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

In the Matter of	)	
	)	
Promoting Interoperability in the 700 MHz Commercial Spectrum	))	WT Docket No. 12-69
	)	
Interoperability of Mobile User Equipment Across Paired Commercial Spectrum Blocks in the 700 MHz Band	)))	RM-11592 (Terminated)

REPLY COMMENTS OF QUALCOMM INCORPORATED

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REPLY COMMENTS OF QUALCOMM INCORPORATED

I. INTRODUCTION AND SUMMARY.

QUALCOMM Incorporated ("Qualcomm") respectfully submits these reply comments in response to the Federal Communications Commission's ("Commission" or "FCC") above-captioned Notice of Proposed Rulemaking ("NPRM").[1] In its initial comments in this proceeding,[2] Qualcomm presented the Commission with test results and analyses that demonstrated that Band 12 consumer devices operating on the Lower B and/or C Blocks would suffer harmful interference from high-power Lower E Block and Channel 51 signals. More specifically, Qualcomm showed that such Band 12 devices would suffer:

(1) Blocking interference due to E Block signals;

(2) Intermodulation interference due to E Block signals; and

1 *Promoting Interoperability in the 700 MHz Commercial Spectrum*, Notice of Proposed Rulemaking, WT Docket No. 12-69, RM-11592 (Terminated) (rel. Mar. 21, 2012) ("NPRM").

2 *Comments of Qualcomm Incorporated*, WT Docket No. 12-69, RM-11592 (Terminated) (filed June 1, 2012) ("Qualcomm Comments").

(3) Reverse intermodulation interference due to Channel 51 DTV signals.

Because Band 17 devices effectively protect against these interference threats but Band 12 devices do not, Qualcomm urged the FCC to reject the proposal to mandate that all Lower 700 MHz devices be capable of operating across the entire Lower 700 MHz band. In other words, due to these valid harmful interference threats, the FCC should not mandate that Lower B and C Block licensees sell devices that operate on Band 12 instead of Band 17.

A paper authored by Mr. Doug Hyslop and Dr. Paul Kolodzy (the "HK Paper"),[3] however, argues that the use of Band 12 devices by B and C Block licensees would not create a threat of harmful interference to customers. Because the technical questions concerning Lower 700 MHz Band interference are central to this proceeding, and because the methods and conclusions of Mr. Hyslop and Dr. Kolodzy differ from those of Qualcomm, these reply comments will focus on analyzing the HK Paper.

The HK Paper contains a series of technical weaknesses that renders its conclusions dubious or invalid. Specifically, the paper's analysis of E Block interference issues produced incorrect results because it:

- Misinterprets 3GPP blocking interference testing levels as being the thresholds at which such interference begins, rather than test points, leading it to rely on incorrect interference tolerances throughout its analysis;
- Relies on improperly conducted tests of consumer LTE devices, leading it to use incorrect device performance levels throughout its analysis;
- Improperly analyzes the relative received powers of E Block and LTE signals and the role and effectiveness of base station collocation, leading it to rely on incorrect device selectivity results throughout its analysis; and

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[3] Doug Hyslop & Paul Kolodzy, *Lower 700 MHz Test Report: Laboratory and Field Testing of LTE Performance near Lower E Block and Channel 51 Broadcast Stations* (Apr. 11, 2012) ("HK Paper"), submitted as attachment to *Ex Parte* Letter of The Lower A Block Licensees to Marlene H. Dortch, FCC, WT Docket No. 12-69 (May 29, 2012).

- Does not account for intermodulation interference from E Block base stations, leading it to omit an important second E block interference threat altogether.

Furthermore, the HK Paper's analysis of Channel 51 interference issues also produces incorrect results because it:

- Relies on an inapplicable formula to attempt to predict reverse intermodulation amplitude;
- Incorrectly assumes that reverse intermodulation products are strictly limited in bandwidth and manifest in simple pulse-like shapes;
- Incorrectly assumes that reverse intermodulation will only occur where an LTE device is transmitting a 10 MHz LTE signal at very high power and, even then, only in the very upper portion of the Lower C block;
- Uses a flawed methodology for testing reverse intermodulation in LTE devices; and
- Does not recognize the correct geographic scope of the reverse intermodulation threat because of incorrect assumptions about intermodulation products and Channel 51 signals.

Due to these flaws, the FCC should not rely on the HK Paper or other analyses that make similar errors. Instead, the analysis contained in Qualcomm's initial comments should lead the Commission to conclude that E Block and Channel 51 signals would cause harmful interference to Band 12 devices operating on the B and/or C Blocks and that existing technology does not offer a solution to these challenges.

It is important to respond to one additional technical assertion made by A Block licensees. Vulcan Wireless argues that manufacturers could easily enable Band 17 consumer handsets already in the field to add support for Band 12 and to use Band 12 instead of Band 17 when operating on the Lower B and C blocks through an over-the-air software update.[4] The

[4] Comments of Vulcan Wireless, Inc., WT Docket No. 12-69 at 38-39 (filed June 1, 2012).

notion that Qualcomm could add Band 12 support to a device that supports Band 17 with a software update is incorrect.[5]

Qualcomm does not offer over-the-air updates to add frequency-band support to legacy phones. Every consumer device model requires FCC and carrier certification based on extensive testing of the model's behavior before the model is sold to the public. Certification ensures that each model passes FCC rules (including rules on SAR RF safety and interference rules) and carrier requirements (including requirements on performance minimums, interference masks, and power consumption). Manufacturers design each model and conduct multiple series of tests based on the specific frequencies on which the model will operate. Compliance with the applicable FCC rules and carrier requirements depends on devices operating within the expected bands.

An over-the-air software update to add a frequency band to legacy devices could invalidate the FCC- and carrier-compliance testing because operation on a new band could affect SAR, interference, performance, and power consumption. Moreover, even if this were not the case, differences in Band 17 and Band 12 filter requirements mean that additional hardware is needed to add support for Band 12.

Qualcomm therefore reiterates its request that the Commission refrain from requiring mobile equipment to be capable of operating over all paired commercial spectrum blocks in the Lower 700 MHz band. This does not mean that Lower A block licensees and their customers will suffer harm due to a claimed lack of interoperability. To the contrary, as Qualcomm showed

[5] It is also important to recognize that an over-the-air software update is not the only impediment to such a change. Additional hardware also would be required to add support for Band 12 since the Band 12 and 17 filters perform differently.

in its initial comments, Lower A block licensees can – and, in fact, are beginning to[6] – offer devices that support Band 12 as well as other frequency bands in which LTE has been or will be deployed, subject to chip limitations described earlier in this proceeding.[7]

II. THE HK PAPER IMPROPERLY ANALYZES THE THREAT OF BLOCKING AND INTERMODULATION INTERFERENCE TO LOWER B AND C BLOCK DEVICES DUE TO HIGH-POWER E BLOCK SIGNALS.

The HK Paper asserts that "[n]o interference would result to Lower B and C Block [Band 12] device reception" in the presence of high-power E Block signals.[8] The paper bases this conclusion, however, on a set of flawed assumptions and testing schemes.

A. The HK Paper Misinterprets the 3GPP Blocking Interference Testing Levels as the Thresholds at Which Such Interference Begins, Leading it to Rely on Incorrect Interference Tolerances Throughout its Analysis.

The HK Paper asserts that 3GPP TS 36.101[9] contains a set of received power levels that are the thresholds at which blocking interference due to E Block signals begins.[10] This is incorrect. The received power levels the HK Paper lists in its Table 4.1 are actually test points that 3GPP established to allow manufacturers to measure device performance. By testing at

6 *See, e.g.*, Press Release, U.S. Cellular, U.S. Cellular Customers Getting The Samsung Galaxy S III In July (June 4, 2012). This device was brought to market even sooner than Qualcomm's projections for devices with the MSM8906/WTR1605L chipset with Band 12 support because the handset OEM used an early, pre-final release of Qualcomm software and completed necessary integration and testing.

7 Qualcomm Comments at 5-6, 59-68.

8 HK Paper at 32.

9 *See*, 3rd Gen. P'ship Project (3GPP); Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Rel. 9), 3GPP TS 36.101 V.9.D.D. (2009-06) ("3GPP TS 36.101").

10 HK Paper at 20. *Cf*. Qualcomm Comments at 11 & n.14 (explaining that blocking interference begins to degrade service even before the 3GPP maximum blocking level is reached).

these received power levels, manufacturers can obtain an effective picture of device performance as measured against a hypothetical blocking interference environment.

But these levels certainly are not the thresholds at which harmful interference begins.[11] In fact, each of these received power levels already includes a level of receiver desensitization, as shown below in Table 1. Table 1 is a reproduction of the HK Paper's Table 4.1, with the level of receiver desensitization that is built into each power level added, and shown in blue and red.

Table 1

	UE Transmit Band			Tx-Rx Transition Gap		UE Receive Band			
700 MHz Block	A Block	B Block	C Block	D Block	E Block	A Block	B Block	C Block	Upper C
Normal 3GPP Band	-44	-44	-44	-44	-56	ACS	Desired	ACS	-56
Band 12	-15	|------ -15 -6 dB	Desense	-30 ------|	-56	14 dB ACS	Desired	14 dB ACS	6 dB
Band 17	-15	-15	-15	-30	-30	ACS	Desired	ACS	-56

Table 4.1: 3GPP Blocking Criteria for Lower B Block Reception

Because the 3GPP testing levels already include significant levels of receiver desensitization, the HK Paper's assertion that "[i]nterfering signals stronger than that shown [in Table 4.1] may degrade the reference receiver performance, causing bit errors or interrupting communications"[12] is misleading. In fact, receivers will begin experiencing interference at E Block power levels significantly lower than the levels shown in Table 4.1. In other words, contrary to the assumptions of the HK Paper, the 3GPP test levels do not constitute a threshold for interference-free operations. No wireless carrier would be able to deliver interference-free operations if its devices suffered 6 dB of desensitization. Rather, service to consumers with devices suffering such desensitization would be significantly impaired. Thus, the HK Paper is simply wrong in using an interference threshold at which substantial interference already exists.

11 *See* Qualcomm Comments at 8-13.

