5. FULL-BANDWIDTH REFERENCE MEASUREMENTS OF ULTRAWIDEBAND EMISSIONS

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5.1 Introduction

Ultrawideband (UWB) signals, by definition, contain energy over a larger range of the frequency spectrum than do conventional radio signals which are relatively narrow-banded. The majority of conventional radio test equipment, however, are designed to measure the signals from the majority of radio systems in use, which constitute mostly narrowband and a few wideband signaling systems. UWB is a new class of signals that places new demands on measurement equipment.

There exists a need to characterize this new class of signals across their full emission bandwidth. This section describes measurements that address that need by capturing the pulse shapes and inner pulse structure from a selection of UWB devices. The UWB signals in this study are very narrow pulses of RF energy that are modulated or envelope-shaped in various ways. This study provides a view of the UWB pulses that cannot be directly measured with common narrower bandwidth equipment. From this full-bandwidth view of the pulses, comparisons can be made with measurement results performed with conventional equipment. The measurement results in this section provide a reference to which other measurement results can be compared, to see how well the reference set of signal parameters can be predicted from measurements using bandwidth-limited equipment.

5.2 Measuring Instruments and Calculation Methods

The signals emitted from a selection of UWB devices (see section 1.2) were measured by the National Institute of Standards and Technology (NIST) Radio-Frequency Technology Division to obtain data that represents the radiated time-domain waveform. The goal of these measurements was to capture a detailed view of a single pulse. The pulses were measured in two different environments. The first environment was called "conducted measurements." The second environment was called "radiated measurements."

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Two different measuring instruments were used in making the full-bandwidth measurements. The first instrument was a sampling oscilloscope. This instrument was capable of achieving very high equivalent sample rates when digitizing the input signal. The instrument used in this study possessed a bandwidth of 20 GHz with the ability to acquire 4,096 samples in a single time-domain record. Due to the nature of how this instrument performs its sampling, it had two limitations. The repetition rate of the pulses to be measured must be constant and the pulse shape invariant. While some UWB devices satisfy this requirement, there are devices that do not and were measured by a second measuring instrument.

The second measuring instrument was a single-event transient digitizer. This instrument had the advantage of placing fewer restrictions on the pulse parameters that it can measure. The digitizer possessed a bandwidth of 4.5 GHz with a maximum of 1,024 samples in a single shot. The instrument was designed to perform high fidelity measurements on a single pulse.

Two quantities were calculated from each measured waveform. The first quantity was "Total Peak Power." Given that there are *i* sample points in the time-domain waveform and *x* is the *i*th sample point, total peak power was calculated using equation 5.1 and was the maximum *i*th value of the power vector.

$$power_i = \frac{x_i^2}{50} \qquad (5.1)$$

The second quantity was "Total Average Power." It was calculated as shown in equation 5.2.

$$Average\ Power = \frac{1}{pri} * \sum_i \left(\frac{x_i^2}{50} \right) * \Delta t \qquad (5.2)$$

where x_i is the *i*th time-domain sample
) *t* is the sample interval
pri is the pulse repetition interval

The PRI that was used in the calculation is the shortest time interval between any two pulses. Effects which could lengthen the PRI such as On-Off-Keying or the quiet time between bursts of pulses were not considered since measuring these parameters was beyond the scope of this investigation. Some devices could operate with more than one mode setting. For these devices, the maximum and minimum PRIs were used in the calculation.

5.3 Conducted Measurements

Two different test setups were implemented for the conducted measurements. The first is shown in Figure 5.1. The RF output of the UWB device-under-test was connected using a coaxial transmission line to an attenuator. The attenuator was used to prevent overloading and damage to the measurement instrument from too strong a signal level. The signal was then split into two equal amplitude levels and fed into a trigger port and a signal port on a sampling oscilloscope. Several pulses were measured to check for pulse shape variations that might induce measurement errors. This setup was used to perform conducted measurements on device A, which has a constant pulse repetition frequency.

The second test setup is shown in Figure 5.2. The only difference from Figure 5.1 is the use of a single-event transient digitizer. This setup was used to perform conducted measurements on devices B and D due to a non-constant pulse repetition rate in the emissions.

