Attachment A

MBOA SIG Technical Reply Comments to 04-352

Table of Contents

1 Introduction

This Attachment provides detailed technical data, explanations, simulations, field test data, and engineering analyses to provide the Commission with the facts regarding the MB-OFDM waveform. We have referenced as well as included here extensive data demonstrating that MB-OFDM systems, tested under normal operating conditions, pose no greater threat of harmful interference than a class of pulsed UWB systems that are permitted by the rules. Further, in this reply, we provide solid engineering analysis and simulations to identify errors, incorrect claims, and incorrect operating environment assumptions made in responses to MBOA-SIG's waiver petition in ET Docket number 04-352. In Attachment A, we provide a summary of our detailed discussion, and it is organized as follows.

In Section 2, we demonstrate that the MB-OFDM waveform will not cause greater interference to C-band systems, 802.11a systems, or other UWB systems. We discuss realistic operating scenarios for C-band systems in Section 2.1 and demonstrate that *MB-OFDM waveforms cause no harmful interference into C-band satellite systems under these realistic scenarios.*

In Section 3, we provide detailed evidence and support that the waiver is soundly based, and we provide technical explanations which identify the errors made in our opposition's responses. We provide the technical discussion of system noise floor[1] (rather than simply thermal noise) in the computation of I/N ratios, and we provide justification for using system noise to represent realistic operating scenarios. We further explain why the MBOA simulations and lab measurements include the right BER criterion to reflect real C-band satellite systems. We provide field tests results, and demonstrate that these tests accurately represent the real world environments. We demonstrate that the MB-OFDM waveform causes no more harm than impulse waveforms already anticipated and allowed by FCC regulations. Finally, Section 3.5 provides the technical rigor to demonstrate that the MB-OFDM APD analysis provided by MBOA-SIG is valid.

In Section 4, we explain why the MB-OFDM waveform complies with the spirit of the FCC regulations when measured, as requested, under normal operating conditions, and *does not* give MB-OFDM systems "unfair advantage" as claimed by our opponents. We explicitly address peak and average power measurements and provide the technical analysis to demonstrate that there is no possibility of arbitrarily high power systems that would be permitted by MBOA-SIG waiver. In addition, we explain why the MB-OFDM waveform clearly meets the 500 MHz minimum bandwidth requirements for UWB systems, and we put to rest the concern that the Waiver could 'open the door' to many other waveforms not considered here.

[1] System noise floor is defined to be the thermal noise floor plus other self-interference experienced in the environment. For example, for C-band receivers, the system noise floor includes adjacent channel and cross-polarization noise from the satellite link (defined as I_{sat} in Section 2.1.1)

In Section 5, we explain that MB-OFDM systems do NOT synchronize and will not lead to an increase in aggregate interference.

In Section 6, we present a discussion on some of the unique advantages of MB-OFDM which makes it a compelling technology to address current market needs as well as future integrated product requirements.

In Section 7, we provide an update of the MB-OFDM waveform description and a list of corrections of minor inconsistencies between the waveform described in the waiver and the IEEE documents presented at the 802.15.3a Task Group meetings. We explicitly identify the minor inconsistencies, none of which affect the potential interference aspects of the waveform, to ensure that there is no confusion regarding the specifics of the MB-OFDM waveform under consideration for these proceedings.

In Attachment B, we provide an updated description of the MB-OFDM waveform with the minor discrepancies in the waiver corrected. This attachment is presented to ensure that the waveform for which we are requesting the waiver is described within our reply filing.

In Attachment C, we present a more complete description of the MBOA Fixed Satellite Services field testing, and thoroughly describe the assumptions and test set up used to generate the results.

2 MB-OFDM will not cause greater harm to C-band satellite systems, 802.11a systems, or other UWB systems

2.1 MB-OFDM will not cause greater harm to C-band satellite systems

The Satellite Industry Association (SIA) and Coalition of C-band Constituents expressed the concern that UWB devices would significantly reduce the link margin of the satellite systems. This concern was effectively addressed during the FCC UWB proceedings where it was found that the Part 15 limits provided sufficient protection to fixed satellite systems under realistic operating scenarios.

We address SIA's technical concern regarding the potential for harmful interference into fixed satellite systems in more detail in the following section. Unfortunately, it appears that the SIA has been led to believe by a 'proponent of a competing technology' that MB-OFDM will cause '5 to 9 dB more interference than DS-UWB.' As we discuss below, in realistic operating environments this contention is wrong. In general, if UWB systems allowed by the rules cause no harmful interference into fixed satellite systems, then MB-OFDM systems will also cause no harmful interference.

2.1.1 UWB systems (including MB-OFDM covered by the waiver) will not cause harmful interference into C-band Satellite systems when considering realistic operating scenarios

The table below shows some of the power spectral density limits for various US government systems adopted in the FCC Final Report and Order.

Table 1: Power spectral density limits for some US government bands

System	Frequency (MHz)	Maximum UWB EIRP (dBm/MHz) UWB Indoors 2 m height	Maximum UWB EIRP (dBm/MHz) UWB Indoors 30 m height	IF Bandwidth	Margin from current Part 15 limits
ARSR-4	1240-1370	-52	-73	690 KHz	23.3 dB (2 m) 2.3 dB (30 m)
SARSAT	1544-1545	-60	-57	800 KHz	15.3 dB (2 m) 18.3 dB (30 m)
ASR-9	2700-2900	-37	-57	653 KHz	14.3 dB (2 m)
NEXRAD	2700-2900	-33	-67	550 KHz	18.3 dB (2 m)
Marine Radar	2900-3100	-34	-45	4-20 MHz	17.3 dB (2 m) 6.3 dB (30 m)
FSS, 20 degrees	3700-4200	-24	-30	40 MHz	17.3 dB (2 m) 11.3 dB (30 m)
FSS*, 5 degrees	3700-4200	-39	-65	40 MHz	2.1 dB (2 m)
CW Altimeters	4200-4400	37	Not Applicable	N/A	78.3 dB (2 m)
Pulsed Altimeters	4200-4400	26	Not Applicable	30 MHz	67.3 dB (2 m)
MLS	5030-5091	-42	Not Applicable	150 KHz	-
TDWR	5600-5650	-23	-51	910 KHz	18.3 dB (2 m)

This table shows that significant margin exists for most systems considered. However, it also shows that the C-band system from 3.7-4.2 GHz is one of the more sensitive systems when using a 5 degree elevation angle. In fact, as will be discussed further in this Attachment, our own testing of an actual C-band satellite system only yielded a 2.5 dB margin. Also, because multimedia distribution is expected to be an important application for future UWB systems, the UWB industry does not want the multimedia content to be disturbed. However, we believe that the concerns raised by comments to the waiver are overstated, and MB-OFDM systems will not cause harm to C-band satellite systems. In addition, we will explain why other types of UWB systems allowed by the rules should also not be a concern to C-band satellite systems.

First, as has been stated many times by the C-band coalition and supporting comments from the C-band satellite industry, these satellite systems have very low margin due to the challenges of communicating over a long satellite link[2]. As a result, interference from UWB systems must be below the systems noise floor of the C-band satellite receiver, denoted as N_{sys} for simplicity and includes thermal noise plus intra-system interference. The FCC adopted a criterion of $I_{uwb}/N < 0$

[2] See Petition for Reconsideration of Satellite Industry Association in docket 98-153, which shows an example link budget margin of 1.4 dB.

dB, as described in the UWB MOO[3], where N in this case refers to the thermal noise floor and I_{uwb} refers to the average UWB interference power level at the receiver. Based upon information provided by the SIA[1], their model assumes an $I_{sat}/N=1.4$ dB, where I_{sat} includes adjacent channel and cross-polarization noise from the satellite link. As a result, the criterion $I_{uwb}/N < 0$ dB corresponds to an $I_{uwb}/N_{sys} < -3.8$ dB, where $N_{sys} = N + I_{sat}$. This analysis shows that the FCC criteria would require the average UWB interference power (for all UWB devices) to be at least 3.8 dB BELOW the system noise floor of the satellite receiver.

In addition, XtremeSpectrum filed a response to the SIA Petition for Reconsideration[4] stating that

> *Using SIA's stated operating levels, XSI demonstrates that an I/N of –6 dB assigned to a UWB device is an appropriate protection level.*

Again, the I/N ratio referred to in the above statement is with respect to the thermal noise floor. Including the intra-system interference expected for satellite systems, this criteria corresponds to an $I_{uwb}/N_{sys} < -9.8$ dB. So, XtremeSpectrum (now part of Freescale Semiconductor) agrees that in realistic operating scenarios, the average interference power from a UWB device should be at least 9.8 dB BELOW the system noise floor of the satellite receiver.

The contention that there could be potential interference concerns by the SIA and Coalition of C-band Constituents into C-band systems seems to be largely based upon detailed simulation results from an Alion report[5]. For the most sensitive receiver tested, an 8-PSK digitally modulated system with a 35 MHz bandwidth, the Alion report found that the C-band receiver could tolerate a total of -102.4 dBm of UWB interference power before noticeable degradation of the system occurred. For a 35 MHz bandwidth, this corresponds to a maximum power spectral density of -117.8 dBm/MHz allowed by potential UWB interferers before noticeable degradation occurred. It should be noted that a C-band receiver can have a thermal noise floor of -117 dBm/MHz[6]. Comparing the maximum acceptable power spectral density from the Alion report (-117.8 dBm/MHz) to the thermal noise floor (-117 dBm/MHz) supports the FCC opinion that an I/N < 0 dB is a reasonable metric for determining harmful interference (again noting that this I/N

[3] FCC Memorandum Opinion and Order and Further Notice of Proposed Rule Making, Docket 98-153, March 12, 2003.

[4] Opposition of XtremeSpectrum, Inc. To Petition for Reconsideration Of the Satellite Industry Association, FCC Docket 98-153, Sept. 4, 2003.

[5] Evaluation of UWB and Lower Adjacent Band Interference to C-Band Earth Station Receivers, Final report for Coalition of C-band Constituents by Alion Science and Technology, February 11, 2004.

[6] *Ex Parte* In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra- Wideband Transmission Systems, ET Docket No. 98-153, filed on behalf of PanAmSat Corporation, March 25, 2003. The -117 dBm/MHz was derived from the -99.88 dBm noise floor in a 50 MHz channel.

ratio is using the thermal noise floor and not the system noise floor which would include both thermal noise plus intra-system interference).

Based upon this study, a coalition of C-band constituents proposed that reducing the current FCC limits by 21 dB 'would prevent reception failure up to a UWB device density of approximately 64 devices per acre', and 'the Coalition believes such a reduction would be a reasonable compromise to protect C-band satellite links.'[7]

In another filing[8], Motorola provided analysis in response to this report which took into account more realistic factors into the simulations. Motorola concluded that:

> *Based on the revised simulations with the more realistic path loss models, building blockage effects for devices high in the air (and near the antenna main beam), the inclusion of a realistic duty cycle (<10%) and realistic density projections, it is clear that no significant interference will result. The aggregate UWB signal power levels drop by 25-60 dB when more realistic assumptions are made in the simulations.*

An MBOA filing addressing the Alion report also supports Motorola's analysis[9]. These results demonstrate that UWB interference will be well below the thermal noise floor, which was the target threshold derived from the Alion report.

The conclusion from evaluating the criteria used by the FCC during the UWB proceedings as well as subsequent analysis filed by XtremeSpectrum, Motorola (who opposes this waiver), and the MBOA shows that the average power from potential UWB interferers will be well below the system noise floor of the C-band satellite receiver when considering realistic system impairments and usage models.

It is also worth pointing out here that Pulse-Link, in their comments opposing the petition for waiver, say the following in "Comments of Pulse-Link", Section VII (b) "Singapore studies show that UWB transmission at 6dB higher levels does not cause harmful interference to licensed services", quoting the IDA results as saying

> *[I]t should also be noted that our field test with a local satellite operator failed to produce any evidence that, under reasonable usage conditions, an FCC-compliant UWB device (short-pulse or MB-OFDM) transmitting in the vicinity of a satellite dish would result in any measurable amount of interference"*[10]

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[7] ET Dockets 98-153 and 02-380 Study of Interference by UWB and Unlicensed Devices to C-Band Earth Station Receivers, by Coalition of C-band Constituents, February 18, 2004.
[8] ET Docket No. 98-153, Ultra-Wideband Transmission Systems, *Ex Parte Communication,* filed on behalf of Motorola, April 9, 2004.
[9] ET Dockets 98-153 and 02-380, Critique of Interference Study of Ultra Wideband Technology, filed by Alereon on behalf of the MBOA, April 12, 2004.
[10] IMPACT of Ultra-Wideband (UWB) INTERFERENCE on A C-band Fixed satellite service (FSS) RECEIVER. Infocomm Development Authority of Singapore (IDA). Document 1-8/95E, June 01, 2004.

Therefore, Pulse-Link believes there is sufficient margin in the FCC rules to even allow increased *average* power spectral density for all UWB devices. The waiver does not advocate such a position, but this statement clearly implies that Pulse-Link should not have any interference concerns with a MB-OFDM transmitter to C-band satellite systems (or any other system), since the increased *peak* power during the 'on' time of the MB-OFDM signal is less than 6 dB (results in Section 3 show that the impact of the MB-OFDM waveform is MUCH less than increasing the average power of a general UWB signal by 6 dB).

This waiver request seeks to allow a novel UWB waveform, which has slightly different characteristics than some of the waveforms considered during the UWB proceedings, to operate under the Part 15 limits of -41.3 dBm/MHz. However, when the average power of the UWB waveform is well below the system noise floor of the receiver, there is virtually no difference among various waveforms. Even the companies opposing this waiver request agree. For example, Freescale commented that "…when you mix one part MB-OFDM energy with 20 parts Gaussian noise, the result is a composite signal that looks very much like noise." In addition, TimeDerivative commented that "At very low I/N ratios the noise dominates and little can be said about the difference between various interferers." The following sections in this Attachment will also demonstrate that, when operating under real world conditions and realistic I/N ratios, there is very little difference between MB-OFDM waveforms and other waveforms allowed under the current FCC UWB rules.

To summarize, we agree that C-band satellite systems have very little margin to allow for significant interference from UWB devices. Fortunately, there have been several different reports submitted to the FCC (many from companies opposing this waiver) which demonstrate that interference from UWB devices will likely be well below the system noise floor (including thermal noise plus intra-system interference) of the C-band satellite receiver. When the average interference of a UWB system is well below the system noise floor of a victim receiver, subsequent analysis will demonstrate, and even companies opposing this waiver agree, that there is very little difference between different types of UWB waveforms.

2.2 MB-OFDM will not cause greater harm to IEEE 802.11a systems

In Section 5.2 of its comment, Freescale questions the potential interference into 802.11a systems. Likewise, TimeDerivative stated in its comments (on pp.4 and 5) that "the cause of the extra interference … is because the MBOA signal burst is at significantly higher than average EIRP as depicted pictorially in Fig.3. … The interference effect of a burst is dramatically more injurious to the victim than the effect of a continuously transmitting UWB pulse signal at the same average EIRP". Then it refers to the IEEE802.11a as a typical victim system.

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http://www.itu.int/md/meetingdoc.asp?lang=e&type=sfolders&parent=R03-TG1.8-C&PageLB=50

In order to ascertain that the MB-OFDM signal does not adversely affect the IEEE802.11a receiver performance, interference measurements were conducted, as discussed below, using an actual IEEE802.11a device and assuming that the MB-OFDM was transmitting in these bands. Two types of the interfering signals were considered, the MB-OFDM signal and AWGN, according to the measurement configuration below.

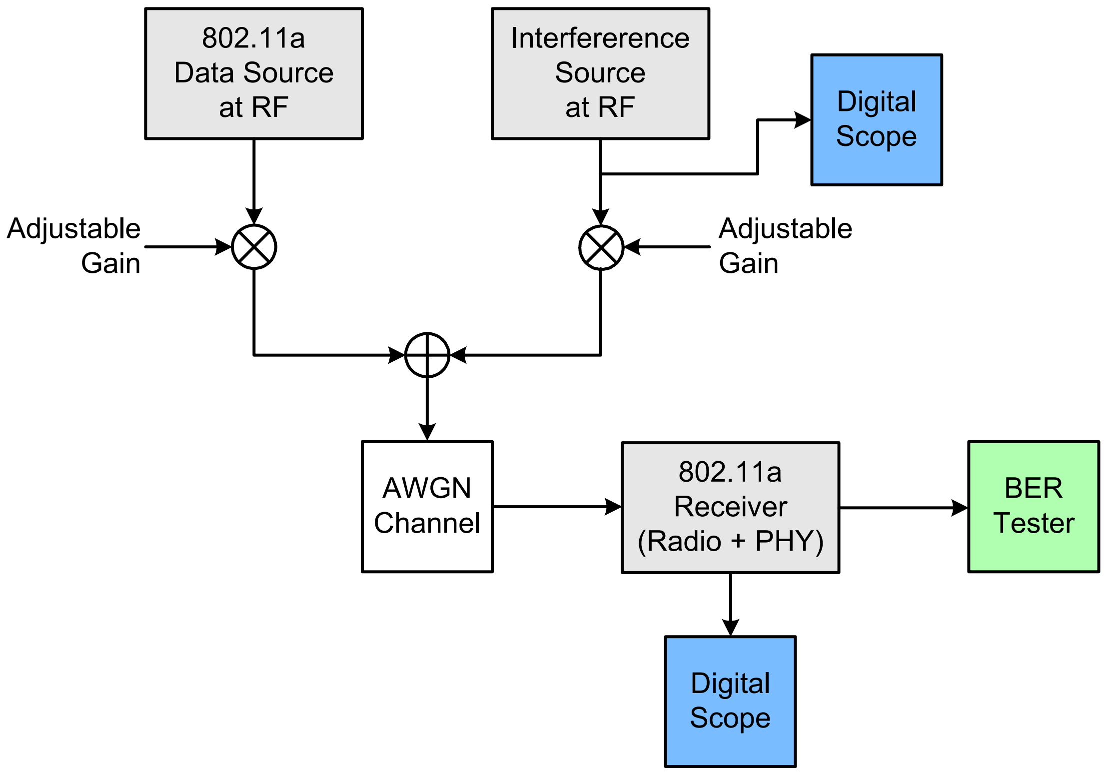

Figure 1 Configuration of the interference measurement

In the test,

1. An IEEE802.11a device was configured with the date-rate of 36 Mbps (16 QAM, R=3/4)
2. The IEEE802.11a signal power was calibrated to the sensitivity level (0 dB at BER=10^{-5}) in the absence of the interference. This defines the operation thermal noise level. Then the IEEE802.11a signal level was adjusted to different levels in order to measure the impact of the interference signal and its power.
3. With the interference added to the calibrated thermal noise, its power level (maximum tolerable interference power (MTIP)) was measured to maintain the IEEE802.11a reception at BER=10^{-5}.

The resultant MTIP levels were then compared between MB-OFDM and AWGN (shown in the table below) for the IEEE802.11a signal power of the range 0.5 dB to 10 dB above the sensitivity level. In this signal power range, the largest difference in the observed MTIP values between the

MB-OFDM signal and AWGN was 0.5 dB. This result shows that the MB-OFDM and AWGN interference has similar impact to the IEEE802.11a receiver. This result should be expected, because 802.11a systems are based upon an OFDM signal with a symbol period of 4 microseconds. During this time, the 802.11a receiver would be integrating over a number of MB-OFDM symbols (including the 'off' periods), and so it is expected that the performance would be dominated by the average interference power rather than the specific shape of the waveform. This property is confirmed in these measurement results. A summary of the results of these measurements are provided in the Table 2 and Figure 2 below.

Table 2: Summary comparison between WGN and MB-OFDM impact on 802.11a systems

Signal Power of 802.11a above sensitivity	I/N	Difference between AWGN and MB-OFDM Interference
10 dB	9.5 dB	0.5 dB
3 dB	0 dB	0.5 dB
2 dB	-2.3 dB	0 dB
1 dB	-5.9 dB	0 dB
0.5 dB	-9.1 dB	-1.5 dB*

* Note that it is challenging to accurately measure maximum tolerable interferer power at very small I/N ratios.

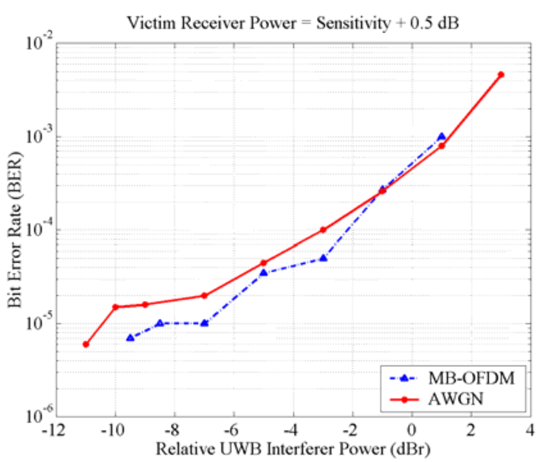

Figure 2: Example BER results for an 802.11a system comparing MB-OFDM and AWGN

Related to the interference to the IEEE802.11a receiver, the proponents of the DS-UWB technology, during discussions held in the IEEE 802.15.3a task group, also contended that the MB-OFDM signal would cause performance degradation of the AGC in the IEEE802.11a receiver.

In order to adequately address this point, a comparison was made in the IEEE802.11a packet detection and the AGC convergence performances between the MB-OFDM signal and AWGN. Here the measurement was conducted with the IEEE802.11a device operating at 3 dB above sensitivity. The measurement was conducted with the MB-OFDM signal level set to the MTIP level as well as to 10 dB higher than the MTIP level. From these results, some of which are shown below in Figure 3, we were not able to observe any impact of the MB-OFDM signal to the IEEE802.11a packet detection and AGC performance.

