THE TEMPORAL AND SPECTRAL CHARACTERISTICS OF ULTRAWIDEBAND SIGNALS

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Ultrawideband (UWB) technology, useful for both communication and sensing applications, uses the radio spectrum differently than the vast majority of radiocommunication technologies. UWB systems make use of narrow pulses and time-domain signal processing. Questions regarding how these systems, with their potentially very wide emission bandwidths, might affect the efficient use of the radio spectrum or cause interference to conventional radio and wireless systems must be answered before there is any large-scale deployment of UWB systems. The investigation reported here examined both the temporal and spectral characteristics of UWB signals, since all radio signals exist in both the time and frequency domains. The investigation was approached with theoretical analyses, measurement of actual UWB devices, and computer simulations. The emissions of several UWB transmitters were measured under controlled, and repeatable, laboratory conditions. Those measurement methods useful for routine measurements using commercially-available test equipment were identified. The characteristics of an aggregate of several UWB signals were examined. An initial assessment of the effects of UWB signals on several Federal Government systems was accomplished through field measurements. This report provides a basis for an assessment of the effects of UWB signals on other communication and radar systems, the study of the spectrum efficiency of UWB technologies, and the development of spectrum sharing policies and regulations.

Key words: emissions, aggregate emissions, ultrawideband, UWB, time domain, frequency domain, radio spectrum, average power, RMS power, peak power, signal strength, pulse measurements, spectrum measurements.

1. THE RADIO SPECTRUM AND ULTRAWIDEBAND

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As the radio spectrum becomes more crowded due to the ever-increasing demand for radio and wireless communications and for sensing, a wide variety of creative approaches have been proposed for allowing more users to share this limited resource. These innovations include new, digital technologies that permit the same amount of information (e.g., an audio signal) to fit into increasingly narrower channels as is occurring in the land mobile radio service; or allow much more information to be transmitted in existing channels as is occurring with high-definition

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television. This investigation is primarily concerned with one such approach called ultrawideband (UWB) technology and its ability to share the spectrum with existing users. There are claims that UWB technology, which uses novel signal generating and processing methods, can use large portions of the already allocated spectrum with minimal or no interference to existing users due to the very low spectral power density of UWB signals. The assessment of that claim is critical to decisions regarding the deployment, and potential ubiquitous use, of UWB devices for both communications and sensing. The radio spectrum, a nondepleting but limited natural resource, is used to support all radio and wireless services for both public and private purposes. Broadcasting, land mobile radio, cellular telephones, radar, satellite communications, remote sensing, and radio astronomy all depend upon the shared use of the radio spectrum which has benefitted mankind for the past century. The rules and regulations that enable this sharing are based on fundamental natural laws (of physics), agreements among proximate users, international treaties, and domestic public law. Spectrum management and frequency assignment represent the disciplines and processes used to allocate bands of the spectrum to various radio services and assign frequencies, each with an associated bandwidth, to individual users. In many cases, users are expected to ensure that their transmitter's emissions do not adversely affect existing users.

This approach is based on the fact that all electromagnetic signals can be both electronically generated and separated by the frequency of those signals. Essentially, all conventional signals use a single-frequency signal – a sinusoidal (sine) wave called a carrier that is modulated with the information it is to "carry." Its amplitude, frequency, or phase is varied according to the information (e.g., voice, video, or data) to be carried.

Radio and wireless communications are managed using tools and techniques that describe signals in the frequency domain; however, it is very important to recognize that every signal exists simultaneously in both the frequency domain and the time domain. These domains are simply alternative ways of describing and processing electronic and electromagnetic (radio) signals. This is easy to visualize. The cycling of a simple sine wave is the time domain perspective and its existence at a single frequency is the frequency domain perspective.

Using a carrier allows good control over the bandwidth any signal occupies and has been an enormously effective approach for dividing the radio spectrum by bands and channels, which has enabled tractable and effective sharing of the spectrum. It has always been possible, however, to generate signals without a carrier. In the case of UWB, these signals are simply pulses of electromagnetic energy shaped by electronic circuitry and a transmitting antenna. Recent advances in electronics and microcircuits have allowed the development of communications and radar systems that use such carrierless pulses. It is a fundamental physical law that the narrower the pulse in the time domain, the wider the emission in the frequency domain.

A classic radar is an example of a device that requires signal processing in both the frequency domain and the time domain. It has a carrier. Pulses of that carrier are transmitted periodically. Reflections of that signal from a target return to the point of origin. The radar receiver uses a filter in the frequency domain to select only that small portion of the spectrum where the radar signal exists. Then, the receiver uses time domain processing to determine how long it took the reflection to return and thus determine the distance to the target.