12 HK Paper at 20.

For example, as explained in Qualcomm's initial comments in this proceeding,[13] 3 dB of desensitization – half of that built into the 3GPP testing level – will impair a consumer device's operations. This level of desensitization will render the device unable to receive a signal at the edges of cellular coverage areas and in many indoor environments. In effect, this level of desensitization shrinks the coverage area of existing cells from the area that the cells would otherwise cover adequately. Furthermore, this desensitization will have network-wide effects in a carrier's local system because devices operating at a distance from their base stations will demand additional network resources to attempt to address desensitization, resulting in degraded service even for devices operating closer to cell sites.

The 6 dB of desensitization built into the 3GPP testing level is far worse, doubling the impact of E Block signals (compared to the 3 dB desensitization level), more severely shrinking the coverage areas of cells, and resulting in dropped calls, service interruptions, and lost system capacity. Because the HK Paper does not account for the desensitization built into the 3GPP testing levels, it improperly asserts that Band 12 receivers experiencing E Block received power levels weaker than -56 dBm will not experience blocking interference, and then relies on this assumption for subsequent analyses. This mistake undermines the validity of the entire study.

B. The HK Paper Does Not Analyze E Block Interference to Devices Using Higher-Level Modulation Formats.

LTE networks and devices shift dynamically between modulation formats depending on how a device is being used and network conditions. The modulation formats identified in the 3GPP specification include:

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13 *See* Qualcomm Comments at 13.

- "QPSK," which provides a relatively lower data rate;
- "16QAM," which provides an intermediate data rate; and
- "64QAM," which provides the highest data rate and fastest data transmission.[14]

For data intensive use, such as downloading a video or receiving a large file, networks will try to shift to a higher-order modulation format with a higher data rate, such as 64QAM or 16QAM. But higher-order modulation formats require higher signal-to-noise ratios ("SNR"), meaning that for a given desired signal, an interfering signal must be lower power for the device to avoid interference. Therefore, a Lower 700 MHz device using a higher-order modulation format will be vulnerable to harmful interference from a lower-power E Block signal level than a device using a lower-order modulation format.

The following published data illustrates the SNR-to-throughput relationship for three different modulation formats in three industry-approved dynamic channel models: AWGN (static), PED (pedestrian), VA120 (Vehicular, 120km/h).[15]

Table 2[16]

	Relative SNR (with respect to QPSK, Static) (dB)		
Modulation	**Static (AWGN)**	**Pedestrian**	**Vehicular (120 km/h)**
QPSK	0 (reference)	1.7	5.3
16QAM	5.9	8.7	11.5
64QAM	10.6	15.0	18.0

14 3GPP TS 36.101 at ch. 8 ("3GPP Performance Requirements").

15 *See*, *e.g.*, Ammar Osman & Abbas Mohammed, *Performance Evaluation of a Low-Complexity OFDM UMTS-LTE System*, IEEE 2008, *available at* http://mnet.skku.ac.kr/data/2008data/VTC2008/DATA/05-05-09.PDF; Asad Mehmood & Abbas Mohammed, *Mobility Aspects of Physical Layer in Future Generation Wireless Networks*, *in Advances in Vehicular Networking Technologies,* 323-38 (Miguel Almeida ed., 2011).

16 The 10^{-1} bit error rate (BER) point is used in Table 2.

As Table 2 shows, the SNR level is much higher in the 64QAM modulation format compared to the QPSK format. Carriers aim to deliver the fastest data rates possible, which means that they must rely on these higher-order modulation formats to deliver an acceptable quality of service for consumers, because of the intensive data usage of today's wireless networks. And, doing so requires operating in an interference-free environment.

The 3GPP TS 36.101 specification therefore provides test requirements for LTE device receivers that include tests for QPSK, 16QAM, and 64QAM.[17] Chapter 7 of TS 36.101 includes tests based on QPSK, and specifies requirements for adjacent channel selectivity, in-band blocking, and out-of-band blocking using QPSK modulation. These are the levels that the HK Paper used in its analysis. But, importantly, Chapter 8 of TS 36.101 specifies the performance requirements for 16QAM and 64QAM modulation formats as well.[18] Nonetheless, the HK Paper's interference analysis ignores these modulation formats.

The HK Paper's analysis is unreliable because it incorrectly based its interference discussion on the QPSK modulation levels only, without considering the higher-order modulation formats also specified by TS 36.101. E Block transmissions therefore will interfere with reception on the B and C Blocks using higher-order modulation formats at much lower power levels than the HK Paper states.

The HK Paper's own data from Fayetteville, Georgia bear this out. Table 3, below, shows the 3GPP TS 36.101 blocking test levels for a static device in QPSK, 16QAM, and 64QAM modulation formats.

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17 *See* 3GPP TS 36.101 at ch. 7 ("3GPP Receiver Characteristics").

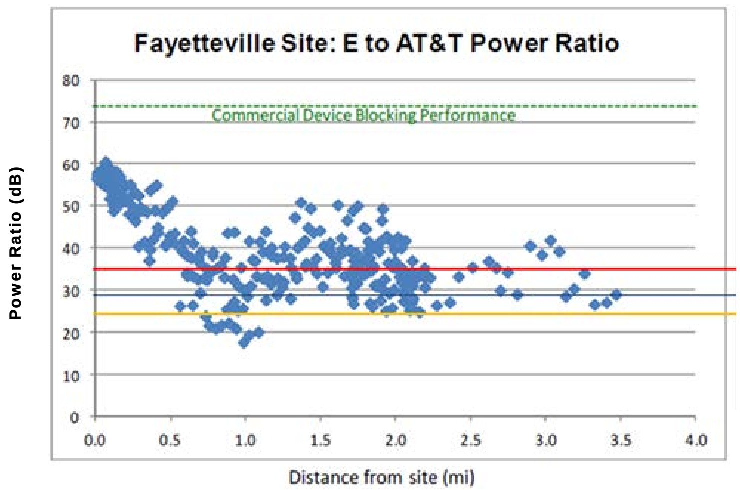
18 *See* 3GPP Performance Requirements. The increase in SNR required for the higher-order modulation formats is shown in Table 8.2.1.1.1-2.

Table 3

	Relative SNR		
Modulation	Effective TS 36.101 Blocking Level (QPSK)	Additional SNR with respect to QPSK Static (AWGN)	Blocking Level per Modulation Format
QPSK	35 dB	0 dB	35 dB
16QAM	35 dB	5.9 dB	29.1 dB
64QAM	35 dB	10.6 dB	24.4 dB

Figure 1 applies this information to the E Block power levels the HK Paper measured in Fayetteville.

Figure 1



Colored lines represent interference thresholds described in Table 3.

The blue diamonds are the HK Paper's power ratio measurements. The colored horizontal lines are the thresholds of interference for QPSK (red), 16QAM (blue), and 64QAM (yellow), and correspond to the colors and data shown above in Table 3. If a device experiences an E Block power level above the threshold that corresponds to its modulation format, it must either abandon that modulation format or suffer harmful interference.

As Figure 1 shows, the E Block power levels measured in Fayetteville would likely prevent 64QAM (high throughput) operation entirely. As a result, devices would be able to operate only at slower data rates and consumers would experience delay or difficulty downloading emails, watching videos, or accessing many websites.

C. The HK Paper's Tests of Commercial LTE Device Performance are Unreliable.

The HK Paper reports that its tests of two LTE devices suggest that "a Band 12 device operating in the Lower B Block would tolerate a Lower E Block signal up to 73 dB stronger than its desired signal."[19] This result is inconsistent with Qualcomm's data. The difference between the results of Qualcomm's study and the HK Paper likely is the result of two major flaws in the HK Paper's testing methodology: (1) the unsuccessful attempt to use Band 17 devices to approximate the performance of Band 12 devices; and (2) the choice of extrapolating limited and unrepresentative test results to produce general conclusions without any controls for expected variables rather than relying on the 3GPP standard.

1. The HK Paper Unsuccessfully Attempts to Test the Behavior of a Band 12 Device by Testing a Band 17 Device.

The HK Paper explains that "no commercial Band 12 devices were available at the time of testing."[20] In an attempt to work around this problem, Mr. Hyslop and Dr. Kolodzy tested a Band 17 device using a testing scheme designed to approximate the performance of a Band 12 device.

Specifically, Mr. Hyslop and Dr. Kolodzy placed the desired LTE signal on the C Block, placed a signal on the B Block to test adjacent channel interference, and another signal on the A Block to test second adjacent channel interference. The second adjacent channel test is critical because the goal of the HK Paper is to approximate the impact of a second adjacent channel E

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[19] HK Paper at 25.

[20] *Id.* at 23.

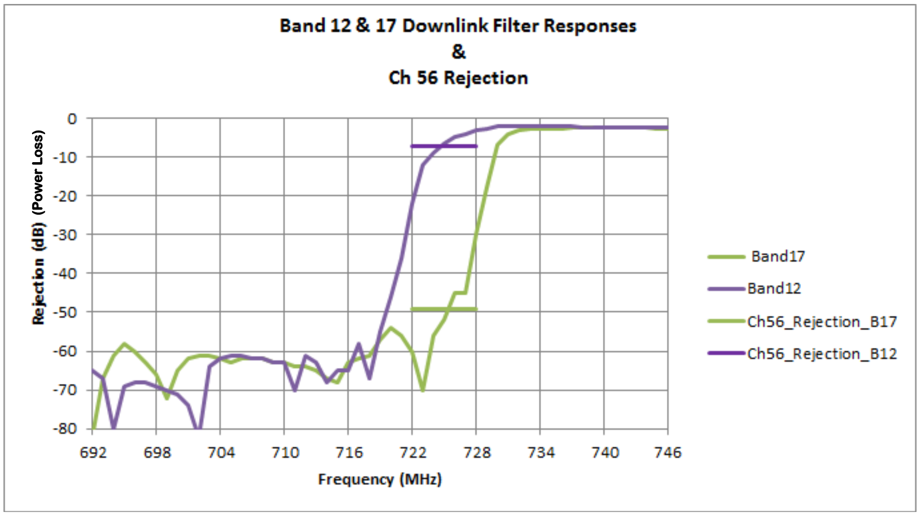
Block signal on a device seeking to receive a signal on the B Block. The study asserts that "[t]his test configuration would be identical to the case of a Lower E Block interferer adjacent to the passband of a Band 12 device duplexer."[21]

Unfortunately, this test configuration is flawed and does not necessarily reflect how an E Block signal would impact a Band 12 device receiving its desired signal on the B Block. The authors of the HK Paper concede that they do not know which filter is used in the AT&T device being tested, what its performance characteristics are, or what level of E Block signal rejection it provides. The HK Paper's subsequent generalization and assertion that this unknown filter will be representative of all devices (existing and future) makes this test configuration, and any generalizations derived from it, unsupported and unreliable.