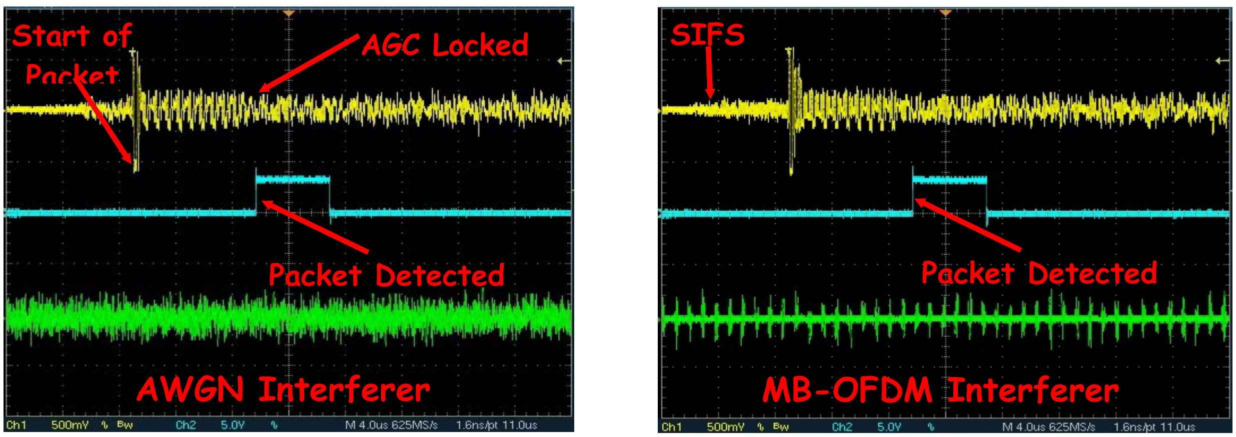

Figure 3: The performance of packet detection and AGC convergence is similar for both an AWGN and MB-OFDM interferer with the same average power.

These measurement results confirm that:
(1) The MB-OFDM signal and AWGN have a similar interference impact to the IEEE802.11a receiver
(2) The MB-OFDM signal does not adversely affect the packet detection and the AGC convergence performance of the actual IEEE802.11a devices.

2.3 MB-OFDM will not cause greater harm to other UWB systems

Some commenters argued that the higher peak power of the MB-OFDM signal somehow results in MB-OFDM causing worse interference to all UWB systems compared to other UWB waveforms.

Freescale states (4.4.2, p. 23 of "Technical Analysis …"): 'Other UWB receivers will be injured by the MB-OFDM emissions at least as much and often more than all the other victim systems since their bandwidths are so similar. While on its face, one would expect the 6dB higher emission limits to single out MB-OFDM devices for a 2X range advantage, the actual outcome is even worse. The noise floor of all other UWB devices would be raised far more by MB-OFDM devices than other classes of UWB devices.'

Pulse-Link states in Section III of their "Comments …" : 'Granting the waiver would allow the MBOA radio to more successfully jam the DS-UWB radio since it will be allowed an increase of power in band.'

TimeDerivative states: 'This additional power poses a significant additional risk to other UWB communications equipment.'

No evidence has been shown to support these claims. On the contrary, take the following example: consider an MB-OFDM signal which occupies a total bandwidth of 3*528 = 1584 MHz, and evaluate the interference experienced due to this signal by an impulse radio system occupying the same total bandwidth of 1584 MHz (for comparison, Freescale's proposed DS-UWB system defines impulse radio modulation using impulses of bandwidth 1320 MHz and a PRF of 220 MHz to deliver a data rate of 110 Mbps.). Also, assume that interference is much higher than the system noise. For the MB-OFDM interferer, the *peak* power spectral density (PSD) during the OFDM symbol 'on' time is 5.8 dB above the average PSD, and the occupied bandwidth is ~500 MHz. At any given instant, one 500 MHz swath of the impulse radio's occupied band is impacted by an MB-OFDM symbol. The receiver matched filter for the impulse radio system integrates all the interference power over the full bandwidth of 1584 MHz.

Thus, the total *instantaneous* interferer power[11] at the output of a 1584 MHz matched filter is
$I_{MB\text{-}OFDM}$ = (-41.3 + 5.8) dBm/MHz + 10*log10(500) MHz = -8.5 dBm

The total *instantaneous* interferer power at the matched filter output from another impulse UWB radio system occupying the same 1584 MHz bandwidth would be
$I_{DS\text{-}UWB}$ = (-41.3) + 10*log10(1584) = -9.3 dBm

The MB-OFDM system offers at worst 0.8 dB higher potential interference in this example. In fact, if we consider a more realistic set of conditions, such as including system noise in addition to the interference, as well as realizing that the target DS-UWB system would have FEC protection, this modest impact would be reduced still further.

To add further perspective to the above example, a couple of other points must be made. First, other impulse UWB radios with lower PRFs up to 1 MHz are allowed under the regulations, and these will have higher peak powers than the MB-OFDM signal, and thus the worst case interferer power for these could be higher. Second, it is for this reason that the target UWB system should be assumed well designed, with sufficient interleaving and FEC protection, etc. such that the correct metric of the effect of other UWB system interference will indeed be the *average* interference power, not the peak as in the above example. Using this metric, it can be seen that the effect caused by UWB system interference is identical whether the interference is from an MB-OFDM system or any other UWB system transmitting with the same average power spectral density over the same bandwidth.

[11] *Instantaneous* interference power refers to the maximum interference power to be expected while the interference source is active or 'on'.

All UWB systems operating in the unlicensed bands must in any case be designed well in order to cope with interference from other unlicensed band systems that operate according to the FCC R&O rules regarding avg. power spectral density and peak power. As we have argued in Section 4, the MB-OFDM signal complies with these rules, and in the matter of interference it should be treated just as any other compliant UWB signal would.

3 MBOA's technical justification for the waiver is correct and accurate

3.1 System noise is a reality and absolutely MUST be included in comparisons

In their comment on the waiver request, Freescale contends that thermal and system noise should not be considered when evaluating the impact of UWB systems on other narrowband systems. While it is an interesting theoretical and academic exercise to compare different waveforms in a completely noise-free environment, it is largely irrelevant to the question of whether one waveform is more harmful than another *under actual operating conditions*. The question of harmful interference MUST include the influences of other noise sources in the environment (including thermal noise plus intra-system noise which may be present). For example, if it's believed that the *average* interference power coming from a UWB source will *always* be below the noise floor, then why should the different waveforms be compared using a different set of conditions? The discussion in Section 2.1 explains why the average interference power of UWB devices will be well below the noise floor of a C-band receiver when considering realistic operating environments, and this is supported by several publicly filed comments by Motorola and XtremeSpectrum (now part of Freescale), both of whom oppose this waiver. The FCC was very clear in the UWB R&O of the importance to not only include thermal noise but also the presence of other external noise sources, as stated in the following[12]:

> *We also note that several of the analyses seek to protect radiocommunications systems to levels below the receiver thermal noise floor. This is a level of performance that does not generally occur under actual operating conditions due to the presence of other sources of radio noise.*

If waveform comparisons are made without considering the presence of thermal noise (let alone additional noise sources which are found in real systems), then incorrect and irrelevant conclusions can result. For example, Figure 4 on page 12 in the Freescale comment seemed to show that impulse radios were the least interfering when compared to WGN and MB-OFDM waveforms[13]. However, Sections 3.3 and 3.4 of this Attachment describe simulations, lab measurements, and field measurements which all come to the opposite conclusion, namely that impulse waveforms were consistently more harmful than WGN and MB-OFDM waveforms

[12] FCC 02-48, UWB Final Report and Order, April 22, 2002, see Section 8 *Summary of Tests and Analysis,* pg. 59-60.

[13] It should be noted that we tried to replicate these results, but we believe these particular results are flawed and don't represent a QPSK modulated C-band satellite system, as will be discussed further in Section 3.4.

when evaluated under more realistic scenarios. In addition, when considering 'actual operating conditions' and more realistic ratios of interference power to system noise power (I/N_{sys}), the differences among different UWB waveforms are shown to be very small. Therefore, it is essential to consider these real world impairments (thermal noise being just one of many) when evaluating the impact of different UWB waveforms.

3.2 BER Criterion used in MBOA data is CORRECT and relevant

Freescale claims that the MBOA analysis is based upon the wrong BER criterion and stated that the BER used in our comparisons were '7 orders of magnitude higher than the specification'. They even charged that 'the curves and corresponding conclusions are misleading, and to a skilled communications engineer, they are fatally flawed and have no technical merit.' These comments are completely misplaced, exaggerated, and untrue. The results shown by the MBOA are at the output of a Viterbi decoder, and most C-band satellite systems employ a concatenated code with an inner convolutional code plus an outer Reed-Solomon code. Indeed, Figure 4 in the Freescale comment is the BER at the output of the Viterbi decoder, but at an unnecessarily low BER. For example, the C-band satellite system used in their own testing (as described in Section 3.1 of the Freescale technical analysis report) employed a concatenated code, and all of the digital C-band receivers used in the Alion report also employed a concatenated code. We agree that digital video needs a low BER, but it is well-known that a BER of 2×10^{-4} at the output of the Viterbi decoder yields quasi-error free performance at the output of the Reed-Solomon decoder (meaning a BER of 10^{-10} to 10^{-11})[14]. Therefore, comparing the performance at the output of the Viterbi decoder at a BER of greater than or equal 2×10^{-4} is completely relevant to this discussion[15], and simulation results and lab measurements both referred to in the Waiver and provided in this Attachment include this operating BER region. Note that Figure 2 in the Freescale response also shows that MB-OFDM has a virtually identical impact to that of white, Gaussian noise (WGN) at this BER at the output of the Viterbi decoder when considering an I/N = -6 dB, which is exactly the same I/N ratio XtremeSpectrum, now part of Freescale, argued would be realistic, as discussed previously in Section 2.1.

In addition to the detailed simulation results, the MBOA also relied on actual lab and field data to better understand the impacts of different types of interference for real systems and considered not just BER impact but also visual impact on actual video signals. These results are presented in the following sections.

TimeDerivative also claimed that comparisons should be based upon an *uncoded* BER of 7.2593×10^{-4}. The simplistic analysis in the TimeDerivative comment focused comparisons on uncoded

[14] For example, see EN 300 421 v1.1.2 (1997-08), Digital Video Broadcasting; Framing Structure, channel coding and modulation for 11/12 GHz satellite services.

[15] Since quasi-error performance is met with a BER of 2×10^{-4} at the output of the Viterbi decoder, it's unclear what would be considered the point at which 'harmful interference' occurs, but this would presumably be at some BER greater than 2×10^{-4}. However, for the sake of comparisons and to err on the conservative side, in this attachment we have primarily focused on BERs at the output of the Viterbi decoder of 2×10^{-4}.

BER curves, but they incorrectly related the 'typical coding gain' to an equivalent uncoded BER criterion. For example, a concatenated rate ½ convolutional code with an outer (204,188) Reed-Solomon code should achieve quasi-error free performance at a useful Eb/No=4.5 dB (see EN 300 421 v1.1.2 (1997-08)) before the Reed-Solomon encoder. This corresponds to an energy-per-chip to noise power spectral density ratio (Ec/No) of about 1.1 dB (even with an implementation loss of 0.8 dB included in the required Eb/No value). The Ec/No ratio is the true uncoded signal to noise ratio prior to any decoding operation. At this Ec/No level, the 'uncoded' BER is well above 10^{-2} which can be found in any digital communications textbooks[16]. Even with a higher rate 7/8 code, the 'uncoded' BER would be well above 10^{-3}. So, the TimeDerivative methodology and uncoded BER criteria of 7.2593 x 10^{-4} does not match values well-known for digital satellite systems. In addition, the comparisons made at an I/N = 0 dB do not take into account the existence of intra-system interference which would be expected in satellite systems. In addition, as previously mentioned, satellite systems have very low additional link margin available, and the above discussion in Section 2.1 describes why low I/N ratios should be expected. TimeDerivative correctly comments that[17] 'The MBOA results generally follow theory and are skewed to relatively high victim BER (greater than 10^{-3}), and for very low victim margin values (less than 1.5 dB), …', and the reasons for these operating points have been clearly described here, not with the intention to 'skew' the results, but rather to correctly reflect real systems and coexistence scenarios. Additional BER simulation results comparing various UWB waveforms are presented in Section 3.4 which correct for the inaccuracies in the TimeDerivative analysis and provide results at a BER of 2×10^{-4} at the output of the Viterbi decoder, which is the correct operating point for these comparisons. These results demonstrate that the modified measurement procedure proposed in Section 7.0 in the TimeDerivative comment is unnecessary.

3.3 MBOA field test results are valid and reflect real world environments

MBOA tests that were conducted using an actual C-band satellite receiver showed that MB-OFDM poses a smaller interference threat than a class of pulsed UWB devices[18]. The tests were performed by comparing the interference potential of MB-OFDM, direct sequence UWB and impulse radio UWB sources when placed in the near field of a C-band satellite dish. A more detailed description of the tests is contained in Attachment C for review.

Based on the observation of consumer C-band satellite reception sites around the Austin, Texas area (where the field tests were performed) it became apparent that there was no practical case of getting the UWB interference source into the far field of the satellite dish unless it was airborne. Furthermore, to trigger disturbances in the satellite's reception (at the PSD levels allowed in

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[16] The actual 'uncoded' BER can be simply computed as BER = $1/2 erfc(\sqrt{E_c / N_0})$ = 5 x 10^{-2} for *Ec/No* = 1.1 dB.

[17] See top of page 9 in the TimeDerivative comment.

[18] Test performed from Dec.8th to 18th 2003, at TDK RF Solutions Antenna Cal Range, FCC Registration No.: 94066, NVLAP Accreditation No.: 200430-0.

FCC Part 15, Subpart F), required that the interference source be located close to the dish antenna. In other words, the only practical place to locate the UWB device for this test was in the antenna's near field. This was the case even when the disturbance source was aligned within the main beam of the dish (a case which is fairly difficult to achieve, refer to Attachment C where a 40 foot mast is mentioned).

In their comments on MBOA tests:

1. Freescale (p14) argues that the MBOA field measurements are invalid since they were taken in the near-field of the C-band satellite dish where they assert that "results are essentially random[19]"

2. Freescale (p14) also argues that the MBOA field tests were conducted by "moving sources around the near field and side lobes of a C-band satellite dish".

These comments leave out important clarifications. In order to arrive at a correct interpretation of the field measurements and their implications, it is important to point out that there were **two major** tasks that were completed during the C-band field measurements: a) Same Position Testing and b) Separation Distance Testing. In addition, it is also important to correctly identify near field versus far field artifacts and phenomena, as they have been confused or exaggerated within the Freescale document.

The MBOA field measurements were divided into two phases: Same Position Testing and Separation Distance Testing.

1. **Same Position Testing**: In the first phase of this field test, **the position of the interference source was kept constant** as the waveform was varied between OFDM, direct sequence UWB and impulse radio UWB. The PSDs of the various waveforms were calibrated and made equivalent. For the Same Position Testing the coupling mechanisms (electromagnetic environment, test geometry, polarization, etc.) between the satellite dish and the discone antenna was the same for all three waveforms. Hence, Freescale's near field variation argument is invalid for the first phase of this field test since **there was no motion of the interference source with respect to the satellite dish**. The results of this test are shown in the table below, which demonstrates that MB-OFDM waveforms are uniformly less harmful than 3 MHz PRF impulse radios when tested in real world systems, and that the differences among the various waveforms are MUCH less than those claimed by Freescale. In no case does the difference between MB-OFDM and DSSS systems exceed 1.6 dB as compared to the 5-9 dB claimed by Freescale. In addition, both MB-OFDM and DSSS systems show less harm than 3 MHz PRF impulse radios that are anticipated in the rules.

[19] Ibid at 7, p. 15.

Table 3: Relative interference potential measurements (positive dB values mean that more average interference power could be tolerated, relative to the 3 MHz PRF impulse radio, while still meeting the interference criteria as discussed in more detail in Attachment C).

Emission	0.5dB above sensitivity	1dB above sensitivity	2.5dB above sensitivity
3MHz PRF impulse	0.0dB	0.0dB	0.0dB
MB-OFDM 3 band	0.8dB	2.6dB	2.4dB
WGN (DSSS)	1.9dB	3.8dB	4.0dB

2. **Separation Distance Testing**: The second phase of testing involved the movement of the interference source in the near field and around the perimeter of the satellite dish as would be encountered in a typical interference scenario.

   It is worth noting that high gain large aperture antennas, such as satellite dish antennas, are primarily designed using near field measurement techniques and microwave holography. This fact alone should dispel any notion that there is a random nature to these measurements and that useful information cannot be gained from near field measurements.

   The results of this test are shown in the following figure, which demonstrates that the separation distance required for different UWB waveforms in a real world environment are small and very unlikely to be encountered in a practical setting.

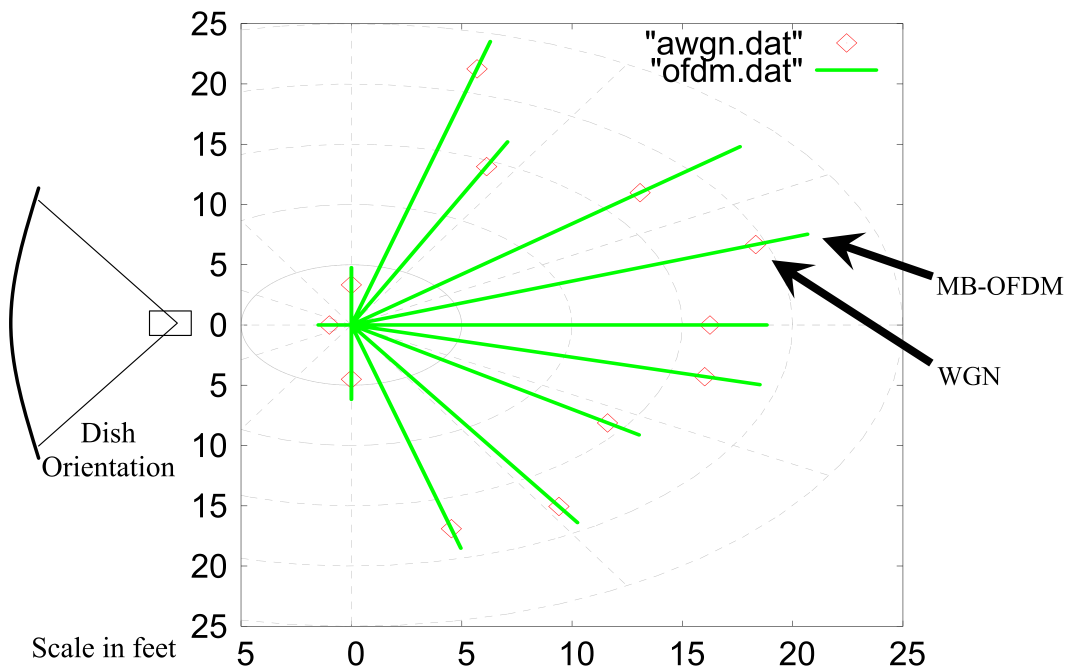


Figure 4: Safe distance from dish

Freescale's arguments with regards to the MBOA satellite tests are flawed for the following reasons:

1. Contrary to Freescale's statement about the measurement "randomness", the near field is anything but random. Co-polarized and cross-polarized near field data of large aperture antennas (such as C-band satellite dishes) exhibit stable amplitude and phase distribution across any given plane or planes of measurement. This near field stability is a major reason for the repeatability of the Same Position Test that Freescale failed to comment on in their filing.

2. Freescale misunderstood the ability for near field coupling based on spatial field distributions. The relationship between the Electric (E) and Magnetic (H) fields in the near field is indeed complex and includes higher order inverse distance terms. The measurement data revealed a trend relating the interference waveform to the "safe" (non-interfering) distance to the satellite dish along evenly spaced radials. This data did not show the marker flags randomly scattered with "no apparent pattern" as claimed by Freescale. It is clear that one waveform disturbs more than the other, but not nearly to the degree claimed in previous Freescale studies.

3. MBOA tests are practical, realistic and conservative. Given the geometry of Fixed Satellite Systems, practical and realistic interference scenarios take place in the near field

and around the perimeter of the satellite dish. The tests were also conservative in that the interfering source was always placed in the near field to allow more source power to be coupled to the satellite dish.

4. Finally, some of Freescale's arguments concerning the near field are contradictory and exaggerated.

   a. Claims are made that the MBOA tests suffer simultaneously from both near field ("random effects") and far field ("side lobes") phenomena. This effectively leads to conflicting conclusions. As stated earlier, satellite dish antennas are predominantly designed with near field measurement data. There is nothing random associated with the near field or its behavior. Side lobes (as used by Freescale in their comments) are artifacts of the far field. It is quite difficult to get nulling, and therefore sidelobes, in the near field (particularly off the main axis).

   b. While the MBOA does not argue that the measurements are in the near field (for practical reasons), Freescale's definition of the near field boundary is exaggerated for dish antenna use giving the misconception that the measurements are off by orders of magnitude. The classical definition of the far field boundary condition starting at $2D^2/\lambda$ is entirely too conservative for dishes (a fact commonly brought out in radiation hazard studies for maximum permissible exposure to human subjects). Empirical field studies have shown that the power density starts to decrease as the inverse square law at around $0.6D^2/\lambda$[20].

To summarize, two sets of measurements were undertaken: one with a fixed position and one with relative motion to the radial axis of the dish.

a) Fixed position results with different waveforms using the same PSD applied to the system consistently showed MB-OFDM to be less interfering than a 3 MHz impulse radio and no more than 1.6 dB from WGN.

b) Radial axis measurement results showed that in realistic usage scenarios the difference between the waveforms is also comparable (within a meter).

3.4 MBOA technical comparisons are correct and clearly show MB-OFDM waveforms do not cause more harm than impulse radios

It is known that different UWB waveforms will interfere to different degrees to victim receivers, even under conditions where the average power spectral density from the different interference sources is identical. The statistical distribution of the waveform plays a strong role in determining the interference impact as does the duration of peaks above the mean value.

[20] See http://www.radhaz.com/satellite.htm, for example.

Given the range of possible waveforms permissible under the Commission's rules, it is to be expected that some waveforms will cause more interference than others. Our contention is that the MB-OFDM waveform falls within the range of interference potential that was already anticipated by the rules. We identify an important class of UWB waveforms that were studied extensively during the rule-making process, which we have found by experiment and simulation to be more interfering than our proposed waveform: namely, low PRF impulse radios. Specifically, we refer to impulse radios where the PRF is significantly less than the bandwidth of the victim receiver. One important case that has been studied by both sides is interference to TVRO satellite receivers, of approximately 30MHz bandwidth.

MBOA companies as well as those who oppose MB-OFDM technology have studied essentially the same systems: e.g., 1MHz impulse radio and MB-OFDM transmitters as interferers and 30MHz QPSK victim receivers to represent a TVRO receiver. Freescale in their 'Technical Analysis Of The MBOA-SIG Petition for Waiver (PFW)' at page 12 in Figure 4 have shown results requiring a 4.5 to 5dB increase in signal power in the case of MB-OFDM relative to DS-UWB to recover the same error rate at the output of the Viterbi decoder. Their figure is reproduced below as Figure 5 for ease of reference.

