Before the
Federal Communications Commission, Washington, D.C. 20554

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

Multispectral Solutions, Inc. Comments in
Reply Comments to Further Notice of Proposed Rule Making (ET Docket 98-153)

Multispectral Solutions, Inc. (MSSI) is pleased to submit the following reply comments in response to the submission by Mr. James Page in the above referenced docket.

According to Mr. Page,

> *"The assumption has been that PRF will be high and peak limits not relevant, but reasons are now emerging why UWB may exploit the high peak limits with low prf (eg range.) Reducing prf enables higher peak, keeping the mean power the same. The higher peak powers (0dBm/50MHz) will clearly cause interference at a greater distance than -41dBm/MHz, albeit for shorter periods. At this distance, victim radio services will lose a packet of data for each UWB pulse, the effect of which will depend on the coding and the service. Clearly services in the 5GHz band and video/audio services will be especially vulnerable. Therefore I would not support an extension of low PRF systems as proposed by MSSI. Furthermore the peak limits should be tightened by requiring measurement at 1MHz (ie -34dBm) and not allowing 50MHz measurements."*

Mr. Page provides no technical justification for his claims that "higher peak powers (0dBm/50MHz) will clearly cause interference at a greater distance than -41dBm/MHz", "victim radio services will lose a packet of data for each UWB pulse," or "[c]learly services in the 5GHz band and video/audio services will be especially vulnerable."

That these claims are in fact false, can be seen from the attached Appendix which contains the recently published (July 31, 2003) Final Report from the Defense Advanced Research Projects Agency (DARPA) NETEX Program on "UWB Parameters for EMC Coexistence with Legacy Systems." After extensive testing of the electromagnetic compatibility of a wide variety of ultra wideband (UWB) waveforms with legacy radio, radar and positioning systems, DARPA concluded:

> *"For most combinations of UWB waveforms and receivers, the EMI impact was related to the average UWB signal in the narrowest passband of the receiver,"*
> and,

> *"Very low PRFs are unlikely to cause interference at any frequency. For purposes of this report, very low PRFs are considered to be any PRF equal to or less than RBW/100."*

Thus, for example, for a 1 MHz resolution bandwidth (RBW) as established by the FCC for EMI compliance measurements, DARPA has concluded that UWB systems having PRFs less than 10 kHz (1 MHz/100) are "unlikely to cause interference at any frequency". For a 50 MHz RBW, PRFs up to 500 kHz will be unlikely to cause interference.

The DARPA results provide further independent verification of MSSI's contention that low PRF UWB emissions are unlikely to pose interference problems to existing systems, narrowband or wideband, regardless of their frequency of operation.

In conclusion, MSSI once again respectfully requests that the FCC not unnecessarily limit the types of low PRF UWB devices (e.g., vehicular radars, tagging systems, etc.) permitted to operate in the 3.1 to 10.6 GHz band under Part 15 Subpart F of the Commission's rules.

Respectfully submitted,

/s/ Robert J. Fontana, Ph.D.
President

25 July 2003

Defense Advanced Research Projects Agency

NETEX Program

Networking in Extreme Environments

UWB PARAMETERS FOR EMC COEXISTANCE WITH LEGACY SYSTEMS

FINAL REPORT

31 JUNE 2003

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The Defense Advanced Research Projects Agency (DARPA)
Networking in Extreme Environments (NETEX) Program

FINAL REPORT
UWB PARAMETERS FOR EMC COEXISTANCE WITH LEGACY SYSTEMS

EXECUTIVE SUMMARY

The goal of the Networking in Extreme Environments (NETEX) Program is to create a wireless networking technology that enables robust connectivity in harsh environments and to support its integration into new and emerging sensor and communication systems. The NETEX program is focused on the development of an improved physical layer for networked communications based on a family of new Ultra-Wideband (UWB) devices. UWB devices have the potential to perform a number of useful military communication and sensing functions that make them very appealing for warfighter applications.

The purpose of this report is to present the final results of the Electromagnetic Interference (EMI) analyses and tests performed on a selected set of legacy military receivers to determine their EMI susceptibility threshold to UWB signals. The UWB EMI testing, modeling and simulation efforts were performed in support of the NETEX program.

UWB systems provide a potential for improved performance compared to legacy systems for certain military radio communication and sensing systems functions. The objective of the EMI analysis and test efforts was to investigate the susceptibility of selected military communication, navigation, and radar receivers to EMI from various types of UWB devices. The results of this investigation will provide the information necessary to evaluate the potential for UWB devices to coexist with legacy systems without causing or experiencing EMI, and help to define UWB system parameters that are required for Electromagnetic Compatibility (EMC).

The approach to accomplishing the NETEX UWB interference project was to test seventeen selected military systems to determine the susceptibility of the receivers to EMI from the very narrow pulses (and pulse trains) of transmitters associated with UWB systems. The selected military systems provide a representative sample of communications, navigation and radar systems that are currently used in military applications.

A Test Master Plan was prepared to provide general guidance for the tests and detailed Test Plans and Test Reports were prepared for each specific system tested.

UWB signal generators that were developed and supplied by Multispectral Solutions, Inc. (MSSI) were used to produce the UWB waveforms, frequencies, and power levels necessary for these tests. Each of the selected receivers was subjected to a number of "worse case" UWB waveforms and conditions, which cause EMI effects on legacy receivers. The results of this task helped to define the receiver susceptibility threshold to these waveforms when the UWB emitter is connected directly to the receive antenna port (through a variable attenuator). These results provided the information necessary to evaluate the potential for UWB signals to interfere with legacy military systems and to understand how the unique capabilities of UWB systems could be implemented without causing EMI.

The results of the testing, which are presented in Section 6, demonstrate that most of the test waveforms caused interference in the Equipment Under Test (EUT) at full power levels. This was expected because the test waveforms were selected to represent worse case EMI threats. In general, the impact of the UWB waveform was a function of the interfering power that fell within the narrowest passband of the receiver. Several of the receivers tested were less susceptible to the UWB waveforms than they were to white noise. Other receivers tested were more susceptible to the UWB waveforms than they were to white noise. The results of the testing indicated that, in approximately eighty percent of the cases, the level of UWB EMI and the level of white noise that cause the same affect are usually within an order of magnitude of each other.

Also a UWB spectral mask and analysis of four potential UWB implementations are provided in this report. The test data was used to establish a spectral mask (i.e., the levels where EMI started to become a problem in legacy systems) to provide design guidelines for UWB systems. The testing also provided information for the development of link budget and EMI analysis of four systems that represent examples of UWB systems of interest.

1.0 INTRODUCTION

DARPA is the central research and development organization for the Department of Defense (DoD). DARPA manages and directs basic and applied research and development projects for DoD, pursuing technology where risk and payoff are usually both very high. High payoff results may provide dramatic advances in communication to support our ability to wage modern warfare. The DARPA NETEX program seeks to create a wireless networking technology for the military user that enables robust connectivity in a wide spectrum of environments and support its integration into new and emerging sensor and communication systems.

Recent advances in microcircuits and other technologies have resulted in the development of pulsed radar and communications systems with very narrow pulse widths and very wide bandwidths. These UWB devices can perform a number of useful radar and communication functions that make them very appealing for both commercial and government applications. For the purpose of this report, a UWB signal is defined as one that at any point in time has a fractional bandwidth equal to or greater than twenty percent or a bandwidth greater than 500 MHz regardless of the fractional bandwidth. These systems have very wide information bandwidths, and are capable of performing a number of useful military functions.

The NETEX program will develop an improved physical layer for networked communications based on a family of new UWB devices. These devices will enable reliable and efficient operations in harsh environments by exploiting the unique properties of UWB systems that allow them to work in a dense multi-path environment and to function as both sensors and communications devices. The program will adapt new and emerging *ad-hoc* routing protocols and multiple access schemes in order to take advantage of the unique properties of UWB to communicate in harsh environments, to very accurately resolve range, and to act as a radar based sensor.

This report presents the final results of UWB EMI testing on a selected set of military receivers. The results of the NETEX sponsored EMI tests provided the information necessary to evaluate the potential for UWB signals to interfere with legacy military systems and to understand how UWB systems could be implemented to make use of their unique capabilities without causing EMI.

2.0 OBJECTIVES

UWB systems provide potentially superior performance when compared to legacy systems in certain military radio communication and sensing systems functions. The objective of this initial effort was investigation of the susceptibility of selected military communication, navigation, and radar receivers to EMI from various UWB waveforms. The results of this investigation may be used to evaluate the potential for UWB devices and legacy systems to coexist without causing or experiencing EMI, and to define UWB system parameters that are required for EMC.

3.0 APPROACH

The approach to accomplishing the objectives of the NETEX UWB interference project was to test seventeen selected military systems to determine the susceptibility of the receivers to EMI from the very narrow pulses (and pulse trains) of transmitters associated with UWB systems. The selected military systems provided a representative sample of communications, navigation and radar systems that are currently used in military applications.

All of the selected systems have previously been tested for susceptibility to EMI in accordance with the procedures of MIL-STD-462/462D/461E and to the susceptibility levels specified in the version of MIL-STD-461, which was current at the time the candidate system was originally procured. The now current version of MIL-STD-461 is MIL-STD-461E. With the approval of MIL-STD-461E, the test procedures previously contained in MIL-STD-462D were incorporated into MIL-STD-461E.

The primary emphasis of these tests was directed toward performing conducted susceptibility tests at the antenna port of the selected military receivers. The reason for concentrating the effort on conducted tests instead of radiated tests was to better control the tests conditions experienced by the EUT. Although the conducted tests formed the bulk of the test procedures, radiated tests were also performed to demonstrate the effects resulting from radiated coupling to a receiver. MIL-STD-461E test procedures provided a guide for performing the tests.

The EMI tests described in this Final Report were conducted at the Electromagnetic Environmental Effects (E^3) Division of the Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, Maryland. This is a unique facility with highly qualified E^3 personnel that are experts in EMI testing. The Patuxent River facility provides an excellent opportunity to perform measurements, under highly controlled conditions, that characterize the EMI effects resulting from operating an UWB device in the presence of military RF receivers.

In order to accomplish the EMI test objective, the DARPA NETEX program developed a Test Master Plan providing guidance for conducting EMI tests on selected military receivers. The Test Master Plan was then used as a guide to determine the test requirements based on the operational characteristics of each selected military receiver. Prior to performing tests on a system, a system specific test plan was developed and is included as an appendix to the Test Master Plan. Also, detailed Test Reports were prepared for each system tested to document the test results.

The NETEX Program Office obtained a set of identical UWB signal generators to emulate a range of UWB characteristics to support the requirements of the Test Master Plan. These devices that were developed and supplied by MSSI were designed to produce the UWB waveforms necessary for the conduct of the tests. A description and characterization of the UWB devices is contained in Section 5.2. The tests were conducted for seven UWB test waveforms. These waveforms are representative of

"worst case" conditions for EMI to typical military receivers. The seven test waveforms are described in Section 5.3 and further discussed in the NETEX Test Master Plan.

