Ultra Wideband (UWB) - Introduction and Signal Modeling

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ABSTRACT

Ultra Wideband is a new technology from commercial or civilian application viewpoint. It uses already allocated radio spectrum without causing significant interference to other users. It uses very low power, which is below the thermal noise of the receiver and is inherently difficult to detect by un-intentional users. Since, FCC approved the regulation for the commercial use of UWB in February 2002, the development of UWB technology is drastically gaining momentum. However, the technology itself is not new. It has already been used in military applications. UWB has three basic areas of applications, which are communication, positioning and imaging (UWB Microwave). The main commercial application will be for communication since it has very high data transfer rate for short distance. It can also be used for both indoor and outdoor 3-D positioning. Another important application is imaging like microwave remote sensing. An UWB sensor can pass through doors and walls and hence detect the objects inside the room.

In this paper, we will introduce about UWB technology along with it's various possible applications. We will also present some models to generate UWB signal and it's analysis using signal-processing tools.

UWB Introduction

When Guglielmo Marconi made radio history by transmitting the Morse code for the letter "S" across the Atlantic ocean on December 12, 1901, little did he know that his brilliant idea of using pulses of electromagnetic energy for radio communication would resurface nearly a hundred years later in the form of ultra-wideband (UWB) technology [7].

Ultra-Wideband (UWB) technology is generally defined as any wireless transmission scheme that occupies fractional bandwidth of more than 0.25. The fractional bandwidth is given by equation 1.

$$B_f = \frac{f_h - f_l}{(f_h - f_l)/2} > 0.25 \quad \textbf{(1)}$$

A very wide bandwidth means better multipath mitigation, interference mitigation by using spread spectrum techniques, improved imaging and ranging accuracy, more users and higher data rate. A lower center frequency for a given bandwidth allows better materials penetration. UWB device transmits millions of very low power radio pulses (impulses), each typically lasting less than a nanosecond over a very large radio spectrum. UWB uses the existing spectrum that is currently being used by other conventional radio communication devices. In this way, it re-utilizes the existing spectrum efficiently. The energy level of UWB signal is much below the thermal noise of other conventional devices (e.g. Wireless LAN, Bluetooth, Cellular Phones etc). UWB system has no carrier. Carrierlessness and very wide bandwidth are the two major characteristics of UWB.

Signal Modeling

UWB signals can be modeled by Gaussian monopulses. The monopulse with a narrow pulse width produces a wide bandwidth signal. The monopulse's width determines the center frequency and the bandwidth. The Gaussian function in time domain is given by equation 2. τ is time decay constant that determines the monocycle's duration and t is time. UWB pulses are also modeled by normalized second derivative of the Gaussian monopulses, which is given by equation 3.

$$v(t) = \frac{t}{\tau} e^{-\left(\frac{1}{\tau}\right)^2} \quad \text{------------} \quad \textbf{(2)}$$

$$v(t) = \sqrt{\frac{4}{3\tau\sqrt{\pi}}}\left(1-\left(\frac{t}{\tau}\right)^2\right)e^{-0.5\times\left(\frac{t}{\tau}\right)^2} \quad \text{----------------} \quad \textbf{(3)}$$

Figure 1 shows the Gaussian monopulse and normalized 2nd derivative Gaussian monopulse. The pulse itself contains no data. Therefore long sequences of pulses defined by the pulse repetition frequency (PRF) with data modulation are used for communication. Data information that is to be sent is modulated onto certain parameters of the transmitted pulse. These parameters may include the pulse position, amplitude or phase. In the case of pulse position modulation, a "1" may cause the transmitted pulse to be slightly advanced in time, whereas a "0" may cause a slight retardation in pulse position.

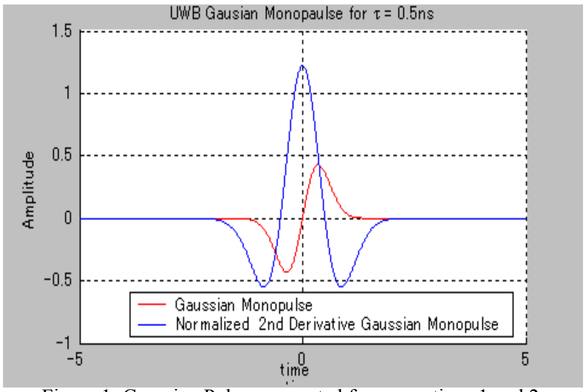

Figure 1: Gaussian Pulses generated from equations 1 and 2

Figure 2 shows a software simulation of UWB transmitter and receiver using SystemView software [6]. The simulation uses ON/OFF Keying modulation of pulses. The pulses are 80e-12 seconds wide with PRF of 40MHz. The pulses are allowed to remain or they are removed by multiplying the pulse stream by +1.0 v or 0.0 v. The +1.0 or 0.0 volts represent the data to be transmitted. Instead of zero and one volts (ON/OFF Keying) multiplication, we can also reverse the phase of the pulse by pi radians. In this case, the modulation is called BPSK (Binary Phase Shift Keying). The phase is reversed whenever the data is zero or one. Figure 3 shows the transmitted OOK modulated pulse train and figure 4 is the zoomed portion of it. Figure 5 is the power spectrum density of the transmitted pulse train. Figure 6 shows the pulse train at the receiver end. The receiver end is modeled with thermal and other noise, that's why wee can see noise in the receiver end.