Figure 2 shows the filter responses for commercial Band 12 (purple) and Band 17 (green) devices that were used in Qualcomm's Comments. The A Block's frequency range is 728 MHz to 734 MHz. Figure 2 shows that while this Band 17 filter rejects the A Block signal to a significant extent, the Band 12 device does not.

21 *Id.*

Figure 2



These important differences show that Band 17 filters can reject A Block signals to a significant extent. If the Band 17 device tested by the HK Paper includes A Block rejection, this fact would invalidate the HK Paper's test results. This is the case because the tested device would not be a good representation of the behavior of a Band 12 device operating near an E Block signal – the Band 12 device would not reject the E Block signal at all. Nonetheless, the HK Paper does not examine or report on the different levels of A Block rejection associated with Band 12 and Band 17 filters, and it admits that it does not know which filters the devices tested employ. As a result, the study's results include an unknown amount of filter rejection, rendering its attempt to use a Band 17 device to test Band 12 device performance unreliable.

2. The HK Paper Extrapolates Limited and Unrepresentative Test Results to Produce General Conclusions Without Any Controls for Expected Variables Rather than Relying on the 3GPP Standard.

The failure to account for A Block rejection likely explains some of the substantial differences between Qualcomm's analysis and that of the HK Paper. But there is another, more fundamental, problem with the study's approach to testing LTE devices that also renders the HK Paper's results unreliable.

Proper interference testing must account for the fact that consumers will use a variety of devices in a variety of operational and environmental conditions. Device performance test results change depending on: (1) the equipment model a consumer chooses; (2) the expected performance differences found between individual units of the same model because of variation in the manufacturing process (known as production margin); (3) operational conditions such as the type and number of other radios that are operating simultaneously and the battery voltage at the moment of testing; and even (4) environmental conditions, such as temperature, humidity, and vibration.

Differences in these variables can substantially alter test results – and consumers must be able to rely on their devices in any of the enormous number of different situations the combination of these factors may produce in the field. It is therefore unwise to extrapolate from the results of only two devices operating in ideal lab conditions, with unknown values for each of these variables, to suggest how LTE devices would tolerate interference in general. But the HK Paper makes exactly this mistake. Consequently, the Commission cannot rely on its results. The FCC cannot justify a wide-reaching rule change based on such flawed and limited testing.

A more prudent approach to assessing device performance would be to use a performance level based on the 3GPP standard.[22] Manufacturers build devices to meet the 3GPP standard, thereby enabling them and the carriers who sell the devices to be able to accurately predict performance no matter what particular device a consumer chooses. Manufacturers also design their manufacturing processes so that all units in an expected production margin meet the 3GPP standard; for that reason, using this standard eliminates the chance that a test of a particular unit

[22] As noted above in Section II.A, the HK Paper attempts to use a portion of the 3GPP standard as an alternative way to studying performance, but mistakenly assumes that 3GPP testing levels are interference thresholds.

produces an unrepresentative result. Furthermore, carriers and manufacturers work together to ensure that devices meet the 3GPP standard no matter what operational condition exists at a particular time (*e.g.*, simultaneous use of multiple radios or battery voltage) and no matter the environmental situation (*e.g.*, variations in temperature, humidity, or vibration).

Qualcomm's analysis, reported in its initial comments, followed this more prudent approach, relying on the 3GPP standard to test the expected ability of LTE devices to operate in the face of blocking interference from E Block signals.[23] The HK Paper's extrapolation of test results conducted (1) on only two devices without any reported controls or accounting for the set of variables described above; (2) without accounting for receiver desensitization levels built into the 3GPP blocking test points; and (3) without accounting for the Band 17 device's partial filtering of A Block signals, renders the HK Paper unreliable.[24]

Similarly, chipset performance varies over time as new chipsets come to market, and this is another reason why it is far more prudent to use a performance level based on the 3GPP standard than to rely on the performance of particular devices, an approach which only takes into account the performance of the chipsets in those selected devices. There are ever-increasing pressures to provide consumers with smartphones that have the longest possible battery lives, while at the same time supporting the most technologies possible and the largest number of frequency bands possible. It cannot be assumed that future smartphone chipsets, with reduced power consumption, will achieve the same extent of in-band blocking of non-linear signals as

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[23] *See* Qualcomm Comments at 7-8.

[24] It is also important to recognize that an LTE device's transmitter affects its receiver selectivity. Consequently, the 3GPP standard requires that carriers and manufacturers test adjacent channel interference with a device's transmitter at or near full power. The HK Paper does not reveal whether it complied with this test requirement. If it did not, this omission would also undermine the validity of its results.

current chipsets, much less sufficient protection against non-linearity, to cope with the interference issues at stake in this proceeding. This is yet another reason why the Commission should use the performance level based on the 3GPP standard, since that is the minimum level of performance that all devices (and their chipsets) will meet now and in the future.

D. The HK Paper Improperly Analyzes the Relative Received Powers of E Block and LTE Signals.

Section 4.3 of the HK Paper asserts that Band 12 devices will not suffer blocking interference from E Block signals based on a two-part argument: (1) "downlink signals from neighboring LTE systems may present ground-level signals which are nearly as strong as Lower E Block signals;" and, (2) because this is the case, "[d]evices designed to handle strong adjacent LTE signals would similarly handle strong Lower E Block signals."[25]

This argument is flawed because the HK Paper improperly analyzes the relative received powers of E Block and LTE signals in four ways. The study: (1) fails to account for differences in E Block and LTE signal patterns; (2) fails to account for the effect of signal fading; (3) relies on received-power tests conducted in an unrepresentative test location; and (4) improperly analyzes the role of collocation as a way of addressing the "near-far" problem. Consequently, the HK Paper's assertion is not reliable.

1. The HK Paper Fails to Account for Differences in E Block and LTE Signal Patterns.

The HK Paper presents a "theoretical comparison of Lower E Block and LTE downlink power" in its Table 4.5.[26] This table suggests a general finding that, throughout a geographic

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[25] HK Paper at 29.

[26] *Id* at 26.

area, consumer devices will experience "a maximum of 8 dB stronger ground-level [E Block] signal than an LTE system."[27] This conclusion is incorrect. While the HK Paper's reported results may be reasonable in the limited situations where a consumer is near an LTE base station, its results are unreasonable in the far more common situation where this is not the case.

As a consumer moves away from an LTE base station, the received LTE power will decrease more rapidly than the received power of the E Block signal, substantially worsening the interferer-to-desired-signal ratio and resulting in harmful interference, as described in more detail below.[28] As the HK Paper recognizes, a "broadcast Lower E Block system attempts to maximize coverage range, employing tall towers and focusing antenna energy toward the horizon."[29] In other words, the E Block operator designs its system to maintain its signal's received power level not only near the transmitter, but over as wide a geographic area as possible. Conversely, the HK Paper also recognizes that an "LTE system attempts to maximize system capacity, employing antennas at lower mounting heights and using antenna down-tilt to confine the RF energy within the sector's coverage area."[30] In regions with high populations (which are very strategic for the operator), and where capacity is critical, the LTE operator designs its system to have a high power level near the base station so that the received power rapidly decreases the farther a consumer travels from the base station. Doing this enables frequency reuse by other nearby base stations without creating self-interference. Because of these differences, LTE signal strength drops much more rapidly than E Block signal strength.

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27 *Id*.

28 *See infra* at 19-20 (analyzing relative power levels in a typical suburban deployment, such as Montclair, NJ).

29 HK Paper at 26.

30 *Id*.

This results in a ratio of interferer-power (E Block) to desired-signal power (the B Block, for example) that deteriorates quickly as a consumer moves farther from an LTE base station. The ratio is at its worst at the edge of a cell. For example, a typical LTE signal can drop by approximately 50 dB at 800 meters from its base station. Eight-hundred meters is a likely midpoint between LTE base stations in a dense LTE deployment, representing a cell edge. On the other hand, a typical E Block signal can drop only by approximately 4 dB at 800 meters from its transmitter. Consequently, even starting with the HK Paper's 8 dB difference near the LTE base station, at the cell edge, the difference swells to 54 dB. Calculating power levels at the cell edge is important for reasons of simple geometry: in markets around the country, the geographic areas covered by cell edges are far larger, and therefore represent a more typical customer experience, than the areas immediately under base stations. Nonetheless, the HK Paper does not properly account for the substantial difference in power ratios expected in these locations.

The HK Paper does appear to recognize the problem that LTE signal drop-off would present to its argument. But instead of accounting for this difference properly, it asserts that LTE received power levels do not decrease more rapidly than E Block signals,[31] despite the substantial design differences between the two types of systems described above (and the fact that it is the goal of each system's operator to create exactly this result).

Even if one were nevertheless to accept the HK Paper's measurements, however, the paper does not properly analyze the E Block to LTE signal-strength ratios that consumer devices would face in practice. The HK Paper analyzes average E Block power levels relative to LTE signal strength over distance.[32] It plots its analysis in the paper's Figure 4.19. This analysis,

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31 *Id.* at 40.

32 *Id.* at 40, Fig. 4.19.

however, depends on the HK Paper's assumption that LTE base stations will be spaced four miles apart.[33] While this may be the case in some rural areas, such spacing is uncommon. The vast majority of consumers lives and works in areas where base stations are located significantly closer together. The paper's approach assumes that relative E-Block-to-LTE-power in this unusual base-station spacing situation would not change in the majority of the country where base stations are spaced closer together. Generalizing from measurements taken in an area with unusually large distances between base stations to conclude that E Block signals will not cause harmful blocking interference is therefore inappropriate and will lead to unreliable results.

