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, and	)	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

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I. INTRODUCTION AND SUMMARY

As the Federal Communications Commission ("Commission" or "FCC") has recognized, the 600 MHz band plan for licensed broadband services also has the potential to enable important new opportunities to expand and improve wireless broadband. Specifically, Broadcom Corporation ("Broadcom") commends the FCC for its decision to permit consumer unlicensed devices to use the duplex gap between licensed FDD uplink and downlink for broadband operations and in the guard band between broadcast television and LTE downlink.[1] To advance from this positive first step to the reality of widespread consumer use of these and other 600 MHz frequencies, however, the Commission must ensure both that the Part 15 rules protect licensees, and also permit a commercially reasonable operating environment for unlicensed use. Rules that overprotect licensees will correspondingly depress the value of this unlicensed spectrum for consumers, chill industry investment in new whitespaces technologies, and scuttle the Commission's vision for these bands. As a global leader in the wireless and broadband semiconductor industry, Broadcom is ideally positioned to assist the Commission in its effort to strike the right balance.

Most critically, the *NPRM* asks whether the Commission's proposed band plan for duplex gap operations and its proposed 40 mW power restriction on unlicensed devices would

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[1] *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*, FCC 14-144, 29 FCC Rcd. 12,248, 12,250, 12,276 ¶¶ 4, 91 (2014) ("*NPRM*").

adequately protect LTE downlink.[2] We have conducted extensive research on this question. Our work, supported by both mathematical analysis and real-world testing, clearly indicates that the answer is "yes." In the comments that follow, Broadcom (1) discusses the appropriate operating assumptions the Commission should take into account when determining operating parameters for unlicensed devices, and (2) analyzes the potential for harmful interference to licensed services from unlicensed out-of-band omissions, blocking, and third-order intermodulation products between an unlicensed device and LTE operations.

Our analysis shows that unlicensed devices can easily coexist with licensees at powers well in excess of 40 mW, even when separated by 4 MHz rather than the 5 MHz separation contemplated in the *NPRM* for the duplex gap.[3] In fact, our analysis shows that unlicensed devices can coexist with licensees at 3 MHz when operating at 40 mW. Our analysis therefore confirms that the Commission can enable unlicensed operations in both the duplex gap and guard band at reasonable power levels.

In particular, our analysis demonstrates that the Commission's proposal for partitioning the duplex gap, which separates the unlicensed channel from LTE downlink by 5 MHz, is unnecessarily conservative.[4] Furthermore, placing the unlicensed channel at the very top of the band, with no spectral separation from LTE uplink, reduces the utility of the unlicensed channel, and is not necessary in order to protect LTE. The Commission should therefore place the 1 MHz buffer at the top of the duplex gap, between the unlicensed channel and LTE uplink, to maximize

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[2] *NPRM* ¶ 96.

[3] *NPRM* ¶¶ 94-95.

[4] *See id*.

the value of this spectrum. Likewise, our analysis confirms that the Commission's proposed power limits for 9 and 11 MHz wide guard bands[5] would provide ample protection for LTE downlink operations in the adjacent band. We also conclude that, if the guard band is only 7 MHz wide, limiting unlicensed power to 9 mW will adequately protect LTE downlink.

The Commission has also proposed to permit Television White Space ("TVWS") operations in channel 37, subject to certain separation distances. Broadcom commends the Commission for its decision to introduce broadband operations in portions of channel 37, while preventing harmful interference to incumbents. In doing so, the Commission should be sure to open channel 37 for use by both fixed and personal/portable devices because the FCC's incumbent-protection approach will work equally well for both types of devices. Broadcom's analysis demonstrates, however, that the Commission's proposed separation distances—especially for personal/portable devices—are much too large.

In addition, Broadcom's analysis supports the Commission's decision to enhance the utility of channels 35, 36, 38, and 39 by removing the onerous and unnecessary out-of-band-emissions restriction imposed on channel 37. As we demonstrate, unlicensed devices may safely operate in the channels immediately adjacent to channel 37 (channels 36 and 38) by observing only a minimal separation distance from White Map Tile Service ("WMTS"). Unlicensed devices may safely operate in channels 35 and 39 without special restrictions.

Finally, for any separation distance, the Commission should also revisit its rigid 50 m location accuracy requirement and 60-second location monitoring interval.[6] As discussed below,

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5 *See NPRM* ¶¶ 87-88.

6 *See* 47 C.F.R. §§ 15.711(b)(1), (2).

this requirement is inconsistent with technology available to manufacturers today, and is unnecessary to protect incumbents.

II. Propagation Loss and Other Assumptions

The Commission has tentatively concluded that, "under reasonable conditions[,] white space devices can operate in the duplex gap and guard bands without causing harmful interference to LTE receivers."[7] To take the next step, the Commission now seeks comment on the technical assumptions it has made in the *NPRM*, and on any additional assumptions it should take into account.[8] Our analysis below demonstrates that the Commission's assumptions are reasonable, and its tentative conclusion is not only reasonable, it is highly conservative.

First, we agree with the Commission that "it is reasonable to assume . . . 15 dB of loss due to a combination of obstructions, body loss and antenna polarization mismatch, etc."[9] More specifically, we find that the following assumptions, common to both unlicensed access points and client devices, are reasonable and consistent with Broadcom's understanding of their performance:

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7 *NPRM* ¶ 82.

8 *See NPRM* ¶ 86.

9 *NPRM* ¶ 84. *See also Advanced Wireless Service Interference Tests Results and Analysis*, Federal Communications Commission Office of Engineering and Technology, WT Docket Nos. 07-195 and 04-356 (rel. Oct.10, 2008) ("OET AWS-3 Interference Test Report").

Antenna Polarization Mismatch Loss	3 dB
Shadowing Loss	3 dB
LTE Antenna Gain	-6 dBi
LTE Body Loss	3 dB

Consistent with the *NPRM*'s assumptions, this totals 15 dB of loss.

Importantly, however, access points and client devices are used in different ways. To account for these differences, the FCC should use different assumptions to characterize certain aspects of access point and client device operations. In particular, while users typically keep client devices on or near their bodies, access points typically are located in fixed locations, considerably farther from users than client devices. For this reason, the FCC should assume that a signal emitted by an access point will not be subject to body loss. Correspondingly, the FCC should assume that an access point will typically be at least one meter further away from the user than a client device, and, accordingly, from the user's LTE handset.

	Client Device	Access Point
LTE/Unlicensed Separation Distance	2 m	3 m
Unlicensed Body loss	3 dB	0 dB

Finally, we attempted to identify an appropriate mathematical propagation model for the likely usage patterns of unlicensed devices in these bands to deepen our analysis. Given the diversity of possible unlicensed applications, however, no single model can accurately capture every significant use case. Therefore, we have made the overly conservative assumption that unlicensed transmitters would always be transmitting in free-space. The FCC should note that this conservative approach over-estimates the potential for interference from unlicensed devices.

