UWB RADIATED EMISSIONS

MEASUREMENT STUDY

PERFORMED BY

MEMBERS OF THE TECHNICAL STAFF

TIME DOMAIN CORPORATION

410-0011A

February 15, 2001

1 Purpose, Background, and Summary of Results and Recommendations

1.1 Purpose

The purpose of this document is to provide a detailed framework for measuring Ultra Wide Band (UWB) emissions in both the frequency and time domains. This document draws from work already submitted to the Federal Communications Commission (FCC) by Time Domain Corporation (TDC) in its Notice of Proposed Rulemaking (NPRM) Reply Comments dated October 30, 2000. This document provides general guidelines that cover test setup calibration and emission measurements, along with a list of required equipment and test setup diagrams. This document also includes an update on testing that has taken place since the previous submission.

1.2 Background

The FCC in its NPRM on UWB has requested technical guidance to support its efforts to establish UWB emission limits, measurement techniques, and test procedures that would be used to verify the compliance of UWB devices with those limits. The FCC has proposed to use a modification of the standard FCC Part 15 class B average electric field strength limit, 500μV/m @ 3m measured over a 1 MHz bandwidth, and two new limits measured in the time domain. These two new proposed limits are intended to consider the attributes of the short pulse, low duty cycle waveforms used by some UWB devices. These two proposed limits are electric field strength limits. One would be measured in a 50 MHz bandwidth and the other one would be measured in a bandwidth greater than the pulse spectrum.

Compliance laboratories have the equipment necessary to conduct the traditional CFR 47 Part 15 frequency domain electric field emission measurement as proposed by the FCC. However, the proposed pulsed waveform electric field time domain emission limits would require expensive equipment that few laboratories would have in their inventory. In order to minimize the expense to compliance laboratories and meet the intent of the NPRM to have measurements related to interference potential, TDC proposes a measurement process, test setup, and procedure that produces repeatable and traceable radiated emission measurements in both the frequency and time domain. ANSI C63.4-

1992 and the NPRM were used as the guiding documents for performing radiated emission measurements except as modified herein. The TDC test procedure shall only covers measurement methods related to intentional UWB radiated emissions. All other emission measurements (conducted and unintentional) are covered in detail in ANSI C63.4[1].

1.3 Summary of Results and Recommendations

1) All 50 MHz measurements were performed using a fixed 1.9 GHz center frequency Bessel 50 MHz bandpass filter with the UWB source set to an average Pulse Repetition Frequency (PRF) of 10 MHz. (The pulse spectrum emission peak is located at 2.15 GHz, which has an average value about 2 dB larger than the value at 1.9 GHz. This is important to keep in mind when reading this report since the measured 50 MHz peak field strengths can be low by roughly 2 dB.)

2) A semi anechoic or fully anechoic chamber is suggested for frequency domain emission measurements and is required for time domain emission measurements. Any ambient emissions are more easily identified in the frequency domain and can be dealt with during the UWB radiated emission measurements at an Open Test Site (OATS). However any ambient OATS emissions such as Personal Communication System (PCS) can corrupt the time domain pulse emission testing and cause a higher reading than what is actually radiating from the UWB device. If an OATS absolutely must be used, then the OATS must not only be "frequency mapped" but also "time domain mapped."

3) The 50 MHz time domain emission limit should be based on PRFs and possibly the pulse volt-sec rating. For example, an UWB source with a 10 MHz PRF that meets the NPRM proposed average emission limit will exceed the 3m 50 MHz limit by approximately 4 to 5 dB using the measurement methods suggested by TDC.

---

[1] TDC's testing was performed prior to receiving the new ANSI C63.4-2000 release, so this document refers to the 1992 ANSI document, which is still that which is incorporated by reference into the FCC rules. TDC is aware that there are many approaches that could be taken to arrive at the same measurement conclusion, however, TDC believes that this procedure is the most accurate, reproducible, and straightforward.

Therefore, the 20 dB 50 MHz peak limit should be increased to account for PRFs below the average limit, and 50 MHz peak crossover PRF of approximately 15 MHz to 17 MHz, depending on the pulse shape.

4) Frequency domain and time domain measurement setups should not be combined due to the adverse affects that spectrum analyzers cause during Digital Sampling Oscilloscope (DSO) time domain measurements.

5) The correlation between filter peak output voltage predictions and measurements are within ± 2 dB.

6) Currently only PRFs below a 50 MHz bandwidth have been investigated. TDC has not yet developed a model to predict a filter's peak output voltage at PRFs greater than the filter bandwidth. Pulses with PRFs lower than the filter bandwidth cause an identical response whether the pulse is periodic or randomly time dithered. This is not true for pulses with PRFs greater than the intercepting bandwidth. Periodic pulses with PRFs greater than the bandwidth can cause large voltage excursions when the PRF causes harmonics to occur within the filter bandwidth (i.e., when a spectral comb line falls within the filter's passband). The filter output voltage gets larger as the PRFs get larger due to the harmonic being closer to the fundamental until the largest filter output would occur when the PRF is at the filter's tuned center frequency. Randomly time dithered pulses with average PRFs greater than the intercepting bandwidth appear more noise-like and do not create harmonics (comb lines) such as would a periodic signal.[2] Two separate equations have to be developed in order to accurately predict a bandpass filter's peak output voltage for PRFs greater than the filter's bandwidth, one for periodic and one for random time modulation. TDC will investigate this issue if time permits.

7) Frequency domain measurements over a ground plane at 3m yield reflection amplitude errors of as much as 3.7 dB from the true free space peak average emission level. Also, when measured at 3 meters, it is difficult to determine the free

[2] There might be less well defined variations in the spectrum if a repetitive pseudo-noise code were toreplace a pure noise code.

space peak frequency to better than 200 MHz, information which is needed for the bandlimited and absolute time domain measurements. Therefore, measurements of the UWB emission spectrum and 10 dB bandwidths should be made at 1 meter in a fully anechoic chamber.

8) If an accurate Effective Isothropic Radiated Power (EIRP) measurement is required, measurements should be done in a fully anechoic chamber to eliminate any ambient signals or reflection components.

9) Based on calculations and test results obtained using TDC's suggested measurement technique, TDC believes that the NPRM absolute peak limit can be met without adversely affecting the deployment of the UWB devices. However, TDC still contends that the absolute peak limit has not been shown to correlate with receiver interference.

10) If the absolute peak is to be measured, then antenna factors have to be provided at closely spaced frequencies with phase information in order to calculate the E-field peak accurately.

11) If the FCC decides to use a time domain technique to verify compliance with the 50 MHz limit, the FCC must also specify a standard filter. Different filters yield different filter peak output voltage levels for the same forcing function. TDC recommends a tunable octave bandpass filter with linear phase within the passband and a normalized peak constant of 0.45 for this purpose.

12) The 50 MHz time domain measurement test setup must be calibrated using an impulse source. The calibration will yield a correction factor that, when applied to the measured filter output peak voltage, will result in the true peak amplitude. There exception: if all components have linear phase characteristics, then the test setup insertion loss or gain with respect to the filter center frequency may be used as a substitute for the correction factor. Measurements have shown that the difference between the impulse correction factor and the insertion loss or gain factor is about 0.5 dB when the phase is linear throughout the test setup.

13) Measurement and calculation of the absolute peak electric field level require an accurate characterization of both forward transmission magnitude and phase of all test setup components, including the antenna, preamp, and filter. If the phase contribution of all components is linear, then reconstruction of the pulse waveform is computationally easier due to elimination of phase distortion. If the test setup phase is linear in the frequency domain, then the time domain equivalent is simply total pulse delay with no distortion. The forward transmission magnitude affects still have to be accounted.

14) The video filter may only be used to perform averaging if the PRF of the UWB source is greater than the spectrum analyzer RBW. If the PRF of the UWB source is less than the RBW, then display averaging or a true average detector must be used with the VBW set to its highest level and, as a minimum, should not be lower than the RBW.

2 Test Results Update

Since filing its reply comments on October 27, 2000, TDC has continued to investigate and refine its UWB intentional radiated emission measurement procedures. TDC has placed heavy emphasis on comparing the measurements with empirical mathematical predictions. Comparison with predictions allow the identification and explanation of unexpected test results and verifies and refines the measurement process. Radiated emission testing has been performed at an OATS as well as in a semi anechoic chamber in order to reveal the strength and weaknesses of both test sites. Both frequency and time domain measurements were performed and compared to the FCC limits proposed in the NPRM. All band limited time domain measurements were performed with a fixed 50 MHz Bessel bandpass filter instead of the tunable filter that TDC planned to use because a tunable bandpass filter has not yet been delivered. The results obtained using a fixed filter can be extended to a tunable filter and will be implemented in the measurement procedure, which will be discussed later in this document. Pictures of the different radiated emission test setups are shown in Figures 1 through 4.

