3 UWB Intentional Radiated Emission Measurement Test Procedure

The purpose of the measurement study was to determine a test procedure that would yield predictable, accurate and repeatable test results. The test procedure and setup must be a balance between complexity and cost in order to reduce the burden to industry. Whatever method is chosen, a wideband microwave receiver or a DSO, the costs will be significant. A wideband microwave receiver will cost approximately $150K; a high frequency sampling scope approximately S75K; a tunable filter about S2.5K; and a pulse rated preamp about $1.5K. In order to characterize the test setup components, including the antenna, a network analyzer is required or access to a facility that can provide forward transmission magnitude and phase information of all test setup components. The following questions and answers explain some of the basic issues with test setup preparation.

3.1 Questions and Answers

1) What are the requirements of the radiated test setup impulse calibrator? Impulse calibration is only necessary for the 50 MHz electric field test. The impulse calibrator must have a PRF and pulse spectrum that encompasses the PRF and pulse spectrum of the UWB device to be tested. The pulse volt second ratings should be specified or calculated by measuring the pulse with a fast sampling DSO, and calculating the pulse edge area as well as the pulse frequency spectrum. A single polarity pulse is the easiest to measure and calculate the volt second rating and the frequency spectrum. The best calibrator would be the UWB device itself. If the antenna of the UWB device could be disconnected and the antenna output port connected to the radiated test setup, both the PRF and pulse spectrum requirements would be met. The manufacturer could supply the pulse characteristics or they could be measured at the test site.

If all of the test setup components (including the antenna and preamplifier) contribute linear phase, then an alternate to the impulse calibration would be to accurately measure the insertion loss or gain of the test setup at the filter center frequency. The value of loss or gain is the correction factor that would be applied to the DSO measured filter output peak voltage.

2) What type of filter should be used to determine the 50 MHz time domain peak limit? TDC used a Bessel filter because of the smooth linear phase within the pass band. A different filter type can be used however the normalized impulse response peak versus filter order must be specified or measured. Whatever filter type is required by the FCC, the 50 MHz limit must be given as a function of the filter type.

3) Is the equation that TDC used to predict the filter peak output voltage valid for all PRFs? The equation that TDC used to predict the filter peak output voltage is valid for PRFs less than the filter 3 dB bandwidth. In order to determine a set of equations for all conditions three regions must be examined: a) PRF less than the filter 3 dB bandwidth, b) PRF greater than the filter 3 dB bandwidth and, c) the transition region where the PRF approaches the filter 3 dB bandwidth from above or below.

4) Exactly what is meant by calibrating the UWB 50 MHz radiated test setup? With traditional frequency domain measurements, calibration refers to documenting gains and losses versus frequency of the test setup components. The gains and losses are then used to calculate the actual antenna terminal voltages in order to determine the electric field strength versus frequency. Calibration of the UWB radiated test setup is similar to the narrowband calibration except for the filter impulse response. The UWB measurement is performed in the time domain through a band limiting filter, which means that not only do the gains and losses versus frequency have to be known, but also the filter's impulse response versus PRF and pulse volt-second level.

A simple way to calibrate the UWB radiated test setup is to stimulate the test setup with a pulse train that encompasses the same PRF, frequency distribution, and volt seconds as the UWB test specimen. The output of the filter is measured with a fast sampling DSO and compared with predicted using the appropriate equations. The difference between the predicted and measured is then used as a correction factor applied to the measured emission data. Another method would be to perform the traditional narrowband gain and loss measurement versus frequency, independently perform the filter characterization, and then combine the gain and loss results with the filter characteristics for a calculated correction factor.

5) What type of characterization needs to be performed on the tunable filter in order to accurately measure the band limited electric field strength? The proposed filter is a constant percentage bandwidth filter, which means that the numerical bandwidth changes as the tuned center frequency changes. The following characteristics need to be specified or measured:

1) Filter insertion loss and phase across the entire filter tuning range.
2) Filter 3 dB bandwidth across the entire tuning range.
3) Accuracy and repeatability of filter mechanical frequency indicator.
4) Out of band insertion loss and phase and VSWR.
5) Filter normalized peak constant, shown in Equation 3.

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

6) What type of characterization is necessary for the radiated test setup components in order to accurately measure the band limited and absolute electric field strength? The gains or losses and phase of each of the test setup components (cables, amplifiers, splitters, couplers, measurement antennas, etc.) versus frequency must be known. The minimum frequency range of coverage must be the 10 dB bandwidth plus and minus 500 MHz of the UWB radiated spectrum. The components must be characterized over a frequency range large enough in order to reconstruct the electric field pulse waveform with little distortion so that the absolute peak pulse amplitude can accurately be determined. If each component has linear phase, then only the gain/loss forward transmission magnitude versus frequency needs to be taken into account in order to reconstruct the electric field waveform at the antenna aperture.

7) What is meant by impulse calibration? Due to the gain/loss and phase variations versus frequency in a typical emission test setup, it is necessary to perform an impulse calibration when making band limited impulse response measurements. A single polarity impulse with short pulse width, with respect to the filter rise time, of known area can be used to stimulate the setup in order to determine a correction factor that accounts for the forward transmission magnitude and phase variations upstream of the DSO measurement

channel. The PRF of the impulse generator must be in the same PRF range as that of the UWB emission source. This is important since the filter response is a function of whether the PRF is below, equal to, or above the filter bandwidth. The correction factor is only used for the band limited peak measurement, not for the absolute peak measurement. The correction factor for PRFs below the filter bandwidth is shown in Equation 4.

$$V_{Pk\_corr\_factor} = \left[\frac{V_{BW_{-3dB}\_Pk} \cdot \left(\frac{50MHz}{BW_{-3dB}} \right)}{2 \cdot \pi \cdot Pulse_{Area} \cdot BW_{-3dB} \cdot Spectrum_{Pk\_PSD\_corr} \cdot V_{PkNormalized}} \right]^{-1} \quad \text{Eq. 4}$$

where:

$V_{BW_{-3dB}\_Pk}$ = Filter impulse response peak voltage measured with the DSO in (volts)

$V_{Pk\_corr\_factor}$ = The linear correction factor to be applied to the DSO measurement

$V_{PkNormalized}$ = 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 is dimensionless.

BW_{-3dB} = Bandpass 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 tuned center

The correction factor, dB, would be added or subtracted, depending on sign, to the voltage, dBμV, measured during the radiated emission test.

8) What information will be required from the UWB manufacturer prior to performing any UWB emission testing? As always, it is best to provide the compliance lab with as much information as possible concerning the device to be tested. The type of data that should be supplied include the modulation type (e.g., random code time dithering, periodic, and bursting), the average PRF, antenna characteristics, whether the transmitter has a dynamic PRF or data rate control, whether the transmitter can be locked into the

worst case transmitting PRF and modulating type, UWB radiated pulse waveform shape, and UWB radiated emission spectrum.

9) What are some important parameters to consider when choosing test setup components? The most desirable UWB radiated emission measurement test setup would be composed of components that have low Voltage Standing Wave Ratio (VSWR), smooth forward transmission magnitude, and linear phase in the bandwidth of measurement. Measurement data from a test setup composed of such components would minimize the post processing effort and yield the most accurate test results. The preamp should be pulse rated, have a low noise figure, high gain, broadband frequency coverage > 3 GHz, and a high input compression power level. Since UWB systems transmit information using pulses, a high peak to average electric field strength ratio can occur, so care must be taken to not overload the preamp and distort the UWB signal.

10) What is the best progression of testing? There are three intentional NPRM radiated emission limits for UWB devices, one frequency domain and two time domain. A certain amount of information is needed from one measurement result before one can proceed to the next measurement. For example, the absolute peak limit cannot be determined if the spectrum 10 dB bandwidth is not known. It would be easier when performing the 50 MHz measurement if the approximate peak emission frequency were known before tuning the bandpass filter. It would be helpful to know if the UWB emissions are periodic or randomly dithered. It would also be helpful for the 50 MHz measurement to know the approximate emission PRF, because the filter output waveform and peak level depend on the PRF incident on the filter input. For these reasons, the frequency domain emission measurement should be performed first, then the 50 MHz, and finally the absolute peak electric field measurement.

3.2 Test Equipment

The test equipment listed in Table II shall be used to perform UWB emission measurements. Substitution of equipment with equivalent capability may be utilized in the performance of the test.