As the Office of Engineering and Technology has explained, "free space propagation yields conservative results as it is a worst case model. In practice the mobile operating environment will result in losses [and therefore less potential for interference] that exceed those predicted by free space propagation."[10] In reality, it is unlikely that an unlicensed signal will truly propagate to an LTE receiver through free space—clothing, furniture, walls, foliage, and many other aspects of the environment significantly attenuate unlicensed signals.[11]

Adopting this model, we arrived at the following intermediate propagation loss results:

	Client Device	Access Point
LTE/Unlicensed Free-space Loss	35 dB	38.5 dB
LTE/Unlicensed Total Propagation Loss	53 dB	53.5 dB

For the sake of simplicity and to add yet another layer of conservatism to the FCC's analysis, we discard the higher 53.5 dB loss figure for access points, and simply assume a total propagation loss of 53 dB between any unlicensed device and LTE handsets.[12] Therefore,

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10 OET AWS-3 Interference Test Report at 13 n. 16. Free space loss calculations assume an unlicensed operating frequency of 669 MHz, corresponding to the minimum possible spectrum recovery scenario. Although free space loss propagation does vary by frequency, the difference across the possible range of frequencies covered by the guard band and duplex gap does not affect this analysis.

11 *See id*.

12 Qualcomm's preferred propagation model, ITU 1411-3 LOS UHF, actually produces an average 1.4 dB *greater* loss than our free space propagation assumption. Like free space propagation, ITU 1411-3 LOS UHF must also be supplemented by realistic assumptions about body loss, shadowing, etc. to adapt it to a typical user environment. This is important because Qualcomm's proffered ITU model was only designed to model "[line-of-sight] situations within street canyons." ITU-R 1411-2 § 4.1 *available at* https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1411-2-200304-S!!PDF-E.pdf.

because the signal from an unlicensed access point will be more attenuated than the signal from a client device, we consider only interference between an unlicensed client device and an LTE handset in the analysis that follows.

Finally, our analysis adopts the Commission's assumption in the *NPRM* that an unlicensed device will transmit at only 40 mW,[13] even though 40 mW is an unnecessarily low power restriction, as explained below. We also conservatively assume 4 MHz spectral separation between the lower bound of the unlicensed band and the top edge of the LTE downlink channel. We conclude that this limit is also, however, unnecessarily restrictive.

III. INTERFERENCE ANALYSIS FOR UNLICENSED DUPLEX GAP OPERATIONS

Taking into account the operating assumptions above, we next analyze each of the possible significant modes of interference by an unlicensed device to downlink operations on an LTE handset. We conclude that the FCC's tentative conclusion is correct: with 4 MHz of spectral separation between the top edge of LTE downlink and the bottom edge of the unlicensed spectrum, LTE handsets will not suffer harmful interference from unlicensed transmissions as a result of (1) out-of-band emissions by the unlicensed device into the LTE downlink channel, (2) blocking, or (3) formation of third-order intermodulation products between the unlicensed device and LTE uplink, even when both transmit at maximum power simultaneously.

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[13] *NPRM* ¶ 96.

A. Out-of-Band Emissions

According to analyses submitted by both Broadcom and Qualcomm, LTE devices are able to tolerate co-channel noise level of, at most, -98.5 dBm.[14] In fact, the Commission itself has previously assumed an even higher noise level of -95.5 dBm.[15] But, in keeping with our conservative approach, we adhere to the substantially more demanding -98.5 dBm co-channel interference threshold. Thus, to err on the side of caution, the Commission's rules should ensure that the out-of-band emissions of an unlicensed device would not exceed -98.5 dBm at the LTE handset antenna. As we demonstrate below, assuming the use of a reasonable out-of-band emissions mask, the emissions received by an LTE handset would fall significantly below this level even at power levels much higher than those proposed by the Commission.

To determine the out-of-band emissions of a white space device, we conducted a laboratory test of a reference TVWS transmitter. The results of our tests are depicted in Figure 1. Next, Figure 2 illustrates the average attenuation of the TVWS signal across a 4.5 MHZ LTE receive channel at a given edge-to-edge separation between that LTE channel and the TVWS transmit channel. The average attenuation at 4 MHz edge-to-edge separation is -65.9 dBr.

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14 *See* Reply Comments of Qualcomm Incorporated, GN Docket No. 12-268, (filed Mar. 12, 2013) ("Qualcomm Reply Comments"); Letter from Paul Margie, Counsel to Google Inc. and Broadcom Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268, Broadcom Corp. WiFi-LTE Interference Analysis at 3 (filed Jan. 30, 2014).

15 *Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions*, Report and Order, FCC 14-50, 29 FCC Rcd. 6567, 6990, Appendix C, ¶ 57 (2014) ("*R&O*").

Figure 1: TVWS Tx Filter Performance

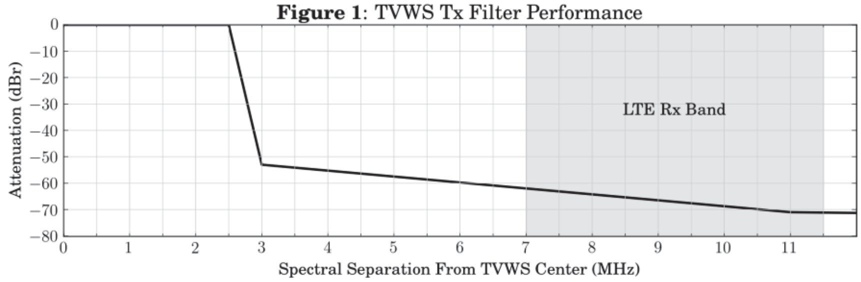
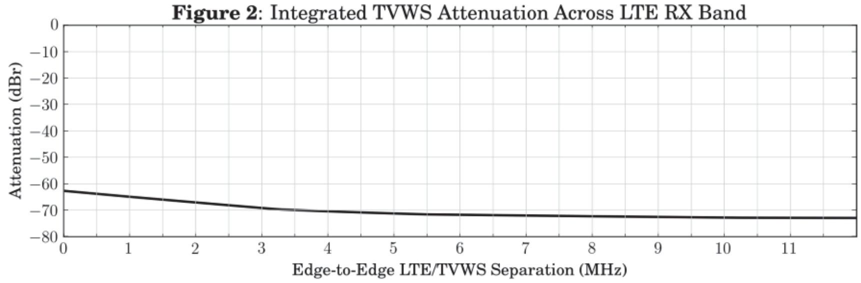


Figure 2: Integrated TVWS Attenuation Across LTE RX Band



Taking these filtering results and our propagation loss assumptions into account, we are able to determine whether out-of-band emissions from a TVWS device are likely to cause harmful interference with LTE handsets. Again assuming 4 MHz edge-to-edge spectral separation between TVWS transmit and LTE receive bands and a TVWS transmit power level of 40 mW, average out-of-band emissions into the LTE receive band would be -103.0 dBm.