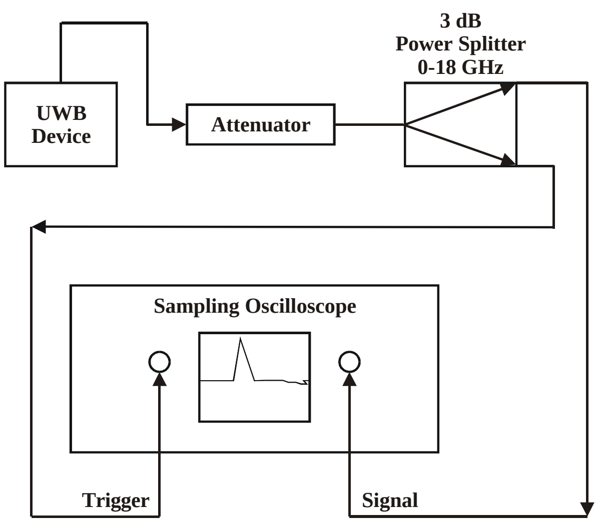

Figure 5.1. Device A, conducted measurement test setup.

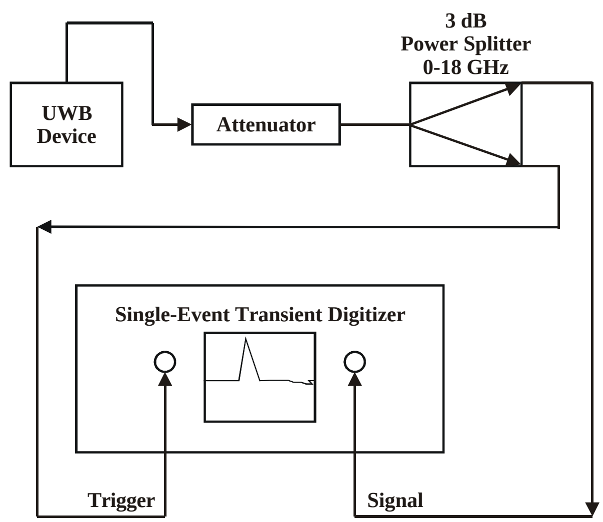

Figure 5.2. Device B and D, conducted measurement test setup.

The measured time-domain waveform for device A is shown in Figure 5.3. It exhibits a large main pulse followed by some damped ringing. The vertical axis represents voltage at the RF output connector of the UWB device. The corresponding frequency-domain power spectrum, which was calculated from the time-domain waveform, is shown in Figure 5.4. The vertical axis represents decibels relative to a milliwatt at the RF output connector of the UWB device. The caption presents a)f number which is the frequency spacing between the graphed points.

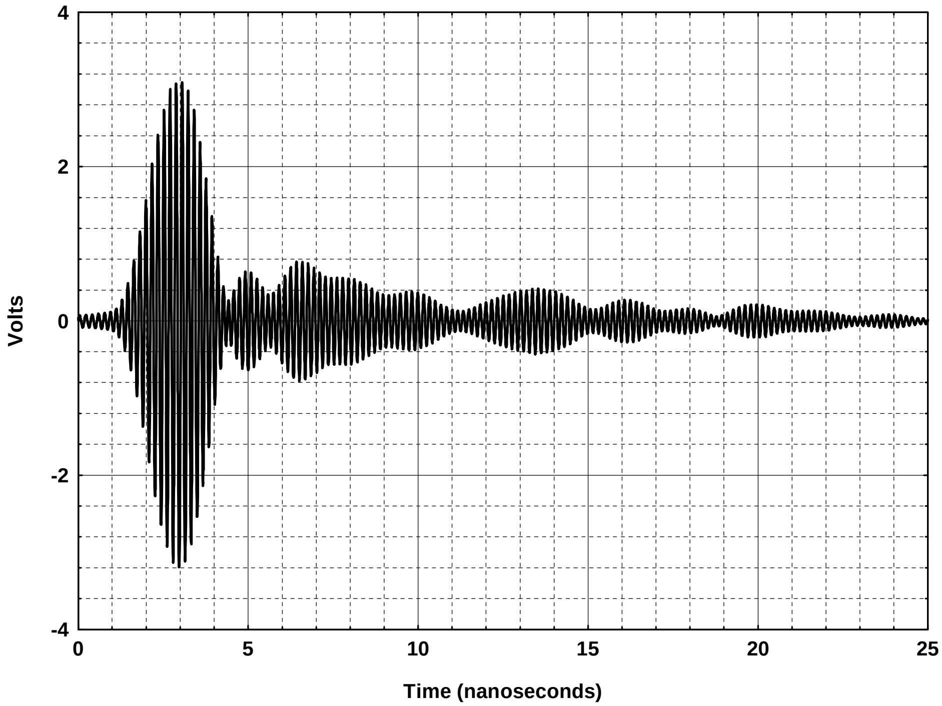

Figure 5.3. Device A, conducted time-domain waveform.