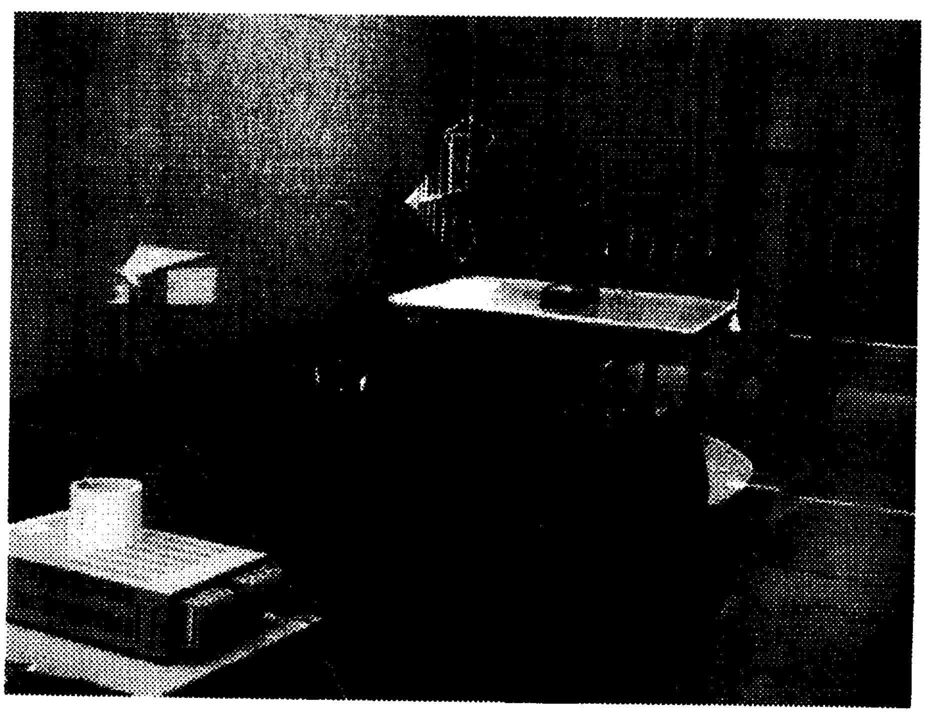


Figure 1. OATS Ground Plane Reflection Experiment

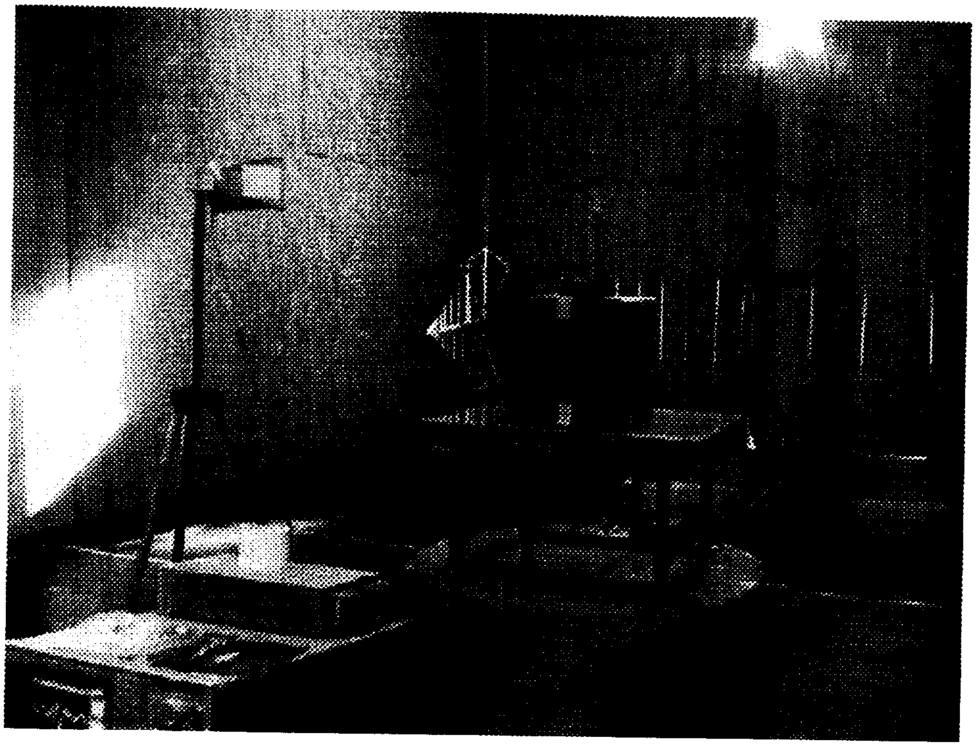


Figure 2. OATS 2m Antenna Height Experiment

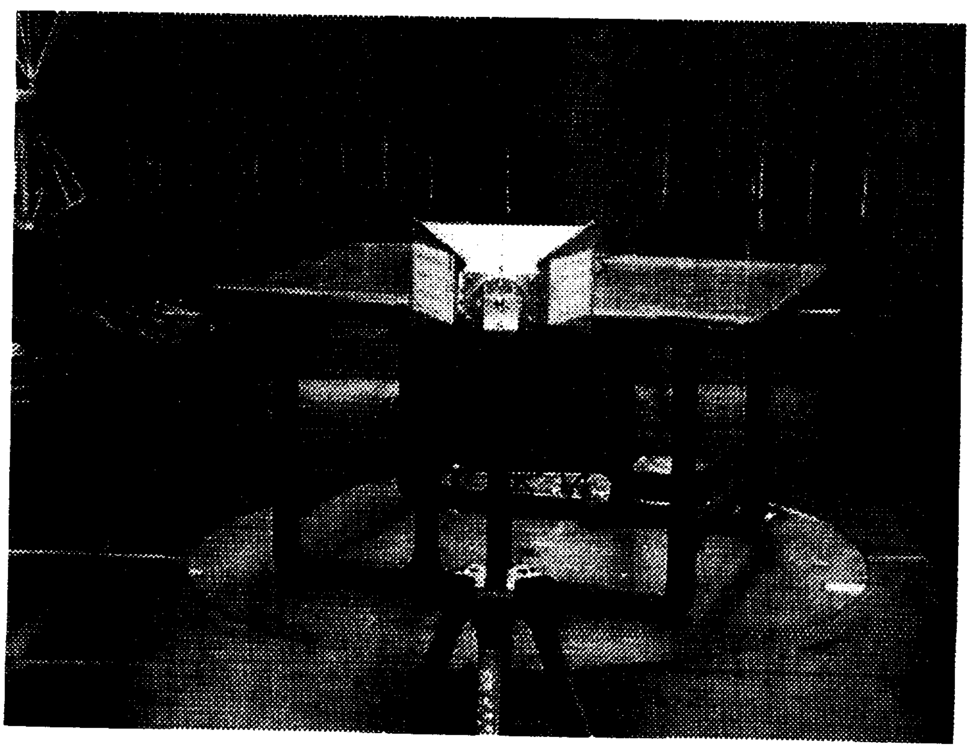


Figure 3. OATS Maximum Intentional Emission Orientation

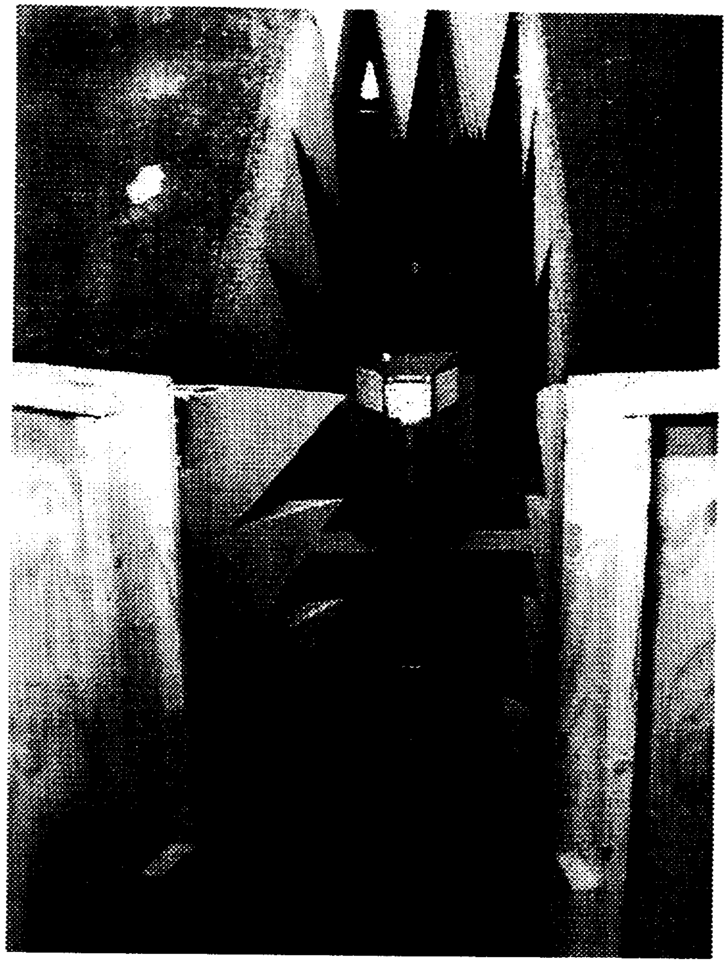
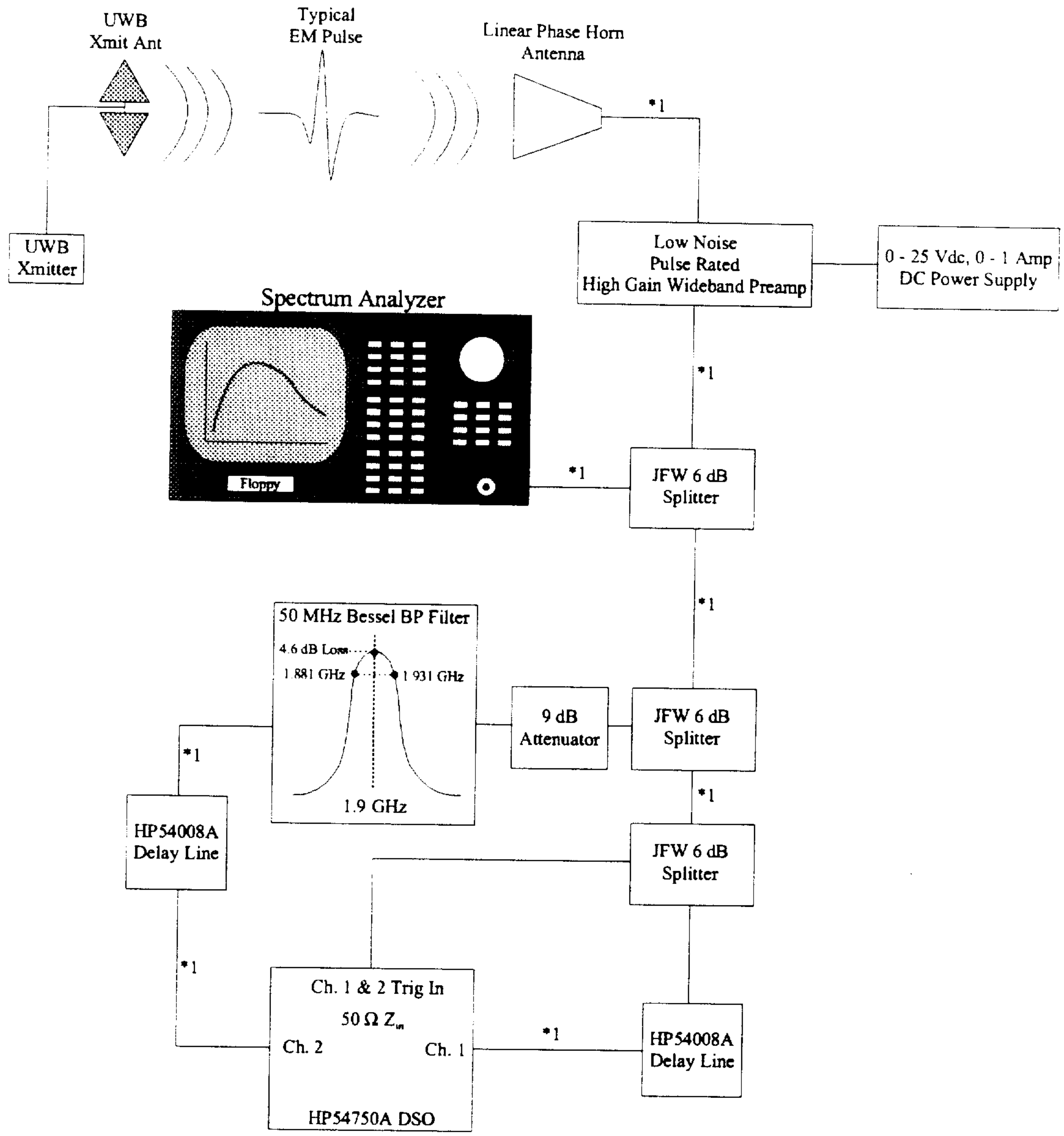