4.0 DISCUSSION OF UWB SYSTEMS

UWB devices can perform a number of useful telecommunication functions that make them very appealing for both commercial and government applications. These systems have very wide information bandwidths; are capable of precision timing; accurate location: detecting nearby objects; imaging; penetrating walls, foliage and ground; communicating at high data rates; and providing improved performance in multipath environments.

The NETEX program explored the EMI effects of UWB on co-located systems and the benefits of combining the attributes inherent in a UWB network to form a distributed communications and sensor system. The UWB system will enable reliable communications to operators, sensors, and robots in harsh and urban terrain, not possible with existing RF devices and systems. Additionally, the system will enable a collection of distributed cooperative sensor network applications such as radar tomography.

4.1 Potential Applications for UWB Systems

Although it is often regarded as new technology, the basic UWB technology has been around as long as wireless. Marconi's original spark transmission and all early wireless telegraphy were UWB. The military spent years investigating the application of UWB signals for high resolution "carrier free" radar systems. Applications for UWB may be categorized as radar, location, and data communications.

UWB radar and location systems provide capabilities for ground-penetration to find faults in roads, bridges, and other asphalt structure. UWB radar systems can also be used to find people buried in rubble. Other applications for UWB radar devices include wall penetrating capability, short-range collision avoidance, and proximity detection for intrusion alarms.

UWB communication systems provide the potential for very high data rates. UWB is being developed as a Physical Layer (PHY) option in the IEEE 802.15.3 Personal Area Network (PAN). It is expected to support data rates of up to 100 Mbps over a range of 10 meters. Because of the high data rate capability, UWB communication systems provide an advantage for transmitting wireless video data over local area networks.

Some of the reported applications for UWB devices are listed below.

Imaging and Sensor Systems:

- Imaging Radar Systems
- Intrusion Detection Systems
- Ground Penetrating Radar Systems
- Through Wall Imaging Systems
- Medical Imaging Systems
- Surveillance Imaging Systems
- Collision Avoidance Systems

Communication Systems:

- Short range – High Data Rates (e.g., 100 Mbits/sec at range of 10 meters)
- Longer Range – Lower Data Rate (e.g., 100 bits/sec at range of 10 kilometers)

4.2 Potential Advantages of UWB Systems

UWB systems have a number of potential advantages over conventional systems. Some of the reported advantages are presented below.

Radars and other Imaging Systems:

High Resolution in Radar and Other Imaging Systems: The short pulses associated with UWB systems permit distances to be resolved in centimeters. As a result of this precise location and dimensioning are possible.

Superior Penetration: The short pulses easily pass through almost any barrier making UWB an ideal choice for looking through structures and seeing beyond walls.

Communications:

Very High Data Rates: Data rates of 20 Mbits/sec to 100 Mbits/sec are easily achievable. Rates to 500 Mbits/sec should be available and 1 Gbits/sec is potentially achievable. There is a trade-off between data rate and range. For some military applications, ranges from 100 meters to 100 kilometers are required.

Low Probability of Intercept/Secure Communications: If the UWB signal is at or below receiver noise, it will be difficult to detect. This plus any additional encryption makes UWB systems secure.

Other Advantages:

Power Efficiency: The low level of duty cycles of UWB pulses will result in low power consumption. UWB applications typically operate at microwatt or milliwatt average power levels.

Spectral Efficiency: UWB signals overlay the existing spectrum. Therefore, if EMI to or from legacy narrow-band systems can be avoided, UWB systems will be spectrally efficient.

Inherent Immunity to Multipath Effects: Because of the very short duration of the UWB pulse, the incident and reflected pulses will tend to arrive at different times. Since the multipath pulses do not overlap in time, the direct and reflected pulses will not interfere with each other. This means that UWB systems should work well in a cluttered environment, such as indoors, which tends to produce a considerable amount of multipath effects.

Simple Circuitry: UWB components can be made with conventional Complimentary Metal-Oxide Semiconductor (CMOS). This tends to simplify the transmitter design. Receivers are somewhat more complex but may be easily implemented in CMOS.

Low Cost: Because standard CMOS can be used and circuits are simpler that most other wireless systems, the cost of a UWB transceiver is potentially much lower than other wireless systems.

Coexist With Legacy Systems: Because of the low average power and the spread spectrum nature of UWB systems, the UWB signal appears as noise to most legacy systems. If the parameters (i.e., pulse width, peak power, pulse repetition rate, and modulation) of the UWB system are selected properly, they can coexist with legacy systems without causing or experiencing EMI.

4.3 Potential Disadvantages of UWB Systems

Although UWB systems offer considerable promise for a number of military applications, in order to realize their potential, it is necessary to also recognize the disadvantages associated with these systems. One of the disadvantages of UWB systems is their potential to cause and in turn be affected by EMI when operating with legacy systems. The EMI tests performed during this project defined the potential EMI problems that UWB systems cause to legacy systems. A Spectral Mask was developed from the results of these tests, which represents the threshold of UWB EMI of legacy systems.

4.4 UWB Trade-Off Parameters for EMC

The major advantages and disadvantages of UWB systems are a consequence of the wide bandwidths associated with the ultra-short pulse waveforms that are used in most implementations of UWB technology. Although these ultra-short pulses result in

potentially high data rates for communications and high-resolution imaging for radar applications, their associated wide bandwidths, result in a possibility of EMI across a wide range of frequencies. In order to take advantage of the desirable characteristics of UWB systems and avoid the potential EMI problems associated with these systems, it is necessary to consider the trade-offs that exist between operational performance and EMC. UWB parameters must be selected, which optimize the performance of the UWB systems without causing EMI, or experiencing EMI from legacy systems. The UWB parameters that should be included in the trade-off analysis are peak power, average power, pulse width, pulse repetition rate, data rate, range, and EMI impact.

5.0 EMI TEST PROCEDURES AND RESULTS

During the NETEX EMI test program, susceptibility tests were performed on seventeen legacy receivers, representing typical communication, radar and navigation systems used by the military, to obtain data that provided specific information on the susceptibility of various types of military receivers to representative UWB waveforms. The susceptibility tests performed during this investigation were focused on antenna port conducted tests, where possible. That is, the desired and/or interfering signals were injected directly into the receiver antenna port. "Conducted" tests were preferred to "radiated" tests because they provide for better control of test conditions and minimize test time and test complexity. The basic concept used in the susceptibility tests was to apply UWB signals to the antenna port of the receiver while monitoring the receiver for degradation and recording the UWB parameters that result in EMI.

5.1 EMI Parameters Measured

Typical parameters that influence receiver susceptibility are the sensitivity of the receiver, the levels of the desired and interfering signal sources, frequency and modulation of the desired signal source, Pulse Repetition Frequency (PRF) of the UWB source, receiver bandwidth, operating frequency, and threshold levels associated with any responses.

The basic approach utilized during the testing was to subject each of the selected receivers to a number of "worse case" UWB waveforms and determine the conditions that cause EMI effects in the receiver. The results of this task defined the receiver susceptibility threshold to these waveforms when the UWB emitter was connected directly to the receive antenna port (through a variable attenuator). The requirements of these tests were to:

- Determine UWB emission conditions that cause EMI effects in selected military receivers.

- Determine the maximum UWB output power for each emission condition to ensure compatibility between UWB devices and selected military communication, radio-navigation, radar, and safety-of-life systems.

It should be noted that the in-band components of the UWB signal are the primary concern. Due to the wide diversity of subsystem designs being developed, the appropriate EMI thresholds must be determined for various combinations of UWB signals and receivers. Also, the thresholds need to be consistent with the signal processing characteristics of the receiver and the particular test procedures used to establish the thresholds**.**

The EMI parameters that were measured include:

- Sensitivity of the receiver to the desired signal.
- Susceptibility of the receiver to both white noise and UWB interfering signals.

The tests were performed at several different frequencies. The tests were conducted with both a desired signal and an interfering signal present. A spectrum analyzer was used to measure the signal levels. The average signal levels (of both the desired and interfering signals) were measured using a Resolution Bandwidth (RBW) that was the widest available spectrum analyzer RBW equal to or less than the IF bandwidth of the receiver under test. If the spectrum analyzer bandwidth was different from the IF bandwidth of the receiver under test, empirical or calculated bandwidth correction factors were used to adjust the readings to the IF bandwidth of the receiver.

The initial test for each receiver was to measure the sensitivity, based on a published standard response, such as Minimum Discernable Signal (MDS), a specified Signal to Interference Plus Noise and Distortion (SINAD), a specified Bit Error Rate (BER), or another mutually agreed upon standard response. This sensitivity was used as the reference signal level for all subsequent tests on that receiver.

To measure the receiver sensitivity, a desired signal, generated by the system test set or some other standard signal source for the particular unit under test was injected into the receiver at a low level (e.g., 20 dB below the nominal sensitivity). The desired signal was then increased until the standard response was achieved and the input signal level for acquisition (ACQ) was measured and recorded. After the standard response was acquired, the level was decreased until Signal Upset (SUPSET) occurred (i.e., the standard response condition was lost). In order to minimize the impact of receiver noise in future susceptibility tests, all subsequent tests were conducted at an injected signal level 6 dB above ACQ. The sensitivity was measured before the susceptibility tests were performed.

In most cases, the difference between ACQ and SUPSET was only one or two dB. However, for some receivers, this difference was in excess of 10 dB. The tests were conducted at each test frequency for the specific receiver except for Frequency Hopping (FH) systems which are not capable of operating on single frequencies. All FH systems were tested in FH mode as well as all other applicable fixed frequency modes. For non-FH systems, which have the capability to be tuned, the receiver was tested at three frequencies across its tuning band: a frequency within the bottom 10% of the tuning band, a frequency within the middle 10%, and a frequency within the top 10%.

Following the system sensitivity test, the receiver was tested for susceptibility to white noise at the receiver Radio Frequency (RF) and within the overall receiver passband. Conducted susceptibility tests were performed using two signals (i.e., the desired signal and an interfering signal were simultaneously injected into the receiver antenna port). The desired signal was provided by a signal generator, transmitter, or Test Set. For purposes of these tests, the Receiver Bandwidth (RXBW) was determined to be the bandwidth of the narrowest RF or Intermediate Frequency (IF) bandpass filter in the receiver chain. Narrower system level filters in the receiver's audio or video processing were not considered.

Low level (below the receiver sensitivity) Broadband White Gaussian Noise (BWGN) was injected into the receiver together with the Desired Signal Level (DSL) at ACQ plus 6 dB. The level of the BWGN was increased until the standard response condition was lost. At the point of loss of the standard response condition, the BWGN average in-band level was recorded from the spectrum analyzer. The RBW of the spectrum analyzer was selected to be the one closest to but not exceeding the bandwidth of the receiver under test. The measured value was corrected to the receiver bandwidth, if necessary, and was recorded as the White Noise Upset Threshold (WNUPSET). The WNUPSET interference to DSL ratio (I/S) in dB was determined by calculating WNUPSET – DSL.

