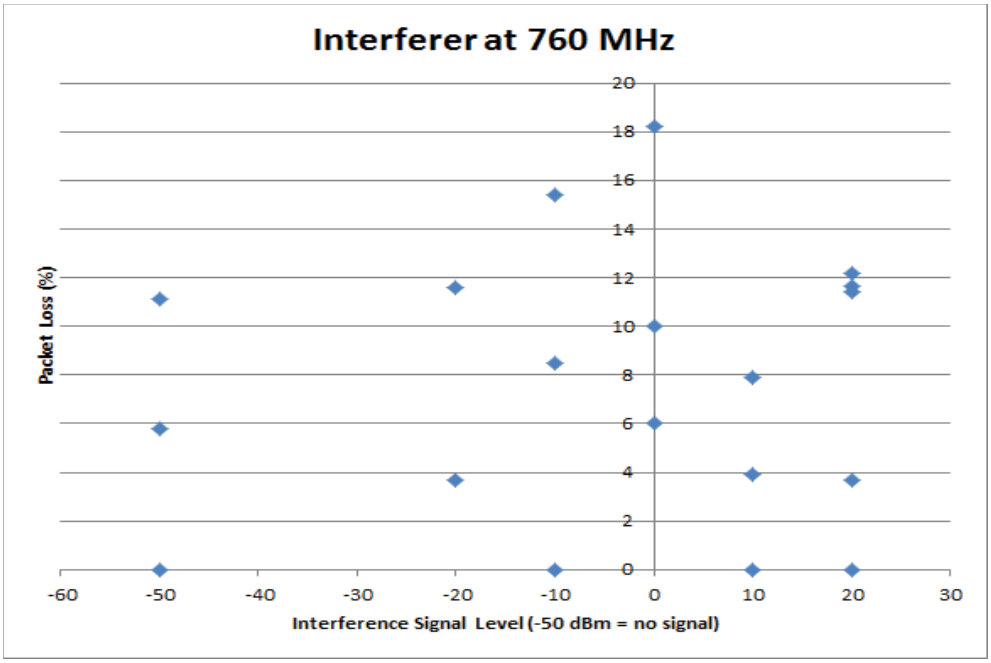

Figure 13: Packet loss - 4 MHz separation between LTE and interfering signal

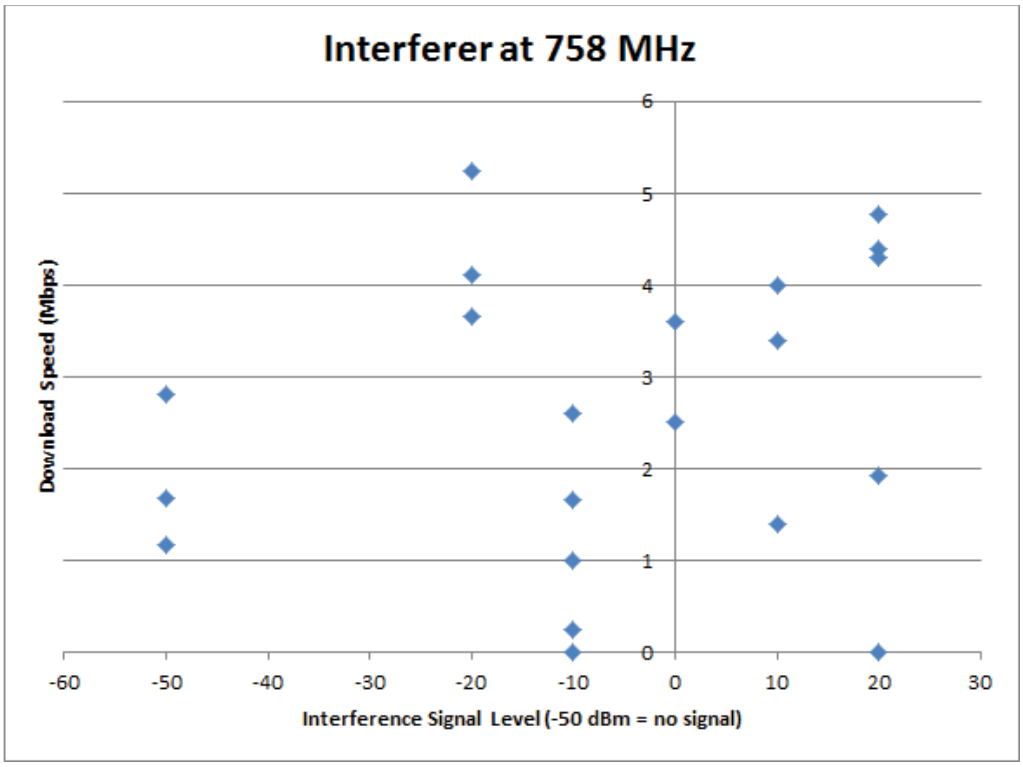

Figure 14: Download speed - 2 MHz separation between LTE and interfering signal

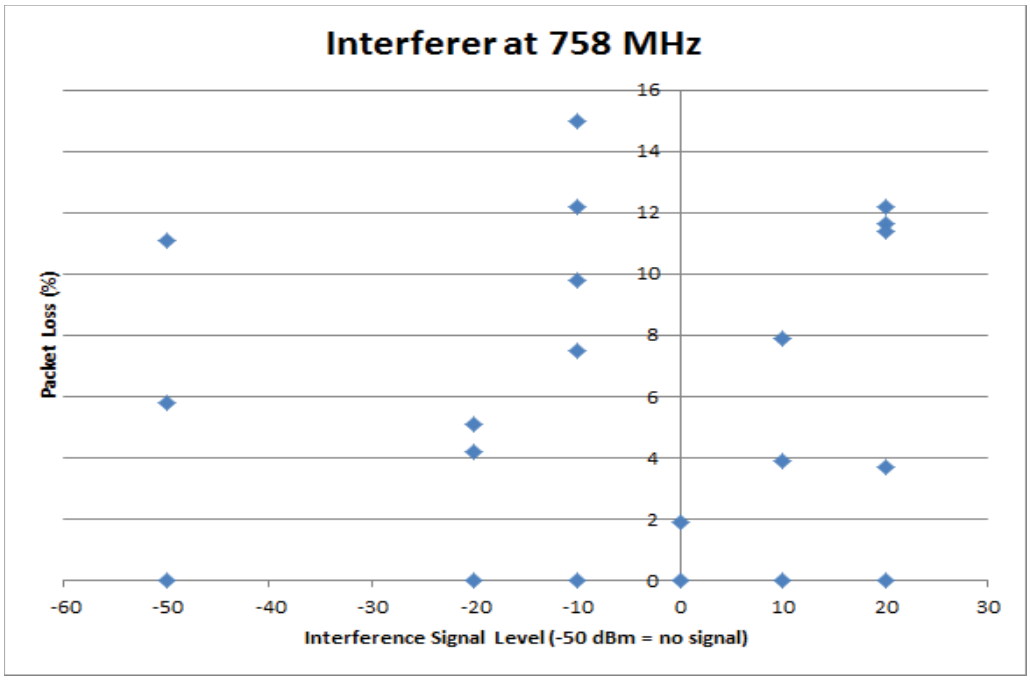

Figure 15: Packet Loss - 2 MHz separation between LTE and interfering signal

Other Factors Affecting Coexistence Between LTE devices and TVWS in Real World Operation

30. Because LTE systems are designed to accommodate high capacity as well as broad coverage, LTE-to-LTE interference—whether self-interference from base stations using the same band or interference from LTE signals in adjacent bands—is likely to dwarf any potential harmful interference from TVWS signals. The analysis below explains why this is the case and attempts to quantify both the very marginal possible impact of TVWS operation on LTE and the potential impact of out-of-band interference from other LTE systems into licensed 600 MHz operation, as compared to TVWS-to-LTE interference.