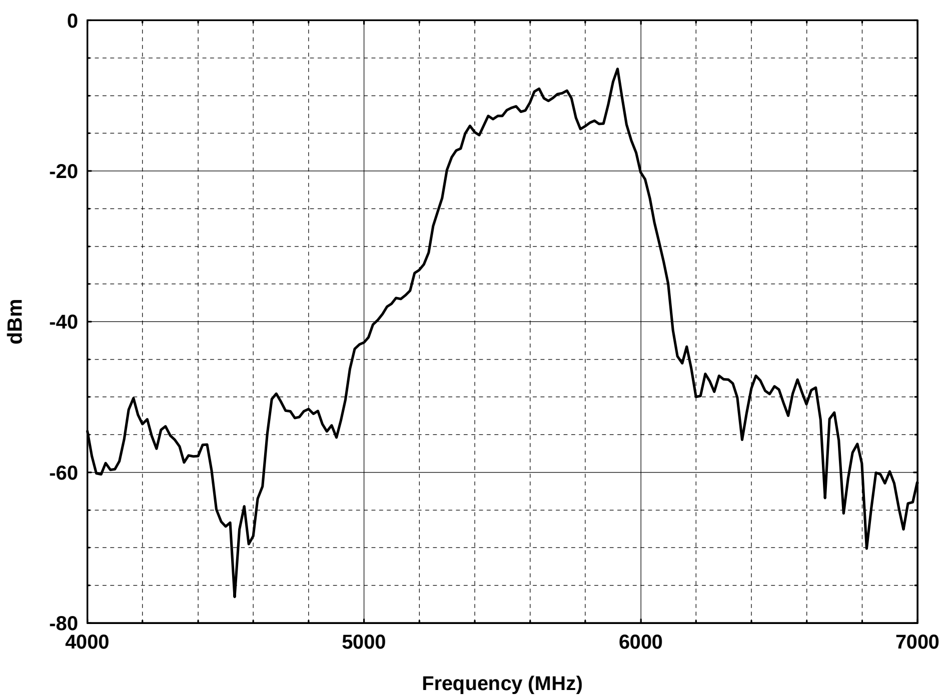

Figure 5.4. Device A, conducted power spectrum,) f = 16.67 MHz.

The following table summarizes the Total Peak Power and the Total Average Power calculated for the devices for which conducted measurements were performed.

Table 5.1. Total Peak and Total Average Powers from the Conducted Measurements.

Device Letter	Total Peak Power (dBm)	Total Average Power (dBm)
A	23.1	-27.8
B	32.0	-4.5
D	17.4	-16.0

The -10 and -20 dB bandwidths were extracted from the frequency-domain power spectrum graphs. These bandwidths, from the conducted measurements, are summarized below.

Table 5.2. Emission Bandwidth from the Conducted Measurements.

Device Letter	-10 dB Bandwidth (MHz)	-20 dB Bandwidth (MHz)
A	616.6	799.9
B	479.9	539.9
D	1349	2597

Appendix D contains the complete set of conducted measurement graphs for devices A, B, and D.