The BWGN level was reduced until the standard response condition was reacquired and the average in-band level was recorded as the White Noise Reacquisition Threshold (WNREACQ). The WNREACQ interference to DSL ratio (I/S) in dB was determined by calculating WNREACQ – DSL. The results of these tests gave an indication of the effect of additive white noise on the Unit-Under-Test's (UUT) ability to acquire a low level signal. The results were used as a metric for the similar performance of the UWB waveforms.

There were two approaches that were used to measure the susceptibility of a receiver to UWB interference. For the first approach, the DSL was fixed at 6 dB above the ACQ. The receiver susceptibility to UWB interference was determined by slowly increasing the UWB signal strength until the output dropped below a standard response condition. The UWB average in-band interference level that caused the output to drop below the standard response level was measured from a spectrum analyzer. The RBW of the spectrum analyzer was selected to be one closest to but not exceeding the bandwidth of the receiver under test. The measured value was corrected to the receiver bandwidth, if necessary, and was recorded as the Interference Upset Level (IUPSET) in dBm. The UWB I/S ratio (in dB) for this condition is IUPSET (dBm) – DSL (dBm).

The UWB interfering signal was slowly reduced until the standard response was reacquired. The average level of the in-band UWB interfering signal at which this occurs is referred to as the Reacquisition Level (IREACQ), in dBm, and the resulting UWB I/S ratio for this condition was obtained by calculating IREACQ (in dBm) –DSL (in dBm). These levels describe the effect of the UWB interfering signal when the desired signal level is close to the receiver sensitivity. The receiver will be more susceptible to UWB

EMI for this condition where the desired signal is at a low level.

For the second approach, a high UWB Interfering Signal Level (ISL) with an average in-band level that was 20 dB above the receiver IUPSET level was injected and the desired signal level was increased until the receiver acquired a standard response condition. The DSL, at which acquisition occurs with the high level interference present, was referred to as HIACQ, in dBm, and the resulting I/S ratio, in dB was ISL (dBm) –HIACQ (dBm).

The DSL was then reduced until the standard response was lost. The DSL at which this occurs was referred to as HIUPSET, in dBm. The resulting I/S ratio, in dB, was obtained by calculating ISL (dBm) – HIUPSET (dBm). These levels provide an indication of the degradation resulting from UWB interference when the receiver has a high ISL present. The information obtained from this test may be used to determine the reduction in range that the receiver will experience as a result of UWB interference.

The tests were conducted for a set of seven generic UWB pulse waveforms that are described in Section 5.3.

5.2 UWB Signal Generators

The UWB signal generators obtained by the NETEX Program Office are able to emulate a range of UWB characteristics to support the test requirements. These devices were developed and supplied by MSSI and are capable of producing the UWB waveforms, frequencies, and power levels necessary for these tests. Generally, the devices have a fixed baseband pulse (which is nominally 250 pico-seconds long) and short pulse RF from 20 MHz to 24 GHz, achieved through the use of passband filtering of the baseband pulses.

The UWB generator was designed to generate two basic pulse shapes: a double exponential, shown in Figure 1, and a Gaussian monocycle. The double exponential was used for the tests. The pulse can be generated with its leading edge as positive-going or negative-going. The UWB generator will also generate pulse doublets of either pulse shape with any combination of leading edges: positive-positive, positive-negative, negative-positive, or negative-negative. Both pulses of the doublet have to be of the same basic form. Pulse spacing within the doublet can be fine-set in increments of 2 nano-seconds to 14 nano-seconds or coarse-set in increments of 10 nano-seconds to 1.27 micro-seconds.

The UWB Signal Generators provide a wide range of possible UWB signal shapes, bandwidths, pulse repetition rates and power levels to facilitate UWB interference testing and evaluation. Through an arbitrary waveform generator in the UWB controller, the UWB signal source can generate an extensive variety of waveforms including, but not limited to, regular Pulse Repetition Rates (PRR) up to 100 million pulses per second (Mpps), randomly jittered PRR up to ± 100% jitter, swept jitter, planned Pulse Position Modulation (PPM), and random PPM.

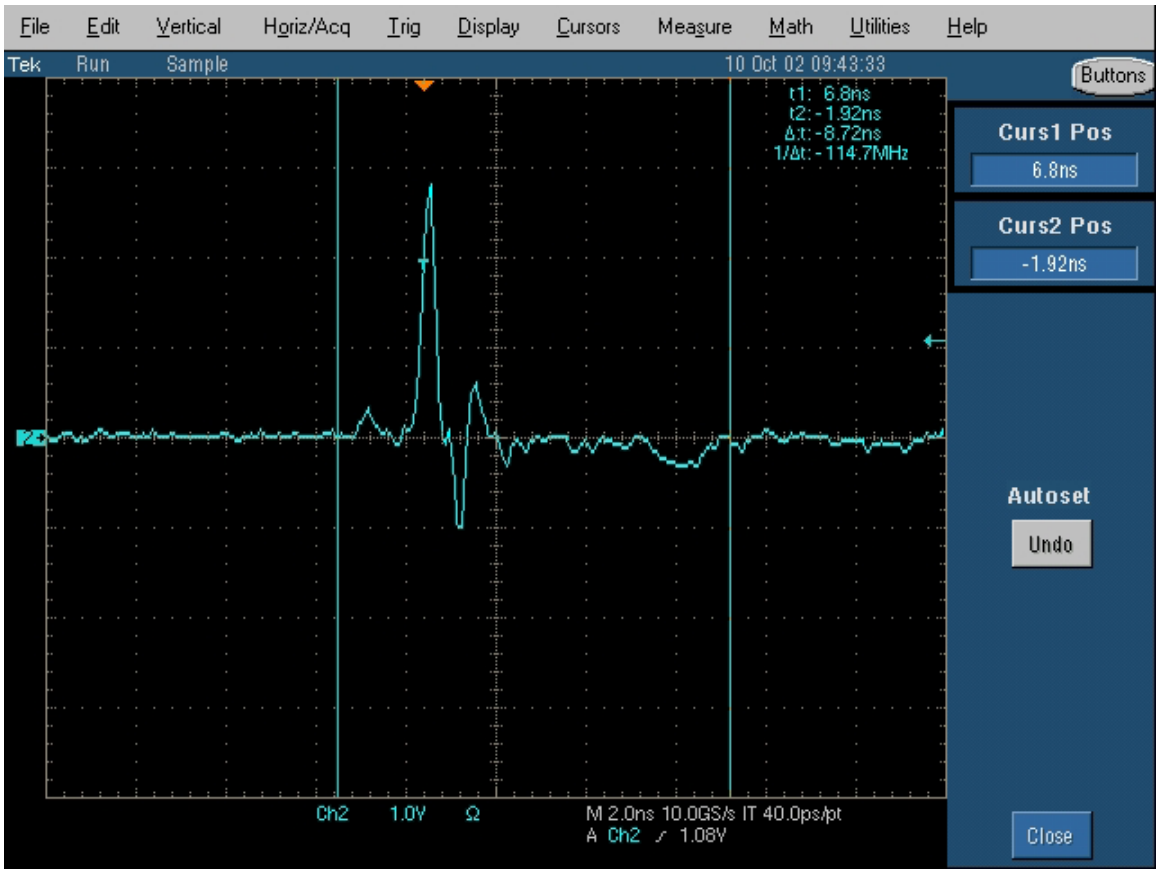

Figure 1. Time Domain Representation: Positive Double Exponential (Pos DE) Pulse

The UWB Signal Generator provides the baseband (0 – 8 GHz) and filtered baseband pulses that are representative of the pulses used for UWB applications. The operating frequency bands for the filtered baseband pulses are tentatively set at: 20 MHz to 88 MHz, 100 MHz to 200 MHz, 200 MHz to 400 MHz, 950 MHz to 1,250 MHz, and 1,100 MHz to 1,600 MHz.

The test program used a range of PRFs and pulse groupings to represent different types of UWB generators, which are being considered for current and future operation. The peak output power of the generators was approximately 1 Watt (W) with frequency occupation of approximately 7 GHz. Because the image was captured with a bandwidth-limited oscilloscope, certain characteristics such as the peak voltage swings are not truly represented, but most of the pulse's characteristics can be determined from this image. This impulse is a non-coherent, non-carrier emission, which is essentially incapable of providing processing gain. This is because individual pulses cannot be reconstructed out of the noise.

Figure 2 shows the frequency occupancy of the UWB generators for a number of PRFs. The spectra in Figure 2 present the average power in a 3 MHz bandwidth for each sample

window within the displayed frequency span, 7 GHz. Since the spectrum analyzer only stores 500 samples per scan, the image is under-sampled, but provides the salient aspects of the spectra displayed. The UWB could also generate a Negative Double-Exponential (Neg DE), which was virtually a mirror image of the Pos DE.

The UWBs can generate any fixed PRF between 1 pulse per second (pps) and 100 Mpps in increments of 1 pps. In addition, PRFs of less than 80 Mpps can be dithered within limits. Specifically, PRFs between 10 Mpps and 80 Mpps can only be dithered at a limited number of percentages, while PRFs at or below 10 Mpps can be dithered at any integral percentage between 1% and 100%. In addition to dithering the PRF can also be On-Off Keyed (OOK) in one of twelve patterns varying from a simple repetitive On-Off (1,0) pattern (Pseudo-Noise (PN) Factor 1) to a fully pseudorandom pattern of 12-bit numbers contained in a 4096-bit register (PN Factor 12).

An unexpected feature of the generic UWB generator was the low stability of the internal oscillator. Although the instability was not noticeable at low harmonics of the desired PRF, at high harmonics the spectral lines began to display significant frequency lobes as shown in Figure 3. At very high harmonics, these lobes begin to dominate the spectrum between spectral lines of the desired PRF, causing the spectrum to become completely noise-like, rather than discrete.

In addition to the UWB generators, the program has obtained a set of reference antennas for the piecewise continuous sub-bands of the UWB generated signal. A set of non-reference antennas has also been obtained and calibrated against the reference antennas.

