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

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's	)	ET Docket No. 98-153
Rules Regarding Ultra-Wideband	)	
Transmission Systems	)	

MOTION TO FILE COMMENTS OUT OF TIME

Fantasma Networks, Inc. ("Fantasma"), respectfully requests that its reply in the above-captioned matter be made a part of the record even though it is being submitted three business-days late. The delay was caused by administrative problems that resulted in the filing of an early and incomplete version of the reply. Fantasma has worked diligently since the error was discovered to assemble the reply comments in final form.[1]

Fantasma's reply responds to issues relating to UWB communication technologies operating above 2 GHz. Because of the importance of these issues and the fact that a brief delay in submitting the reply will not prejudice the interests of other parties given that a second comment cycle still remains to be completed in this proceeding, Fantasma asks that the Commission grant this motion to file out of time.[2]

Respectfully submitted,

By: /s/ W. Kenneth Ferree
W. Kenneth Ferree

GOLDBERG, GODLES, WIENER & WRIGHT
1229 Nineteenth Street, N.W.
Washington, D.C. 20036
(202) 429-4900
Its Attorneys

November 1, 2000

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[1] Fantasma has requested by separate transmittal that the Electronic Comment Filing System ("ECFS") administrator delete Fantasma's previously-filed reply comments. However, in the event that the prior reply comments are not deleted from the ECFS system, the attached reply should be regarded as superceding the prior version.

[2] Indeed, NTIA now reports that its UWB complete test results will not be available until February 2001.

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REPLY COMMENTS OF FANTASMA NETWORKS, INC.

FANTASMA NETWORKS, INC.
James F. Lovette
Director of Strategic Policies
3250 Ash Street
Palo Alto, CA 94306

Of Counsel:
Henry Goldberg
W. Kenneth Ferree
GOLDBERG, GODLES, WIENER & WRIGHT
1229 Nineteenth Street, N.W.
Washington, DC 20036
(202) 429-4900

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REPLY COMMENTS OF FANTASMA NETWORKS, INC.

Fantasma Networks, Inc. ("Fantasma") hereby replies to the comments filed on the above-captioned Notice of Proposed Rulemaking ("NPRM").

INTRODUCTION

As evidenced by the comments filed in this proceeding, there is widespread support for amending the Part 15 rules to permit the deployment of ultra-wideband ("UWB") technologies. Public safety groups, educators, medical organizations, groups representing the elderly and disabled, federal and local government agencies, and other potential users and beneficiaries of UWB technologies have filed comments and letters supporting the Commission's proposals. Each of these parties has recognized the numerous benefits that may be realized from this new broadband transmission technology.

Some parties filed comments addressing technical issues relating to UWB operations. These parties fall into two categories: (1) those that oppose the introduction of UWB technologies below 2 GHz because of concerns regarding possible harmful interference to global positioning satellite systems ("GPS") and (2) those that, for commercial reasons, oppose any additional use of the spectrum in which their radio systems operate — even if the new use poses no realistic threat of harmful interference.

Because Fantasma has designed its UWB communications technologies to operate above 2 GHz, it confines these reply comments to issues relating to UWB communications systems operating above 2 GHz. As explained below and in the attached technical materials, none of the comments filed in this proceeding refutes the Commission's tentative conclusions regarding the ability of UWB technologies to operate above 2 GHz without causing harmful interference to radio systems in those bands. The Commission should, therefore, proceed quickly to adopt service rules under Part 15 for UWB operations above 2 GHz.

DISCUSSION

I. There Is Wide-Ranging Support For The FCC's Proposal To Permit UWB Technologies Above 2 GHz.

The great majority of comments filed in this proceeding supports operation of unlicensed UWB technologies under Part 15, particularly UWB wireless communications systems being developed for operation above 2 GHz. The parties filing these comments recognize that UWB may hold the key to the development of new broadband technologies that will enhance the quality of life for many Americans, particularly for those with special needs.

For example, numerous groups representing the disabled, elderly, and medically infirm have urged the Commission to move quickly to allow the implementation of UWB technology that will provide greater independence to those with impaired physical abilities.[1] Other parties support adoption of UWB rules under Part 15 to foster the development of highly specialized communications technologies to support critical services. The U.S. Navy notes, for example, that UWB technologies "offer the ability to provide a nearly

[1] E.g., Comments of The Amyotrophic Lateral Sclerosis Association; Comments of the Alzheimer's Association; Comments of the Alliance on Mental Illness; Comments of the American Association of People with Disabilities (filed Oct. 12, 2000); Comments of the Disability Rights Education and Defense Fund (filed Oct. 10, 2000).

undetectable communications link for covert operations that are typically required for naval maneuvers."[2]

Many others including Fantasma, Xtreme Spectrum, Inc., and Time Domain Corporation, have recognized that UWB wireless communications technology offers a once-in-a-generation opportunity to improve the educational experience and to help bridge the "digital divide" that increasingly separates technological "haves" from the "have-nots."[3] By providing a simple, flexible means of connecting numerous digital devices to each other within the home and to external broadband networks, such as the Internet, UWB technologies can help bring broadband services to the underserved populations that currently are excluded from the communications and information revolution.[4] UWB communications devices operating above 2 GHz fulfill this need ideally, offering a unique combination of very high data rates, low cost, and wireless mobility.

UWB technologies can, in short, play a vital role in the evolution of existing narrowband wired and wireless facilities into broadband wireless networks and provide the impetus for the development of new, communications products and services. The Commission should, therefore, move expeditiously to complete the first stage of this rulemaking and adopt UWB service rules under Part 15, particularly for UWB communications technologies operating above 2 GHz.

II. Concerns Regarding UWB Operations Above 2 GHz Have Been Overstated.

A number of parties agree with the Commission's conclusion that UWB technologies operating above 2 GHz will pose little or no threat of harmful

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[2] Comments of the Department of the Navy.
[3] See Comments of Rainbow/PUSH Coalition; see generally "Falling Through The Net: Toward Digital Inclusion," U.S. Department of Commerce White Paper (Oct. 2000).
[4] See generally Comments of Hewlett-Packard Company.

interference to existing services.[5] Some existing users of this portion of radio spectrum, however, oppose the introduction of UWB into the bands in which they operate. Although a "not in my backyard" attitude is to be expected, the concerns raised and the remedies proposed regarding UWB operations have been overstated.[6]

A. A Few Parties Have Resisted The Introduction Of UWB Technologies Without Providing Any Technical Support.

A few of the parties who have questioned whether UWB technologies can operate above 2 GHz without causing harmful interference have failed to make any substantial technical showing. Instead, they simply assert that UWB operation will be incompatible with existing radio services. These parties have provided no evidence that they understand principles of UWB transmissions , no technical analyses of possible interactions between their systems and UWB systems, and no specific rationale that such interactions might occur. The Commission, therefore, should discount these unsupported objections.

For example, the National Association of Broadcasters ("NAB") questions the Commission's tentative decision to allow UWB operations above 2 GHz because broadcasters use the 1.990-2.110 GHz band for electronic news gathering ("ENG") operations.[7] The NAB does not, however, provide any basis for its supposed concern. Indeed, as the NAB itself recognizes, ENG systems use high-gain directional antennas that render ENG transmissions extremely robust and

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[5] See, e.g., Comments of XtremeSpectrum, Inc.

[6] One party, MultiSpectral Solutions, Inc. ("MSSI"), raised a concern about interference from "unfiltered" UWB systems. MSSI stated that an antenna should not be assumed to be an effective filter for a transmitted signal because damage to the antenna or anomalies in the local environment can alter the frequency response of the antenna. Although true, this phenomena is not limited to UWB antennas, but applies to various other types of antennas used by radio technologies. See Analysis Of MSSI Antenna Filtering Issues (attached). Accordingly, Fantasma has designed a system that does not rely on antenna filtering to shape the signal. As a regulatory matter, however, the Commission's focus should remain on establishing reasonable and practical out-of-band emissions limits for UWB operations and not on specifying the means of achieving those limits.

[7] Comments of NAB at 3.

resistant to all forms of interference. The Commission should assume, therefore, absent any technical showing to the contrary, that UWB signaling will not cause harmful interference to ENG operations.

Similarly, the National Business Aviation Association, Inc. ("NBAA") and Rockwell-Collins, Inc. ("Rockwell") adopt a "sky-is-falling" posture with regard to UWB operations above 2 GHz. The NBAA opposes UWB operations in "any portion of the RF spectrum … due to the absence of data and corresponding analysis of the effects of UWB-generated interference."[8] Rockwell urges the Commission to raise the UWB frequency floor to 5.15 GHz because radio altimeters and microwave landing systems operate in the 4 GHz and 5 GHz bands.[9]

Neither NBAA nor Rockwell, however, has made a showing that UWB would cause any actual harmful interference to the services that they identify, nor have they described reasonable scenarios that would suggest that effect. Instead, they rely on their own lack of analysis to oppose authorization of UWB above 2 GHz. The Commission should not permit any obstructionist tactics to delay the introduction of new, innovative UWB technologies. UWB proponents already have demonstrated that UWB transmissions will, as a practical matter, be invisible to other radio services.[10] If any party has a serious concern about harmful interference from UWB operation, it has an obligation to provide at least some minimal technical showing in support of that position.