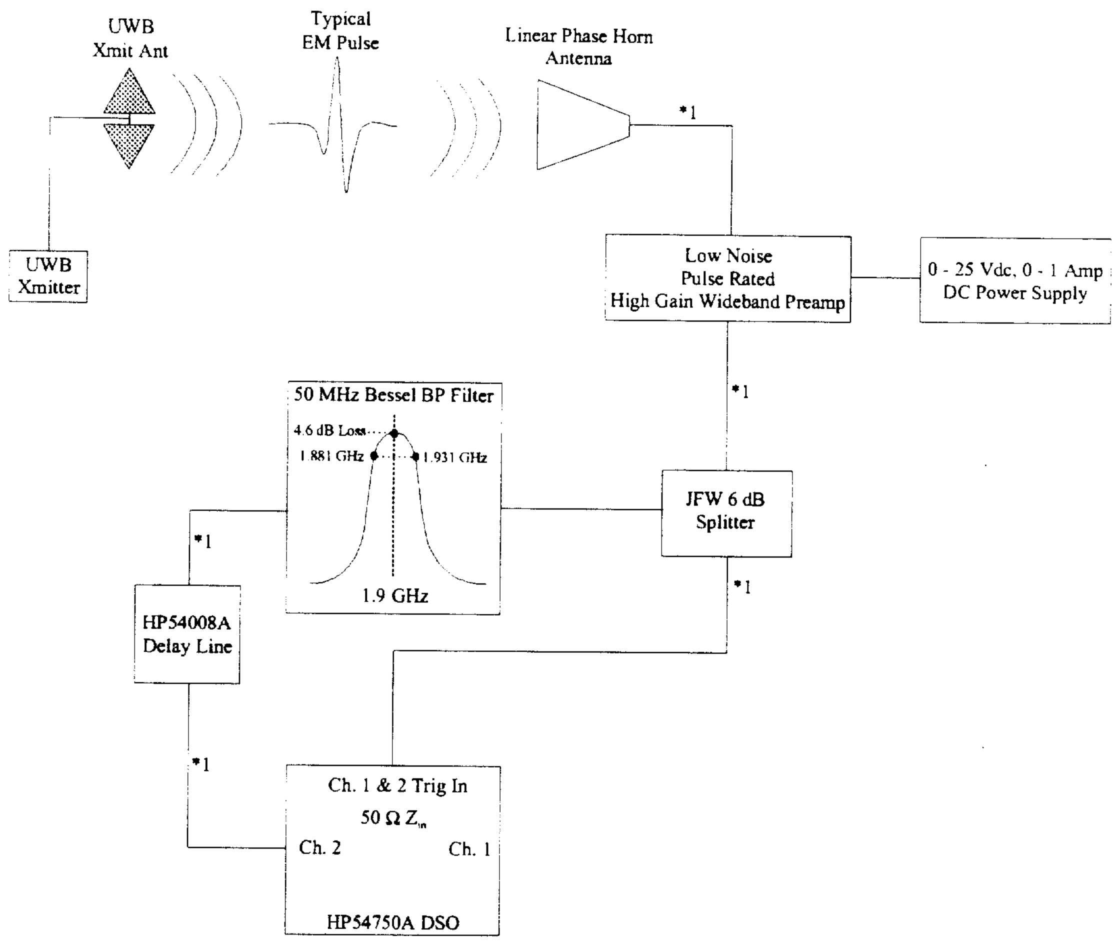
Figure 4. Semi Anechoic Chamber 2m Antenna Height Experiment

Measurements were performed at antenna heights of 1.2 and 2 meters, as well as at distances of 1 and 3 meters, in order to understand the impact of reflections on both the frequency and time domain measurement results. In some instances anechoic material was placed on the ground plane between the transmitting and receiving antenna to minimize reflections. Drawings of the test setups utilized during the measurement study are shown in Figures 5 through 7. The same setups were used for both the OATS and semi anechoic chamber measurements in order to remove setup variations from the test results. Analysis of the test data leads to some predictable and not so predictable conclusions that should help the FCC evaluate measurement issues as well as UWB emission limits.



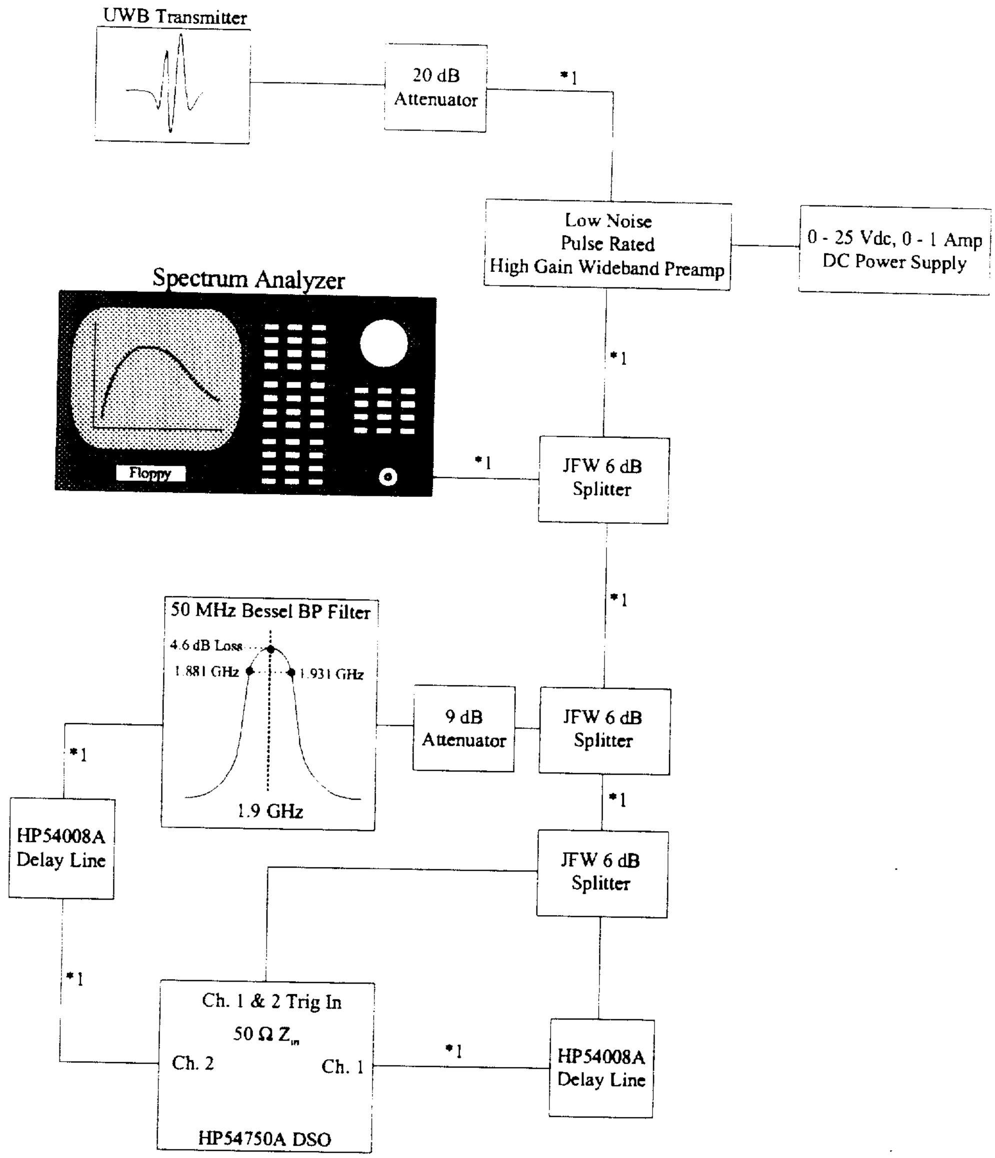
Notes:
*1) Low Loss Cable
*2) All components must be accurately characterized with a network analyzer to determine S_{21}, S_{11}, phase delay, antenna factor, and preamp gain all versus frequency.

Figure 5. Combined Time and Frequency Domain Radiated Emission Test Setup



Notes:
*1) Low Loss Cable
*2) All components must be accurately characterized with a network analyzer to determine S_{21}, S_{11}, phase delay, antenna factor, and preamp gain all versus frequency.

Figure 6. Alternate 50 MHz Impulse Response Test Setup



Notes:
*1) Low Loss Cable
*2) All components must be accurately characterized with a network analyzer to determine S_{21}, S_{11}, phase delay, antenna factor, and preamp gain all versus frequency.

Figure 7. Impulse Calibration Test Setup

2.1 Frequency Domain Emissions

Intentional radiated emissions of an UWB transmitter were measured in the frequency domain at an OATS and in a semi anechoic chamber using the test setup shown in Figure 5. The full spectrum as well as the peak of emissions was measured for each antenna height and test distance. In order to determine how the radiated environment might change, a mathematical prediction of the UWB emissions is provided on each spectrum plot. All displayed frequency domain emissions are average as defined by ANSI C63.4 and were measured using the spectrum analyzer peak detector, 1 MHz RBW and a 1 kHz VBW. It was found during the testing at the OATS that maximum emissions at an antenna height of 1.2 meters was 15 degrees clockwise relative to the transmitting antenna free space maximum gain azimuth, as shown in Figure 3. At an antenna height of 2 meters the maximum emission orientation was zero degrees clockwise relative to the transmitting antenna free space maximum gain azimuth, as shown in Figure 2. All measurements in the semi anechoic chamber used the same maximum orientation for each antenna height as determined at the OATS measurements. Results of the semi anechoic chamber UWB radiated emission measurements are shown in Figure 8. Correlation between the predicted free space emissions and the 1 and 3-meter measurements was quite good with the best correlation occurring at a 1 meter test distance. The main difference between the 1 and 3 meter UWB emissions was caused by the ground plane reflection component, which is also true of the OATS radiated emission measurements shown in Figures 9 through 11. As shown in Figures 8 through 10, the true free space maximum average level and frequency spectrum can only be measured at a 1 meter test distance; preferably in a semi anechoic chamber in order eliminate ambient signal masking affects. At one meter, the difference in emissions levels between the 1m and 2m antenna heights is negligible because the majority of incident electric field is due to the direct path with very little reflection. Measurement of the UWB radiating electric field at 3m in both a semi anechoic chamber and an OATS leads to an inaccurate representation of the free space maximum average level and peak frequency as shown in Figure 12, because the sum of the direct path and reflected paths signals creates an interference pattern.

