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FILTER RECOMMENDATIONS FOR COEXISTENCE WITH LTE AND WIMAX

ABSTRACT: This white paper contains filtering specifications to facilitate coexistence between *Bluetooth* wireless technology and WiMAX or LTE interferers in the same product.

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1. Introduction

1.1 SCOPE

This white paper proposes filter masks and guard bands to enable simultaneous operation of *Bluetooth* wireless technology and collocated Mobile Wireless Standards (MWS) systems such as LTE and WiMAX, operating in frequency bands adjacent to the 2.4 GHz Industrial, Scientific, and Medical (ISM) band within the same product. MWS systems utilizing both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) mechanisms are considered.

This white paper assumes that transmitter and receiver implementations are better than the minimal requirements from the relevant standard or specification.

The proposed filter masks result in realizable filter implementations with flexibility in system performance to enable system designers and filter suppliers to trade system performance for size and cost.

1.2 BACKGROUND

New Mobile Wireless Standards are being developed for use in the radio spectrum adjacent to the 2.4 GHz ISM band that *Bluetooth* wireless technology and Wireless LAN (WLAN) currently operate in. Figure 1 shows the current spectrum allocations from 2300 to 2690 MHz.

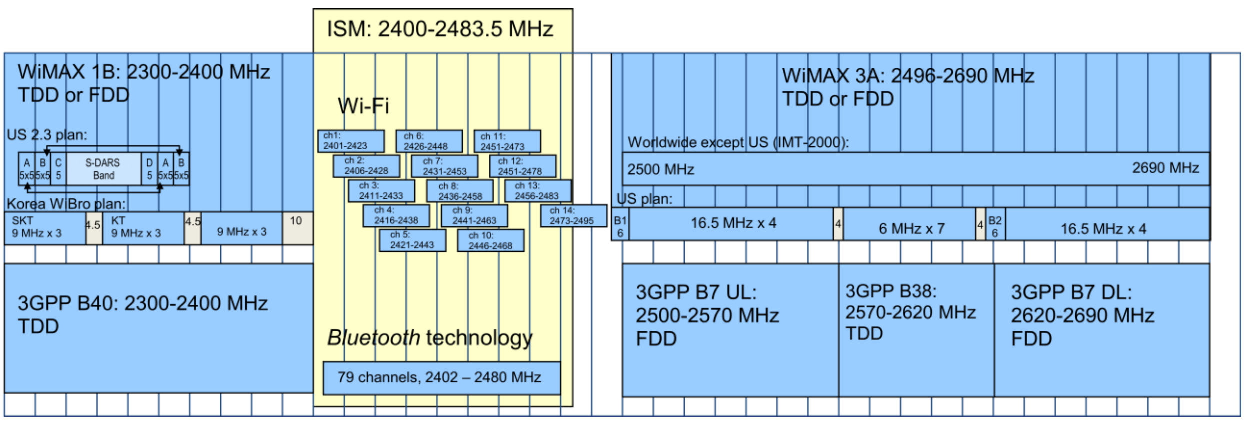

Figure 1 – Spectrum Allocations from 2300 to 2690 MHz

Bluetooth wireless technology utilizes the 2.4 GHz ISM band with center frequencies from 2402→2480 MHz. MWS services are planned for operation in 2300→2400 MHz and 2496→2690 MHz.

For LTE, Band 7 (B7) is allocated for 3G/4G FDD services with the uplink in 2500→2570 MHz and downlink in 2620→2690 MHz. Band 38 (B38) is between the FDD uplink and downlink bands, from 2570→2620 MHz, and is earmarked for TDD operation. Band 40 (B40) is from 2300→2400 MHz and is TDD.

For WiMAX, Band Class 1 is 2300→2400 MHz and Band Class 3 is 2496→2690 MHz (though 2500→2690 MHz is used in this whitepaper). Both are designated as TDD bands. WiMAX may also support FDD in 2500→2690 MHz.

These collocated radio systems in mobile phones have serious implications for simultaneous operation and, thus, the end user experience as both radio systems can interfere with each other.

The Bluetooth SIG does not state how MWS systems will function in actual deployments. Statistics related to transmit power control and resource allocation, which directly influence MWS emissions into the ISM band,

and thus the achievable *Bluetooth* receiver performance, are not taken into account. Instead, maximum allowed transmit power and full resource allocation are assumed.

It is possible that knowledge of statistical aspects of the MWS system can be considered when defining filter specifications; however, this is beyond the scope of this white paper.

2. Assumptions

Following are high-level system performance assumptions:

1. Some receiver desensitization between each system is acceptable and unavoidable.
2. Receivers have an appropriate RF front-end and AGC algorithm to defend against interference.
3. Transmit out-of-band (OOB) noise levels are more stringent than the minimum required by the relevant standard or specification.
4. Antenna isolation is 10 dB.

Additional assumptions are detailed in the following sections.

The underlying system architecture plays a very important role in achieving system performance with collocated interferers. Section 5 provides a reference radio architecture used for the analysis presented in this white paper. As all implementations are different, it is not the intention of the authors of this white paper to claim that all radio implementations will perform the same as the reference system.

2.1 RECEIVER DESENSITZATION

The following levels of desensitization were used for each system:

Table 1 – Desense Levels

Receiver	Desense Level	Comment
***Bluetooth* technology**	3 dB	-87 dBm at IC, -85 dBm at Antenna
	10 dB	-80 dBm at IC, -78 dBm at Antenna
	20 dB	-70 dBm at IC, -68 dBm at Antenna (specification limit)
LTE	3 dB	
WiMAX	3 dB	
	6 dB	

The desense levels of LTE and WiMAX radios used in this white paper (i.e., 3 dB or 6 dB) are based on projected sensitivity margins between real-world implementations and corresponding specification requirements. We note that the acceptable desense level of the MWS system is a decision of the network provider. It is not the intention of this white paper to recommend any desense level for the MWS system. For the LTE analysis, three different *Bluetooth* desense levels (3 dB, 10 dB, 20 dB) are used in combination with an LTE desense level of 3 dB. For the WiMAX analysis, the *Bluetooth* 3 dB desense level is used in combination with a WiMAX desense level of 3 dB, while *Bluetooth* 10 dB and 20 dB desense levels are used with a 6 dB WiMAX desense level.

2.2 TRANSMIT EMISSIONS

The transmit out-of-band emission levels assumed in this white paper are more stringent than those allowed by the corresponding standard or specification. These values were taken based on performance of typical devices beating specification limits by margins of 10 to 20 dB.

Transmit noise at a specified frequency offset is taken to be the sum of the Gaussian noise and modulation distortion/noise. Gaussian noise is dominated by the transmit line-up, whereas modulation distortion/noise is generated by non-linearities principally in the RF PA. For *Bluetooth* technology, the limit is set by Gaussian noise, for LTE or WiMAX, the limit is set by either or both of them, depending on the uplink output power and modulation bandwidth configuration (e.g. a wider bandwidth or more power, generates a larger contribution from modulation distortion).

Table 2 – Transmit Out-Of-Band Emission Levels

Transmitter	Assumed Limit	Specification Limit
***Bluetooth* technology**	Transmit out-of-band emission of -55 dBm/MHz assumed 20 MHz away from transmitted channel	The *Bluetooth* specification limit is -40 dBm/MHz.
LTE	Transmit out-of-band emission of -50 dBm/MHz assumed 20 MHz away from the edge of the transmitted channel	LTE specification limit is -30 dBm/MHz
WiMAX	Transmit out-of-band emission of -50 dBm/MHz assumed 20 MHz away from the edge of the transmitted channel	WiMAX specification limit is -37 dBm/MHz -30 dBm/MHz for ETSI and -41 dBm/MHz for FCC

This white paper does not make any assumptions on the emission levels outside of the ISM and MWS bands.

It is assumed that there is a 20 MHz frequency guard band between the lowest or highest *Bluetooth* center frequency (2402 and 2480 MHz respectively) and the edge of the MWS signals. The importance of a frequency guard band is described in Section 3 and is the basis for any filtering solution.

2.3 TRANSMIT POWER, PEP, AND PAR

The following assumptions are made for the average transmitter power level, Peak to average Ratio (PAR), and Peak Envelope Power (PEP) for each system:

Table 3 – Transmit Power Levels

Transmitter	Average Power	PAR	PEP
***Bluetooth* technology** (note 1)	7 dBm	0 dB	7 dBm
LTE (note 2)	25 dBm	6 dB	31 dBm
WiMAX	23 dBm	10 dB	33 dBm

Note 1: GFSK is assumed. For π/4 DQPSK (2 Mbps) & 8DPSK (3 Mbps), the PEP is modeled the same as GFSK.

Note 2: SC-OFDM

It should be noted that the *Bluetooth* specification allows transmit power of up to +20 dBm though in some regulatory regimes the π/4DQPSK and 8DPSK are limited to approximately +10 dBm.

GFSK is assumed throughout the whitepaper, although *Bluetooth* technology also supports π/4-DQPSK and 8DPSK which may have higher out of band emissions than GFSK 20 MHz from center frequency.

The *Bluetooth* Core Specification also enables high speed data over an 802.11 physical channel. This physical layer will typically have higher power and wider spectral mask than was used for the coexistence analysis.

3. Frequency Guard Band

As the scope of this white paper is coexistence between MWS systems and *Bluetooth* wireless technology when collocated in the same product, it is assumed that a frequency guard band between the frequency bands used by the respective technology is available. As will be shown in Section 4 and based on information from the filter manufacturers shown in Appendix B: Available Filter Performance, a reasonable bandwidth of such a guard band is 20 MHz. At the upper end of the ISM band such a guard band is available[1], whereas at the lower end of the ISM band it is not.

In principle, for the purpose of coexistence, a 20 MHz guard band can be located anywhere between 2380 MHz and 2420 MHz. The guard band can be located entirely within the MWS band, entirely in the ISM band, or anywhere in between. However, taking into account backward compatibility with the more than two billion devices using *Bluetooth* wireless technology and the fact that the frequency range 2380-2400 MHz will be severely compromised when WLAN is using Channel 1 (centered at 2412 MHz), this whitepaper assumes that the guard band is located at 2380-2400 MHz.

When the MWS system is not collocated with *Bluetooth* wireless technology or any other technology using the ISM band, the need for a guard band depends among other things on the distance between the transmitters and the service that needs to be supported. How to deal with these non-collocated situations is not within the scope of this white paper.

[1] Note that some WiMAX deployments start at 2496 MHz which reduces the guard band to 16 MHz

4. Filter Masks

The filter masks presented in this section are intended to be worst case from the perspective of process, temperature and the assumptions in Section 2. Droop in the ISM passband is shown to facilitate filter development.

4.1 LTE FDD FILTER MASKS

4.1.1 *BLUETOOTH* FILTER MASKS FOR LTE B7

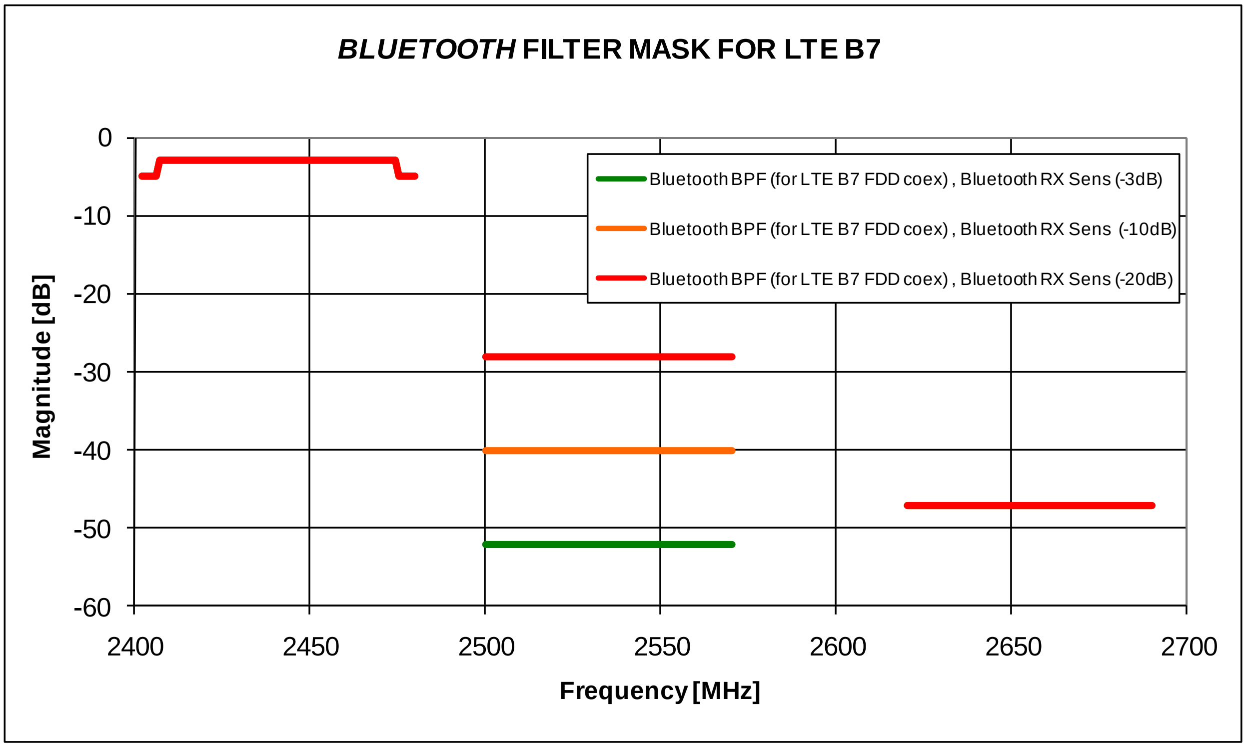

Table 4 – *Bluetooth* Filter Mask for LTE B7

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2402-2405		5		5		5
	2405-2475		3		3		3
	2475-2480		5		5		5
Absolute Attenuation (dB)	2500-2570	52		40		28	
	2620-2690	47		47		47	

Three different LTE transmit level attenuations are presented. These correspond to the three levels of *Bluetooth* desensitization. The filter response curves converge at the LTE receive band frequencies (2620→2690 MHz) as the LTE desensitization is set to be less than 3 dB. The attenuation is set by the need to attenuate *Bluetooth* transmit noise (-55 dBm/MHz) to below the LTE Rx noise floor.