B. Some Parties With Technical Objections To UWB Have Based Their Claims On Unrealistic Assumptions Or Incomplete Analysis.

Several parties raise technical objections to the NPRM, either with regard to UWB operations themselves or with regard to the Commission's proposed

[8] Comments of NBAA at 12.
[9] Comments of Rockwell at 5.
[10] See, e.g., NPRM ¶¶ 1-6.

UWB rules. For example, a number of parties question the Commission's tentative conclusion in the NPRM that "only the closest [UWB] transmitter placing an emission on the frequency of concern would be of importance, obviating the need for additional attenuation to compensate for cumulative effects."[11] Others question some of the Commission's assumptions regarding appropriate UWB power measurements.

In each case, however, analysis of the technical materials submitted by these parties reveals that the Commission's original conclusions are sound and that the objections raised are based on unrealistic assumptions or incomplete analysis.

1. <u>As a practical matter, emissions from the single closest UWB transmitter will predominate so that UWB aggregation effects will be negligible.</u>

In the NPRM, the Commission tentatively concluded that:

> The cumulative impact [of UWB transmitters] appears to be negligible at the power levels and with the modulation types being proposed, especially when compared to the interference potential from a single land mobile transmitter. This leads us to believe that only the closest transmitter placing an emission on the frequency of concern would be of importance, obviating the need for additional attenuation to compensate for cumulative effects.[12]

AT&T Wireless Services, Inc. ("AT&T Wireless"), The Boeing Corporation ("Boeing"), Cisco Systems, Inc. ("Cisco"), and Rockwell all question, in one form or another, the Commission's tentative conclusion.[13] Cisco in particular devotes a large part of its technical analysis attempting to demonstrate that it is at least theoretically possible for the calculated level of interference from multiple UWB transmitters to exceed the interference potential of the closest UWB transmitter.

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[11] NPRM ¶ 47.
[12] NPRM ¶ 47.
[13] <u>See</u> Comments of AT&T at 6; Comments of Boeing at 10-15; Comments of Cisco at 11 & Technical Appendix; Comments of Rockwell at 5-6.

Although it may be possible to create a theoretical scenario in which the calculated level of cumulative emissions from a mass of UWB transmitters could become high enough to cause harmful interference, such a scenario simply does not mirror the real-world operating environments, today or, most likely, in the future. To the contrary, as explained in the attached paper by Dr. Timothy J. Shepard of the Massachusetts Institute of Technology, Understanding Aggregations of Many UWB Emitters, as a practical matter, "the level of harmful interference from a single nearby UWB emitter will dominate the level of interference from an aggregation of millions of emitters scattered throughout a metropolitan area."

According to Dr. Shepard, even when millions of UWB emitters are distributed throughout an area, the potential for the aggregation to raise the noise floor is well bounded and the level of aggregate signals will be comparable to the signal from a single nearby emitter.

In many cases, a single UWB emitter will be close enough to any victim receiver to produce this eclipsing effect. Indeed, even in indoor environments in which multiple UWB transmitters may operate, one would expect to find many situations in which a single UWB transmitter would be the predominate source of UWB emissions. In outdoor environments, in which the distribution of UWB technologies is expected to be less dense, this eclipsing affect will be even more pronounced.

Moreover, the Commission was correct in its conclusion that "[t]he cumulative impact [of UWB] appears to be negligible at the power levels and with the modulation types being proposed, especially when compared to the interference potential from a single land mobile transmitter."[14] In metropolitan areas today, many existing sources of harmful interference, including spurious

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[14] NPRM ¶ 47.

emissions from high-power VHF and UHF transmitters, intermodulation effects (including the incidental mixing of authorized transmissions in metal structures), existing unintentional radiators, and existing incidental radiators, already "aggregate" to create an increased level of interference or a raised noise floor. Because the link budget and the number of and site selection for central stations of radio systems being designed today must already account for this radio noise, authorizing UWB emissions at levels comparable to these already existing non-thermal noise sources will not lead to an "aggregation" problem.

In short, although millions of UWB devices may operate in any geographic area, in all realistic scenarios, the interference experienced by a receiver reliably can be determined by considering the interference from the nearest single UWB transmitter. There is no reason, therefore, to add a layer of complexity to UWB interference analysis by attempting to account for, and factor in, multiple aggregated UWB transmitters.

2. UWB emissions should be measured in the frequency domain with a 1 MHz resolution bandwidth.

In the NPRM, the Commission asked for comment on a variety of issues relating to UWB measurement procedures. Among other things, the Commission asked for comment on two proposed methods of measurement for UWB technologies: (1) the peak level of emission when measured over a bandwidth of a 50-MHz; and (2) the absolute peak output of the emission over the entire UWB bandwidth.[15] The Commission's intent is to "develop measurement procedures that are reasonably simple and straightforward and can apply to a wide range of UWB devices."[16]

Several parties filed comments supporting the adoption of an UWB emission measurement protocol using 50 MHz resolution bandwidth ("RBW"),

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[15] NPRM ¶ 42.
[16] NPRM ¶ 49.

apparently seeking to gain additional protection from UWB transmissions.[17] Others further proposed a time domain-based measurement procedure, apparently with the same protection goal in mind.[18]

The current Part 15 rules already include simple and straightforward measurement procedures. The measurement technique for Part 15 unlicensed devices involves an average measurement of 1 MHz RBW and 10 Hz video bandwidth ("VBW"). The rules also specify a maximum "peak" emission level, measured in 1 MHz RBW and VBW, that is 20 dB higher than the average measurement.

As set forth in the Technical Appendix, there is no need to change the Part 15 measurement rules for UWB. Indeed, measuring UWB emissions in the frequency domain over a 1-MHz bandwidth will provide more accurate information and a more protective standard than the proposed alternatives. The Commission should, therefore, apply current Part 15 measurement protocols to UWB technologies. Such measurements are well understood in the industry and they can be made at most RF testing facilities. Therefore such measurements meet the Commission's standard of being "simple and straightforward" and they provide the requisite degree of accuracy.

3. There is no basis for imposing additional power restrictions on UWB technologies operating above 2 GHz.

A few parties have sought to raise issues relating to possible UWB interference into existing and planned wireless and satellite services in the 2 GHz to 3 GHz bands.[19] For example, Motorola, Inc. ("Motorola") claims that UWB technologies above 2 GHz should be required to reduce peak power by 12 dB

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[17] E.g., Comments of Cisco; Comments of Metricom, Inc. ("Metricom").
[18] See Comments of Lucent Technologies, Inc. ("Lucent").
[19] See Comments of Cisco at 3; Comments of Metricom, Inc. (2.3 GHz WCS band); Comments of XM Radio, Inc. at 9; Comments of Sirius Satellite Radio Inc. at 10; Comments of Mobile Communications Holdings, Inc. at 3.

below Part 15 standards.[20] Similarly, Cisco claims that the signal fall-off that will occur above 2 GHz will not be fast enough and that Part 15 requirements alone offer inadequate protection from harmful interference by UWB devices.[21] As set forth in the Technical Appendix, however, there are a number of problems with these assumptions and with the analysis upon which these parties have drawn their conclusions.

First, the parties advocating a UWB power reduction have based their analysis on unrealistic models that do not reflect real world operating conditions. For example, the Friis model used by both Cisco and Motorola provides for path loss in free space. It is not, therefore, useful for predicting actual path loss in most real world situations because of attenuation and defraction by objects in the environment such as terrain, buildings, foliage, etc. The results gleaned from models based on free space path loss, therefore, are unreliable in most real-world situations.

Motorola also uses the Hata model, which provides path loss data for more cluttered environments. Motorola, however, uses the Hata model at a frequency assumption of 2 GHz and separation distance assumption of greater than 100 meter. Both assumptions are unrealistic in the MDS application. Using the actual MDS frequency of 2.5 GHz and a more realistic MDS minimum separation distance assumption of 10 meters, there will be 3 to 7dB more attenuation than Motorola's analysis suggests.

Based on more realistic assumptions, the specific concerns of Motorola and Cisco regarding interference to Multipoint Distribution Service ("MDS") base stations and subscribers are unfounded.

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[20] Motorola's claim is based on a link budget calculation using two models for path loss: the Hata model and Friis model.

[21] Cisco at 5.

a. UWB technologies will not cause interference to MDS base stations.

Fantasma agrees with Motorola's assumption that it is highly unlikely that a UWB transmitter will be located within 50 meters of an MDS base-station tower. Motorola and Cisco, however, then apply unrealistically pessimistic path-loss models to estimate a 73-meter and 380-meter, respectively, minimum acceptable separation between a UWB emitter and a victim MDS base station. [22] Using the more realistic path loss models outlined above, Fantasma estimates the minimum required separation to be from 27 to 35 meters – well within the 50-meter boundary as assumed by Motorola.

Furthermore, Motorola overstates the potential for interference by assuming that base stations employ omni-directional antennas. Using a more realistic assumption that base stations may employ directional antennas, potential interference is reduced still further. Factoring in realistic assumptions for both signal path loss and antenna configuration, UWB emitters will not pose a significant risk of harmful interference to MDS base stations.

b. UWB technologies will not cause interference to MDS subscribers.