It is important to note that Freescale chose to perform simulations in the absence of any Gaussian or thermal noise whatsoever. This can be observed from the definition they provide for the Eb/No given in the figure title, viz., "Eb/No after Viterbi decoder, where No is the RMS interference power." Hence, it is clear that simulations were performed with the only impairment being the interference source (*i.e.*, corresponding to $I/N = \infty$). This condition strongly emphasizes the impact of the interference, and has no corresponding physical equivalent in the real world. It is as if the receiver were cryogenically cooled to zero degrees Kelvin, a purely theoretical state known as "absolute zero".

3.4.1 Simulations Under Conditions of Zero Thermal Noise

Notwithstanding that we find the choice of $I/N = \infty$ unwarranted, MBOA companies have made good faith efforts to reproduce the result obtained by Freescale. New simulation results are presented in this sub-section trying to replicate as closely as possible the simulation conditions used by Freescale. Following this section, simulations and laboratory measurements representing more reasonable conditions (i.e., finite I/N ratios) were carried out and are reported in the following sub-section 3.4.2.

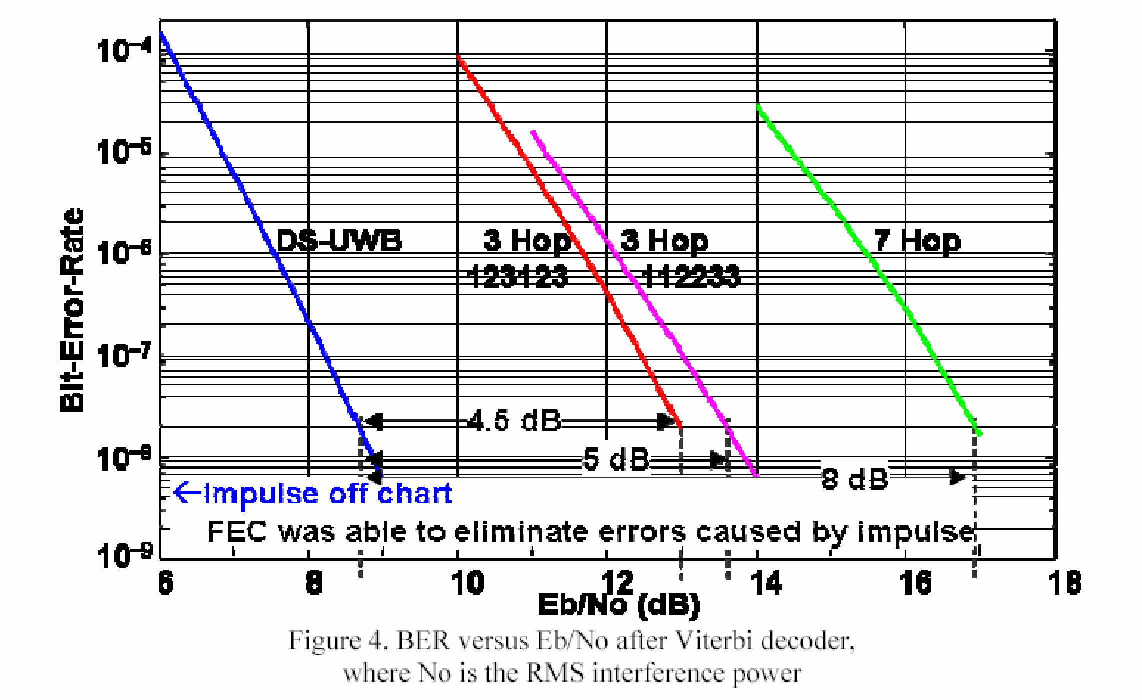


Figure 5: Freescale's Simulation Results under Noiseless Conditions

Referring to the above figure Freescale concludes that "the impulse is least interfering, DS-UWB is next, and the MB-OFDM proposed under the waiver causes the greatest interference. The errors caused by the 1 MHz PRF impulse system were completely corrected by the FEC".

In order to investigate this claim, we simulated a 33MHz bandwidth QPSK system, using FEC parameters taken from EN 300 421 V1.1.2 for the inner FEC. Both 7/8 and ¾ code rates were selected for simulation.

In an attempt to reproduce the results obtained by Freescale, the first simulations were done with $I/N = \infty$ (*i.e.*, the only channel impairment was the interference source).

Initially, uncoded QPSK results were obtained as shown in Figure 6. The graph contains traces for uncoded BER as impacted by MB-OFDM using both 1,2,3,1,2,3, and 1,1,3,3,2,2, TFI sequences, by White Gaussian Noise, and by a 1MHz PRF impulse UWB signal. The theoretical BER equation for the case of Gaussian noise is also plotted. Root raised cosine filters are used at transmitter and receiver.

Note that the uncoded QPSK BER matches the theoretical equation given by $BER = 0.5\,\mathrm{erfc}\left(\sqrt{E_b/N_0}\right)$. Both types of MB-OFDM waveform have identical uncoded BER curves, which are offset by about 3dB compared to the AWGN noise case. The impulse radio, however, requires a much higher Eb/Io to obtain low BER than the MB-OFDM waveforms. This can be expected because of the more extreme duty cycle in the time domain.

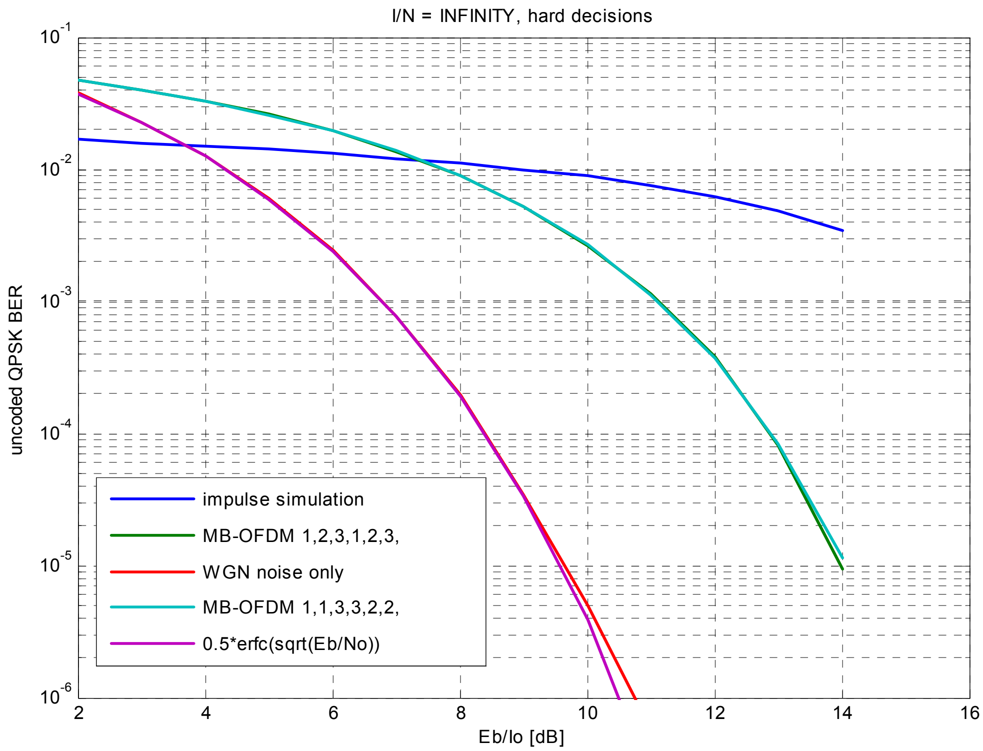


Figure 6: Uncoded QPSK Results Under Noiseless Conditions

In order to understand the BER for the impulse simulation, consider that for a 1MHz PRF, the duty cycle of impulse waveform as measured in the victim receiver bandwidth of 30MHz is approximately 1 in 30. Thus, the energy of each impulse that occurs is approximately 30 times greater than the impacted QPSK symbol, assuming both signal and interferer have equal power. Given this 30:1 ratio, an Eb/Io of approximately 12dB is required to make the impulse of equal amplitude to the impacted QPSK symbol. The actual number of bits in error for each collision depends on the relative phase of the QPSK symbol and the interfering impulse, and on the timing offset between the impulse and the sampling point used for decimation by the TVRO satellite receiver. Assuming that the worst case timing has occurred, the maximum number of induced errors per collision is given by the following table.

Condition	**Applicable Eb/Io (for BW/PRF=30)**	**Max[21] number of induced errors per event**
$\text{abs}(impulse) \geq \text{abs}(QPSK)$	**<12dB**	**2**
$\text{abs}(QPSK) > \text{abs}(impulse) \geq \text{abs}(QPSK)/\sqrt{2}$	**12-15dB**	**1**
$\text{abs}(impulse) < \text{abs}(QPSK)/\sqrt{2}$	**>15dB**	**0**

In order to properly model the impact of relative phase between the interfering impulse and the wanted QPSK symbols, the impulse waveform was generated with a randomly chosen absolute phase uniformly distributed between 0 and 2π.

It is important to consider that relatively high energy of the impulse waveform, as measured over the duration of the QPSK symbol impacted by a collision, may result in a highly confident soft decision metric for that QPSK symbol, whereas the value of at least one of the corresponding bits is likely to be wrong. **These confident, but wrong soft decisions in the case of impulsive interference were found to have a potentially significant impact on the correct trace-back of the Viterbi algorithm.** In order reduce the potential for large disturbances to the path metrics, we applied a clipping algorithm[22] to the soft decisions before processing them with the Viterbi algorithm. Failure to do this could increase the impact of the impulse interference well beyond that shown in the figures below.

[21] For very large magnitude impulses, the side lobes of the receiver filter impulse response may induce additional errors, if the dynamic range of the receiver permits. Our simulations modeled this too.
[22] We selected the clipping level to be 50% higher than the mean of absolute values of the soft decisions vector.

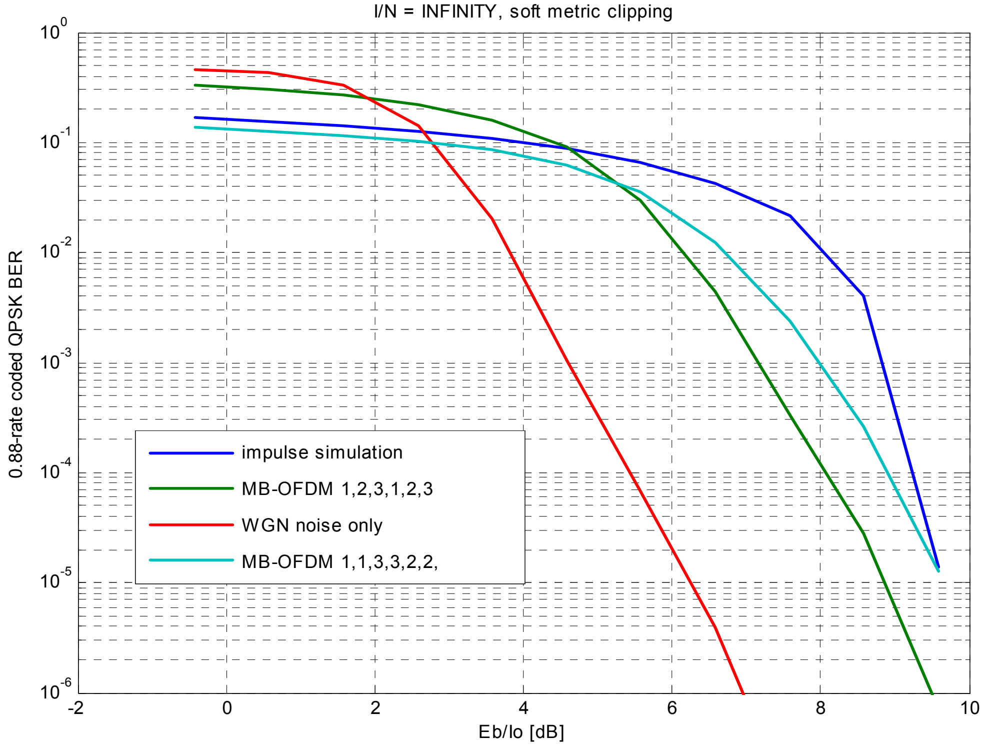


Figure 7: 7/8-Rate Coded Results Under Noiseless Conditions

The above Figure 7, should be comparable with Figure 4, from the Freescale Technical Analysis document, reproduced here as Figure 5. Comparing the graphs, we find a 2.8dB – 3.8dB increase in required Eb/Io for the two MB-OFDM waveforms relative to the pure WGN interference measured at $BER = 2\times10^{-4}$. (Bear in mind that the plots have been produced under the unrealistic condition of $I/N = \infty$. More representative results at reasonably chosen I/N ratios will be presented in the next sub-section.)

The impact of the impulse waveform, far from being off the chart, remains higher than either of the MB-OFDM waveforms. This is a major discrepancy between the two sets of results. **However, further consideration shows that there simply must have been some decoding errors for the rate 7/8 code if the impulse interference was correctly modeled**. The logic behind this conclusion is as follows:

1. It is known that the 7/8 rate code has a free distance $d_{free} = 3$.
2. It is further known that for Eb/Io<12dB, double bit errors are possible, with increasing likelihood as Eb/Io is reduced.
3. When two consecutive errors occur, an incorrect decoded sequence may exist with a shorter hamming distance to the received sequence than the transmitted one. Therefore,

two consecutive errors[23] may be sufficient to cause incorrect trace-back. This will not happen for every double error event, but it will happen quite frequently.

4. Finally, we can state that under the range of Eb/Io used for the Freescale simulation experiment numerous decoding error events <u>should have been</u> observed.

Since the above argument is expressed in terms of hard decision decoding principles, we may expect the predicted result to hold for hard decision decoding. As a test of this, the above simulation was repeated with hard decision decoding, even though this would not be a compliant implementation for a Digital Video Broadcasting terminal.

As can be observed, similar results were obtained, except with the usual 2dB offset for hard decision decoding. Also, the break-point between double and single error events can be observed for the impulse interferer at around Eb/Io=12dB.

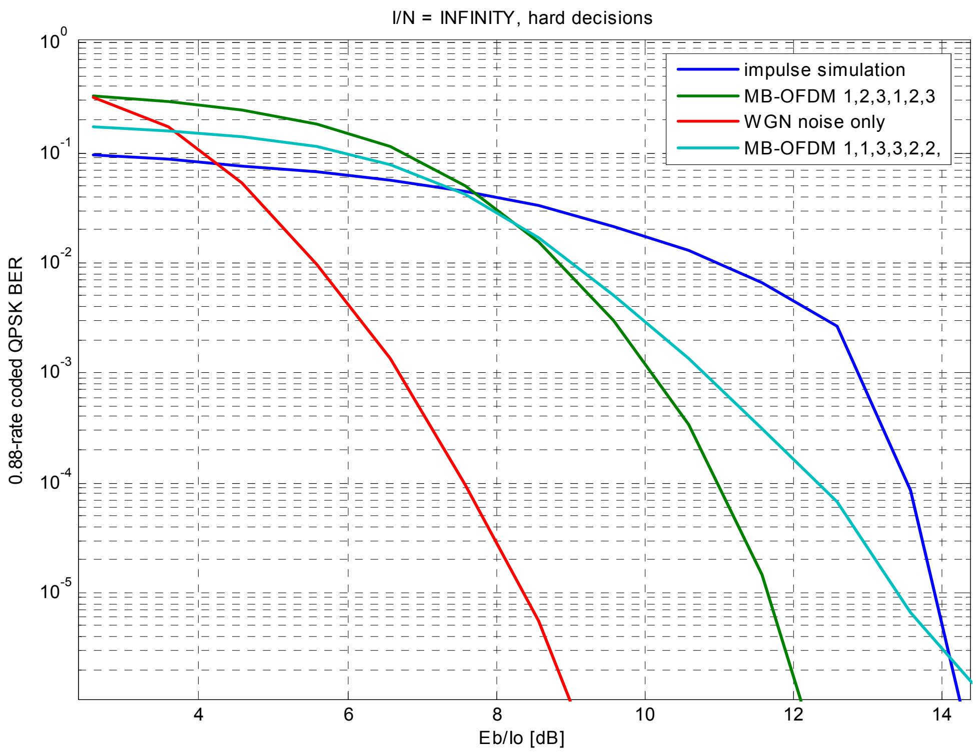


Figure 8: 7/8-Rate Coded Results Under Noiseless Conditions, with hard decision decoding

Finally, it should be restated that these 'Noiseless' results should have no bearing on this proceeding, since they do not reflect actual operating conditions of real systems. They were included here to try and replicate Freescale's results and try and provided a link between

[23] For the DVB system specified in European Standard EN 300 421 V1.1.2, no interleaver is used to protect the inner convolutional code from the channel, although an interleaver is used between the inner convolutional code and outer Reed-Solomon code.

Freescale's results and what happens in realistic environments. However, even using aggressive clipping algorithms and even hard decision decoding to prevent the propagation of strong impulse signals impacting Viterbi metrics, we were not able to replicate Freescale's results and we even explained why Freescale's results don't even match theoretical expectations. However, these results showed that, even in this theoretical 'Noiseless' environment, MB-OFDM systems are still less interfering than impulse radios already allowed by the rules. The following sections present more realistic results based upon simulations and lab measurements which is more relevant to this proceeding.

3.4.2 Simulations with Finite I/N_{sys} Ratios

In the following series of plots, we have introduced a realistic I/N_{sys}[24] ratio, in contrast the previous simulations and Freescale's plot, which had $I/N_{sys} = \infty$. In order to match the conditions used for practical experiments, a rate ¾ FEC is used. The soft decision metrics have once again been clipped in a manner realistic for a practical implementation.

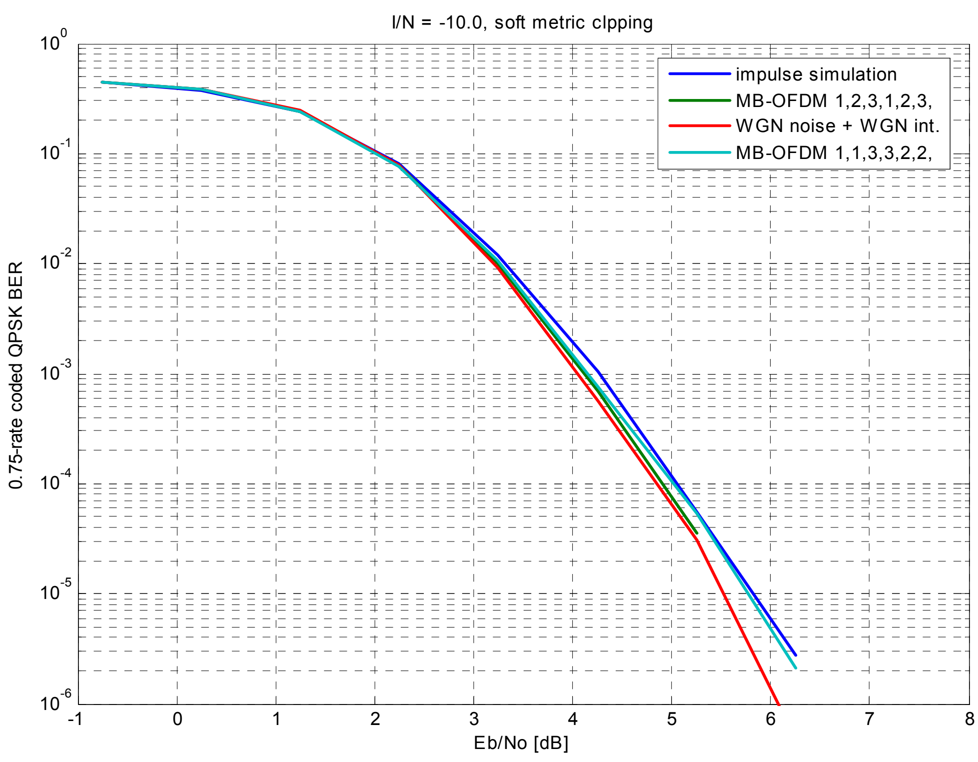


Figure 9: 3/4-Rate Coded Results with I/N_{sys} =-10dB, soft decision decoding

24 In the following Sections, $I/N_{sys} = I/(N+I_{sat})$ refers to the interference-to-system-noise ratio, where the system noise includes the contributions of thermal noise (N) plus intra-system interference from the satellite systems (I_{sat}).

From the above results at I/N_{sys} = -10dB, we can see little difference between the impact of MB-OFDM and an equivalent amount of thermal noise. The 1MHz impulse radio shows a 0.3dB offset at $BER = 2 \times 10^{-4}$.

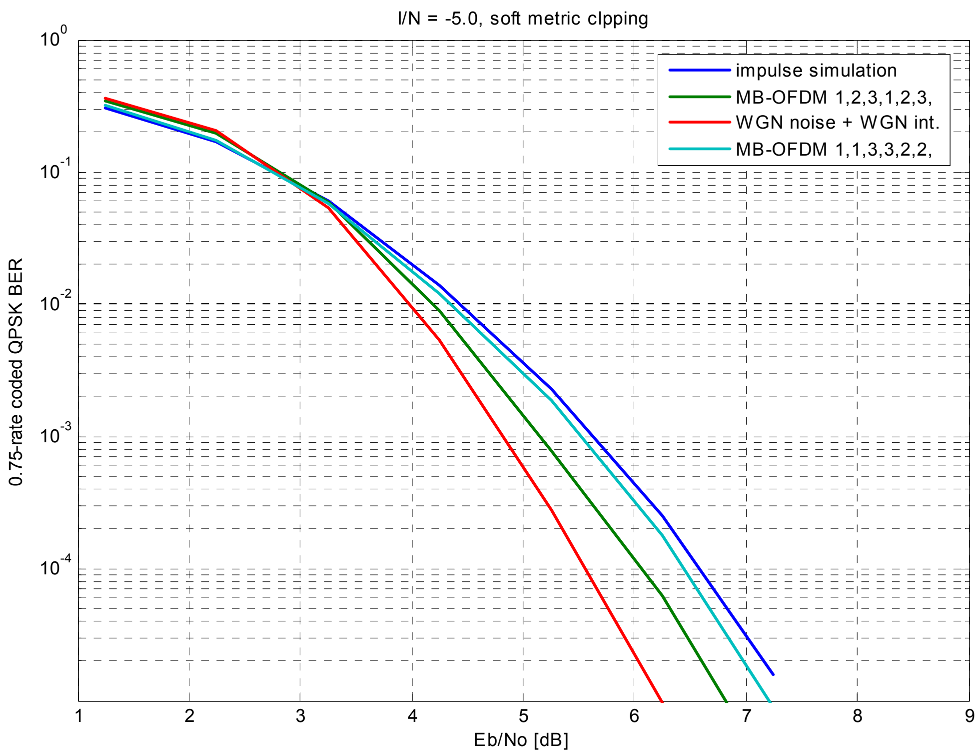


Figure 10: 3/4-Rate Coded Results with I/N_{sys} =-5dB, soft decision decoding

The same simulations have been repeated with I/N_{sys} = -5dB. Now the difference between the two types of MB-OFDM waveform, and the case where the interferer is WGN, is 0.5 to 1dB. Again the 1MHz impulse radio is worst case of the waveforms studied.