Because these emissions are well below the -98.5 dBm LTE interference threshold, the LTE device would operate without harmful interference. In fact, the Commission could permit TVWS transmit power as high as 112.5 mW (20.5 dBm) before TVWS out-of-band emissions reached the interference threshold. Alternatively, the Commission could decrease edge-to-edge spectral separation from LTE downlink and the unlicensed channel to as little as 2 MHz. *See* Figures 3-4.

Figure 3: TVWS OOBE @ 4 MHz Spectral Separation

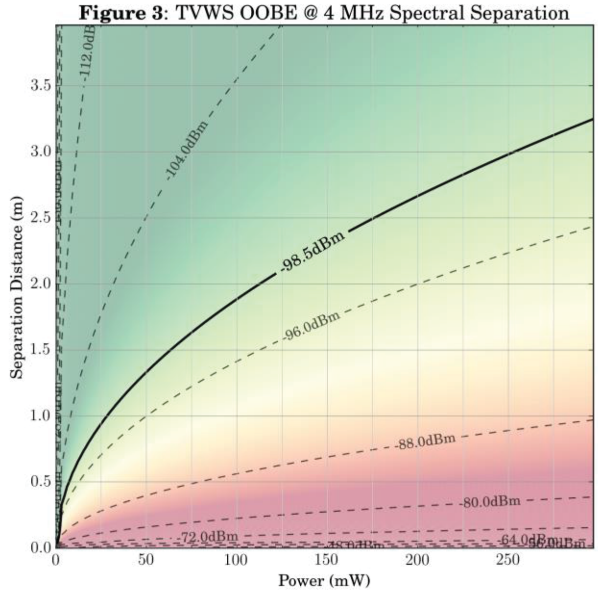
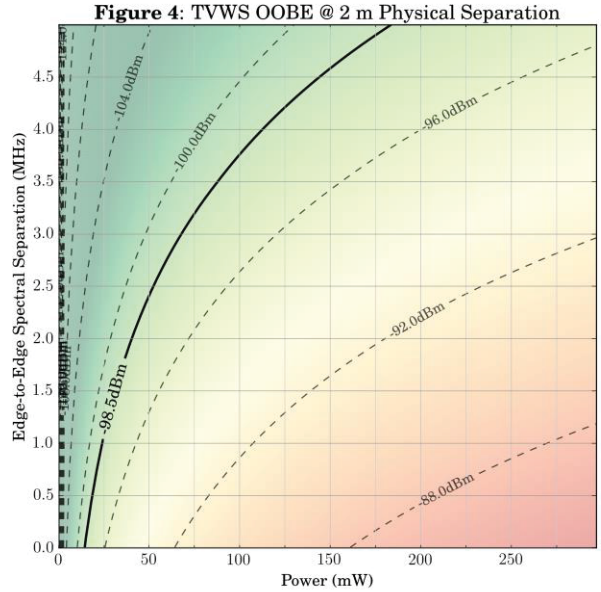


Figure 4: TVWS OOBE @ 2 m Physical Separation



B. Blocking

We also evaluated the potential for blocking interference between an unlicensed device and an LTE handset. In this analysis, the crucial assumption relates to the performance of the duplexer filter and the degree to which that filter is capable of attenuating unlicensed transmissions in nearby channels. We have conducted analyses under three different filtering scenarios: (1) the unreasonably poor, worst-case-scenario performance[16] of a B20 filter, manufactured by TDK, used in Europe to isolate LTE handsets from digital television signals transmitted 9 MHz below the bottom of the LTE band; (2) the typical B20 filter performance; and (3) the performance of a hypothetical filter consistent with Commission's conclusions about

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[16] *I.e.*, taking into account potential sources of variability in filter performance.

reasonable LTE filter performance in the technical appendix of the *Incentive Auction Report and Order* ("*R&O*").[17] We depict the performance of each filter below.

Figure 5: B20 Worst Case

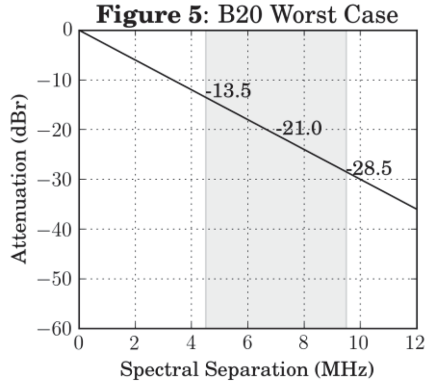


Figure 6: B20 Typical

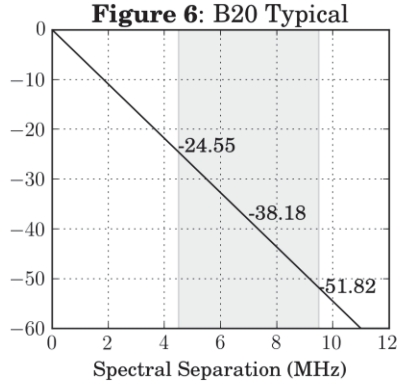
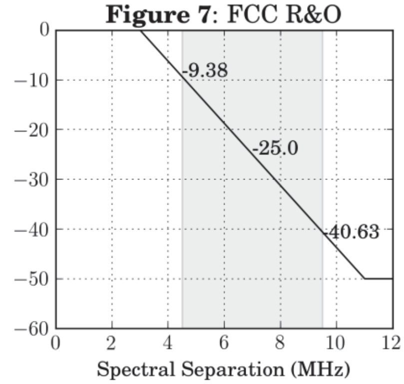


Figure 7: FCC R&O



As is the case throughout our analysis, we assume that the Commission's designated channel for unlicensed duplex gap operations would separate the bottom edge of the unlicensed band from the top edge of the LTE downlink band by 4 MHz. Importantly, however, while the IEEE 801.11af standard requires a 6 MHz channel, 802.11af contemplates that a white space device will only transmit at frequencies in a 5 MHz-wide channel[18] centered within those 6 MHz. Thus, while the unlicensed and LTE downlink bands will be separated by 4 MHz, an unlicensed designation that is 4 MHz away will actually separate LTE downlink by an additional 0.5 MHz

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[17] *R&O*, Appendix C, ¶¶ 10-21. The Commission's assumptions, however, did not address the performance of a filter at a spectral separation of less than 7 MHZ. While the attenuation offered by real-world filters will gradually taper off towards 0 dBr attenuation as spectral separation approaches 0, we have conservatively assumed that the filter performance remains linear below 7 MHZ's separation, and reaches 0 at 3 MHz's separation.