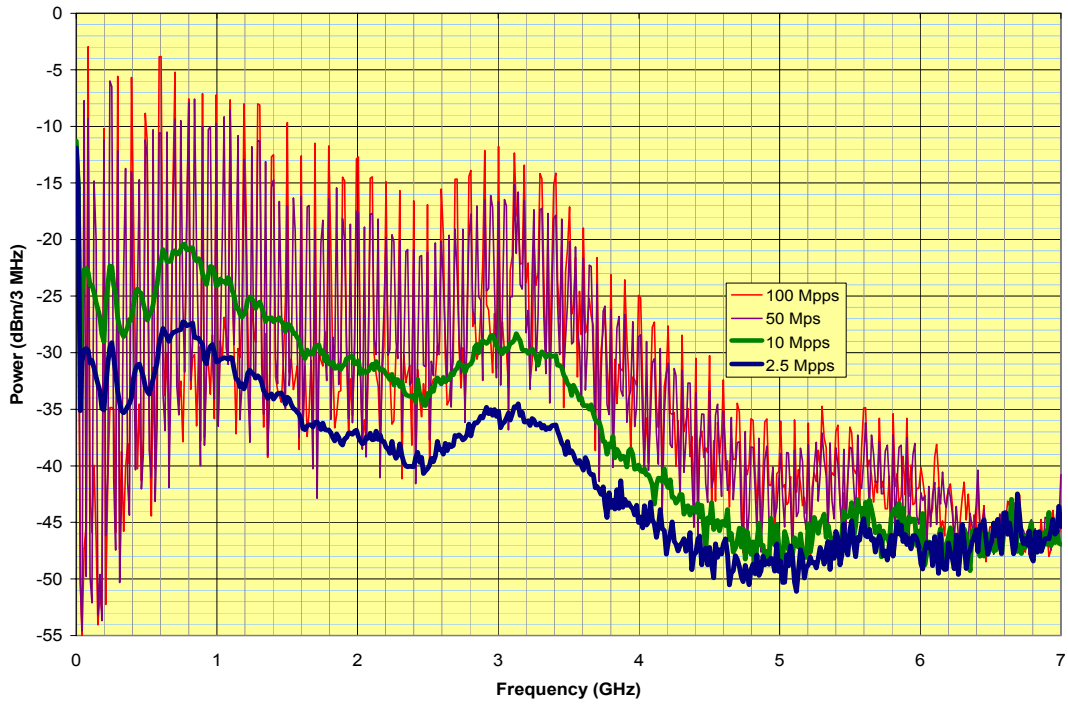

Figure 2. Frequency Occupancy of the Positive Double Exponential Pulse for PRFs of 100 Mpps, 50 Mpps, 10 Mpps, and 2.5 Mpps

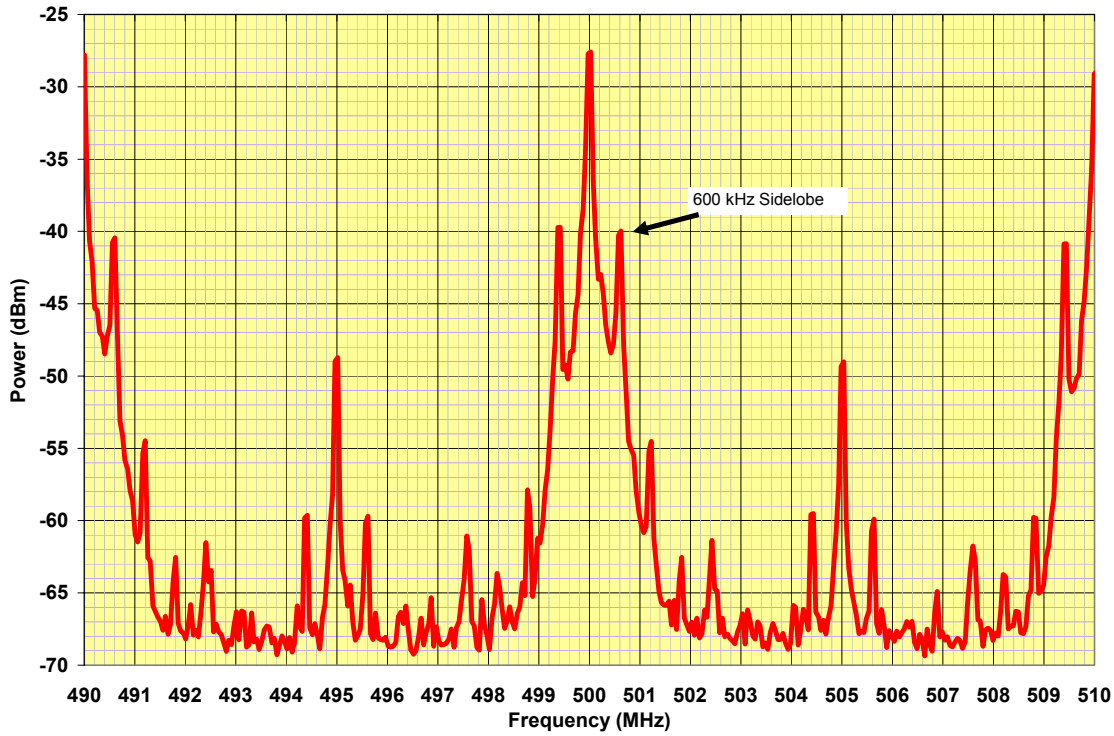

Figure 3. Sidelobes in UWB Clock Harmonics of 10 Mpps Pulse about Fiftieth Harmonic

5.3 EMI Test Waveforms

A set of seven UWB waveform parameters were selected for the tests. The parameters used for the test waveforms were based on the characteristics of the receiver under test and waveforms were selected to represent the worse case from the standpoint of EMI. The parameters for each Test Waveform (TW) are described below and the parameters are summarized in Table 1.

TW1 – The PRF was set to the maximum value available from the pulse generator that resulted in the fundamental or a harmonic of the PRF falling within the receiver RF passband, as close as possible to the actual receiver tuned frequency (i.e., the test frequency). For test frequencies above 100 MHz, the PRF was determined by dividing the TF by the smallest integer (n) which would yield a value less than or equal to 100 MHz. Thus the PRF = TF/n. For TFs at or below 100 MHz, n was 1. TW1 was not modulated.

TW2 – The base PRF of TW2 was similar to TW1 except that TW2 was dithered in a manner to attempt to partially fill the receiver passband. Since the UWB does not dither any PRFs greater than 80 Mpps, the PRF of TW2 must be equal to or less than 80 Mpps. Therefore the TW2 PRF was determined by dividing the TF by the smallest integer (m, m ≥ n) which would yield a value less than or equal to 80 MHz. Thus the PRF = TF/m. For TFs at or below 80 MHz, m was 1. TW2 was

dithered by the largest available percentage which would not cause the occupied bandwidth of the dithered signal to exceed the RXBW, or if all available dither percentages resulted in an excessive dither bandwidth, the lowest available dither percentage was used.

TW3 – The base PRF of TW3 was the victim RXBW. TW3 was dithered by the largest available percentage which would not cause the occupied bandwidth of the dithered signal to exceed the RXBW, or if all available dither percentages resulted in an excessive dither bandwidth, the lowest available dither percentage was used.

TW4 – The base PRF of TW4 was the victim RXBW. The TW4 modulation was selected on a case-by-case basis to try to cause the most interference to the victim receiver. Three different modulations were used: (1) an externally generated swept Frequency Modulated (FM) PRF at the victim RXBW with a deviation of 1 Hz and a rate of 1 kHz; (2) an internally generated OOK with a symbol rate equal to the victim RXBW using PN Factor 1, a continuous stream of alternating 1s and 0s; or (3) an internally generated OOK with a symbol rate equal to the victim RXBW using PN Factor 12, a continuous stream of random 1s and 0s.

TW5 – The PRF of TW5 was one tenth of the victim RXBW. TW5 was not modulated.

TW6 – The PRF of TW6 was ten times the victim RXBW. TW6 was not modulated.

TW7 – The PRF of TW7 was one hundredth of the RXBW. TW7 was not modulated.

For Waveforms 1 and 6, the PRF was greater than the receiver IF bandwidth and the waveforms were not modulated. Therefore, the spectral components were separated by more than the receiver bandwidth, and at most, only one spectral component could occur in the receiver passband and the EMI was most severe when the receiver was tuned to that spectral component. For these cases, the PRF is fast relative to the receiver response time. Therefore, these waveforms resulted in a signal in the receiver that appears to be continuous and the affect on the receiver was the same as would occur with a Continuous Wave (CW) signal.

For Waveform 2, the PRF was also greater than the receiver IF bandwidth. However, the pulses were dithered randomly. This will result in a noise like signal in the receiver passband and the receiver should be tuned for maximum impact from the UWB signal.

TABLE 1
DESCRIPTIONS OF UWB TEST WAVEFORMS

TW	PRF	Modulation of PRF
1	TF/n	Not Applicable (N/A)
2	TF/m (m ≥ n)	Dithered at greatest available percentage which was less than the full receiver RXBW.
3	RXBW	Dithered to fill all or a portion of RXBW
4	RXBW	Modulation designed to cause maximum interference to selected victim
5	RXBW/10	N/A
6	RXBW*10	N/A
7	RXBW/100	N/A

For Waveforms 3 and 4, the PRF was equal to the receiver IF bandwidth. This results in a signal within the receiver IF passband across the entire tuning range of the receiver. The third test waveform was dithered randomly. This resulted in a noise like signal in the receiver passband. The fourth waveform was modulated to create a worst case EMI impact condition.

For Waveforms 5 and 7, the PRF was less than the receiver IF bandwidth and the pulses were not dithered or modulated. For these cases, the receiver response time was faster than the PRF and this resulted in a pulse like signal in the receiver passband. The EMI was present over the entire tuning range of the receiver.

It should be noted that Waveforms 6 and 7 applied only to receivers with an IF bandwidth that is much lower than the maximum PRF of the UWB emitter, which is 100 MHz. Therefore, Waveforms 6 and 7 applied to receivers with IF bandwidths less than 1 MHz and did not apply to receivers with IF bandwidths equal to or greater than 10 MHz. For receivers with IF bandwidths between 1 MHz and 10 MHz the applicability of Waveforms 6 and 7 depended on the receiver characteristics.

6.0 UWB EMI TEST RESULTS

The objective of the UWB EMI study effort was to investigate the susceptibility of selected military communication, navigation, and radar receivers to EMI from various UWB waveforms. The results of this investigation were used to define parameters for UWB systems to coexist with legacy systems without causing EMI.

6.1 Summary of EMI Test Results

A total of seventeen different receivers, operating in a total of thirty-nine modes at a total of sixty-five fixed frequencies and five frequency hop-sets from 30 MHz to 16 GHz, were tested. Altogether over 1,600 individual tests were conducted over a period of five months. Receivers tested included communications, aircraft guidance systems, and radars. Testing, data reduction, and analysis on the seventeen receivers were completed.

The effort included identifying UWB waveforms that would result in EMC, identifying waveforms that probably would cause EMI to legacy systems, defining UWB thresholds for EMI, and comparing UWB EMI levels to BWGN levels for equivalent impact.

