Modelling of Ultra-wideband (UWB) Radio System

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Abstract: This paper gives an introduction to one of the revolutionary technology for wireless communication - Ultra-Wideband (UWB) radio. MATLAB simulations of such system have been performed and the performance of such system due to different pulse shaping scheme is compared. Different spectra are produced and their properties are measured. Further study explores possible ways in suppressing the spectrum and means to quantify the spectrum. The implications that signal bandwidth and power have on the possible applications of the technique are also considered.

1. Introduction

Bandwidth inadequacy has always been the bottleneck for the development of wireless communication systems as spectrum is a limited recourse and is becoming more valuable. New technologies aiming to allow new services to use already allocated spectrum to establish the services without causing significant interference to present users leads to the concept of Ultra Wideband (UWB) systems. UWB uses low power radio techniques allowing previously designated RF bands to be reused without interfering with the normal low bandwidth channels [1], [2]. Because the power spectral density of such systems is very low, it is inherently difficult to detect and appears like noise to other system. Therefore these allocated RF bands are reutilised by effectively hiding signals under the noise floor.

In this paper, the underlying basic technology of WUB systems is briefly introduced. A simulated system model is then followed, the effect on Power Density Spectrum (PSD) employing data modulation and different pulse position scheme are described and compared.

2. UWB Technology Basic

There are different approaches to the implementation of UWB employed by companies for a variety of applications. In this paper time modulated implementation of UWB (TM-UWB) will be the main focus.

2.1 Gaussian Monocycle

The basic element in UWB radio technology is the use of Gaussian monocycle [3] as shown in figure 1. in both time and frequency domains. The monocycle with a narrow pulse width produces a wide bandwidth signal. The monocycle's width determines the centre frequency and the bandwidth.

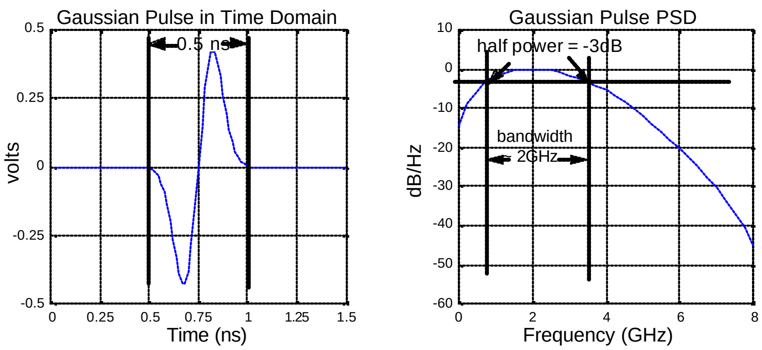

Figure 1:2GHz Centre frequency Gaussian Monocycle in Time and Frequency Domains

The Gaussian function in the time domain is given by;

$$v(t) = \frac{t}{t} e^{-(\frac{t}{t})^2} \qquad (1)$$

t is a time decay constant that determines the monocycle's duration and *t* is time. For the Gaussian monocycle showed in figure 1, the pulse duration is 0.5 ns and the centre frequency is 2GHz with the half power bandwidth approximately 2GHz. Hence, the centre frequency is the reciprocal of the monocycle's duration and the bandwidth is 116% of the monocycle's centre frequency. A typical UWB pulse range between 0.2 and 0.5 nanosecond.

By applying Fourier transform, the magnitude spectrum of the Gaussian monocycle in the frequency is given by;

$$\left| \mathbf{F}\left\{ \frac{t}{t} \cdot e^{-\left(\frac{t}{t}\right)^2} \right\} \right| = pft^2 \sqrt{p}\, e^{-(pft)^2} \qquad (2)$$

2.2 Monocycle Sequence

The monocycle itself contains no data, therefore a long sequence of monocycles termed a "pulse train" with data modulation is used for communication. A pseudo-random (PN) noise code can be used as a channel code to add a time offset to each impulse as illustrated in Figure 2. It can be seen that the monocycles in the time domain are transformed to energy spikes ("comb lines") at intervals in the frequency domain, therefore the power is spread among the comb lines. By shifting each monocycle's at a pseudo-random time interval, the pulses appear to be white background noise to users with a different PN code. PN coding can be used to eliminate energy spikes that would have interfered with conventional RF system at short range if pulses were placed uniformly in the time domain. This channel code also allow the data to be detected by the intended receiver, therefore data transmitted is more secure in hostile environment and also with less interference with multiple users [3]. The use of PN sequence in time hopping may theoretically imply that system could have infinite number of unique users all on different PN channels.