On the subscriber side of an MDS system, Motorola and Cisco again overstate the potential for interference from UWB emitters. As with the calculations for base stations, the Motorola and Cisco calculations for subscriber receivers are based on unrealistic path-loss models and on the assumption of omni-directional receiver antennas. MDS subscriber receive antennas often will be located on a rooftop, affixed to the side of a building, or otherwise positioned favorably with respect to the associated base station – a significant isolation from the locations of UWB emitters, which are likely to be inside the building at some

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[22] In its analysis, Motorola also assumes a high-gain, omni-directional antenna at the base-station. As discussed in the Technical Appendix, this assumption, too, is highly unrealisitic.

distance from the outdoor MDS receive antenna Losses from building material and other objects in the local environment will further reduce the potential interference from any nearby UWB transmitters. Furthermore, MDS subscriber antennas are generally high gain and narrow beam width, rather than omni-directional – a factor that further reduces the number of potential interferers. Thus, the overall potential for UWB interference with MDS subscribers is substantially lower than the Motorola and Cisco estimates suggest, and the 12-dB reduction in UWB power proposed by Motorola is not necessary.

c. An additional 12 dB power reduction would be contrary to the public interest.

The parties that have expressed concern regarding possible harmful interference from UWB emissions have, at best, shown only that it is possible to construct theoretical scenarios in which a particular receiver may experience harmful interference. It is certain, on the other hand, that a significant additional power reduction on UWB emissions would be highly detrimental to the operation of UWB technologies.

As explained in the Technical Appendix, a power reduction by as much as 12 dB, as suggested by Motorola, would reduce the range of a wireless networking UWB application by a factor of four. Alternatively, if the range is held constant, a power reduction of 12 dB would increase the bit error rate from 10^{-6} to 0.5, or reduce the data rate by 100 Mbps to 6.25 Mbps, resulting in an unusable system.[24] Thus, a UWB communications technology previously capable of providing service throughout a home, school, or library would be so limited in range that it might be capable of providing adequate service to only a single room.

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[23] In its analysis, Motorola also assumes a high-gain, omni-directional antenna at the base-station. As discussed in the Technical Appendix § I, this assumption, too, is highly questionable.
[24] See Technical Appendix § I.C.

III. UWB Technologies Should Be Authorized Under Part 15.

As the Commission notes in the NPRM,

> "most near-term applications for UWB technology involve relatively low powers and short operating ranges. Further, … most UWB devices are intended to be mass marketed to businesses and consumers and [therefore] individual licensing of each device would be impractical."[26]

Accordingly, the Commission tentatively has determined that it will authorize UWB operation under Part 15. A few parties question that determination.

Sirius Satellite Radio, Inc., for example, argues that the Commission should adopt some form of blanket licensing mechanism for UWB devices rather than allowing them to operate on an unlicensed basis. Sirius notes that, unlike Part 15 devices, UWB devices will "radiate into restricted bands."[27] Similarly, Boeing favors blanket licensing and suggests further that the Commission should impose rules that would limit distribution of UWB technologies to public safety agencies.[28]

The fact that UWB will "radiate" in restricted bands is irrelevant because UWB radiation will not cause harmful interference to other systems using the spectrum. Indeed, one of the most important benefits of UWB technology is that they can employ spectrum without occupying the spectrum to the exclusion of others.[29] The technical standards and certification process that will be developed

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[25] Id.
[26] NPRM ¶ 18.
[27] See Comments of Sirius at 20-21.
[28] Comments of Boeing at 14. It is not clear from Boeing's comments whether they are meant to address UWB communications technologies as well as UWB radiolocation technologies. To the extent that they address UWB communications technologies, Boeing's comments are based on a fundamental misunderstanding of the nature of UWB and the public benefits that it will yield.
[29] Leander Kahney, The Third generation Gap, Scientific American (Oct. 2000) (the article may be found on-line at http://www.scientificamerican.com/2000/1000issue/1000kahney.html#author).

for UWB devices governed by Part 15 will be sufficient to ensure that there is an extremely low probability that UWB technologies will cause harmful interference to other services.

The suggestion that only public safety agencies should have access to new UWB technologies is based on a misconception of the uses and potential for UWB. Boeing, for instance, claims that UWB systems "would not expand the types of services available to the public [but] simply provide a new, but not necessarily more spectrally efficient, means to provide an existing consumer service."[30] Boeing has overlooked the unique capabilities of UWB to deliver high bandwidth services, for education, medical care, and underserved populations, and to consumers seeking better connectivity. The nature of UWB emissions and the applications for which UWB is well suited, make it appropriate to authorize the technology on an unlicensed basis under Part 15. By doing so, the FCC will help open a door to the future.

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[30] Comments of Boeing at 11.

CONCLUSION

For the reasons stated herein and in its initial comments, Fantasma urges the Commission to move expeditiously to complete this rulemaking and permit UWB operations above 2 GHz.

Respectfully submitted,

FANTASMA NETWORKS, INC.

By: /s/James F. Lovette
James F. Lovette

Director of Strategic Policies
3250 Ash Street
Palo Alto, CA 94306
lovette@fantasma.net
web site: www.fantasma.net

Of Counsel:
Henry Goldberg
W. Kenneth Ferree
GOLDBERG, GODLES, WIENER & WRIGHT
1229 Nineteenth Street, N.W.
Washington, DC 20036
(202) 429-4900

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TECHNICAL APPENDIX[1]

I. Comments on Interference Issues in MDS and UWB Band Sharing

Several parties have expressed concerns that single or multiple UWB transmitters positioned within certain distances from MDS receivers can cause harmful interference to such receivers. Generally, the parties seeking protection from UWB consider any potential degradation of the MDS signal to noise or, as is often described, any "rise in the noise floor" of even a fraction of one dB at the extreme limits of expected coverage, to be a basis for blocking deployment of UWB technology.

This paper does not address the question of what the reasonable expectations for interference protection should be. Note, however, that some portrayals of UWB appear to be "chambers of horrors" scenarios with UWB the sole possible cause of signal degradation in an interference-limited environment, ignoring the plethora of uncertainties about hardware, environment, installation, and other factors affecting MDS operation.

This paper examines the representations about potential harmful interference from UWB that do not appear to be justified or supportable.

A. Requirements for a "minimum acceptable separation distance" are not supported.

Cisco and Motorola strive to show that UWB transmitters must be far removed from MDS receivers to prevent harmful interference. Both Cisco and Motorola define the minimum acceptable separation distance ADS_{min} as follows: If a UWB transmitter is located less than the ADS_{min} from the subject or "victim" MDS receiver, then the noise floor of the victim MDS receiver will be raised by an unacceptable amount. Cisco derives the ADS_{min} for a victim MDS subscriber receiver with an antenna having 20 dBi of directional gain to be 380 meters. Motorola shows the ADS_{min} to be 13 meters for a victim MDS subscriber receiver with –8 dBi omni-directional antenna gain and 70 meters for a victim MDS base-station with 12 dBi of antenna gain.

Based on these raw distances, Motorola computes the probability that a UWB transmitter will be located closer than the $ADS_{min.}$ Motorola then concludes that the maximum authorized power output of *all* UWB transmitters must be reduced by 12 dB compared with the limits proposed by the FCC in the UWB NPRM. Motorola provides simulations to support these conclusions, but these simulations are based on unrealistic assumptions for the MDS application.

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[1] This Technical Appendix has been prepared under the direction of Roberto Aiello, Ph.D.

In reality, any valid calculation of an ADS_{min} will depend upon assumptions about the local environment. In a typical urban or suburban environment, the UWB signal can be affected by absorption, shadowing and diffraction caused by buildings, vegetation, terrain and other "clutter" in the environment that will significantly increase the signal attenuation between a UWB transmitter and a victim receiver. In addition, although UWB systems *per se* have near-immunity to multipath fading, relatively narrow band conventional receivers, such as those used for MDS, will be subject to frequency-selective multipath attenuation of the UWB signals, representing further erosion of the ADS_{min} derivation.

Cisco and Motorola both assume path loss in free space to compute ADS_{min} between a UWB transmitter and a victim MDS subscriber receiver. For the base-station, Motorola adds to the path loss in free space another 5 dB of loss due to "clutter." Such calculations of potential signal levels from UWB transmitters that are based simply on the path loss in free space will yield overstated levels for potentially harmful interference to MDS links. In fact, in the 2.5 GHz MDS band, more realistic path loss models such as the COST-231 model or a model using a propagation coefficient of 2.8 instead of the free space coefficient of 2.0 will show 20 to 35 dB more attenuation of the UWB signal (at a distance of 1 km) than would a model based on path loss in free space. Table 1 shows the ADS_{min} recomputed for these other path loss models.