5.4 Radiated Measurements

Four different test setups were implemented for the radiated measurements. All of the test setups were performed in the NIST anechoic chamber. The first test setup is shown in Figure 5.5. The UWB device-under-test radiates using its manufacturer supplied antenna into the chamber. A ridged horn antenna was used in this configuration. The measurement frequency range using this antenna was 1 GHz to 4 GHz. Two stages of amplification were needed in this configuration to provide enough signal to drive the measuring instrument. A calibration was performed on the amplifiers to provide a frequency response correction. The signal was then split into two equal amplitude levels and fed into a trigger port and a signal port on a single-event transient digitizer. This setup was used to perform radiated measurements on device C. Figure 5.6 shows the second test setup that was used. The only difference from the previous test setup is a single stage of amplification since this UWB device produced a stronger signal. This setup was used to perform radiated measurements on device D. Figure 5.7 shows the third setup. The only difference from the previous test setup is the use of a different receiving antenna. The receiving antenna was a NIST 30 cm TEM horn, which produces minimal waveform distortion. The measurement frequency range using this antenna was 200 MHz to 4000 MHz. This setup was used to perform radiated measurements on device E (1500 MHz and 900 MHz modes). Figure 5.8 shows the fourth test setup. The only difference from the previous test setup is the addition of an attenuator to trim the measurement system gain down to an optimum level for the measurement. The NIST 30 cm TEM horn was used in this measurement as the receiving antenna. This setup was used to perform radiated measurements on device E (300 MHz mode) and B.

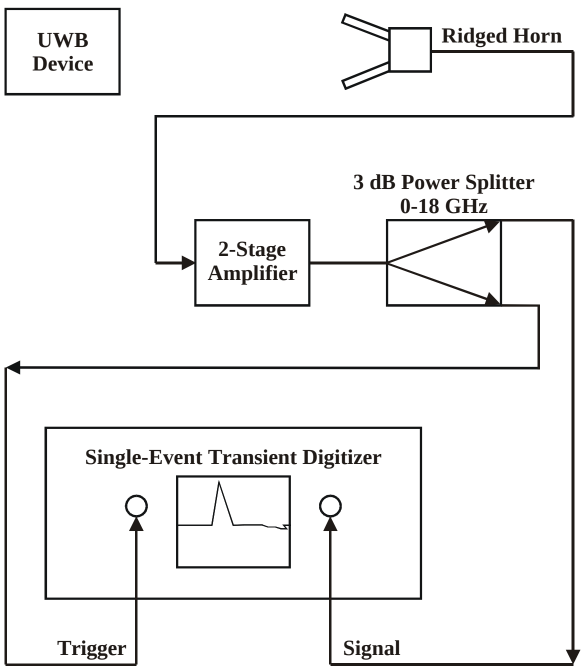

Figure 5.5. Device C, radiated measurement test setup.

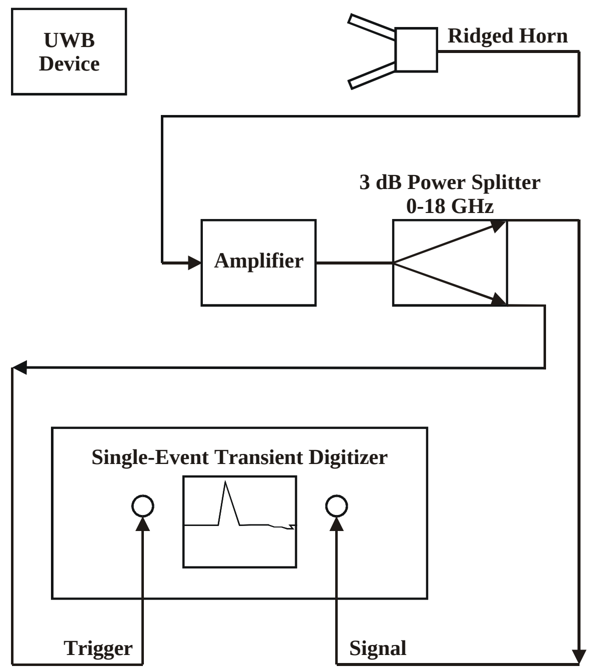

Figure 5.6. Device D, radiated measurement test setup.

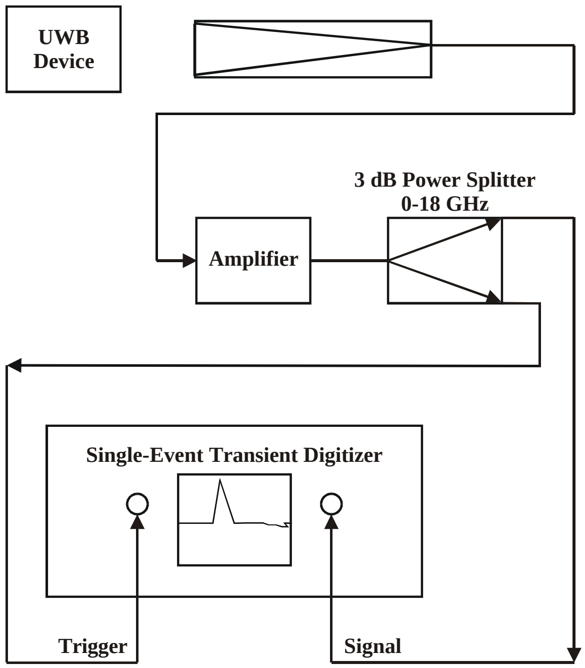

Figure 5.7. Device E (1500 MHz and 900 MHz), radiated measurement test setup.