[18] The precise width of the channel is 4.875 MHz, but we round this to 5 MHz for our analysis. Not only does this simplify the analysis, it also provides an additional, conservative margin since with this simplification, unlicensed transmissions are assumed to be closer to LTE downlink than they actually will be.

from the transmissions in the center of the unlicensed band for a total separation of 4.5 MHz, as depicted in Figures 5 and 7 above.

In each scenario we considered, the filter achieves significant attenuation performance across the transmit band of an 802.11af device. Specifically, the average attenuation of even the unreasonably poor performing B20 filter across the band is -19 dBr. A typical B20 filter would achieve -32.5 dBr. And the FCC's own hypothetical filter would achieve -18.1 dBr. These attenuations represent the average attenuation across the LTE receive band, which is a more conservative measure of expected performance than the attenuation at a single point in the center of the LTE band.

Each of these attenuation levels is sufficient to avoid blocking interference in nearby LTE handsets. As explained above, we conservatively project total propagation loss from an unlicensed device to an LTE handset to be 53 dB. Thus, for an unlicensed device transmitting at 40 mW EIRP (16.0 dBm), the total received power from an unlicensed device by an LTE handset would be -69.5 dBm if the handset used a typical B20 filter, -56.0 dBm for the underperforming B20 filter, and -55.1 dBm with the FCC's own filtering assumptions.

	FCC R&O Assumptions	Worst-Case B20	Typical B20
Wi-Fi Power	40 mW	40 mW	40 mW
Propagation Loss	53 dB	53 dB	53 dB
LTE Rx Filter Attenuation	-18.1 dBr	-19 dBr	-32.5 dBr
Total LTE Received Power	-55.1 dBm	-56.0 dBm	-69.5 dBm

Under each of these scenarios, the total LTE received power falls well below the applicable blocking threshold, which we calculate below.

We begin with the minimum blocking required by the 3GPP specifications. Although the 3GPP specifications provide the required blocking thresholds at 0 and 5 MHz separation from an interfering signal, we can interpolate between those values to establish a baseline blocking threshold at any given spectral separation, yielding a blocking threshold of -57 dBm at a separation of 4 MHz.[19]

Laboratory testing reveals, however, that real-world LTE devices exhibit far better blocking performance than the minimum 3GPP specification. We tested three of the most popular LTE handsets on the market today[20] and found that each exhibited in-band blocking performance *more than 20 dB better* than the 3GPP specification. This result is not surprising. These 3GPP standards were originally established for the now-outdated 3G generation of cellular devices. But today's LTE devices must also comply with more stringent performance specifications imposed by LTE network operators. Indeed, to achieve the maximum possible market penetration and economies of scale, handset and LTE chipset manufacturers must comply

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[19] The 3GPP specifications require an LTE device to tolerate a signal at 45.5 dB higher than the receiver's reference sensitivity in the adjacent channel—separated from the desired frequency channel by 0 MHz—when the desired signal is 14 dB above reference sensitivity. When the interfering signal is 5 MHz away, it requires that LTE devices tolerate a signal at -56 dBm when the desired signal is only 6 dB above reference sensitivity. In order to interpolate between these requirements, we first calculate a new adjacent-channel selectivity requirement when the desired channel is only 6 dB above reference sensitivity. In doing so, we assume a reference sensitivity of -97 dBm, consistent with the specifications for 700 MHz LTE in bands 12, 13, and 17. We thus arrive at a 3GPP minimum blocking threshold of -61 dBm for adjacent-channel signals (*i.e.*, 0 MHz spectral separation) and -56 dBm at 5 MHz separation. Thus, the interpolated 3GPP change of threshold is 1dB per MHz, beginning at -61 dBm at a spectral separation of 0 MHz.

[20] We tested the iPhone 5s, Samsung Galaxy 4, and the Samsung Galaxy Note.

with the most exacting carrier's requirements. In other words, the strictest carrier requirements—not the theoretical 3GPP minimum specifications—typically set the baseline for device performance.

Given that LTE handsets are subject to stringent carrier requirements that exceed 3GPP performance standards, and our empirical results that LTE handsets exceed 3GPP blocking performance standards by 20 dB, it is reasonable—and, in fact, quite conservative—to assume that LTE handsets achieve blocking performance that is only 10 dB better than the 3GPP.[21] At a spectral separation of 4 MHz, therefore, we conclude that a typical LTE handset will exhibit a blocking threshold of at least -47 dBm.

Significantly, however, for each of the filtering scenarios we have considered—typical B20, underperforming B20, and the assumptions of the FCC *R&O*—the received power from an unlicensed device operating in a channel 4 MHz away from the LTE channel will be significantly lower than this -47 dB blocking limit.

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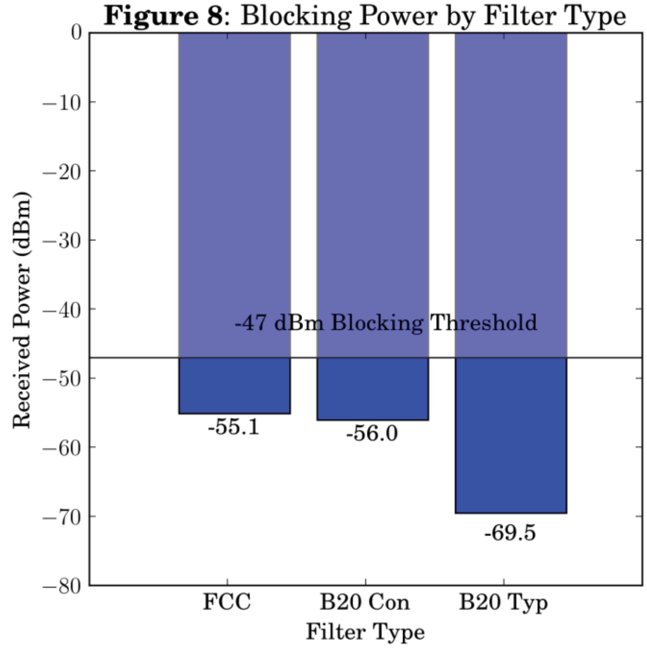
[21] Note that, in addition, operator tests typically assume a 3dB weaker desired signal than 3GPP tests, with the exception of the carrier requirement at a 6.5 MHz gap, which assumes a desired signal 5dB higher than the comparable 3GPP test.