Antenna Gain (dBi)	Motorola / Cisco ADS_{min}	COST-231 ADS_{min}	PC=2.8 ADS_{min}
-8 dBi subscriber	13 meters	9 meters	6 meters
12 dBi base-station	73 meters	35 meters	27 meters
20 dBi subscriber	380 meters	62 meters	54 meters

Table 1: Calculated minimum acceptable separation distance (ADS_{min}) between a UWB transmitter and a victim MDS receiver within the main antenna beam width

As stated in the comments by Motorola, it is unlikely that a UWB transmitter would be used within 50 meters of an MDS base-station antenna site, as the base station antenna would often be on the highest available site. Therefore, as shown in Table 1, it is unlikely that a UWB transmitter will be located within the ADS_{min} of an MDS base-station.

An MDS subscriber antenna will usually be located atop a building or affixed to its side with a clear line of sight to the base station and at a typical distance of 10 meters from the ground level. That subscriber antenna will be highly directional with a narrow antenna beam width. For a UWB transmitter to be within the half-power beam width of the MDS receiving antenna, it would need to be positioned some distance above the ground, as depicted in Figure 1. Since the MDS antenna will be directed towards its associated base station, any nearby UWB transmitter is likely to be lower, inside a building, or with a rooftop or a wall between the UWB transmitter and the MDS subscriber. There will be losses from a rooftop or wall in between the UWB transmitter and the MDS subscriber, in addition to the physical "clutter" in the area. These conditions would further increase attenuation of a UWB transmitter emission and reduce the ADS_{min}.

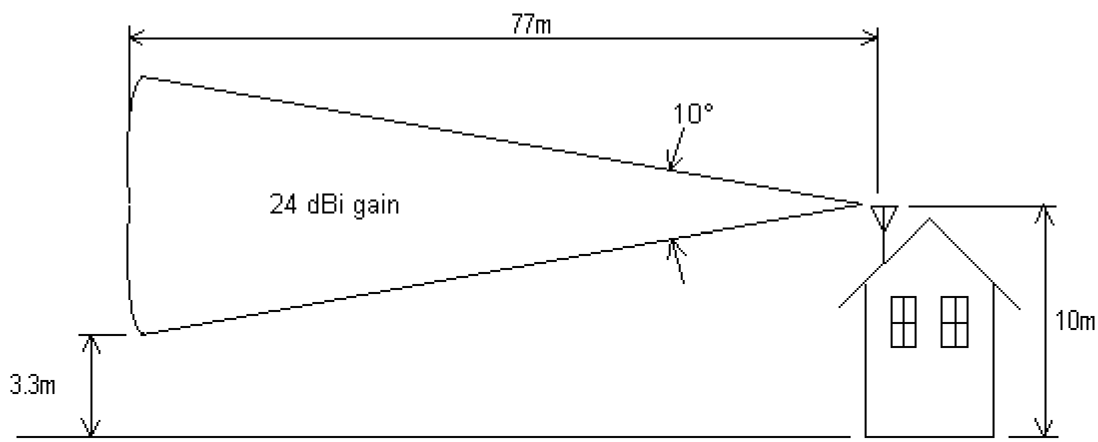

Figure 1: MDS subscriber antenna pattern

B. There is no need to decrease the output power of UWB transmitters.

In calculating the UWB energy that might appear at a base station, Motorola assumes that the typical base station employs a single high-gain omni-directional antenna. It is more likely that the base-station comprises four receivers with four associated antennas, each of which covers a sector of 90 degrees. A 12 dBi antenna might therefore have an azimuthal half-power beam width (HPBW) of 90 degrees and an elevation HPBW of 20 degrees.

As the gain of an antenna increases, the antenna beam width decreases, as seen in Figure 2.

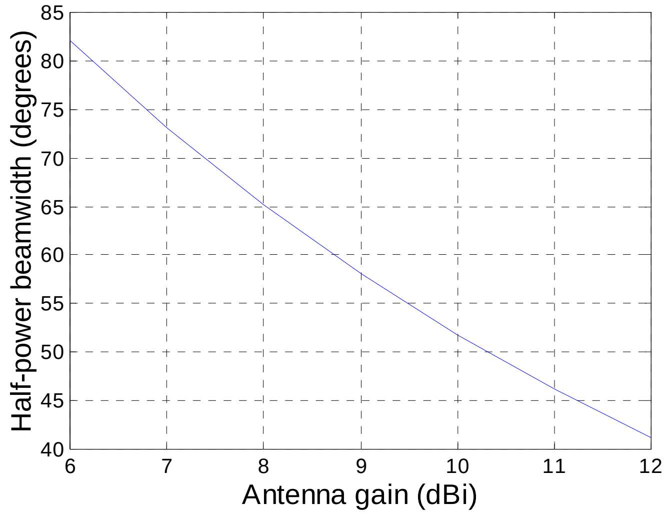

Figure 2: Relationship of Antenna Gain and Directivity if $HPBW_{azim} = HPBW_{elev}$

The relationship between antenna gain and beam width can be described as follows:

$$Gain = 10 * \log 10\left(\frac{41253 * Eff}{HPBW_{elev} HPBW_{azim}}\right). \quad (1)$$

In this equation, *HPBW* denotes the width of the beam in degrees, measured from the –3 dB power points in elevation and in azimuth respectively. The variable *Eff* denotes the efficiency of the antenna and is related to the antenna aperture.

If we assume that the antenna gain drops significantly just outside the HPBW (an idealized situation) we can reexamine Motorola's calculations to include only those UWB transmitters located within the $HPBW_{azim}$ of one sector. In this case the number of UWB devices in any sector is reduced by a factor of four, so the power of the UWB emissions is reduced by 6 dB. This adjustment alone provides one half of the 12 dB reduction in power that Motorola seeks for all UWB transmitters. When added to other factors reducing the power received from a UWB transmitter, Motorola's concerns about harmful interference are overstated. As a result, there is no need for an additional 12 dB reduction in power.

We simulated the interference seen by an MDS subscriber or a base-station. For the subscriber simulation, we used an antenna gain of 24 dBi with HPBWs of 10 degrees. We assumed that UWB transmitters outside the HPBW will not affect the MDS subscriber and we used the "PC=2.8" channel model. Under these assumptions, UWB interference does not raise the noise floor of any MDS subscriber more than 1 dB. For the base-station simulation, we assumed the same channel model, with the use of an antenna with 90 degree sectors and a height of 150 meters. Under these assumptions, lowering the transmit power by 1 dB decreases the probability of a victim base-station to nothing, as shown in Figure 3. Once again, there is no need for an additional 12 dB reduction in UWB power.

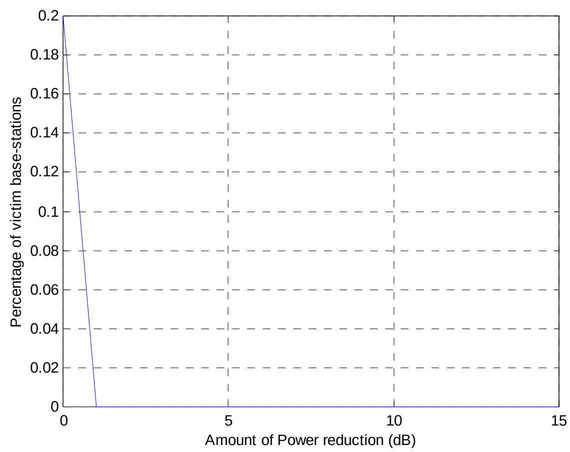

Figure 3: Percentage of victim MDS base-stations

C. An additional power reduction of 12 dB would void the benefits of UWB communications systems.

As shown above, Motorola's call for an additional 12 dB decrease in UWB transmitter power to prevent harmful interference to MDS is unnecessary. Moreover, if a 12 dB decrease in power were required of UWB systems, it would destroy the functionality of UWB for most applications.

Table 2 shows the effects of a 12 dB reduction in power on data rate, distance, and bit error rate (BER). Note that the data rate will drop, the bit error rate will increase, or the maximum distance between two UWB devices (the range) will decrease. The performance parameters using the power proposed by the FCC were chosen to be similar to those of Fantasma's first-generation products.

Parameter of Interest	With power per FCC NPRM	With power reduced 12 dB
Data Rate	100 Mbps	6.25 Mbps
Range	150 feet	37 feet
Bit Error Rate	10^{-6}	0.5

Table 2. Effects of reduction in authorized UWB power output below FCC proposal.

If the average power drops by 12 dB, the data rate drops by a factor of 16. This can be shown as follows. Suppose a UWB signal has bandwidth W in Hz, baud period T in seconds, and it is modulated using binary antipodal modulation, so that '0' is represented by a pulse with unit energy multiplied by A and '1' is represented by a unit energy pulse multiplied by –A. In this case, the average power of the signal is

$$P = \frac{A^2}{T}, \quad (2)$$

and the probability of error is given by

$$\Pr(error) = Q\left(A\sqrt{\frac{2W}{N}}\right), \quad (3)$$

where N is the variance of the added noise. From these equations, we see that if the average signal power drops by 3 dB (a factor of 2), then for the probability of error to remain constant, the baud period must increase by a factor of 2. This means that the pulses must be spaced twice as far apart, which lowers the data rate by a factor of 2. If the average signal power drops by 12 dB, the data rate decreases by a factor of 16.