4.1.2 LTE B7 FILTER MASKS FOR *BLUETOOTH* COEXISTENCE

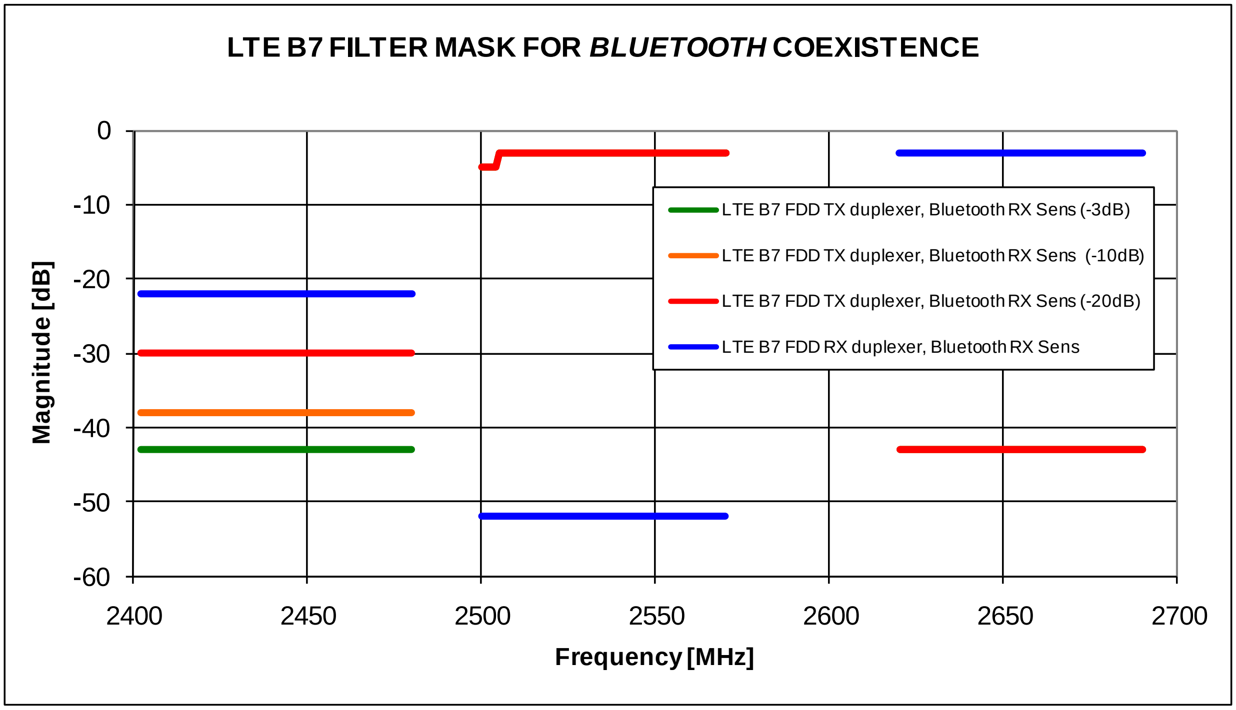

Table 5 –LTE B7 Transmit Filter Masks

Specification	**Frequency Range (MHz)**	**3 dB Desense**		**10 dB Desense**		**20 dB Desense**	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2500-2570		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	43		38		30	

Table 6 –LTE B7 Receive Filter Masks

Specification	**Frequency Range (MHz)**	**3 dB Desense**		**10 dB Desense**		**20 dB Desense**	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2620-2690		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	22		22		22	
	2500-2570	52		52		52	

Three levels of transmit duplex filter attenuation are defined. These correspond to the levels of desensitization defined for the *Bluetooth* receiver. The relaxation is necessary because as the *Bluetooth* receiver front end gain is reduced in response to the blocking signal. It is important to have this level of flexibility to permit a solution from a wide range of duplexer technologies. The receiver attenuation in the *Bluetooth* band (2402→2480 MHz) is set by the LTE receiver compression point and *Bluetooth* PEP. Given the need to protect the LTE receiver against the LTE transmit signal, this part of the specification should be easy to meet. The difficult part of the specification is the transmit duplexer response (Table 5).

4.1.3 NOISE BREAKDOWN

The noise breakdown for each case is shown below.

3dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-103.0dBm/MHz	NF rise=0.0dB
Bluetooth Noise due to transmit noise	-104.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-112.0dBm/MHz	IP2=27.0dBm
Bluetooth Noise due to Reciprocal Mixing	-114.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-100.0dBm/MHz	degradation=3.0dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB

10dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-97.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-103.0dBm/MHz	IP2=42.0dBm
Bluetooth Noise due to Reciprocal Mixing	-102.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-93.0dBm/MHz	degradation=10.0dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB

20dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-86.5dBm/MHz	NF rise=16.5dB
Bluetooth Noise due to transmit noise	-90.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-92.0dBm/MHz	IP2=55.0dBm
Bluetooth Noise due to Reciprocal Mixing	-90.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-83.1dBm/MHz	degradation=19.9dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB

3 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-103.0dBm/MHz	NF rise=0.0dB
Bluetooth Noise due to transmit noise	-104.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-112.0dBm/MHz	IP2=27.0dBm
Bluetooth Noise due to Reciprocal Mixing	-114.0dBm/MHz	-137.0dBc/Hz

Noise Sum	-100.0dBm/MHz	degradation=3.0dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB
10 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-97.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-103.0dBm/MHz	IP2=42.0dBm
Bluetooth Noise due to Reciprocal Mixing	-102.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-93.0dBm/MHz	degradation=10.0dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB
20 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-86.5dBm/MHz	NF rise=16.5dB
Bluetooth Noise due to transmit noise	-90.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-92.0dBm/MHz	IP2=55.0dBm
Bluetooth Noise due to Reciprocal Mixing	-90.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-83.1dBm/MHz	degradation=19.9dB
LTE Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE Noise due to transmit noise	-105.0dBm/5MHz	-50dBm/MHz
LTE Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=47.0dBm
LTE Noise due to Reciprocal Mixing	-103.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.8dBm/5MHz	degradation=3.2dB

4.2 LTE TDD FILTER MASKS

4.2.1 *BLUETOOTH* FILTER MASKS FOR LTE RB40

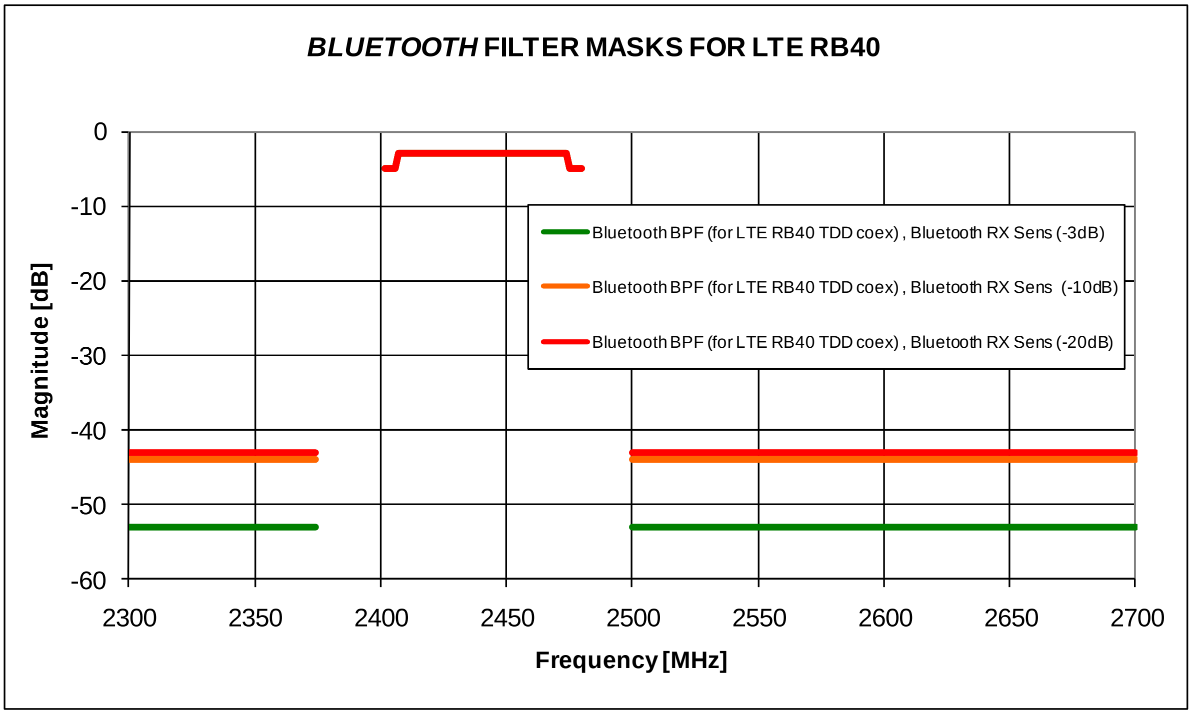

Table 7 – *Bluetooth* Filter Mask for LTE RB40

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2402-2405		3		3		3
	2405-2475		3		3		3
	2475-2480		5		5		5
Absolute Attenuation (dB)	2500-2570	53		44		43	

The *Bluetooth* band filter attenuation mask for LTE TDD mode has a much more aggressive response than the FDD mode shown previously. Furthermore, the relaxations that allow a 20 dB desense in the *Bluetooth* receiver are not permitted due to the need to attenuate the *Bluetooth* transmit noise in the LTE TDD receive channels.

4.2.2 LTE RB40 FILTER MASKS FOR *BLUETOOTH* COEXISTENCE

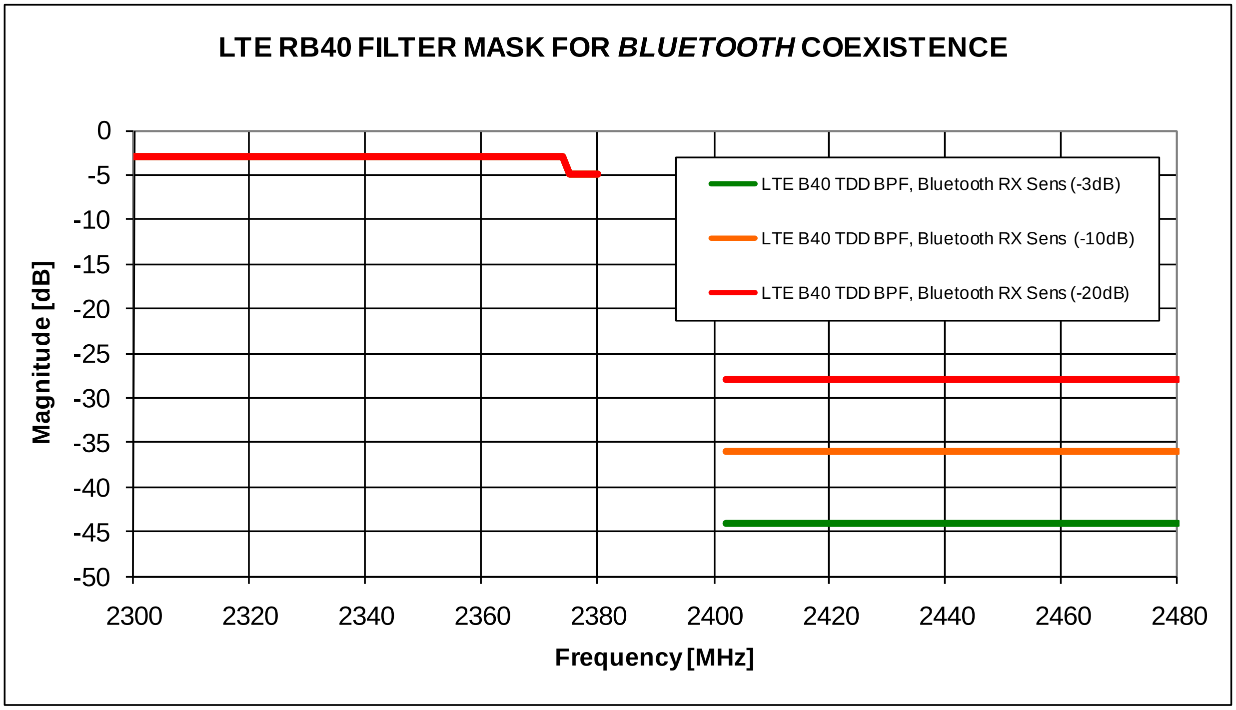

Table 8 –LTE RB40 Filter Masks

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2300-2380		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	44		36		28	

Three levels of receiver desensitization are shown here, corresponding to the three *Bluetooth* sensitivity levels. The 20 dB degradation level does not have a corresponding mask in the *Bluetooth* filter graphs due to *Bluetooth* transmit noise. This means that if possible, the 10 dB degradation limit should be the worse case the system/filter designers should strive to achieve. Failure to do so would result in the *Bluetooth* receiver that is desensitized by 20 dB due to the LTE TDD transmit noise alone.