Figure 8: Blocking Power by Filter Type



In fact, the substantial margin between the received power and the likely blocking threshold means that an unlicensed device could operate at significantly higher power than 40 mW without causing blocking interference. Taking the most conservative of our three filtering scenarios, the Commission's filtering assumptions in the *Incentive Auction Report and Order*, an unlicensed device could operate at a power as high as 257.0 mW (24.1 dBm), or at an edge-to-edge spectral separation from LTE of only 2.8 MHz, before encountering any significant risk of blocking.

Figure 9:Blocking Power @ 4 MHz Spectral Separation

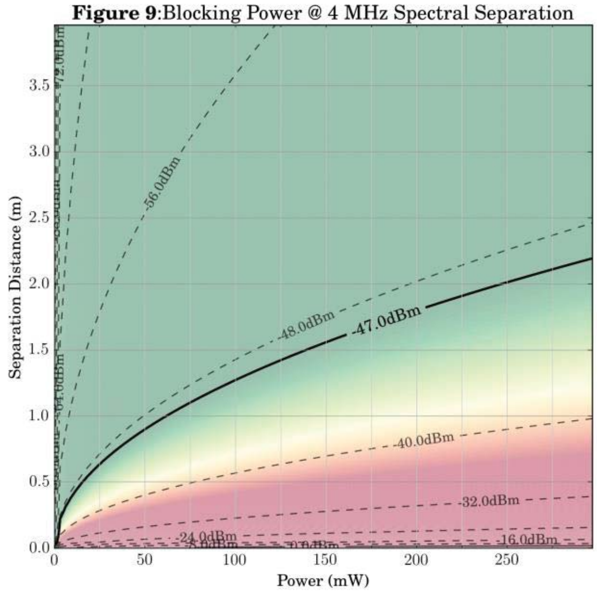
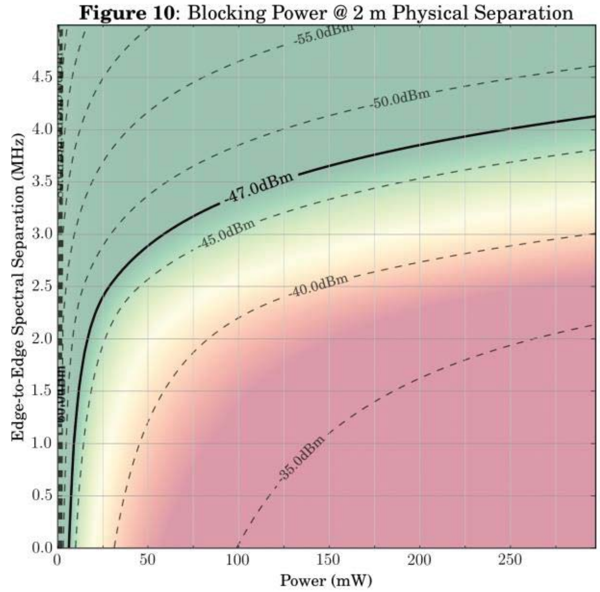


Figure 10: Blocking Power @ 2 m Physical Separation



C. Intermodulation

Finally, we studied the potential for interference in the LTE downlink channel by a third-order intermodulation product of an unlicensed signal and LTE uplink. We tested this scenario empirically with an unlicensed device and an LTE uplink signal at its maximum permissible power. This experiment demonstrated conclusively that third-order intermodulation interference is of even less concern than blocking or out-of-band emissions from white space devices, further demonstrating that the FCC's tentative conclusion to permit 40 mW unlicensed operation in the duplex gap is reasonable and, if anything, overprotective of LTE.

For our tests, we examined LTE devices currently designed to operate in band 20. As we have discussed elsewhere, this band is closely similar to the spectral environment contemplated by the Commission's *R&O*. In particular, band 20 includes an 11 MHz wide duplex gap across which LTE devices exhibit an attenuation slope nearly identical to the LTE devices that will operate on either side of the duplex gap in the former television bands. We designed our experiment to be identical to that prescribed by the 3GPP blocking procedures, with only two modifications: we introduced an unlicensed device operating in the band 20 duplex gap and, for the most conservative possible result, configured the LTE device to transmit in the uplink band at the highest permissible power.

But even in this worst-case scenario, we found no harmful interference with the LTE handset's downlink capabilities. In fact, our LTE device continued to pass the conservative 3GPP interference tests with signals from the white space device above -10 dBm at the LTE antenna connector. Given our prior propagation loss assumptions, this translates into a maximum white space transmit power of 20 W (43 dBm), much higher than the maximum power at which other forms of interference would constrain white space operations. For these reasons, third-order intermodulation interference will never be the dominant mode of interference between unlicensed and LTE downlink under any plausible operating scenario.[22]

D. Overall Assessment

The Commission's proposed power limits and spectral separation will more than adequately protect LTE downlink from unlicensed operations in the duplex gap. Figures 11 and 12 below illustrate the relationships between unlicensed operating parameters and interference (out-of-band emissions, and blocking) into LTE downlink. Note that while out-of-band emissions are the limiting source of interference at 4 MHz spectral separation, regardless of physical separation or unlicensed power, blocking interference becomes the limiting factor when spectral separation between unlicensed and LTE downlink becomes sufficiently small.

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[22] For more details, *see* Letter from Jennifer. K. Bush, Assoc. Gen. Counsel, Broadcom Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 (filed Mar. 3, 2014).

Figure 11: TVWS OOBE and Blocking @ 4 MHz Spectral Separation

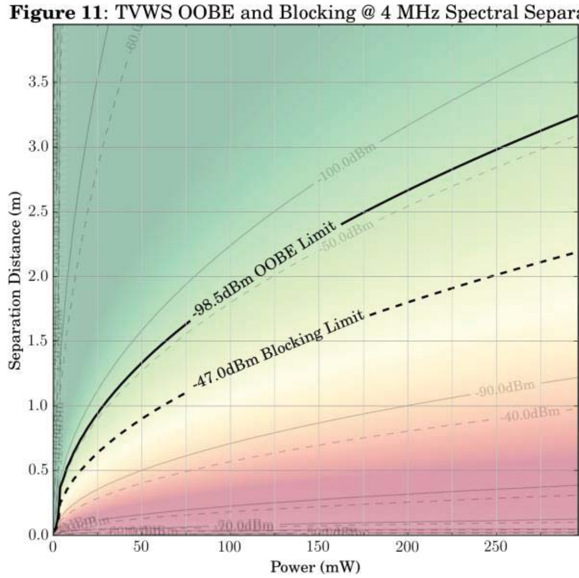
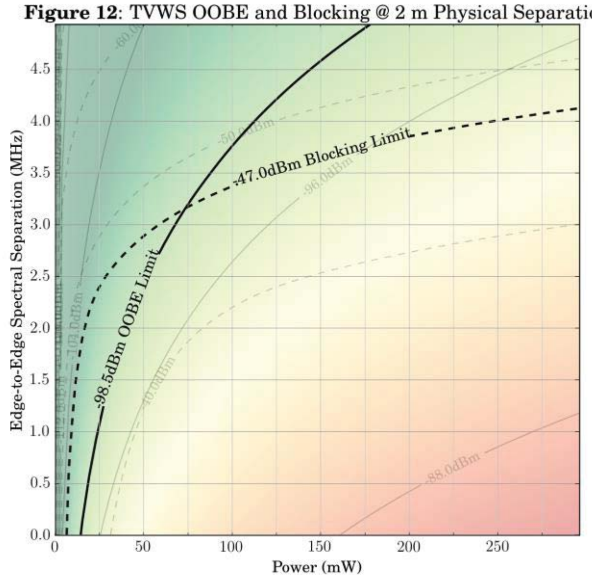