Table II. Test Equipment

Item Description	Freq. Range	Mfr/Model No.	Qty
Spectrum Analyzer	DC to 26.5 GHz	R&S/FSEM 30	1
Preamplifier	1 GHz to 4.5 GHz	Miteq/AFS3-001004-22-LN	1
Low loss cable	DC to 22 GHz	Storm/90-195-240	1
6 dB splitter	DC to 26.5 GHz	HP/11667B	1
Double Ridged Guide Horn	30 Hz to 50 MHz	EMCO/3115	1
Delay Line	DC to 26.5 GHz	HP/54008A	1
Digital Sampling Scope Mainframe	NA	HP/54750A	1
Dual Output DC Power Supply, 0 – 25 Vdc, 0 – 1 Amp	NA	HP/E3620A	1
Vertical Plug In	DC to 20 GHz	HP/54751A	1
Tunable Octave Band Bandpass Filter	1.5 to 3 GHz	K&L/5BT-1500/3000-2.5-N/N-5	1

3.3 Preparation

Prior to performing any testing, all test setup components, including preamps, antennas, delay lines, cables, etc., shall be characterized for forward transmission magnitude and phase versus frequency. The spacing of the frequency increments shall be small enough to capture variations in forward transmission magnitude and phase such that the interpolation error between any two points shall be less than 1 dB. For well-behaved components the frequency separation can be quite large, but for components that are ill-conditioned, such as some broadband preamps that are not pulse rated, the frequency spacing may have to be much smaller in order to accurately characterize the component's forward transmission magnitude and phase. The bandwidth of characterization is determined by the UWB radiated emission spectrum. The UWB device manufacturer should be able to give a rough estimate of the device's radiated emission spectrum. The component characterization should occur over a bandwidth that is equal to the UWB emission spectrum 10 dB bandwidth plus and minus 500 MHz.

Since the component data must be used in a post-processing program, it is advisable that all data be saved on digital media in an ASCII format. If "S" parameter data is gathered, then the "S" parameters will have to be converted to magnitude and phase. In order to compute forward transmission magnitude and phase parameters only S_{21} data is required. Equations 5 and 6 will convert S_{21} to linear magnitude and radian phase.

$$|\Gamma_{mag\_21}| = \sqrt{\left(\left(\Gamma_{Re\_21}{}^2\right)+\left(\Gamma_{Im\_21}{}^2\right)\right)} \qquad \text{Eq. 5}$$

$$\theta_{Radians} = \tan^{-1}\left(\frac{\Gamma_{Re\_21}}{\Gamma_{Im\_21}}\right) \qquad \text{Eq. 6}$$

It is also advisable that all measurement equipment, DSO and spectrum analyzer, have the capability to store ASCII data directly to digital media to expedite post processing.

It is advisable that the test site be characterized for both frequency and time domain ambient signals. Normally a test site is "frequency mapped" for ambient emitters such as PCS, FM, TV, paging service, etc. However, compliance labs are not usually concerned about the affects of wireless services on a time domain measurement. Large narrowband signals can distort and in some cases totally mask the UWB signal at an OATS, so knowledge of the time domain ambient is of utmost importance. The test site can be "time domain mapped" by using the test setup shown in Figure 28.

3.4 Frequency Domain Intentional Radiated Emission Measurement Procedure

Frequency domain measurements of UWB radiated emissions should follow the procedure called out in ANSI C63.4-1992 for intentional radiators except that an average detector should be used above 1 GHz and a RBW of 1 MHz. If the spectrum analyzer has a video filter and it is used to perform averaging, then it shall be set to a bandwidth of no larger than 10 kHz for effective averaging. **The video filter may only be used to perform averaging if the PRF of the UWB source is greater than 1 MHz. If the PRF of the UWB source is less than 1 MHz then display averaging or a true average** detector shall be used with the VBW set to its highest level and, as a minimum, shall not be lower than 1 MHz.

If the PRF of the UWB device is not known, then perform a full sweep using the VBW averaging technique and save the trace in the spectrum analyzer memory. With the VBW set to the highest bandwidth record an average display sweep using 32 sweeps. Compare the saved trace with the display averaged trace. If the difference between the two traces is greater than 2 dB across the entire spectrum with the display averaged trace being the higher of the two, then the narrow VBW averaging technique cannot be used to accurately measure the average electric field strength of the UWB device.

Prior to performing any radiating emission testing, the spectrum analyzer shall be calibrated and the measurement system, shown in Figure 23, checked using a synthesizer as a stimulus source. The spectrum analyzer shall be set at the same frequency as the synthesizer and the difference between the synthesizer output amplitude and the spectrum analyzer reading (without antenna factors) shall be the same as the system loss or gain previously measured during the component characterization process.

The NPRM proposed the frequency domain limit for an UWB device radiating above 1 GHz shown in Figure 24. TDC has already noted that because of measurement sensitivity issues, measurement accuracy of the true spectrum peak, and accurate determination of the 10 dB emission bandwidth, all measurements should be performed at 1m inside a semi or fully anechoic chamber. If the measurements are performed at 1m, then TDC suggests adjusting the NPRM 3m limit by adding $20\text{Log}_{10}(3) = 9.54$ dB to the 3m limit.

One of the most important aspects of testing an intentional radiator is to cycle through all the operational modes of the device during testing. ANSI C63.4-1992 gives guidance for choosing operational modes and this guidance applies to UWB devices. Clearly, it is necessary to have knowledge of the maximum effective PRF, modulation capabilities, etc., in order to determine the worst-case emission mode. The UWB device manufacturer should already know the worst-case UWB emission mode, but some experimentation may be necessary and should be undertaken to build confidence in the validity of the assertion that the chosen UWB operational mode is the worst-case emission mode.