4.2.3 NOISE BREAKDOWN

The noise breakdown for each case is shown below.

3 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-103.0dBm/MHz	NF rise=0.0dB
Bluetooth Noise due to transmit noise	-104.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-111.0dBm/MHz	IP2=22.0dBm
Bluetooth Noise due to Reciprocal Mixing	-116.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-100.0dBm/MHz	degradation=3.0dB
LTE TDD Noise due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE TDD Noise due to transmit noise	-112.0dBm/5MHz	-50dBm/MHz
LTE TDD Noise due to IP2 distortion	-109.7dBm/5MHz	IP2=0.0dBm
LTE TDD Noise due to Reciprocal Mixing	-115.0dBm/5MHz	-135.0dBc/Hz
Noise Sum	-100.0dBm/5MHz	degradation=1.0dB

10 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-96.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-104.0dBm/MHz	IP2=35.0dBm
Bluetooth Noise due to Reciprocal Mixing	-106.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-93.0dBm/MHz	degradation=10.0dB
LTE TDD Noise Floor due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE TDD Noise Floor due to transmit noise	-102.0dBm/5MHz	-50dBm/MHz
LTE TDD Noise due to IP2 distortion	-113.7dBm/5MHz	IP2=20.0dBm
LTE TDD Noise due to Reciprocal Mixing	-109.0dBm/5MHz	-137.0dBc/Hz
Noise Sum	-98.0dBm/5MHz	degradation=3.0dB

20 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-88.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-99.0dBm/MHz	IP2=30.0dBm
Bluetooth Noise due to Reciprocal Mixing	-106.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-87.1dBm/MHz	degradation=15.9dB
LTE TDD Noise Floor due to AGC stealing	-101.0dBm/5MHz	NF rise=0.0dB
LTE TDD Noise Floor due to transmit noise	-102.0dBm/5MHz	-50dBm/MHz
LTE TDD Noise due to IP2 distortion	-112.7dBm/5MHz	IP2=35.0dBm
LTE TDD Noise due to Reciprocal Mixing	-109.0dBm/5MHz	-145.0dBc/Hz
Noise Sum	-97.9dBm/5MHz	degradation=3.1dB

4.3 WIMAX FDD / *BLUETOOTH* FILTER MASKS

4.3.1 *BLUETOOTH* FILTER MASKS FOR WIMAX BAND CLASS 3

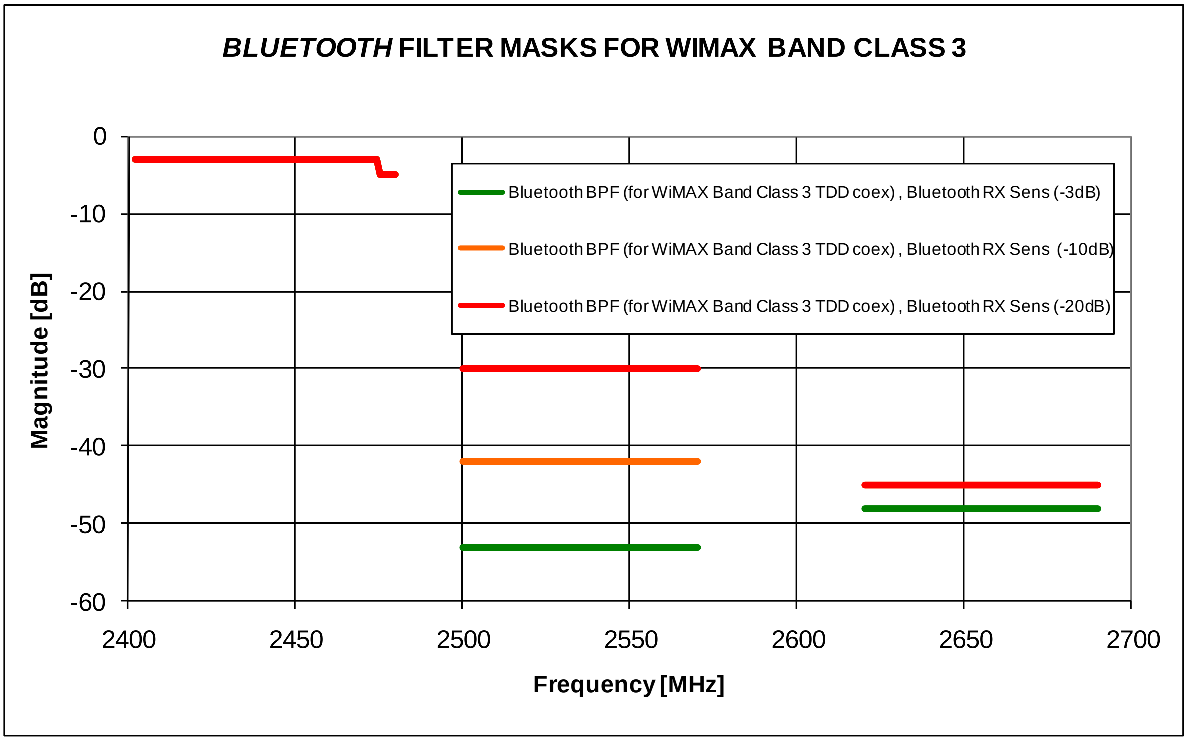

Table 9 – *Bluetooth* Filter Mask for WiMAX Band Class 3

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2402-2405		3		3		3
	2405-2475		3		3		3
	2475-2480		5		5		5
Absolute Attenuation (dB)	2500-2570	53		42		30	
	2620-2690	48		45		45	

The WiMAX FDD filter attenuation specifications are 2 dB more stringent than the corresponding LTE FDD filter because of the higher PAR of the WiMAX transmission. The attenuation at 2620→2690 MHz is relaxed for the higher *Bluetooth* desense cases due to the 6 dB WiMAX desense allowance

4.3.2 WIMAX BAND CLASS 3 FDD FILTER MASK FOR *BLUETOOTH* COEXISTENCE

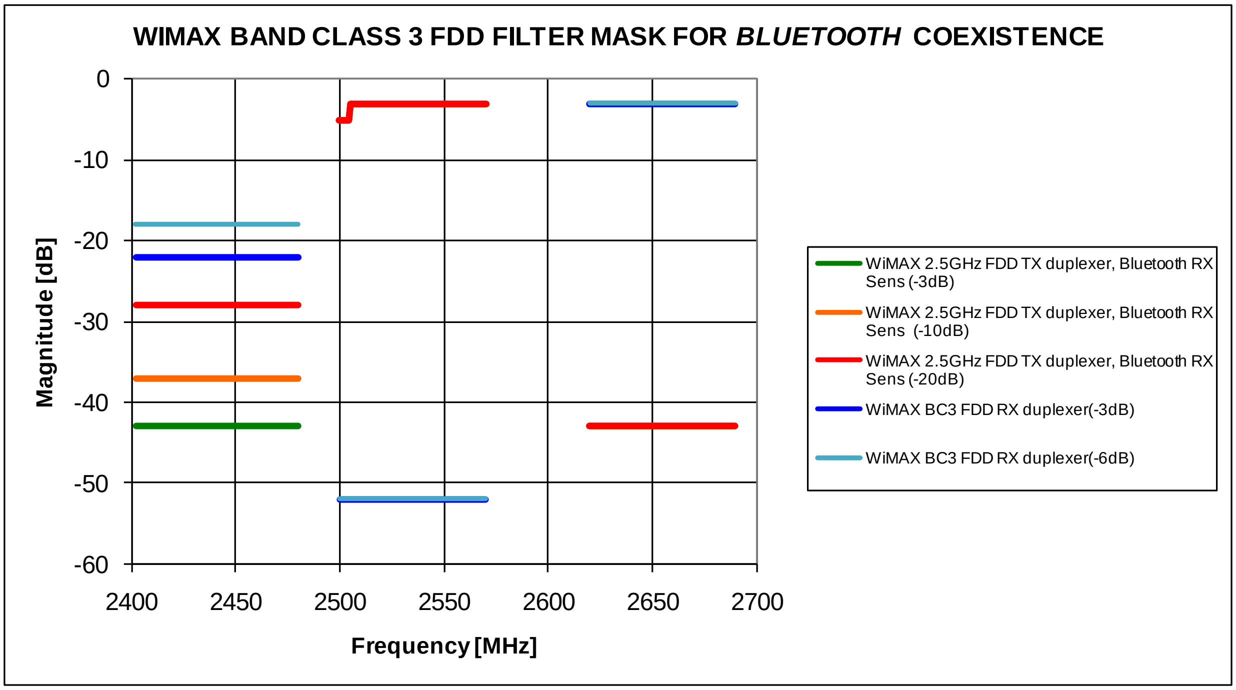

Table 10 – WiMAX Band Class 3 Tx Filter Masks

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2500-2570		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	43		37		28	

Table 11 – WiMAX Band Class 3 Rx Filter Masks

Specification	Frequency Range (MHz)	3 dB Desense		6 dB Desense	
		Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2620-2690		N/A		N/A
Absolute Attenuation (dB)	2400-2480	22		18	
	2500-2570	52		52	

The WiMAX transmit duplexer attenuations in the *Bluetooth* band are 2 dB lower for the 20 dB desense and 1 dB lower for the 10 dB desense compared with the LTE duplexer. This may be a surprising result given the higher PEP of the WiMAX signal. The reason the attenuations are lower is that the *Bluetooth* filter specification is driven by PEP, which is 2 dB higher for WiMAX than for LTE, so the average power in the *Bluetooth* front end is actually 1 to 2 dB less than for the LTE case. This means that reciprocal mixing and IP2 generated noise is lower (assuming similar receiver characteristics for WiMAX and LTE). There is more “room” for the transmit noise from WiMAX in the overall budget, hence the slight specification relaxation.

4.3.3 NOISE BREAKDOWN

The noise breakdown for each case is shown below.

3 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-103.0dBm/MHz	NF rise=0.0dB
Bluetooth Noise due to transmit noise	-104.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-110.6dBm/MHz	IP2=20.0dBm
Bluetooth Noise due to Reciprocal Mixing	-118.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-100.0dBm/MHz	degradation=3.0dB
WiMAX Noise due to AGC stealing	-98.0dBm/10MHz	NF rise=0.0dB
WiMAX Noise due to transmit noise	-103.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-112.7dBm/10MHz	IP2=47.0dBm
WiMAX Noise due to Reciprocal Mixing	-100.0dBm/10MHz	-145.0dBc/Hz
Noise Sum	-95.0dBm/10MHz	degradation=3.0dB
10 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-96.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-104.6dBm/MHz	IP2=38.0dBm
Bluetooth Noise due to Reciprocal Mixing	-106.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-93.0dBm/MHz	degradation=10.0dB
WiMAX Noise due to AGC stealing	-96.0dBm/10MHz	NF rise=2.0dB
WiMAX Noise due to transmit noise	-100.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-104.7dBm/10MHz	IP2=47.0dBm
WiMAX Noise due to Reciprocal Mixing	-96.0dBm/10MHz	-145.0dBc/Hz
Noise Sum	-91.9dBm/10MHz	degradation=6.1dB
20 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-86.5dBm/MHz	NF rise=16.5dB
Bluetooth Noise due to transmit noise	-88.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-92.6dBm/MHz	IP2=50.0dBm
Bluetooth Noise due to Reciprocal Mixing	-94.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-83.2dBm/MHz	degradation=19.8dB
WiMAX Noise due to AGC stealing	-96.0dBm/10MHz	NF rise=2.0dB
WiMAX Noise due to transmit noise	-100.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-104.7dBm/10MHz	IP2=47.0dBm
WiMAX Noise due to Reciprocal Mixing	-96.0dBm/10MHz	-145.0dBc/Hz
Noise Sum	-91.9dBm/10MHz	degradation=6.1dB