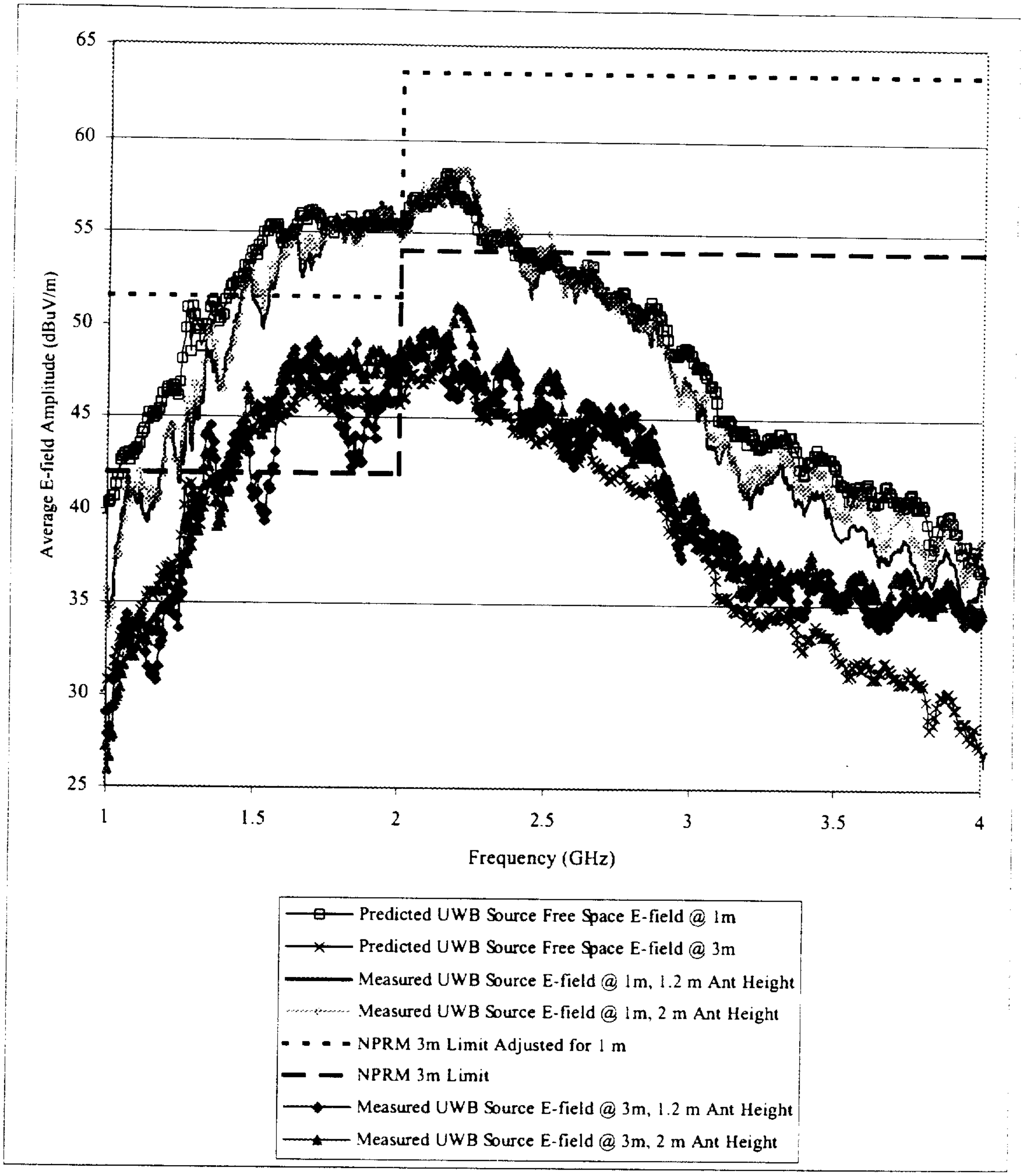


Figure 8. Semi Anechoic Chamber UWB Radiated Emissions

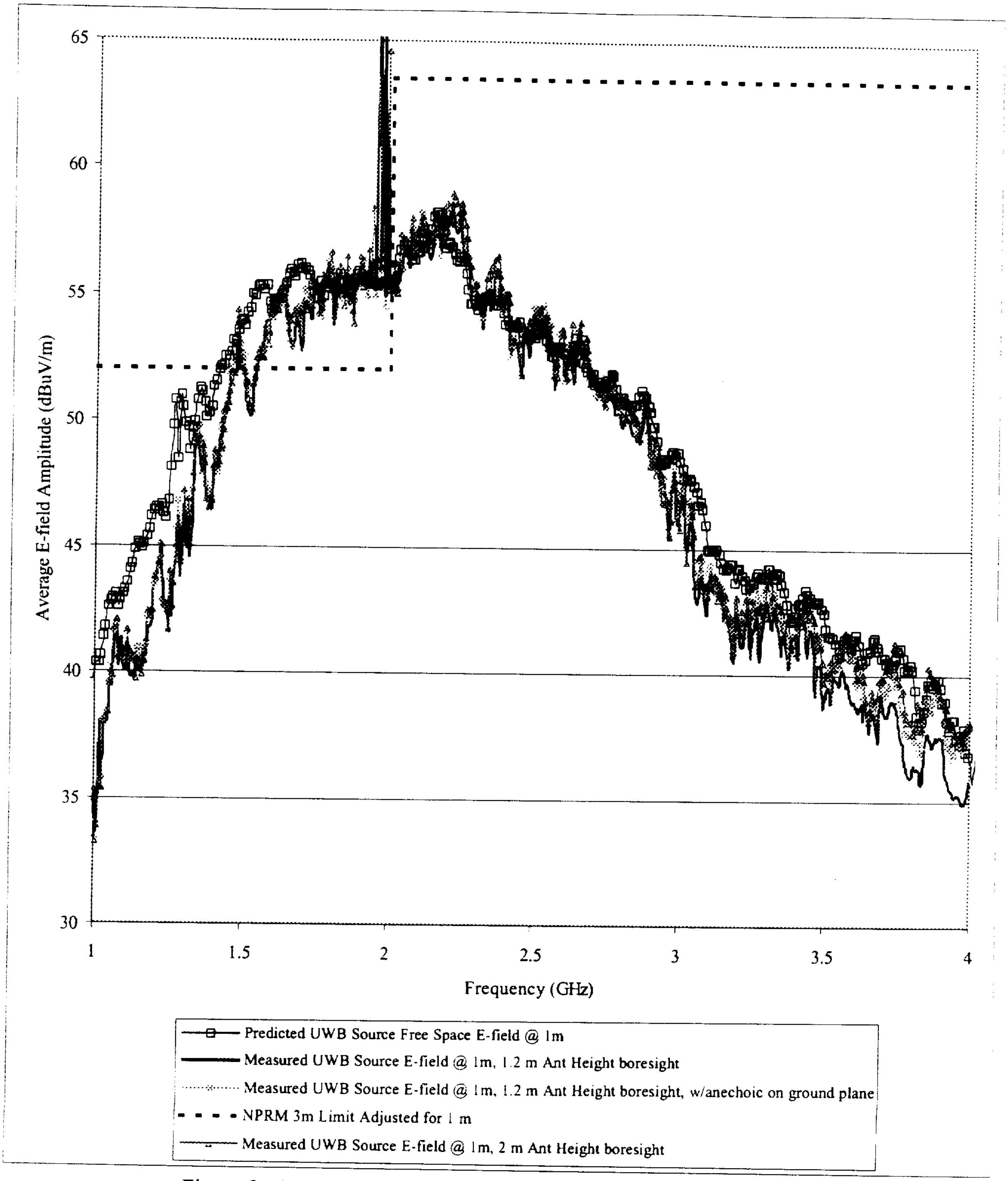


Figure 9. 1m OATS UWB Radiated Emissions

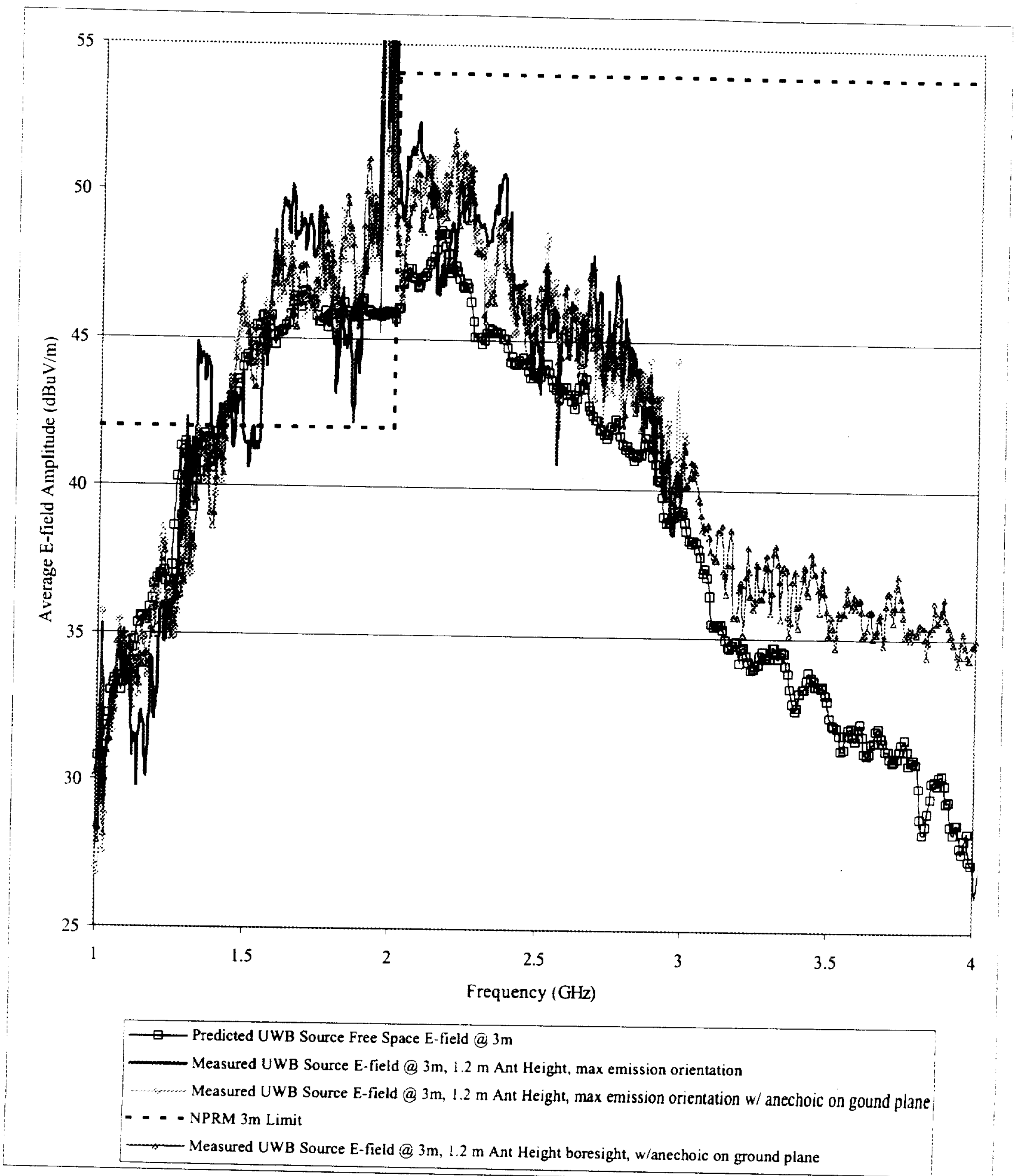


Figure 10. 3m OATS UWB Radiated Emissions, 1.2m Antenna Height

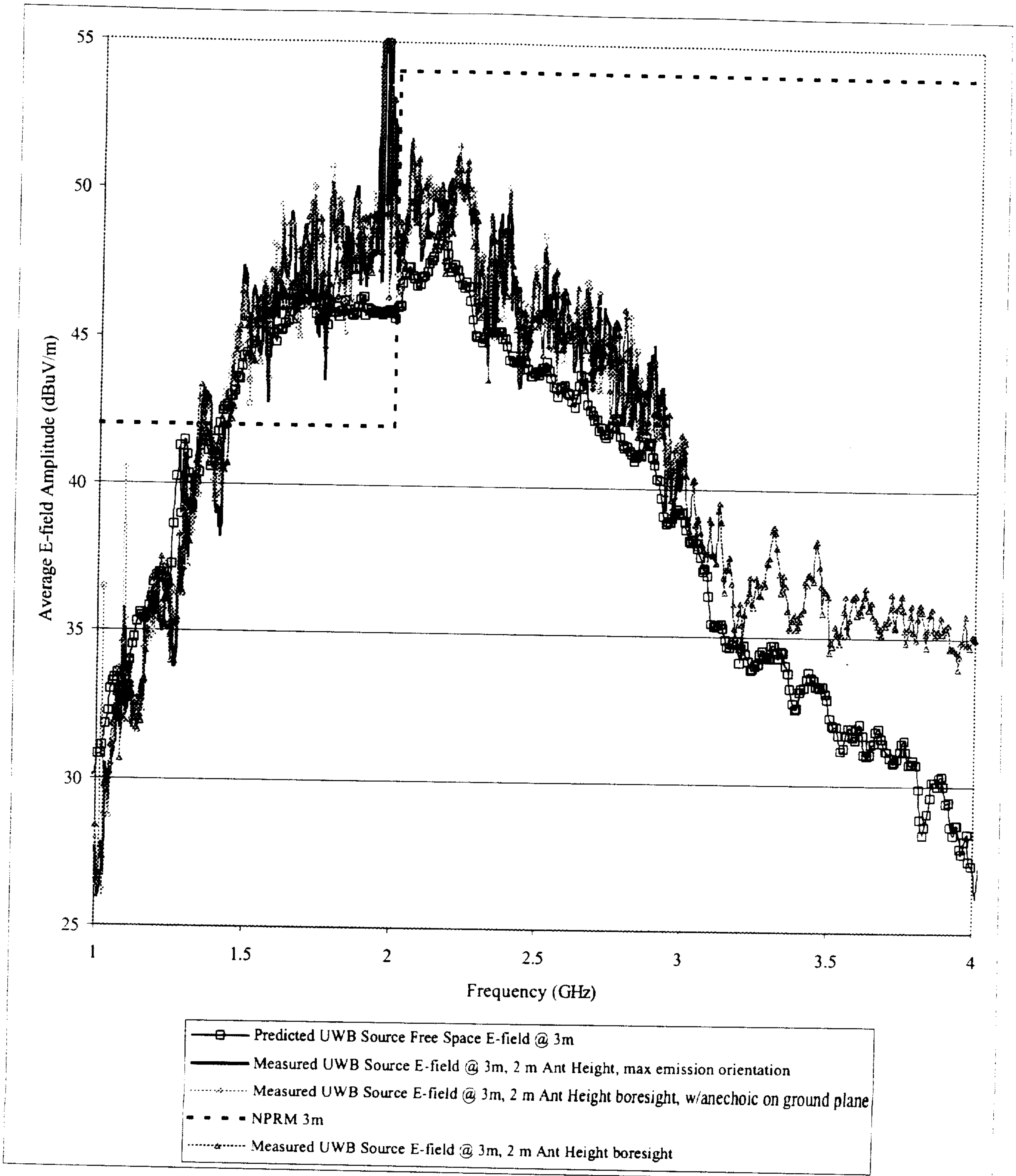


Figure 11. 3m OATS UWB Radiated Emissions, 2m Antenna Height

Measurements at 3m will most likely indicate an incorrect peak frequency, which will also lead to an incorrect assessment of the UWB 10 dB bandwidth because of the spectral shaping (interface pattern) created by reflections. Since the allowable absolute peak limit is based on the 10 dB bandwidth, an incorrect absolute peak limit will be calculated. As discussed; in the TDC reply comments of October 30, 2000, measurements at a 3m distance limit the minimum signal that can accurately be measured due to signal-to-noise issues. In order to make high fidelity measurements, TDC used a preamp with a 2.2 dB noise figure and 30 dB of gain, and a spectrum analyzer that has a noise figure that is 8 dB better than many commonly used spectrum analyzers. Even then, the high frequency 10 dB bandwidth point was located in the noise floor as can be seen in Figures 8, 13 and 14.