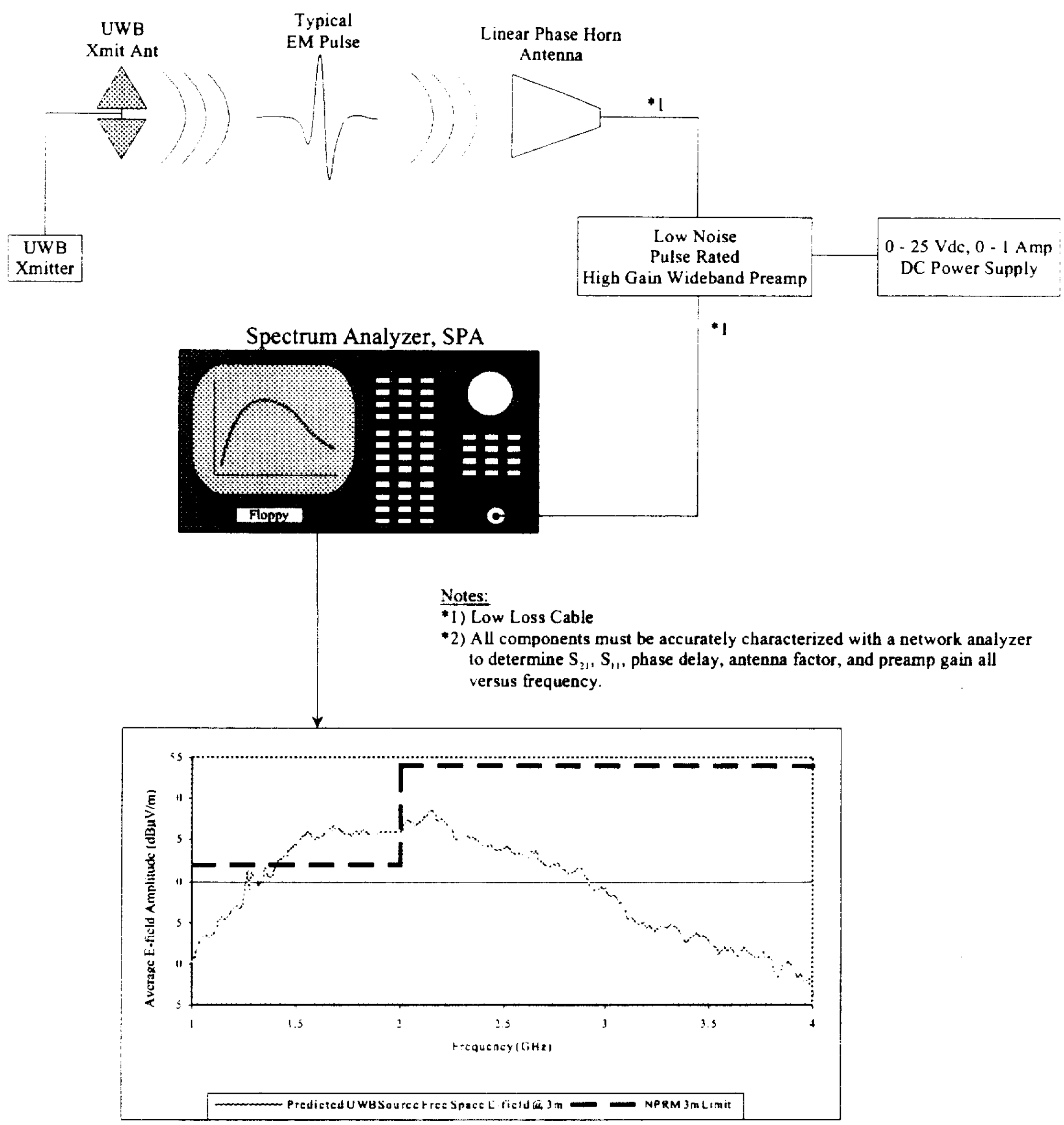


Figure 23. Frequency Domain UWB Radiated Emission Test Setup

The data gathered in the frequency domain should be the maximum average emission level and frequency, the signal's 10 dB bandwidth relative to the maximum average free space emission level, and the effective PRF. Additionally, it is necessary to know if the system is periodic or has random time dithering.

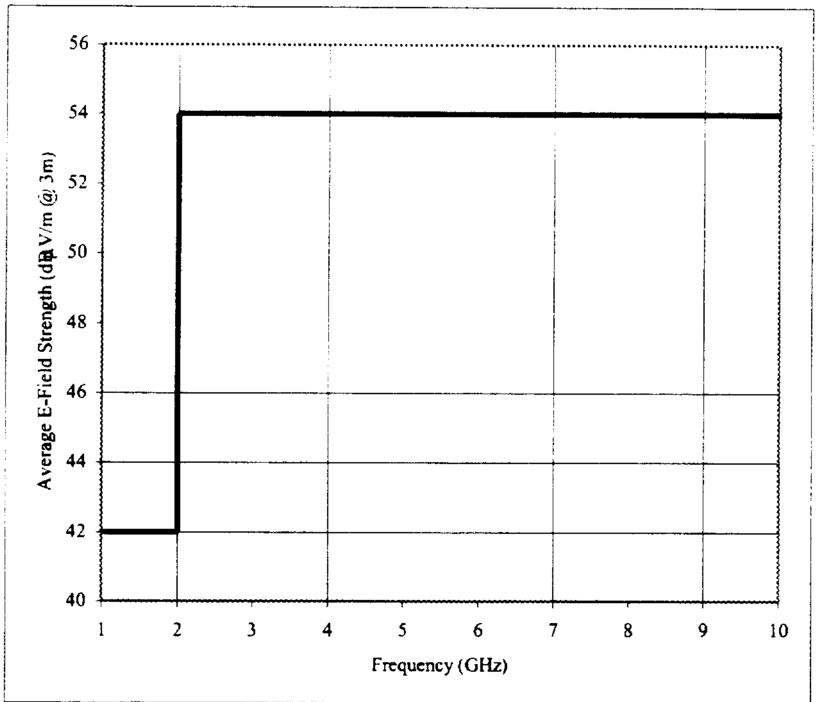


Figure 24. NPRM 3m UWB Radiated Electric Field Emission Limit

3.5 50 MHz Peak Time Domain Electric Field Measurement Procedure

The NPRM has suggested an UWB emission limit that requires measurement in the time domain in order to verify compliance. The limit is given in units of dBµV/m/50 MHz @ 3m and is shown in Figure 25. The UWB emission is measured at the output of a 50 MHz filter tuned to a frequency that maximizes the filter peak output voltage. The filter peak output voltage measurement is converted to electric field strength by utilizing Equation 7.

$$E_{Pk\_50MHz}(dB\mu V/m/50MHz) = A.F._{Filter\_Center\_Freq.}(dB) + DSO_{Pk\_Volt}(dB\mu V) + T.S._{corr}(dB) + BW_{corr}(dB) \quad \text{Eq. 7}$$

where:

E_{Pk_50MHz} = Peak Electric Field Measured in a 50 MHz bandwidth

$A.F._{Filter\_Center\_Freq.}$ = Receiving antenna factor at the filter center frequency

DSO_{Pk_Volt} = Filter output peak voltage as measured by the DSO

$T.S._{corr}$ = Test setup correction factor as measured by the impulse calibration or component characterization method. This factor can be negative for gain or positive for loss depending on the test setup.

$BW_{corr} = 20 \cdot Log_{10}\left(\frac{50MHz}{BPF_{-3dB\_BW}}\right)$ for PRFs ≤ 50 MHz