4.4 WIMAX TDD / *BLUETOOTH* FILTER MASKS

4.4.1 *BLUETOOTH* FILTER MASKS FOR WIMAX TDD BAND CLASS 1 AND 3

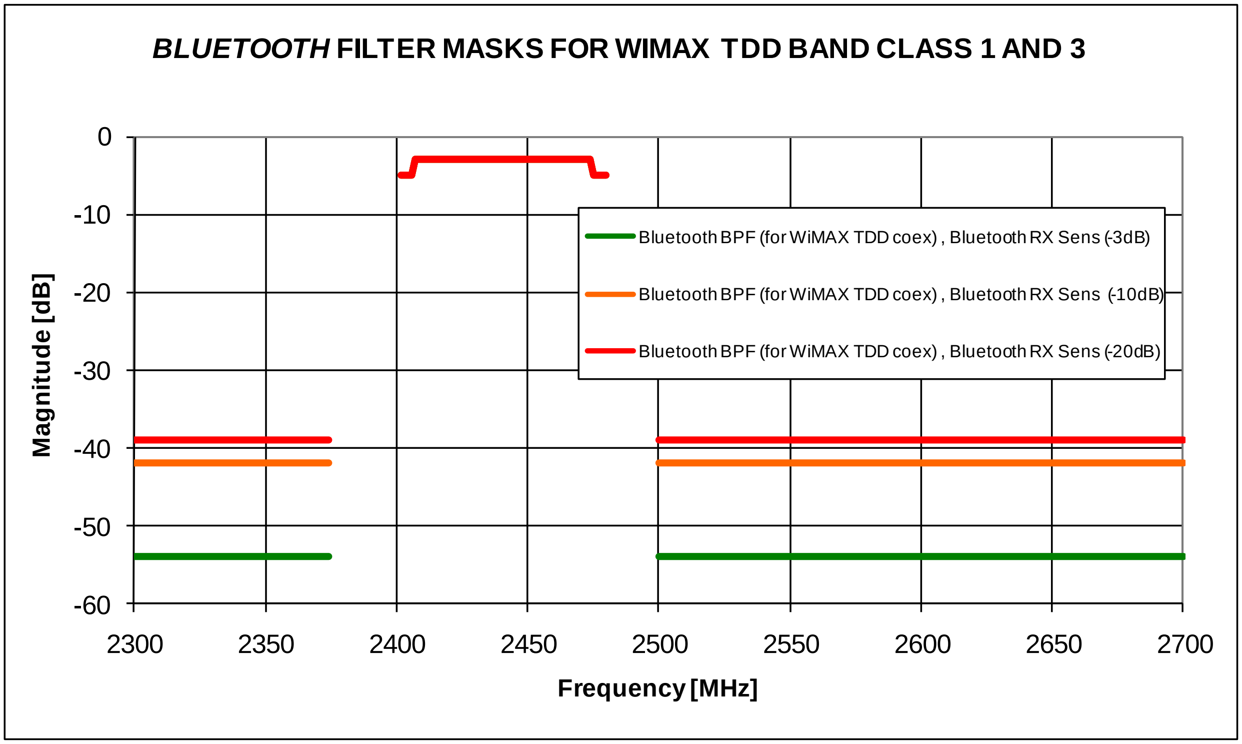

Table 12 – *Bluetooth* Filter Mask for WiMAX TDD Band Class 1 and 3

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2402-2405		5		5		5
	2405-2475		3		3		3
	2475-2480		5		5		5
Absolute Attenuation (dB)	2300-2380	54		42		39	
	2500-2690	54		42		39	

The ISM band filter attenuation mask for WIMAX TDD mode has a much more aggressive response than the FDD mode shown previously. Furthermore, the relaxations that allow a 20dB desense in the *Bluetooth* receiver are not as drastic due to the need to attenuate the *Bluetooth* transmit noise in the WIMAX TDD receive channels. Note that the attenuations are shown above and below the ISM band, but in practice, it is expected that WIMAX TDD will only be deployed in one of the bands in any given geographic area.

4.4.2 WIMAX TDD BAND CLASS 1 TDD FILTER FOR *BLUETOOTH* COEXISTENCE

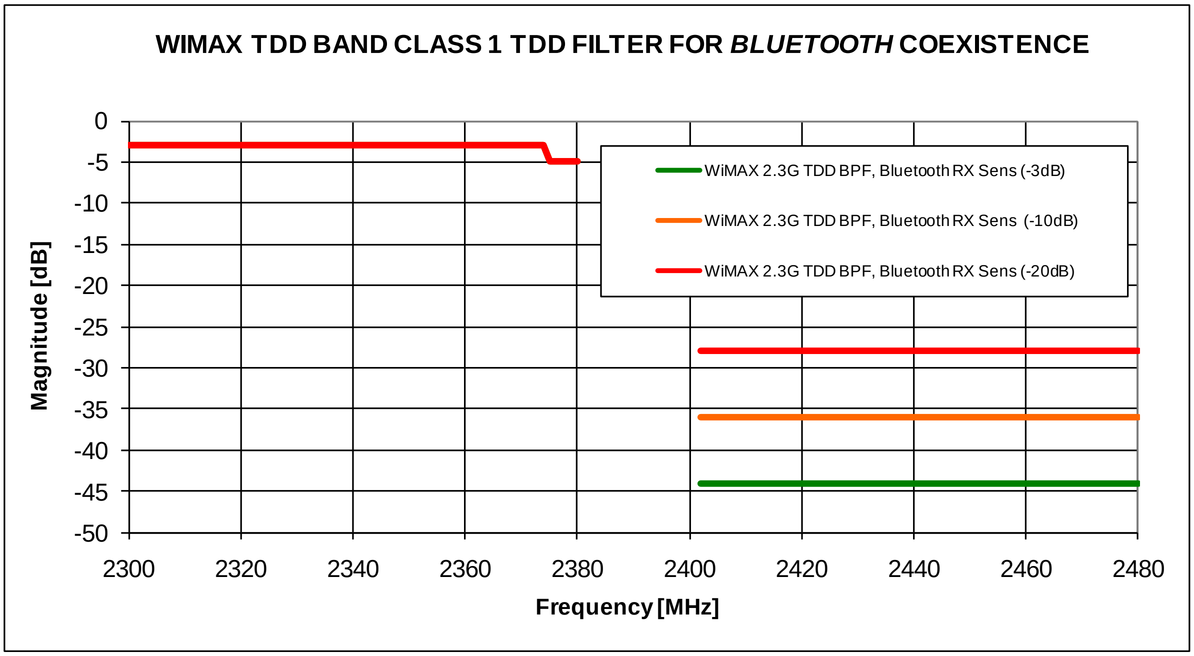

Table 13 – WiMAX TDD Band Class 1 Filter Masks

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2300-2380		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	44		36		-28	

4.4.3 WIMAX TDD BAND CLASS 3 TDD FILTER FOR *BLUETOOTH* COEXISTENCE

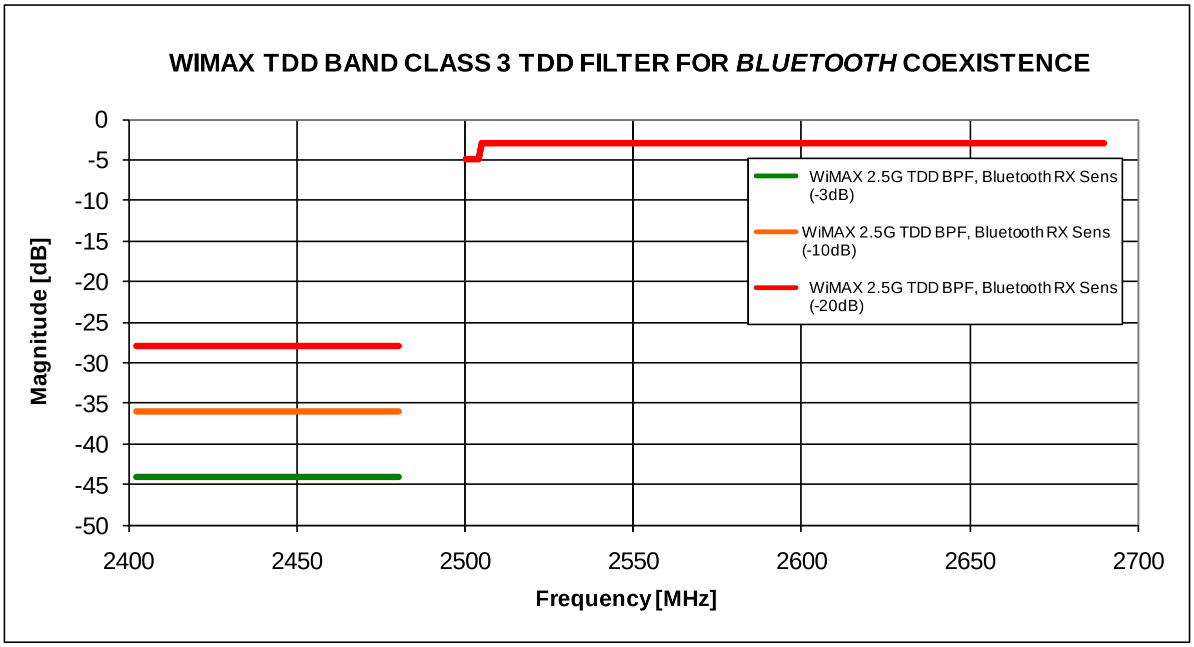

Table 14 – WiMAX TDD Band Class 3 Filter Masks

Specification	Frequency Range (MHz)	3 dB Desense		10 dB Desense		20 dB Desense	
		Min	Max	Min	Max	Min	Max
Pass Band Insertion Loss (dB)	2500-2690		N/A		N/A		N/A
Absolute Attenuation (dB)	2400-2480	44		36		28	

Three levels of desensitization are shown here, corresponding to the three *Bluetooth* sensitivity levels.

4.4.4 NOISE BREAKDOWN

The noise breakdown for each case is shown below.

3 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-103.0dBm/MHz	NF rise=0.0dB
Bluetooth Noise due to transmit noise	-104.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-110.6dBm/MHz	IP2=20.0dBm
Bluetooth Noise due to Reciprocal Mixing	-118.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-100.0dBm/MHz	degradation=3.0dB
WiMAX Noise due to AGC stealing	-98.0dBm/10MHz	NF rise=0.0dB
WiMAX Noise due to transmit noise	-109.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-109.7dBm/10MHz	IP2=0.0dBm
WiMAX Noise due to Reciprocal Mixing	-112.0dBm/10MHz	-135.0dBc/Hz
Noise Sum	-97.3dBm/10MHz	degradation=0.7dB

10 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-97.2dBm/MHz	NF rise=5.8dB
Bluetooth Noise due to transmit noise	-96.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-104.6dBm/MHz	IP2=38.0dBm
Bluetooth Noise due to Reciprocal Mixing	-106.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-93.0dBm/MHz	degradation=10.0dB
WiMAX Noise due to AGC stealing	-98.0dBm/10MHz	NF rise=0.0dB
WiMAX Noise due to transmit noise	-97.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-118.7dBm/10MHz	IP2=25.0dBm
WiMAX Noise due to Reciprocal Mixing	-104.0dBm/10MHz	-135.0dBc/Hz
Noise Sum	-94.0dBm/10MHz	degradation=4.0dB

20 dB desense Spec	**Noise Breakdown**	**Spec Requirement**
Bluetooth Noise due to AGC stealing	-92.5dBm/MHz	NF rise=10.5dB
Bluetooth Noise due to transmit noise	-88.0dBm/MHz	-55dBm/MHz
Bluetooth Noise due to IP2 distortion	-90.6dBm/MHz	IP2=30.0dBm
Bluetooth Noise due to Reciprocal Mixing	-103.0dBm/MHz	-137.0dBc/Hz
Noise Sum	-85.1dBm/MHz	degradation=17.9dB
WiMAX Noise due to AGC stealing	-98.0dBm/10MHz	NF rise=0.0dB
WiMAX Noise due to transmit noise	-94.0dBm/10MHz	-50dBm/MHz
WiMAX Noise due to IP2 distortion	-102.7dBm/10MHz	IP2=25.0dBm
WiMAX Noise due to Reciprocal Mixing	-106.0dBm/10MHz	-145.0dBc/Hz
Noise Sum	-92.0dBm/10MHz	degradation=6.0dB

4.5 SUMMARY OF TRANSCEIVER SPECIFICATIONS

4.5.1 LTE FDD & TDD AND *BLUETOOTH* TECHNOLOGY

LTE FDD/*Bluetooth* Transceiver (-3dB) Requirements		**ETSI spec**
Bluetooth IP2 Requirement	27.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE Phase Noise Requirement	-145.0dBc/Hz	
LTE Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE Rx	IP2=47.0dBm	
LTE FDD/*Bluetooth* Transceiver (-10dB) Requirements		
Bluetooth IP2 Requirement	42.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE Phase Noise Requirement	-145.0dBc/Hz	
LTE Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE Rx	IP2=47.0dBm	
LTE FDD/*Bluetooth* Transceiver (-20dB) Requirements		
Bluetooth IP2 Requirement	55.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE Phase Noise Requirement	-145.0dBc/Hz	
LTE Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE Rx	IP2=47.0dBm	
LTE TDD/*Bluetooth* Transceiver (-3dB) Requirements		
Bluetooth IP2 Requirement	22.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE TDD Phase Noise Requirement	-135.0dBc/Hz	
LTE TDD Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE TDD Rx	IP2=0.0dBm	
LTE TDD/*Bluetooth* Transceiver (-10dB) Requirements		
Bluetooth IP2 Requirement	35.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE TDD Phase Noise Requirement	-137.0dBc/Hz	
LTE TDD Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE TDD Rx	IP2=20.0dBm	
LTE TDD/*Bluetooth* Transceiver (-20dB) Requirements		
Bluetooth IP2 Requirement	30.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
LTE TDD Phase Noise Requirement	-145.0dBc/Hz	
LTE TDD Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
LTE TDD Rx	IP2=35.0dBm	

4.5.2 WIMAX FDD & TDD AND *BLUETOOTH* TECHNOLOGY

WiMAX FDD/*Bluetooth* Transceiver (-3dB) Requirements		**ETSI spec**
Bluetooth IP2 Requirement	20.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-145.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=47.0dBm	
WiMAX FDD/*Bluetooth* Transceiver (-10dB) Requirements		
Bluetooth IP2 Requirement	38.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-145.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=47.0dBm	
WiMAX FDD/*Bluetooth* Transceiver (-20dB) Requirements		
Bluetooth IP2 Requirement	50.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-145.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=47.0dBm	
WiMAX TDD/*Bluetooth* Transceiver (-3dB) Requirements		
Bluetooth IP2 Requirement	20.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-135.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=0.0dBm	
WiMAX TDD/*Bluetooth* Transceiver (-10dB) Requirements		
Bluetooth IP2 Requirement	38.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-135.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=25.0dBm	
WiMAX TDD/*Bluetooth* Transceiver (-20dB) Requirements		
Bluetooth IP2 Requirement	30.0dBm	
Bluetooth Phase Noise Requirement	-137.0dBc/Hz	
WiMAX Phase Noise Requirement	-145.0dBc/Hz	
WiMAX Tx noise (>20MHz ΔFTx)	-50dBm/MHz	-30dBm/MHz
Bluetooth Tx noise (>20MHz ΔFTx)	-55dBm/MHz	-40dBm/MHz
WiMAX Rx	IP2=25.0dBm	

5. Appendix A: Reference System Model

The development of filter requirements is based on a representative system model. This appendix describes that model. Actual implementations may be different and so the filter requirements should be adjusted accordingly.