Studying a network deployment with base stations spaced at 1 mile intervals would produce a more typical result – although this base-station deployment still would not represent a worst-case, or even average, scenario because most consumers operate their devices in cities where base stations may be spaced as close as every quarter mile. Adjusting for this more representative spacing, and using the HK Paper's own data for the sake of argument, it is clear that the harmful effect of E Block signals is far greater than the HK Paper reports.[34] In this situation, the HK Paper's own data shows that blocking interference from an E Block transmitter would be a significant problem.

To illustrate this point, Qualcomm used the Longley-Rice method (the FCC's preferred prediction tool for broadcast television) to predict signal level for a 50 kW E Block transmitter positioned at the location of the WNJN transmitter in Montclair, NJ. This is a more representative location than that examined by the HK Paper. Qualcomm predicted signals at a number of points, starting from the WNJN transmitter location on a straight line to and beyond

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33 *Id.*

34 In many urban areas, covering large portions of the nation's population, cell sizes will be much smaller because base stations will be placed at 500 meter (or less) intervals.

JFK International Airport, because this line covers a densely populated area with several major transportation routes. Then, using the Hata-Urban model to be consistent with the HK Paper, Qualcomm predicted the Band 17 signal levels a device would receive along this line. Qualcomm assumed a network deployment with base stations spaced 1.7 km (approximately 1 mile) apart, rather than the unrepresentative 4-mile spacing used by the HK Paper. This change is critical, because 4-mile spacing is unrealistic (as described above), while 1.7-km would be more common. The resulting power level predictions on this 30-mile line are shown in Figure 3 below.

Figure 3

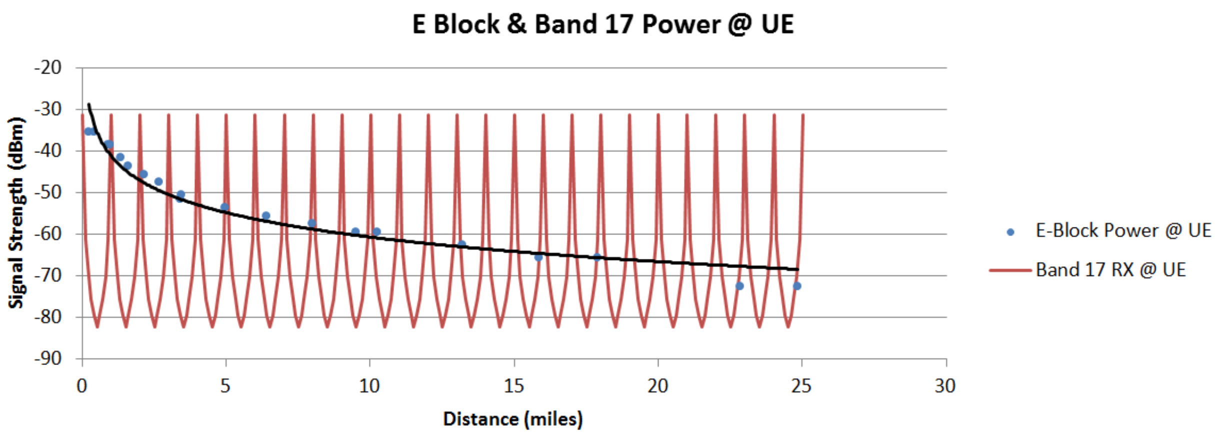
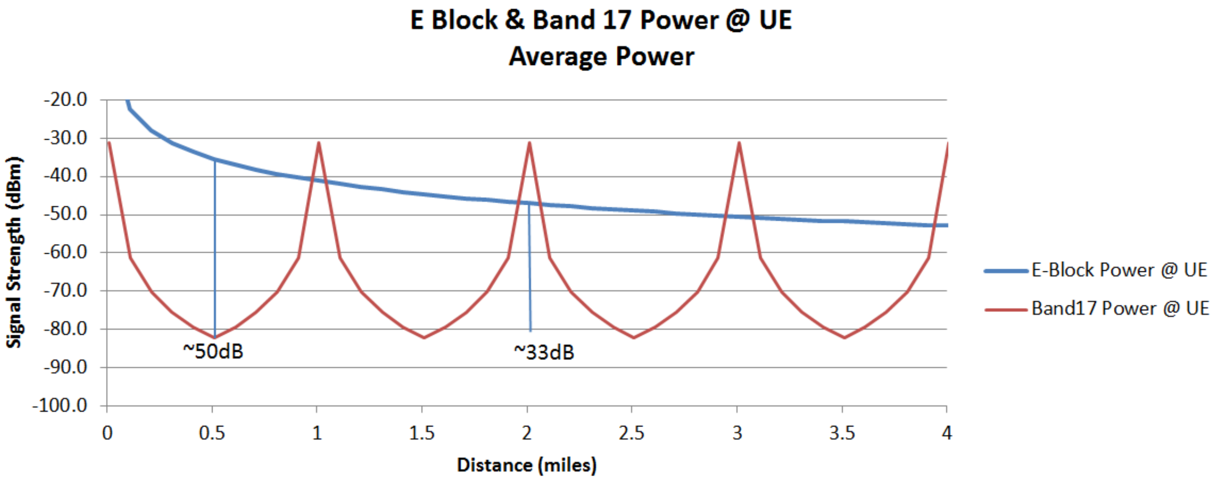


Figure 4, below, expands this image to show only the relative power levels of the E Block and the LTE signal within 4 miles of an E Block transmitter in order to show how LTE signals from five base stations compare to the E Block signal.[35]

[35] Note that the predicted E-Block power level in Figure 4 at 3 miles from the transmitter is approximately -50 dB, which is very close to the predicted level depicted in Figure 4.17 of the HK Paper. *See* HK Paper at 39.

Figure 4



As Figure 4 shows, the "trough" where the LTE signal is weakest is located approximately 0.5 miles from the E Block transmitter (the mid-point between two base stations spaced 1 mile apart). At this distance, the E Block received power level is almost 50 dB greater than the LTE signal – far worse than the 33 dB the HK Paper assumes would be representative. This difference stems from the fact that in the more typical one-mile spacing network, the LTE signal's trough is four times closer to the E Block transmitter than in the atypical network studied by the HK Paper.[36] Because it is far closer, the E Block signal is far stronger, producing a far worse signal-to-noise ratio. The HK Paper's receiver selectivity analysis for second adjacent channel (Lower B/Lower E) interference concluded that a device would not experience blocking interference unless the difference between the two signals exceeded 35 dB. Therefore, even using the HK Paper's own analysis for the sake of argument, analyzing a more typical LTE network shows that blocking interference will significantly impair Band 17 devices in proximity to a "co-located" E Block transmitter and LTE base station.

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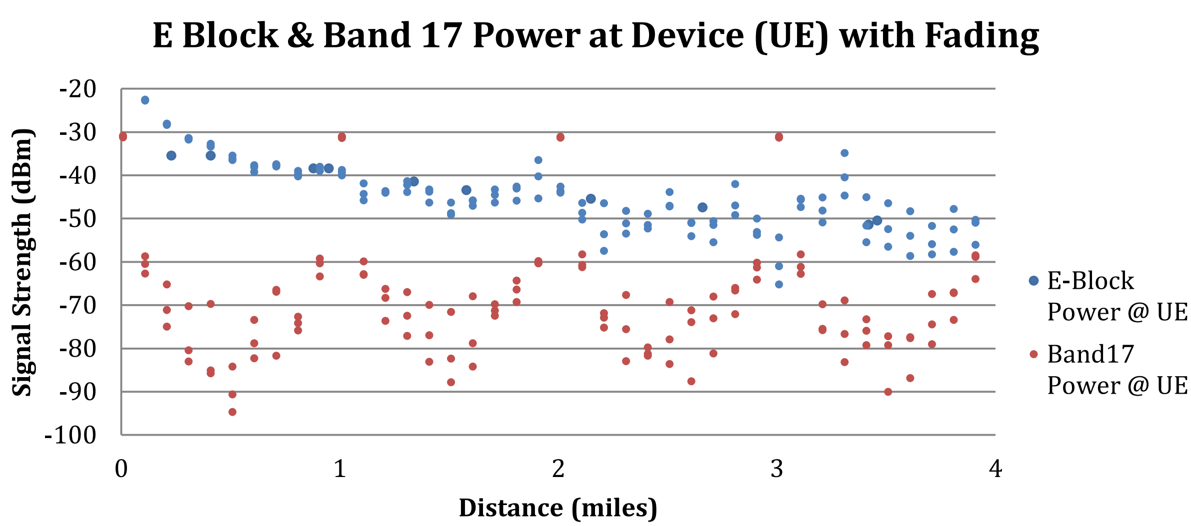
36 HK Paper at 40.

2. The HK Paper Fails to Account for the Effect of Signal Fading on E Block and LTE Power Levels.

Importantly, the HK Paper's analysis of relative E Block and LTE system power levels also does not account for the effect of signal fading, compounding the problems described above. Signal fading is an effect of multipath propagation – when signals reflect off objects in the environment before arriving at a device, they can either cancel or strengthen each other, resulting in variations in received signal strength. Including signal fading in interference analysis is critical to predicting the environment consumers will face.

The scattered dots in Figure 5 below depict fading.[37] As this figure shows, signal fading can lead to a variation in received signal power of up to ±20 dB.

Figure 5



Because of the significant variation caused by signal fading, network operators calculate a performance margin that will accommodate fading when they determine threshold levels for interference. This allows operators to ensure that, even with fading, users will not experience

[37] Interestingly, the figures in Part 4 of the HK Paper also depict signal fading. *See* HK Paper at 32-41. But the HK Paper does not account for signal fading in its later analysis.