1.1 Objectives of this Work

The primary objective of this investigation was to develop an understanding of UWB signal characteristics based on several currently available devices. Both temporal and spectral characteristics of the UWB signals were sought, with the latter being of particular interest. The nature of the emission spectrum, whether smooth, comprised of lines, or a combination of both, is needed for interference analyses. How that emission spectrum depends on the temporal characteristics such as UWB pulse width, type of signal modulation, and the use of dithering may be needed to develop sharing policies and regulations. Finally, the nature of the aggregate of many individual UWB signals is important in understanding how the radio spectrum might be affected if and when large numbers of UWB devices are deployed.

Practical and repeatable measurement methods to obtain values for particularly useful UWB signal parameters with available commercial-off-the-shelf (COTS) test equipment may also be needed for compliance testing related to regulation. Where possible, these practical methods are identified and any limitations are described. Highly accurate time domain measurements are used to ensure that the COTS-based measurement methods are reliable.

Finally, an initial assessment of the effects of UWB signals on existing systems will indicate if, and how much, additional work is needed in this area. A limited effort to determine how much UWB signal power can pass through the front-end (antenna, amplifiers, and filters) of selected receivers provides a basis for more detailed investigations of the effects on victim system performance and allows the calculation of desired signal-to-noise and interference-to-noise ratios for the selected systems.

1.2 Specific Ultrawideband Systems Measured

The actual UWB emitters used in this work were borrowed from a number of sources, including UWB device manufacturers and owners of systems that contain UWB devices or that use UWB signals to perform their functions. These included prototype, experimental, and operational systems. Since the objectives of this work were to understand and characterize the radiated signals and not to evaluate the performance of the systems, the sources of UWB equipment are not identified. Of the dozen or so devices available, five were selected for the measurements described in subsequent sections of this report, and are labeled with letters, e.g. Device A. For comparison, the emissions of an electric drill were also characterized. It is identified simply as “electric drill.” The devices selected are intended to provide a realistic sample of the various UWB signal structures being used today.

1.3 Organization of this Report

This investigation of UWB signal structure involved a number of aspects ranging from theoretical analyses to measurements, both in the laboratory and field, and computer simulations. As is often the case with broad investigations such as this, a number of workers with different skills were involved. To give proper credit to the researchers in each area, the author (or authors) of each major section of the report is identified at the beginning of each section. The editor was responsible for assembling the full report.

The first two sections provide orientation and background for the reader. This section contains some essential background information and the objectives of the work. Section 2 provides the reader with a brief technical description of UWB technology and some of its salient applications; this same section also gives a brief history of UWB development and early applications. It also contains a brief overview of the regulatory issues.

Sections 3 and 4 examine the UWB signal from first principles. Using typical temporal characteristics of UWB waveforms, the associated spectral characteristics are derived in Section 3. Then in Section 4, the characteristics of a group of individual UWB signals, called the aggregate signal, is examined.

Sections 5 through 7 describe a variety of measurements of UWB signals and their effects on selected receivers. Section 5 describes the procedures and results for fundamental measurements in the time domain. Where possible, the waveform of individual pulses is obtained. Section 6 describes procedures for, and results of, making similar measurements using commercially-available test equipment. This section also describes procedures for, and results of, band limited spectral measurements. Section 7 describes the effects that were observed in the receivers of several Federal Government systems. These measurements do not include an assessment of the overall performance of those systems; only those effects that are observable in the radio-frequency (RF) or intermediate-frequency (IF) sections of those systems.

Section 8 summarizes the observations made throughout this investigation. These observations include: the general character of UWB signals (spectra) based on theoretical analyses (Sections 3 and 4); the nature of the actual UWB pulses, both conducted and radiated (Section 5); the nature of the UWB signal in both the time and frequency domains when received in a range of bandwidths (Section 6); and the effects on selected receivers (Section 7). Other observations include which procedures may be best suited for other laboratories that may have only commercial-off-the-shelf (COTS) test equipment; and the effects various detectors have on measurements.

Section 9 contains a comparison of results from measurement, theory, and simulation.

The Appendices to this report contain supporting information and detailed measurement results. Appendix A is a brief tutorial on the amplitude probability distribution (APD) which was chosen as a key measurand for this work. Appendix B describes simulations on the UWB signal temporal and spectral characteristics of a UWB signal when passed through a limited bandwidth (receiver or test instrument). Appendix C describes how to convert and/or correct certain measured values. Appendix D contains the measured data for the five UWB devices and an electric drill. Appendix E contains the measured data for an aggregate of two, independent UWB signals.