5.1 SYSTEM BLOCK DIAGRAM

MWS systems use a wide modulation bandwidth and the transceivers have stringent transmit/receive linearity and noise requirements, hence the use of interstage RF SAW filters and Cartesian modulation. The *Bluetooth* transceiver does not need an interstage filter because of the relaxed specifications and uses an internal Tx/Rx switch to facilitate TDD operation.

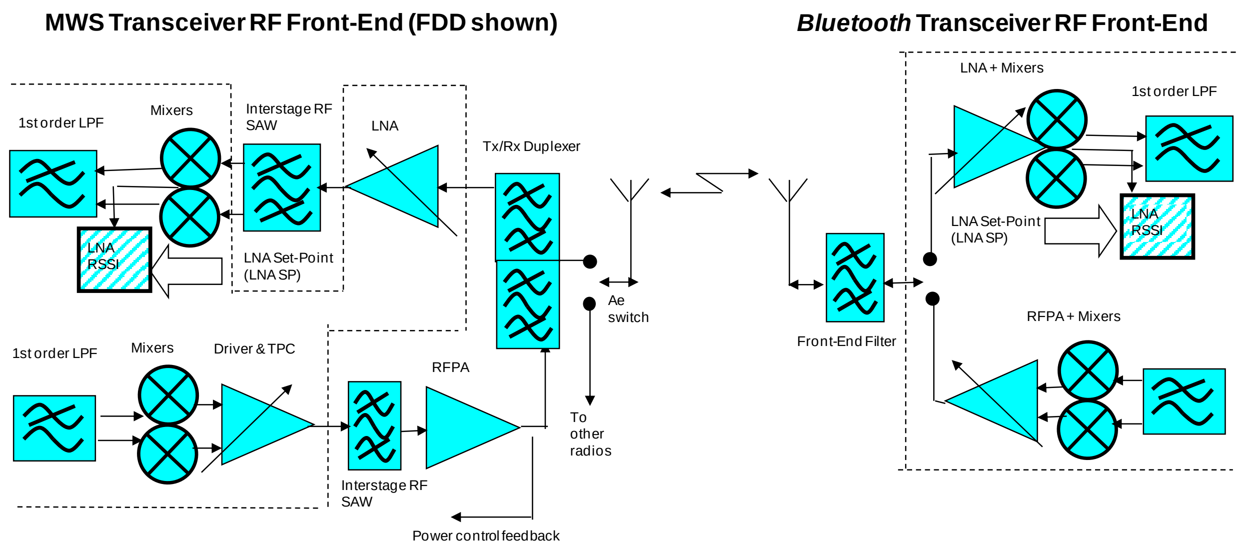

Figure 2 – Example System Block Diagrams

5.2 RECEIVER BLOCKING PERFORMANCE

For frequency offsets greater than 20 MHz from the edge of the received channel, receiver blocking should take place in the RF front end, with the mixer being the weak link. Each receiver has an appropriate RF front-end + Wideband RSSI + AGC algorithm to defend against interference. A block diagram of such a system is shown below:

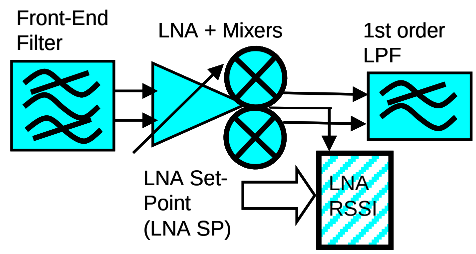

Figure 3 – Example RF Front-End + Wideband RSSI + AGC

The rest of the receiver has been omitted for clarity. The LNA/mixer RSSI (or saturation detector) indicates when the receiver front end is being overloaded by a strong blocking signal. The AGC algorithm reduces the receiver front end gain in response so as to prevent overload. The penalty for this is an increase in receiver noise figure, but this is better than allowing saturation to take place. A plot of receiver noise figure rise vs blocker level for a candidate *Bluetooth* receiver is shown below:

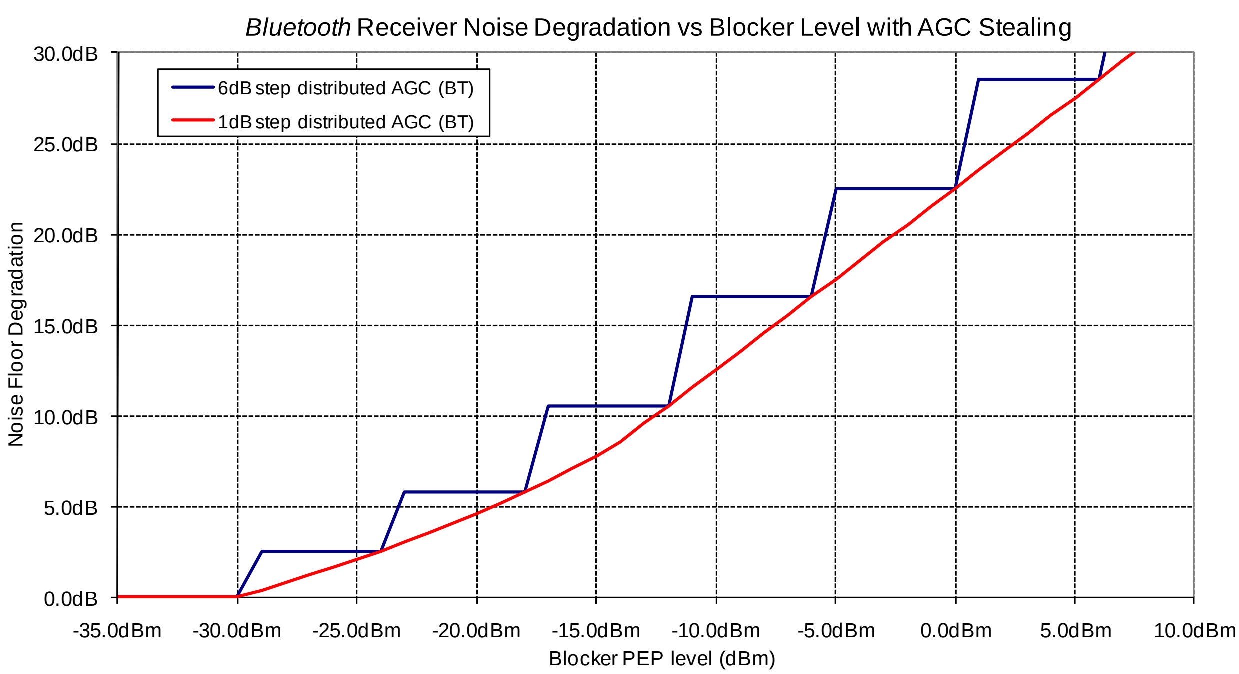

Figure 4 – *Bluetooth* Receiver Noise Degradation vs. Blocker Level With LNA AGC stealing

For the curve in Figure 4 to hold true:

1. Square law distortion due to IP2 is always below the receiver noise floor.
2. Reciprocal mixing from the receiver synthesizer is always below the receiver noise floor.

These two aspects are covered later and are shown to contribute to the overall coexistence performance. The specifications are set such that they are not the dominant source of disturbance however their combined effect needs to be accounted for.

In the curve in Figure 4, the onset of compression blocking is at -30 dBm PEP. For the MWS receivers, the assumed noise vs. gain characteristic is shown in Figure 5.

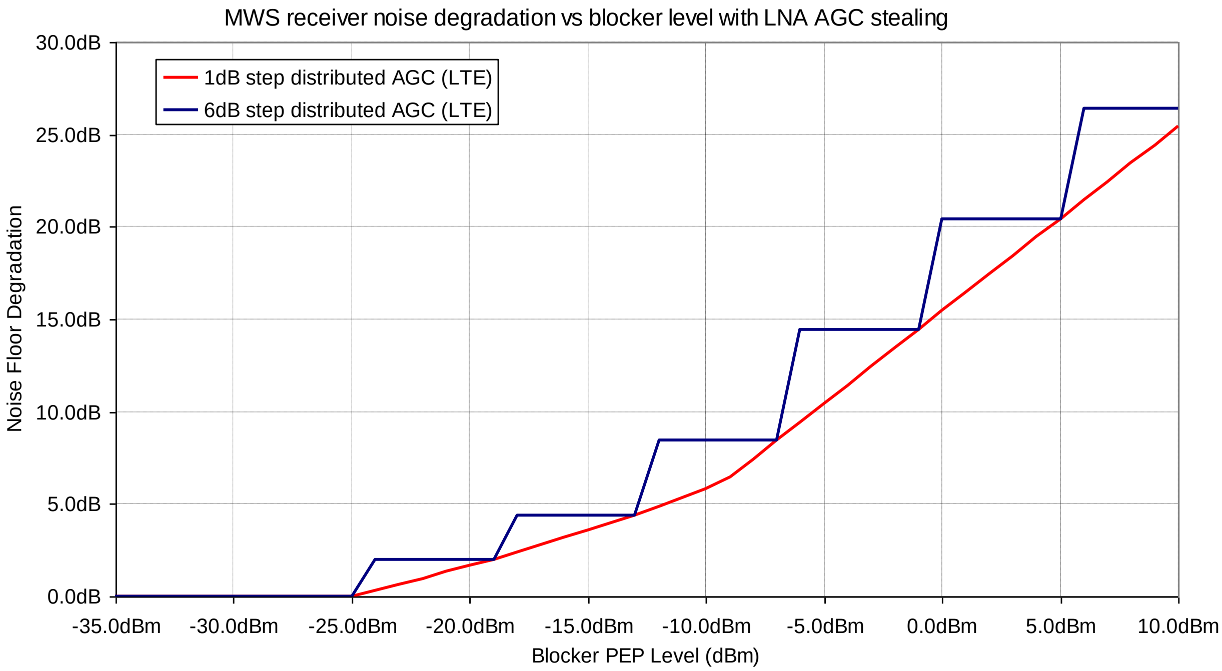

Figure 5 – MWS Receiver Noise Degradation vs. Blocker Level With LNA AGC Stealing

The onset of compression blocking is at -25 dBm PEP. For the LTE cases, no additional compression is allowed. For the WiMAX cases, a 6 dB desense case is analyzed which gives rise to one gain step being activated and a corresponding compression improvement of 6 dB for a 2 dB increase in noise figure. The other sources of noise, transmitter noise, receiver phase noise and receiver IP2 noise contribute to make up the 6 dB desense. For 3 dB desense cases, a gain step is prohibitive as it does not allow any room for other noise sources.

5.3 TDD VS FDD

Filtering requirements for FDD and TDD systems show significant differences. The filter requirements in TDD mode are considerably more aggressive since the MWS system transmits and receives on the same channel, whereas in FDD mode the channel duplex distance (120 MHz for band VII), pushes the MWS receive channels away from the *Bluetooth* band.

5.4 FILTER PASSBAND INSERTION LOSS

To facilitate as wide a range of solutions as possible, a relaxation in the passband insertion loss for each of the filters at the band edge is allowed. This will give the filter designer a wider transition frequency range between the passband and the stopband. An example is shown in Figure 6. Clearly, the filter designer should strive to achieve the minimum insertion loss over as much of the filter passband as possible.

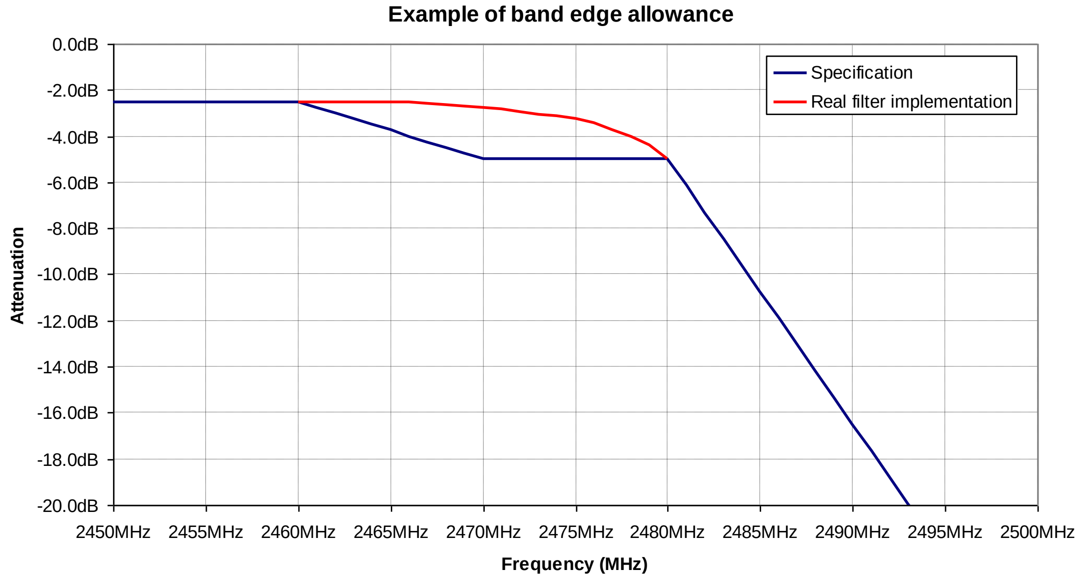

Figure 6 – Example of Band Edge Allowance

5.5 MAIN INTERFERENCE MECHANISMS

Two main interference mechanisms need to be addressed:

- Compression
- Noise floor rise

5.5.1 *BLUETOOTH* BPF RESPONSIBILITY

The functions of the *Bluetooth* bandpass filter are

- Prevent / reduce *Bluetooth* receiver compression
- Reduce *Bluetooth* technology out of band emissions (protecting MWS receiver)

As seen in above curves the *Bluetooth* receiver can withstand an input signal of about -30 dBm prior to compressing the LNA (or prior to reducing LNA gain). Reducing the MWS signal to this level must be achieved by the *Bluetooth* BPF alone. The *Bluetooth* BPF must also attenuate the *Bluetooth* out-of-band emissions in order not to raise the MWS noise floor.