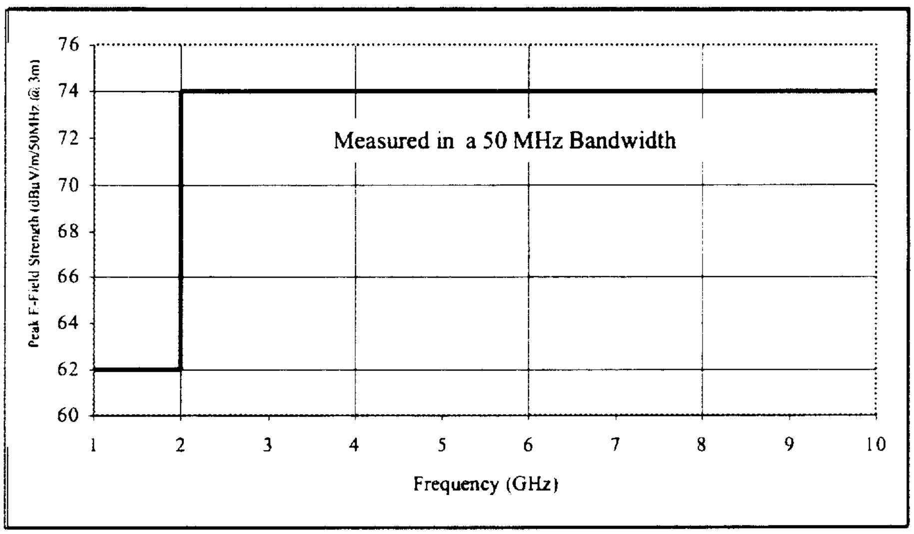


Figure 25. 50 MHz Peak Electric Field Time Domain NPRM 3m Limit

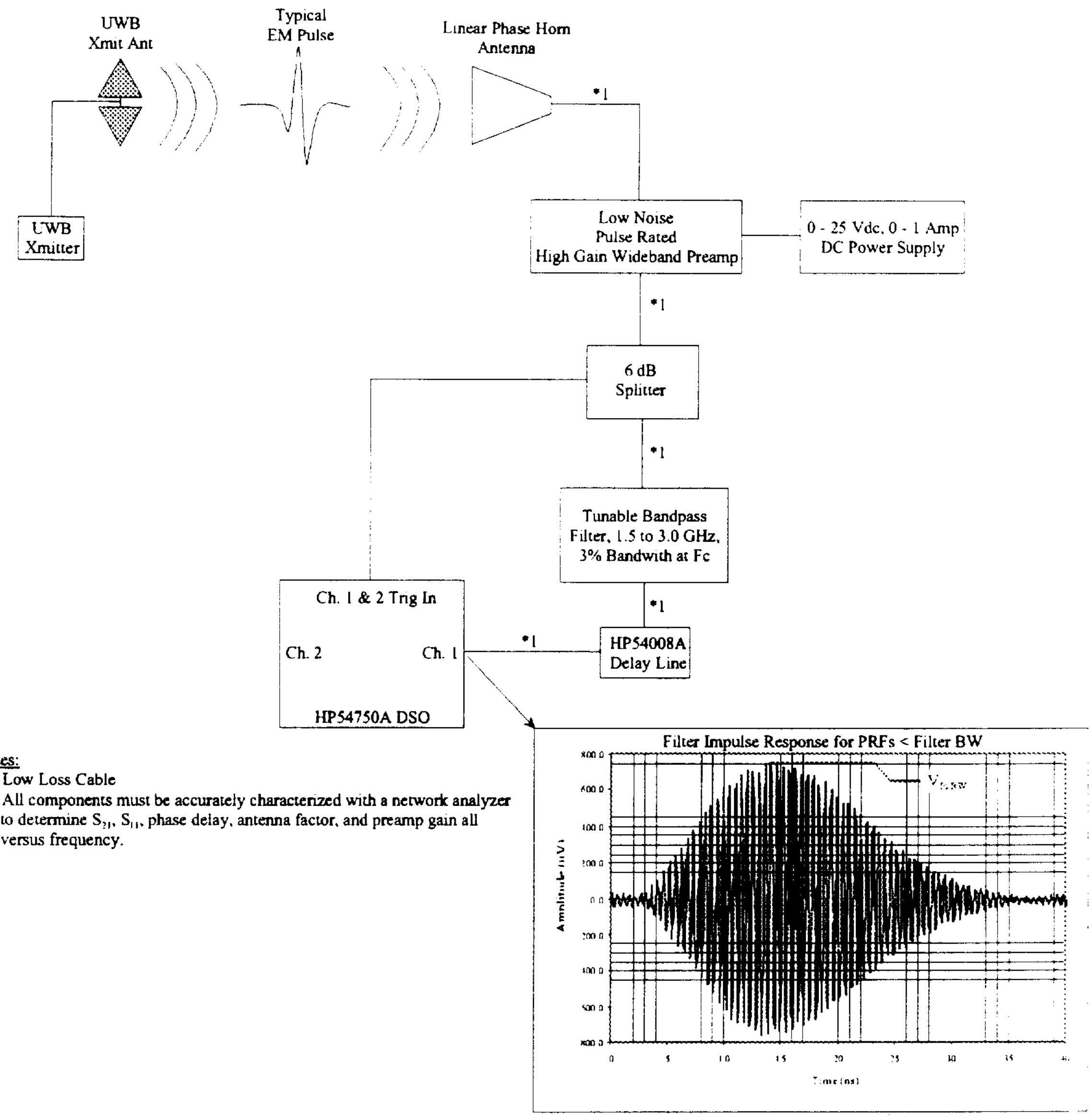
The bandwidth correction factor, BW_{corr}, contained in equation 7 is required because the tunable filter that TDC has chosen is a constant percentage octave bandpass filter whose bandwidth changes as the center frequency changes. For example, a filter that is designed to cover 1.5 GHz to 3 GHz with a constant percentage bandwidth of 2.5% will have a bandwidth range of 37.5 to 75 MHz – a 6 dB variation in voltage across the range for PRFs less than or equal to 50 MHz.

The tunable filter is the key element of the measurement test setup, shown in Figure 26, and will allow the measurement personnel to adjust the filter center frequency for a maximum indication on the DSO. The measurement should be performed at 1m, for reasons previously discussed, with an adjusted NPRM limit of 83.5 dBμV/m @ 1m. Data taken during the frequency domain measurements will expedite the time domain measurement process by indicating the approximate frequency region where the maximum filter output will occur.

Test results from measurements of a TDC UWB device, shown in Figure 12, indicate that if frequency domain measurements are taken at 1m then the recorded frequency domain peak frequency will be within a 60 MHz range of the frequency that yields the maximum filter output voltage. If the frequency domain measurements are taken at 3m then the recorded frequency domain peak frequency will be within a 220 MHz range of the frequency that yields the maximum filter output voltage. The frequency at which the maximum spectral component occurs is not necessarily the frequency at which the maximum filter output voltage occurs. This also means that the UWB device orientation that yields the maximum spectral component may not be the device orientation that yields the maximum filter output voltage. In general the maximum filter output voltage will occur at the device orientation that delivers the most pulse power to the receiving antenna. The maximum pulse power of a dipole antenna is delivered when the receiving antenna and the dipole antenna are aligned along each antenna's maximum gain axis and facing each antenna's maximum beam pattern, usually called "boresight."

The waveform displayed on the DSO will look similar to the waveform shown in Figure 26 for PRFs lower than the filter bandwidth, but will look different for UWB systems with PRFs greater than the filter bandwidth. For UWB systems that use random time dithering, the waveform will look like a series of continuous envelopes similar to the one shown in Figure 26, but with the decay truncated. As the PRF increases the waveform envelopes compress together because the filter cannot discharge before the next pulse occurs. The width of each envelope will not be the same because each pulse charges the filter at random intervals.

For UWB systems that emit a periodic spectrum (i.e., a comb spectrum) the waveform will look similar to the random dithered case with equal width envelopes and amplitudes that increase and decrease with changing PRF. The output amplitude changes with PRF because the harmonic combs sweep through the filter center frequency as the PRF varies. The highest output of the filter would occur when the PRF is equal to the filter center frequency. Even though the filter output voltage does increase when the harmonics occur at the filter center frequency, there are regions where the filter output is lower at a higher PRF than at a lower PRF because the filter does not always intercept a harmonic.



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 26. 50 MHz Peak Electric Field Measurement Test Setup

3.6 Impulse Calibration Procedure

If at all possible the test setup components should be chosen such that they exhibit linear phase across the pulse spectrum. If the test setup has linear phase then it is not necessary to perform an impulse calibration. However, if the test setup does not exhibit linear phase or the components have not been characterized, as previously mentioned, then an impulse calibration is required. The impulse calibration shall be performed with the bandpass filter set at the peak frequency determined during the 50 MHz measurement. The impulse calibrator shall be set at the same PRF and modulation (random or periodic) that the UWB device emits. As already stated, the best impulse calibration source would be the UWB device being tested. If the UWB device can be disconnected from its transmit antenna and connected to the emission test setup antenna cable, the impulse calibration will be the most accurate. If the UWB device cannot be connected to the emission test setup cable, then it would be beneficial if the UWB device manufacturer could provide a sample UWB device with the same PRF, wave shape, and modulation characteristics as the device to be tested. The sample device should have a SMA or type N connector that can easily interface with emission test setup antenna cable. Prior to performing calibration the impulse source must be characterized for wave shape (volt-seconds), PRF, and modulation type.

Perform the impulse calibration measurement using the test setup shown in Figure 27 and calculate the test setup correction factor using Equation 4. The test setup correction factor shall be utilized in Equation 7 to determine the 50 MHz peak electric field amplitude.