If an Effective Isothropic Radiated Power (E.I.R.P.) measurement is required, then measurements in a fully anechoic chamber would be the most accurate method to characterize the UWB free space radiated power.

All measurements were performed with an EMCO 3115 horn antenna with antenna factors as shown in Table I.

Table I. Antenna Factors
EMCO 3115 / SN: 9501-4401

Freq. (GHz)	1m (dB)	3m (dB)	(3m - 1m) dB
1.0	24.2	25.9	-1.7
1.5	25.5	27.0	-1.5
2.0	27.8	29.2	-1.4
2.5	29.0	30.7	-1.7
3.0	30.5	32.3	-1.8
3.5	31.9	33.5	-1.6
4.0	33.2	34.7	-1.5
4.5	32.9	34.4	-1.5
5.0	34.1	35.6	-1.5
5.5	34.8	36.4	-1.6
6.0	35.2	36.5	-1.3
6.5	35.4	36.5	-1.1
7.0	36.5	37.4	-0.9
7.5	37.4	38.5	-1.1
8.0	37.7	39.0	-1.3
8.5	38.1	39.3	-1.2
9.0	38.5	39.7	-1.2
9.5	38.0	40.2	-2.2
10.0	38.8	40.5	-1.7

TDC suspects that the 1m antenna factors are in error due to the difference between the 1m frequency domain electric field prediction and the measured, especially below 1.5 GHz and above 3 GHz, as seen in Figures 8 and 9. If the delta was only encountered in the frequency domain measurements, then TDC would not question the 1m factors, however a similar result was found in the time domain measurements as well, which indicates a discrepancy in the 1m antenna factors.

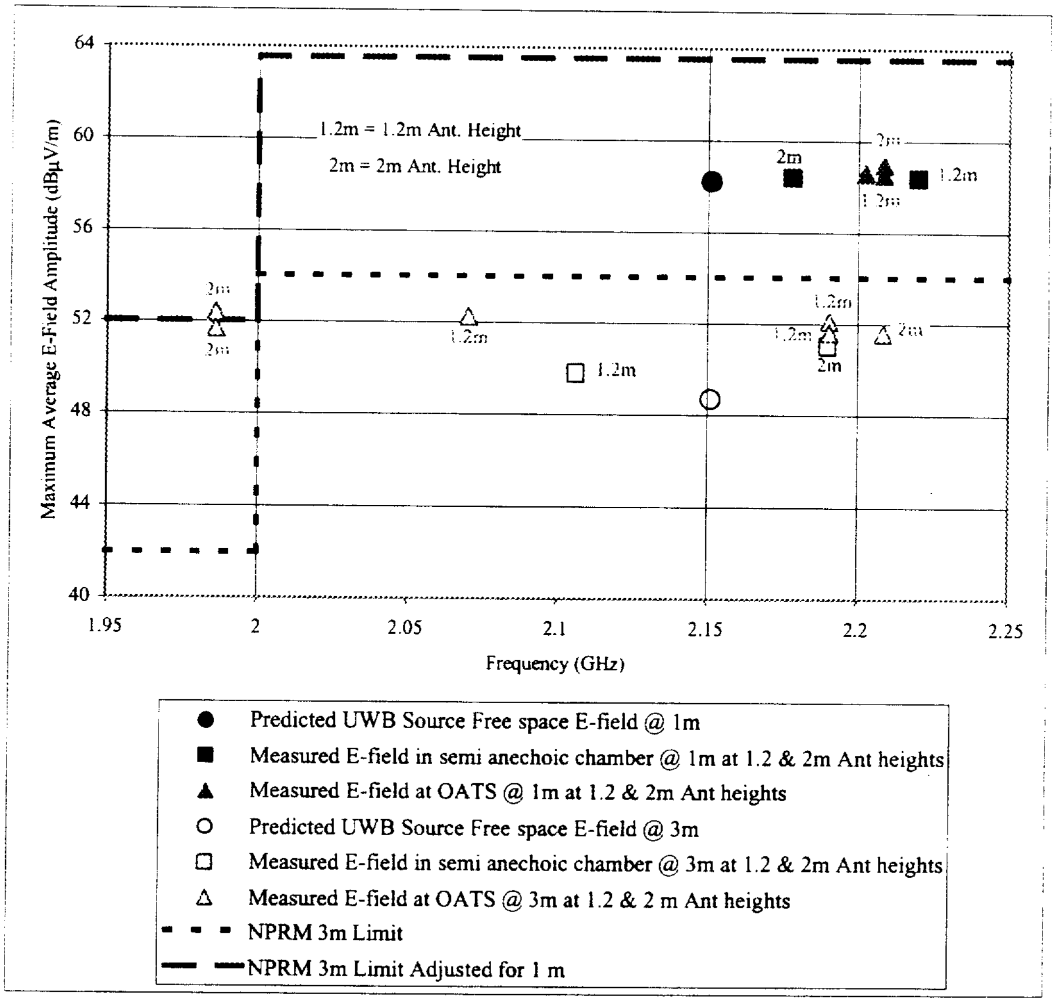


Figure 12. Comparison of Maximum Average Emission Level Measurements

2.2 *Time Domain Emissions*

TDC has developed a simple method for measuring the equivalent peak pulse electric field in a 50 MHz bandwidth and in the pulse spectrum 10 dB bandwidth. The NPRM has suggested a 50 MHz limit as 20 dB above the average electric field strength limit and the absolute peak electric field strength limit is given by equation 1.

$$\text{Average Limit (dB}\mu\text{V/m)} + \left[20dB + 20Log_{10}\left[\frac{BW_{-10dB}(Hz)}{50\cdot 10^{6}(Hz)}\right] \leq 60dB \right] \qquad \text{Eq. 1}$$

The proposed 3m 50 MHz limit is 74 dBμV/m and the 3m absolute peak limit for the UWB source that TDC used during testing is 106 dBμV/m. Since 1m tests were also performed, TDC adjusted the 3m limits for 1m by adding 9.54 dB to each 3m limit, obtaining 83.54 and 115.54 dBμV/m @1m 50μHz and absolute limits.

TDC has performed extensive testing to develop a method for measuring peak pulse time domain emissions from UWB sources. The NPRM suggested both frequency and time domain methods for verifying compliance with the proposed limits. TDC has concentrated on the time domain technique because of simplicity, repeatability, and correlation with analytical predictions. The time domain technique can also identify the average PRF of a UWB system using random time modulation. This is important if the FCC limits are given in terms of PRF. A spectrum analyzer method cannot easily determine the PRF of an UWB emission with random time modulation. The reason the PRF is important is because it determines how the front end of a receiver with a given bandwidth responds to a series of pulses.

The test setups that TDC used to evaluate the UWB time domain emissions are shown in Figures 5 and 6. The impulse calibration test setup is shown in Figure 7. Time domain emissions were measured at an OATS and semi anechoic chamber in order to determine any propagation and ambient issues related to both test sites. The results of the testing also aided TDC in determining the final test setups and procedures that will be covered later in this document. Photographs of the test setups are shown in Figures 1 through 4.

2.2.1 50 MHz Pulse Electric Field Measurements

TDC used two different test setups to measure the impulse response of a fixed 50 MHz Bessel bandpass filter. TDC was planning on performing limited testing with a tunable bandpass filter, but the filter could not be delivered in time. All test results obtained from the fixed filter testing are applicable to the tunable filter method. The tunable filter is an integral part of the measurement technique that TDC is suggesting that the FCC adopt for UWB emission measurements and will be covered in the test procedure section of this document.

Measurements were made at 1 and 3m test distances as well as 1.2 and 2m antenna heights at an OATS and in a semi anechoic chamber. The method of validating the filter's impulse response output peak voltage measurement was to compute the peak voltage based on the time domain electric field waveform at the receiving antenna aperture in conjunction with Equation 2 below.

$$V_{PkBW} = V_{PkNormalized} \cdot 2 \cdot \pi \cdot BW_{-3dB} \cdot Pulse_{Area} \cdot Spectrum_{Pk\_PSD\_corr} \qquad \text{Eq. 2}$$

where:

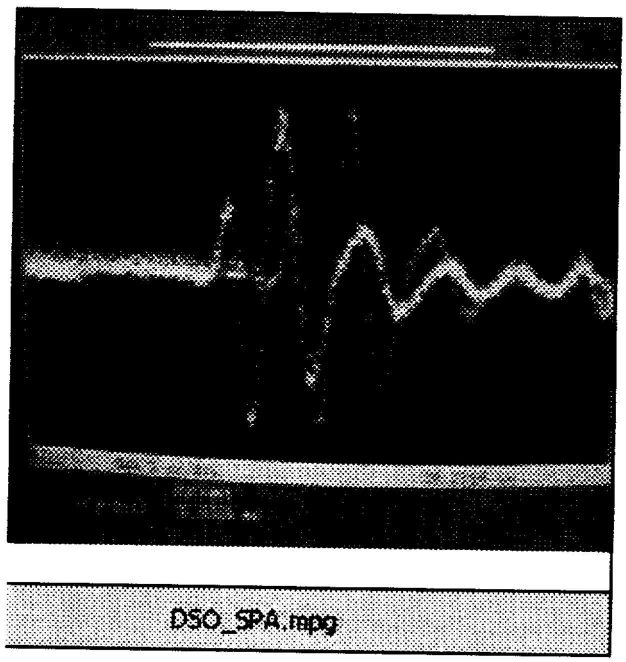
$V_{PkNormalized}$ = Peak value of the normalized low pass filter impulse response. The normalized curves are based on the filter type such as Bessel, synchronously tuned, Elliptic, etc. This term can be determined through calibration if normalized curves are not readily available. This term is dimensionless.

BW_{-3dB} = Filter 3dB bandwidth in (Hz).

$Pulse_{Area}$ = Leading edge impulse area, for each leading edge in (Volt seconds).