If the average power drops by 12 dB, the range for a wireless networking application drops by a factor of 4, from 150 feet to 37 feet, assuming a free space path loss, as shown in Figure 4. Alternatively, using Equation (3), if the range is held constant, a power reduction of 12 dB would increase the bit error rate from 10^{-6} to 0.5, resulting in an unusable system.

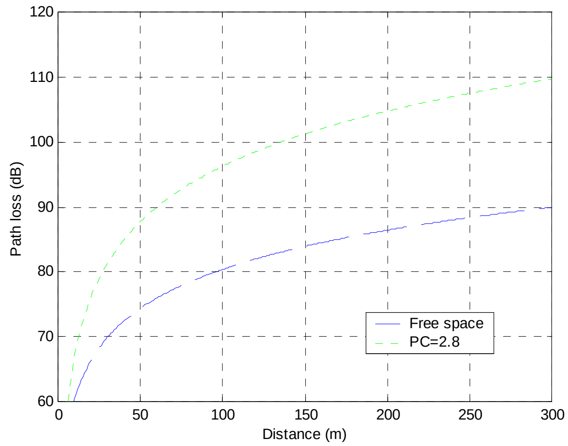

Figure 4: Path loss versus distance

II. Analysis Of Measurement Issues

The current measurement techniques for part 15 unlicensed devices specify "average" measurement in a 1 MHz resolution bandwidth (RBW) and 10 Hz video bandwidth (VBW). They also specify maximum "peak," measured in 1 MHz RBW and VBW, as 20dB higher value than the average measurement.

The FCC requests comments on two proposed methods of measurements: "1) the peak level of the emission when measured over a bandwidth of 50 MHz which we believe is comparable to the widest victim receiver that is likely to be encountered, and 2) the absolute peak output of the emission over its entire bandwidth."

Cisco is requesting to explore further "the potential interference impacts of large UWB signal peaks into existing systems." Cisco is also requesting to explore further the "limitations of 1 MHz interference measurement when broadband services are being impacted." Lucent recognizes that the "proposed average and peak power limits are sufficient," but proposes a time domain method in 50 MHz bandwidth to measure the peak level.

This analysis shows that the current measurement technique for part 15 unlicensed devices, over 1 MHz bandwidth, is adequate to protect wider bandwidth receivers. It also shows that the absolute peak output of the emission over its entire bandwidth is not relevant.

A. UWB emission should be measured in 1 MHz resolution bandwidth, because it adequately protects wider bandwidth receivers.

The FCC requests comments on the proposed methods of measurements: "the peak level of the emission when measured over a bandwidth of 50 MHz which we believe is comparable to the widest victim receiver that is likely to be encountered". Lucent proposes to measure the UWB emission in a 50 MHz bandwidth with a measurement setup in the time domain.

A combination of measurements and analysis shows that current measurement technique for part 15 unlicensed devices, over 1 MHz bandwidth, is adequate to protect wider bandwidth receivers.

1. Frequency domain measurements are more accurate

A UWB signal is usually defined as a short pulse that generates a very wide spectrum. The spectrum envelope is defined by the pulse shape, not by the particular sequence of pulses.

An example of UWB signal, used in the measurements and analysis contained in this document, is shown in Figure 5. It was measured in the time domain with a high speed digitizer.

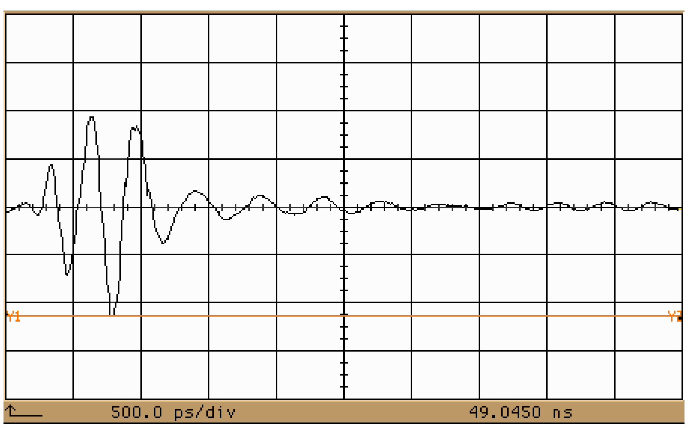

Figure 5. UWB signal.

Its spectrum envelope is shown in Figure 6, and it approximately spreads between 2 and 4 GHz at the –10dB points.

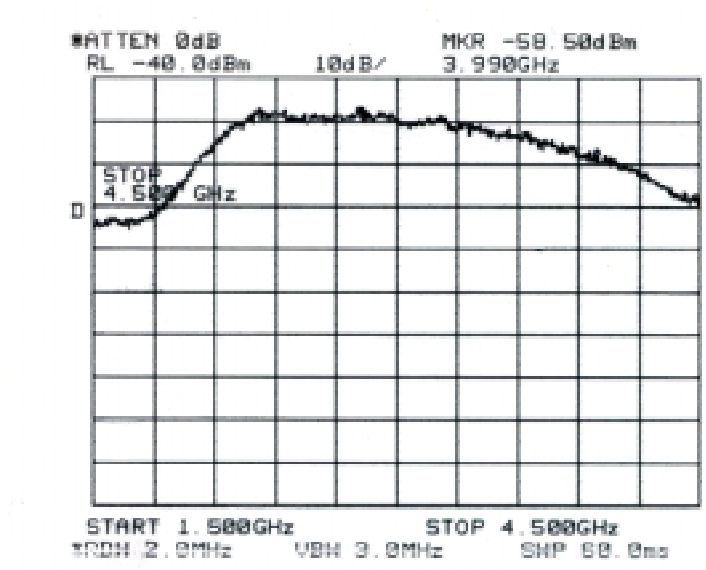

Figure 6. UWB spectrum.

A narrowband receiver, defined here as a receiver whose frequency of operation is smaller than the one utilized by the UWB transmitter, captures only a subset of the whole frequency band. The receiver behavior is expected to be linear and the total power captured by the narrowband receiver to be proportional to the power in its frequency band.

A sequence of UWB signals was measured into different filter bandwidth receivers, using both time and frequency domain techniques. The sequence was chosen to be random to approximate the expected 10dB per decade increase. The plot in Figure 7 shows the measurement results. The data points were normalized to the total peak.

The three measurements shown in the top right were taken with a high speed digitizer, one with the full bandwidth, normalized to 0dB, the other two respectively with 1,000 MHz and 130 MHz bandpass filters. The remaining four measurements shown in the plot were realized with a spectrum analyzer, changing the resolution bandwidth from 1 MHz to 10 kHz.

The equivalency of time and frequency domain measurements is evident from Figure 7, however the plot also shows the inaccuracy of the time domain measurement as compared to the frequency domain measurement. This is because digitizers are not designed for calibrated measurement as spectrum analyzers.

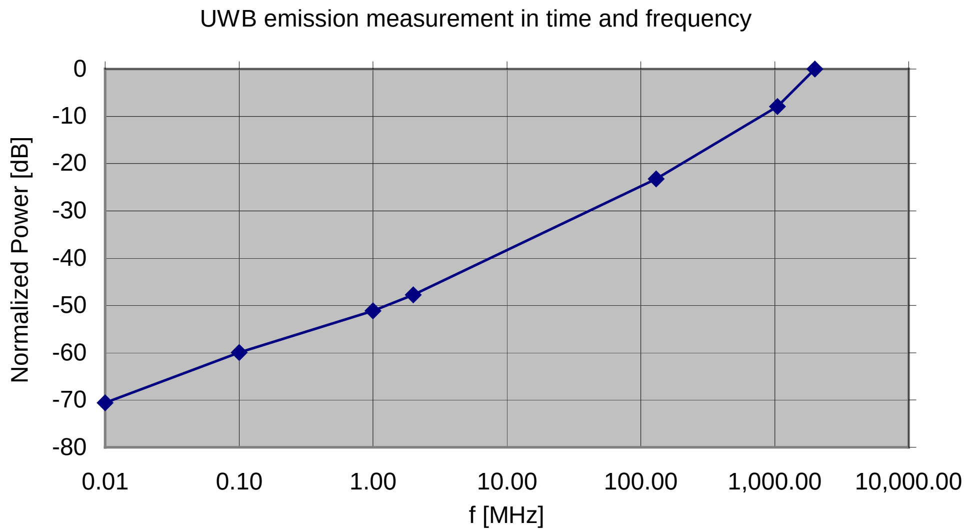

Figure 7. Comparison of UWB emission measurement in time and frequency for different receiver bandwidths.

In conclusion, the emission level of a UWB signal can be measured either in time or in frequency domain but the frequency domain method gives more accurate results.

2. Measurements in 50 MHz bandwidth are difficult

The FCC proposal to use a microwave receiver to measure the emission level in 50 MHz bandwidth, supported by Lucent, is not practical.

Lucent has proposed a measurement technique in the time domain, using a passive mixer. The second input of the mixer would be a reference oscillator. The IF output of the mixer would be connected to a low pass filter and an oscilloscope. Lucent claims that by changing the oscillator frequency over the range to be observed it is possible to measure the power in the frequency of interest.