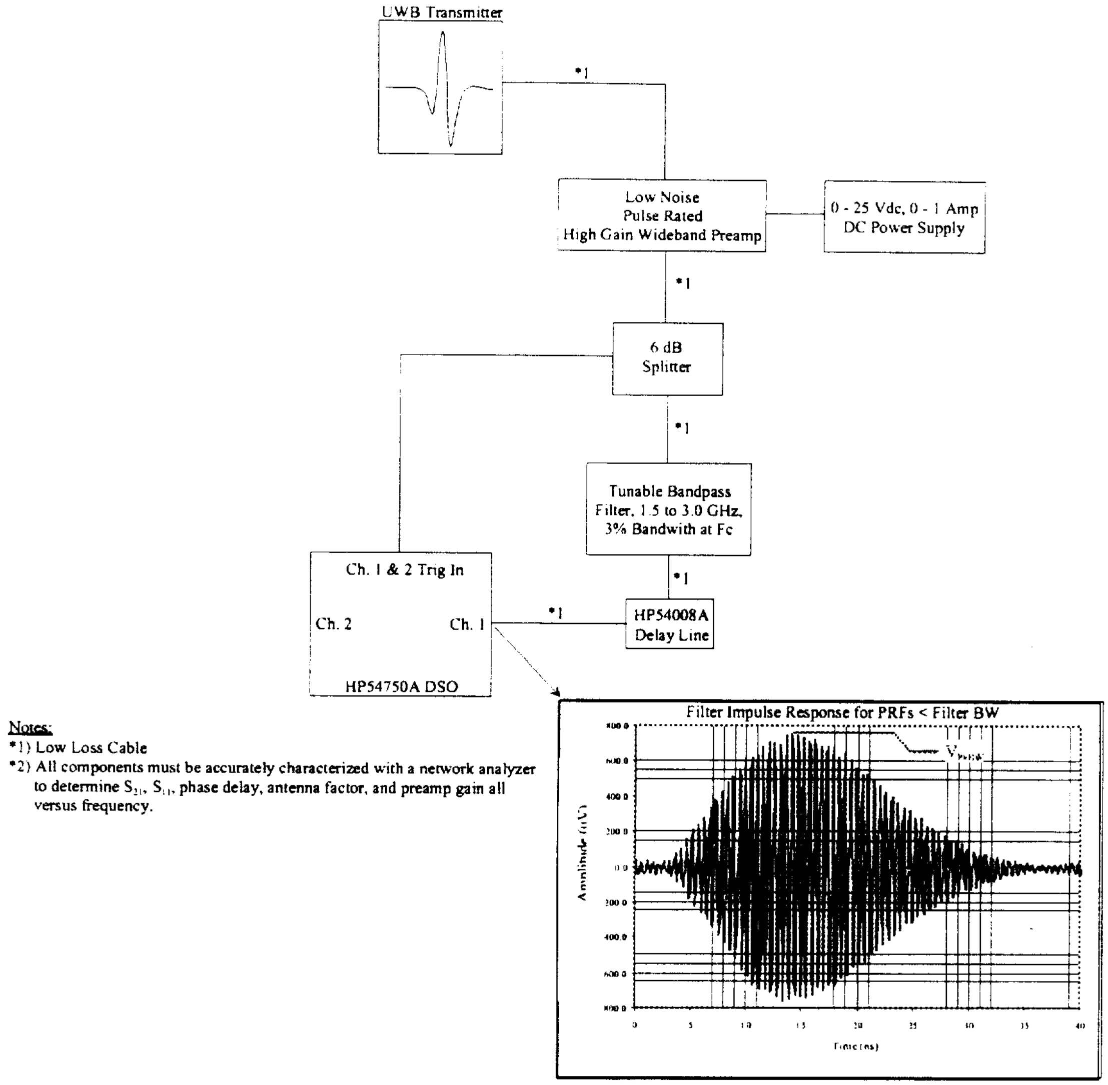


Figure 27. Impulse Calibration Test Setup.

3.7 Absolute Peak Time Domain Electric Field Measurement Procedure

The absolute peak electric field limit suggested by the NPRM requires a significant amount of post processing in order to determine whether the UWB device complies with the limit. The limit is given in units of dBμV/m @ 3m and is shown in Figure 28. The example limit shown in Figure 28 is based on a UWB spectrum with a 10 dB bandwidth of 1.75 GHz. Since the absolute peak limit is proportional to the 10 dB bandwidth of the UWB emission spectrum it is necessary to accurately measure the UWB free space emission spectrum in the frequency domain.

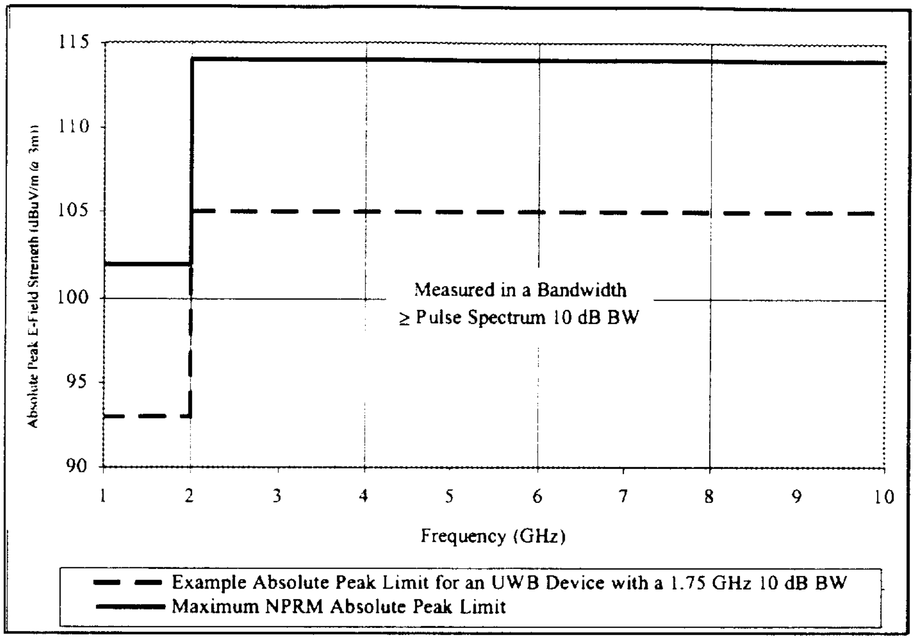


Figure 28. NPRM Absolute Peak Electric Field Time Domain NPRM Limit

The absolute peak electric field measurement is the simplest of the three UWB emission procedures to perform, using the measurement test setup shown in Figure 29, but the most demanding to calculate. The waveform measured by the DSO is proportional to the absolute electric field but not linearly related, as shown in Figure 30. A simple correction factor cannot be applied to the DSO measurement in order to determine the instantaneous peak of the electric field incident on the receiving antenna. The mathematics involved in solving for the radiated electric field is illustrated in Figure 31. The term h(t) represents all of the test setup components including the antenna, r(t) represents the DSO measurement, and f(t) represents the electric field incident on the receiving antenna all in the time domain. As previously discussed all components are to be measured for magnitude and phase characteristics versus frequency. The component's magnitude and phase values are represented by $H(j\omega)$, the magnitude and phase of the DSO measurement is represented by $R(j\omega)$, and the electric field magnitude and phase is represented by $F(j\omega)$ all in the frequency domain. Once $F(j\omega)$ has been determined, then the electric field waveform can be calculated by converting $F(j\omega)$ to f(t) using an inverse

FFT algorithm. The absolute peak electric field is the maximum absolute value of f(t). A Mathcad file located in Attachment A performs the process illustrated in Figure 30. The Mathcad file in Attachment A assumes that all components contribute linear phase delay to the test setup. The components used in the TDC setup were selected for their linear phase and well-behaved magnitude characteristics, thus eliminating the need to account for phase in the mathematics. Most of the work required to determine the absolute peak electric field amplitude is in gathering the component data and aligning the frequency and magnitude arrays with the same number of elements, the same Δt, and Δf increments for the FFT and IFFT conversions.