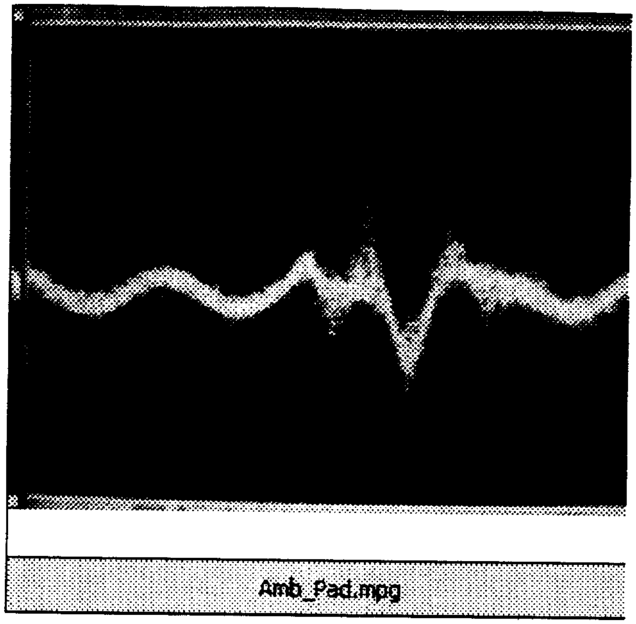
$Spectrum_{Pk\_PSD\_corr}$ = Ratio of the impulse spectrum peak amplitude to the frequency component amplitude of the impulse at the center frequency of the band pass filter. This term is dimensionless.

The initial measurement test setup is shown in Figure 5. This setup was intended to provide a means for measuring both frequency and time domain data. However some interesting measurement issues surfaced that required changes to the combined setup. The setup changes shown in Figure 6 increased the signal level and isolated the filter driving pulse from the spectrum analyzer input mixer port isolation. There are many Local Oscillator (LO) and mixer products that are fed back into the input port of the spectrum analyzer that normally do not cause any corruption of the stimulus device output signal. However, when a DSO is connected through a splitter to the spectrum analyzer input, those same mixer products corrupt the DSO measurement of the filter input waveform as seen in the Videos 1, 2 and 3[3].



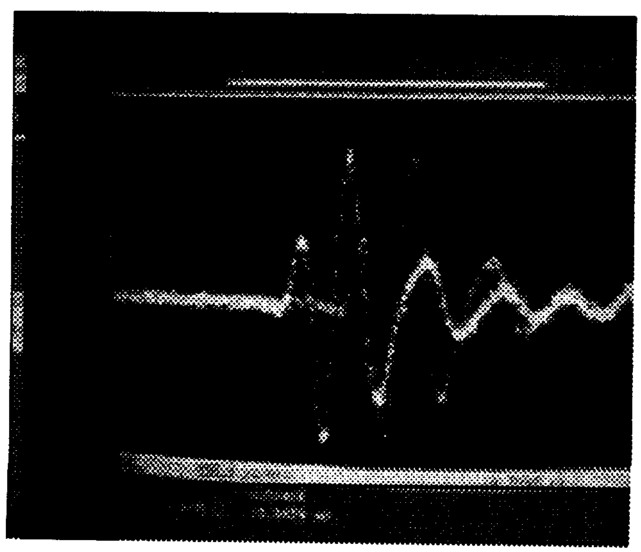
Video 1. The impact of mixer products from the spectrum analyzer leaking into the input of a digital sampling oscilloscope. Measurement range was 1 meter. (Double click the images and the videos will play.)

[3] Since the FCC's Electronic Comment Filing System does not allow electronic filing of video files, TDC has placed a file containing this document and the video files on its web site: http://www.timedomain.com/fcc/uwbemissions.zip.



Video 2. The impact of mixer products from the spectrum analyzer leaking into the input of a digital sampling oscilloscope. Measurement range was 3 meters. The impact is more dramatic than with the 1 meter measurement because the signal level is 9.5 dB lower. (Double click the images and the videos will play.).

Video 3 shows when the spectrum analyzer is not connected, then the correct response is obtained.



Video 3. The time domain response when measured without being corrupted by the spectrum analyzer's mixer products. (Double click the images and the videos will play.)

The noise floor of the DSO is much worse than the spectrum analyzer's, and it also suffers from sampling induced distortion of low-level signals because of the analog to digital conversion process. This is illustrated in Figures 13 and 14, which are measurements of the filter output voltage using the combined test setup shown in Figure 5 at 3m.

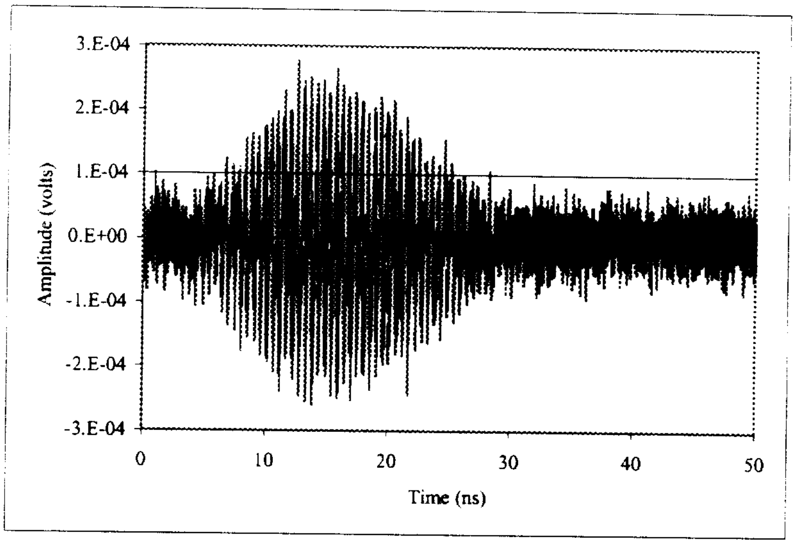


Figure 13. Combined Test Setup 3m Filter Response Measurement

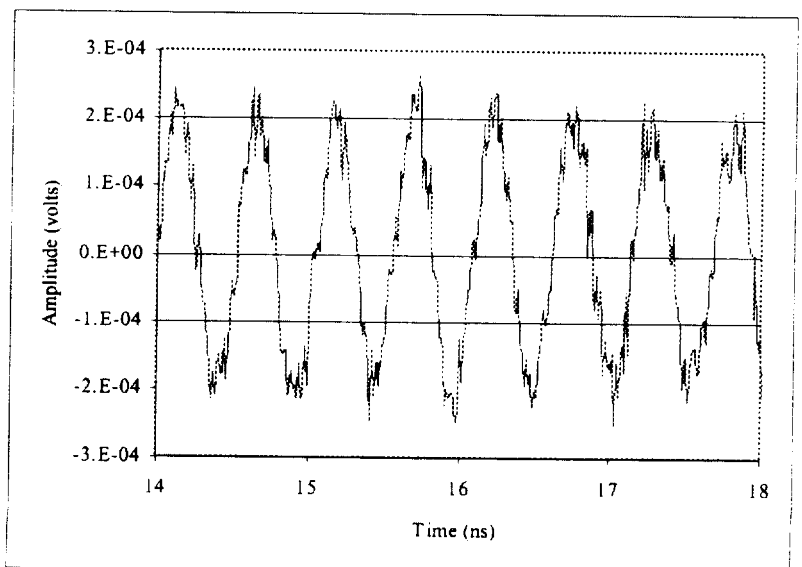


Figure 14. Combined Test Setup Expanded Filter Impulse Response

As can be seen from Figure 13, the filter output signal is about 8 dB above the DSO noise floor so the DSO measurement should be fairly accurate. A closer inspection of the filter output voltage shown in Figure 14 reveals a significant amount of distortion that affects the measurement accuracy and hence skews the prediction versus measurement comparison. The same 3m filter output voltage measurements were made using the alternate test setup of Figure 6, and are shown in Figures 15 and 16. The signal distortion has dramatically been reduced as shown in Figure 16, and noise and sampling spikes are not occurring in Figure 15 as they were in Figure 13. Because of the increase in the measured signal fidelity that the alternate setup yields, TDC does not recommend a combined test setup (as shown in Figure 5), but advocates a separate frequency domain and time domain setup.

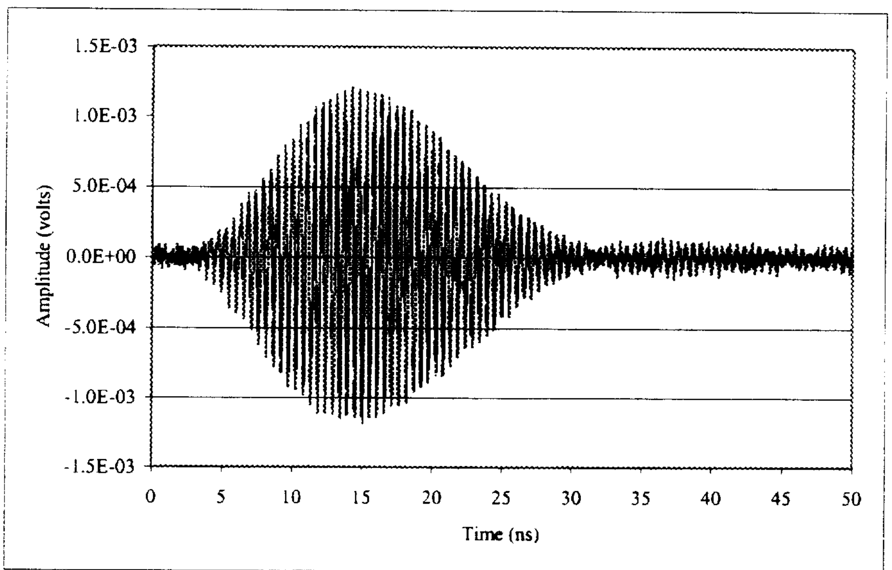


Figure 15. Alternate Test Setup 3m Filter Response Measurement

The filter peak output voltage is predicted using the time domain electric field waveform present at the receiving antenna aperture. The electric field waveform is calculated using various test setup parameters, one of which is the antenna factors. If the antenna factors are in error, then the predicted filter output peak voltage will also be in error. It was previously mentioned that TDC suspected the EMCO 3115 1m antenna factors due to some inconsistencies between the predicted and measured E-field spectrum. Similar inconsistencies were found between the predicted and measured time domain E-field waveform, as shown in Figures 17, 18 and 19.

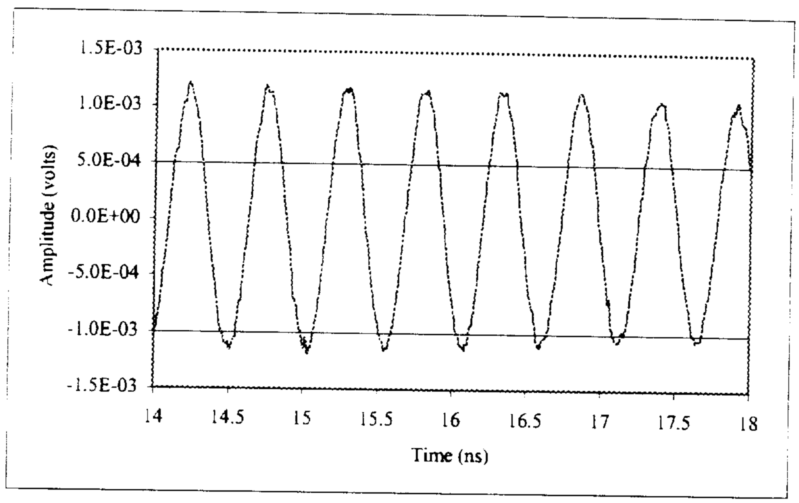


Figure 16. Alternate Test Setup Expanded Filter Impulse Response

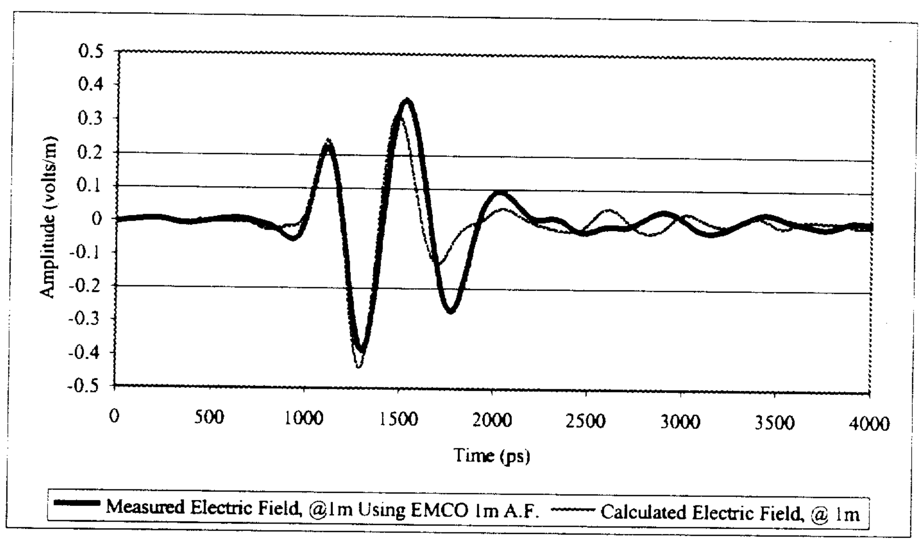


Figure 17. 1m Electric Field Comparison w/ EMCO 1m A.F.