This is a good method to detect narrowband signals but it doesn't work well for UWB signals. The problem is that the image frequency cannot be filtered out when it is downconverted to DC. The mixing of the measured signal with the image would give results that are inaccurate or not repeatable.

A viable alternative would be to use a spectrum analyzer with 50 MHz resolution bandwidth, because it would allow to remove the image frequency with the RF filter, but they are not readily available in the market.

3. UWB emission never increases with bandwidth more rapidly than thermal noise.

The thermal noise detected by a receiver is directly proportional to its bandwidth. That is why wider bandwidth receivers are less sensitive than narrowband receivers and can typically tolerate a larger amount of interference in terms of power spectral density.

When a noise source is measured in increasingly wider bandwidths, as shown in Figure 8, the noise power increases proportionally, at the rate of 10dB per decade. Conversely, if a periodic signal like a sinewave is measured in increasingly wider bandwidths, the measured power remains constant.

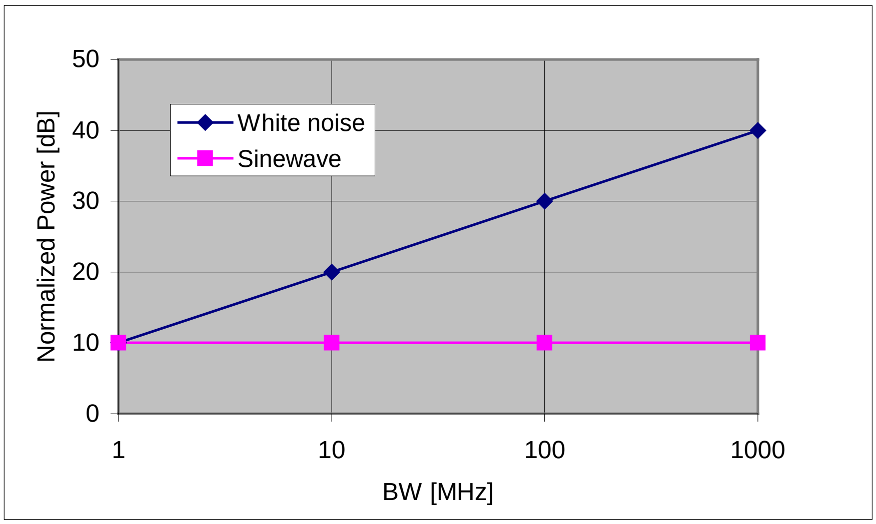

Figure 8. Noise and signal power comparison.

UWB signals can be random, can have some periodicity, or can be extremely periodic. A sequence of UWB signals at a fixed pulse repetition frequency larger than the receiver's filter bandwidth, for example, would appear as a single spectral line and have an effect similar to a non modulated sinewave. A highly random sequence of UWB signals, instead, may appear as white noise to a narrowband receiver.

Let's assume that the UWB signal emission is measured in a 1 MHz bandwidth and that subsequent measurements are made at larger bandwidths. If the UWB signals are periodic the measured emission will remain constant. If the UWB signals are random, the measured emission will increase at 10dB per decade. If the UWB signals are not as periodic and not as random, the measured emission will increase at a rate lower than 10dB per decade.

The same UWB signal shown in Figure 5 was generated by a typical Fantasma transmitter. This sequence of UWB signals is not as random as the one shown in the paragraph above. The emission was measured with a spectrum analyzer with different resolution bandwidth settings. A noise source was also measured with the same bandwidth settings and compared in Figure 9. The resolution bandwidth was changed from 1 kHz to 1,000 kHz. Although the bandwidth didn't span from 1 MHz to 1,000 MHz, as in the ideal plot in Figure 8, it is obvious that the results scale proportionally. It can be seen from the plot that the UWB emission doesn't increase as much as the noise power with increasing measurement bandwidth. This particular UWB sequence presented some periodicity and that is why its power lays between the ideal noise and ideal sinusoidal sources as in Figure 8.

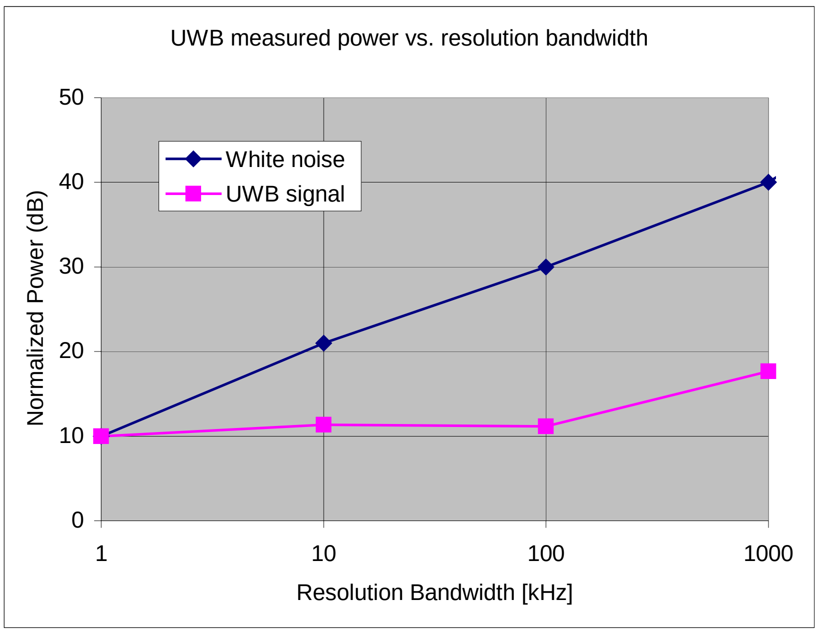

Figure 9. UWB and noise power comparison.

This means that for increasing receiver bandwidths the emission from a UWB transmitter increases by 10dB per decade, as thermal noise, in the worst case, while in the typical case, when a combination of more periodic and more random sequences are combined, the emission doesn't increase as much.

As a consequence a wider bandwidth receiver is more protected when the emission from a UWB signal is measured in a 1 MHz bandwidth, because the UWB emission will increase at most as thermal noise by 10dB per decade.

B. The absolute peak signal over its entire bandwidth is not relevant to a narrowband receiver.

A narrowband receiver, as explained above, captures only a subset of the whole frequency band. The receiver behavior is expected to be linear and the total power captured by the narrowband receiver is proportional to the power in its frequency band. As a consequence, the narrowband receiver is expected to be insensitive to the total peak power across the whole UWB transmitter bandwidth, and only the in-band spectral power density is relevant.

In other words: given any fixed-bandwidth receiver, the power captured by that receiver is proportional to the power in its bandwidth. Any power outside the receiver frequency bandwidth is out-of-band and as such is not detected by the receiver. This means that the total UWB signal peak power, which naturally spans a much larger frequency band, has no meaning to a narrow bandwidth receiver. This can be seen in Figure 7, where the emission level was measured at different receiver bandwidths.

C. Conclusions

According to the previous analysis and measurements, UWB emission should be measured in 1 MHz resolution bandwidth, as in current Part 15 regulations. That is because measurements in 50 MHz bandwidths are difficult and because it is not necessary to measure UWB emission in the time domain.

Measurements in a 1 MHz bandwidth adequately protects wider bandwidth receivers because UWB emission never increases with bandwidth more rapidly than thermal noise, at 10dB per decade.

Additionally, the absolute peak signal over its entire bandwidth is not relevant to a narrowband receiver, because a narrowband receiver captures only the in-band signal.

ANALYSIS OF MSSI ANTENNA FILTERING ISSUES

MultiSpectral Solutions, Inc. ("MSSI") makes the point that an antenna should not be assumed to be an effective filter for a transmitted signal because either damage to the antenna or peculiarities of the local environment may alter the frequency response of the antenna, and thus the entire system. MSSI is particularly concerned about the effect of transmitting a very wide band pulse, *e.g.* a voltage step with a time rise of a few pico seconds, which could have a very large frequency response. The question then is what filtering effect can an antenna provide, or rather what is the total frequency response of any antenna.

A. Out-Of-Band Antenna Response

Few antennas actually are single-band devices; that is, they will have good frequency responses in limited bands well away from the specified system band. These can be termed antenna "harmonics." A few examples are given below of typical antenna behavior.

1. Monopole on a ground plane

A quarterwave monopole on a conducting ground plane will have a resistance of around 35 to 40 ohms at resonance, when the reactance is zero. It is quite usual to put up with the mismatch to 50 ohms and not include a balun (balance-to-unbalance transformer). Figure 1 (below) shows the Return Loss of such a monopole when it is 0.25 meters long and resonant at 285 MHz. There are narrowband responses all the way up to 10 GHz. The ratios between successive resonances are fixed for a particular geometry, but will vary from geometry to geometry. For example, one monopole may be a rod of constant diameter while another varies in diameter from the ground plane (active) end to the tip.

Physical damage to the monopole will shift the first resonant frequency up in frequency and move up all the others. Local structure has to be within the reactive near-field of the monopole to affect the frequency, and such a distance is of the order of a half-wavelength or less for low gain antennas. The ratio of successive resonances will almost certainly be different from the response of the undamaged monopole and the main resonance will be moved down in frequency.