6.2 Systems Tested

The systems that were tested are listed below:

- AN/ARN-147 Commercial Instrument Landing System
- AN/ARC-210 VHF/UHF Communication System
- AN/APN-194(V) Radar Altimeter
- AN/APX-100 Identification Friend or Foe (IFF) Transponder
- AN/ARA-63 Aircraft Carrier Landing System (CILS)
- AN/ARN-118 Tactical Air Navigation (TACAN)
- AN/PRC-117F VHF/UHF Communication System (fixed frequency modes).
- AN/UPX-38 IFF Interrogator
- Enhanced Position Location Reporting System (EPLRS)
- Joint Tactical Information Distribution System (JTIDS)
- AN/SPN-35 Carrier Approach Control Radar
- AN/SPN-43 Carrier Marshal Radar
- AN/ARQ-44 Light Airborne Multipurpose System (LAMPS) MK III
- AN/SRQ-4 Light Airborne Multipurpose System (LAMPS) MK III
- AN/SLQ-32 Shipboard Electronic Warfare System
- SHF SATCOM Anacom Anasat – Ku Transceiver AMC-06
- Global Positioning System (GPS)

6.3 UWB Waveform Impact on EMI

The results of the tests demonstrated that most of the test waveforms caused interference in the receivers when operated at full power levels. This was expected because the test waveforms were selected to represent worst case EMI threats. In general, the impact of the UWB waveform was a function of the average interfering power that fell within the narrowest passband of the receiver.

The EMI analysis included tests to determine EMI to legacy systems for BWGN that is often considered as the metric against which other interference sources are compared. Figure 4 displays a histogram that shows the number of occurrences that were observed during the tests within the specified range for the ratio of (UWB EMI /DSL) to (White Noise EMI/DSL) to cause the same impact in the receiver. If DSL was the same level in both the UWB EMI and White Noise tests (which it was supposed to be), then the ratio would be just the UWB EMI UPSET Level (IUPSET) in dB – the White Noise UPSET Level (WNUPSET) in dB. In this case, the histogram would present the number of occurrences for a range of IUPSET – WNUPSET that would result in the same impact in the receiver.

Figure 4 represents a total of 240 data points i.e., the 17 different systems measured at different frequencies and operating modes (if applicable). Referring to Figure 4, approximately eighty percent of the data points (i.e., 190 data points) fall within the interval where IUPSET – WNUPSET is between – 12.5 dB and + 12.5 dB.

Histograms for Test Waveforms 1-6 are included in Appendix B.

Several of the receivers tested were less susceptible to the UWB waveforms than they were to white noise. That is white noise caused an EMI upset in the receiver at lower levels than the test waveforms did. Other receivers tested were more susceptible to the UWB waveforms than they were to white noise. The results show that in approximately 80% of the cases, the level of UWB EMI and the level of white noise that cause the same effect are within an order of magnitude of each other.

Therefore the general conclusion can be made that for most waveform and receiver combinations, UWB signals will cause about the same affect as white noise that is at an equivalent level.

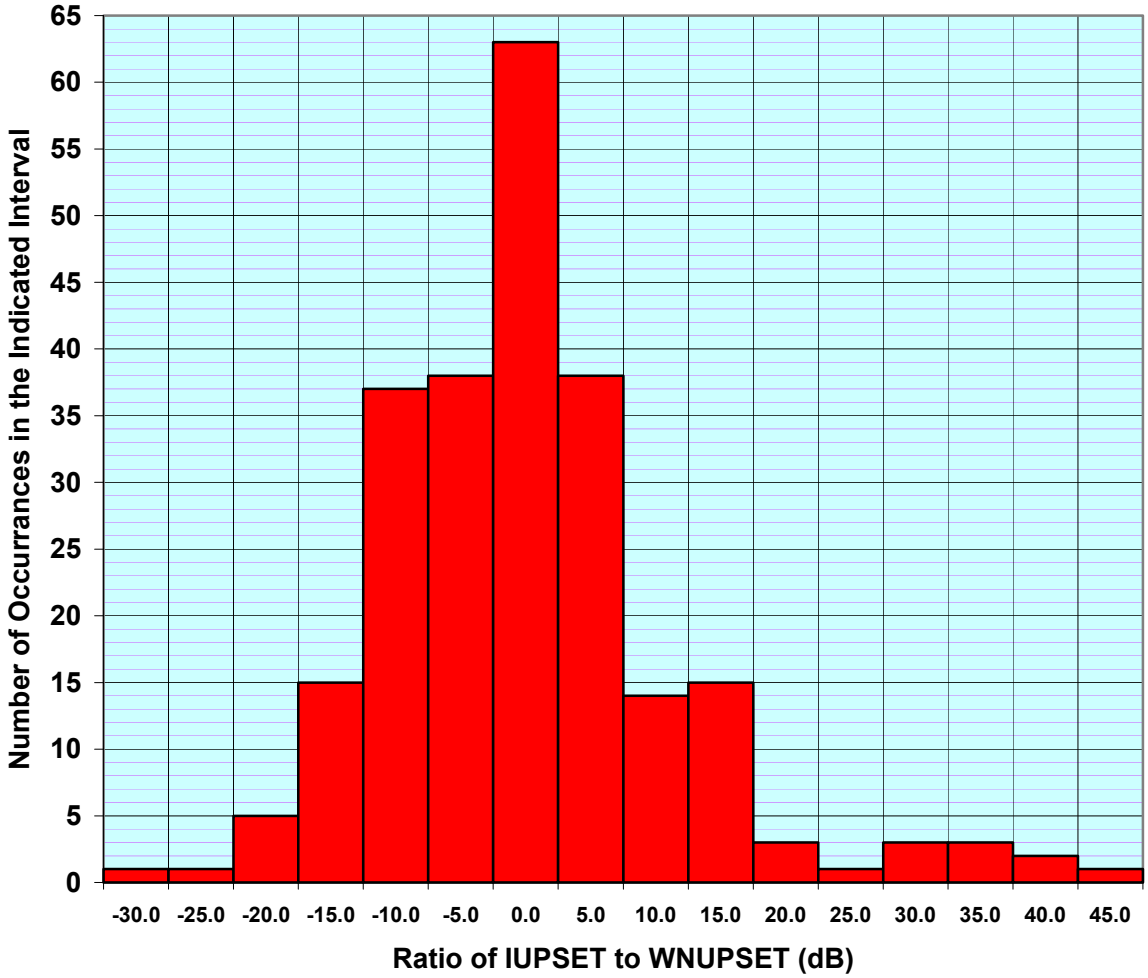

Figure 4 Histogram for Composite Data for All Test Waveforms

The parameters for several of the test waveforms were selected so the UWB signal would result in a signal at the input to the receiver that would occupy only a narrow portion of the receiver tuning-band. For example, test waveforms 1, 2 and 6 resulted in spectra that occupied only narrow bands at frequencies that were harmonics of the PRF. The EMI caused by these waveforms was most severe when the receiver was tuned to a harmonic of the PRF. Other waveforms, 3, 4 and 5 were selected so their spectra would occupy the entire tuning band of the receiver. These waveforms caused EMI over the entire tuning band of the receiver.

The PRF for test waveform 7 was low, so the average power was lower than the other waveforms. Most of the receivers were not susceptible to waveform 7. This is probably because there was not sufficient power within the receiver passband to cause EMI.

The results showed that all waveforms tested caused interference to at least some of the receivers under test. However, certain waveforms were less likely to cause interference than others. Two very general observations were:

(1) High PRFs result in a spectrum that exhibits significant spectral components at the PRF and frequencies that are harmonically related to the PRF. However, there is a significant amount of spectral space between the lines where there is very little or no interference. As an example consider a system operating in a band of 490 – 510 MHz with 1 MHz channel spacing and 1 MHz RBW and an UWB system operating in the vicinity of 500 MHz with a steady PRF of 10 Mpps. An examination of Figure 3 indicates that 3 channels of the 21 available (those at 490 MHz, 500 MHz, and 510 MHz) have a high level of interference. Interference on the 4 adjacent channels is 20 dB lower, and interference on 2 other channels (495 MHz and 505 MHz) is about 28 dB lower. The result is that these 6 channels have a low probability of EMI. The other 13 channels are potentially interference free. If the PRF was higher, the major spectral components would be further separated and the probability of interference (which is most severe when the receiver is tuned to a major spectral component) would be reduced even more.

(2) Very low PRFs are unlikely to cause interference at any frequency. For purposes of this report, very low PRFs are considered to be any PRF equal to or less than RBW/100. Most of the receivers tested did not experience EMI at these low PRFs. In receivers that respond to average power, even a very strong signal that is present only 1% of the time or less is not capable of causing much interference, even when the desired signal strength just barely exceeds the sensitivity level. Error correction coding reduces the probability of interference even more. Receivers that respond to peak signals are more susceptible to interference from low PRF UWBs, but even these can benefit from interference cancellation techniques.

Other waveform generation and frequency management techniques are also available to help reduce the probability of the occurrence of interference to legacy receivers that may be operating in the vicinity of a UWB system.

7.0 UWB EMI THRESHOLDS

In order to provide design guidelines for UWB systems, the test data was used to establish a Spectral Mask (i.e., the levels where EMI started to become a problem in legacy systems). Figure 5 shows the average power level, adjusted for a 1 kHz RXBW, for the onset of UWB interference for each of a selected set of legacy systems. The

resulting Spectral Mask is the Blue Line in Figure 5. UWB signal levels that are below the Blue Line should not cause EMI problems in legacy systems. For reference purposes, Figure 5 also provides lines indicating the thermal noise at room temperature (-144 dBm/kHz), galactic noise, manmade noise for suburban and urban areas, and an adjusted FCC mask (the FCC field strength limits have been converted to the signal level (dBm/kHz) at the input to a receiver with an isotropic antenna located 3 meters from the UWB signal source). This figure shows that many legacy military systems are susceptible to UWB interference at levels well below those allowed by the FCC, but significantly above the noise levels expected in rural areas.

8.0 LINK BUDGET AND EMI ANALYSIS

During the initial EMI investigation, link budget and EMI analyses were performed for four systems that represent examples of UWB systems of interest. The assumptions used for the analysis are shown below.

- EMI to legacy systems is determined by average UWB power in legacy RX passband.
- UWB TX and RX Bandwidths are matched.
- Narrow-Band Path Loss models (Free Space or Plane Earth) were used.
- UWB signal is pulsed with one bit per pulse.
- Victim RX is tuned to maximum of UWB spectrum.
- Enhancement resulting from signal processing was not considered.
- Aggregate EMI effects were not considered.

Operational requirements and system parameters for the four UWB systems of interest are shown in Table 2.