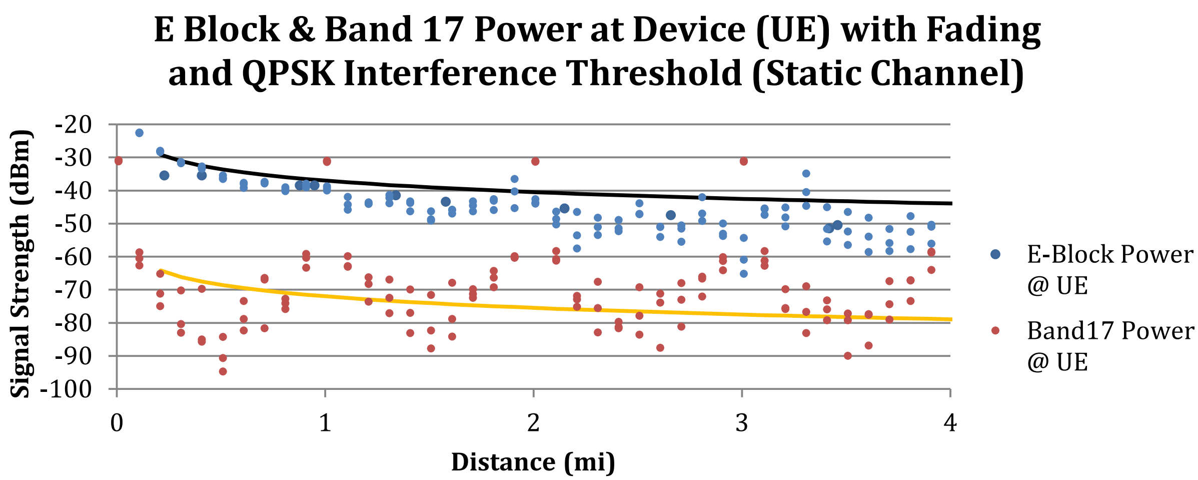
interference. To make this calculation, each operator makes a determination about average signal power levels once fading is predicted. These average power levels then allow each operator to determine if consumers will experience interference.

In the context of analyzing interference in the Lower 700 MHz band, if the E Block received power level is measured at -35 dBm, an operator would apply a margin of, for example, 10 dB to a predicted E Block signal to account for the fact that both the desired signal and the interfering signal will experience fading and may be stronger or weaker than the level at a given point. The proper approach is to set the average power level based on the upper limit of the faded E Block power levels. Failing to account for fading by not including this margin could make a tremendous difference in interference analysis. Nonetheless, the HK Paper did not include a fading margin, and therefore assumed too low an average E Block power level, producing an unreliable result.

3. The HK Paper Fails to Account for the Effect of Signal Fading at Different Modulation Formats.

A proper analysis of blocking interference also must account for the different modulation formats a device may use. As described in detail in Part II.B above, higher-order modulation formats used for faster data downloading are particularly vulnerable to blocking interference. The HK Paper did not, however, analyze E Block interference in different modulation formats. Carriers and network operators add an additional margin to account for modulation formats when determining interference thresholds. Importantly, the fading margin and the modulation format margin are cumulative, and their effect is demonstrated in the figures below.

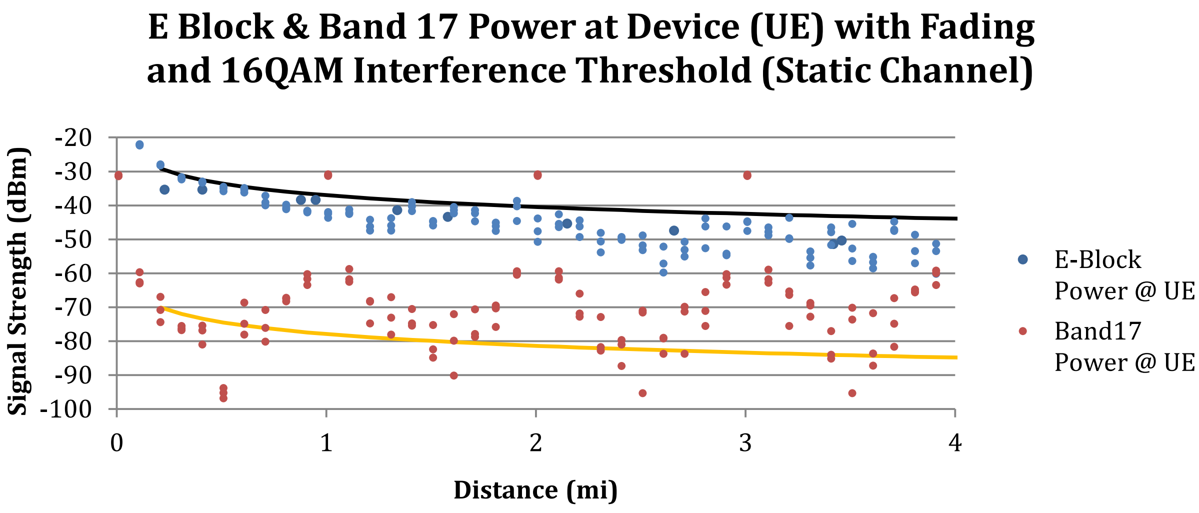
Figure 6



The average power level lines shown in Figure 6 reflect that, because of signal fading, the E Block power level typically varies ±10dB. The black line represents the average E Block power level including signal fading. The yellow line represents the interference threshold at the second adjacent channel (*e.g.*, Lower B block). Red dots represent the Band 17 LTE signal received at the device. Red dots appearing above the yellow line represent locations where the E Block signal will cause interference with Band 17 devices.

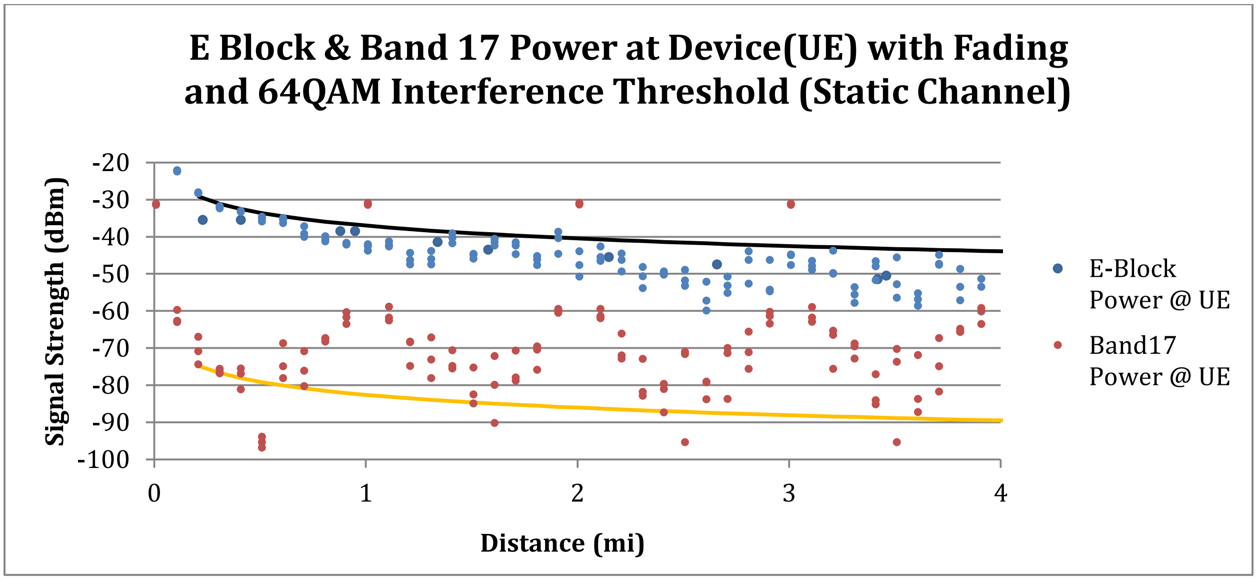
Blocking interference worsens as devices shift to higher-order modulation formats and become more sensitive to interference. The 16QAM modulation format, offering intermediate data rates, will likely experience harmful blocking interference as depicted in Figure 7 below.

Figure 7



Finally, blocking interference will almost completely prevent devices from operating at the 64QAM modulation format, as shown in Figure 8 below.

Figure 8



Because the HK Paper does not account for fading and modulation formats, its results are not reliable.

4. The HK Paper Relies on Received-Power Tests Conducted in an Unrepresentative Test Location.

The HK Paper claims that its "Atlanta field measurements confirm the [study's] theoretical calculations regarding the Lower E Block power level relative to LTE base station signals."[38] The unrepresentative nature of the Atlanta test site, however, renders the study's field test results unreliable. The HK Paper chose Atlanta because "the only operational Lower E Block system in the country was located in Atlanta."[39] As the study reveals, this E Block system was a "DISH Network E Block video broadcast trial"[40] with only four towers, one of which was not transmitting at full power.[41] It is not a fully developed commercial system.

The limited nature of DISH's Atlanta test system means that it fails to present an interference environment suitable for predicting interference more generally. DISH had only four transmitters in Atlanta. A commercial system would have far more transmitters, which would result in many more locations where E Block signal levels would be at their highest. The locations of E Block transmitters would affect test results as well. The locations of DISH test transmitters were not necessarily designed to maximize signal power throughout Atlanta, but only to test the system. As Qualcomm knows well from operating its analogous FLO TV service, a commercial system would place transmitters in exactly the locations that would present the largest interference challenges for a B or C Block licensee because the goal would be to ensure customers received the highest power possible everywhere in the area.

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38 HK Paper at 27.

39 *Id.* at 11.

40 *Id.* at 12

41 *See id.* at 12-13.

Studying only these test locations also means that the important relationship between E Block transmitters and B Block base stations in Atlanta is not representative of what consumers would face were DISH to deploy a commercial E Block system in Atlanta, and certainly does not reflect the situation consumers would face in other markets throughout the country. In fact, the relative positions of test E Block transmitters and B Block base stations in Atlanta are mere happenstance.

Because of these important limitations, Atlanta is an inappropriate test site and is likely to produce misleading results. It represents neither the worst-case situation that prudent interference testing must always analyze to protect consumers, nor the typical environment a consumer might experience.

Fortunately, testing the inappropriate Atlanta environment is not the only option. Qualcomm's FLO TV system was a full-fledged commercial system that presents the Commission with a far more realistic test of how a commercial E Block system would operate. Channel 55 signals behave almost identically to the E Block signals at Channel 56, and Qualcomm designed its system in a manner that is likely to closely match how DISH would build its E Block system. The Commission should therefore rely on the actual commercial measurements presented in Qualcomm's initial comments in this docket,[42] not those submitted by the HK Paper.