Figure 12: TVWS OOBE and Blocking @ 2 m Physical Separation



1. Duplex Gap

Unlicensed devices can safely operate at both higher power levels, and at a smaller spectral separation from LTE uplink than the Commission has proposed. At 4 MHz separation, an unlicensed device can conservatively operate at a power level as high as 112.5 mW before the odds of interference with LTE uplink becomes significant. In fact, at the 5 MHz spectral separation the Commission has proposed, an unlicensed device in the duplex gap could operate at a power as high as 183.5 mW. Or, holding the power variable constant at 40 mW, an unlicensed device could operate at only 2.8 MHz[23] spectral separation from LTE downlink before harmful interference became likely. While we recognize that the Commission may find some degree of overprotection desirable, the proposed rules limit transmit power to only 21.8%

[23] Note that this aligns closely with the Commission's proposal to permit unlicensed devices to operate at up to 40 mW in the guard bands so long as they maintain a 3 MHz separation from the lower edge of the LTE downlink band. *See NPRM* ¶ 87.

of the maximum safe transmit power, and spectrally separate unlicensed from LTE 179% further than required.

Importantly, these results also demonstrate that the Commission can ensure sufficient protection for LTE while improving the efficiency of duplex gap operations by adopting a different partitioning scheme for the duplex gap than the one it has proposed.[24] Specifically, by placing the 1 MHz buffer at the top of the duplex gap (between LTE uplink and the unlicensed channel) rather than at the bottom (between LTE downlink and the 4 MHz channel set aside for wireless microphones), the Commission can significantly enhance the value of the unlicensed channel while maintaining extremely robust protective margins for LTE.

2. Guard Bands

Our analysis also confirms that the Commission can enable unlicensed guard band operations at reasonable power levels. In an 11 MHz wide guard band, as the Commission has pointed out, a 6 MHz unlicensed channel would be separated by 5 MHz from the nearest LTE downlink channel. As we discuss above, unlicensed devices could transmit at power levels as high as 183.5 mW before harmful interference with LTE downlink became likely.[25] Therefore, Commission's rules should enable unlicensed devices in an 11 MHz guard band to operate under the existing TVWS power rules: *i.e.*, a power limit of 100 mW in the absence of an adjacent broadcast TV station.[26] In a guard band that is 9 MHz wide, our results similarly support the Commission's conclusion that unlicensed devices may safely operate at 40 mW, because harmful

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[24] *NPRM* ¶ 94.

[25] *See* p. 18 *supra*.

[26] *See NPRM* ¶ 87.

interference is unlikely to occur at that power level even with a spectral separation of less than 3 MHz between LTE downlink and the unlicensed device. Finally, in spectrum recovery scenarios yielding 7 MHz guard bands, safe operation using a 6 MHz unlicensed channel remains possible at lower power levels. While these power levels are not sufficient for many 802.11af applications, they may be useful for future, low-power unlicensed technologies. As indicated below, in Figure 14, power levels of 9 mW are possible when the guard band is 7 MHz wide (i.e., 1 MHz edge-to-edge spectral separation). The Commission's amended Part 15 rules should therefore permit operation at this reduced power level if the amount of spectrum recovered in the auction process results in a 7 MHz guard band, and otherwise at least 40 mW if the guard band is 9 MHz wide or more.

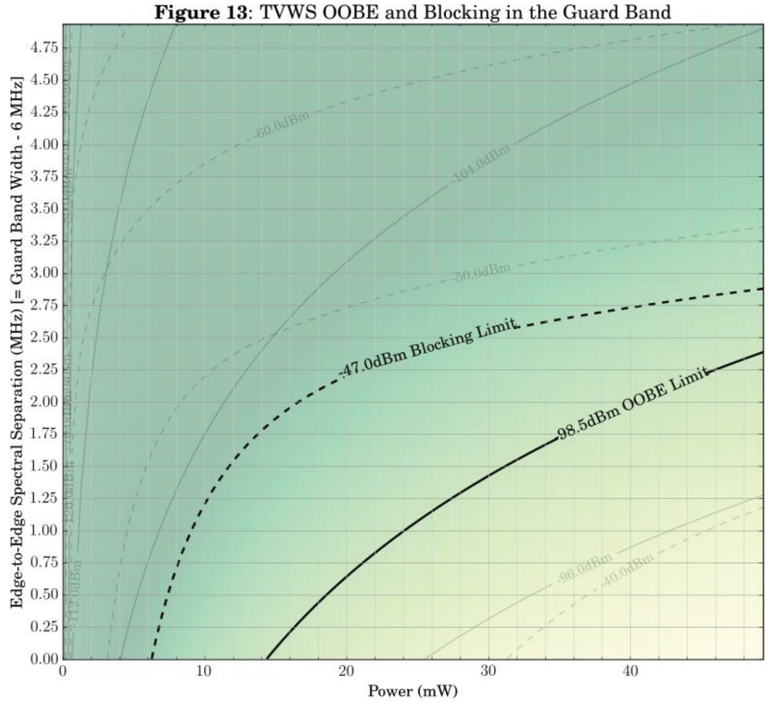

Figure 13: TVWS OOBE and Blocking in the Guard Band

IV. TVWS OPERATIONS IN AND ADJACENT TO CHANNEL 37

Broadcom supports the Commission's proposal to permit TVWS operations in channel 37,[27] and to ease the extreme out-of-band emissions limits it currently imposes on unlicensed devices operating in the television bands.[28] By reserving the entirety of channel 37 for WMTS systems and radioastronomy, the existing rules effectively require an entire 6 MHz channel to lie fallow in the vast majority of the country, including urban areas—even though incumbents do not use these frequencies in most areas. Moreover, as the Commission has noted, the very stringent out-of-band emission limit that currently applies to emissions into channel 37 severely hampers the use of channels 35, 36, 38, and 39,[29] greatly handicapping a total of 30 additional megahertz everywhere in the country. But as the Commission recognizes in the *NPRM*, experience has proven that these one-size-fits-all national rules are not the only way to protect WMTS and radioastronomy from interference. Instead, the Commission can ensure that TVWS devices maintain a prescribed separation distance from these sites through the use of a spectrum access database.