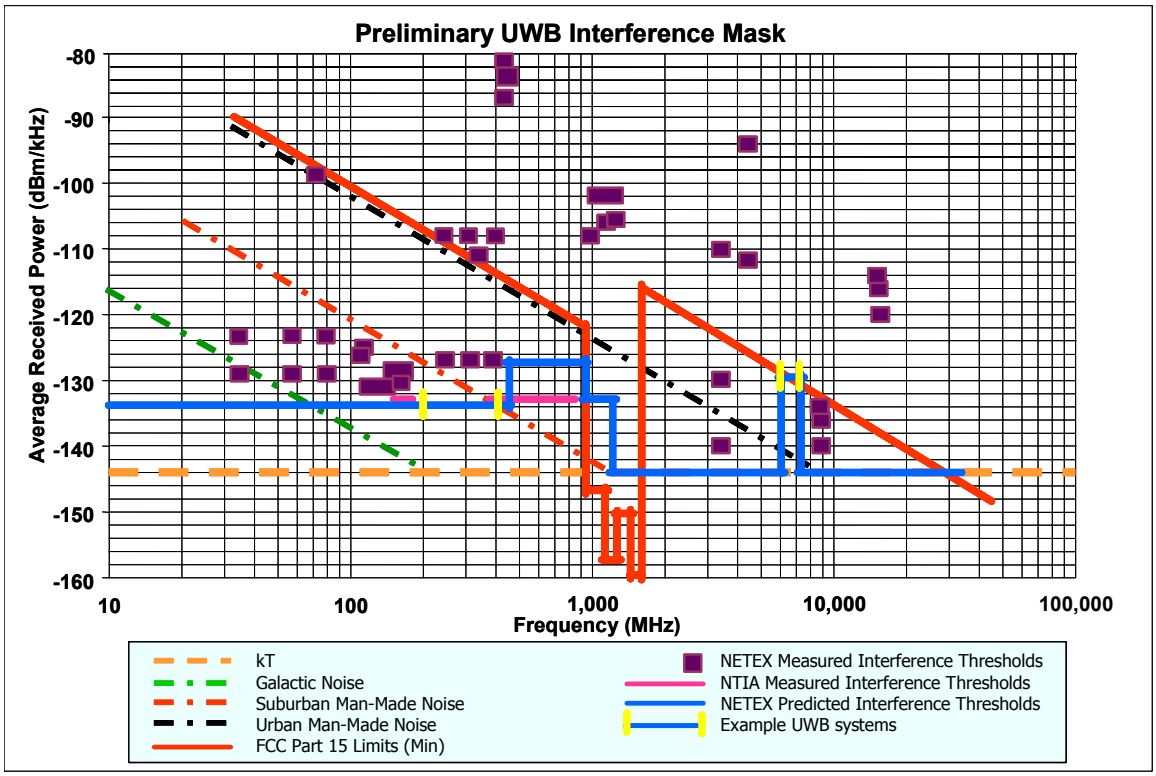

Figure 5. Spectral Mask for UWB Systems

8.1 Link Budget and EMI Analysis Equations

The equations that were used to perform the link budget and EMI analyses for each of the example systems are shown below and the equation definitions are listed in Table 3. The propagation loss model used for the link budget analysis for the two communication systems was a combination of the free space propagation loss model which applies for short range conditions and the plane earth propagation loss model for longer range conditions. The propagation loss used for the link budget analysis was obtained by calculating both the free space loss and the plane earth loss and selecting the one that resulted in the largest loss, which provides the most conservative result. The free space loss propagation model was used for the radar system and for the EMI analysis.

Table 2
Performance Requirements and Operational Parameters for Example Systems

SYSTEM TYPE	HAND HELD	HIGH DATA/ SHORT RANGE	RADAR 1 m^2	RADAR PERSONNEL 1 m^2
POWER dBm	14	10	40	50
RANGE Meters	500	100	100	100 Foliage 10% of Range*
DATA RATE	10 Kbps	10 Mbps	10 Kpps	100 pps
FREQUENCY	200 – 400 MHz	6 -7 GHz	6 – 7 GHz	700 – 1000 MHz
BANDWIDTH	200 MHz	1 GHz	1 GHz	300 MHz
SIGNAL/NOISE dB	10	7	2	6.6
INTERFERENCE/ NOISE dB	6 @20 m	-9 @10 m	- 21 @10 m	20 @10 m

* One Way Foliage Loss = $0.2\ F^{0.3}\ R^{0.6} = 0.2\ (850)^{0.3}(10)^{0.6} = 0.2(7.57)(3.98) = 6.0$ dB
Round Trip Foliage Loss = 12 dB

<u>Equations</u>:

Link Budget: $S/N = P_T + G_T - L_T - L + G_R - L_R - P_N$

Free Space Propagation Loss: $L = (-28 + 20 \text{ Log } F + 20 \text{ Log } D)$

Plane Earth Propagation Loss: $L = 40 \text{ Log } D - 20 \text{ Log } H_T H_R$

Radar: $S/N = 17 + P_T + G_T + 10 \text{ LOG } A_T + G_R - L_S - 40 \text{ Log } R - 20 \text{ Log } F - P_N$

Interference Analysis: $I/N = P_{TP} + 10\text{Log } [(DC)\ (BWCF)] + G_{TR} - L_T - (-28 + 20\text{Log}F + 20 \text{ Log } D) + G_{RT} - L_R - (-174 + NF + 10\text{Log}BW)$

Table 3
Link Budget and EMI Analysis Equations

DEFINITIONS	
S/N = Signal to Noise Ratio (dB)	P_T = TX Power (dBm)
G_T = Gain of TX Antenna (dB)	L_T = System Loss at the TX (dB)
L = Propagation Loss (dB)	G_R = Gain of RX Antenna (dB)
L_R = System Loss at RX (dB)	P_N = RX Noise (dBm)
D = Distance (meters)	= - 174 + NF + 10 Log BW (Hz)
H_R = Height of RX Antenna (meters)	F = Frequency (MHz)H_T = Height of TX
NF = RX Noise Figure (dB)	Antenna (meters)
DC = Duty Cycle = (PW) (PRF)	P_{TP} = Peak UWB Power (dBm)
PRF = Pulse Repetition Rate (pps)	BW = RX Bandwidth (Hz)
BWCF = (BW) (PW) for BW > PRF	PW = Pulse Width (Seconds)
BWCF = (PRF) (PW) for BW < PRF	BWCF = 0 for BW > 1/PW
I/N = Interference to Noise in dB	BWCF = (PRF) (PW) for BW < PRF
L_S = Total System Loss (dB)	G_{TR} =TX Antenna Gain in Direction of RX
R = Range (meters)	G_{RT} = RX Antenna Gain in Direction of TX
A_T = Radar Cross Section (m^2)	

8.2 Example UWB System Applications

1. **Handheld UWB communications network.** A handheld device is needed to enable and support mobile, ad-hoc network applications in a tactical environment. As a minimum, the system should be able to support voice and 10 kb/s data communications at a range of up to 500 meters. The system should consider unique approaches to the networking protocols that enable simultaneous transmissions by networked systems without causing interference to legacy systems. The UWB receiver should be capable of operating within 20 meters of a minimum of three in-band legacy transmitters without experiencing interference (the UWB system should be capable of achieving a 10^{-3} uncorrected BER). The UWB system should be capable of operating without external power for a period of 2 days (i.e., without changing batteries) and have the capability to use an external power source if available. The system should be demonstrated for a network consisting of 20 nodes and should be extensible to more than 10,000 nodes in a 1 km^2 area.

   The system parameters that were used for the link budget and EMC analyses are shown in Table 4. They resulted in a 10 dB S/N at maximum range and the UWB transmitter resulted in an I/N that was 6 dB when the UWB device was 20 meters away from a typical legacy system that operates in the 200 to 400 MHz frequency band.

Table 4
Hand Held Communication Network Parameters for Link Budget and EMI Analysis

HAND HELD UWB SYSTEM PARAMETERS		EMI PARAMETERS	
Range:	500 m	EMI Zone:	20 m
Data Rate:	10 kbps	I/N:	6 dB
S/N@ Max Range:	10 dB	Noise Figure:	10 dB
Peak Power:	14 dBm	Band Width:	25 kHz
Pulse Width	5 nsec	Antenna Gain:	2 dB
Center Frequency:	300 MHz	System Loss:	1 dB
Bandwidth:	200 MHZ	Antenna Height:	2 m
Antenna Gain:	2 dB		
Noise Figure:	1 dB		
System Loss:	1 dB		
Antenna Height:	2 m		

2. **Ground-based UWB Network**. A high data rate short range communication system is required for transmitting video and other information in a tactical environment. The system should provide data communications at 10 Mb/s with a range of 100 meters. The UWB system, when transmitting should not cause interference to in-band legacy receivers and the UWB receiver should be capable of achieving a 10^{-3} uncorrected BER when operating within 20 meters of a minimum of three in-band legacy transmitters. The UWB system should be capable of operating without external power for a period of 30 days (i.e., without changing batteries), and have the capability to use an external power source if available. The system should be demonstrated for a network consisting of 50 nodes and should be extensible to more than 10,000 nodes in 1 km^2.

   The system parameters that were used for the link budget and EMC analyses are shown in Table 5. They resulted in a 7 dB signal-to-noise ratio at maximum range and the UWB transmitter resulted in an I/N that was -9 dB when the UWB device was 10 meters away from a typical legacy system that operates in the 6 to 7 GHz frequency band.

Table 5
Ground-Based UWB Sensor Parameters for Link Budget and EMI Analysis

UWB SENSOR SYSTEM PARAMETERS		EMI PARAMETERS	
Range:	100 m	EMI Zone:	10 m
Data Rate:	10 Mbps	I/N:	-9 dB
S/N@ Max Range:	7 dB	Noise Figure:	5 dB
Pulse Width	1 nsec	Band Width:	5 MHz
Center Frequency:	6.5 GHZ	Antenna Gain:	-10 dB
Bandwidth:	1 GHz	System Loss:	1 dB
Peak Power:	10 dBm	Antenna Height:	2 m
Antenna Gain:	2 dB		
Noise Figure:	1 dB		
System Loss:	1 dB		
Antenna Height:	2 m		

3. **Radar Sensor.** A radar sensor is required for high resolution imaging involving foliage or wall penetration and other applications. The radar should be able to detect a 1 m^2 target at a range of 500 meters (direct line of sight), at a range of 20 meters through walls, and at a range of 100 meters through moderately dense foliage. The radar when transmitting should not cause problems to in-band legacy receivers and the UWB receiver should be capable of achieving a probability of detection greater than 99% and a probability of false alarm less than 1% when operating within 20 meters of a minimum of three in-band legacy systems. The UWB system should be capable of operating without external power for a period of 30 days (i.e., without changing batteries), and have the capability of using an external power source if available. The system should be demonstrated for a network consisting of 50 nodes and should be extensible to more than 10,000 nodes in 1 km^2 area.

   The system parameters that were used for the link budget and EMC analyses are shown in Table 6. They resulted in a 2 dB S/N at maximum range and the UWB transmitter resulted in an I/N that was -21 dB when the UWB device was 10 meters away from a typical legacy system that operates in the 6 to 7 GHz frequency band.