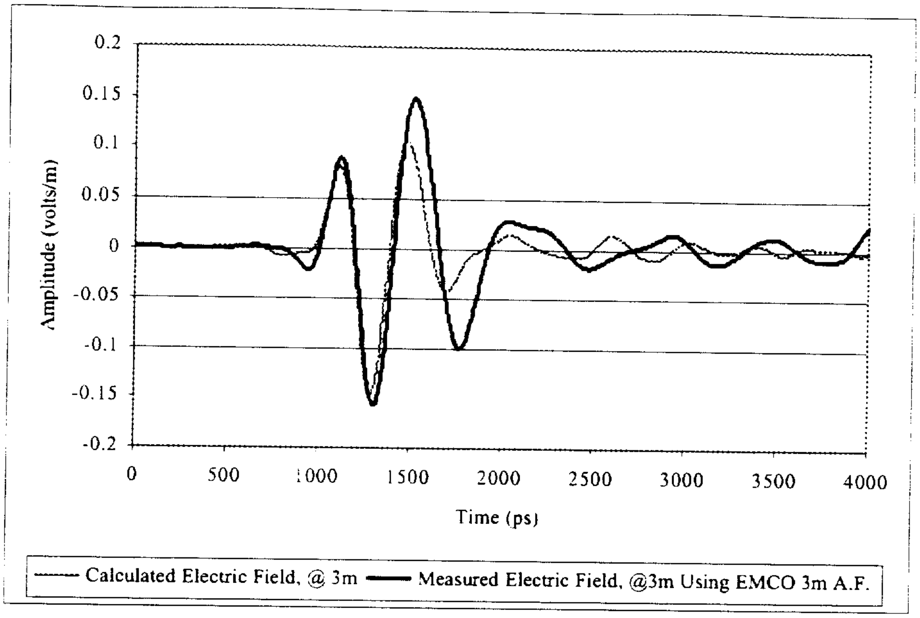


Figure 18. 3m Electric Field Comparison w/ EMCO 3m A.F.

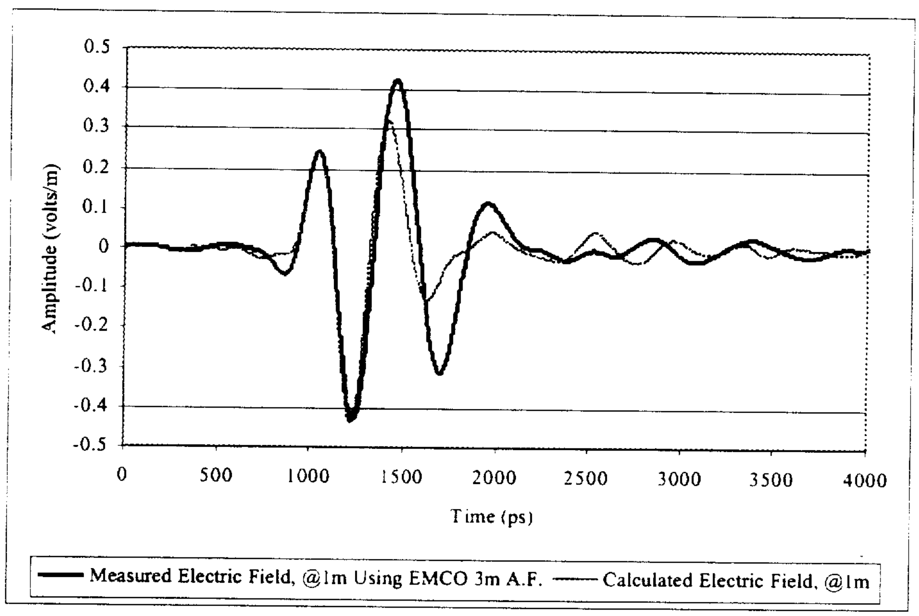


Figure 19. 1m Electric Field Comparison w/EMCO 3m A.F.

The uncertainty in most antenna factors is on the order of plus or minus 2 dB, so some of the delta between the predicted and measured can be attributed to the antenna calibration uncertainty. If antenna measurements at both 1m and 3m are in the far field, then the difference between the 1m and 3m amplitude measurements should follow a linear trend of 3 to 1. The measured antenna terminal voltage at both 1 and 3 meters followed the 3 to 1 trend very closely, however, the computed E-field, using the EMCO 3115 antenna factors, indicated a 2.4 to 1 change, which is -1.9 dB lower than the antenna terminal voltage ratio. TDC calculated what the radiated electric field strength waveform should be at 1m and 3m and compared the calculated levels to those measured using the EMCO antenna factors. Figures 16 and 17 show a comparison between the 1m and 3m calculated electric field waveforms relative to the waveforms measured using the EMCO 1m and 3m antenna factors. TDC also compared the calculated E-field at 1m to that measured using the EMCO 3m antenna factors at 1m and the comparison is shown in Figure 18. Comparing Figures 17 and 18 indicate the correct E-field ratio with respect to distance change TDC provides filter impulse response data for both the 1m case using 1m factors and. the 1m case using 3m factors (see Figure 21). TDC contends that since the filter impulse response peak voltage measurement follows the 3 to 1 ratio; the corresponding electric field levels must change at the same ratio; hence, the EMCO 1m antenna factors are probably in error, but within the uncertainty specified, ± 2 dB, by the calibration facility. This could also be caused by too coarse of a frequency increment in the antenna factors (they are 500 MHz apart). Some of TDC's measurements indicate that there are undulations in the antenna gain between the specified factors, which can lead to interpolation errors relative to the true antenna factor.

Finally, time domain emission measurements at an OATS yield incorrect readings of UWB 50 MHz and absolute peak levels because of ambient emissions. What would appear as a single spectral line in the frequency domain appears as a modulated sinewave in the time domain. In some severe cases, the ambient can completely mask the pulse waveform, as shown in Video 4. This video demonstrates the impact of a 2.4 GHz cordless telephone on the measurement. The cordless phone was chosen because many compliance sites and locations adjacent to the sites use them. Typical pulse distortion can be seen by comparing the same UWB pulse waveform measured at an OATS and in a semi anechoic chamber, as shown in Figure 20.

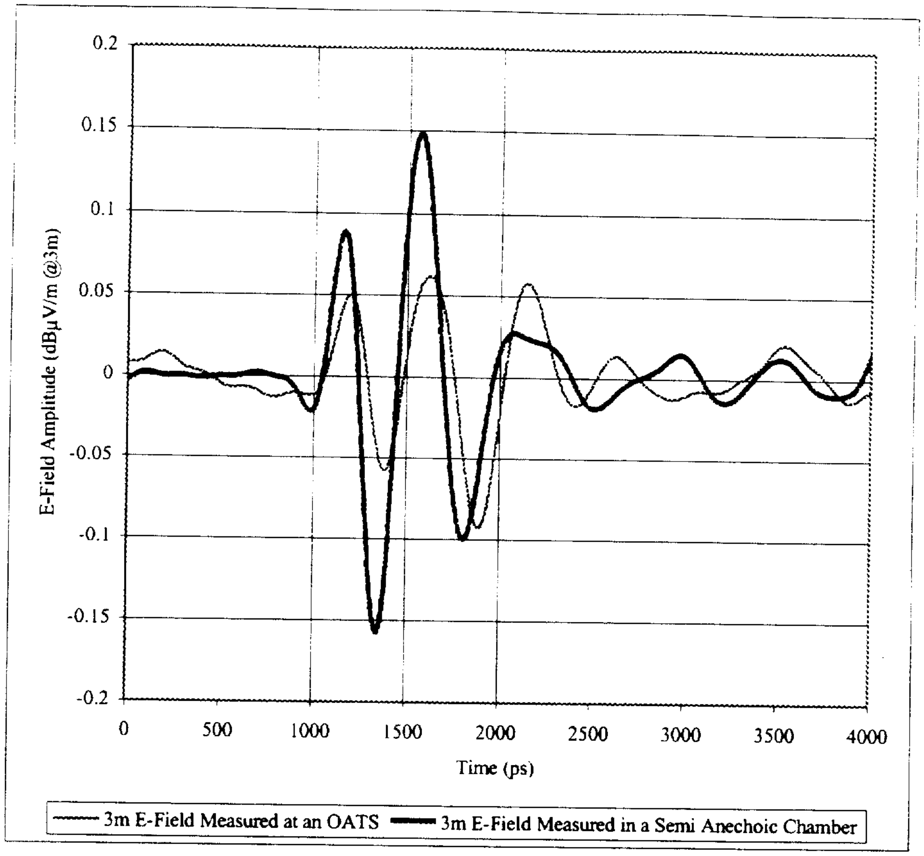
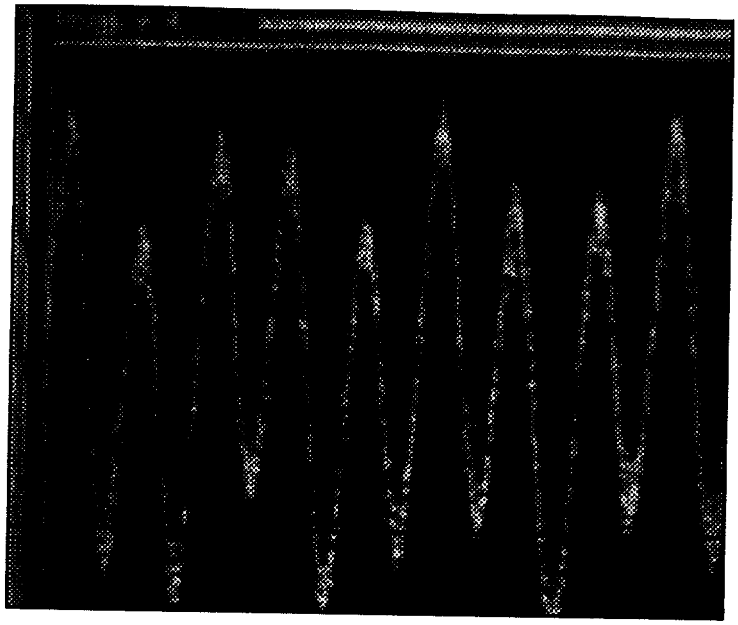


Figure 20. OATS vs. Chamber 3m UWB E-Field Measurement



Video 4. The impact of ambient sinusoidal signals on a time domain measurement.