UWB Applications

The three basic fields of application of UWB are communication, ranging and imaging. UWB can communicate at very high rate compared to present communication systems (e.g. mobile phones, bluetooth, wireless lan etc). Since, the bandwidth of UWB is very wide, it is multipath resistance and by using spread spectrum it can be made immune to interference and multiple users are possible like GPS signal. It has no interference to other narrowband systems, since an UWB signal for other systems would appear as noise, which would be filtered. However, it may have interference to other wideband systems like GPS which depends on pulse repetition frequency [3]. Interference from UWB to other communication systems are not well not yet and there are lot of research being conducted in this field. We can imagine to have UWB systems to connect all our communications, data, audio/video and peripheral devices using UWB in future. For example, a PC can download a movie using UWB, can play it on the PC and then display on TV using UWB. Since, UWB does not need carrier, the design itself is simpler and hence single chip implementation is possible.

UWB can also be used for ranging or positioning. Experiments have shown good 3D positional accuracy of few decicentimeters within a few hundred meters [5]. Thus it could be a future positioning device both for indoor and outdoor applications. Imaging is another important application of UWB. UWB can penetrate objects to sudden depth and hence it can detect buried objects like land mines. It can see through the walls and doors, which make it possible to see inside the room or find people buried in debris. Location of steel reinforcement bars in concrete, electrical wiring and pipes hidden in walls can be detected.

Conclusions

We have presented briefly about UWB technology and it's applications. Since, FCC gave approval for public use of UWB in February 2002, lot of research are undergoing. UWB can be used successfully not only for communication but also for positioning and imaging. However, it still needs lot of research to be done on designing the signal models, hardware designs (especially single chip concept), interference effect to other devices as well as software part.

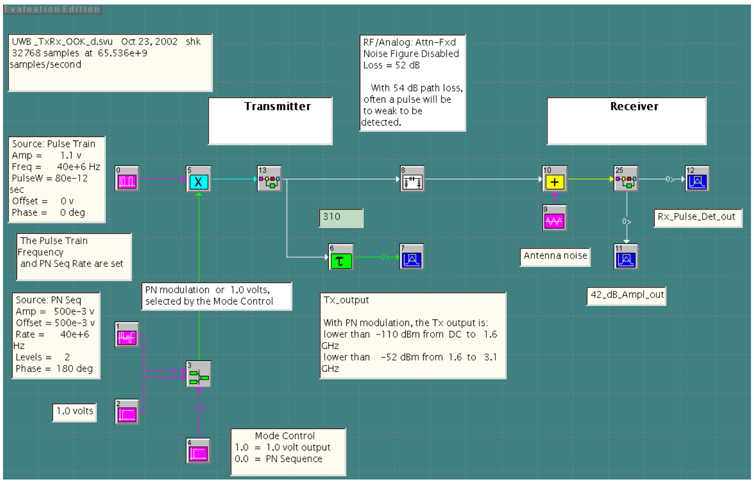

Figure 2: UWB Simulation in System View Software

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[8] http://www.aetherwire.com/CDROM/Welcome.html

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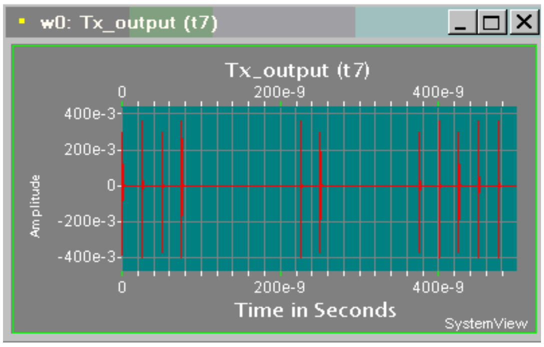

Figure 3: Transmitted Pulse Train using OOK

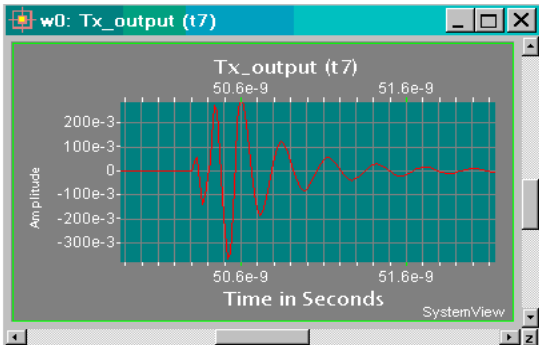

Figure 4: Zoom view of Transmitted Pulse using OOK

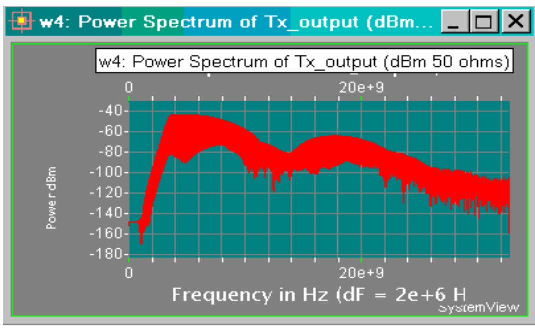

Figure 5: Power Spectrum Density of Transmitted Pulse

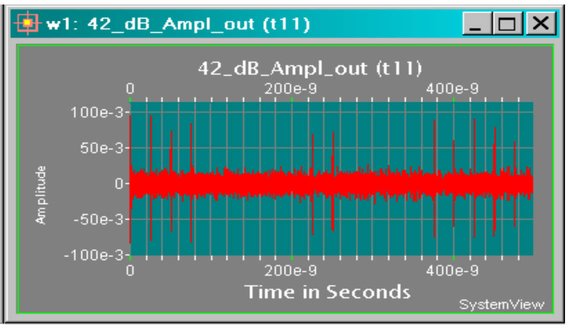

Figure 6: UWB Pulses at Receiver End with noise