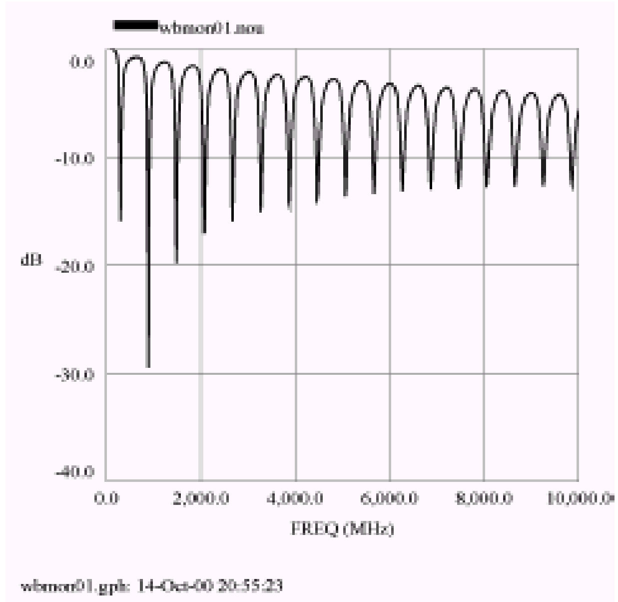

Figure 1 Return Loss of Monopole from 150 MHz to 10 GHz. The monopole is resonant at 285 MHz

2. Dipole in free space

A half-wave dipole has a similar theoretical behavior to a monopole over a wide band width. However the resistance at resonance is about 80 ohms and this would provide a poor match to 50 ohms and a balun or other matching device is always used except for very crude systems. A balun is by its nature a narrow band device and so provides a filter for the dipole. The resultant bandwidth is mostly limited to the first resonance unless the designer has deliberately introduced a wideband balun. So even if there is something in the reactive nearfield or the dipole is damaged, the balun will act as an effective filter for the transmitter. This is for narrowband (less than 40%) use and dipole behavior becomes very similar to that of a monopole when the dipole is matched for wideband use.

3. Bow-tie antennas

These are used as a replacement for dipoles when a wideband omnidirectional antenna is required. The method of manufacture controls the out-of-band response. Two actual examples are shown in Figures 2 (below) and 3 (below).

Example I (Figure 2) has a very wide band response from 900 MHz to 6 GHz and above.

Example II (Figure 3) was intended to operate between 300 and 800 MHz, but has a considerable response above 800 MHz.

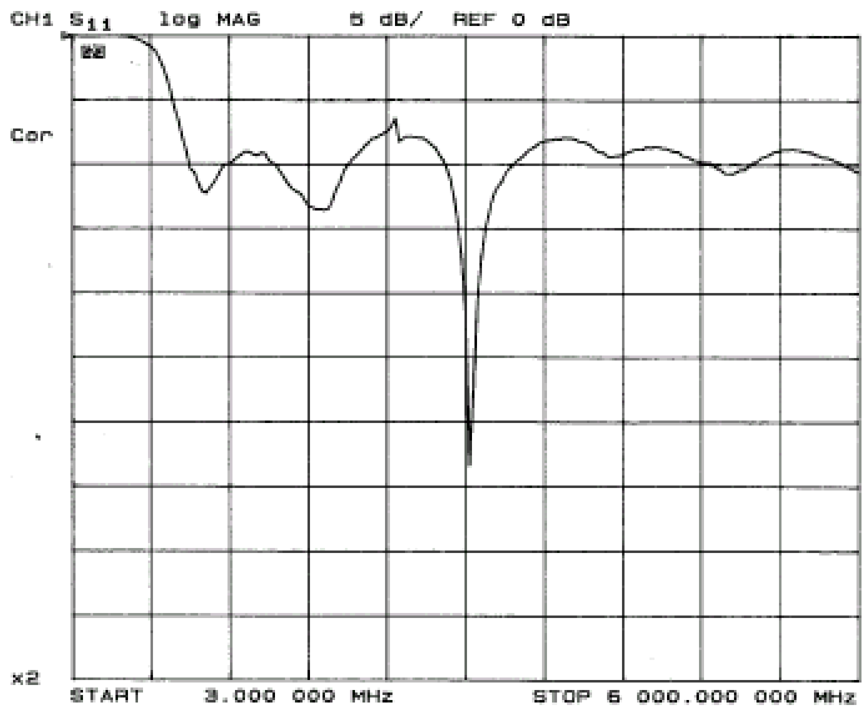

Figure 2 Example I:-Wide band Omnidirectional Antenna based on bow-tie antenna

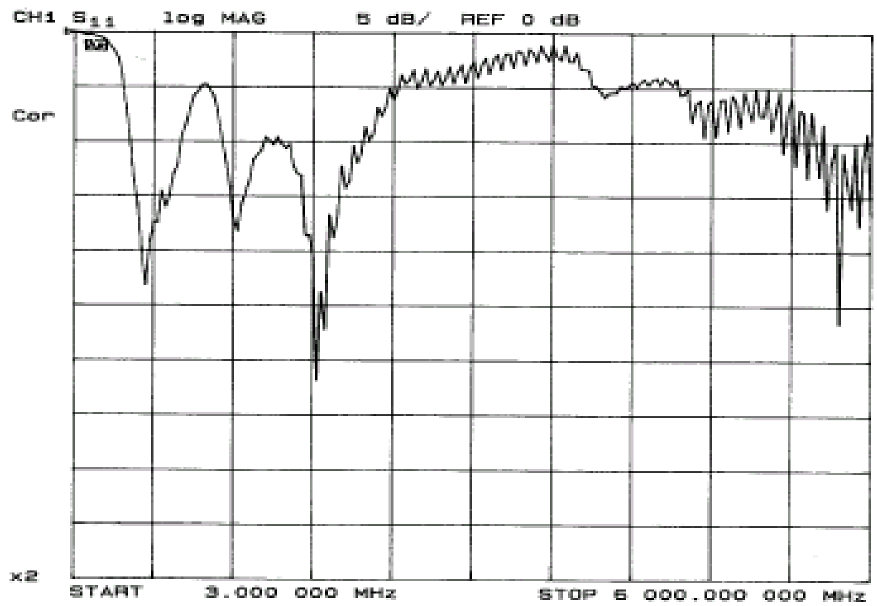

Figure 3 Example II:-Wide band Omnidirectional Antenna based on bow-tie antenna

4. Waveguide antennas

Antennas based on waveguide, even if they have a coaxial connector as output, have a low frequency cut-off because of the waveguide dimensions. Above the lower cut-off, the response depends on the components in the waveguide chain which may generate high order modes. In theory there is a higher frequency cut-off which depends on the waveguide cross-section. Rectangular waveguide, for example, has an octave bandwidth before higher order modes set in. These will affect the Return Loss but there are few frequencies where the waveguide cannot radiate. A waveguide antenna will not have its frequency response affected much by physical damage and objects in the nearfield are more likely to make the antenna stop radiating at any frequency.

B. Conclusions

In general, all antennas have good responses well outside the their design bandwidth. There is no way in which any antenna type can be designed to provide perfect in-built filtering. If the antenna is damaged or has conducting objects placed within the near field region, the frequency response will shift as will the out-of-band performance. Since this type of behavior cannot be predicted, system designers should not rely upon the antenna to do the filtering.

Because these affects are so dependent on the particulars of the antenna damage or the local environment, it is impossible to regulate every set of circumstances that might affect antenna performance. Instead, regulation may specify the system requirement for out-of-band performance under all circumstances, including damage to an antenna or suitable positioning. With respect to UWB operations in particular, there is no reason to suppose that raising the frequency floor will help in removing possible sources of degradation.

Understanding Aggregations of Many UWB Emitters

Prepared for Fantasma Networks, Inc.
by
Timothy J. Shepard
shep@alum.mit.edu

October 26, 2000

Abstract

The interference from an aggregation of a large number of UWB emitters deployed in an urban environment can be understood relative to the level of interference from a single nearby UWB emitter. The interference from the aggregation of millions of UWB emitters remains comparable to the interference from a single nearby UWB emitter, even employing a pessimistic model of propagation (free-space).

If we think of a receiver sitting in a densely populated metropolitan area, then the interference it will receive will be limited by the horizon (since we do not live on a flat earth) and the contribution to the interference from UWB emitters hidden by the horizon will be negligible. So we only need to worry about the free-space propagation of interference from UWB emitters inside a circle around the receiver. This circle might contain all the UWB emitters in the metropolitan area if, for example, the metropolitan area was in the middle of a bowl-shaped valley.

For this analysis we will model all propagation as free-space (falling off as $\frac{1}{r^2}$ in power). This will over-estimate the interference from a large aggregation of sources. More realistic models would attenuate the interference from distant sources even more. We will also assume that the receiver is using an omni directional antenna. The gain of the antenna (over an isotropic model antenna) is otherwise irrelevant as we are only going to compare the interference from a nearby emitter to the aggregation of many more distant emitters.

So, the question is: How will the amount of interference grow as the number of UWB sources is increased to a large number?