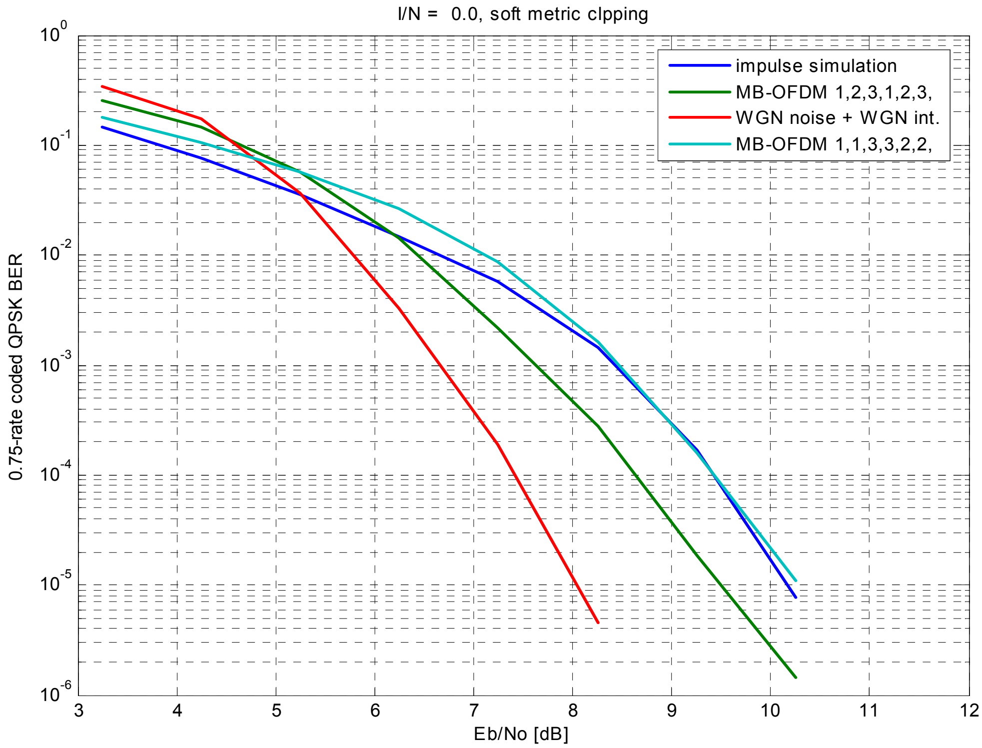


Figure 11: 3/4-Rate Coded Results with I/N_{sys} =0dB, soft decision decoding

For the above simulation, the I/N_{sys} ratio was set to 0 dB. This is regarded as an extreme case[25], since it is rare to find physical geometries where the UWB interference power equals the total of thermal noise and other satellite interference. The red curve that shows the combined effect of a Gaussian noise source and a Gaussian interferer is offset by exactly 3dB compared to the case of only thermal noise. The impact for changing the interferer type from Gaussian to an MB-OFDM or impulse radio can be read from the graph by reading the Eb/No value where the curves intersect $BER = 2 \times 10^{-4}$. These differences are approximately 1.2dB for MB-OFDM (1,2,3,1,2,3), 2.0dB for MB-OFDM (1,1,3,3,2,2) and also 2.0dB for impulse radio with a 1MHz PRF. These results clearly show that MB-OFDM is less harmful than impulse radios already allowed by the rules, and only marginally worse than WGN, even in this worst case scenario.

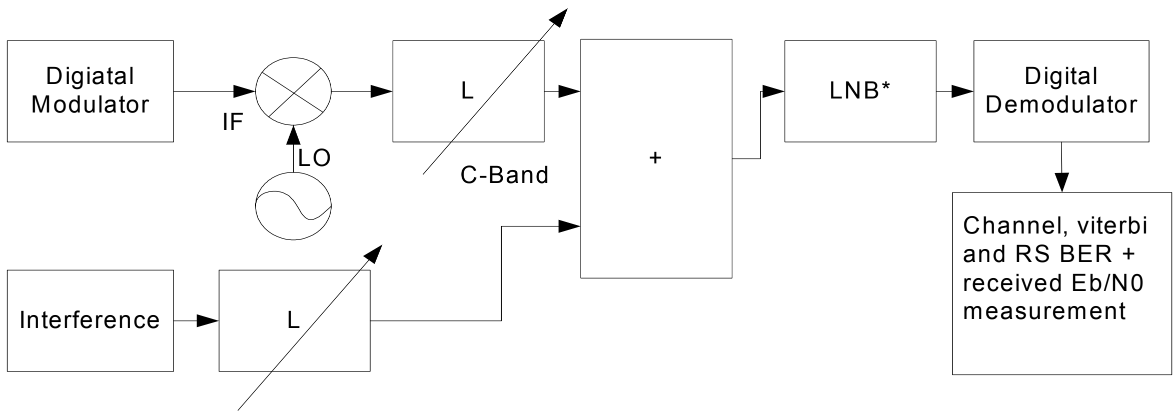
Again, these extreme cases show worst-case results in the relative comparisons between various UWB waveforms. Based upon our field measurements (see Section 3.3 and Attachment C), the satellite system only had a 2.5 dB link margin, so an I/N_{sys} = 0 dB would have completely

[25] The FCC criteria for C-band interference was I/N=0 dB referenced to thermal noise. For realistic intra-system satellite interference (see Section 2.1.1 for a detailed discussion of this), this results in an I/N_{sat} = -3.8 dB, so an I/Nsys=0 dB is considered extreme and even higher than the FCC criteria, and a more realistic I/N_{sys} would be less than -3.8 dB (typically much less…again, see Section 2.1.1 for other examples).

removed that available link margin for any UWB signal. In more practical scenarios, the interference should be well below the system noise floor (I/N_{sys}<-5 dB or more).

3.4.3 Lab Measurement Results of interference to C-Band satellite receivers

Measurements were made with a digital C-Band victim receiver in a carefully calibrated laboratory environment using the setup shown in Figure 12 and Figure 13. The tests were performed for 2.5 Msps and 20 Msps setups with rate ¾ convolution code concatenated with an RS encoder. The measurement results matched with simulation results when considering measurement accuracy and implementation degradation.



Remark: *LNB sets the initial noise level. Interference is added on top.

Figure 12: Measurement set-up block diagram

Results are shown in Figure 14 and Figure 15, which demonstrate that MB-OFDM is less interfering than a 1 MHz pulse system allowed by the current FCC rules under realistic operating conditions and similar to simulation and analysis results. No difference can be seen between MB-OFDM and AWGN for 2.5 Msps receivers.

Figure 13: Measurement set-up

These results used different working points to account for realistic I/N_{sys} values similar to those used under FCC analysis and even higher:

- Working point #1: Eb/No of 1 dB above sensitivity to allow interference of up to I/N_{sys} =-6 dB for an AWGN interference before reaching the sensitivity threshold.
- Working point #2: Eb/No of 0.5 dB above sensitivity to allow interference of up to I/N_{sys} =-9 dB for an AWGN interference before reaching the sensitivity threshold.

We expect that under real life scenarios the I/N_{sys} will be much lower. We also expect that the victim receiver will have more link margin. We selected these working points to show that even under these worst case scenarios (i.e. large I/N_{sys} values and small margin in the victim receiver link) MB-OFDM signals cause less interference than signals already allowed by the rules. We observe that the differences between the different types of interference become smaller as I/N_{sys} decreases. This is intuitive due to the fact that in realistic scenarios the victim receiver will mainly see the thermal white Gaussian noise and other satellites interference (Isat). Under these conditions the victim receiver will not be able to differentiate between the different UWB interference types, since they are much lower than other noise sources.

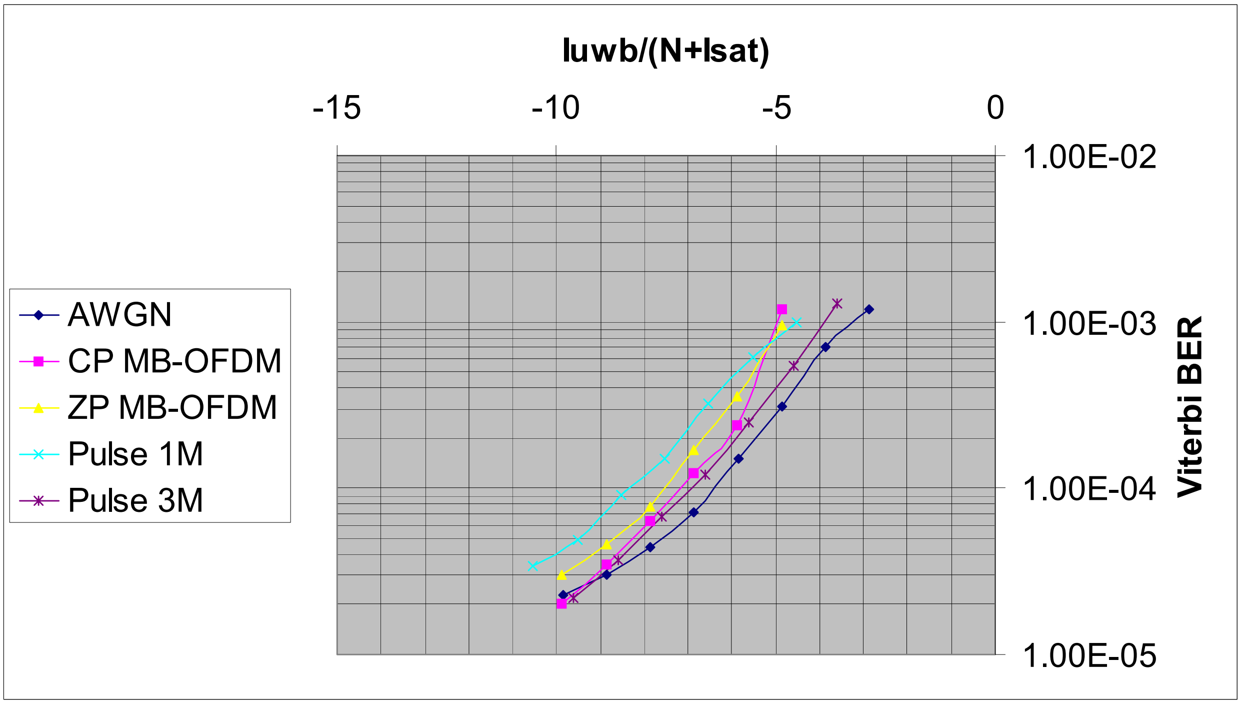


Figure 14: Eb/No 1 dB above sensitivity (BER=2e-4)

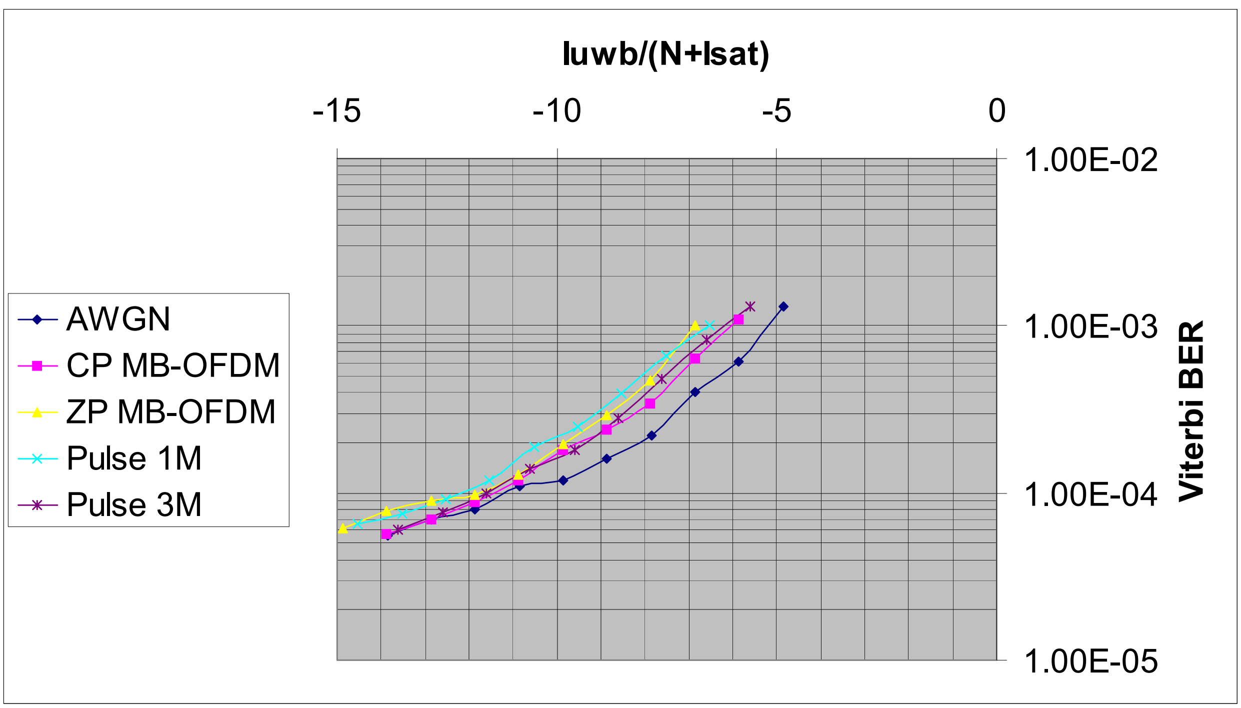


Figure 15: Eb/No of 0.5 dB above sensitivity (BER=2e-4)

3.4.4 Calculated BER for a QPSK/BPSK Victim Receiver

Decawave takes an analytic approach to predicting the BER of QPSK/BPSK as impacted by an MB-OFDM interfering waveform. While the approach is sound in principle, it is marred by basic arithmetic and mathematical errors. When these are corrected, some valid plots of BER versus SIR can be produced in the style of the Decawave Comments Submission.

Decawave's submission under the heading of Case 1 AWGN Error Rate, starts off with an the well-known probability of bit error for BPSK, viz.:

$P_{en} = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{g^2T}{\sigma_n}}\right)$, where (using rather unconventional notation), σ_n is taken to be the variance of the noise measured in the receiver bandwidth, and g^2T is taken as the received signal power. Decawave's submission then incorrectly states that

$$P_{en} = 1\times10^{-6} \Rightarrow \frac{g^2T}{\sigma_n} = 3.4$$

This fails to take account of the square root sign in the given equation for the error rate, thus the correct statement should have been:

$$P_{en} = 1\times10^{-6} \Rightarrow \frac{g^2T}{\sigma_n} \approx 3.4^2$$

Thus in the equations that follow, the value 3.4 should be replaced by 3.4^2. For example, the probability of error for the DS-UWB + AWGN should have been written as:

$$P_{ec} = \operatorname{erfc}\left(\sqrt{\frac{1}{\left(\frac{1}{3.4}\right)^2 + \frac{\sigma_c}{g^2T}}}\right) \quad \text{rather than} \quad P_{ec} = \operatorname{erfc}\left(\sqrt{\frac{1}{\frac{1}{3.4} + \frac{\sigma_c}{g^2T}}}\right)$$

A further algebraic error occurs under the heading Case 3 MB-OFDM + AWGN error rate. Decewave assumes that during the active part of the duty cycle the *variance* is multiplied by *square root* of the duty factor, $\sqrt{m}$. In fact, the variance is increased by the duty factor m. (The noise power/variance is m times as powerful, for $1/m$ of the time.)

The probability of error for MB-OFDM should, therefore, have been written as:

$$P_{em} = \frac{1}{2m}\operatorname{erfc}\left(\sqrt{\frac{1}{\left(\frac{1}{3.4}\right)^2 + \frac{m\sigma_c}{g^2 T}}}\right) + \frac{(m-1)}{m} 1\times 10^{-6}$$

rather than,

$$P_{em} = \frac{1}{2m}\operatorname{erfc}\left(\sqrt{\frac{1}{\frac{1}{3.4} + \frac{\sqrt{m}\sigma_c}{g^2 T}}}\right) + \frac{(m-1)}{m} 1\times 10^{-6}.$$

Using the corrected form of these equations, it is simple to write a short MATLAB® script to provide a corrected version of figure 2 in the Decawave Comments submission:

```
eb=1;  % arbitrary unit bit energy
m=3;   % duty cycle
bert=1e-6;  % asymptotic target BER
sir=linspace(1,30);
linsir=10.^(sir/10);
i0=eb./linsir;
n0=eb/(erfcinv(2*bert)^2);
a=sqrt(eb/n0);
pem=(1/(2*m))*erfc(sqrt(1./((1/a)^2+m*i0/eb)))+(m-1)*bert/m;
pec=0.5*erfc(sqrt(eb./(n0+i0)));
figure(1)
semilogy(sir,pem,sir,pec)
legend('BER MB-OFDM','BER DS-UWB')
xlabel('SIR [dB]')
ylabel('BER')
grid
```

The resulting plot is shown in Figure 16. However, it should be noted that this corresponds to an unrealistically low target *uncoded* BER of 10^{-6}. If the system employs FEC, the target uncoded BER should be between 10^{-2} and 10^{-3}. Changing the target BER to 10^{-3} resulted in the plot shown in Figure 17.

Finally, we deal with a logical flaw in section 2 of the Decawave Comments, which states that "This error rate curve demonstrates that MB-OFDM creates greater interference than was anticipated by the FCC when the UWB rules were made." This statement assumes that interference performance of DS-UWB was the only interference type anticipated by the FCC, when the rules were formulated, and that DS-UWB is thereby the standard by which other waveforms must be judged. This construction totally ignores a large class of waveforms that were the very foundation of UWB technology, namely impulses.

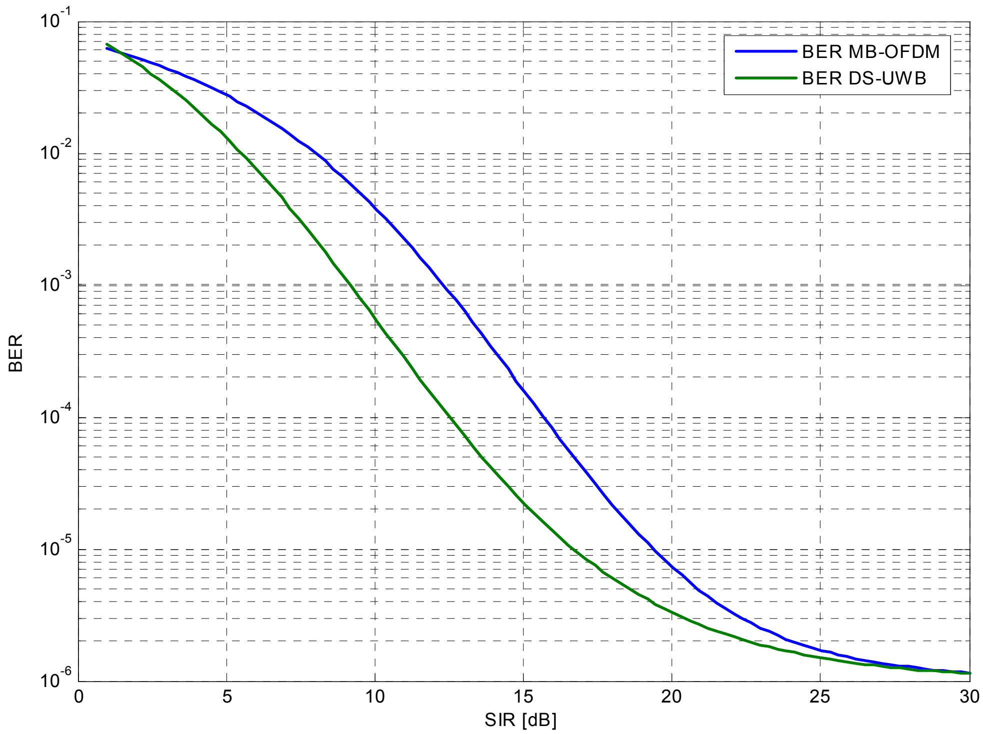


Figure 16: BER vs. SIR for MB-OFDM compared to DS-UWB for a noise-limited BER of 10^{-6}

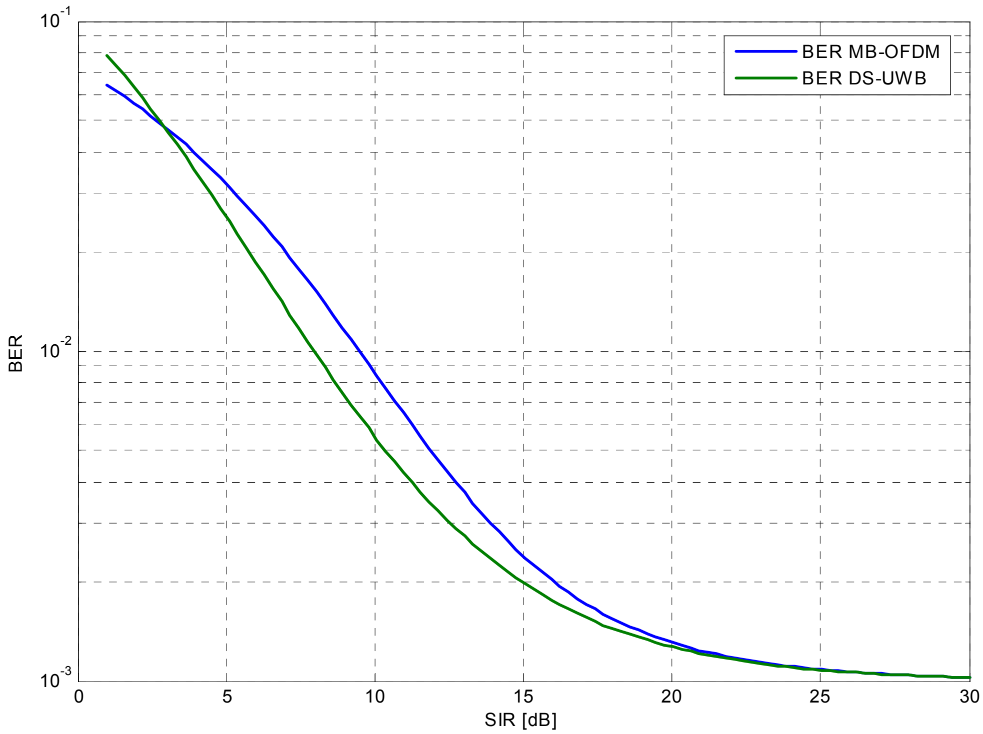


Figure 17: BER vs. SIR for MB-OFDM compared to DS-UWB for a noise-limited BER of 10^{-3}

3.4.5 Conclusions

Comparison of the interference impact of various UWB waveforms must be done considering a non-zero system noise power, based on a finite I/N_{sys} ratio, in order to be representative of a potential real world scenario. Nevertheless, in a good faith effort to reproduce Freescale's simulation results for the noiseless case, simulations were carried out with the noise floor removed. Even when this was done, we were not able to see the 4.5 to 5dB offset reported by Freescale; a more modest offset of 2.8 – 3.8dB was observed (see Figure 7). More significantly, the 1MHz impulse radio resulted in an even higher offset, rather than being completely corrected by the FEC per the Freescale results.