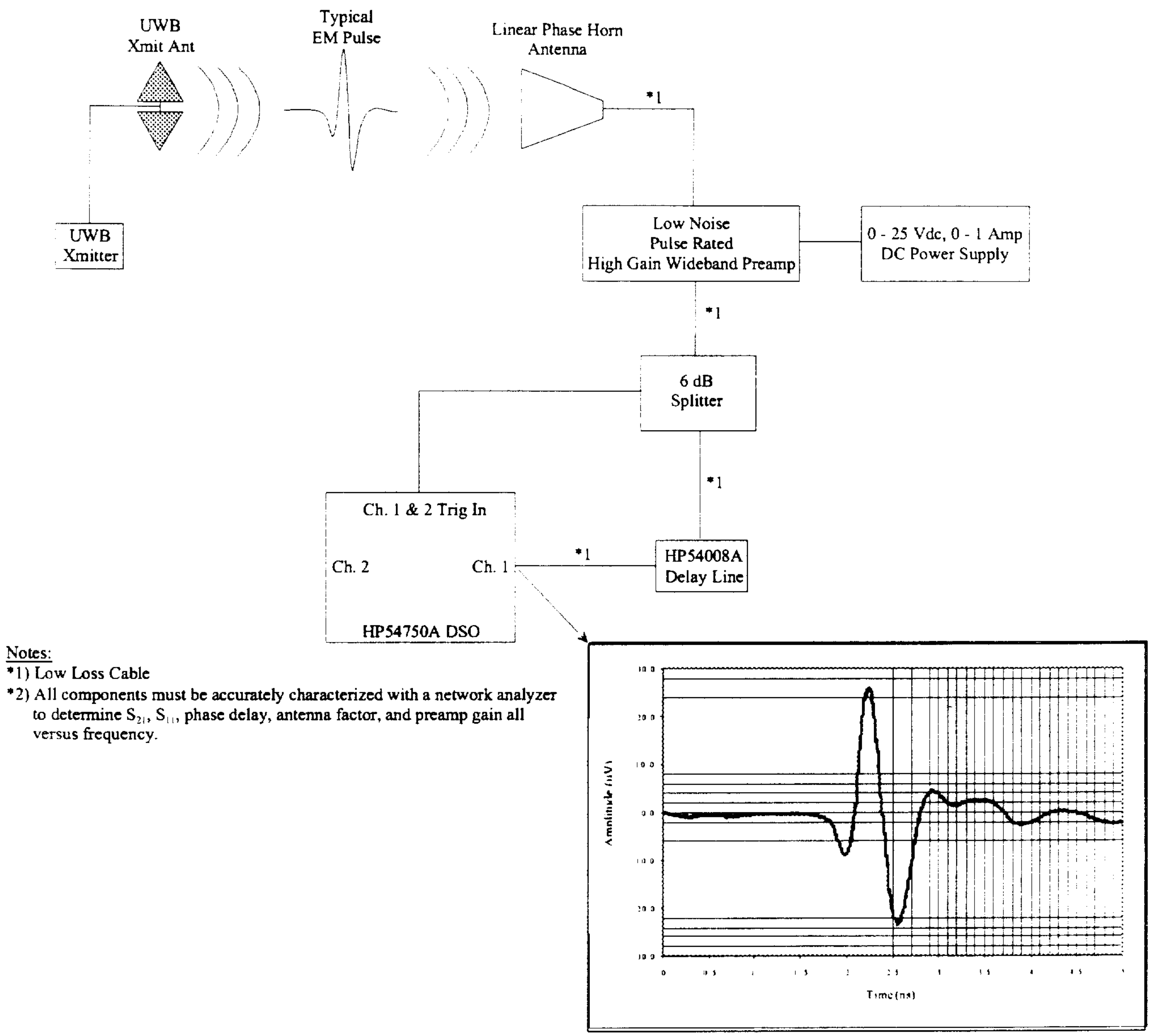


Figure 29. Absolute Peak Electric Field Measurement Test Setup

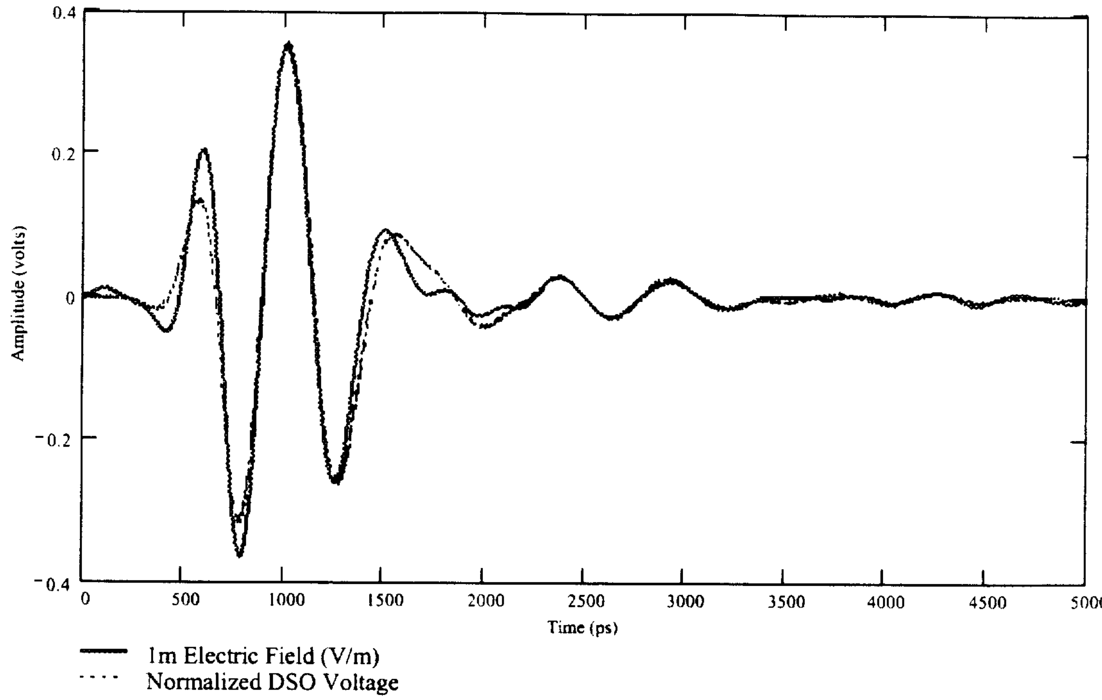
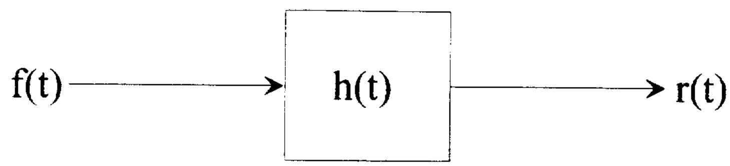


Figure 30. Comparison of DSO Waveform and Absolute 1m Electric Field

Since the DSO does not indicate the true electric field waveform it may be difficult to use the DSO display as an indicator of maximum peak electric field. The maximum value of the absolute peak electric field should occur with the UWB device at the same orientation that was determined in the 50 MHz test. It is a good idea to make at least two measurements: one at the device orientation that yielded the maximum 50 MHz value and the second that indicates the maximum value using the setup shown in Figure 29. Both measurements will have to be post processed in order to determine which orientation had the highest peak value.

$$f(t) * h(t) = r(t)$$



$$\Im\{r(t)\} = \Im\{f(t) * h(t)\} = R(j\omega) = F(j\omega)H(j\omega)$$

$$F(j\omega) = R(j\omega)/H(j\omega)$$

$$f(t) = \Im^{-1}\{F(j\omega)\} = \Im^{-1}\{R(j\omega)/H(j\omega)\}$$

$\Im$ and $\Im^{-1}$ are the Fourier transform pair

$*$ is the convolution operator

Figure 31. Absolute Peak Electric Field Calculations

ATTACHMENT A

CALCULATION OF THE UWB ABSOLUTE AND 50 MHz

PEAK ELECTRIC FIELD STRENGTH

USING MATHCAD

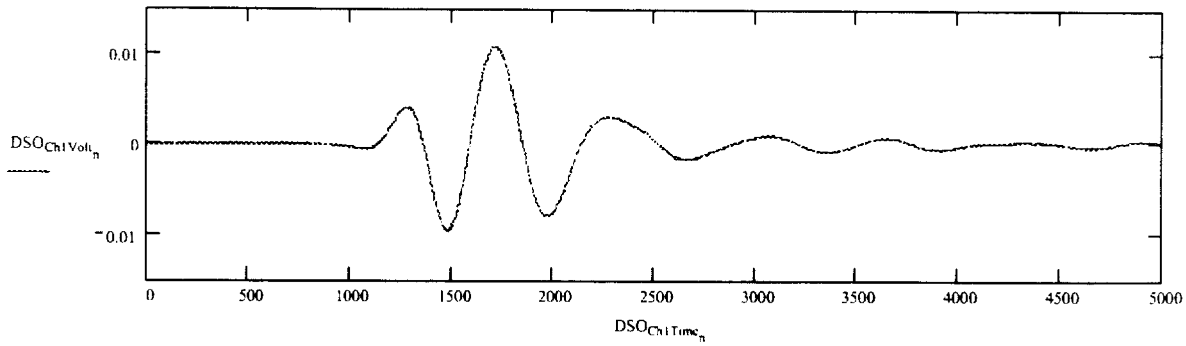
ASSUMING ALL

TEST SETUP COMPONENTS HAVE LINEAR PHASE

$DSO_{Ch1Time}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Wyle Chamber\Ch2mh3mdTime.txt")

$DSO_{Ch1Volt}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Wyle Chamber\Ch2mh3mdAmplTime.txt")

