EXECUTIVE SUMMARY

Objectives of this Work

A preliminary objective was to develop a description and gain an understanding of the Ultrawideband (UWB) signal structure based on current, and hopefully typical, UWB system capabilities and applications. This began with a determination, from specifications and/or direct measurement, of the salient temporal characteristics of UWB signals that included minimal descriptions of their modulation schemes for data and/or voice and detailed descriptions of their pulse shape, width, repetition rate, dithering, and gating characteristics. Then, key fundamental aspects of UWB signal behavior were derived from first principles. This provided a basis for identifying what to measure and the effects certain temporal characteristics have on the spectral characteristics.

The primary objective was to observe and record the temporal and spectral characteristics of various UWB signals using both highly accurate measurement methods and practical approaches with commercial off-the-shelf (COTS) test equipment. The measurements are supported by the theoretical work noted above and confirmed through simulation. Meeting the primary objective has provided the technical information needed by NTIA to develop policies for use of UWB by the Federal government and to work with the Federal Communications Commission (FCC) to develop rules and regulations for UWB emissions. Secondary objectives included the development and description of reliable and repeatable measurement methods using COTS test equipment and to measure the effects UWB signals have on several, selected Federal Aviation Administration (FAA) radar systems.

There are unanswered questions and claims regarding UWB. Some say that the 2 GHz bandwidth (nominal, based on a pulse width of 1 ns) is ideal in many applications because the already low total power of a UWB signal is spread so “thinly” that the spectral power density in any conventional (bandwidth limited) channel is inconsequential. The claim goes further to say that the signal is similar to Gaussian, or white, noise therefore it is like the background noise any communications or radar receiver experiences.

UWB Technology and the Radio Spectrum

UWB technology may offer very effective solutions for various communications and sensing applications; but its uncommon approach of using narrow pulses, or impulses, as a basic signal structure rather than generating and modulating a sinusoidal carrier results in an unusually wide emission bandwidth. Since such a wide signal covers many radio bands and services, the conditions under which it can operate without causing undue interference must be determined before UWB systems are allowed to proliferate.

The use of a carrier signal by nearly all existing services that share the radio spectrum helps ensure that the bandwidth of the emissions of those signals can be kept as narrow as possible for any given application, i.e. the bandwidth required to transmit the information of interest or perform the necessary sensing functions. This approach allows for effective and efficient spectrum management and frequency assignment procedures for sharing of the radio spectrum among diverse applications and users. Can UWB share the radio spectrum with existing users? What frequency-related limits such as emission bandwidth and lower frequency limit should be imposed on UWB signals? Should limits be established for time-related characteristics such as pulse width and pulse repetition rate (PRR)? If UWB systems proliferate, what are the effects of the aggregate of independent UWB signals?

Measurements of Ultrawideband Signals

From over twenty UWB devices available to ITS, five were chosen to be fully measured. This selection represents a sampling of the various UWB signal waveforms in use. This group included communications and sensing devices that used pulse-position and on/off keying modulation methods, some did not incorporate pulse dithering, another used relative dither and yet another used absolute-time-base pulse dithering, one had gated pulse groups.

A very fast transient digitizer was used to capture the individual pulses directly in the time domain (in some cases a sampling oscilloscope was used) at the output of each device (a “conducted” measurement) and “in space” as measured by a known antenna (a “radiated” measurement). Figure ES.1 shows examples; (a) is a narrow impulse about 1.5 ns in length from one of the UWB devices, and (b) is a longer, very complex pulse shape about 15 ns in length from a different device. The former occupies about 3.5 GHz of spectrum and the latter about a fifth or sixth of that. Although some devices generate an impulse like that shown above in ES.1(a), when radiated by an antenna, the impulse may be changed quite dramatically. Figure ES.1(c) shows what the pulse shown in (a) is like after being radiated by an antenna designed to radiate UWB signals.

Measurements of the UWB signal power in various bandwidths were made using spectrum analyzers and it was determined that the measurement of the signal amplitude probability distribution (APD) is a very informative measurand. It shows, sometimes in a dramatic way, the general nature of a UWB source, whether it resembles Gaussian noise or very impulsive noise. Figure ES.2 shows two APD curves on a Rayleigh probability scale. Curve A, actually a straight line, represents a signal that is Gaussian distributed; while curve B is the APD for one of the UWB devices measured. Notice that the signal exceeds about -55 dBm for 1% of the time and exceeds -80 dBm for about 12% of the time that it is on. Both signals here are noise-like; the former, a Gaussian distribution, is a truly random signal and the latter is a highly impulsive signal.