In order to investigate claims that the errors induced by the impulse radio were completely corrected by the FEC, a logical argument was developed that showed that this simply could not be the case for the rate 7/8 code used in the Freescale simulations. Furthermore our own simulations with hard and soft decision decoding confirmed this point.

Moreover, simulations were conducted with finite, defined I/N_{sys} ratios of –10, –5 and 0dB, with soft decision decoding enabled. The relative severity of the impact of the different waveforms was consistent throughout these simulation experiments: AWGN being the most benign, followed by MB-OFDM (1,2,3,1,2,3), then by MB-OFDM (1,1,3,3,2,2) and finally by the 1MHz PRF impulse radio[26]. The absolute severity of the impact had a strong dependency on the assumed I/N_{sys} ratio. Even in the extreme case of I/N_{sys} =0dB, the worst-case MB-OFDM (1,1,3,3,2,2) waveform resulted in only a 2dB offset compared to the case where the interferer was selected to be White Gaussian Noise, but it was still more benign than a 1 MHz impulse radio.

Finally, a laboratory experiment was made using conducted measurements to crosscheck the simulation results. As can be observed, broadly similar results were obtained: the 1MHz impulse radio being the worst case, MB-OFDM waveforms somewhere in the middle, and Gaussian noise being the best case in both plots (see Figure 14 and Figure 15). The offset between the MB-OFDM waveforms and the case where the interferer was selected to be a Gaussian Noise, was again found to be in the range of 1.5dB to 2dB at $BER = 2 \times 10^{-4}$.

Analytical expressions for BER in the presence of combined noise and interference were also presented, based on a corrected version of Decawave's Comments. These showed a maximum offset of <1.5dB, when a noise limited, uncoded BER of 10^{-3} was assumed, which are consistent with the previous simulation and lab measurements.

3.5 APD analysis provided by MBOA-SIG is VALID

Since November 2003, MBOA companies have published many APD plots at the IEEE[27]. Although several different conventions were used in how these plots were presented, this did not impact the coordinate pairs that can be read from these graphs, and therefore could not change the derived conclusions. The MATLAB code from the NTIA for APD analysis was first made available to the IEEE on August 25th, 2004[28], a useful contribution that will no-doubt improve the readability of future publications. In fact, some of the plots undertaken in later work by the MBOA were repeated using the recently published NTIA MATLAB routines, in order to prove this point. The results were unchanged, although the presentation was improved. See Figure 18 and Figure 19 for some examples.

A significant charge by Freescale is that the MBOA has doctored APD plots by mixing them with an arbitrary amount of Gaussian noise. In fact the MBOA has generally plotted APD for a wide range of I/N_{sys} ratios, including in some instances zero noise power. The rationale for not always using zero noise power is that we would like to illustrate the situations that are likely to be encountered in practice in realistic geometries. If it were assumed that I/N_{sys} > 0 dB are a likely occurrence, then even the most benign interferer waveform would often cause a reduction

[26] In one case, the 1,1,3,3,2,2 MB-OFDM was identical to the 1MHz PRF impulse radio within the statistical error range of the simulations.
[27] See IEEE 802.15-03/506r0, "UWB Interference Comparison" from Wisair, November, 2004
[28] See IEEE 15-04-0428-00-003a, "Estimating and Graphing the Amplitude Probability Distribution Function of Complex-Baseband Signals" from the NTIA, August 2004.

in link budget of the victim by at least 3dB! Hence we do not consider 0dB or higher I/N_{sys} ratios as normal, but rather exceptional and improbable cases. Nonetheless, we have provided APD plots using as high an I/N_{sys} ratio as +20dB[29], to allow the Commission to study the MB-OFDM waveform in isolation, if desired, although we maintain that comparisons made under unrealistic operating scenarios are irrelevant to this discussion. However, the MBOA has published theoretical equations to predict the APDs of MB-OFDM waveforms of any given duty cycle and any desired I/N_{sys} ratio for interested parties to use.

Another comment by Freescale on the subject of APD plots is that they are not susceptibility tests and are blind to time-scale effects. We concur with this as factually correct. However, the use of APD plots can still provide valuable insight into a given waveform's potential to cause interference. For example, in the case of analog C-band transmissions, the best estimate of difference in required Signal to Interferer ratios can be obtained from the APD plots, considering a reasonable I/N_{sys} ratio. Even in the extreme and improbable case that the I/N_{sys} ratio is as high as 0dB, we can read from the APD graphs that the difference in required SIR cannot exceed 3.4dB at a probability of exceeding the ordinate of 0.0001%. Clearly, to obtain measured differences of between 5 and 6dB, highly positive I/N ratios would be required (in excess of 8dB). However, such a high I/N ratio, even were it feasible in some unlikely geometry, would easily exceed the link margin of the satellite link and cause it to fail regardless of which type of UWB interferer was present. Therefore, from the APD analysis alone, it seems unlikely that subjective observations of Analog C-band TV reception, under realistic conditions, could confirm the 5 dB extra required SIR as claimed by Freescale on page 9 of their Opposition to this petition. However, we also understand the limits of APD analysis and recommend that APD plots be considered as just one source of information along with other relevant data to obtain the best overall assessment of the likely interference impact.

[29] See Figure 4 in comments of Philips Electronics North America Corporation on this docket (04-352).

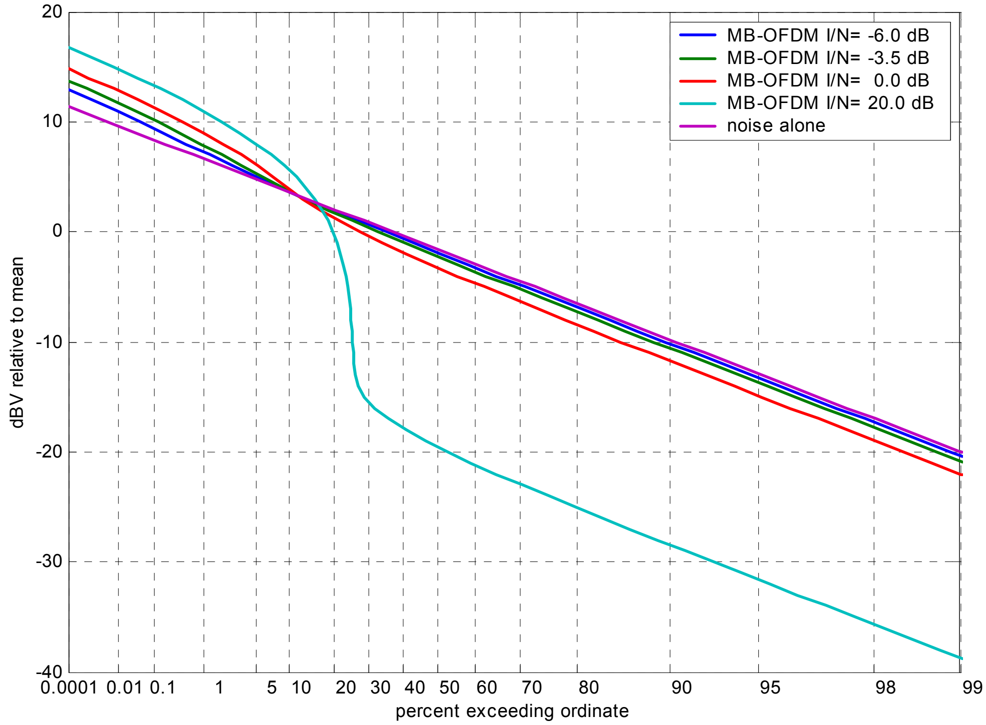


Figure 18: Analytically derived APD plots for various I/N_{sys} ratios, plotted using NTIA-supplied code

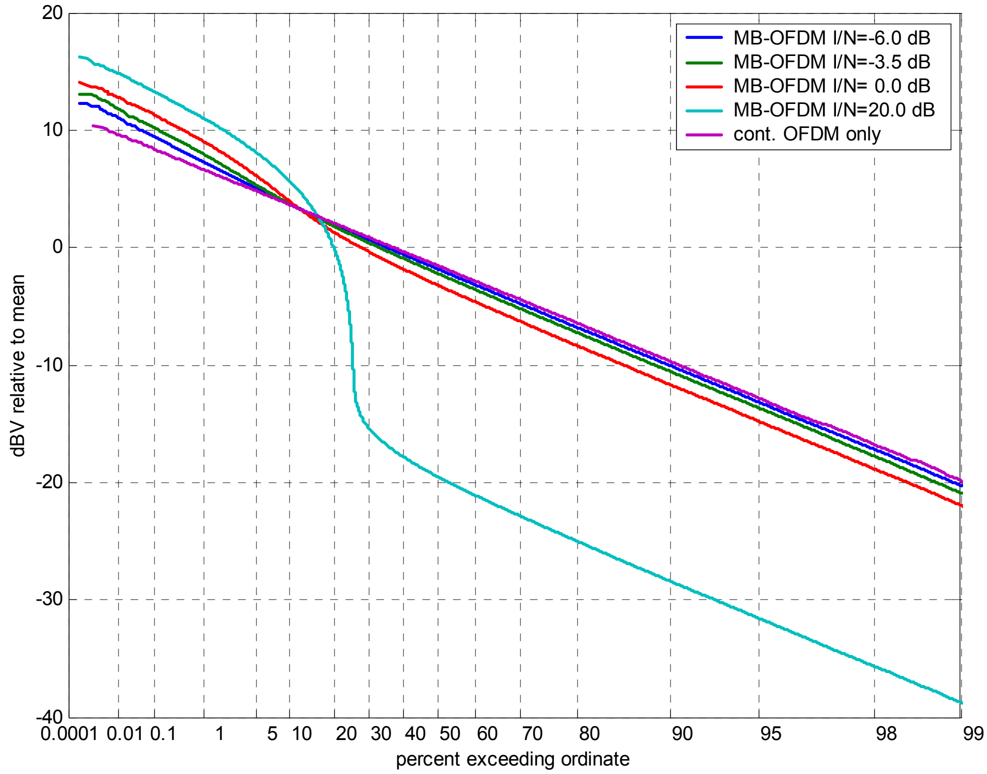


Figure 19: Simulated APD plots for various I/N_{sys} ratios, evaluated and plotted using NTIA APD code

Finally, to address comments from Freescale regarding the potential impact of other time-frequency codes (*i.e.*, 1,1,3,3,2,2 as one example), it turns out that APD analysis will be identical for the different time-frequency codes. Since APD plots represent the CCDF of the signal, they are entirely determined by the PDF of the signal. It follows that a given waveform is independent of whether it is transmitted quickly or slowly, and therefore it will have the same wideband APD plot.

This can be clearly seen from the equations used to predict the (wideband) APD of a MB-OFDM waveform[30].

$$APD'(r) = \frac{1}{d}\exp(-r^2/d)$$

The APD normalized with respect to the mean power, depends only on the duty cycle factor, d. Thus the wideband APD of the MB-OFDM waveform using time-frequency code 1,2,3,1,2,3, is found to be identical to that using the TFI code 1,1,3,3,2,2. Figure 20 below shows the peak power characteristics derived from APD plots for a 1 MHz impulse radio and MB-OFDM with

[30] See comments of Philips of North America Corp.

different time-frequency codes and various victim receiver bandwidths. These results show that the peak power characteristics for these different time-frequency codes are virtually identical for victim receiver bandwidths greater than 5 MHz with only slight deviations for smaller bandwidths for which simple forward error correction codes would easily be able to smooth out.

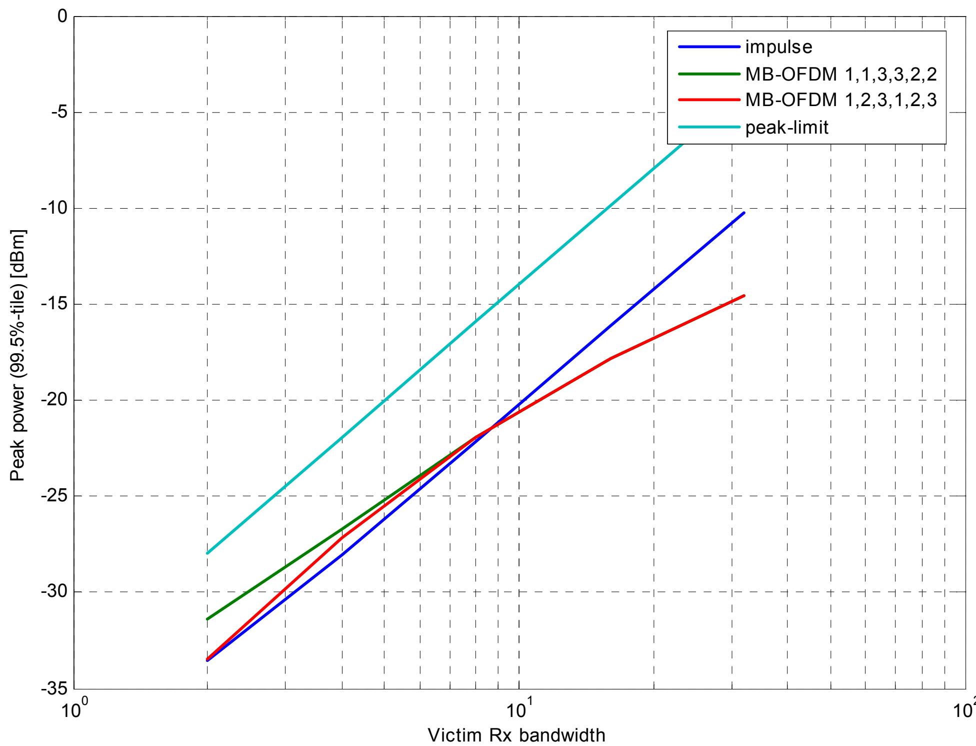


Figure 20: Comparison of peak power for impulse and MB-OFDM systems with different time-frequency codes

4 MB-OFDM Systems comply with the spirit of the rules when measured as requested by the Waiver and will not give MB-OFDM systems an 'unfair advantage'

In this section, we deal with the concerns of increased average and peak powers which are claimed would result if the Waiver were approved, and we address the false claims that this Waiver would allow for arbitrarily high transmit powers for MB-OFDM transmitters. We also show that MB-OFDM systems meet the minimum bandwidth requirements for UWB systems, and we address concerns about the scope of the Waiver and how the FCC may prevent people from trying to use the Waiver to by-pass other FCC rules.

4.1 Refutation of Claims of Increased Power for MB-OFDM Under the Waiver

4.1.1 No Increase to Average or Peak Emissions Compared to other Compliant UWB Devices

One of the most direct statements of Freescale's position is quoted below:

Now, MBOA seeks a waiver so as to measure emissions of an MB-OFDM device with the frequency hopping running. But this is tantamount to an increase in the emissions limits. UWB emissions are measured in 1 MHz frequency regions, one at a time. A frequency hopping system that uses (say) three hops spends only one-third of its time on a given frequency. The waiver would allow three-fold increased instantaneous emissions over a nonhopping system, yet still yield the same average emissions. The adverse impact would be plain if it were possible to monitor emissions over the entire spectrum simultaneously. Somewhere in the spectrum, at every instant, the MBOA system would be emitting at three times the level permitted to an impulsive or direct sequence system.

Pulse-Link similarly states in Section III of its "Comments …"
To grant a waiver would allow MBOA devices to transmit at power levels not allowed for non-MBOA devices. Currently, the transmit power is averaged over a millisecond in a one megahertz bandwidth. The MBOA devices transmit three "bursts" of energy within a microsecond window on three different hopped frequencies. In frequency hopping mode, the three bursts are sequenced through the three bands. Averaging across any one band the device is limited to –41.3 dBm/MHz. If this measurement is made with frequency hopping turned on the device may transmit at up to –35.4 dBm/MHz for the duration of each burst. A true "impulse radio" type of UWB system would still be limited to –41.3 dBm/MHz

The above statements mention 3-fold increased instantaneous emissions over a non-hopping system, whereas a more accurate statement would have been that *the waiver would allow three-fold increased instantaneous emissions over <u>an otherwise identical</u> non-hopping system.* The waiver would not represent a three-fold increase in instantaneous power over other radios permitted by the rules, nor would it come close to violating the Commission's peak power limits. Indeed, the Commission's rules already allow for instantaneous powers that well exceed the average power limits. For example, in a 3MHz measurement bandwidth, the ratio between the Commission's peak and the mean power limits is 12dB. Hence, an impulse radio UWB system would be allowed to transmit at much higher peak powers than say a DS-UWB radio would typically use. Yet, the current rules permit both.

The statement that *somewhere in the spectrum, at every instant, the MBOA system would be emitting at three times <u>the level permitted</u> to an impulsive or direct sequence system* is plainly false. Neither the peak nor the mean values permitted to impulsive or direct sequence devices would be exceeded. Analysis of the peak powers from an MB-OFDM transmitter measured in a variety of bandwidths has shown that the MB-OFDM waveform is at least 5dB inside the existing FCC limits on peak power[31]. Furthermore, a measuring instrument capable of monitoring emissions over the entire spectrum would experience the same average power from an MB-OFDM transmitter operating under the present waiver as it would from a direct sequence or impulsive UWB signal occupying the same bandwidth.

In another comment, TimeDerivative claims that 'To grant a waiver would allow MBOA devices to transmit at power levels not allowed for non-MBOA devices.' This is clearly false, and MB-OFDM waveforms would be required to meet the same average PSD and peak PSD as all other UWB devices. The following figures show the results of measuring the average and peak EIRP limits of a MB-OFDM waveform using normal operating conditions (as requested in the waiver) and according to the 1st Report and Order 02-48 and ANSI C63.4 specification. These figures clearly show that the waiver would NOT result in the MB-OFDM waveform violating the FCC average and peak emissions limits as allowed for other UWB waveforms. In fact, the peak limit is well below the FCC limit.

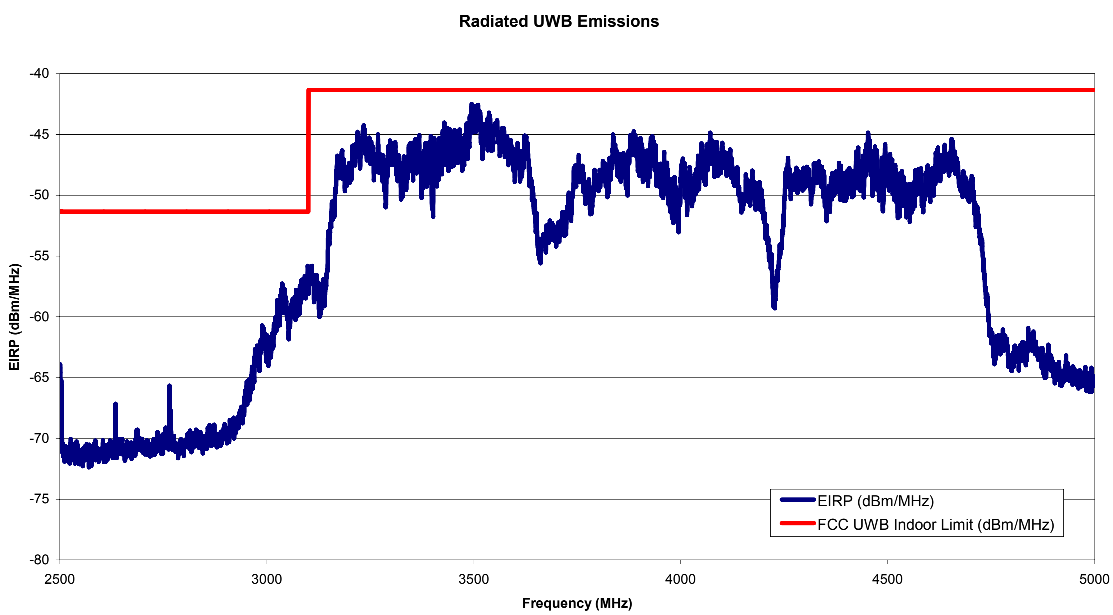


Figure 21: Example average EIRP measurement for a MB-OFDM transmitter using intended operational mode according to the waiver

[31] See Figure 20 in this Attachment A and Figure 8 in the Comments of Philips North America Corporation.