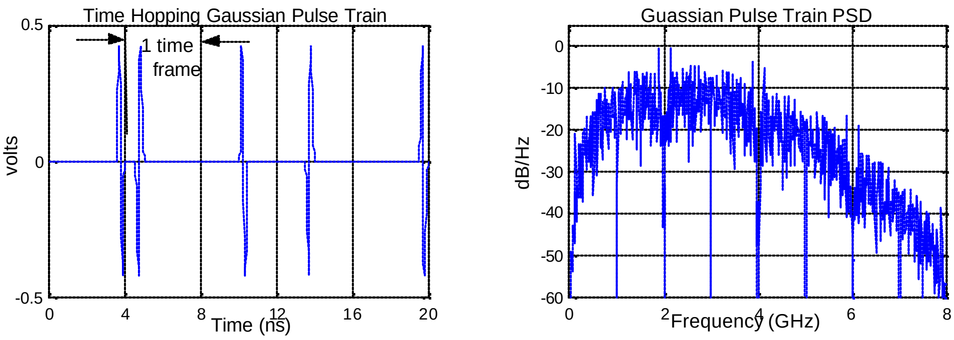

Figure 2: The impact of PN time modulation on energy distribution in the frequency domain.

3. UWB System Model

In the initial simulation, a UWB mathematical model basing on Gaussian pulse train in time and frequency domain with MATLAB using Fast Fourier Transform (FFT) were made, Figure 3a) and e), the effect on the spectrum by changing the pulse duration and/or repetition rate of each pulse were examined. The key findings from the simulated results are;

- Figure 3b) and f): Increasing the pulse rate in the time domain increases the magnitude in the frequency domain, i.e. the pulse rate influences the magnitude of the spectrum.
- Figure 3c) and g): The lower the pulse duration in the time domain, the wider spectral width, i.e. the pulse duration determines spectral width
- Figure 3d) and h): A random pulse-to-pulse interval produces a much lower peak magnitude spectrum than a regular pulse-to-pulse interval since the frequency components are unevenly spread over the spectrum; the additions of magnitude at the same are less effective. Therefore Pulse-to-pulse interval controls the separation of the spectral components.

It was found that halving pulse rate halves the spectrum's magnitude, therefore alternating the pulse rate had a greater effect on the spectrum since. But lower pulse rate simply means less input power in transmitting less number of pulses, therefore lowering the pulse rate is not an efficient way in flattening the spectrum.