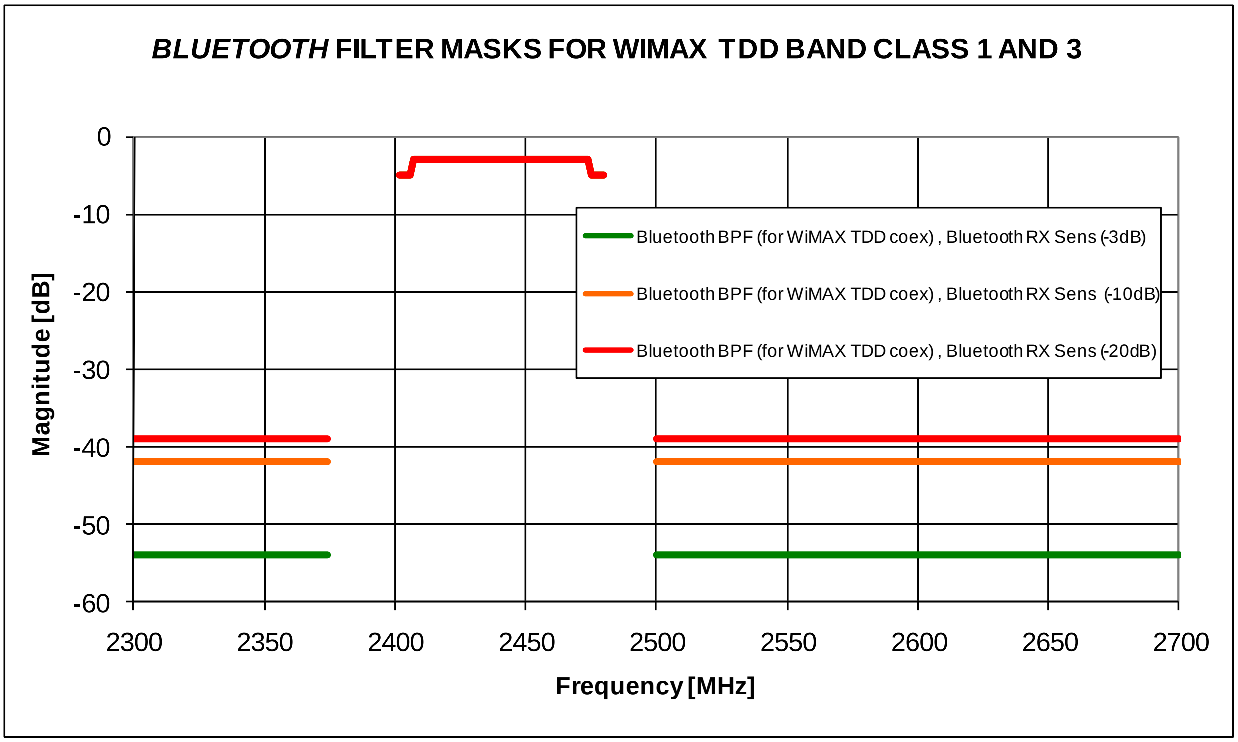

Figure 7 – Example of ISM Band Edge Allowance

Above 2500 MHz, MWS signal will be attenuated by *Bluetooth* BPF to reduce *Bluetooth* reception compression. To get MWS signal below -30dBm, ~40dB attenuation is needed (+23 dBm -10 dB – 40 dB = -27 dBm) Larger attenuation enables higher front end gain without compression.

Below 2380 MHz, in addition to reducing MWS signal strength at *Bluetooth* receiver input, *Bluetooth* out of band emissions need to be reduced to a level of about -105 dBm/MHz (or lower). To achieve this 40 dB attenuation is needed (-55 dBm/MHz -10 dB – 40 dB = -105 dBm/MHz).

5.5.2 MWS FILTER RESPONSIBILITY

The functions of the MWS filter are:

- Prevent / reduce MWS receiver compression
- Reduce MWS out of band emissions (protecting *Bluetooth* receiver)

MWS receivers can withstand an input signal of about -25 dBm before their LNA goes into compression. Lowering the *Bluetooth* transmit signal to this level must be done by MWS filter alone. The MWS filter must also attenuate the MWS out-of-band emissions in order to enable *Bluetooth* reception with additional in band noise. The maximal allowed MWS out-of-band emission in the *Bluetooth* band is at a level of -83 dBm/MHz. Any level higher than that will prevent the *Bluetooth* device from complying with specification sensitivity limits.

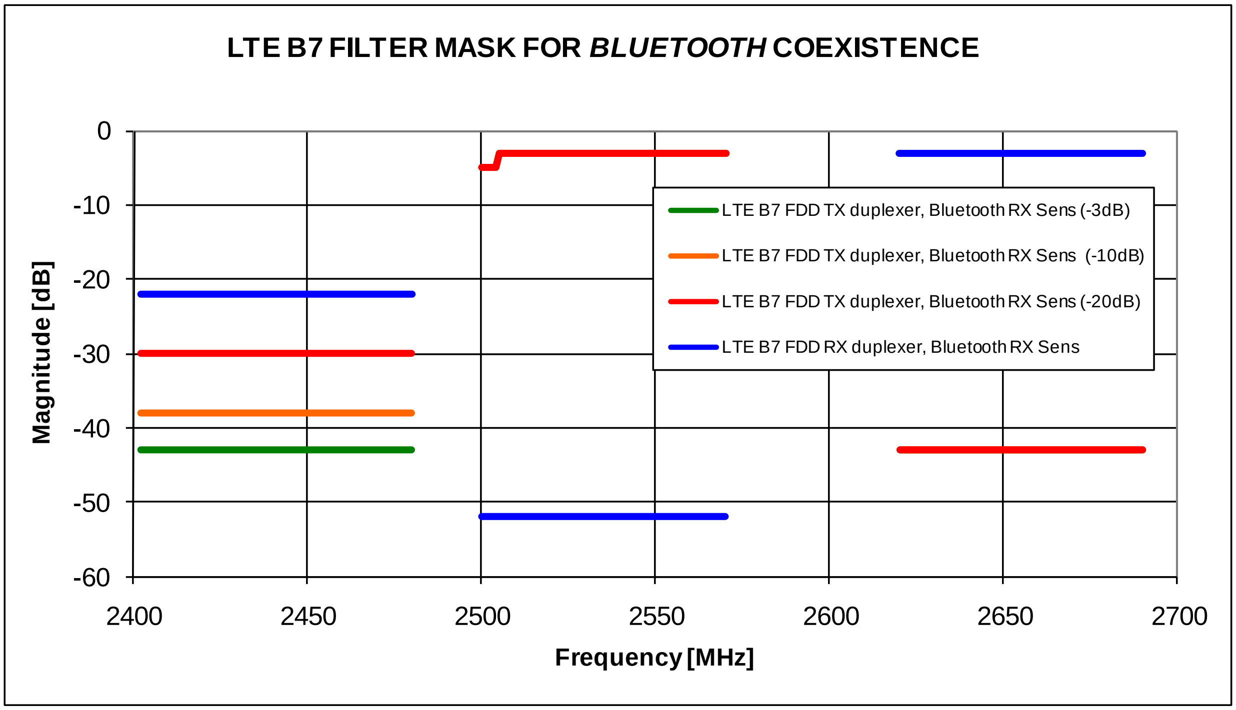

Figure 8 – Example of ISM Band Edge Allowance

The requirements shown by blue line (LTE B7 FDD RX duplexer line) are designed to protect the MWS receiver. To get *Bluetooth* transmit signal lower than -25 dBm, 22 dB attenuation is needed (+7 dBm -10 dB – 22 dB = -25 dBm).

The requirements shown by red line (LTE B7 FDD TX duplexer) are designed to reduce the MWS out of band emissions to a level lower than -80dBm/MHz. For this 33dB attenuation is needed (-50dBm/MHz -10dB – 30dB = -80dBm/MHz). MWS out of band emissions are the major contributor to *Bluetooth* performance degradation.

6. Appendix B: Available Filter Performance

This Appendix describes the performance of filters presented to the Bluetooth SIG's Filter Expert Group at the September 2009 face to face meeting. What follows is a snapshot of specific filter capabilities at a specific time; performance can be expected to change over time achieving better performance as technology advances. Filters from other sources are available but are not discussed here.

Disclaimers:

- Filter manufacturing and temperature tolerances are examples only and do not reflect actual performance of any of the presented filters.
- Results are for room temperature only. Variations over temperature and production need to be examined for each filter with its vendor. This whitepaper assumes production tolerances of 1000 ppm and a negative frequency slope of -40 ppm/°C.
- All assumptions for transmit power, emissions and sensitivity degradation due to noise and compression taken in Section 2 apply.
- Filter responses were based on measured prototypes and simulation

6.1 PRODUCTION TOLERANCE

A filter cut off frequency can shift by ±1000 ppm of its target location due to production tolerances and can be calculated as follows:

Frequency_offset_due_to_production_tolerance = (Production_tolerance_PPM*Cutoff_frequency)/1000000

Therefore, a cutoff frequency of 2480 MHz can shift by (1000*2480 MHz)/1000000=~2.5 MHz.

6.2 TEMPERATURE TOLERANCE

To this we need to add the temperature shift

Frequency_offset_due_to_temperature = (Temperature_coef_slope_PPM*Temperature_rance*Cutoff_frequency)/1000000.

A -20°C to +80°C temperature range results in an additional frequency offset of:

(-40)*100*2402[MHz]/1000000=~10[MHz]

At -20°C the cutoff frequency shifts to ~2490 MHz and at +80°C the cutoff frequency shifts to ~2480 MHz.

6.3 FILTER TECHNOLOGY AND POWER RATING

Two types of filter technology are presented in this discussion: SAW (Surface Acoustic Wave) and BAW (Bulk Acoustic Wave) technology. The FBAR filter mentioned in the following section below falls under the general category of BAW filters. Power handling of SAW and BAW filters within the context of this whitepaper (ISM and MWS coexistence) are designed to be at +15 dBm and +30 dBm respectively.

6.4 *BLUETOOTH* BANDPASS FILTER

Two sets of filters are described here. The first set is the standard design focusing on low insertion loss in the pass band whereas the second set is targeted to meet stop band attenuation requirements.

6.4.1 LOW INSERTION LOSS *BLUETOOTH* BANDPASS FILTER

This group of filters is designed for minimal insertion loss in the pass band, achieving less than 3 dB insertion loss over the entire pass band.

The green line in the pass band is set to 3 dB insertion loss. All filters shown achieve less insertion loss.

The area between the green and red lines in the stop band is a range in which the *Bluetooth* transmission emissions are not suppressed to a level where they do not influence the MWS receiver, in addition the MWS transmission signal may reach the *Bluetooth* receiver at a level forcing it to reduce its front end gain (thus degrading *Bluetooth* receiver sensitivity).

As shown, FBAR filter presented enables achieving both low in band insertion loss and high stop band attenuation at levels exceeding that required for 3 dB degradation limit (green line).

Using a SAW filter of this type would result in some degradation to reception sensitivity of either *Bluetooth* receivers, MWS receivers, or both.