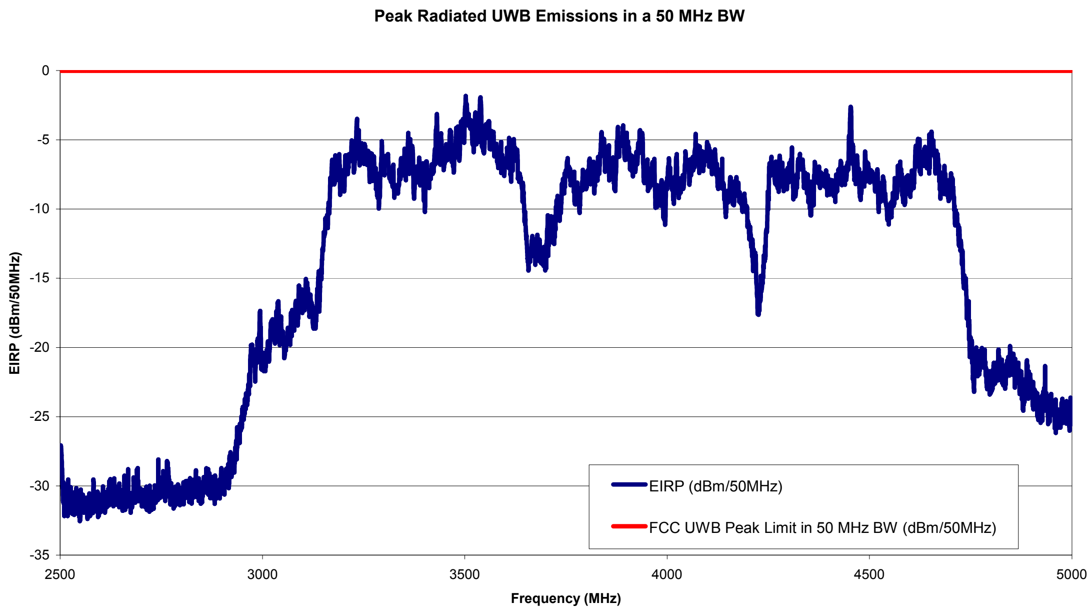


Figure 22: Example Peak EIRP measurement for a MB-OFDM transmitter (Measurements taken at a RBW of 3 MHz and compensated by 20Log(3/50) RBW factor to compare with FCC UWB peak limit in a 50 MHz RBW)

4.1.2 No Possibility of Arbitrarily High Power

Freescale claims that the requested waiver could permit instantaneous emissions that are much higher than implied by the waiver taken at face value[32]. An extreme example described by Freescale, shows a 3-hop system that spends 87.5% of its time in each hop band gated off, resulting in a peak power that is an additional 9dB above the system for which we are requesting a waiver. That system would clearly violate the existing peak power limit and would not be permitted by the Commission's current rules. Therefore, it should be immediately clear that the Commission's existing peak power limits prevent the "arbitrarily high power" claimed in the Freescale opposition comments.

4.2 MB-OFDM meets the FCC's minimum bandwidth requirement for UWB systems

On p. 8, and again on p. 10 of "Comments of Motorola Inc.", the authors argue that the MB-OFDM signal should be treated as a frequency hopping signal and the measurements should be made with frequency hopping turned off. They state "To this end, the Commission must look closely at the waveform proposed by the MBOA-SIG, since it is not clear that it meets the FCC's minimum 500 MHz bandwidth requirement. If true, OET should not further consider this request and should reject the waiver immediately. There is no need to rule on the measurement

[32] See at page 16 of The Opposition of Freescale Inc. on this docket

techniques for a UWB design that does not otherwise satisfy the FCC's UWB technical requirements."

The petition for waiver referred to two documents which, by reference, included a complete definition of the MB-OFDM signal, in addition to the text in Attachment B of the petition:

a. IEEE P802.15-03/268r4, the updated MB-OFDM proposal to the IEEE 802.15 TG3a. This document number has been corrected to IEEE P802.15-04/493r1 – due to a quirk in the IEEE document numbering rules we had to create a new document number greater than 300.
b. IEEE P802.15-04/220r3, the MB-OFDM proposal update presented to the IEEE 802.15 TG3a in May 2004, which is based on the above updated proposal document 493r1.

In addition, Section 7 and Attachment B attached to this document presents clarification on the issue of the bandwidth occupied by the MB-OFDM symbols on each band. To summarize the relevant information, the number of OFDM subcarriers which are bearing data is 122 (110 data + 12 pilot subcarriers). Thus, the bandwidth of the OFDM symbol is 122*4.125 = 503.25 MHz.

Therefore, it should be clear that the MB-OFDM signal meets the FCC's minimum bandwidth rule for UWB systems.

4.3 Scope of the Waiver is narrow and can prevent misuse

Some reply comments have asserted that a waiver for the three-band MB-OFDM will open the door to systems with more than three active bands and "gating" designs intended to allow arbitrarily high peak power levels. This assertion is false for the following reasons.

- The scope of this waiver is limited to the 3-band MB-OFDM system and TFI codes in the accompanying system description (see Section 7 and Attachment B for a more complete description of the waveform to be considered for the Waiver).
- Any alteration to the system that would materially affect the interference potential of the transmitted signal is outside the scope of the waiver.
- The FCC rules restricting peak power to 0 dBm in a 50 MHz bandwidth still apply. The 3-band MB-OFDM system meets these restrictions with margin to spare. (See Section 15.521 of the rules, UWB Report & Order Paragraph 225)
- The current rules already prevent the use of gating to generate arbitrarily high peak power levels. The waiver would have no effect on those rules.

5 MB-OFDM waveforms do NOT synchronize and will not lead to any increased aggregation of interference

Freescale state in their "Technical Analysis …", on p. 17, "Waiver allows increased aggregation" and on p. 19, "Synchronization of MB-OFDM devices" that MB-OFDM devices can synchronize their time-frequency codes in a unique way in order to coordinate transmissions amongst themselves with a resultant increase in interference to other devices.

MB-OFDM devices belonging to the same network, just like all other such UWB devices, employ MAC level coordination techniques to share the spectrum among themselves. Freescale refers to the MBOA presentations on efficient and effective clear channel assessment (CCA) algorithms, and insinuate that somehow the MBOA intends to use CCA as an implicit means of synchronization between uncoordinated devices. An effective CCA mechanism in a UWB system would actually lead to causing lower overall interference to all systems due to efficient use of the spectrum. This is actually something to be greatly desired in all systems that operate using CSMA/CA channel access protocols in the unlicensed bands, but a CCA mechanism does not mean the devices will be coordinated.

MB-OFDM devices belonging to different networks DO NOT coordinate their transmissions. The timing offset between different piconets will be random, and these devices cannot intentionally synchronize to fill the gaps between each other's transmissions. Thus, when a very large number of MB-OFDM piconets are aggregated (e.g., in a dense urban area monitored from a suitable distance), the resultant interference signal will benefit from the Central Limit Theorem, such that the overall statistics will appear complex Gaussian and stationary, and thus indistinguishable from thermal noise. Thus, MB-OFDM devices do not result in any different aggregate interference levels than those which result from aggregations of other compliant UWB devices.

The notion that MB-OFDM devices might coordinate was among a number of ideas discussed in IEEE presentations referred to in Freescale's comments. It was generally recognized that coordination among devices operating in the unlicensed bands is a complicated issue, and one that has potential to cause harmful interference to other devices sharing the spectrum. For these and other reasons, synchronization of devices in the manner described is not facilitated in any manner by the MBOA system[33]. It is also worthwhile to point out that synchronization on such fine time-scales is also possible in principle with an impulse radio system such as the DS-UWB system. There too, in theory, devices with the same pulse repetition frequency can coordinate their transmissions so that they are orthogonal in time. Thus, this is not a 'feature' that is unique only to MB-OFDM devices.

6 MB-OFDM has important advantages compared to other UWB waveforms

The MBOA has converged on and adopted the MB-OFDM UWB system because we regard this as a technically superior approach to high data rate UWB systems operating in challenging multipath environments, and because we believe it provides us with important abilities to more easily control emissions in different parts of the spectrum in a flexible way. Further, the technical parameters of the MB-OFDM system were chosen carefully keeping in mind the

[33] In a vote taken on February 2nd, 2004, a decision was taken (1 vote per company present on the call) to not employ Synchronous TFI as part of the MBOA specifications. (The voting was 1-For, 7-Against, 4-Abstain.).

compliance with FCC regulations and market requirements such as range, data rates, cost/complexity (including CMOS circuit feasibility), etc.

Freescale states, on p. 17 of "Opposition of Freescale Semiconductor, Inc.", that 'MBOA lists four supposed performance advantages due to MB-OFDM: improved multipath capture; flexibility in avoiding potential sources of interference; lower out-of-band emissions; and "flexibility in balancing performance against implementation complexity." Three of these are simply wrong, and we find one incomprehensible.' The discussion below addresses this comment.

6.1 MB-OFDM Performance Advantages

Freescale agrees with MBOA about one thing – energy capture is a property of the OFDM signal, not the multi-band nature of the signal. But one very important point is missed in their comment – the sequencing between bands of the OFDM signal is an innovative solution, under the FCC MO&O regulations, that provides some important benefits to the system designer among which are:

1. it provides coarse grained spectral flexibility by dividing the entire UWB spectrum into 528 MHz bands (which is a unique advantage of the MB-OFDM system in terms of dealing with worldwide regulatory evolution as well as interference mitigation), while at the same time providing the frequency diversity over an approximately 1.5 GHz bandwidth (the 3-band MB-OFDM signal through coding and interleaving steps spreads information bits across the entire 1.5 GHz frequency band group in order to exploit this diversity).
2. it allows the overall system complexity, power consumption, etc. to be lowered due to the use of lower bandwidth filters, analog to digital converters (ADCs) etc.

Freescale, in "A Technical Analysis of the MBOA-SIG PFW", uses very simplistic arguments based on performance of a coded system in Rayleigh fading to suggest that DS-UWB or impulse radio can obtain performance that is 'fundamentally' better than MB-OFDM. These suggestions are refuted below:

1. In Fig. 9 and Fig. 10 and the associated statements on pp. 24-26 they suggest that there is a fundamental loss associated with OFDM performance due to the narrowband carriers that cannot be overcome through signal processing. This is demonstrably false – at the September 2004 IEEE meeting, an MBOA presentation (document IEEE 802.15-04/0533r0) showed that using intelligent signal processing that takes advantage of the information in the MB-OFDM signal, it is possible to improve on the performance beyond what is asserted in Freescale's figures. This is but one example – other techniques exist to improve multipath performance further. This is not a surprise to most people conversant with the state of the art. OFDM techniques have been adopted widely in systems dealing with dense multipath precisely because of their superior multipath performance. The benefits apply wherever the channel coherence bandwidth (inverse of the delay spread) is small compared with the occupied bandwidth of the signal.

2. Freescale also seems to imply a level of performance of the DS-UWB or impulse UWB system that appears to be unsustainable upon examining the facts. For example, Figure 10 of their Technical Analysis seems to imply that the DS-UWB system has a 'gap to AWGN' of only 1 dB in the multipath channels considered in the IEEE selection criteria. We include in Figure 23 a plot which shows the fraction of total signal energy captured by the rake receiver, as a function of number of rake fingers. For the 16-finger rake often quoted by DS-UWB proponents, it can be seen that there is a loss of at least ~2.4 dB[34] – and this is assuming optimal placement and estimation of coefficients of the rake fingers, optimal tracking of the fingers, no losses due to fixed point effects, and so on. The second point to note from this figure is that the signal-to-ISI ratio is only around 9 dB, and as the data rate is increased the ISI should also increase commensurately. Thus, the equalization requirements for the DS-UWB system should also become significant in a given channel environment.

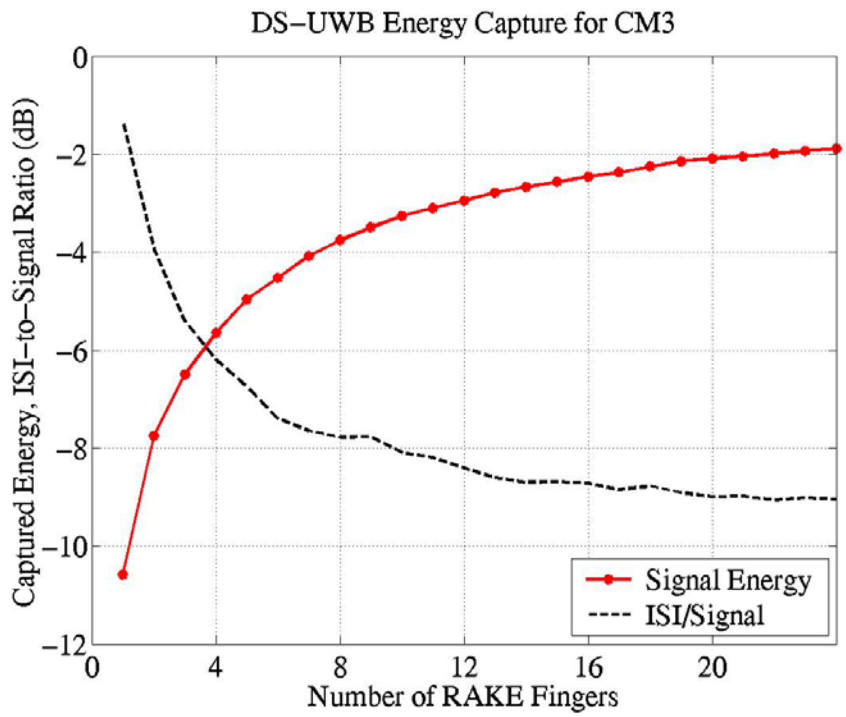


Figure 23: Multi-path energy capture of a DS-UWB system in 4 – 10 m, NLOS channel environment (for 90% of channels).

Regarding the issue of complexity, it is well known in the industry that the FFT based processing of the MB-OFDM signal offers an efficient means of processing at the receiver compared to a time domain rake receiver. For example using chip-rate sampling at 1368 MHz, the 16-finger

[34] For comparison, the MB-OFDM system incurs a loss of ~0.2 dB due to un-captured signal energy in multipath in the same channel environment.

rake alone would require about 21.9 complex multiplies per nanosecond[35], while the FFT based MB-OFDM system uses 1.9 complex multiplies per nanosecond for the FFT and complex equalization operations. This comparison does not take into account the additional complexity due to ISI equalization in the DS-UWB receiver. Of course, some complexity reduction techniques are possible for both systems, but this comparison shows that the MB-OFDM system does fundamentally offer some important performance advantages at a reasonable complexity.

6.2 MB-OFDM Spectral Emissions Advantages

The fact that UWB systems will be sharing a large part of the spectrum from 3.1 – 10.6 GHz with many other wireless systems which may actually be integrated into the same device (cell phones, PDAs, laptops) or sharing the spectrum in very close proximity (within a few feet) presents a challenging design problem not just for the receiver, but also for the transmitter to prevent possible interference in these extreme cases. To address these cases, an OFDM-based waveform offers substantial advantages over impulse-based waveforms for "sculpting" the spectrum of its transmitted signal.[36]

The MB-OFDM waveform is described in more detail in Attachment B, which illustrates that the data in an MB-OFDM system employs hundreds of simultaneous, separable tones. Like a giant musical chord with tones that can be included or deleted under software control, the spectrum of an OFDM signal can be surgically shaped to mitigate potential interference to other systems in the case of co-located radios in the same device or extremely close operation of radios sharing the same spectrum. The control may be automatic, through sensing of another system's presence, or ad hoc, based on an internal "policy engine" and local regulations. The spectral sculpting capabilities of OFDM are also a good match to the *Cognitive Radio* initiative.[37] An example of the capability is shown in the following figure, which demonstrates a notch depth of more than 20 dB, obtained by simply deleting 20 adjacent tones from the OFDM signal generator. Several additional techniques exist that can improve still further on this simple tone-deletion approach.

[35] J. Balakrishnan, et al., "Complexity and Performance Analysis of a DS-CDMA UWB System," IEEE P802.15-03/388r0, September 2003.
[36] D. Leeper et al, "Spectral Sculpting and a Future-Ready UWB", IEEE P802.15-03/425r0, September, 2004.
[37] FCC NPRM ET-03-108, Dec 17, 2003

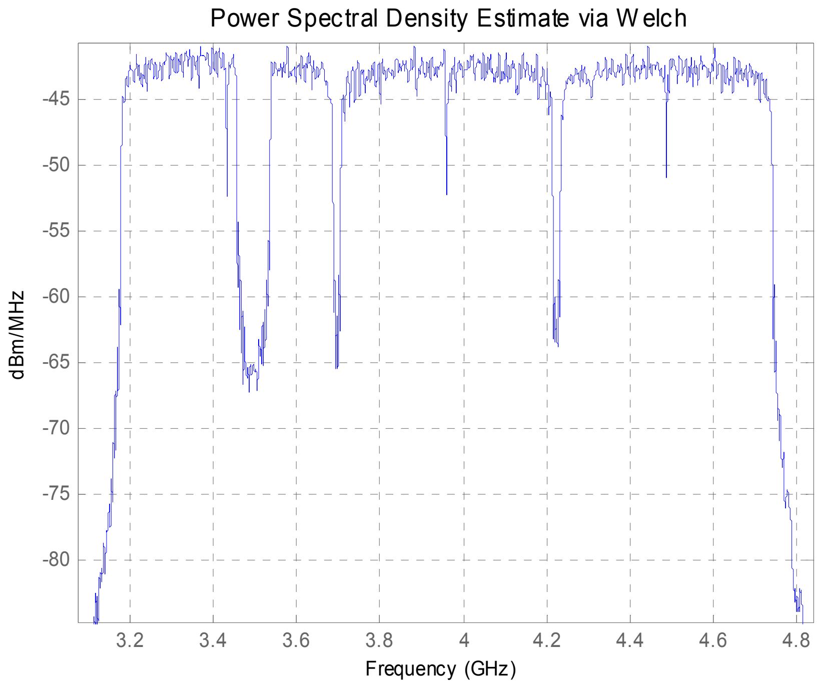


Figure 24: Example MB-OFDM transmitted signal spectrum showing a notch of ~22 dB depth around 3.5 GHz.

Finally, because the MB-OFDM is formed in the frequency domain rather than the time domain, it has a natural advantage in terms of how the out-of-band (OOB) emissions are controlled and imposes less demanding requirements on external filtering when compared with an impulse-based technique. Combined with the same "good system design" approaches advocated by Freescale, MB-OFDM systems can actually achieve an OOB emission mask substantially better than that required by Part 15 rules to more practically enable co-located radio designs.

These "good-neighbor" and "future-ready" advantages are among the many reasons that MBOA chose OFDM-based modulation over impulse-based modulation. An unnecessary performance penalty, which this Waiver seeks to avoid, would restrict the adoption of MB-OFDM systems, denying the benefits to the public that are offered by OFDM's inherent spectral emission advantages.

7 Update to Waveform Description and Correction of Inconsistencies

In Appendix A of the Freescale comment, they state there were inconsistencies and ambiguities regarding the MB-OFDM waveform. They were correct that the information in the Attachment B in the original Petition did not match exactly the information contained in the IEEE proposal references, and it turned out that one of the IEEE references (*IEEE P802.15-03/268r4)* does not exist due to a change in the document numbering system for this proposal which happened after the submission of the Waiver. Therefore, we would like to correct these minor inconsistencies to ensure that there is no confusion as to the specifics of the MB-OFDM waveform under consideration for these proceedings. These changes don't affect the transmit waveform or its emitted power and it doesn't affect the original waiver request. An update is provided in Attachment B, which includes the following changes from the original Attachment B in the Petition:

- On page 1 of Attachment B, just above the '**Table of Contents'**, there is a reference to an IEEE document (*IEEE P802.15-03/268r4)*, which does not exist due to a change in the numbering for the MB-OFDM proposal. The correct document is *IEEE P802.15-04/493r1*. Please note that the information provided in Attachment B was for informational purposes and was provided as a short summary of the more technical detail provided in document *IEEE P802.15-04/493r1*. It is our intention that the document *IEEE P802.15-04/493r1* contains the necessary details to fully describe the MB-OFDM waveform, and information in this document supersedes information contained in Attachment B which is provided for informational purposes.
- On page 2, in Section 1 'Introduction', the data rates of 55 Mbps and 106.67 Mbps have been removed, since these do not exist in the current document *IEEE P802.15-04/493r1*.
- On page 2, in the first equation of Section 2.1 'Mathematical description of the signal', f_k has been changed to $f_{(k \bmod 6)}$ to correctly reflect the time-frequency patterns. Further explanation of this equation is provided below the equation to ensure proper understanding.
- On page 3, the second equation of Section 2.1 'Mathematical description of the signal' has been simplified to match the terms and parameters provided in document *IEEE P802.15-04/493r1*.
- On page 4, in Section 2.3 'OFDM Modulation', references to data rates of 50 Mbps and 106.67 Mbps have been removed.
- On page 5, in Section 2.4 'Pilot subcarriers', the locations of the pilot subcarriers have been changed slightly, which is reflected in a slight modification to $P_{n,k}$.
- On page 6, in Section 2.5 'Guard subcarriers', the definition and use of the guard subcarriers has been updated to match the method described in *IEEE P802.15-04/493r1* as well as referred to in document *IEEE 802.15-04/0220,* which was a presentation referenced in the original Petition. This simply changes the guard subcarriers located on the edge of the band to data subcarriers.
- On page 6, in Section 2.6 'Time-domain Spreading', the reference to data rates 55 Mbps and 106.67 Mbps has been removed.
- On page 7, in Section 2.7 'Timing-related parameters', Table 2 has been updated by defining $T_{ZP} = T_{CP} + T_{GI}$ in order to simplify the timing related parameters.
- On page 7, in Section 3.1 'Rate-dependent parameters', the data rates of 55 Mbps and 106.67 Mbps have been removed since they are no longer supported in the proposal document *IEEE P802.15-04/493r1.*
- On page 9, following Section 3.2 'Convolutional Encoder', a new Section 3.3 'Bit interleaving' has been added to more accurately reflect the proposal document *IEEE P802.15-04/493r1*.

- On page 10, in Section 4.3 'Time Frequency Codes', the Section title has been changed to Section 4.3 'Channelization' to better match proposal document *IEEE P802.15-04/493r1*. In addition, Table 5 has been updated to include TFC Number 5 and 6, as described in proposal document *IEEE P802.15-04/493r1.* Additional descriptions of TFC Number 5 and 6 are also provided in the text above Table 5.

Finally, it should be noted that none of the above changes have a material affect on possible interference between MB-OFDM devices and other narrowband services. Freescale also expressed concern about the 'future changes to the MB-OFDM waveform'. As mentioned above, the scope of the waiver is narrow and should prevent any changes which would impact the potential for interference beyond that considered by this proceeding.

8 Summary and Conclusions

In the previous sections of this annex, we have provided extensive data and field tests to demonstrate that MB-OFDM systems, tested under normal operating conditions, pose no greater threat of harmful interference than a class of pulsed UWB systems that are permitted by the rules. In addition, we provided detailed engineering analyses and simulations to identify errors, incorrect claims, and incorrect operating environment assumptions made in responses to MBOA-SIG waiver 04-352.

In summary, we have provided sound technical analyses to conclude that the MB-OFDM waveform described in Waiver Request 04-352:

1. causes no more harmful interference than pulsed UWB waveforms anticipated during the FCC rulemaking and allowed under the FCC regulations.
2. causes no harmful interference into C-band satellite systems using I/N ratios provided by the FCC, SIA, and even Freescale in its own filings. These values represent the operation of C-band satellites in realistic application scenarios.
3. complies with the spirit of the FCC regulations when the signal is measured in its normal operating mode.
4. has no unfair advantage over alternative UWB waveforms when measured as requested in Waiver Request 04-352; furthermore, arbitrarily high power MB-OFDM waveforms would NOT be permitted by this waiver
5. serves the public interest by providing an alternative UWB solution that offers several key performance, global regulatory, and implementation advantages over other methodologies.