Table 6
UWB Radar Parameters for Link Budget and EMI Analysis

UWB RADAR SYSTEM PARAMETERS		EMI PARAMETERS	
Range:	500 m	EMI Zone:	10 m
Radar Cross Section:	1 m^2	I/N:	-21 dB
Pulse Repetition Rate:	10 Kpps	Noise Figure:	5 dB
S/N@ Max Range:	2 dB	Band Width:	5 MHz
Pulse Width	1 nsec	Antenna Gain:	-10 dB
Center Frequency:	6.5 GHZ	System Loss:	1 dB
Bandwidth:	1 GHz	Antenna Height:	2 m
Peak Power:	40 dBm		
Antenna Gain:	24 dB		
Noise Figure:	1 dB		
System Loss:	2 dB		
Antenna Height:	2m		

4. **Low Power – Long Duration Network Sensor System.** A small low power – long duration distributed radar system is required for personnel detection. The radar should be capable of detecting personnel (with an effective target area of 1 m^2) through foliage (10% of the path) at a distance of 100 meters. The radar when transmitting should not cause EMI problems to in-band legacy receivers. The design goals for the UWB receiver are to achieve a probability of detection of greater than 99% and a probability of false alarm that is less than 1%, for a target search area of at least 500m by 200m, when operating within 20 meters of a minimum of three in-band legacy transmitters. The system should be capable of operating for a period of one year without changing batteries or other power source. The system should be demonstrated for a network consisting of 30 nodes connected through an *ad hoc* wireless, communications network capable of transmitting coordinated target information from all sensors to a remote site which is located at least 500 meters away and should be proven through simulation or other means to be extensible to more that 1,000 nodes in 1 km^2 area.

   The system parameters that were used for the link budget and EMI analyses for this network sensor system are shown in Table 7. They resulted in a 6.6 dB S/N at maximum range and the UWB transmitter resulted in an I/N ratio that was 20 dB when the UWB device was 10 meters away from a typical legacy system that operates in the 700 MHz to 1000 MHz band.

Table 7
UWB Personnel Radar Link Budget and EMI Analysis

UWB PERSONNEL RADAR SYSTEM PARAMETERS		EMI PARAMETERS	
Range:	100 m	EMI Zone:	10 m
Foliage	10% of Range	I/N:	20 dB
Radar Cross Section:	1 m^2	Noise Figure:	5 dB
Pulse Repetition Rate:	100 pps	Band Width:	6 MHz
S/N@ Max Range:	6.6 dB	Antenna Gain:	2 dB
Pulse Width	3.3 nsec	System Loss:	1 dB
Center Frequency:	850 MHz		
Bandwidth:	300 MHz		
Peak Power:	50 dBm		
Antenna Gain:	2 dB		
Noise Figure:	1 dB		
System Loss:	1 dB		

9.0 SUMMARY

A total of seventeen different receivers, operating in a total of thirty-nine modes, at a total of sixty-five frequencies and five frequency hop-sets from 30 MHz to 16 GHz, were tested. Altogether over 1,600 individual tests were conducted over a period of five months. Receivers tested included communications, aircraft guidance systems, and radars.

The results enabled the development of a Spectral Mask that represents the average power level at the receiver input, adjusted for a 1 kHz RXBW, for the onset of UWB interference in legacy military systems. UWB signal levels that are below the Spectral Mask should not cause EMI problems in legacy military systems.

The results showed that all waveforms tested caused interference to at least some of the receivers under test. However, certain waveforms were less likely to cause interference than others. The general observations were:

- For most combinations of UWB waveforms and receivers, the EMI impact was related to the average UWB signal in the narrowest passband of the receiver.
- For most waveform and receiver combinations, UWB signals will cause about the same affect as white noise that is at an equivalent level.
- High PRFs result in a spectrum that exhibits significant spectral components at the PRF and frequencies that are harmonically related to the PRF. However, there is a significant amount of spectral space between the lines where there is very little or no interference.

- Very low PRFs are unlikely to cause interference at any frequency. For purposes of this report, very low PRFs are considered to be any PRF equal to or less than RBW/100.

The test also resulted in the identification of a broad range of UWB operating parameters that will support militarily useful functions, such as sensor and networked communication systems that can coexist with legacy military systems and will not cause undesired EMI that impacts their operation.

ACRONYM LIST

- A -

ACQ	Standard Response Acquisition Threshold
AM	Amplitude Modulation
ARB	Arbitrary Waveform Generator
AWG	Arbitrary Waveform Generator

-B-

BER	Bit Error Rate
BW	Bandwidth
BWGN	Broadband White Gaussian Noise

-C-

CW	Continuous Wave
CMOS	Complimentary Metal-Oxide Semiconductor

-D-

dB	Decibel
dBm	Decibel relative to one milliwatt
DH	Decision Height
DSL	Desired Signal Level

-E-

E3	Electromagnetic Environmental Effects
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test

-F-

FH	Frequency Hopping
FM	Frequency Modulation

-G-

GHz	Gigahertz
G/S	Glide Slope

-H-

HIACQ	High level interference at which acquisition occurs
HIUPSET	High level signal is reduced and then lost
Hz	Hertz

-I-

IF	Intermediate Frequency

ILS	Instrument Landing System
IM	Inner Marker
IREACQ	Reacquisition Level
I/S	Interference-to-Signal Ratio
ISL	Interference Signal Level
IUPSET	Interference Upset Level

-J-

-K-

KHz	Kilohertz

-L-

LOC	Localizer

-M-

MB	Marker Beacon
MDS	Minimum Detectible Signal
MHz	Megahertz
MM	Middle Marker
Mpps	Million pulses per second

-N-

NAS	Naval Air Station
NAWC AD	Naval Air Warfare Center, Aircraft Division
Neg DE	Negative Double Exponential
NETEX	Networking in Extreme Environments
NM	Nautical Miles

-O-

OM	Outer Marker
OOK	On-Off Keyed

-P-

PAN	Personal Area Network
PHY	Physical Layer
PN	Pseudonoise
Pos DE	Positive Double Exponential
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
PRR	Pulse Repetition Rates
PPM	Pulses Per Minute
PW	Pulse Width

-Q-

-R-

RBW	Resolution Bandwidth
REACQ	Interfering Signal Reacquisition Threshold
RF	Radio Frequency
RXBW	Receiver RF Bandwidth

-S-

S/N	Signal to Noise Ratio
SINAD	Signal-to-Interference, Noise and Distortion
SINCGARS	Single Channel Ground and Airborne Radio System
SUPSET	Signal Upset Threshold

-T-

T&E	Test and Evaluation
TF	Test Frequency
TW	Test Waveform

-U-

UHF	Ultra High Frequency
UUT	Unit Under Test
UWB	Ultra-Wide Band

-V-

VBW	Video Bandwidth
VHF	Very High Frequency
VOR	Omni-Directional Range

-W-

WNREACQ	White Noise Reacquisition Threshold
WNUPSET	White Noise Upset Threshold

-X-

-Y-

-Z-

Test Waveform Histograms

Figures B-1 through B-6 show the individual histograms for Test Waveforms 1 through 6. Because Test Waveform 7 did not cause EMI in a number of cases, there were not enough data points to define a meaningful histogram.