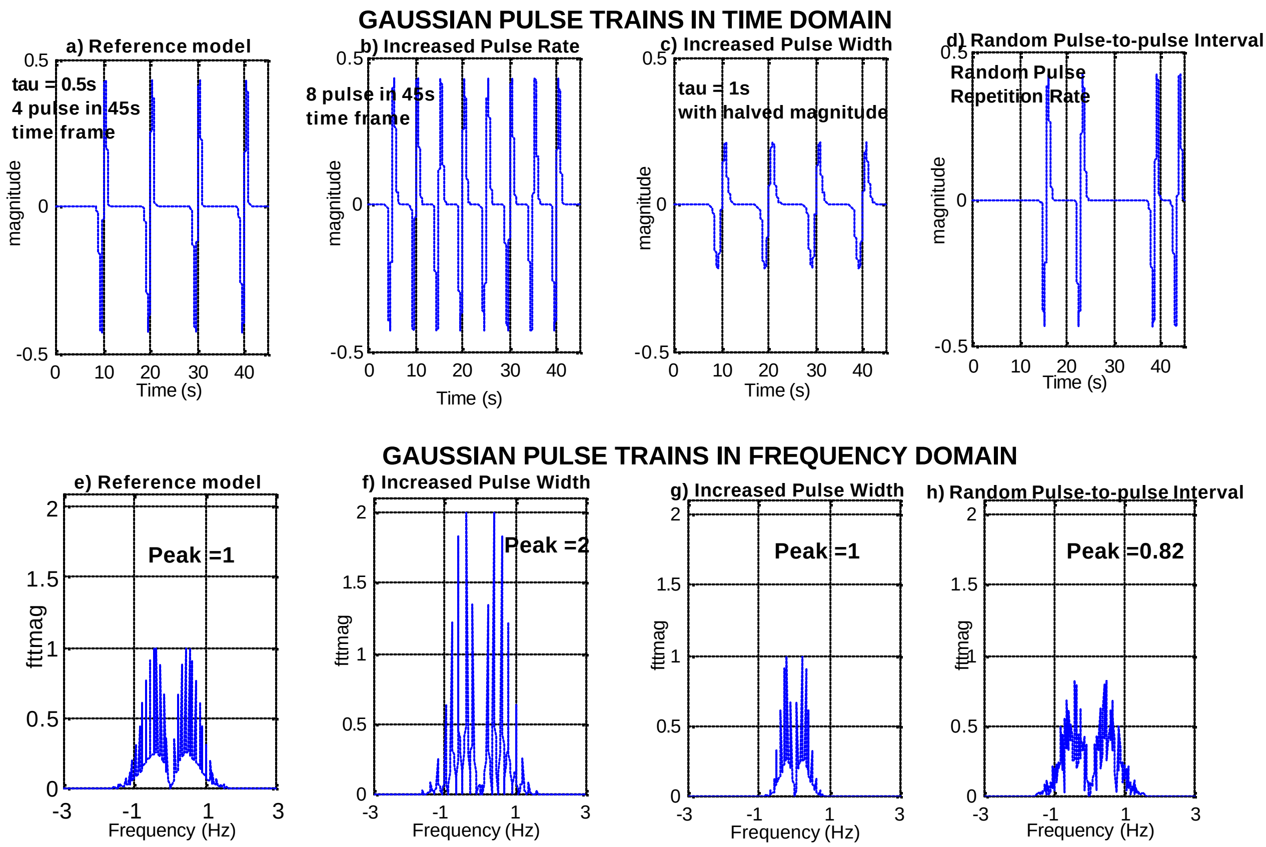

Figure 3: UWB system models

4. UWB System Performance - MATLAB Simulations And Results

Simulations using long sequence of Gaussian monocycles in a practical time scale with data modulation achieved by changing pulse polarity were preformed and the consequence on PSD of using time hopping technique in positioning the Gaussian monocycle in the pulse train was investigated. A time hopping Gaussian monocycle pulse train is illustrated in Figure 5.3. The time axis is divided into frames and each frame is subdivided into 8 slots. During each frame only one time slot is allow to contain a Gaussian monocycle. The particular time slot chosen for a given frame depends on the time hopping scheme employed. Three time hopping schemes namely fix time hopping, random hopping and PN code hopping were preformed and the results are shown in Figure 5.