5. The HK Paper Improperly Analyzes the Role of Collocation as a Way of Addressing the "Near-Far" Problem.

In its initial comments in this proceeding, Qualcomm explained that collocating LTE base stations with E Block transmitters would not be an effective strategy for mitigating E

42 Qualcomm Comments at 12-18.

Block-to-LTE interference,[43] but that LTE operators can mitigate LTE-to-LTE interference by collocating LTE base stations.[44] The HK Paper argues that exactly the opposite is true. It asserts that LTE operators can manage E Block interference by collocating base stations with E Block transmitters, but cannot manage LTE-to-LTE interference by collocating LTE base stations. The HK Paper is incorrect.

Mobile phone customers may experience service degradation when they are located far from their service provider's nearest base station but near a base station of a potentially interfering system. In these situations, the customer's desired signal is low because their base station is so far away, but a potentially interfering signal from another operator is high because the transmitter is so near. This is therefore called the "near-far" problem.

Cellular operators rely heavily on collocation to address the near-far problem. But this strategy is effective only where the antenna patterns and coverage areas of two radio systems are similar. This is the reason that collocation can successfully manage LTE-to-LTE interference. Two operating LTE systems will have a similar number of base stations and similar cell sizes, and will seek to minimize cell sizes to allow frequency reuse, all of which yields similar signal patterns. So when two LTE base stations are collocated, their signals will attenuate at approximately the same rate over distance, resulting in a desired-signal-to-interfering-signal ratio that remains stable.

Nonetheless, the HK Paper claims that "[s]ite coordination is not a feasible approach to manage LTE-base-to-LTE-device interference throughout a system . . . [because] [a]ttempting to coordinate site locations with multiple operators across thousands of locations is an impossible

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43 Qualcomm Comments at 29-31.

44 *Id.* at 33-34.

task."[45] But this is exactly what cellular system operators do today in many different frequency bands all around the world.[46]

On the other hand, collocation does not work when two radio systems have different antenna patterns and coverage areas. In these situations, even with collocation, the two signals will not attenuate at the same rate over distance, so the desired-signal-to-interfering-signal ratio will not remain stable. Consequently there may be too many locations where, compared to the desired signal, the interfering signal will be strong enough to result in harmful interference. In these mismatched situations, it is also often the case that the locations that one type of system would choose for its transmitters are very different from the locations the second system would choose, because the systems have different signal propagation goals.

For these reasons, collocation will not work to address E Block interference to LTE signals—LTE and E Block systems are too dissimilar. FCC rules permit an E Block licensee to operate towers at 50,000 watts, more than eight times the permitted power of a B or C Block

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45 HK Paper at 31.

46 *See*, *e.g*., Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96, 126 Stat. 156, § 6409(a)(1) (2012) (codified as amended at 47 U.S.C. § 1455) ("[A] State or local government may not deny, and shall approve, any eligible facilities request for a modification of an existing wireless tower or base station that does not substantially change the physical dimensions of such tower or base station."); *see also Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services*, Fifteenth Report, 26 FCC Rcd. 9664, 9843 ¶ 312 (2011) ("Collocating base station equipment on an existing structure is often the most efficient and economical solution for existing and new wireless service providers that need new cell sites. PCIA estimates that the average cost to build a new tower is between $250,000 and $300,000, whereas the average deployment cost for a collocation is between $25,000 and $30,000. Collocation is also commonly encouraged by zoning authorities to reduce the number of new communications towers. Due to the high cost to construct new towers, and the often considerable delay to obtain approvals from state and local authorities, wireless service providers will typically look first for existing towers or other suitable structures for new cell sites. Collocation is particularly useful in areas in which it is difficult to find locations to construct new towers." (citations omitted)).

base station in suburban and urban areas and more than four times the permitted power in rural areas.[47] As a result, E Block operators will be able to use far fewer base stations to cover significantly larger cells than can B or C Block operators, and the antenna patterns of the two systems will be substantially different. As discussed in Qualcomm's initial comments:

- B and C Block operators likely will site base stations only 1.7 km or less apart, while E Block operations likely will place their transmitters much further apart;
- B and C Block licensees likely will down-tilt antennas to reduce coverage areas and allow frequency reuse, while E Block operators likely will position their transmitters to maximize coverage and achieve maximum received signal strength some distance away from their base stations; and
- B and C Block operators likely will place base stations throughout their license areas, while E Block operators again likely will take the opposite approach, locating towers on mountaintops and other areas that allow maximum coverage for each tower (on top of very tall buildings), whenever such locations are available.

It is also important to recognize that many B and C Block antennas are already in place and serving customers.[48] But DISH has deployed only one test market, in Atlanta. Even if collocation could somehow manage E-Block-to-LTE interference, it would be unreasonable to force B and C Block licensees to decommission their base stations and reposition them near E Block transmitters.

E. The HK Paper Study Does Not Account for Intermodulation Interference.

Finally, the HK Paper does not address the threat of E Block intermodulation interference to B and C Block consumer devices. As demonstrated in detail in Qualcomm's initial comments, consumer devices operating in either the Lower B or C Blocks alone, or using the combined B

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47 *See* 47 C.F.R. §§ 27.50(c)(3)-(4).

48 *See, e.g.*, Comments of AT&T Inc. at 10, WT Docket Nos. 12-69, RM-11592 (Terminated) (filed June 1, 2012) ("AT&T Comments").

and C Blocks as a unit, are susceptible to intermodulation interference, which is caused by high-power E Block signals entering the consumer device's duplexer.

Qualcomm's analysis showed that:

- In locations where a consumer device operating on either the B or C Block experiences E Block power of -31.4 dBm or greater, it will experience desensitization of 3 dB or greater due to harmful intermodulation interference. With E Block power of -29 dBm, it will experience 6 dB of desensitization, doubling the amount of interference;[49] and

- In locations where a consumer device operating on both the B and C Block experiences E Block power of -34.5 dBm or greater, it will experience desensitization of at least 3 dB due to intermodulation interference. E Block power of -32.1 dBm will generate 6 dB or greater of desensitization, also doubling the amount of interference.[50]

Importantly, even the HK Paper's tests of Fayetteville, GA reveal numerous locations where E Block received power levels exceed these values.[51]

Importantly, the negative impact of intermodulation and blocking interference suffered by B and C Block devices would be cumulative. Nonetheless, the HK Paper does not account for intermodulation interference. For this reason alone, its conclusion that high-power E Block signals will not cause harmful interference to B and C Block consumer devices is unreliable.

III. THE HK PAPER IMPROPERLY ANALYZES THE THREAT OF REVERSE INTERMODULATION INTERFERENCE TO LOWER B AND C BLOCK DEVICES DUE TO HIGH-POWER CHANNEL 51 SIGNALS.

Qualcomm's initial comments demonstrated that signals from Channel 51 could cause harmful reverse intermodulation interference to consumer devices seeking to receive on the B and C Blocks if those devices lacked a filter that could sufficiently attenuate the Channel 51

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49 Qualcomm Comments at 23.

50 *Id.*

51 HK Paper at Figure 4.17.

signal at the devices' transmission (output) channel.[52] Through its measurements, Qualcomm has determined that a Band 17 filter can successfully protect against this reverse intermodulation interference, but a Band 12 filter cannot.

The HK Paper, however, argues that its "lab and field measurements conclusively demonstrate that reverse PA [power amplifier] IM [intermodulation] from Channel 51 broadcast transmissions will not interfere with device reception, even under the worst case conditions."[53] As with E Block interference, however, the study based this conclusion on a set of flawed assumptions and testing schemes, as described below.

A. The HK Paper Relies on an Inapplicable Formula for Predicting Reverse Intermodulation Amplitude.

The HK Paper mathematically predicts the amplitude of reverse intermodulation products in the Lower B and C Block receive frequencies.[54] These predictions are unreliable, however, because they rely on a formula that is not generally accepted. In fact, as recently reported by a U.S. Army-supported study, there is no generally accepted formula for mathematically predicting such interference.[55]

Furthermore, the HK Paper appears to use a formula for predicting *forward* intermodulation interference.[56] Forward intermodulation interference occurs when two signals enter the device's input port, which is a different mechanism from reverse intermodulation, when

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52 Qualcomm Comments at 34; *see also* NPRM at ¶ 33-36, 40.

53 HK Paper at 63.

54 *Id.* at 47, Table 5.1.

55 *See, e.g.,* Allen Katz *et al*., *Sensitivity and Mitigation of Reverse IMD in Power Amplifiers* at 53 (2011 IEEE Topical Conference on Power Amplifiers for Wireless & Radio Applications (PAWR) (2011)); *see also* Qualcomm Comments at 36.

56 *See* HK Paper at 65.

one signal enters the device's output port and one signal enters the input port. The HK Paper does not offer a justification for applying this forward-intermodulation formula to reverse intermodulation.[57] Because the HK Paper relies on this inappropriate formula, the Commission should not give weight to this portion of its analysis. In the absence of an accepted formula to predict reverse intermodulation, the only prudent approach is to measure reverse intermodulation. Qualcomm reports on such measurements in its initial comments in this proceeding.[58]

B. The HK Paper Assumes that Reverse Intermodulation Products are Strictly Limited in Bandwidth, But Qualcomm's Tests Demonstrate that this is Incorrect.

The HK Paper's analysis also depends on the assumption that a mathematical formula allows precise predictions of the bandwidth of reverse intermodulation products, and that these products are strictly pulse-shaped in frequency.[59] Using this assumption, the HK Paper theorizes that reverse intermodulation will only pose potential interference issues in a 10 MHz LTE channel, and even then will only affect 0.5 MHz (or ~ 5.6%) of the total transmission bandwidth.[60]

Qualcomm's laboratory measurements of the reverse intermodulation interference created by Channel 51 and B and/or C Block signals (which did not depend upon assumed positions calculated through a formula) demonstrate that this theorizing in the HK Paper is incorrect. In fact, reverse intermodulation products have much less predictable bandwidth than the bandwidth

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57 *See id*. at 47.

58 Qualcomm Comments at 35-42.

59 *See* HK Paper at 45-46.

60 *Id.* at 47 & Table 5.1.

assumptions upon which the HK Paper depends.[61] Qualcomm's laboratory measurements found that reverse intermodulation products spread in bandwidth to cover *more* than "the difference between twice the UE transmit frequency and the Channel 51 DTV frequency."[62] Reverse intermodulation products "do not suddenly drop like a pulse function to minimal power outside the bandwidth; their power levels gradually decrease."[63] Consequently, in the context of the Lower 700 MHz band, Qualcomm's data show that reverse intermodulation products created by Channel 51 signals affect A, B, and C Block receive frequencies. Indeed, Qualcomm's measurements show that reverse intermodulation will cause harmful interference even in a 5 MHz LTE channel transmitting and receiving in the C Block. The HK Paper is flawed because it does not account for this interference.