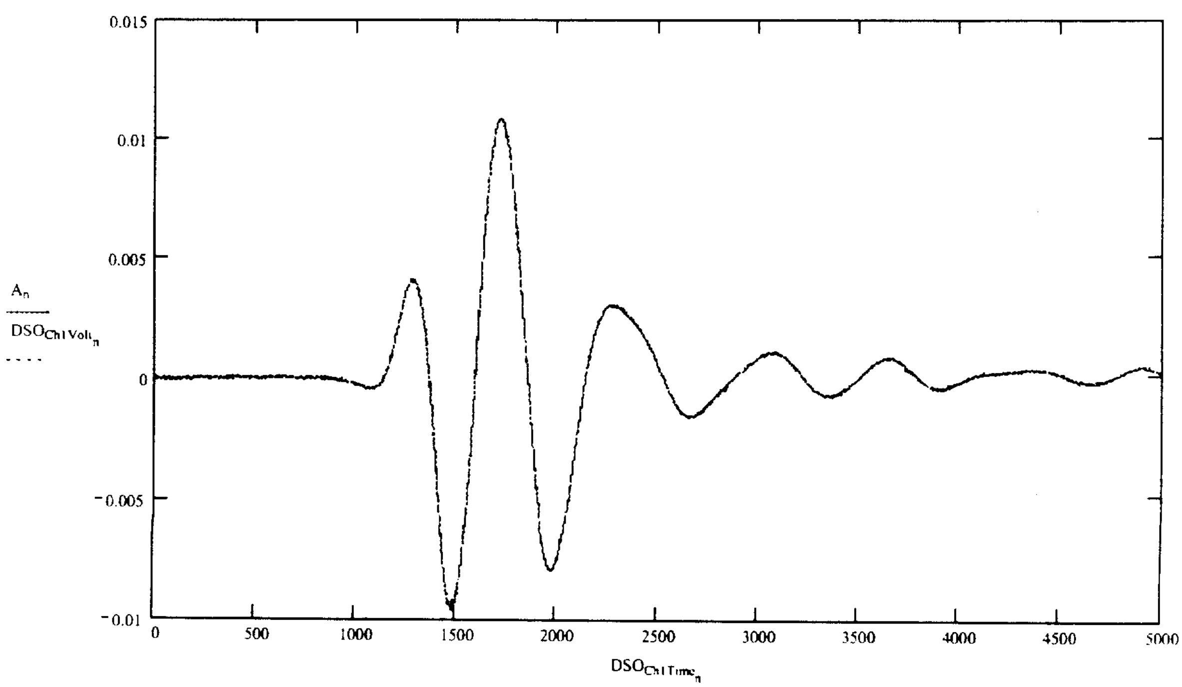
$n := 0 .. 4095$

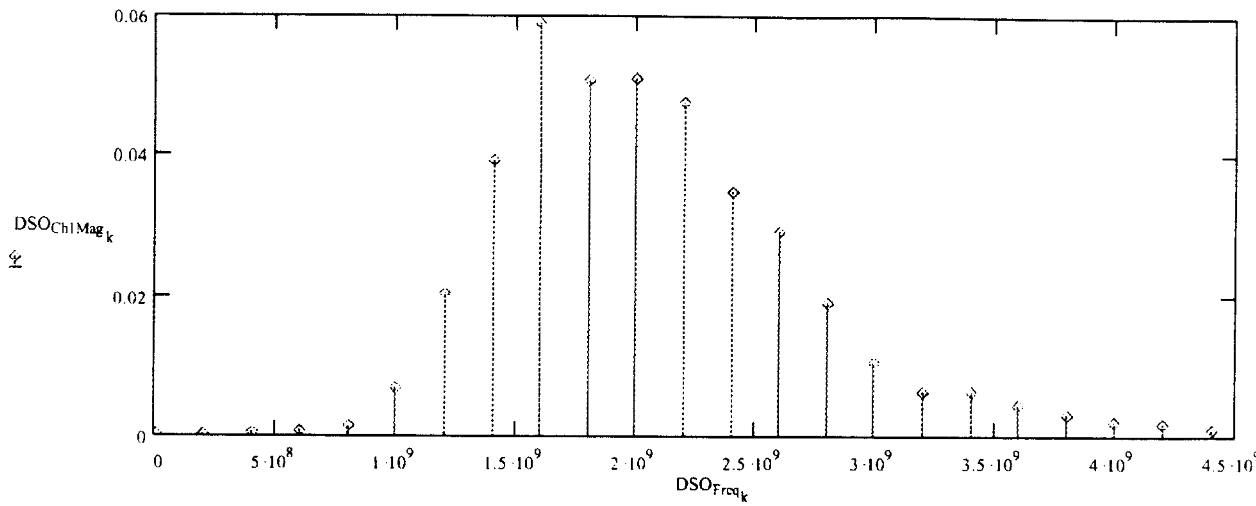


$DSO_{Ch1Mag} := \overrightarrow{\left(\left|fft\left(DSO_{Ch1Volt}\right)\right|\right)}$ $DSO_{Ch1\theta} := \overrightarrow{arg\left(fft\left(DSO_{Ch1Volt}\right)\right)}$ $N := rows\left(DSO_{Ch1Time}\right)$ $k := 0, 1 .. \frac{N}{2}$

$DSO_{Freq_k} := \frac{k}{N \cdot \Delta t}$ $\Delta t := \left(DSO_{Ch1Time_1} - DSO_{Ch1Time_0}\right) \cdot 1 \cdot 10^{-12}$ $\Delta t = 1.221 \times 10^{-12}$ $\Delta f := \frac{1}{N \cdot \Delta t}$

$Q := fft\left(DSO_{Ch1Volt}\right)$ $A := \overrightarrow{ifft(Q \cdot Zero)}$ $\Delta f = 1.99951372 \times 10^{8}$ $Zero_k := if[(k < 3) + (k > 22), 0, 1]$





$G3_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\Spltr6dBFreq.txt")

$G3_{Loss}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\Spltr6dBLoss.txt")

$$f := 0, \left(\frac{\Delta f}{1\cdot10^9}\right) .. \max\left(\frac{DSO_{Freq}}{1\cdot10^9}\right) \qquad G3_{interpolated}(f) := \mathrm{linterp}(G3_{freq}, G3_{Loss}, f) \qquad G3_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot10^9}\right)}} := G3_{interpolated}(f)$$

$G6 := G3$ $\qquad$ $G8 := G3$

$G1_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\Storm20Freq.txt")

$G1_{Loss}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\Storm20Loss.txt")

$$G1_{interpolated}(f) := \mathrm{linterp}(G1_{freq}, G1_{Loss}, f) \qquad G1_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot10^9}\right)}} := G1_{interpolated}(f)$$

$G9_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\ShrtCblFreq.txt")

$G9_{Loss}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\ShrtCblLinLoss.txt")

$$G9_{interpolated}(f) := \mathrm{linterp}(G9_{freq}, G9_{Loss}, f)$$

$G12 := G9$

$$G9_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot10^9}\right)}} := G9_{interpolated}(f)$$

$G2_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\AmpFreq.txt")

$G2_{Gain}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\AmpGain.txt")

$$G2_{interpolated}(f) := \mathrm{linterp}(G2_{freq}, G2_{Gain}, f) \qquad G2_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot10^9}\right)}} := G2_{interpolated}(f)$$

$G11_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\DlyLn_5Freq.txt")

$G11_{Gain}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\DlyLn_5Loss.txt")

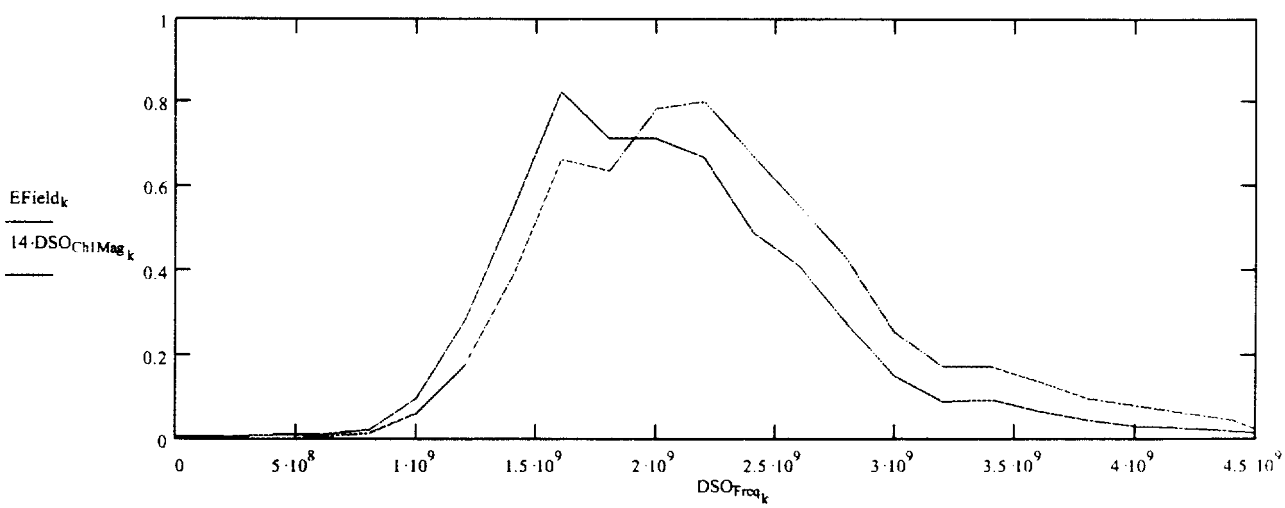
$$G11_{interpolated}(f) := \mathrm{linterp}(G11_{freq}, G11_{Gain}, f) \qquad G11_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot 10^9}\right)}} := G11_{interpolated}(f)$$

$A1_{freq}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\EMCOFreq.txt")