Attachment B

Update to Attachment B in Waiver Request
Multi-band OFDM (MB-OFDM) Waveform Summary

ATTACHMENT B (Updated)

Multi-Band OFDM
Waveform Summary

Excerpted from IEEE P802.15-04/0493r1 "Multi-Band OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a". If there are any discrepancies found herein, the IEEE document shall take precedence over this excerpt.

1 Introduction

This description specifies the signal for a UWB system that utilizes the unlicensed 3.1 – 10.6 GHz UWB band, as regulated in the United States by the Code of Federal Regulations, Title 47, Section 15. The UWB system provides a wireless PAN with data payload communication capabilities of 53.3, 80, 110, 160, 200, 320, and 480 Mb/s. Transmitting and receiving at data rates of 53.3, 110, and 200 Mb/s is mandatory. The proposed UWB system employs orthogonal frequency division multiplexing (OFDM). The system uses a total of 122 sub-carriers that are modulated using quadrature phase shift keying (QPSK). Forward error correction coding (convolutional coding) is used with a coding rate of 1/3, 11/32, ½, 5/8, and ¾. The proposed UWB system also utilizes a time-frequency code (TFC) to interleave coded data over 3 frequency bands (called a band group). Four such band groups with 3 bands each and one band group with 2 bands are defined, along with four 3-band TFCs and two 2-band TFCs. Together, these band groups and the TFCs provide the capability to define eighteen separate logical channels or independent piconets. Devices operating in band group #1 (the three lowest frequency bands) are denoted Mode 1 devices, it shall be mandatory for all devices to support Mode 1 operation, with support for the other band groups being optional and added over time.

2 Time Domain Waveform

2.1 Mathematical description of the signal

The transmitted RF signal is related to the baseband signal as follows:

$$r_{RF}(t) = \mathrm{Re}\left\{ \sum_{k=0}^{N-1} r_k(t - kT_{SYM}) \exp(j2\pi f_{(k \bmod 6)} t) \right\},$$

where Re(·) represents the real part of a complex variable, $r_k(t)$ is the (possibly complex) baseband signal representing the k^{th} OFDM symbol occupying a symbol interval of length T_{SYM}, and N is the number of OFDM symbols transmitted. The carrier frequency or band that the k^{th} OFDM symbol is transmitted over is denoted as f_k. The values of f_k range over 3 frequencies assigned to the Band Group that the system is operating in (ref. Section 4.1) – these frequencies are organized into sequences of length 6, called time-frequency codes (TFCs).

All of the OFDM symbols $r_k(t)$ can be constructed using an inverse Fourier transform with a certain set of coefficients C_n, where the coefficients are defined as either data, pilots, or training symbols:

$$r_k(t) = \begin{cases} \sum_{n=-N_{ST}/2}^{N_{ST}/2} C_n \exp(j2\pi n\Delta_f)(t) & t \in [0, T_{FFT}] \\ 0 & t \in [T_{FFT}, T_{FFT} + T_{ZP}] \end{cases}$$

The parameters Δ_f and N_{ST} are defined as the subcarrier frequency spacing and the number of total subcarriers used, respectively. The resulting waveform has a duration of $T_{FFT} = 1/\Delta_f$. The time parameter T_{ZP} specifies a zero pad period for the OFDM symbol which is used to mitigate the effects of multipath as well as to provide a guard period to allow for switching between the different bands.

2.2 Subcarrier constellation mapping

The OFDM subcarriers use QPSK modulation. The encoded and interleaved binary serial input data shall be divided into groups of two bits and converted into complex numbers representing QPSK constellation points. The conversion shall be performed according to the Gray-coded constellation mappings, illustrated in Figure 1, with the input bit, b_0, being the earliest in the stream. The output values, *d*, are formed by multiplying the resulting (I + jQ) value by a normalization factor of K_{MOD}, as described in the following equation:

$$d = (\mathrm{I} + \mathrm{jQ}) \times K_{MOD}.$$

The normalization factor, KMOD, is $1/\sqrt{2}$. In practical implementations, an approximate value of the normalization factor can be used, as long as the device conforms to the modulation accuracy requirements.

For QPSK, b_0 determines the I value, and b_1 determines the Q value, as illustrated in Table 1.

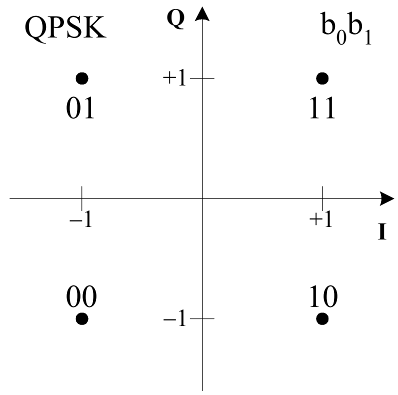


Figure 1 – QPSK constellation bit encoding

Table 1 – QPSK encoding table

Input bit (b_0 b_1)	I-out	Q-out
00	-1	-1
01	-1	1
10	1	-1
11	1	1

2.3 OFDM Modulation

For information data rates of 53.3 and 80 Mb/s, the stream of complex symbols is divided into groups of 50 complex numbers. We shall denote these complex numbers $c_{n,k}$, which corresponds to subcarrier n of OFDM symbol k, as follows:

$$c_{n,k} = d_{n+50\times k} \qquad n = 0,1,\ldots,49, k = 0,1,\ldots,\mathrm{N_{SYM}}-1$$
$$c_{(n+50),k} = d^{*}_{(49-n)+50\times k}$$

where $\mathrm{N_{SYM}}$ denotes the number of OFDM symbols in the MAC frame body, tail bits, and pad bits.

For information data rates of 110, 160, 200, 320, 400 and 480 Mb/s, the stream of complex numbers is divided into groups of 100 complex numbers. We shall denote these complex numbers $c_{n,k}$, which corresponds to subcarrier n of OFDM symbol k, as follows:

$$c_{n,k} = d_{n+100\times k} \qquad n = 0,1,\ldots,99, k = 0,1,\ldots,\mathrm{N_{SYM}}-1$$

where N_{SYM} denotes the number of OFDM symbols in the MAC frame body, tail bits, and pad bits.

An OFDM symbol $r_{data,k}(t)$ is defined as

$$r_{data,k}(t) = \sum_{n=0}^{N_{SD}} c_{n,k} \exp(j2\pi M(n)\Delta_F (t - T_{CP})) + p_{\mathrm{mod}(k,127)} \sum_{n=-N_{ST}/2}^{N_{ST}/2} P_n \exp(j2\pi n\Delta_F (t - T_{CP}))$$

where N_{SD} is the number of data subcarriers, N_{ST} is the number of total subcarriers, and p_n *and* P_n together describe the contribution of the pilot and guard subcarriers, as further defined in Section 2.4 and Section 2.5. The function *M(n)* defines a mapping from the indices 0 to 99 to the logical frequency offset indices –56 to 56, excluding the locations reserved for the pilot subcarriers, guard subcarriers, and the DC subcarrier, as shown below:

$$M(n) = \begin{cases} n-56 & n=0 \\ n-55 & 1 \le n \le 9 \\ n-54 & 10 \le n \le 18 \\ n-53 & 19 \le n \le 27 \\ n-52 & 28 \le n \le 36 \\ n-51 & 37 \le n \le 45 \\ n-50 & 46 \le n \le 49 \\ n-49 & 50 \le n \le 53 \\ n-48 & 54 \le n \le 62 \\ n-47 & 63 \le n \le 71 \\ n-46 & 72 \le n \le 80 \\ n-45 & 81 \le n \le 89 \\ n-44 & 90 \le n \le 98 \\ n-43 & n=99 \end{cases}$$

The subcarrier frequency allocation is shown in Figure 2. To avoid difficulties in DAC and ADC offsets and carrier feed-through in the RF system, the subcarrier falling at DC (0^{th} subcarrier) is not used.

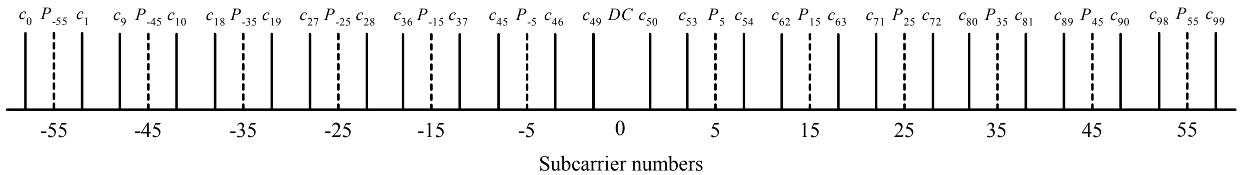


Figure 2 – Subcarrier frequency allocation

2.4 Pilot subcarriers

In each OFDM symbol, twelve of the subcarriers are dedicated to pilot signals in order to make coherent detection robust against frequency offsets and phase noise. These pilot signals shall be put in subcarriers numbered –55, –45, –35, –25, –15 –5, 5, 15, 25, 35, 45, and 55. The contribution due to the pilot subcarriers for the k^{th} OFDM symbol is given by the inverse Fourier Transform of the sequence $P_{n,k}$ below, which includes BPSK modulation by a pseudo-random binary sequence, p_l (defined further below), to prevent the generation of spectral lines.

$$P_{n,k} = p_{\mathrm{mod}(k,127)} \times \begin{cases} \frac{1+j}{\sqrt{2}} & n = 25, 55 \\ \frac{-1-j}{\sqrt{2}} & n = 5, 15, 35, 45 \\ 0 & n = \pm 1 ..., \pm 4, , \pm 6, ..., \pm 14, \pm 16, ..., \pm 24, \pm 26, ..., \pm 34, \pm 36, ..., \pm 44, \pm 46, ..., \pm 54, \pm 56 \end{cases}$$

For modes with data rates less than 110 Mbps:

$P_{n,k} = P^*_{-n,k}$, $\quad n = -5, -15, -25, -35, -45, -55$

For 110 Mbps and all higher rate modes:

$P_{n,k} = P_{-n,k}$, $\quad n = -5, -15, -25, -35, -45, -55$

The length 127 pseudo-random sequence, p_l, which modulates the pilot subcarriers is defined below:

$p_{0 \ldots 126}$ = {1, 1, 1, 1, -1, -1, -1, 1, -1, -1, -1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, 1, 1, -1, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, 1, -1, 1, -1, -1, 1, -1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1, -1, -1, -1, 1, -1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, -1, 1, 1, -1, 1, -1, 1, 1, 1, -1, -1, 1, -1, -1, -1, 1, 1, 1, -1, -1, -1, -1, -1, -1, -1}.

Only one element of this sequence shall be used for an OFDM symbol.

2.5 Guard subcarriers

In each OFDM symbol ten of the subcarriers at the edges of the occupied frequency band shall be termed guard subcarriers and defined as in this subsection. Implementations may exploit the guard subcarriers for various purposes, including relaxing the specs on transmit and receive filters as well as possible performance improvements. The relation of the power level of the guard subcarriers to the data bearing subcarriers shall be implementation dependent, except that the same relation shall be employed for all OFDM symbols that define guard subcarriers. Note that this includes both the CE sequence and payload. Thus, implementations may use reduced power levels for the guard subcarriers as long as the resultant transmit signal meets the local regulatory requirements of minimum occupied bandwidth, etc.

There are five guard subcarriers on either edge of the OFDM symbol occupied band, located in subcarriers with indices –61, –60, …, –57, and 57, 58, …, 61. These guard subcarriers shall be created by copying over the five outermost data-bearing subcarriers from the nearest edge of the OFDM symbol as shown in Figure 3 (note the intervening pilot subcarrier is not copied).

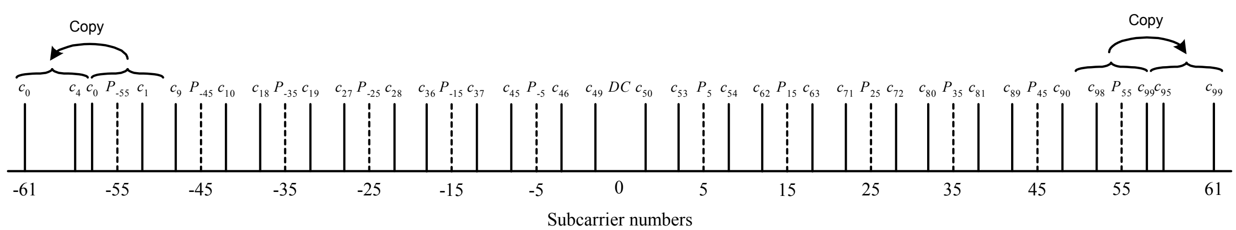


Figure 3 - Guard subcarrier creation based on edge subcarriers of the OFDM symbol

More precisely, the guard subcarrier symbol definition for the n^{th} subcarrier of the k^{th} symbol shall be given as follows:

$$P_{n,k} = c_{m,k}\ ,\quad l = 0,1,2,3,4;\ n = 57 + l;\ m = 95 + l$$
$$P_{n,k} = c_{m,k}\ ,\quad l = 0,1,2,3,4;\ n = -61 + l;\ m = l$$

2.6 Time-domain Spreading

For data rates of 53.3, 80, 110, 160 and 200 Mbps a time-domain spreading operation shall be performed with a spreading factor *TSF =2*, in order to provide additional frequency diversity and SOP performance. The time-domain spreading shall consist of transmitting the same information over two OFDM symbols. Let the k^{th} original OFDM symbol, represented as $r_k(l)$, be generated as specified in Section 2.2 and Section 2.3. The repeated version of this OFDM symbol, represented as $r_k^{'}(l)$, shall be obtained in the time domain as follows:

$$r_k^{'}(l) = \begin{cases} \{\mathrm{Im}\{r_k(l)\} + j\,\mathrm{Re}\{r_k(l)\}\} p_{\mathrm{mod}(k+6,127)} & \text{no conjugate symmetry} \\ r_k(l)\, p_{\mathrm{mod}(k+6,127)} & \text{with conjugate symmetry} \end{cases}$$

where the values of the index k are OFDM symbol numbers *before* time spreading. Also, the values for p_k are selected from the same linear-feedback shift register (LFSR) sequence used to scramble the pilot subcarriers. Defining the time-domain spread OFDM symbol in the above manner ensures that a second IFFT operation can be avoided for the repeated symbol at the transmitter. At the same time, the LFSR sequence ensures a flat PSD in the frequency domain.

The time-domain spreading operation may also be implemented in the frequency domain at the transmitter. This is achieved by reversing the order of the bits in the bit vector obtained after the interleaving operations, and using this as the input for the operations outlined in Sections 2.2 and 2.3. The pilot subcarriers for the repeated symbol shall be appropriately defined such that after processing with the IFFT, the same output is obtained as in the time domain definition above.

2.7 Timing-related parameters

The timing parameters associated with the OFDM PHY are listed in Table 2.

Table 2 – Timing-related parameters

Parameter	Value
N_{SD}: Number of data subcarriers	100
N_{SDP}: Number of defined pilot carriers	12
N_{SG}: Number of guard carriers	10
N_{ST}: Number of total subcarriers used	122 (= $N_{SD} + N_{SDP} + N_{SG}$)
Δ_F: Subcarrier frequency spacing	4.125 MHz (= 528 MHz/128)
T_{FFT}: IFFT/FFT period	242.42 ns ($1/\Delta_F$)
T_{ZP}: Zero pad duration	70.08 ns (= 37/528 MHz)
T_{SYM}: Symbol interval	312.5 ns ($T_{CP} + T_{FFT} + T_{GI}$)

3 Data Rate Modes and Convolutional Encoding

3.1 RATE-dependent parameters

The data rate-dependent modulation parameters are listed in Table 4.

Table 4 – Rate-dependent parameters

Data Rate (Mb/s)	Modulation	Coding rate (R)	Conjugate Symmetric Input to IFFT	Time Spreading Factor (TSF)	Overall Spreadin g Gain	Coded bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
80	QPSK	1/2	Yes	2	4	100
110	QPSK	11/32	No	2	2	200
160	QPSK	1/2	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	1/2	No	1 (No spreading)	1	200
400	QPSK	5/8	No	1 (No spreading)	1	200
480	QPSK	3/4	No	1 (No spreading)	1	200

3.2 Convolutional Encoder

The convolutional encoder shall use the rate R = 1/3 code with generator polynomials, $g_0 = 133_8$, $g_1 = 165_8$, and $g_2 = 171_8$, as shown in Figure 4. The bit denoted as "A" shall be the first bit generated by the encoder, followed by the bit denoted as "B", and finally, by the bit denoted as "C". The various coding rates are derived from the rate R = 1/3 convolutional code by employing "puncturing". Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy "zero" metric into the convolutional decoder on the receive side in place of the omitted bits. The puncturing patterns are illustrated in Figure 5 through Figure 8. In each of these cases, the tables shall be filled in with encoder output bits from the left to the right. For the last block of bits, the process shall be stopped at the point at which encoder output bits are exhausted, and the puncturing pattern applied to the partially filled block.

Decoding by the Viterbi algorithm is recommended.

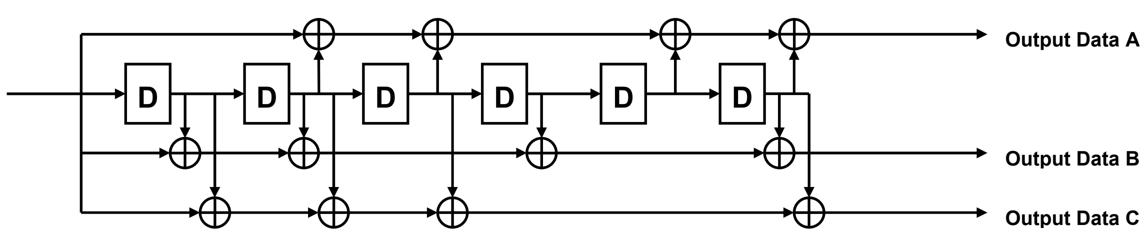


Figure 4 – Convolutional encoder: rate R = 1/3, constraint length K = 7

Figure 5 – An example of the bit-stealing and bit-insertion procedure (R = 11/32)

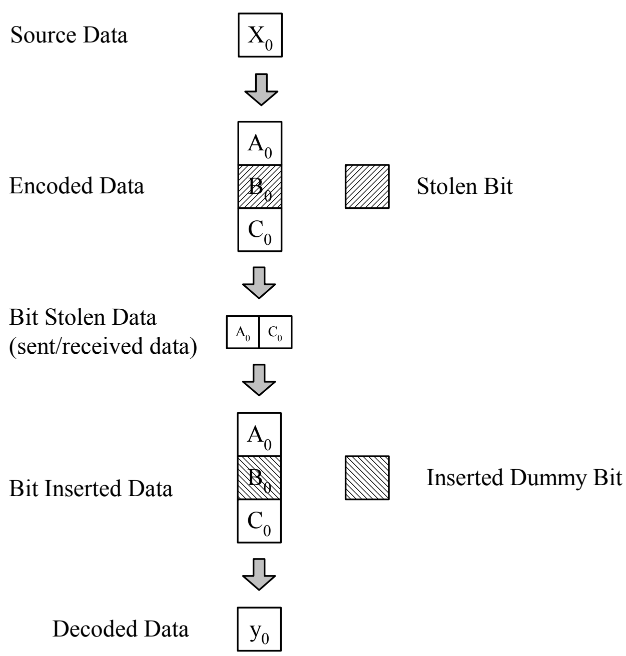


Figure 6 – An example of the bit-stealing and bit-insertion procedure (R = 1/2)

Figure 7 – An example of the bit-stealing and bit-insertion procedure (R = 5/8)

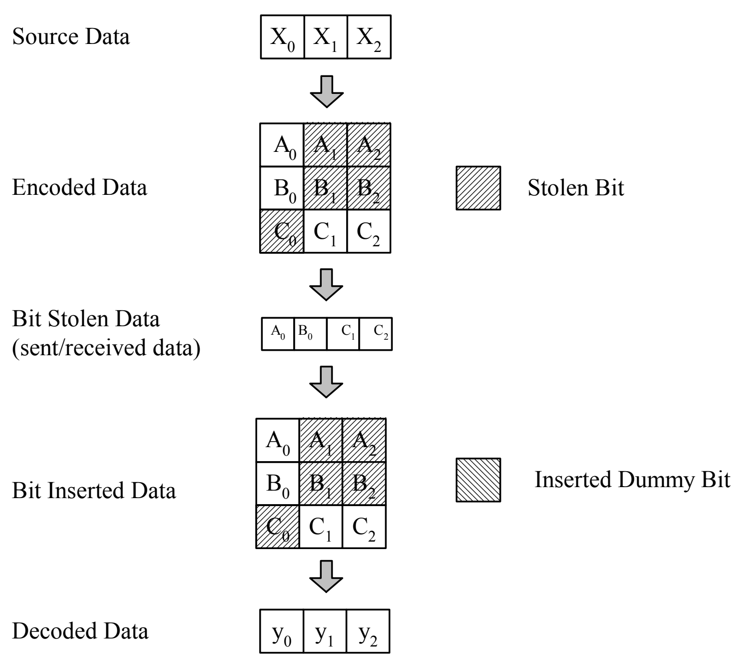


Figure 8 – An example of the bit-stealing and bit-insertion procedure (R = 3/4)

3.3 Bit interleaving

The coded and padded bit stream is interleaved prior to modulation. Bit interleaving provides robustness against burst errors. The bit interleaving operation is performed in three stages: (i) symbol interleaving across the OFDM symbols, followed by (ii) intra-symbol tone interleaving, and (iii) intra-symbol cyclic shifts. The symbol interleaver permutes the bits across OFDM symbols to exploit frequency diversity across the sub-bands, while the tone interleaver permutes the bits across the data tones within an OFDM symbol to exploit frequency diversity across tones and provide robustness against narrow-band interferers. The length of the symbol interleaver is determined by the time spreading factor (TSF) defined in Table 4. The symbol interleaver shall interleave among $(6/TSF)*N_{CBPS}$ coded bits, where N_{CBPS} is the number of coded bits per OFDM symbol. Following this, the symbols shall each be cyclically shifted by a different amount as described further in this section. This is done to exploit frequency diversity, especially in the modes that do not employ time spreading.