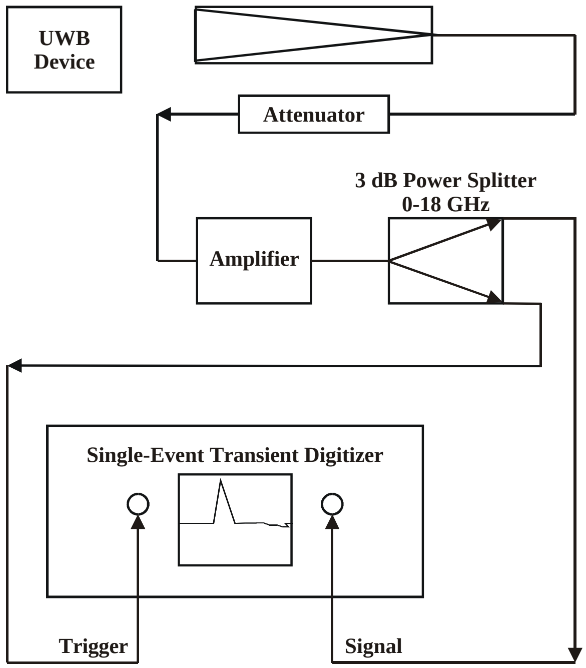

Figure 5.8. Device E (300 MHz) and B, radiated measurement test setup.

The measured time-domain waveform for device C is shown in Figure 5.9. The vertical axis represents voltage at the receiving antenna terminals. The separation distance between the receiving antenna and the transmitting antenna was one meter. The corresponding frequency-domain spectrum is shown in Figure 5.10. The vertical axis represents field strength (decibels relative to a microvolt per meter), calculated from the time-domain waveform, at the receiving antenna's location. The caption presents a)f number, which is the frequency spacing between the graphed points.

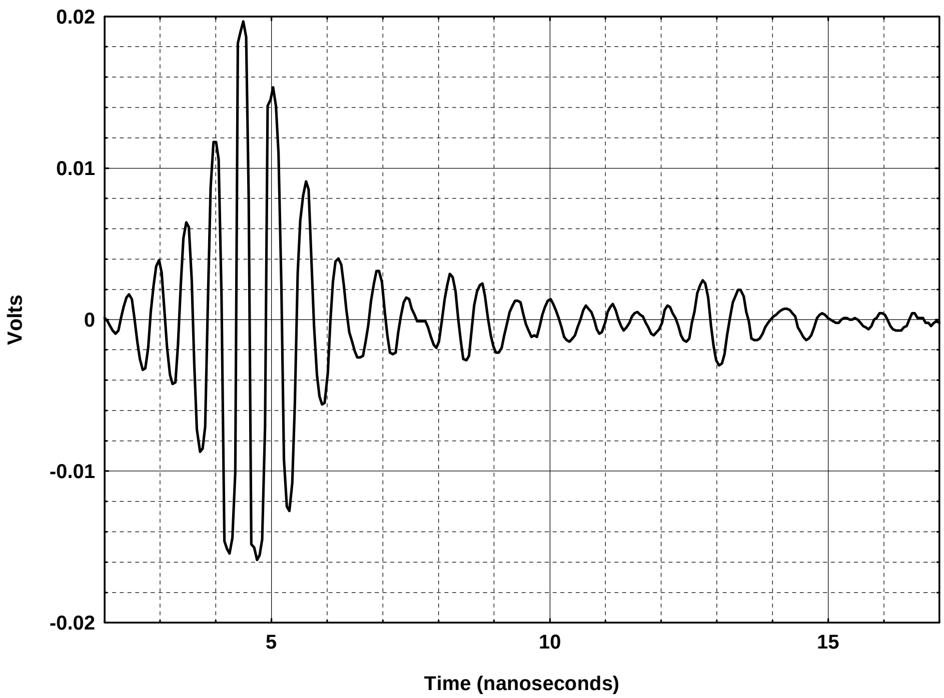

Figure 5.9. Device C, radiated time-domain waveform.