$A1_{Gain}$:= READPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Components\EMCO3m.txt")

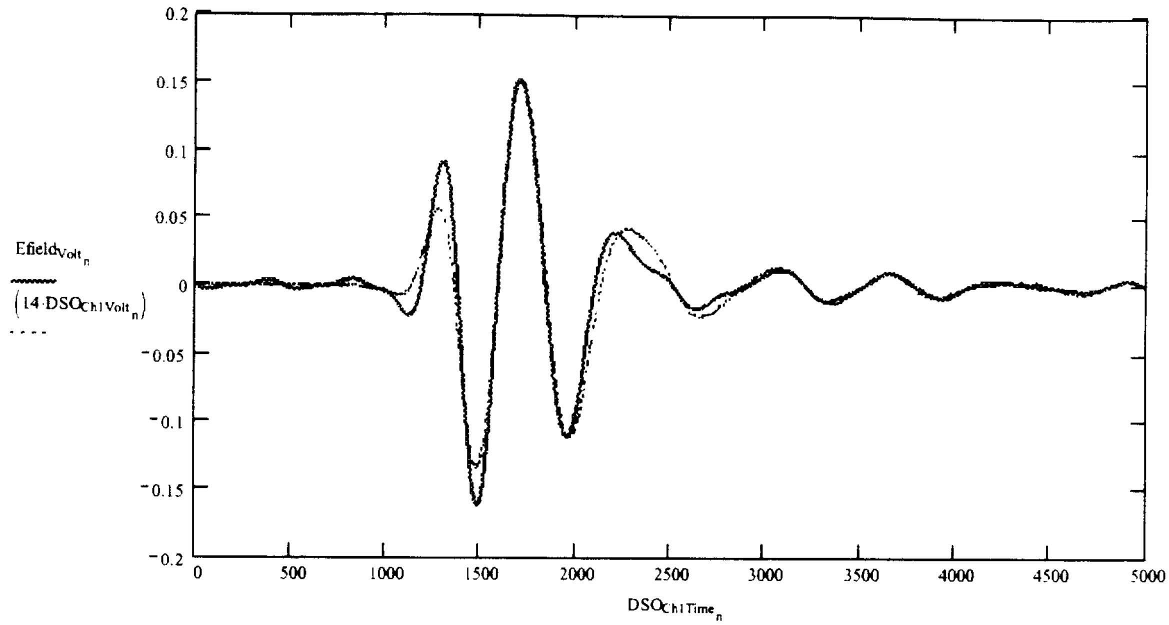
$$A1_{interpolated}(f) := \mathrm{linterp}(A1_{freq}, A1_{Gain}, f) \qquad A1_{\frac{(f)}{\left(\frac{\Delta f}{1\cdot 10^9}\right)}} := A1_{interpolated}(f)$$

$$EField := \overrightarrow{\left[Zero\cdot\frac{(DSO_{Ch1Mag}\cdot A1)}{(G1\cdot G2\cdot G3\cdot G6\cdot G8\cdot G9\cdot G11\cdot G12)}\right]} \qquad Complex := \overrightarrow{\left[EField\cdot(\cos(DSO_{Ch1\theta}) + i\cdot\sin(DSO_{Ch1\theta}))\right]}$$



$$Efield_{Volt} := \mathrm{ifft}(Complex)$$

WRITEPRN("c:\Tdc\Fcc\Measurement Techniques\TDC Procedure\Wyle Chamber\ch2mh3mdEfieldCorr.txt") := $Efield_{Volt}$



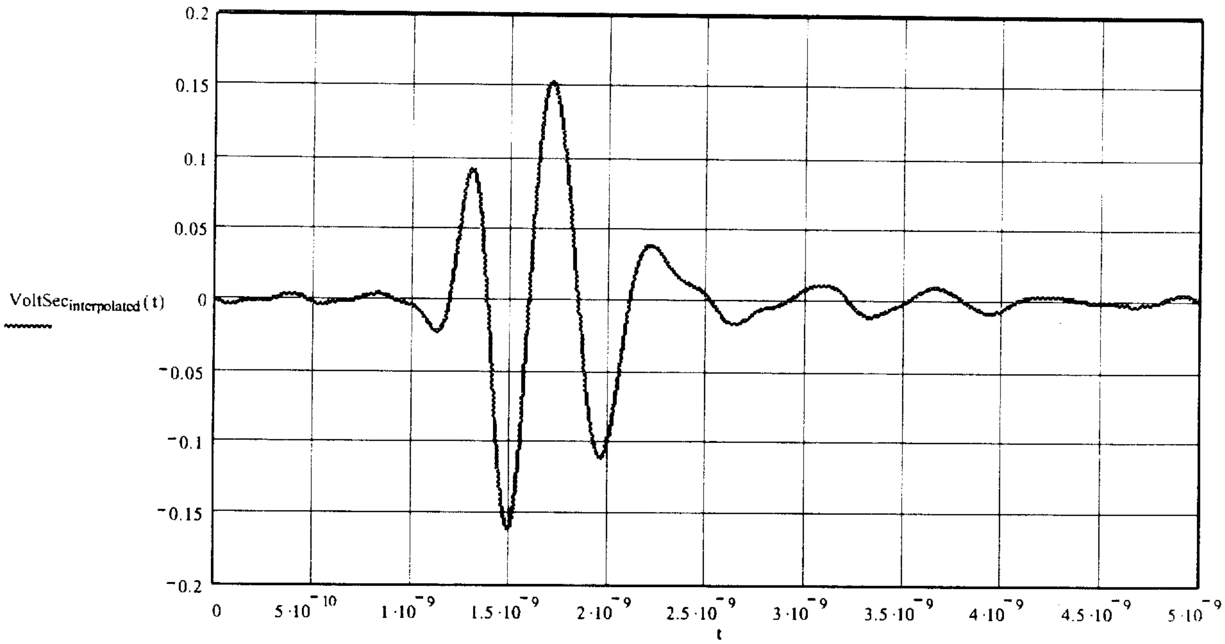
$t := 0, 1 \cdot 10^{-12} .. 5 \cdot 10^{-9}$

$$VoltSec_{interpolated}(t) := linterp\left(DSO_{Ch1Time} \cdot 1 \cdot 10^{-12}, Efield_{Volt}, t\right)$$

$$P_{edgeArea} := \left(\int_{904 \cdot 10^{-12}}^{1181 \cdot 10^{-12}} VoltSec_{interpolated}(t)\,dt + \int_{1377 \cdot 10^{-12}}^{1587 \cdot 10^{-12}} VoltSec_{interpolated}(t)\,dt + \int_{1839 \cdot 10^{-12}}^{2100 \cdot 10^{-12}} VoltSec_{interpolated}(t)\,dt \ldots \\ + \int_{2514 \cdot 10^{-12}}^{2905 \cdot 10^{-12}} VoltSec_{interpolated}(t)\,dt + \int_{3.212 \cdot 10^{-9}}^{3.514 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt + \int_{3.8 \cdot 10^{-9}}^{4.065 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt \right)$$

$$P_{edgeArea1} := \left(\int_{1.182 \cdot 10^{-9}}^{1.376 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt + \int_{1.588 \cdot 10^{-9}}^{1.838 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt + \int_{2.101 \cdot 10^{-9}}^{2.513 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt \ldots \\ + \int_{2.906 \cdot 10^{-9}}^{3.211 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt + \int_{3.515 \cdot 10^{-9}}^{3.799 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt + \int_{4.066 \cdot 10^{-9}}^{4.427 \cdot 10^{-9}} VoltSec_{interpolated}(t)\,dt \right)$$

$P_{edgeArea1} = 4.843 \times 10^{-11}$ $P_{edgeArea} = -4.855 \times 10^{-11}$



$EField_{50MHz} := 2 \cdot \pi \cdot 50 \times 10^{6} \cdot P_{edgeArea} \cdot 45 \cdot .888$ $\quad \max\left(\overrightarrow{\left|Efield_{Volt}\right|}\right) = 0.161$

$EField_{50MHz} = -6.095 \times 10^{-3}$

$$20 \log\left(\frac{\left|EField_{50MHz}\right|}{1 \cdot 10^{-6}}\right) = 75.699$$ dBμV/m 50 MHz BW @ 3m

$$20 \log\left(\frac{\max\left(\overrightarrow{\left|Efield_{Volt}\right|}\right)}{1 \cdot 10^{-6}}\right) = 104.14$$ dBμV/m Absolute Peak @ 3m