C. The HK Paper Incorrectly Assumes that Reverse Intermodulation Will Only Occur Where an LTE Device is Transmitting at Very High Power.

Furthermore, the HK Paper relies on the assumption that "the LTE device must be transmitting at very high power" for reverse intermodulation interference to occur.[64] Qualcomm's laboratory tests demonstrate that this assumption is also incorrect.

Mobile devices transmit over a range of output levels and switch between gain states to conserve battery life. As reported in Qualcomm's initial comments, lab tests show that reverse intermodulation interference varies depending on the particular gain state and power level of the device at any time. Contrary to the HK Paper's assumption, Qualcomm's measurements found that reverse intermodulation interference occurs at multiple gain states, not only at the highest

61 *See* Qualcomm Comments at 35-42; *see also* AT&T Comments, Exhibit A ("Reed/Tripathi Study") at 21-22.

62 HK Paper at 45.

63 Reed/Tripathi Study at 21-22.

64 HK Paper at 43.

power levels.[65] In fact, Qualcomm's data revealed that, at least for some consumer devices, reverse intermodulation was at its worst when the device was operating in a mid-gain state rather than at its highest power. Because the HK Paper assumes that only devices operating at very high power can create reverse intermodulation interference, it underestimates the negative impact of such interference on consumers.

D. The HK Paper's Methodology for Testing Reverse Intermodulation in LTE Devices Is Flawed.

1. The Test Does Not Account for Channel 51 Rejection by the Band 17 Device Duplexer it Studies.

The HK Paper concludes that based on its tests of two AT&T commercial Band 17 devices, reverse intermodulation from a Channel 51 signal poses no interference risk. This conclusion is unreliable because the testing methodology is flawed.

The Band 17 devices that the HK Paper tested have a Band 17 transmit filter between the antenna connector (the port used during the testing) and the power amplifier, where the reverse intermodulation products are created. This filter's function is to attenuate the signal entering the power amplifier. It therefore plays a vital role in controlling reverse intermodulation. But the authors of the HK Paper admit that they knew neither which filter AT&T used in the devices being tested, nor its characteristics.[66] Instead of determining which filter AT&T used in its devices, or, better yet, designing a test that accounts for variation in filter performance, the study instead chose one particular filter, the Triquint Band 17 filter, and then assumed that the AT&T

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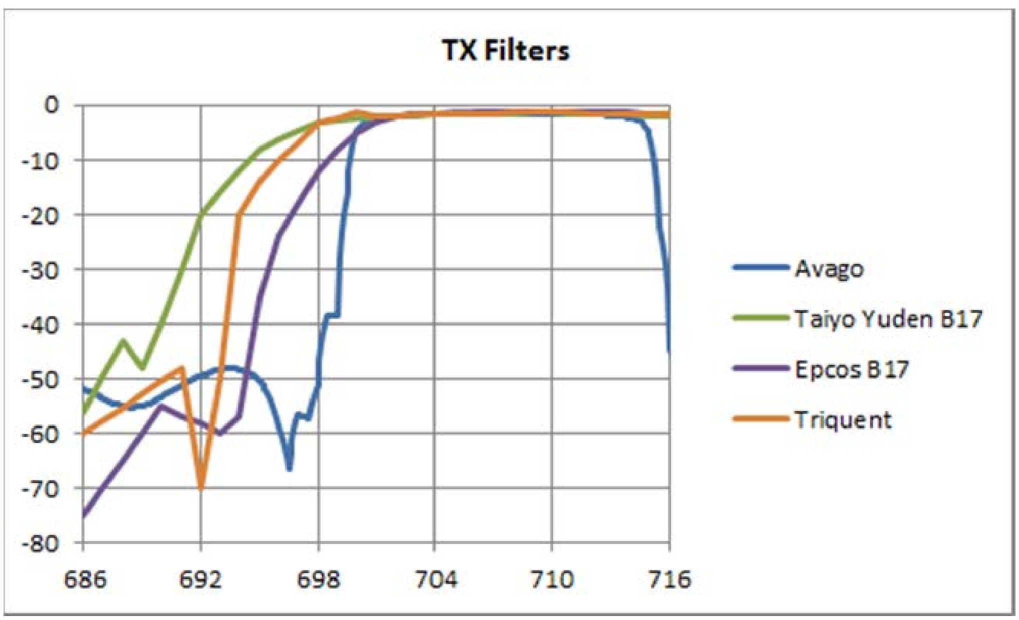
65 Qualcomm Comments at 38-42 & Figs. 19, 21.

66 *See* HK Paper at 59 ("While it is not known whether the AT&T devices make use of this [Triquint] or another duplexer model, the filter shape is expected to be representative of typical filter technology for this band.").

devices tested use (and that all future Lower 700 MHz devices will use) a filter with similar performance.

This is a significant error because different Band 17 duplexers demonstrate substantial differences in Channel 51 rejection levels – meaning that relying on the behavior of the Triquint filter to predict the behavior of the unknown filter in the test devices will produce unreliable conclusions. In fact, responses from filters manufactured by Triquint, Epcos, MuRata, and Avago provide Channel 51 rejection levels ranging from a few dB of rejection to nearly 50 dB of rejection, as shown below in Figure 9.

Figure 9



The level of Channel 51 signal attenuation that a filter provides has an enormous effect on a device's performance level. The greater the Channel 51 rejection, the more protection a filter provides from reverse intermodulation interference. The HK Paper does not specify how it attempted to account for the ability of the unknown filter to reject the reverse intermodulation product. For this reason, and because the HK Paper assumed that the unknown filter in the devices it tested would behave like a Triquint filter, and that the performance of two individual devices in a laboratory setting could be extrapolated to describe all Band 17 filters and devices, its analysis is unreliable. In analyzing Channel 51 reverse intermodulation interference, Qualcomm measured signal levels directly at the power amplifier output, to avoid this very problem.[67]

2. The HK Paper's Measurement of Only 1 or 5 Resource Block Narrowband Signals is Inappropriate.

LTE signals are composed of a number of sub-channels known as "resource blocks" ("RBs"). A transmission using a single RB will produce a signal with a bandwidth of 180 kHz; 5 RBs will produce a signal with a bandwidth of 900 kHz; and 50 RBs will produce a signal with a bandwidth of 9.0 MHz. For a 10 MHz LTE channel, a device's uplink signal uses between a minimum of 2 or 4 RBs and a maximum of 50 RBs. Figure 10, below, which is drawn from 3GPP TS 36.101, illustrates this configuration.

[67] Qualcomm Comments at 34-42.

Figure 10

Table 5.6-1: Transmission bandwidth configuration N_{RB} in E-UTRA channel bandwidths

Channel bandwidth $BW_{Channel}$ [MHz]	1.4	3	5	10	15	20
Transmission bandwidth configuration N_{RB}	6	15	25	50	75	100

Figure 5.6-1 shows the relation between the Channel bandwidth ($BW_{Channel}$) and the Transmission bandwidth configuration (N_{RB}). The channel edges are defined as the lowest and highest frequencies of the carrier separated by the channel bandwidth, i.e. at F_C +/- $BW_{Channel}$ /2.

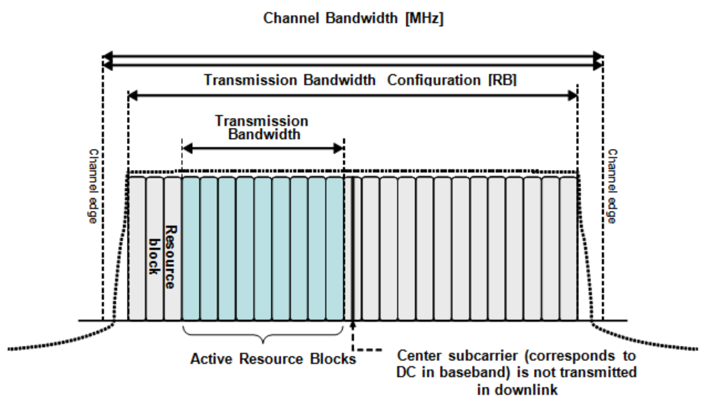


Figure 5.6-1: Definition of Channel Bandwidth and Transmission Bandwidth Configuration for one E-UTRA carrier

In an effort to measure reverse intermodulation interference in LTE devices, the HK Paper measured device transmissions of only 1 RB and 5 RBs, resulting in signals that are much narrower than the maximum of 10 MHz that is permitted under the 3GPP specifications. As a result, this test configuration does not account for the full range of possible device transmission configurations, including the much wider bandwidth signals that LTE will in fact transmit. The use of narrowband signals in measurements will lead, in turn, to unreliable and unrealistically optimistic results.

A narrow signal bandwidth produced by a 1 or 5 RB transmission will result in reverse intermodulation products that affect a narrower bandwidth than those produced by a 50 RB transmission. Consequently, the HK Paper's measurements show much less interference than would be observed in many real-world conditions.[68] Indeed, the HK Paper acknowledges that device transmit frequency and Channel 51 DTV frequency both "are typically wideband signals,"[69] but then fails to account for this fact in its testing parameters. As a result, this test configuration certainly cannot be used to describe a worst-case scenario, as is required in proper interference analysis.

3. The Test Underestimates and Fails to Account for the Role of the Tested LTE Devices' Transmit Filters in Eliminating Intermodulation Interference.

The HK Paper's reverse intermodulation test appears to measure the level of the Channel 51 signal as well as the reverse intermodulation product in reference to the tested devices' antenna connector.[70] It then uses this result to calculate the point at which reverse intermodulation would occur.[71] This is an error.

Reverse intermodulation occurs when the Channel 51 signal reaches the device's power amplifier output via the transmit filter. The HK Paper's authors acknowledge that they do not know the characteristics of the transmit filter in the devices tested, so they have no way to know the actual Channel 51 and reverse intermodulation levels at the power amplifier output.[72] Without knowing the filter characteristics, it is impossible to know the signal levels at the device power amplifier. And that means there is no way to calculate the third order intercept point ("OIP3"), even assuming that the formula used in the HK Paper were applicable to reverse

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68 HK Paper at 54. *Cf. id.* at 45 ("Since both signals [the UE transmit frequency and the Channel 51 DTV frequency] are typically wideband signals, the IM products have a wide bandwidth as well.").