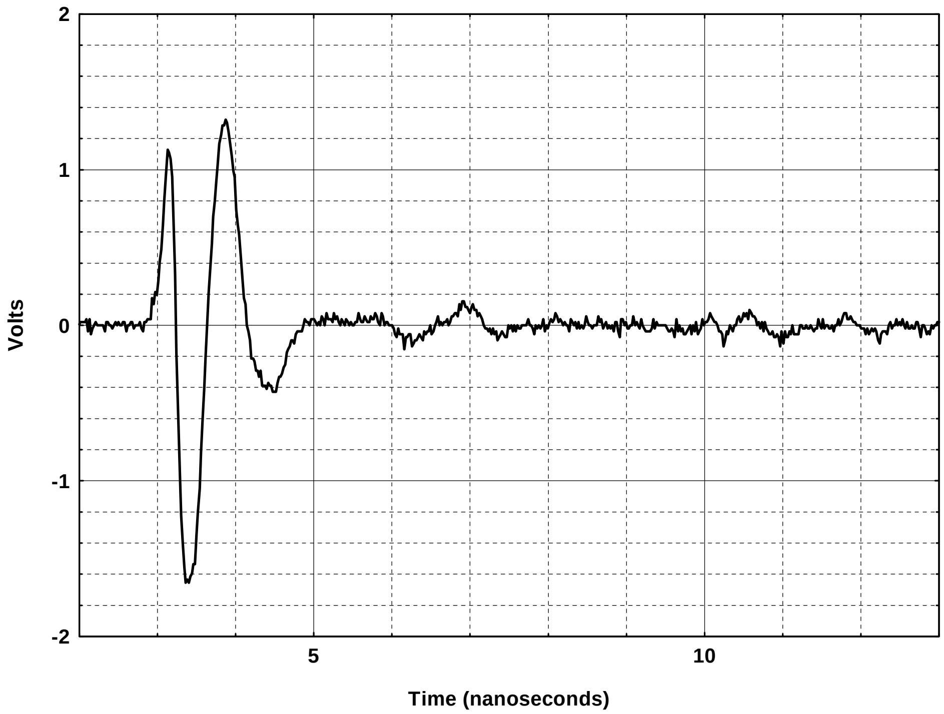

Figure ES.1(a). An example of a short UWB pulse.

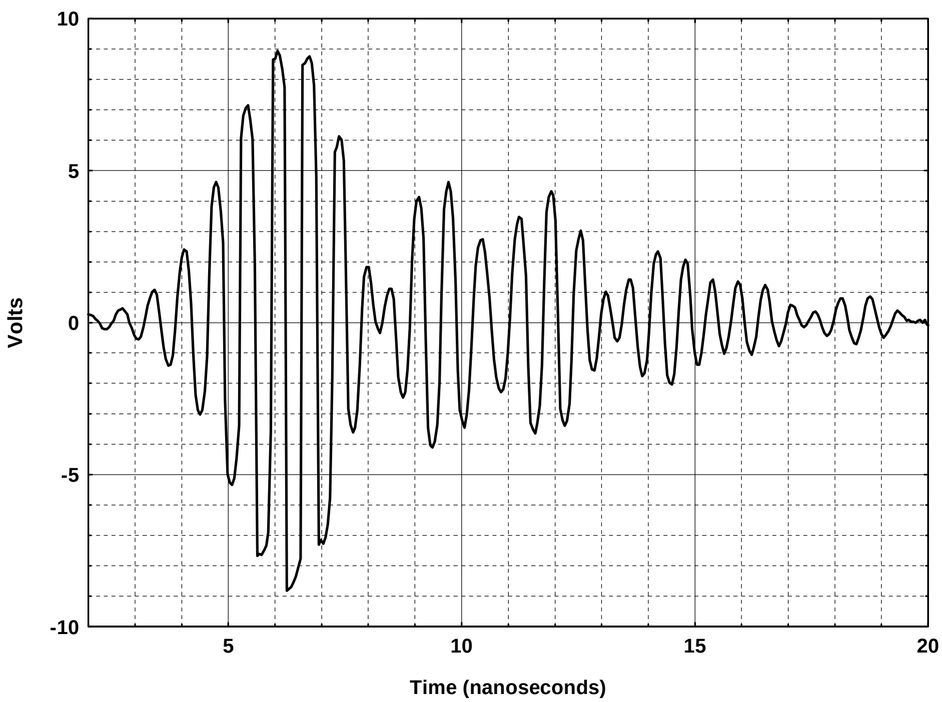

Figure ES.1(b). An example of a long UWB pulse.