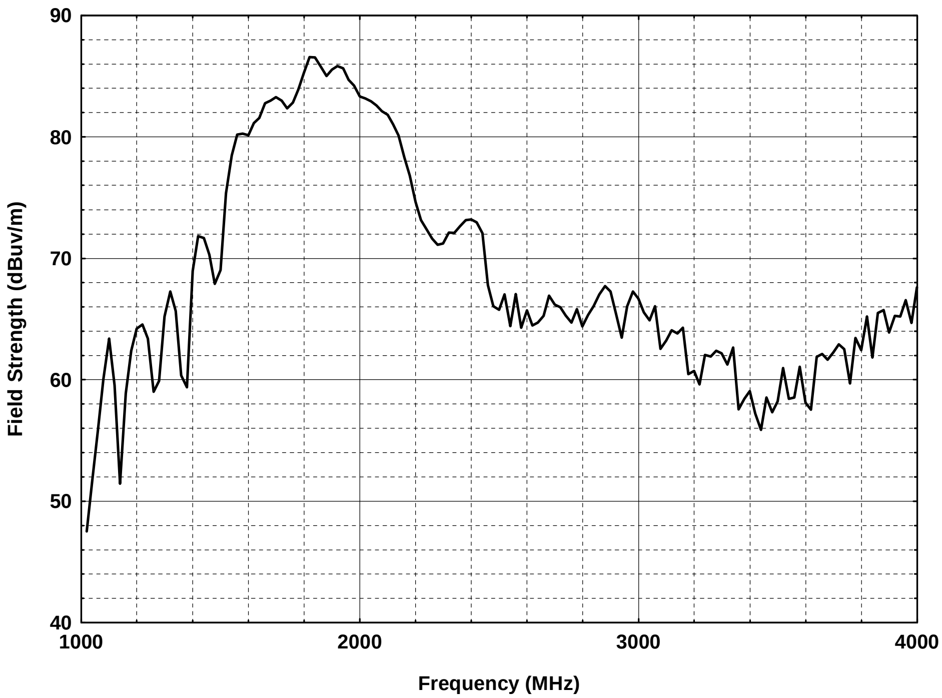

Figure 5.10. Device C, radiated peak field strength at 1 m,) f = 20 MHz.

The following table summarizes the Total Peak Power and the Total Average Power calculated for the devices for which radiated measurements were performed.

Table 5.3. Total Peak and Total Average Powers from the Radiated Measurements.

Device Letter	Total Peak Power (dBm)	Total Average Power (dBm)
B (maximum PRI)	-3.2	-39.8
B (minimum PRI)	-3.2	-33.7
C	-21.1	-48.6
D (maximum PRI)	-20.5	-51.8
D (minimum PRI)	-20.5	-41.8
E (1500 MHz)	-7.9	-55.6
E (900 MHz)	-3.7	PRI unknown
E (300 MHz)	12.5	PRI unknown

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The -10 and -20 dB bandwidths were extracted from the frequency-domain radiated spectrum graphs. Some of the devices had combinations of center frequency and bandwidth such that the portion of the spectrum of interest exceeded the valid frequency range of the radiated measurements. The bandwidth could not be determined so these cases are marked with "NA". The bandwidths, from the radiated measurements, are summarized below.

Table 5.4. Emission Bandwidths from the Radiated Measurements .

Device Letter	-10 dB Bandwidth (MHz)	-20 dB Bandwidth (MHz)
B	319.9	539.9
C	659.8	1080
D	NA	NA
E (1500 MHz)	2799	NA
E (900 MHz)	1650	NA
E (300 MHz)	NA	NA

Appendix D contains the complete set of radiated measurement graphs for devices B, C, D, and E. It is interesting to compare the conducted and radiated results for devices B and D. For both devices, the radiated and conducted waveforms are significantly different. While device B's conducted and radiated spectrums look similar, device D's conducted and radiated spectrums are significantly different over the 1 GHz to 2 GHz regions.

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