31. In urban and suburban areas, LTE systems are optimized for capacity. As a result, a handset typically communicates with the closest tower, and switches towers as necessary as it moves. Because they serve many end-users in a small area, cellular systems in urban and suburban areas are designed to meet capacity constraints with densities of cell towers well in excess of those required from the standpoint of mere coverage. In such deployments, a handset rarely operates at the edge of the user equipment's thermal noise floor-limited range.

32. The recent CTIA Ex Parte illustrates this phenomenon. On May 8th, CTIA filed an ex parte letter with the Commission showing that the vast majority of end user equipment in suburban areas operates at 0 dBm or less. From the data submitted by CTIA, we can also infer the vast majority of users operate at 0 dBm or less in urban areas, given that deployments in urban areas are more dense than in suburban areas. In suburban and urban areas, then, most users enjoy a full 23 dB margin from the

maximum power of 23 dBm that we would expect for a user near the edge of range.[15] CTIA's chart shows that 90% of suburban users are transmitting at powers of 7 dBm or below--with a margin of 16 dB from cell-edge transmit power conditions.[16] Operating 16 dB or more from the edge of cell transmit power is indicative of relatively short range, dense cellular operation: a 16 dB reduction in transmission power represents operation at only 30% of the range of a full-power transmission, assuming even a conservative d^3 path loss model.

33. In these settings, where LTE devices are not operating at the edge of range, background cellular interference from nearby LTE base stations reusing the same channel will far exceed the user equipment's thermal noise floor. As such, minimal increases in the user equipment's effective thermal noise floor caused by the presence of TVWS signals will have no measurable impact on the end user performance because the dominant noise source observed by the LTE user equipment will be from co-channel and adjacent band frequency reuse of the cellular system itself.

34. So, to the extent that unlicensed transmissions are thought by Qualcomm and CTIA to have the potential to cause interference into licensed services, the phenomenon is predominantly rural (where systems are designed to optimize for coverage, as opposed to capacity), rather than urban or suburban. However, even for rural users, the CTIA probability curves show that 90% of users are operating transmit powers of 16 dBm or below, with 7 dB or more of margin from cell edge transmit power of 23 dBm.[17] As such, even the vast majority of rural users are operating well away from

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[15] *See* 3GPP TS 36.101 V8.26.0, Table 6.2.2-1 (2015-2).

[16] CTIA Ex Parte, Attach. at 7.

[17] *Id.*

the edge of range.

35. And even in these corner-case, rural users will experience minimal impact to actual operations. In its analyses, Broadcom relied on -98.5 dBm as the maximum level of noise that could be transmitted into the LTE band by a white space device without causing harmful interference, assuming that the LTE signal could also be received at levels of -98.5 dBm.[18] In 2013, Qualcomm also endorsed these numbers.[19] When the received interference power (-98.5 dBm) corresponds to the device's thermal noise floor (also approximately -98.5 dBm), this results in 3 dB loss in downlink link budget.

36. To estimate the impact of a 3 dB loss in downlink budget for the minimal number of total LTE end users (1) operating in a thermal noise-limited scenario in the 600 MHz band (2) in very close proximity to a TVWS transmitter (3) that is capable of causing 3 dB of effective thermal noise floor rise, we can look at LTE physical layer (PHY) rates supported and their signal-to-interference-plus-noise ratio (SINR) requirements. In particular, the following PHY-rate pairs all exhibit a difference in SINR requirements of roughly 3 dB: (1) quadraphase shift-keying (QPSK) ½ rate coding and QPSK ⅓ rate coding, (2) 16 Quadrature Amplitude Modulator (QAM) ⅔ rate coding and 16 QAM ½ rate coding PHY rates, and (3) 64 QAM ⅘ rate coding and 64 QAM ⅔ rate coding.[20] The throughput differences between these pairs of PHY rates, each of which are separated by a 3 dB SINR

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[18] *See* Letter from Paul Margie, Harris Wiltshire Grannis, Counsel to Broadcom Corporation, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268, at slide 8 (filed July 22, 2014).