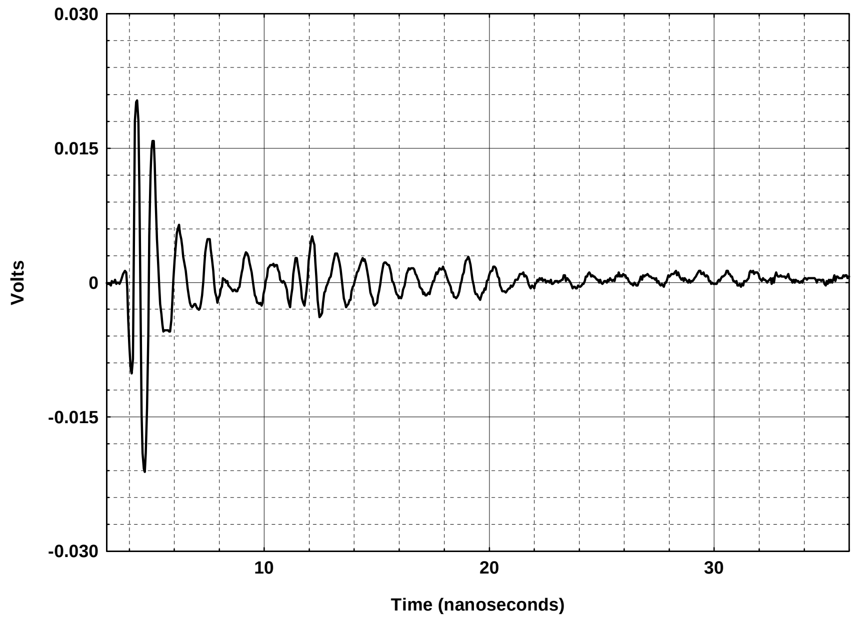

Figure ES.1(c). The shape of the pulse shown in (a) radiated, i.e. "in space."

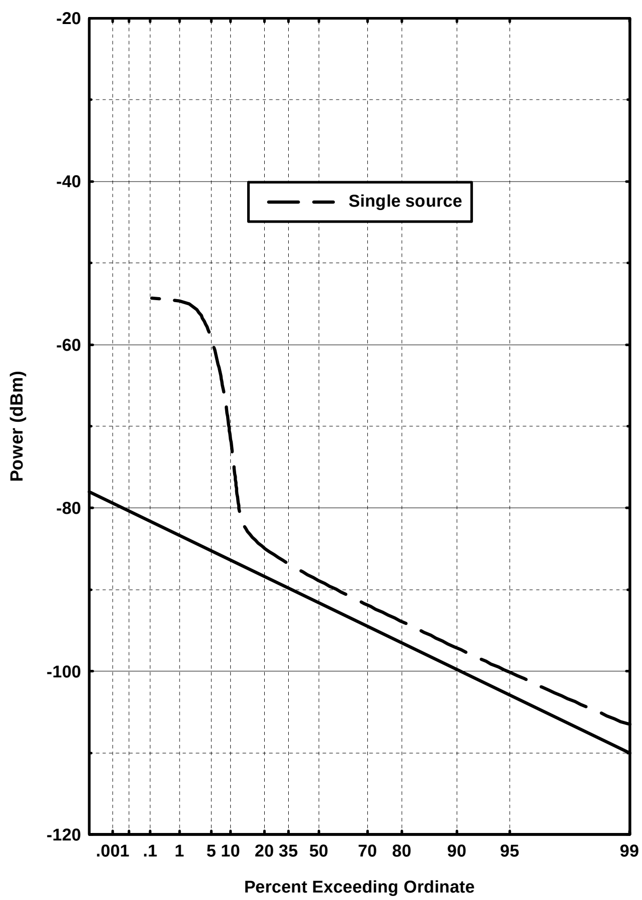

Figure ES.2. APDs for Gaussian noise and a UWB signal.

Companion Report and Other Investigations

The research, observations, measurements, and analyses presented in this report were performed at the NTIA Institute for Telecommunication Sciences (ITS), an independent laboratory located in Boulder, Colorado. The National Institute of Standards and Technology (NIST) Radio Frequency Technology Division, also located in the same building as ITS in Boulder, performed some of the measurements reported herein. The NTIA Office of Spectrum Management (OSM) has used the results of this investigation to examine the options and constraints appropriate for allowing UWB to share the use the radio spectrum. In their report, a companion to this one, separation distances are developed for widely accepted receiver protection and interference criteria. It discusses the operation of UWB under unlicensed and licensed conditions.

A follow-on research effort at ITS has made use of the knowledge of UWB signal characteristics from this work to develop a test facility to measure the effects of UWB signals on Global Positioning System (GPS) receivers. The results of this GPS interference investigation will be published by ITS in a report similar to this one and OSM will use the GPS receiver performance data to determine the federal government's position regarding the potential for UWB to share the spectrum, in particular, the GPS band at 1.5 GHz.