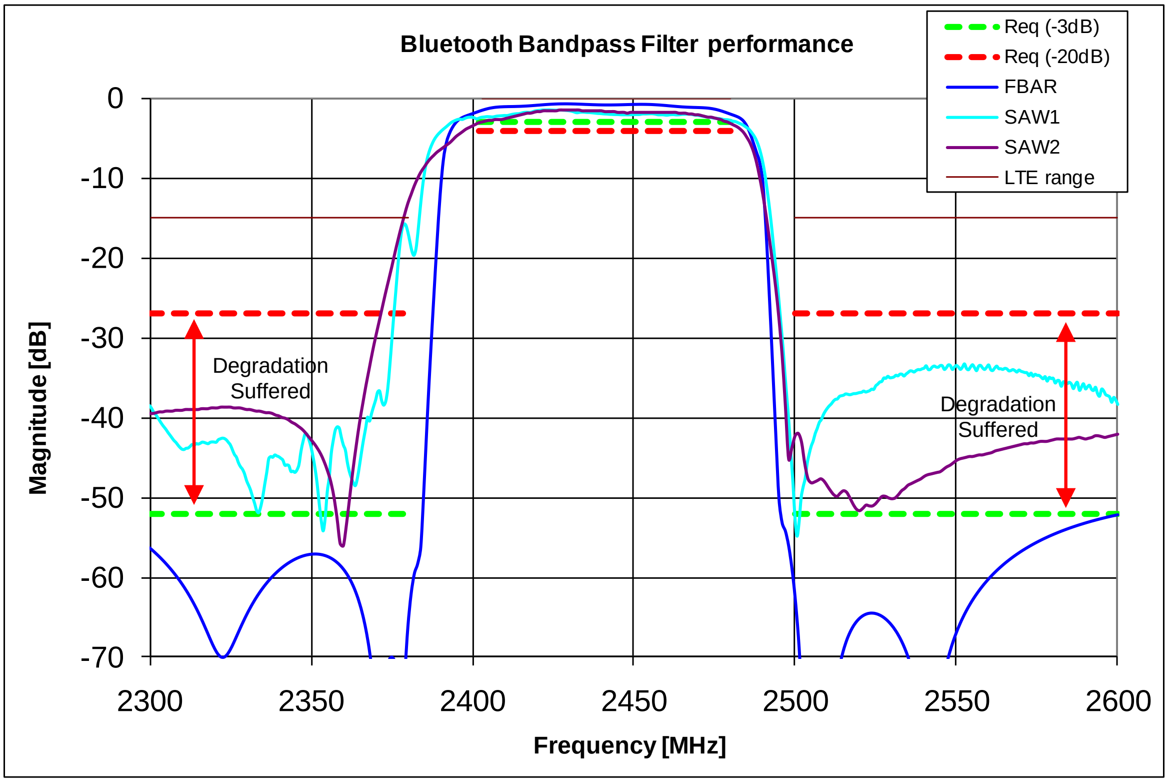

Figure 9 – *Bluetooth* Bandpass Filter Performance

6.4.2 MEDIUM INSERTION LOSS BLUETOOTH BANDPASS FILTER

This group of filters is designed to provide the required attenuation in the stop band at the expense of pass band insertion loss and package size. These filters can be achieved by cascading filters either as separate devices or dies inside the filter package.

The insertion loss of the cascaded filters is up to 6 dB.

The attenuation achieved in the stop band guarantees that the interference between the *Bluetooth* technology and MWS transceivers is lowered to a level where they do not interfere with each other. The increased insertion loss is a constant loss to the link path in both the transmit and receive paths.

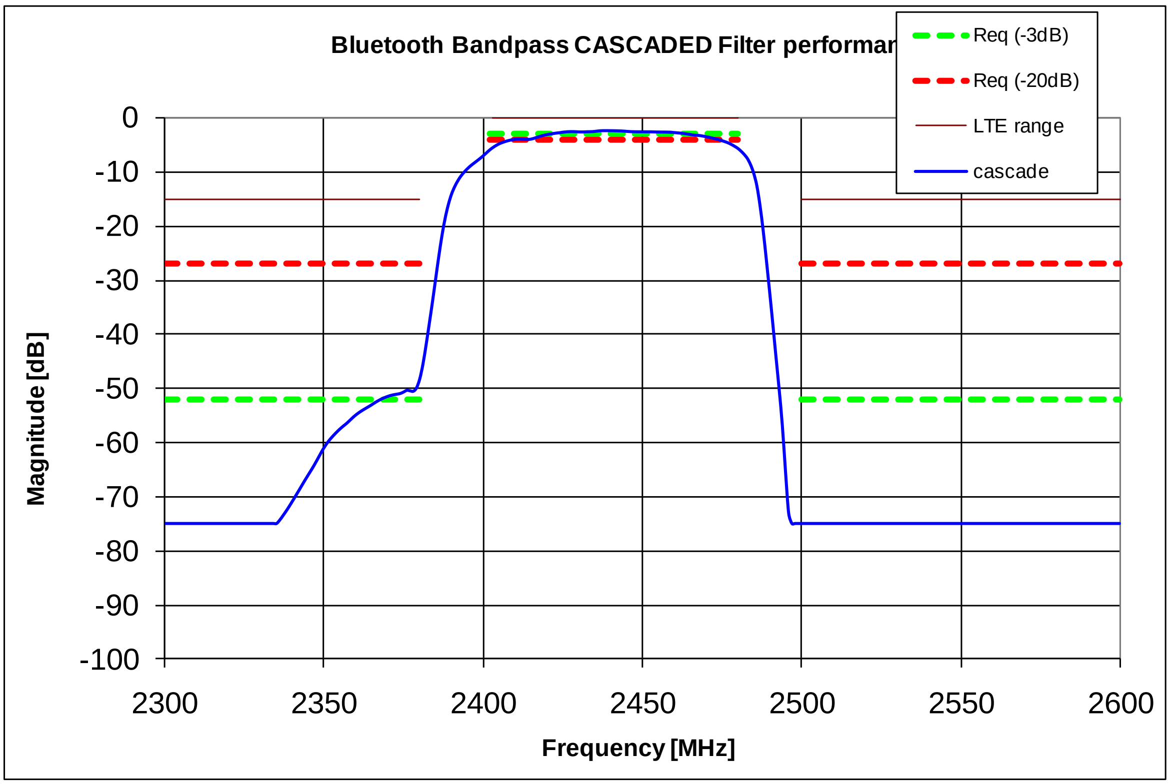

Figure 10 – *Bluetooth* Bandpass Cascaded SAW Filter Performance

6.5 LTE B7 FILTER

The FBAR filter in Figure 11 achieves both low in band insertion loss and high stop band attenuation at levels exceeding that required for 3 dB degradation limit (green line).

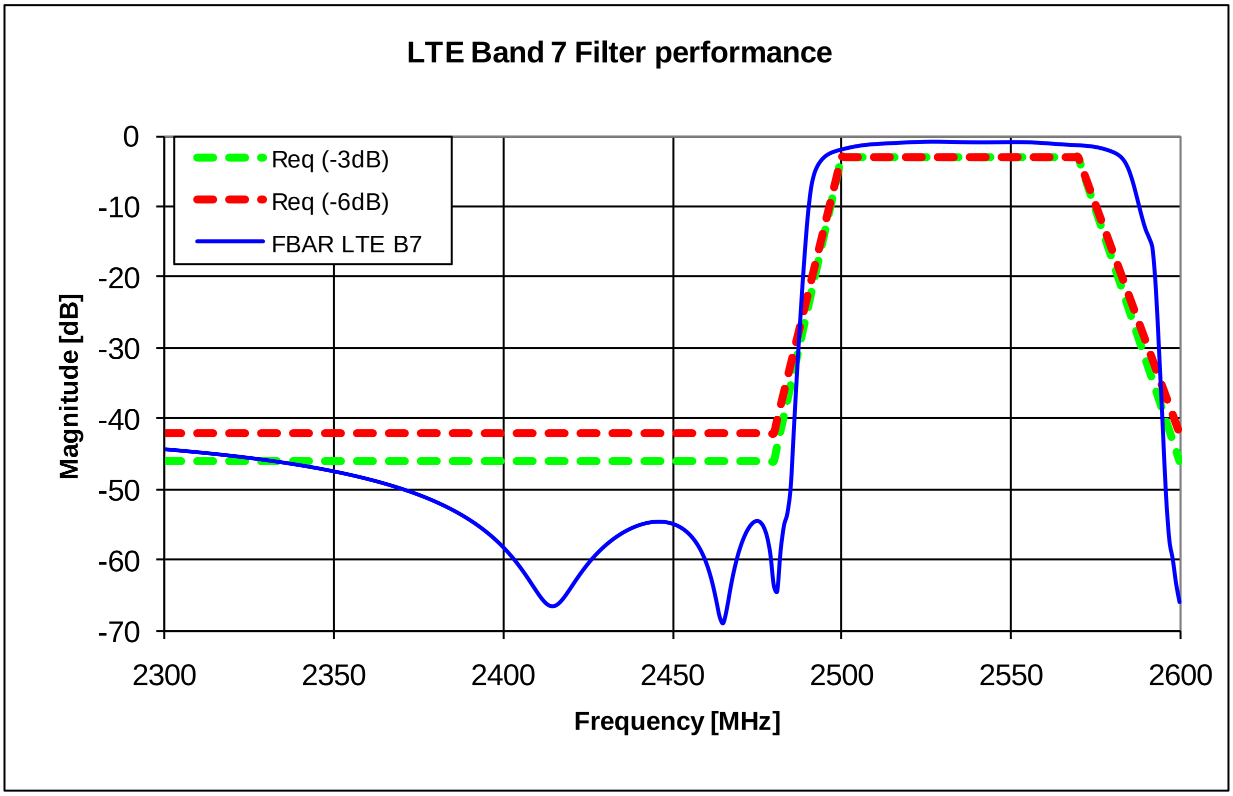

Figure 11 – LTE Band 7 Filter Performance

6.6 WIMAX 2.5 GHZ TDD FILTER

The FBAR filter presented does not fully meet both low in band insertion loss and high stop band attenuation at levels exceeding that required for 3 dB degradation limit (green line).

This results in some degradation to reception sensitivity of the *Bluetooth* receiver due to emissions from WiMAX (approximately 7 dB off target at 2466 MHz, total of ~10 dB degradation in *Bluetooth* sensitivity).

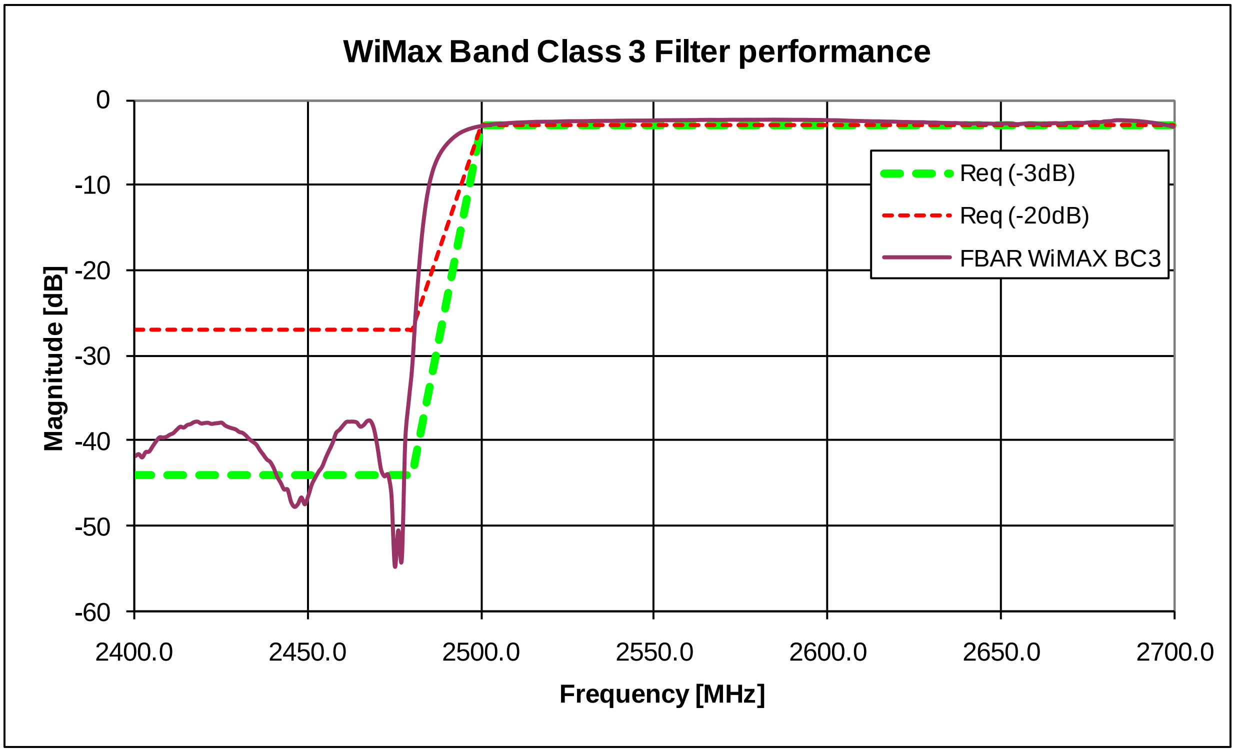

Figure 12 – WiMAX Band Class 3 Filter Performance

6.7 LTE RB40 / WIMAX BAND CLASS 1 FILTER

Figure 12 shows the filter performance in RB40. The FBAR filter achieves both low in band insertion loss and high stop band attenuation at levels exceeding that required for 3 dB degradation limit (green line).