[19] Reply Comments of Qualcomm Inc. at 4, GN Docket No. 12-268 (filed Mar. 12, 2013).

[20] Stefania Sesia et al., LTE - The UMTS Long Term Evolution 478, Table 21.7 (2011)

requirement, are all approximately 15%. Therefore, for the small percentage of LTE users that may observe any impact, the expectation of a 3 dB loss of downlink link budget equates to 15% or less reduction in throughput. To put this context, based on our test measurements set forth above with an average user throughput of 2 Mbps, this minimal degradation might equate to a loss in throughput of roughly 300 kbps—from the 2 Mbps rate observed to a hypothetical rate of 1.7 Mbps. As shown in the figures above, this minimal reduction in throughput is substantially less than the variation observed in the multiple rounds of testing conducted, and is likely to be overshadowed by ordinary variations in real-world operation. Finally, as noted above, based on CTIA's own charts, this circumstance is likely to be extremely rare, and the "vast majority" of users will see no impact.[21]

37. Finally, the out-of-band emissions rules for adjacent band licensed operations further demonstrate that the Commission recognizes that LTE systems are interference-tolerant. The FCC's rules for out-of-band emissions in the 700 MHz band are set forth at 47 C.F.R. § 27.53. For 3GPP Band 13 operation between 746 MHz and 758 MHz, section 27.53 specifies that the power of any emissions outside of the desired band be attenuated by 43 + 10*log10(P) dB for cellular transmit power P in Watts.[22] Compliance with this rule is based on measurement bandwidths of 100 kHz or greater.[23] Taken together, these requirements translate to an out-of-band emissions limit for cellular operations of -43 dBW / 100 kHz for a given transmit power P, or -13 dBm / 100 kHz for a given transmit power P (30 dBm is 0 dBW).

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[21] CTIA Ex Parte, Attach. at 6.

[22] 47 C.F.R. § 27.53(c).

[23] *Id.* § 27.53(c)(5).

38. By comparison, the TVWS out-of-band emissions emissions levels contemplated by the NPRM are far lower. For a TVWS transmit power of 16 dBm (40 mW) in 6 MHz, the equivalent transmit power in 100 kHz is -1 dBm. With a transmit emissions mask of -60 dBc at a spacing of 4 MHz from the TVWS channel edge, as shown in sample TVWS emissions mask in Figure 8 above, the TVWS out-of-band-emissions into the nearest LTE downlink channel, as measured at the TVWS transmit antenna, would be -61 dBm / 100 kHz.

39. Of course, a TVWS transmitter may be placed much closer to an LTE receiver than an LTE base station. To adjust for this difference in distance, I assume that the minimum distance for between an LTE base station and an LTE handset is 100 meters, whereas the minimum separation distance between TVWS and LTE devices is 2 meters. To compare transmitted out-of-band-emissions power from a base station with a 100 meter minimum distance assumption to a TVWS out-of-band-emissions level with a 2 m minimum distance assumption, we subtract 34 dB from the cellular out-of-band-emissions level, which is the difference in free space path loss between 2 meters and 100 meters. Thus, the constraints applied to out-of-band emissions from licensed mobile operations—if adjusted to account for smaller distances between TVWS and LTE—would allow up to -47 dBm/100 kHz interference levels, fully 14 dB *higher* than the operations the NPRM proposes to authorize.[24]

[24] The difference between -61 dBm/100 kHz (the out-of-band emissions exhibited by 6Harmonics equipment) and -47 dBm/100 kHz is 14 dBm/100 kHz.

I, Donald Breslin, declare under penalty of perjury under the laws of the United States that the foregoing declaration is true and correct. Executed on May 22, 2015.

Donald Breslin