69 *Id.* at 45.

70 *See* HK Paper at 54-61.

71 *Id.* at 62-63.

72 *Id.* at 59.

intermodulation interference (which it is not).[73] But the HK Paper does so nonetheless, simply assuming that a filter measured in the lab under ideal conditions would "be representative of typical filter technology in this band," without accounting for performance variations between the filter measured, typical filters in Band 17, or even the actual filter in the AT&T device included in the test configuration.

Figure 11, below, examines the performance of an Epcos Band 17 duplexer to illustrate why knowing the performance characteristics of a specific filter is so important. The red line shows the performance of the transmit filter in the Epcos Band 17 duplexer, which provides significant rejection to both Channel 51 (black) and the reverse intermodulation product at Channels 58 and 59 (blue).

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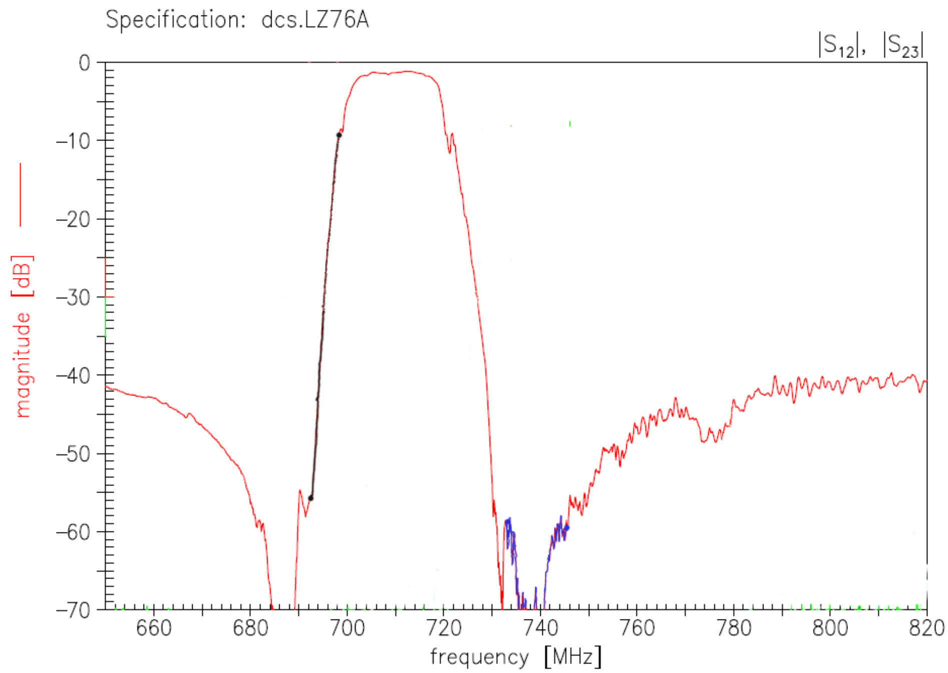
73 *Supra* Section III.A.

Figure 11



The Epcos Band 17 filter will provide rejection of the Channel 51 signal (black portion of the curve) and of the reverse intermodulation product (blue portion of the curve). This demonstrates that the transmit filter's role in attenuating a Channel 51 signal is vital. But the HK Paper mistakenly assumes that the "power amplifier third order intercept point is of much greater impact in eliminating intermodulation concerns than the RF transmit filter."[74] The measurements in Figure 11 demonstrate that this is incorrect. Power amplifier linearity (*e.g.*, OIP3) and RF transmit filter rejection play an essentially balanced role in the generation of reverse intermodulation products. The HK Paper fails to recognize the importance of RF transmit filter rejection. For these reasons, the HK Paper's results are not reliable

74 HK Paper at 59.

4. The FCC and Commenting Parties Cannot Evaluate the Test's Block-Error-Rate Analysis Because the Paper Does Not Indicate How it Configured the Receiver Signal.

The HK Paper also states, without describing its test configuration, that a block-error-rate ("BLER") test demonstrates no problems with reverse intermodulation interference from Channel 51.[75] The fundamental role of any wireless communication system is to transport information without error. Modern communications systems arrange information to be transported onto blocks. A block refers to a partition of data that includes multiple bits of information. A BLER test consists of sending a known sequence of data (or block), and evaluating the received data (block) for errors. Because the HK Paper provides no information about how it configured the receiver signal in its BLER test, the Commission cannot evaluate these test results, and therefore should not rely on them. LTE specifications (*e.g.*, the 3GPP standard) do not include a specific BLER, so there is no uniform standard that the FCC can assume the HK Paper used. Even if there were a standard level, the HK Paper's test cannot be replicated or interpreted based on its report.

When performing a BLER test, engineers begin with a test signal at a known level, preferably the reference sensitivity ("REFSENS") level in test mode, which should produce a very low BLER. To conduct the test properly, the test should use an LTE device transmitting at full power, add the Channel 51 signal, and then increase the Channel 51 signal strength until a measurable BLER occurs. That is the point at which interference begins.

The HK Paper provides no information about its test configuration, so there is no way to know if the receiver signal was set appropriately. This is important because a receiver measured at REFSENS +20 or 30 dB will produce entirely different – and less meaningful – results than a

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[75] HK Paper at 57.

receiver set at REFSENS. Therefore, without knowing the receiver configuration, there is no way to interpret the results or to judge the HK Paper's claim that a "measurable BLER" does not occur until the Channel 51 signal reaches +18 dBm.[76]

E. Reverse Intermodulation Will Have Broader Geographic Impact Than the HK Paper Reflects.

The HK Paper assumes that "reverse PA IM may only be generated within a device which is transmitting in Lower C while receiving in Lower B."[77] It next assumes, "[t]herefore reverse PA IM is only a possibility in those markets where the same licensee owns both the Lower B and C Blocks and Channel 51 delivers very strong signals to the LTE coverage area."[78] Based on these assumptions, the HK Paper excludes from its analysis markets where a carrier owns only one of the Lower 700 MHz blocks, claiming that such markets are "automatically immune" from reverse intermodulation.[79] It then excludes locations where Channel 51 towers are located remotely from a populated area. With all of these assumptions, it concludes that only three locations exist where a carrier (AT&T) currently owns both B and C Blocks: Kansas City, KS; Montclair, NJ; and Dayton, OH. For these three locations, the HK Paper states that the horizontal directional antenna of the DTV transmitter means that the DTV signal near the tower will be very low.

The HK Paper incorrectly assumes that (1) reverse intermodulation interference can only occur where a licensee holds both the B and C Blocks, (2) only a small number of Channel 51

76 *Id.*

77 HK Paper at 48.

78 *Id.*

79 *Id.*

stations are close enough to important coverage areas, and (3) horizontal directional antennas will solve the reverse interference problem.[80]

First, it is not the case that Channel 51 markets where AT&T owns just one Lower 700 MHz block are "automatically immune" from reverse intermodulation "since the IM products do not overlap with the device receive frequencies."[81] Qualcomm's measurements showed that harmful reverse intermodulation interference can occur where a device is transmitting and receiving a 5 MHz LTE signal in the Lower C block.[82] The risk comes from the fact that, when measured, reverse intermodulation products spread in bandwidth significantly more than the formula relied upon in the HK Paper would suggest. These tests show that the reverse intermodulation product of a Channel 51 and 5 MHz C Block signal is wide enough to fall on the receive frequencies of the A, B, and C Blocks. Reverse intermodulation products in the real world simply do not present themselves as the neat, mathematical pulse-shaped frequencies the HK Paper assumes will occur.[83] Consequently, the HK Paper erroneously excludes markets where AT&T holds only the C Block from its analysis.

Second, Channel 51 signals present reverse intermodulation threats to larger and more densely populated communities than assumed by the HK Paper. This is the case because the locations of many Channel 51 towers do not necessarily reduce signal strength enough within LTE coverage areas to eliminate the threat of interference. Although Channel 51 towers frequently are located on mountaintops or tall buildings in order to maximize their coverage

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[80] This portion of the HK Paper also appears to assume that reverse intermodulation products are strictly band limited, which Qualcomm demonstrated is not the case. *See supra* Section II.B.

[81] HK Paper at 48.

[82] Qualcomm Comments at 38-40.

[83] *See supra* Section II.B.

range, this does not necessarily mean they are "remote." In fact, some towers may be located on tall buildings in very densely populated areas, such as is the case in Chicago,[84] a city excluded from the HK Paper's analysis. Other towers may be located in areas deemed non-urban but that are densely populated suburban areas (*e.g*., the Providence, RI area), and pose risks of harmful interference to tens of thousands of consumers.[85]

Third, the fact that DTV towers are horizontally directional does not, without more support, mean that they effectively restrict the threat of reverse intermodulation interference to areas close to Channel 51 towers. Using the FCC's own data on DTV signal strength, Qualcomm's initial comments in this proceeding showed that signal strength in many areas close to Channel 51 towers will be higher than the HK Paper asserts and will lead to harmful interference across large and densely populated areas.[86]

Therefore, the basic assumptions on which the HK Paper bases its analysis of the geographic areas affected by reverse intermodulation are incorrect. Consequently, its conclusion that this area will be small is not reliable.

IV. CONCLUSION.

Qualcomm demonstrated in its initial comments that Band 12 devices operating on the Lower B and/or C Blocks would suffer harmful interference from high-power Lower E Block and Channel 51 signals. While the HK Paper disagrees with these findings, it is unreliable because it contains a series of interrelated and important flaws, as shown in these reply comments. The Commission therefore should not rely on the HK Paper and, instead, should

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84 *See* Qualcomm Comments at 45-47.

85 *See id.* at 52-53.

86 *Id.* at 43-54.

agree with Qualcomm's finding that E Block and Channel 51 signals would cause harmful interference to Band 12 devices operating on the B and/or C Blocks. Qualcomm therefore urges the Commission to refrain from requiring mobile equipment to be capable of operating over all paired commercial spectrum blocks in the Lower 700 MHz band.

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