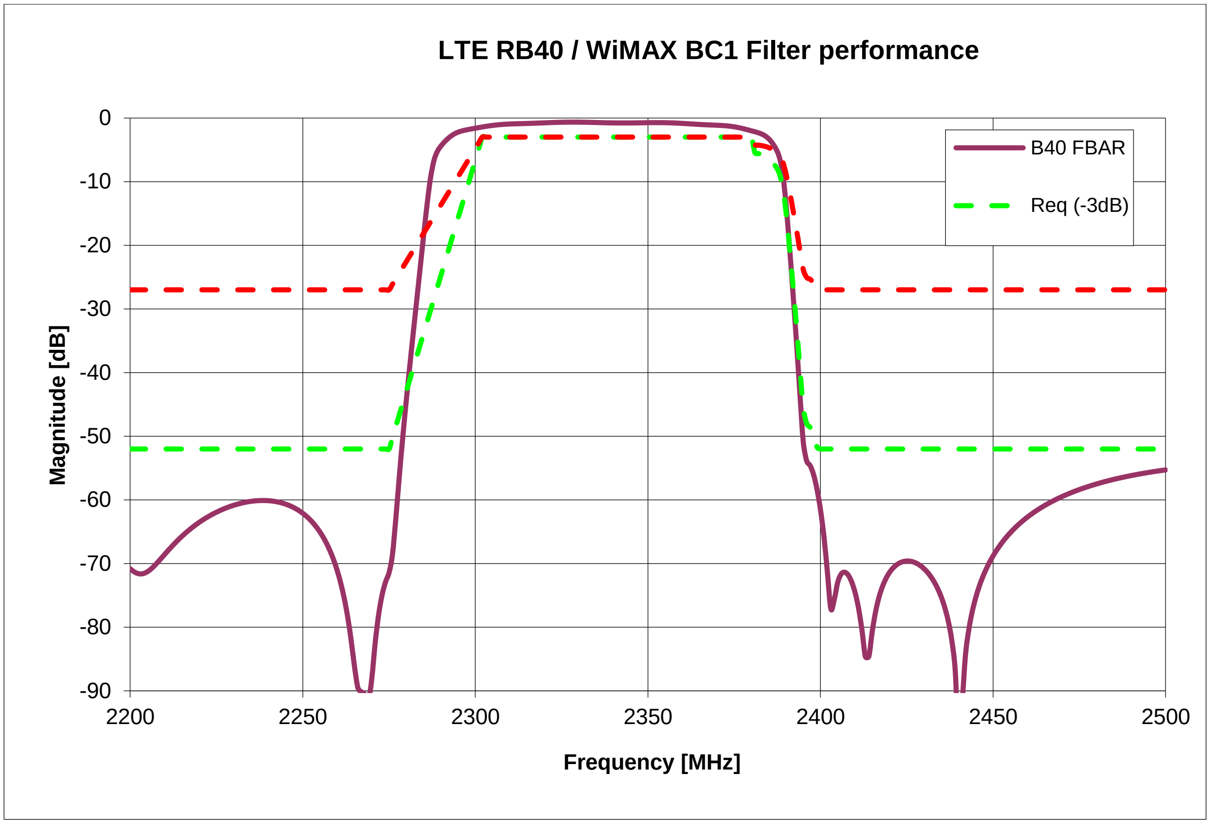

Figure 13 – LTE Band 40 / WiMAX Band Class 1 Filter Performance

7. Appendix C: Hybrid Coexistence Solution

When filters are only used to address interference in one direction, from the *Bluetooth* transmitter to the WiMAX receiver, the WiMAX filter masks can be substantially relaxed as long as additional techniques are implemented to mitigate the interference issues caused by the WiMAX transmitter desensing the *Bluetooth* receiver. We call this type of coexistence solution a “Hybrid Solution” since it relies on filtering as only part of the solution. Requirements for such relaxed filters are presented in this appendix based on similar analysis as Section 4.

Section 6 shows that in order to minimize desense to the victim receiver, the filter masks in Section 4 require use of some of today’s (circa early 2010) most advanced filter technology. In cases such as WiMAX TDD in band class 3, not even the best filters allow for full system performance (see Section 6.6).

There is an effort by the Bluetooth SIG to find a system level solution based on time division techniques for coexistence of WiMAX and *Bluetooth* technology.radios. This activity is ongoing and should not be relied on at this time. Such a solution will probably require changes to *Bluetooth* specification, special interface signals between WiMAX and *Bluetooth* radios, and/or proprietary changes to WiMAX and *Bluetooth* radios.

The Bluetooth SIG cannot guarantee interoperability or performance of proprietary solutions. The *Bluetooth* radio will have throughput and performance degradation due to loss of operational time to co-located WiMAX radios and may have interoperability and backwards compatibility issues.

7.1 HYBRID FILTER MASKS FOR WIMAX TDD SYSTEM

7.1.1 *BLUETOOTH* HYBRID FILTER MASKS FOR WIMAX BAND CLASS 1

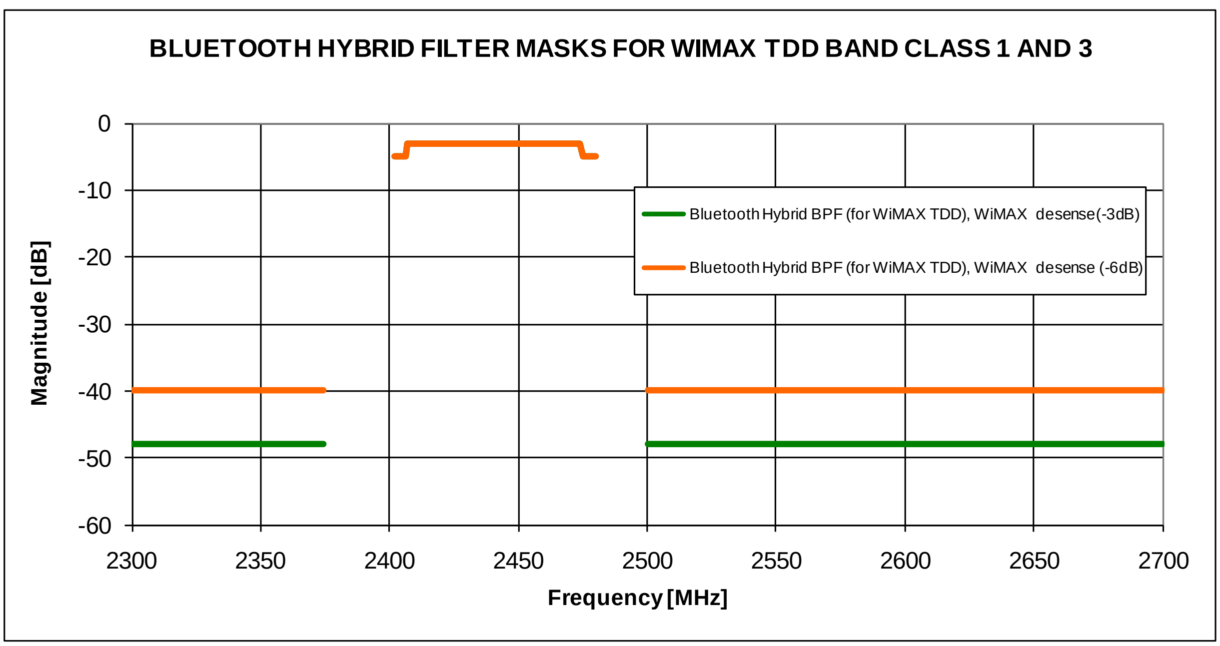

Table 17 – *Bluetooth* Hybrid Filter Mask for WiMAX Band Class 1 and 3

Specification	Frequency Range (MHz)	3 dB WiMAX Desense		6 dB WiMAX Desense	
		Min	Max	Min	Max
Insertion Loss	2402-2405		5		5
	2405-2475		3		3
	2475-2480		5		5
Absolute Attenuation	2300-2380	-48		-40	
	2500-2690	-48		-40	

When the *Bluetooth* Bandpass Filter is designed to protect WiMAX TDD reception only, the required attenuation in WiMAX Band Class 1 and 3 is 48 dB for 3 dB WiMAX sensitivity degradation and 40 dB for 6 dB WiMAX sensitivity degradation.

7.1.2 WIMAX TDD BAND CLASS 1 HYBRID FILTER MASKS

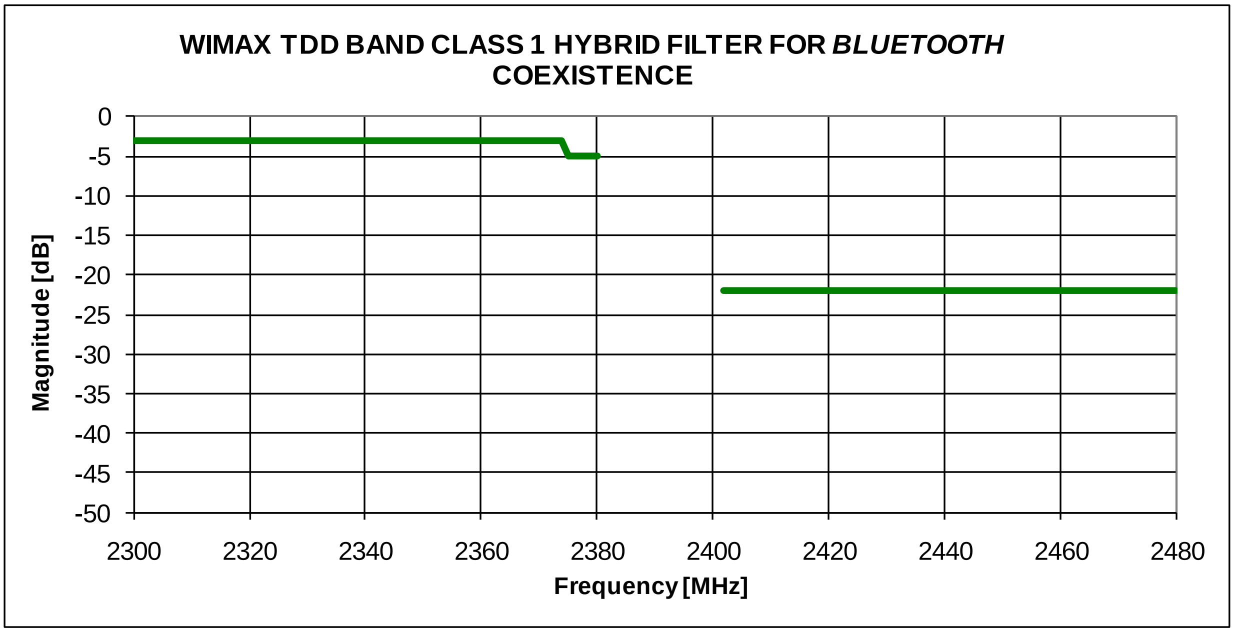

Table 18 – WiMAX TDD Band Class 1 Hybrid Filter Masks

Specification	**Frequency Range (MHz)**	Min	Max
Insertion Loss	2300-2380		N/A
Absolute Attenuation	2400-2480	-22	

If the WiMAX filter is designed to protect WiMAX TDD reception only, the attenuation in ISM band could be relaxed to 22 dB.

7.1.3 WIMAX TDD BAND CLASS 3 HYBRID FILTER MASKS

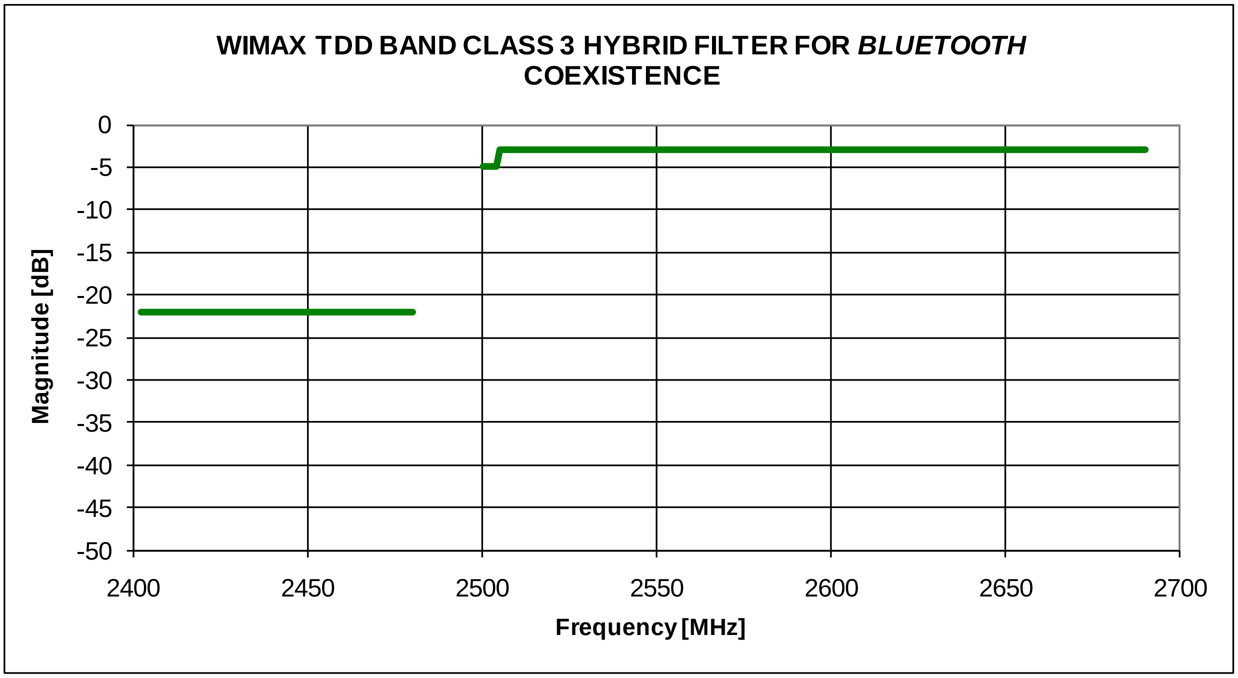

Table 19 – WiMAX TDD Band Class 3 Hybrid Filter Masks

Specification	**Frequency Range (MHz)**	Min	Max
Insertion Loss	2500-2690		N/A
Absolute Attenuation	2400-2480	-22	

If the WiMAX filter is designed to protect WiMAX TDD reception only, the attenuation in ISM band could be relaxed to 22 dB.