2.2.1.1 50 MHz Test Results

The 50 MHz filter impulse response test data and their differences from predictions are shown in Figure 21 Since all of the test data (some reliable and some with anomalies) is displayed in Figure 21 a brief explanation of how to interpret the different data points follows:

1) Ignore all test data taken with the combined test setup since the combined test setup data has been shown to be noise distorted and erroneous, as discussed in section.

2) All predictions using the EMCO 1m antenna factors are suspect, as discussed in section 2.2.1.

3) Finally, all data taken at the OATS are suspect because of the ambient interference, as discussed in section 2.2.1.

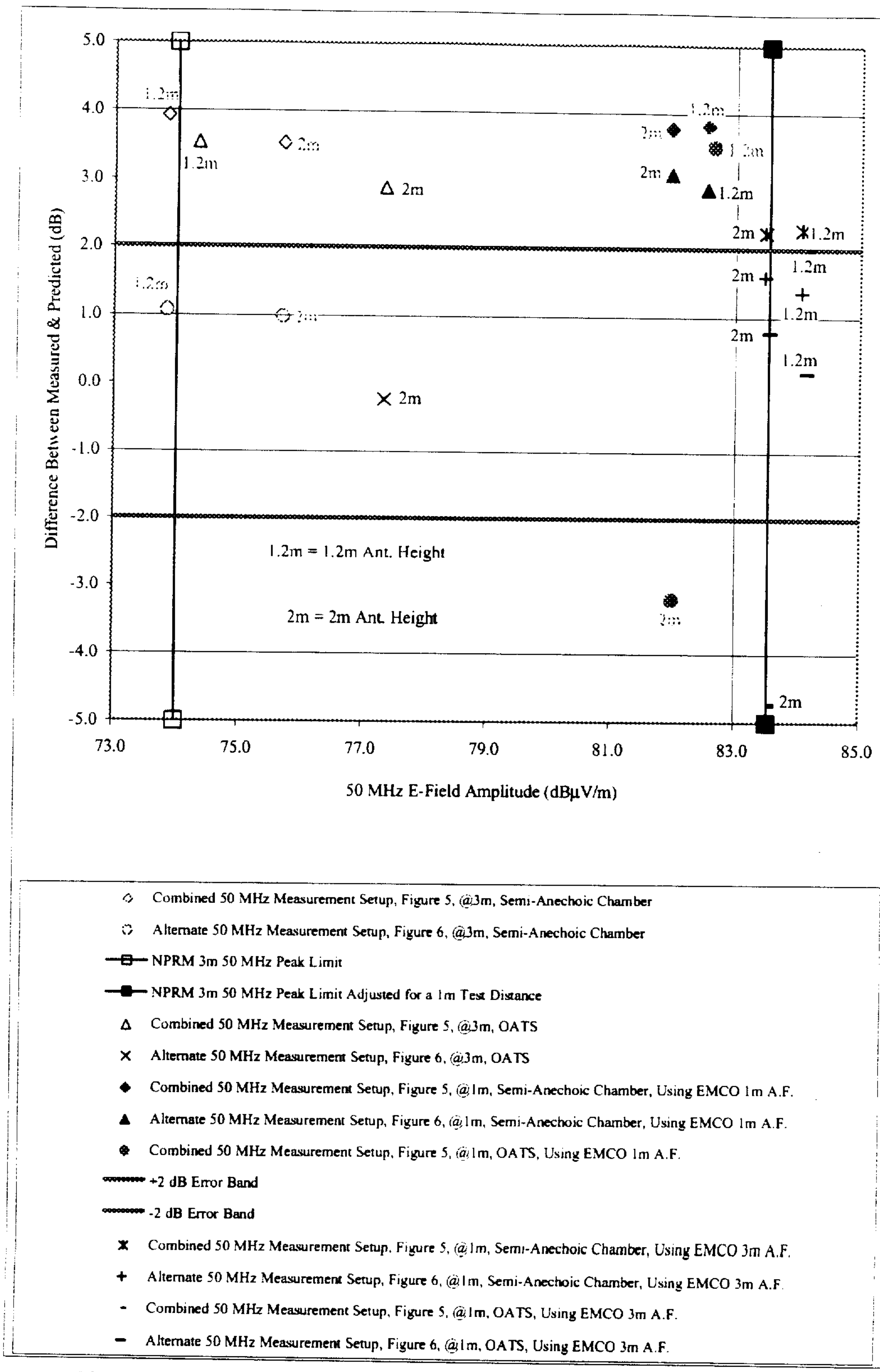


Figure 21. 50 MHz Electric Field Test Results

With these points in mind, TDC's 50 MHz predictions differ from measurements to within an error band of ±2 dB and from all data (reliable and anomalous) to within a +4 dB and −5 dB error band, as shown in Figure 20.

2.2.1.2 Impulse Calibration

To determine the 50 MHz peak voltage it was necessary to perform an impulse calibration on the measurement setup. Initially the impulse calibration was performed on the test setup (Figure 5) as shown in Figure 7. The correction factor determined by this impulse calibration technique was 21.8 dB. Thus, 21.8 dB was added to the DSO measurement to correct for all forward transmission magnitude and phase variations across the measured spectrum. Since (1) the phase characteristics of all test setup components were linear, including antenna and filter, and (2) the filter bandwidth was narrow with respect to the pulse spectrum, TDC decided to compare the correction factor with the setup insertion loss or gain at the filter center frequency. The difference between the test setup loss at the filter center frequency and the impulse correction factor was 0.56 dB, with the filter insertion loss being the greater of the two. With such a small deviation, TDC decided to use the insertion loss of each test setup, at the filter center frequency, as the impulse correction factor. The insertion loss method is easier to determine and requires very little computational capability, while the impulse calibration method requires a mathematical analyses software package.

2.2.2 Total Pulse Electric Field Measurements

In order to determine if a UWB device meets the NPRM absolute peak limit, the measurement test setup must be characterized across a bandwidth equal to or greater than the radiating pulse's 20 dB bandwidth. Characterization refers to measuring and documenting the loss or gain and phase of each test setup component with respect to frequency. This includes the measuring antenna such as a double-ridged guide horn, broadband dipole, or any other antenna that might be used as the electric field sensing element. Almost all antenna calibration facilities provide antenna factors of high frequency antennas at coarse increments of 500 MHz and do not usually provide any phase information. In order to accurately calculate the UWB absolute peak electric field level, antenna factors (magnitude and phase) should be supplied at small enough increments to minimize uncertainties between the points when an interpolation algorithm is used to determine the factors and phase between the points. A special case can eliminate the phase calculation if all components, including the antenna, contribute linear phase, which equates to a simple time delay of the pulse without distortion. All components in the TDC test setup were measured and selected for linear phase characteristics including the preamplifier and antenna. Reconstruction of the electric waveform present at the aperture of the antenna is simplified due to not having to address phase distortion in the mathematics. Without phase distortions, it is only necessary to account for attenuation or gain with respect to frequency. The time domain electric field waveform can be reconstructed using a mathematical analysis software or even a spreadsheet program. However, not every compliance lab has a mathematical analysis software package due to cost, and although one could use a spreadsheet program, it is very tedious because of the care needed to convert from the time domain to the frequency domain and back again, and to use high fidelity interpolation functions.

2.2.2.1 Absolute Peak Test Results

The absolute peak electric field test data and their variances from predictions are shown in Figure 22. The 1 and 3 meter free space UWB peak time domain electric field amplitudes were calculated to be 112.8 dBμV/m @1m and 103.3 dBμV/m @3m, and are shown in Figures 17 and 18. The proposed NPRM absolute peak limits for 1 and 3m are 115.54 and 106 dBμV/m respectively. All of the test data falls within a ± 2 dB prediction versus measurement error band except for two measurements performed at an OATS. The two data points are outside of the main grouping due to ambient signals and/or the connection to the spectrum analyzer shown in Figure 5.

Based on calculations and test results obtained using TDC's suggested measurement technique, TDC believes that the NPRM absolute peak limit can be met without adversely affecting the deployment of the UWB devices. However, TDC still contends that the absolute peak limit has not been shown to correlate with receiver interference.

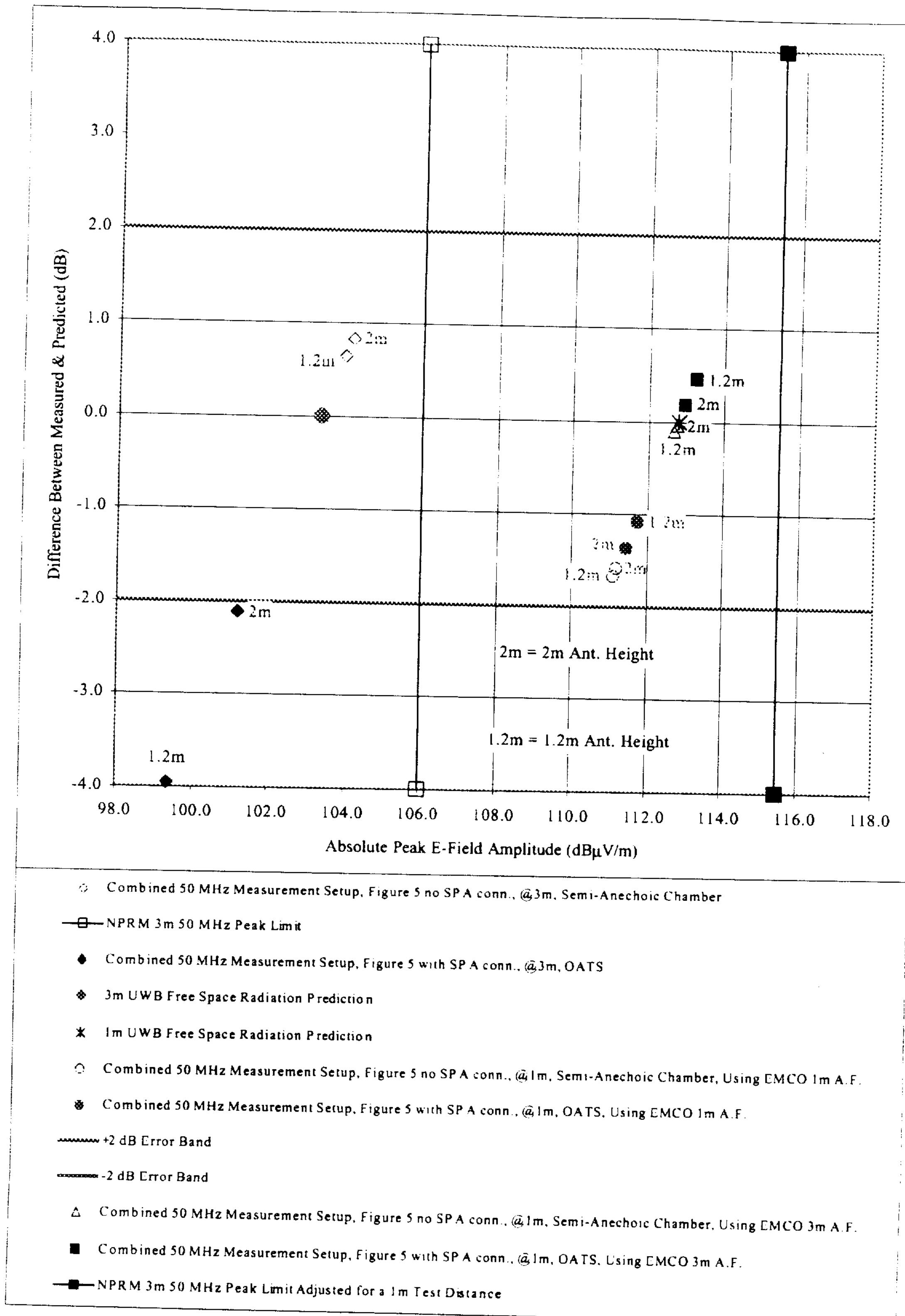


Figure 22. Absolute Peak Electric Field Test Results