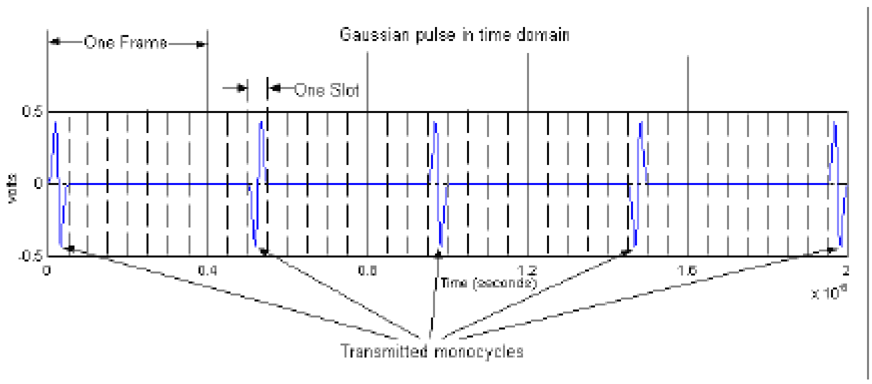

Figure 4: Time Hopping Gaussian Monocycle Pulse Train

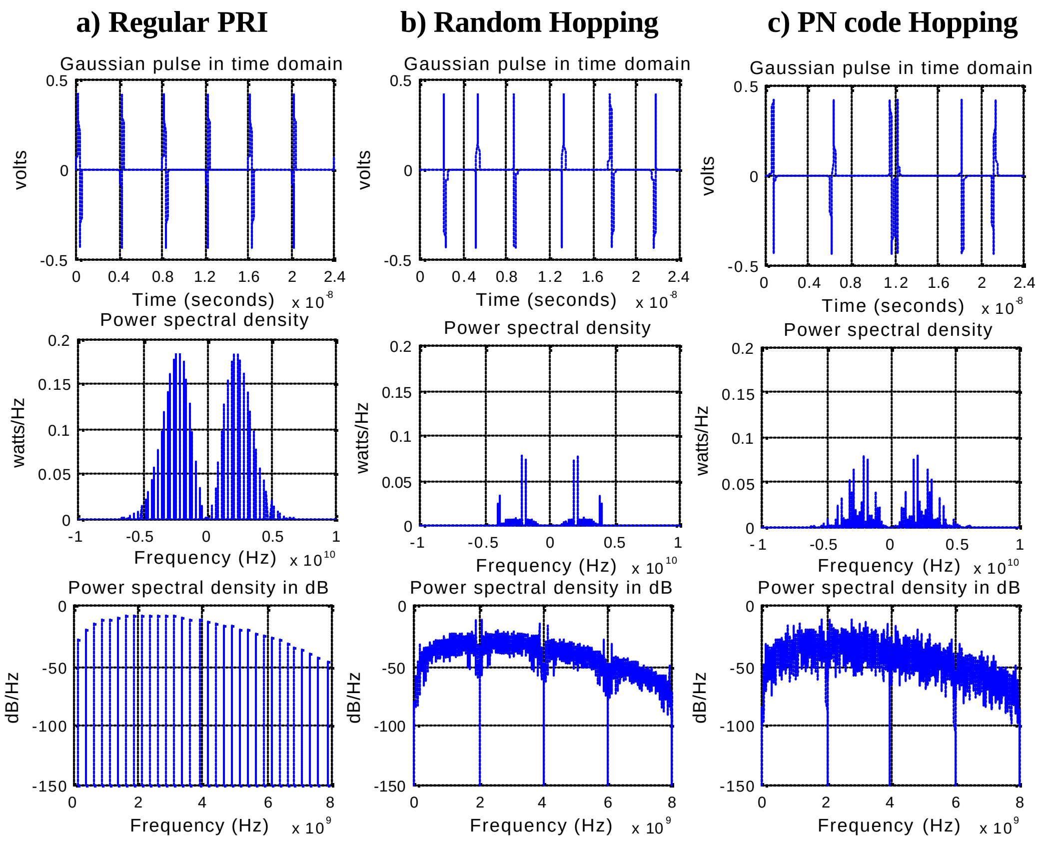

Figure 5: UWB System Performances employing different time hopping schemes

It can be seen that the use of long sequence random yields the smoothest PSD and produces a noise like signal. However, if the signal was to be transmitted over a communication link, this random sequence used had to be known on the receiver side in order to translate the signal back to useful information. This can be achieved by the use of long sequence random fix hopping, i.e. eventually a PN code which not only flattens the spectrum but provided a means of channelisation.

5. Conclusion

UWB technology basic is introduced and the effect of system performance by employing different pulse positioning schemes has been discussed. The ultra-wide band provided by the narrow monocycle implies a large modulation bandwidth and a high data transmission, together with low PSD, UWB radio system is well suited for wireless application. The ultra-low PSD generated by random time hopping makes the signal appears as "white noise" in the "noise floor" to other radio frequency devices and therefore the already crowded spectrum can be re-utilised. The decision of whether to use a random hoping sequence or a PN code hopping sequence would be depended on the application. In a situation where multiple access capability is required, PN code will provide the channelisation as a different hopping code can be given to each user.

References

[1]: Moe Z. Win & Robert A. Scholtz, "Impulse Radio: How it works", IEEE Communication Letters, February 1998.

[2]: Terry Mitchell, "Broad is the way", IEE review, January 2001.

[3]: "PlusON Technology Overview", http://www.timedomain.com ,July 2000.

[4]: Cooper G.R and McGillem C.M, "Modern Communications and Spread Spectrum", McGraw-Hill Book Company, 1986