Broadcom's studies indicate, however, that the Commission's proposed separation distances for TVWS devices operating in channel 37 are far larger than necessary. Our analysis indicates that, even under highly pessimistic assumptions, a separation distance of 65 meters would be adequate for TVWS devices operating in channel 37, much less than the Commission's

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27 *NPRM* ¶ 99.

28 *NPRM* ¶ 128.

29 *NPRM* ¶¶ 126-128.

proposed 300 meters, as discussed below.[30] To add an additional margin of safety, however, we support increasing this separation distance to a total of 150 meters.[31]

For TVWS devices in channels 36 and 38, the rules need only ensure that the TVWS device is not inside the WMTS site itself to prevent harmful interference. Thus, we propose a separation distance of 1 meter. This will effectively ensure that no TVWS devices operate on these channels within a WMTS facility, particularly when the added location accuracy margin is taken into account. In addition, we agree with the Commission that the highly restrictive emissions limit into channel 37 is unnecessary and should be removed.

Finally, for each of these channels, we urge the Commission to permit the operation of Mode II personal/portable in addition to fixed devices. The Commission's regulations already include robust geolocation and location accuracy rules,[32] and there is no substantial evidence in the record to indicate that these or other rules would not be adequate to ensure that Mode II devices respect the relevant separation distances. There is therefore no reason to compromise the value of these bands by limiting channel 37 only to fixed devices, which provide far less value to consumers than personal/portable devices.

A. TVWS Operation in Channel 37

To determine the appropriate minimum separation distance between a WMTS site and a TVWS device operating in channel 37, we began with the selection of an appropriate

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30 *NPRM* ¶ 112.

31 As with all other separation distances, devices' location accuracy would, in effect, be added to this distance. Thus, for example, a device with a location accuracy of +/- 50 meters would observe an effective separation distance of 200m.

32 *See* 47 C.F.R. §§ 15.711(a), (b).

propagation model. Given the distances involved, we concluded that free-space propagation conditions are very unlikely to exist between a WMTS site and TVWS transmitter. It is clear that, with any plausible separation distance, the TVWS transmitter will not operate within a hospital facility on channel 37. Thus, we can safely assume that the TVWS signal will be obstructed by the exterior wall of the hospital and potentially the exterior wall of the structure in which the TVWS device is located. We selected the Winner+ Urban Micro propagation model, used to model the propagation between antennas at rooftop levels and outdoor devices at ground level.

On January 17, 2014, Broadcom submitted a filing to detail reasonable assumptions for an analysis of the potential for co-channel interference between white space devices and WMTS.[33] Like GE Healthcare, we assumed a WMTS noise floor of -110 dBm/10 kHz.[34] We also assumed that any TVWS signal will be subject to a building penetration loss of 20 dB. In addition to these assumptions, we also now suggest a more conservative WMTS receiver I/N ratio of 0 dB.

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33 Letter from Jennifer. K. Bush, Assoc. Gen. Counsel, Broadcom Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 (filed Jan. 17, 2014).

34 *See* Comments of GE Healthcare at 40, GN Docket No. 12-268 (filed Jan. 25, 2013).

To summarize our assumptions:

TVWS Power	-11.4 dBm/10kHz[35]
Building Penetration Loss	20 dB
WMTS Noise Floor	-110 dBm/10kHz
I/N Ratio	0 dB

From the WMTS noise floor and I/N ratio we derive a maximum WMTS interference level of -110 dBm/10kHz. Adding to this the -11.4 dBm/10kHz TVWS power level, and taking into account the 20 dB building penetration loss, we arrive at a required path loss of 78.6 dB to ensure that any interference that a WMTS receiver receives from a TVWS transmitter remains below the WMTS interference level. To determine the distance required to achieve this degree of propagation loss we apply the Winner+ Urban Micro propagation model discussed above. On this model, we arrive at a separation distance of 65 meters.

On March 28, 2014, Broadcom submitted an additional filing that further discussed the derivation of appropriate separation distances from the technical analyses submitted in this proceeding.[36] Broadcom continues to believe, as we explained in our filing, that considering the average expected path loss between an unlicensed transmitter and a WMTS receiver, and adding

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35 We integrate the -1.4 dBm/100kHz power spectral density limit that currently applies to TVWS devices, 47 C.F.R. § 709(a)(5)(ii), across 10 kHz to align with the units used to express the WMTS interference level below. We do not consider the combined transmission strength from multiple TVWS transmitters because the politeness protocols built into Wi-Fi will generally prevent multiple TVWS devices from broadcasting simultaneously. We also do not consider the aggregation effect of multiple WMTS antennas, since any aggregation of the noise received by such a system would be offset by the corresponding aggregation of the desired signal.

36 Letter from Jennifer. K. Bush, Assoc. Gen. Counsel, Broadcom Corp., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-268 (filed Mar. 28, 2014).

an additional protective margin, would strike an appropriate balance between the Commission's dual goals of maximizing the utility of channel 37 while minimizing the potential for any interference with WMTS systems. And we continue to believe that, in the typical urban scenario, considering average expected path loss and adding an additional margin of protection would result in a protection radius of 150 m. Adding an additional 50 meter margin to account for the location accuracy of unlicensed devices would yield a total separation distance of 200 meters. Importantly, however, if the Commission adopts an approach that allows the database to account for the particular situations of individual hospitals, this particularized information could be used to produce more precise separation distances.

B. TVWS Operation in Adjacent Channels

We have also studied the risk of interference to WMTS systems from TVWS systems operating in bands adjacent to channel 37. We conclude that the 75.6dbm/100 kHz out-of-band-emissions limit imposed under current white-space rules for emissions into channel 37 is much lower than necessary to protect WMTS. Broadcom therefore strongly supports the Commission's proposal to remove this limit.[37] We also conclude that TVWS devices on adjacent channels pose no risk of blocking interference to WMTS reception so long as they do not operate on those channels inside the WMTS site itself. Thus, a minimal WMTS separation distance for TVWS devices on channels 36 and 38 is appropriate to protect WMTS.