Let M be the number of UWB emitters, and R be the distance from the receiver to the (circular) horizon. The average density of UWB emitters is then

$$\rho = \frac{M}{\pi R^2}, \tag{1}$$

and a characteristic distance of this average density of UWB emitters is

$$R_0 = \rho^{-\frac{1}{2}}. \tag{2}$$

This distance R_0 can be thought of in a few different ways. It is the radius of a circle in which we would expect to find π emitters in a random distribution. It is a length which roughly divides “distant” and “nearby”. It is a length that is representative of the density ρ.

We need one additional parameter, η which is the fraction of time that each emitter spends transmitting (the “duty cycle”). The constant α will be used to capture the details of the radio systems being used. The UWB emitters are assumed to all be identical, and in each case, we are looking at this from the point of view of a single receiver. Since we are only trying to compare the interference from a particular nearby emitter with the interference from an aggregation of many more distant emitters, we can hide almost all the complicated details of radio system engineering in this constant α by assuming that the nearby emitter is identical to all of the emitters in the aggregation.

We will call the power of the interference from the nearby emitter N and the total power from the aggregation A. We will begin our comparisons assuming that the nearby emitter not so near but is exactly at this characteristic distance of R_0.

Now we can determine the amount of interfering power received from the nearby emitter,

$$N = \frac{\alpha}{{R_0}^2} \tag{3}$$

$$= \frac{\alpha}{\left(\frac{1}{\sqrt{\rho}}\right)^2} \tag{4}$$

$$= \alpha\rho, \tag{5}$$

and the level of interference from the aggregation of M emitters,

$$A = \int_{R_0}^{R} \alpha \frac{1}{r^2} \eta\rho 2\pi r \, dr \tag{6}$$

$$= \alpha\eta\rho 2\pi \left. \ln r \right]_{R_0}^{R} \tag{7}$$

$$= \alpha\eta\rho 2\pi \left[\ln R - \ln R_0\right] \tag{8}$$

$$= \alpha\eta\rho 2\pi \ln \frac{R}{R_0} \tag{9}$$

$$= \alpha\eta\rho 2\pi \ln \sqrt{\frac{M}{\pi}} \tag{10}$$

$$= \alpha\eta\rho\pi \ln \frac{M}{\pi}. \tag{11}$$

When we take the ratio,

$$\frac{N}{A} = \frac{\alpha\rho}{\alpha\eta\rho\pi \ln \frac{M}{\pi}} \tag{12}$$

$$= \frac{1}{\eta\pi \ln \frac{M}{\pi}}, \tag{13}$$

most everything drops out, leaving an inverse proportional dependency on the duty cycle and the log of the the number of emitters in the aggregation. Note that this ratio does not depend upon scale length. This ratio is plotted in Figure 1 for a few different duty cycles. Most importantly, this ratio falls only very slowly as the number of emitters grows beyond one thousand. In the 100% -duty-cycle case it falls to -16 dB at around one million emitters and falls to -18 dB at around one trillion (10^{12})emitters.

Results, Assumptions, and Consequences

Above we assumed that the nearby UWB emitter to which we are comparing is not so near. (We assumed that it was located at a distance of R_0.) We can easily understand the effect of moving it closer or further by recalling that each

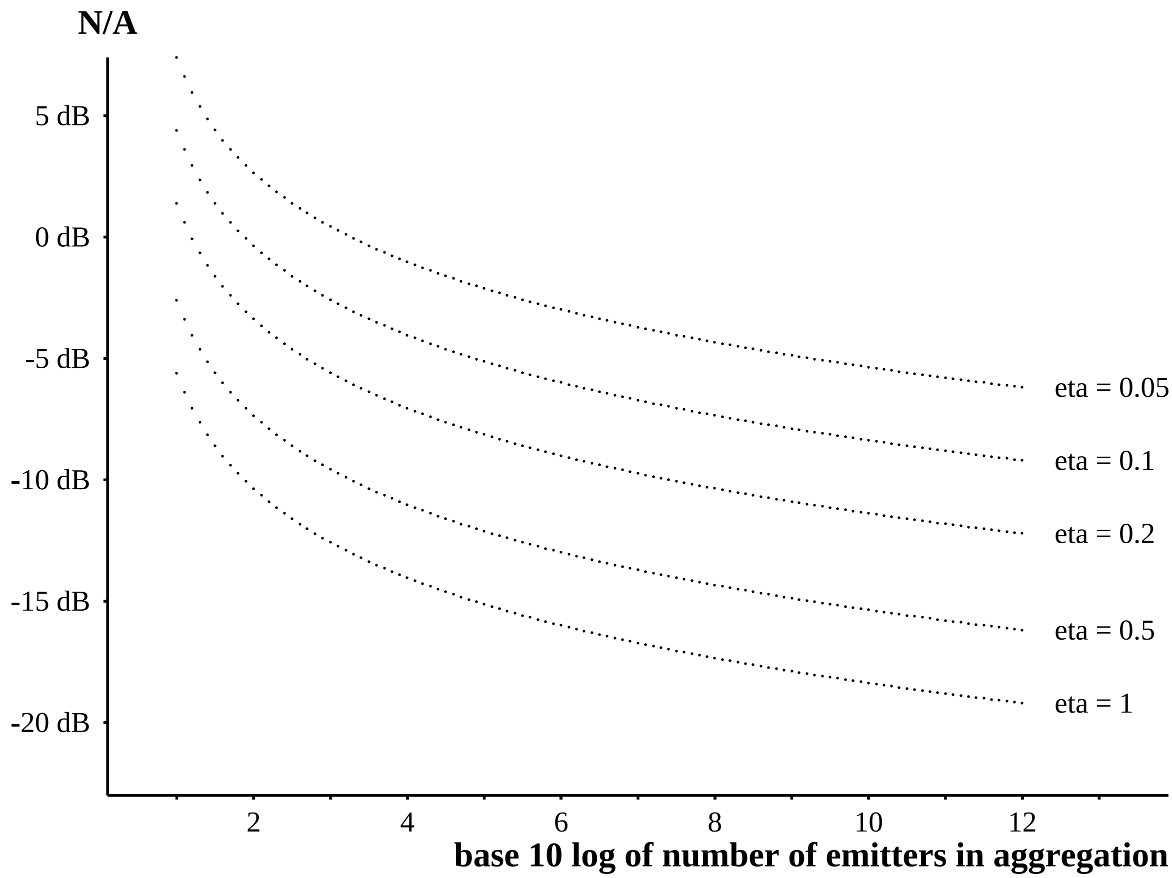

Figure 1: The ratio of N (nearby) to A (the aggregation) as M, the number of emitters in the aggregation, grows (Eq. 13). Each member of the family of curves is for a different value of the duty cycle, η (denoted as "eta" in the curve labels).

doubling or halving in distance changes a signal level by 6 dB. So if we bring it to a distance of $\frac{R_0}{4}$, the level of interference from this nearby UWB emitter will be increased 12 dB. Note that this is more interference than from an aggregation of 100 emitters at 100% duty cycle. At a distance of $\frac{R_0}{8}$, the interference from this nearby UWB emitter would dominate an aggregation of millions of UWB emitters at 100% duty cycle.

We assumed random distribution of emitters. The probability of finding an empty circle of radius $\frac{R_0}{k}$ in a random distribution is $e^{-\frac{\pi}{k^2}}$. From this we can compute that the probability of finding at least one emitter closer than R_0 is greater than 95%. The probability of finding at least one emitter closer than $\frac{R_0}{4}$ is 18%. The probability of finding at least one emitter closer than $\frac{R_0}{8}$ is 5%. In these cases, the emissions from a nearby UWB emitter will dominate even the largest of aggregations of UWB emitters.

We assumed that the receive antenna was omni-directional. An antenna that provided gain over omnidirectional would tend to hold constant the amount of power received from the aggregation (think of it as looking at fewer distant UWB emitters but with higher gain) while increasing the amount of power received from any nearby UWB emitter at which the antenna is pointed.

We assumed a free-space model propagation. Because of this we have (perhaps dramatically) over-estimated the amount of power in the aggregation. All more realistic models of propagation would attenuate the propagation from distant emitters more than from nearby sources. In a more complicated analysis involving more realistic models of propagation, the power from a nearby emitter would dominate the power from the aggregation at even greater distances.

Conclusions

We have shown that the level of interference from a single nearby UWB emitter will dominate the level of interference from an aggregation of millions of emitters scattered throughout a metropolitan area. The FCC was correct in the NPRM when it stated that "the noise floor would be set by the closest UWB transmitters." [FCC proceeding 98-153, NPRM issued 10-May-2000, Paragraph 46.]

The analysis presented here is very similar to the analysis presented in Chapter 2 of my Ph.D. thesis *Decentralized Channel Management in Scalable Multihop Spread-Spectrum Packet Radio Networks* which can be downloaded from
`ftp://ftp.lcs.mit.edu/pub/lcs-pubs/tr.outbox/MIT-LCS-TR-670.ps.gz`
and a SIGCOMM'96 paper based on the thesis can be downloaded from
`http://www.acm.org/sigcomm/sigcomm96/papers/shepard.html`.