For the bit interleaving operation, the coded bits shall first be grouped together into blocks of $(6/TSF)*N_{CBPS}$ coded bits (corresponding to six OFDM symbols over the air). Each group of coded bits shall then be permuted using a block interleaver of size $(6/TSF)*N_{CBPS}$. Let the sequences $\{U(i)\}$ and $\{S(i)\}$, where $i = 0,\ldots, (6/TSF)*N_{CBPS}-1$, represent the input and output bits of the symbol block interleaver, respectively. The input-output relationship of this interleaver shall be given by:

$$S(i) = U\left\{ \text{Floor}\left(\frac{i}{N_{CBPS}} \right) + (6/TSF) * \text{Mod}\left(i, N_{CBPS}\right) \right\},$$

where the function Floor(·) returns the largest integer value less than or equal to its argument value, and where the function Mod(·) returns the remainder after division of i by N_{CBPS}.

The output of the symbol block interleaver is then passed through a tone block interleaver. The outputs of the symbol block interleaver are grouped together into blocks of N_{CBPS} bits and then permuted using a regular block interleaver of size $N_{Tint} \times 10$, where $N_{Tint} = N_{CBPS}/10$. Let the sequences $\{S(i)\}$ and $\{T(i)\}$, where $i = 0,\ldots, N_{CBPS}-1$, represent the input and output bits of the tone interleaver, respectively. The input-output relationship of the tone block interleaver is given by:

$$T(i) = S\left\{ \text{Floor}\left(\frac{i}{N_{T\text{int}}} \right) + 10\text{Mod}\left(i, N_{Tint}\right) \right\},$$

where the function Mod(·) returns the remainder after division of i by N_{Tint} .

The output of the tone interleaver is then passed through the last stage, which consists of a different cyclic shift of each block of N_{CBPS} bits within the span of the symbol interleaver defined above. Let *{T(b,i)}* and *{V(b,i)}*, where $i=0,1,\ldots,N_{CBPS}-1$, represent the input and output sequences, respectively, of the cyclic shift for the b^{th} block. Then,

$$V(b,i) = T\left(b, \mathrm{mod}\left(i + A(b), N_{CBPS}\right)\right)$$

For conjugate symmetric modes, $N_{CBPS}=100$: $A(b) = b*33,\ b=0,1,2.$

For non-conjugate symmetric modes with time spreading ($TSF = 2$), $N_{CBPS}=200$: $A(b) = b*66,\ b=0,1,2.$

For non-conjugate symmetric modes with no time spreading ($TSF=1$), $N_{CBPS}=200$: $A(b) = b*33,\ b=0,1,2,\ldots,5.$

4 Operating band frequencies

4.1 Operating frequency range

The Multi-band OFDM PHY operates in the 3.1 – 10.6 GHz frequency as regulated in the United States by the Code of Federal Regulations, Title 47, Section 15, as well as in any other areas that the regulatory bodies have also allocated this band.

4.2 Band numbering

The relationship between center frequency and band number is given by the following equation:

$$\text{Band center frequency} = 2904 + 528 \times n_b,\ n_b = 1 \ldots 14\ \text{(MHz)}.$$

This definition provides a unique numbering system for all channels that have a spacing of 528 MHz and lie within the band 3.1 – 10.6 GHz. Based on this, five band groups are defined, consisting of four groups of three bands each and one group of two bands. Band group 1 is used for Mode 1 devices (mandatory mode). The remaining band groups are reserved for future use. The band allocation is summarized in Table 4.

Table 4 – OFDM PHY band allocation

Band Group	BAND_ID	Lower frequency	Center frequency	Upper frequency
1	1	3168 MHz	3432 MHz	3696 MHz
	2	3696 MHz	3960 MHz	4224 MHz
	3	4224 MHz	4488 MHz	4752 MHz

2	4	4752 MHz	5016 MHz	5280 MHz
	5	5280 MHz	5544 MHz	5808 MHz
	6	5808 MHz	6072 MHz	6336 MHz
3	7	6336 MHz	6600 MHz	6864 MHz
	8	6864 MHz	7128 MHz	7392 MHz
	9	7392 MHz	7656 MHz	7920 MHz
4	10	7920 MHz	8184 MHz	8448 MHz
	11	8448 MHz	8712 MHz	8976 MHz
	12	8976 MHz	9240 MHz	9504 MHz
5	13	9504 MHz	9768 MHz	10032 MHz
	14	10032 MHz	10296 MHz	10560 MHz

The frequency of operation for Mode 1 devices is shown in Figure 9.

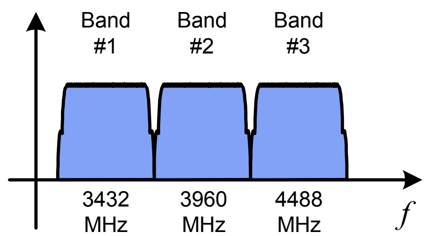


Figure 9 – Frequency of operation for a Mode 1 device.

4.3 Channelization

Unique logical channels corresponding to different piconets are defined by using up to four different time-frequency codes (TFCs) for each band group. The TFCs are defined in Table 5 using BAND_ID values for Band Group 1. The TFCs for the Band Groups 2-4 shall be defined in a similar manner by substituting the BAND_ID values appropriate for each Band Group as defined in Table 4. For example, for Band Group 2, the three BAND_ID values 4,5,6 shall replace the values 1,2,3 respectively in Table 5 to generate the TFCs. For Band Group 5 only, TFCs 5 and 6 shall be defined (with the appropriate BAND_ID values specified in Table 4).

Table 5 – Time Frequency Codes for Band Group 1

TFC Number	Length 6 Time Frequency Code					
1	1	2	3	1	2	3
2	1	3	2	1	3	2
3	1	1	2	2	3	3
4	1	1	3	3	2	2

5	1	2	1	2	1	2
6	1	1	1	2	2	2

5 Transmitter specifications

5.1 Transmit PSD mask

The transmitted spectrum shall have a 0 dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 260 MHz, –12 dBr at 285 MHz frequency offset, and –20 dBr at 330 MHz frequency offset and above. The transmitted spectral density of the transmitted signal mask shall fall within the spectral, as shown in Figure 10.

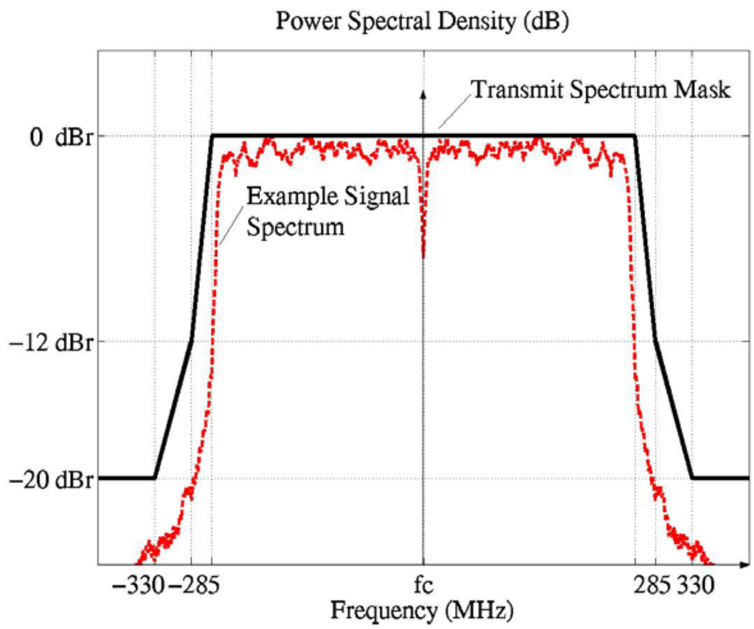


Figure 10 – Transmit Power Spectral Density Mask

Attachment C

MBOA Fixed Satellite Services Field Testing

1 Introduction

This section describes field tests conducted by the MBOA to determine interference potential to fixed satellite systems (FSS) operating in the C band. The objectives of the tests were as follows:

- Measure interference potential to C-band TV service operating in the FSS C-band 3.7-4.2GHz
- Compare White Gaussian Noise (WGN), MB-OFDM & Impulse UWB signals
- Quantify relative interference potential of each UWB signal
- Determine safe distance from dish antenna to avoid interference

Two separate but related tests were conducted. The first test compared the different UWB signals in terms of their potential to cause interference to the FSS receiving system. The results quantify the relative emission power level for each UWB signal where interference to the FSS receiver was observed. The goal of the second test was to determine the safe distance from the dish that must be maintained to avoid interference to the FSS receiver.

2 Test system and facility

The tests described here were conducted at the TDK RF test facility in Austin, TX on December 8-18, 2003. A local satellite TV company was hired to install a C band system in the outdoor RF test range. The system used the following equipment:

- C-band system with auto positioning dish
- 10 foot Sami dish selected by provider as typical for Austin area
- Motorola DSR-922 receiver selected due to popularity

Figure 1 is a diagram of the test setup showing how all the components of the system were connected.

2.1 UWB Interference sources

The following signal generators were used as interference sources:

- Broadband noise source (WGN) band limited to the UWB band using a microstrip filter
- Wisair EVT generator supported two modes
    - MB-OFDM transmitter 528MHz BW with zero padding (no CP)
    - Impulse UWB, 30MHz PRF

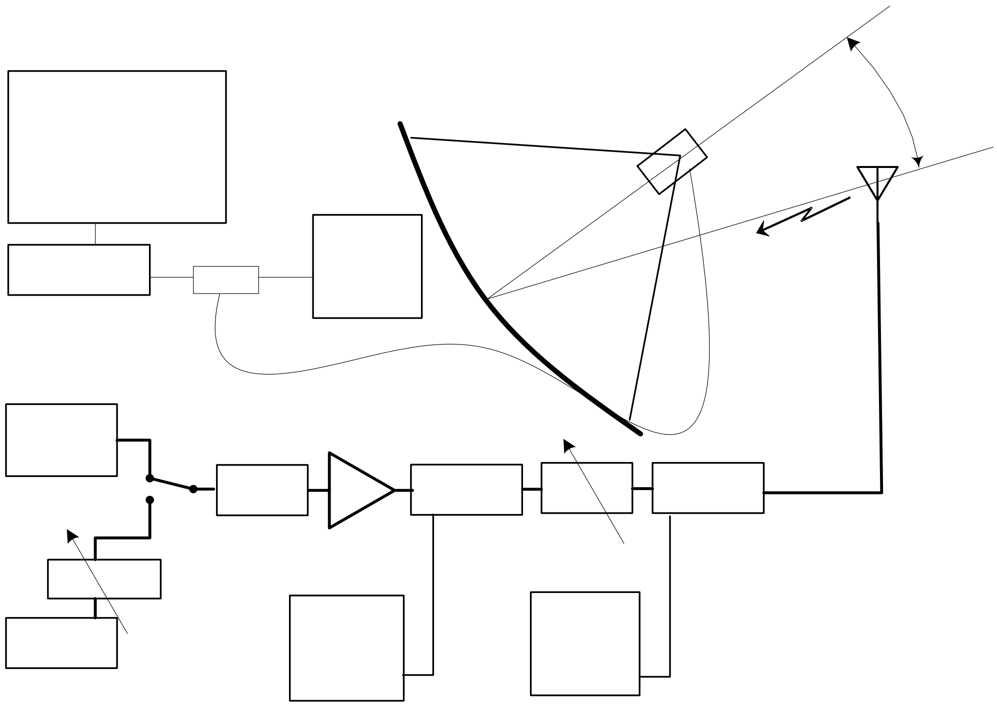
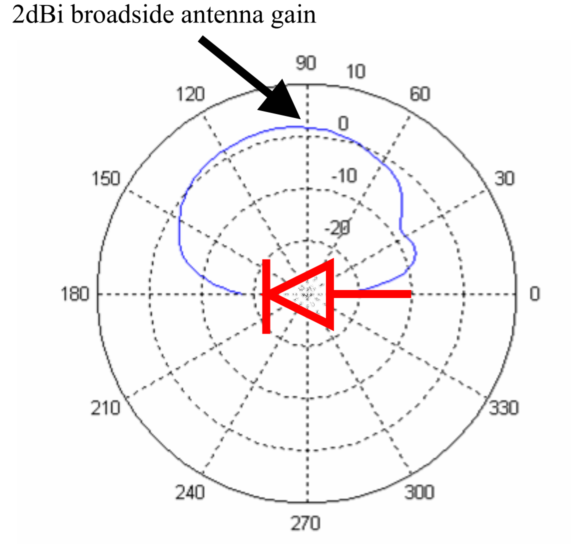


Figure 1: Test Setup

2.2 UWB emission power calibration

All test equipment used in the testing had up to date calibration traceable to NIST standard. Accuracy of the spectrum analyzer was also double checked against a precision thermal power meter. The effective radiated power of each UWB signal generator was derived by adding 2dBi antenna gain to power measurements made on the spectrum analyzer using 1Mhz bandwidth per FCC rules. UWB generator power was checked before, during and after each test to ensure that power drift was not a concern. Figure 2 shows how the 2dBi antenna gain was derived. All power measurements were measured via the conducted method connected directly to the antenna port at the end of the 100 foot feed cable.



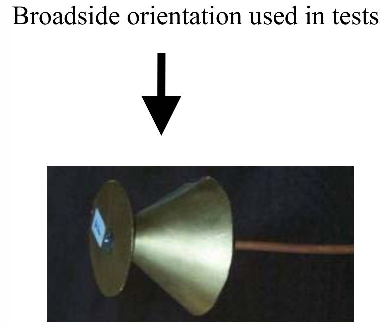


Figure 2. Test antenna gain

3 Satellite signals and interference assessment

All test results reported here were measured using live signals received from the Galaxy 1R (G1) satellite with the receiver tuned to channel MMAXW (fc=4.16GHz), Digicipher II stream (QPSK, 7/8 FEC, 29.27Ms/s). Other satellite signals and channels were tested to verify that measurement results were consistent and repeatable.

Interference was assessed by visually observing the TV display for signs of blocking artifacts which indicate unrecoverable errors in the MPEG data stream. Observation of blocking artifacts were repeatable to within 0.1dB interference power.

3.1 Receive signal margin

Since the receive signal margin available to the satellite receiver has a significant effect on interference resistance this parameter was carefully established. Receive signal margin is defined here as the received signal power presented to the satellite receiver that is in excess of the absolute minimum for error free performance. This minimum is defined here as the receiver sensitivity.

To establish the available margin, a spectrum analyzer was connected to measure the signal power presented to the receiver as shown in Figure 1. Two measurements were then taken. The first was with the dish in its optimal position and the second was taken after the dish elevation was increased aiming at open space. The second measurement was taken at the receiver's sensitivity point. Figure 3 shows the measurements and establishes that the maximum signal margin was 2.5dB. This is not surprising given that to increase this margin one would have to deploy a dish larger than necessary. Note that the automatic positioning system was able to find the optimum signal without assistance.

We believe that failure to establish a real world signal margin is the cause for the skewed results reported by Freescale. If you look close at the results of our test you will see that as the signal margin increases the difference in interference potential grows. However never does the MB-OFDM signal reach the interference potential of the impulse signal.

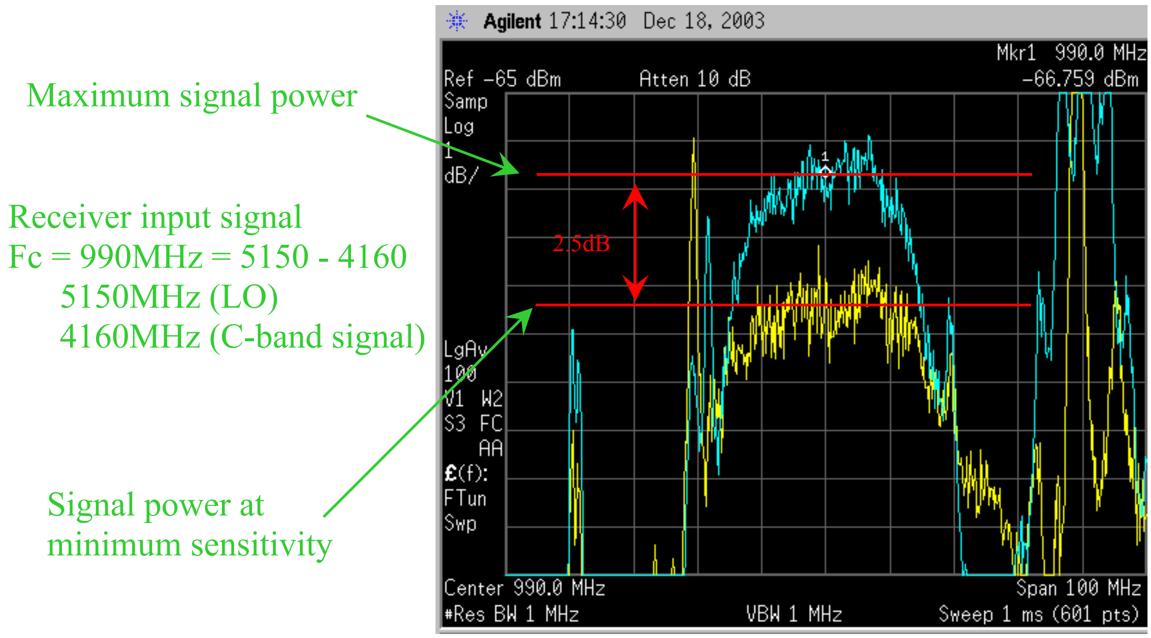


Figure 3: Receive Signal Margin

4 Relative interference tests

The objective of this test was to accurately measure the relative interference potential of MB-OFDM signal as compared to the impulse signal. UWB emission power was set to -41.3dBm/MHz per the aforementioned calibration method. Alternating the coaxial RF switch allowed quick and accurate verification that both UWB signal sources were set to the -41.3dBm/MHz. Next the test antenna was placed close enough to the FSS dish to cause visible block artifacts on the TV monitor. With the coaxial switch set to impulse UWB the emission power was reduced just enough until consistent error free video performance was observed (error threshold). Lastly the coaxial switch was set to MB-OFDM and the emission power was increased until again the error threshold was found.

The relative interference power was measured by directly reading the dial on the variable attenuator and noting the delta from impulse to MB-OFDM. This method is accurate to less than 0.1dB since it relies only on a controlled power loss rather than a measurement with a spectrum analyzer.

Table 1, Relative interference potential measurements.

Emission	0.5dB above sensitivity	1dB above sensitivity	2.5dB above sensitivity
3MHz PRF impulse	0.0dB	0.0dB	0.0dB
MB-OFDM 3 band	0.8dB	2.6dB	2.4dB
WGN (DSSS)	1.9dB	3.8dB	4.0dB

The results presented in table 1 show that, under real world operating conditions, the FSS receiver can withstand 2.4dB more interference power from MB-OFDM than from an impulse radio which is currently allowed by FCC rules.

This test was run repeatedly while placing the antenna in different locations and the results were reliable and repeatable. Also note that during each test the UWB antenna was not moved or disturbed in any way to ensure that the specific signal propagation mode remained the same. Claims that these tests produced random results have no basis in fact.

5 Safe Distance test

The objective of this test was to determine how far should a UWB device be kept from an FSS receiving system to ensure that no harmful interference would occur. An additional objective was to compare the safe distance of the different UWB signals.

To begin this test the dish was set to the proper elevation and the satellite receiver was allowed to align the azimuth and polarization for maximum signal. Then after the UWB signal generators were calibrated and set to -41dBm/MHz emission power a hunt for sensitive spots was conducted in the test range. Indeed interference was observed when the UWB antenna was placed in the main beam of the dish. However since in order to receive a satellite signal, the dish must be pointed at unobstructed sky, a 40 foot mast was required to place the UWB antenna into this position. As such we eliminated this as a possible source of interference for real world operation.

We then moved the UWB antenna to a height to simulate a hand held device which was approximately 20degrees below the bore-sight of the dish. We then moved the UWB antenna around the test range and found that it had to be within 20 feet of the dish before interference was observed. We then found the most sensitive spots around the dish and placed flags at the maximum distance where interference was observed. For each sensitive spot we compared the safe distance of MB-OFDM and WGN (DSSS) signals. The resulting safe distance measurements are plotted in Figure 4.

From Figure 4 one can see that even at the most sensitive points a safe distance of 25feet will always avoid interference. Also notice that there is little practical difference in the required safe distance between the different UWB signal types.

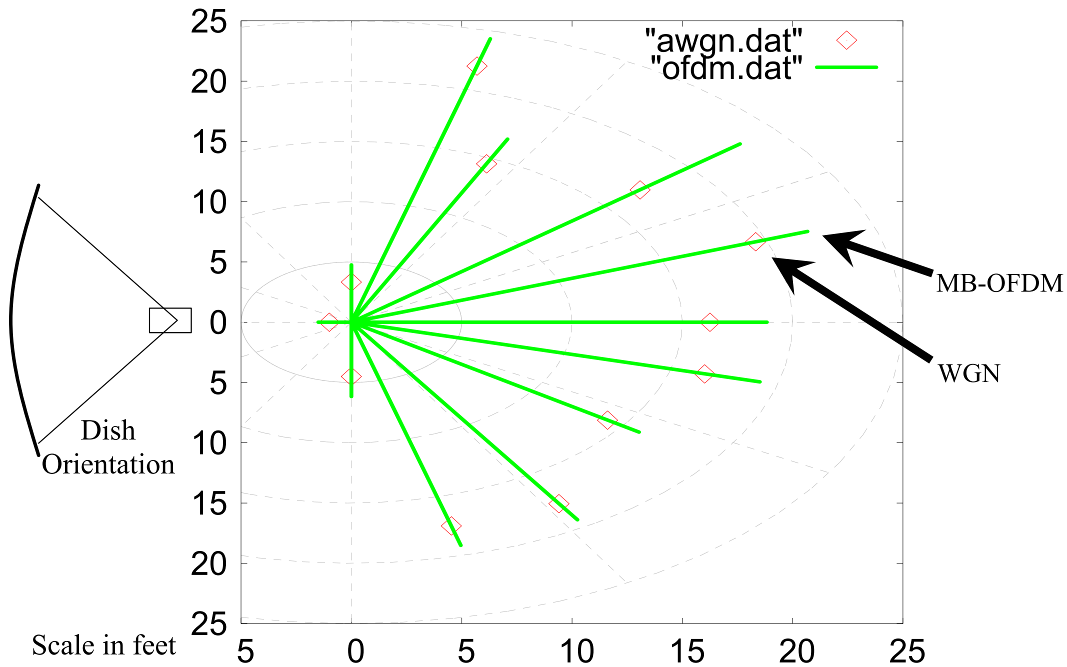


Figure 4: Safe distance from dish