Turning first to our out-of-bands emissions analysis, we return to the assumptions used in our TVWS/LTE Downlink interference analysis. This is appropriate because here we consider

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[37] *NPRM* ¶ 128.

the possibility that a TVWS device could operate at a much smaller separation distance from WMTS than in our analysis of co-channel operations in channel 37. This makes our modified free-space-propagation model more appropriate in this context than the Winner+ model used above. Thus, consistent with our LTE analysis, our assumptions are as follows:

Antenna Polarization Mismatch Loss	3 dB
Shadowing Loss	3 dB
TVWS Body Loss	3 dB
WMTS/Unlicensed Separation Distance	2 m
WMTS/Unlicensed Free-Space Loss @ 2 m	35 dB

These assumptions yield a total propagation loss of 44 dB. In addition, consistent with the analysis above, we make the following assumptions about the interference resistance of WMTS receivers:

WMTS Noise Floor	-100 dBm/100 kHz[38]
I/N Ratio	0 dB

Therefore, our assumed WMTS interference level is -100 dBm/10 kHz. Then, taking propagation loss into account, we arrive at a TVWS out-of-band-emissions limit of -56 dBm/100

38 This is equivalent to -110 dBm/10 kHz.

kHz. This is far less stringent than the limit currently imposed on emissions into channel 37, -75.6 dBm/100 kHz.[39]

We also studied the potential effect of blocking interference caused by TVWS devices operating in channels 36 and 38. According to GE Healthcare, non-hardened WMTS systems can tolerate a TVWS signal in the adjacent channel of no more than -30 dBm. Factoring in the -44 dB of propagation loss explained above, we arrive at a received TVWS power of -28 dBm for a TVWS device operating at a power of 40 mW, or 16 dBm. While this is slightly higher than the -30 dBm blocking level, the FCC can account for this level by requiring a minimal separation distance between WMTS and TVWS devices operating on channels 36 and 38. Even a five-meter separation would increase the free-space loss from 35 dB (at a separation of 2 m) to 42 dB, and correspondingly reduce the power received by a WMTS receiver from -28 dBm to -35 dBm, well below the -30 dBm blocking level. Realistically, the imposition of any separation distance at all will ensure that at least one building wall will stand between the TVWS transmitter and WMTS receiver, guaranteeing that the actual power received will be far lower still.[40]

V. Location Accuracy

While it is crucial to ensure the accuracy of the separation distances enforced by the database, the Commission's fixed 50 m accuracy requirement[41] is technically unnecessary, is often not feasible in indoor environments, and will increase the costs of TVWS devices, while

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[39] 47 C.F.R. § 15.711(c)(4).

[40] In channels 35 and 39, the WMTS SAW filter will also contribute significant additional attenuation, rendering this separation distance unnecessary. *See R&O* at 7010, Appendix C, Table 10.

[41] *See* 47 C.F.R. § 15.711(b)(1).

foreclosing innovative approaches to geolocation. The Commission should, instead, simply require that every device accurately report its own location accuracy capabilities to the database when it queries for available channels. The database would then take that error into account by adding it to the nearby separation radii in determining the device's permissible channels of operation.

The Commission also requires Mode II personal/portable devices to determine its location once every 60 seconds in order to calculate whether it has moved far enough from its previous location that it must re-query the database.[42] However, many devices will be able to reliably determine whether or not they have moved through the use of, accelerometers or similar technologies. When a device is able to determine with certainty that it has not been moved, it is unreasonable to require that the device nonetheless expend limited battery power to once again determine its location. A device should instead be permitted to determine whether or not it has moved using other technologies, so that the device can avoid wasting a significant amount of power unnecessarily activating its GPS receiver once every 60 seconds. This power drain would significantly diminish devices' battery life and, therefore, diminish their value to consumers. Likewise, for fixed devices, the Commission's periodic location-determination requirement is unnecessary. Fixed devices that draw their power from the power grid cannot move once they are powered on. Therefore, to require them to continually re-determine their location after they have been powered on introduces needless complexity and expense in the design of fixed devices, with no corresponding benefit.

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[42] *See* 47 C.F.R. § 15.711(b)(2).

Finally, a device with motion sensing capabilities should be permitted to add its projected future motion to the uncertainty margin built into the location accuracy data that it provides to the database, as an alternative to periodically determining its precise location using GPS or other geolocation technologies. To economize on battery life at the expense of available channels, a device should be permitted to choose a longer location re-check interval than 60 seconds. A device can accommodate this greater uncertainty by incorporating the worst-case assumptions about its future movement into its location accuracy data.

Consider, for example, a handset with a location accuracy of +/- 50 meters, travelling at a speed of 1 m/s, that, for efficiency reasons, can only determine its location every 300 seconds. When this device queries the database for additional channels, it would add the projected travel in the next 240 seconds after the otherwise required 60-second recheck interval[43] to its location accuracy, yielding a location accuracy of +/- 290 meters. This approach assumes the worst-case scenario where the device begins its motion at the outer bound of its location accuracy capabilities (i.e., as far from its reported location as possible, given the device's location accuracy performance), and travels in a straight line directly away from its previously reported location. Since, in real life, this scenario will be extremely rare, this approach would actually result in larger separations and, thus, greater protection of incumbents, than the Commission's proposal. Moreover, it does so while reducing the cost of devices and improving battery life.

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[43] Because a device's base location accuracy will already incorporate its likely motion within a 60-second interval, we avoid double counting that uncertainty by considering only potential motion after that 60-second interval.

VI. Conclusion

The results of our studies demonstrate that unlicensed devices can easily operate without interfering with LTE downlink at a power of 40 mW when separated physically from an LTE handset by 2 meters, and spectrally separated by 4 MHz. Indeed, unlicensed devices can safely operate with a combination of higher power and less spectral separation. Moreover, unlicensed devices can safely operate at 100 mW within an 11 MHz guard band and at 40 mW within a guard band as narrow as 9 MHz. In the event that the Commission adopts a 7 MHz guard band, unlicensed devices can still safely operate at 9 mW. Because the margins between the Commission’s proposed power limits and the substantially higher limits suggested by our analysis represent missed opportunities for technological innovation and economic growth, we urge the Commission to permit unlicensed devices to operate at power levels higher than those proposed in the NPRM.

Likewise, TVWS devices can operate in and near channel 37, without risking interference to WMTS. For operations in channel 37 itself, TVWS devices should be permitted to operate at 40 mW so long as they remain no less than 150 meters from the perimeter of a WMTS site. In channels 36 and 38, TVWS devices can safely operate anywhere outside the walls of WMTS facilities and need not be held to any out-of-band-emissions limit into channel 37 beyond that imposed for all other bands.

Finally, the Commission should revise its unreasonable requirement that all personal/portable TVWS devices be capable of determining their location with an accuracy of 50 meters, and that every such device must determine its location once every 60 seconds. These requirements are not necessary to protect incumbents and reduce the value of the TVWS bands by increasing the cost, and diminishing the battery life of TVWS devices.

Respectfully submitted,

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