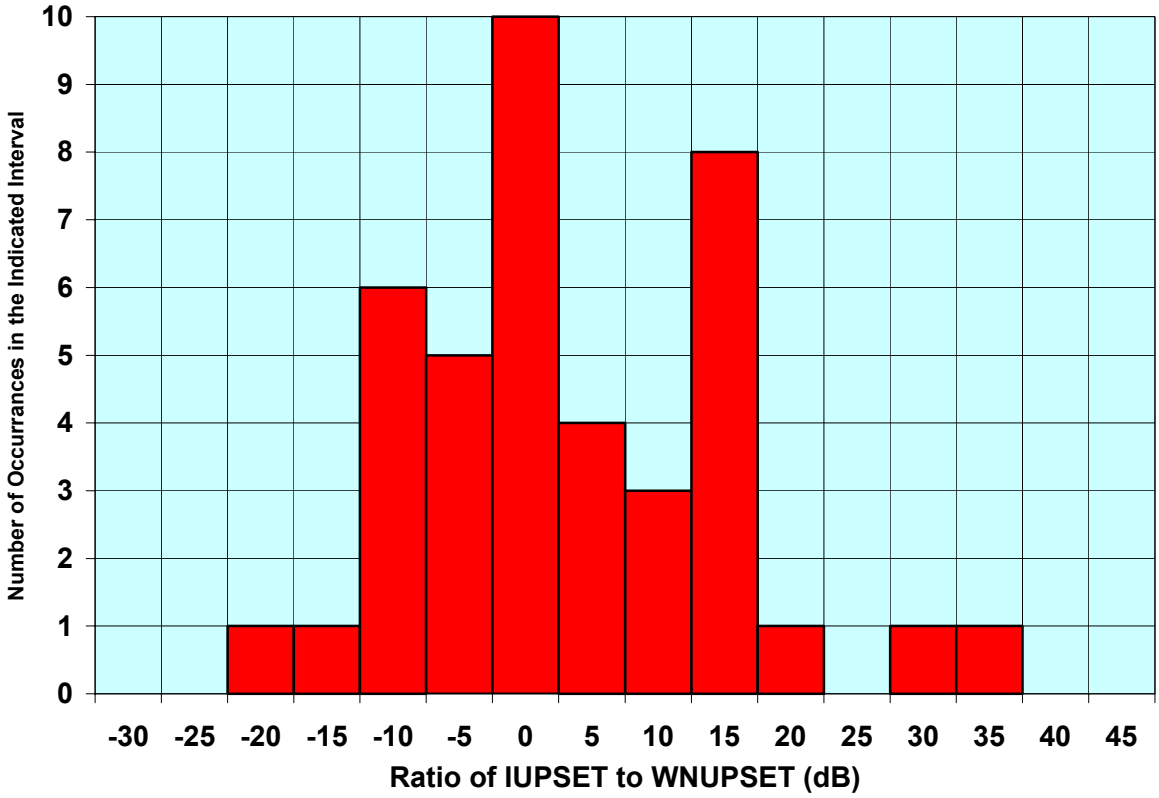

Figure B-1 Histogram For Test Waveform 1

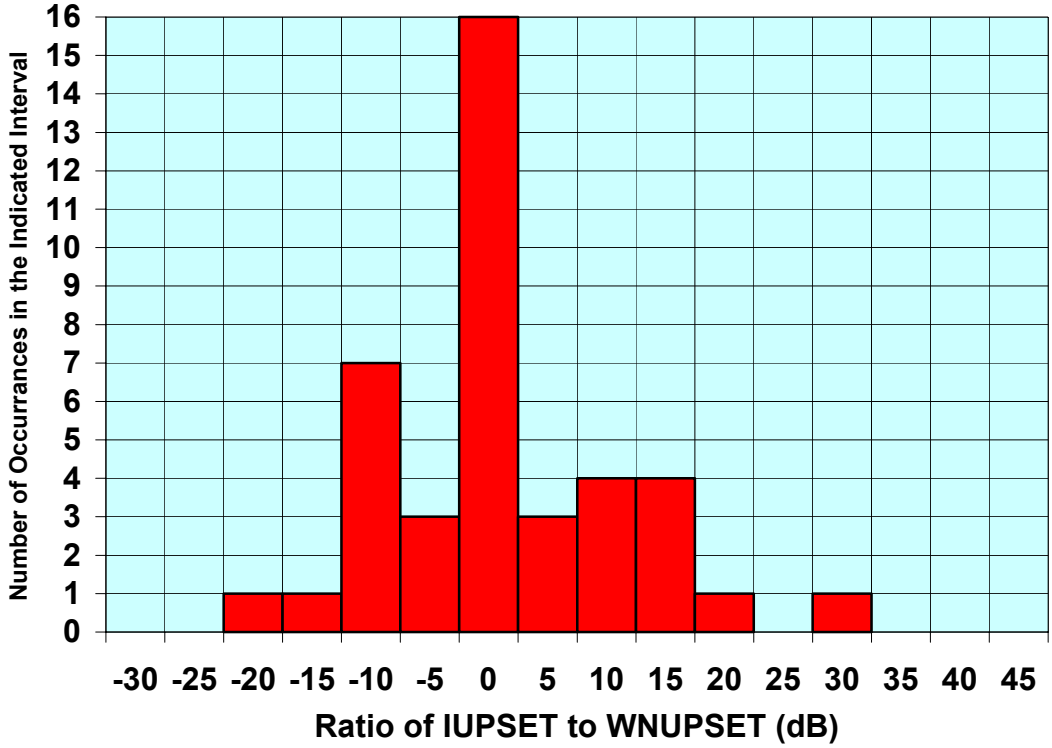

Figure B-2 Histogram for Test Waveform 2

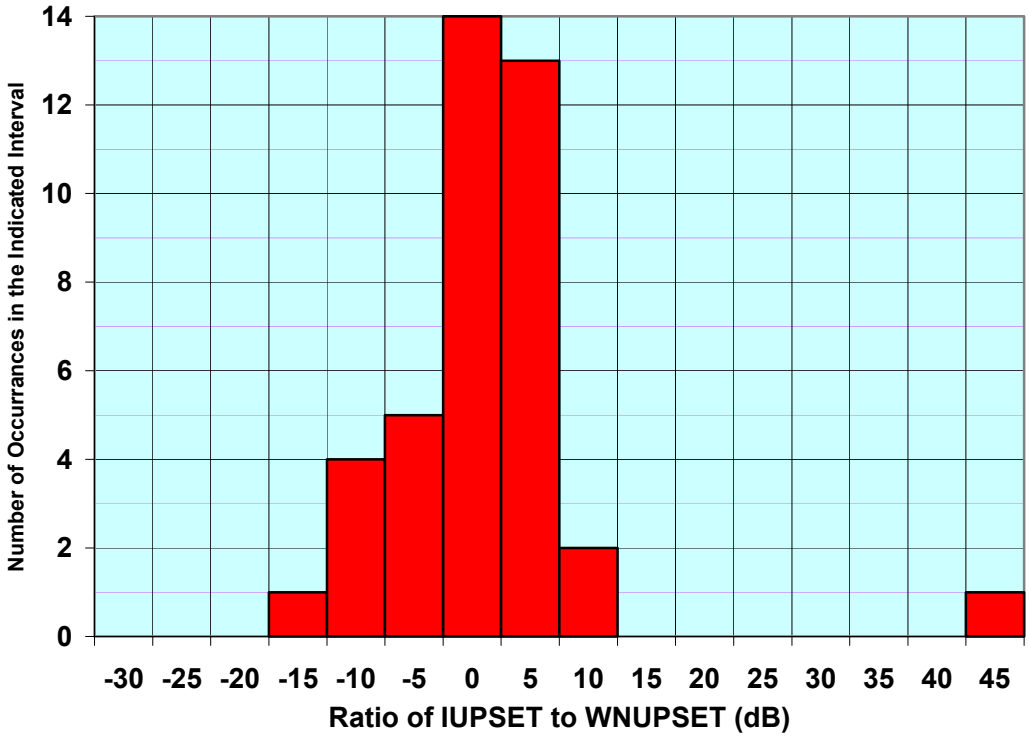

Figure B-3 Histogram for Test Waveform 3

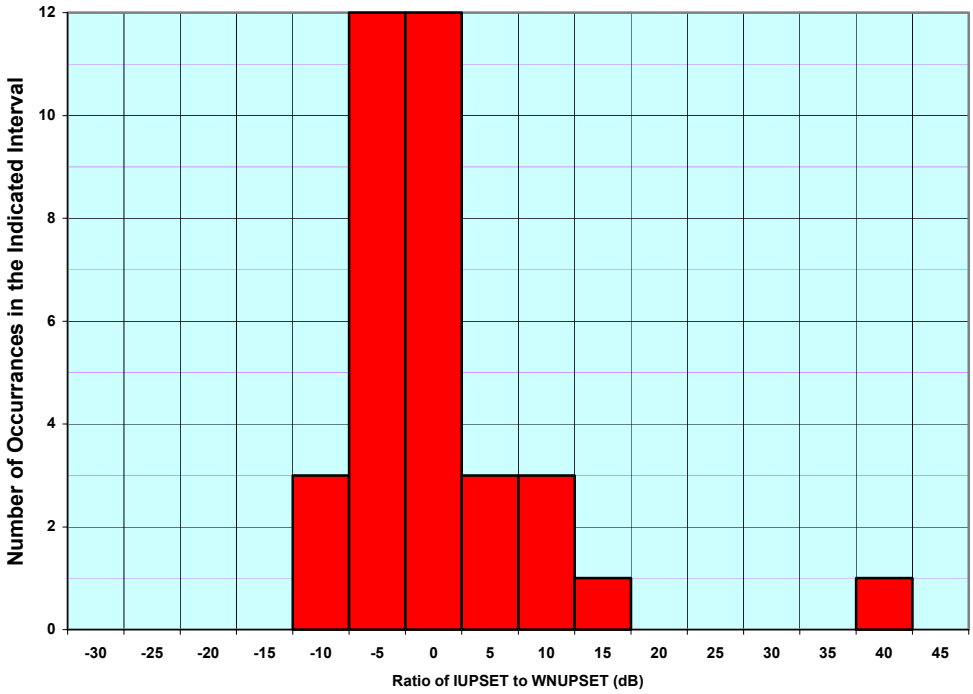

Figure B-4 Histogram for Test Waveform 4

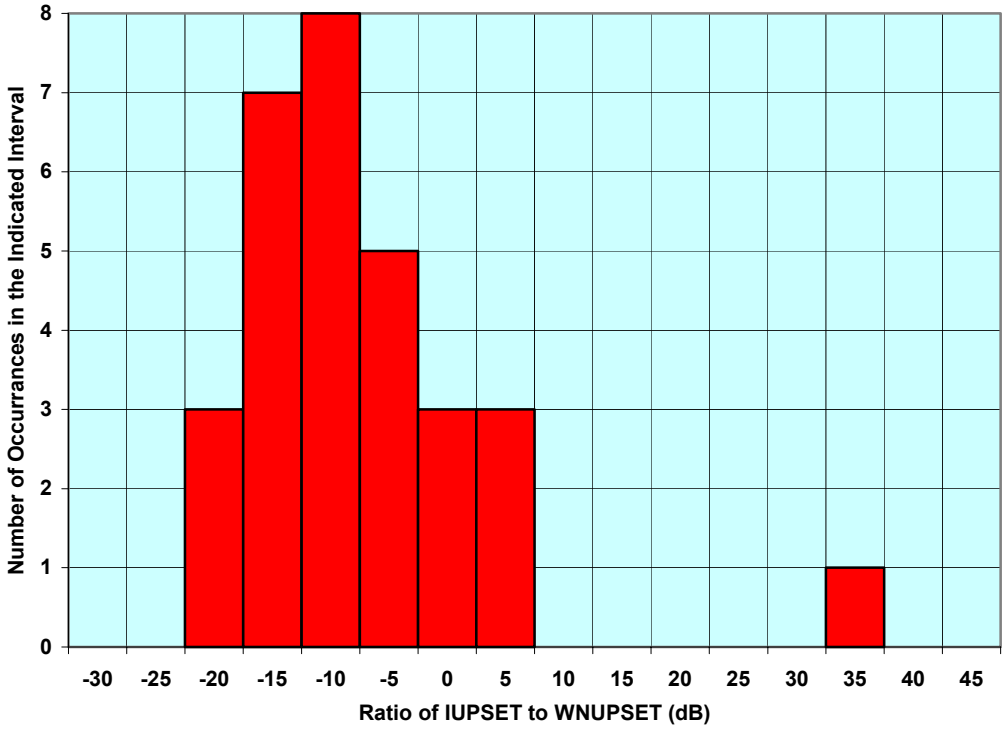

Figure B-5 Histogram for Test Waveform 5

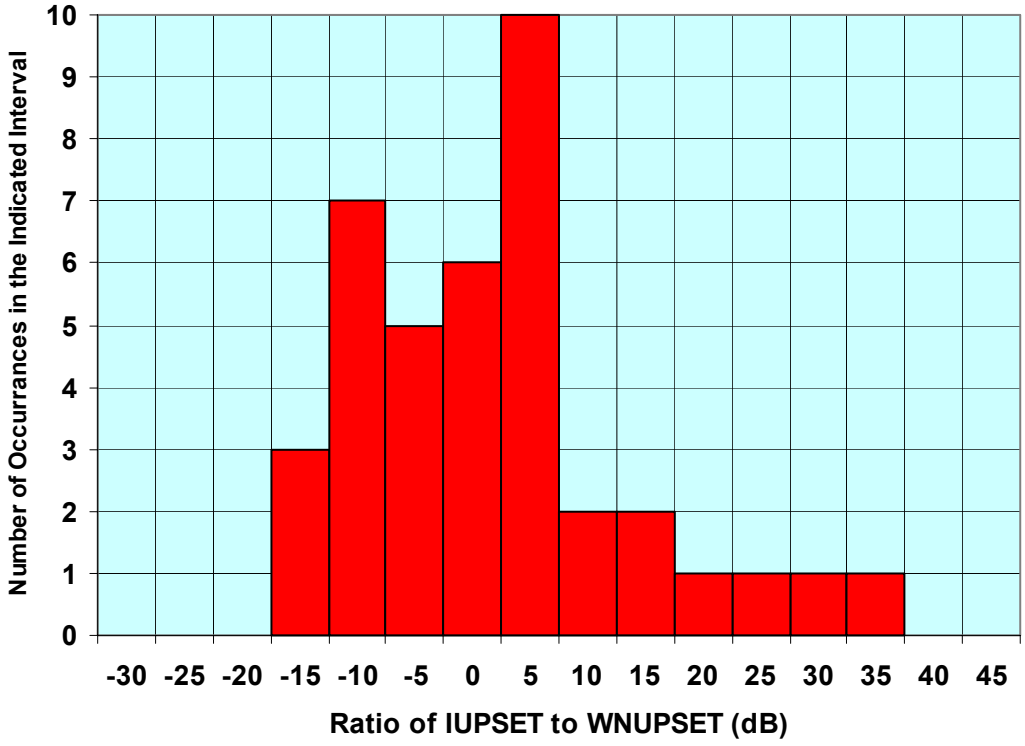

Figure B-6 Histogram for Test Waveform 6