Simulation Study of Ultra-Wideband Communication System

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Abstract: This paper provides a brief overview of one of the emerging wireless radio technologies, Ultra-Wideband (UWB) communication system. Using the Matlab package a simulation platform that facilitates the study and performance assessment of UWB is demonstrated with illustrative outputs presented.

1. Introduction

Radio spectrum is very scarce, finite and its lower band is considered to be fully utilised. UWB has the potential to address this problem and revolutionise radio communications, radar & positioning. It allows co-existence with the already licensed operators in the lower band of the radio spectrum & can also be used in the higher band as well. UWB radio signals, sometimes referred to as baseband, impulse or carrierless radio, employ the generation & transmission of ultra short impulses of radio energy whose characteristic spectrum signature extends across a very wide range of frequencies. They involve bandwidths in excess of 1 GHz. Their inherent low power spectral densities (PSDs), their diversity in frequency and thus their immunity to multipath effects have attracted growing interest as a viable candidate for short range high speed indoor radio communication services.

In section 2, the technology basics of UWB signal generation and their properties in the Time and Frequency domains are noted. Transmission of Gaussian pulse trains (polycycle), the receiver's detection performance in the presence of noise, the system's processing gain & its resistance to interference is explained. Section 3 indicates on-going work and provides some concluding remarks. Some samples of the simulation programs are presented in the Appendix.

2. Technology Description

An Ultra - Wideband (UWB) signal is generally defined to be a radio signal with a fractional bandwidth larger than 0.25, where fractional bandwidth (h) is defined as

$$h = 2\,(f_H - f_L) / (f_H + f_L) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where f_H & f_L are the highest & lowest frequencies in the transmission respectively. Conventional radio service transmission and radar systems have small fractional bandwidths of much less than 0.25. This is illustrated in Figure 1 below.

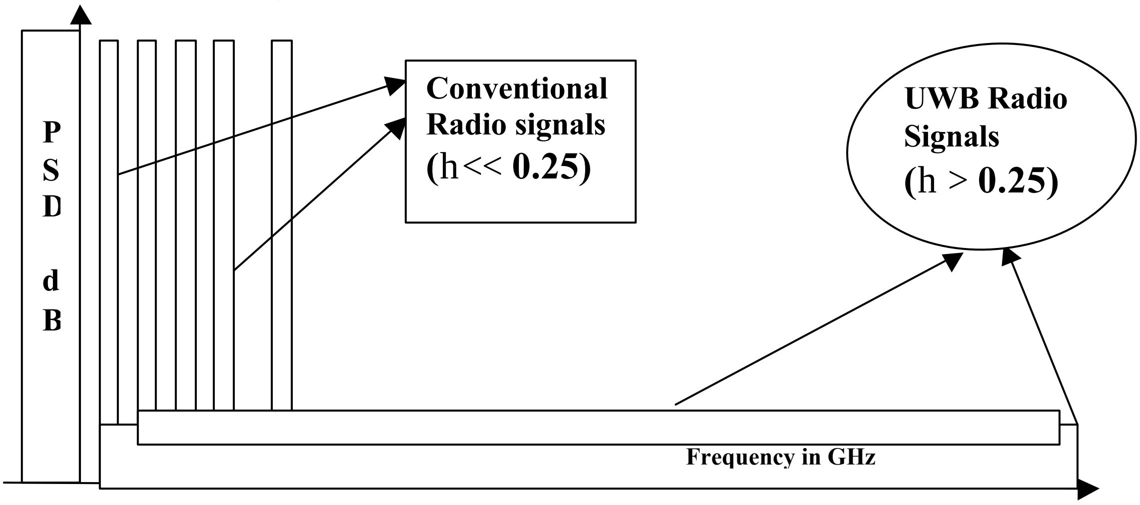

Figure 1. **PSD** and h of UWB Vs Conventional radio signals.

2.1 UWB waveform generation, Gaussian mono-pulse & poly-cycle, their properties in the Time & Frequency domains

UWB signals are produced by pulsed emissions, where a very wide RF bandwidth is related to a narrow pulse width. Unlike many conventional radio transmitters in which a modulated signal is upconverted & amplified, in UWB systems information is encoded in the series of baseband pulses and transmitted without a carrier. Hence, the transmitters require precise pulse shaping to produce the required spectrum and maximise the antenna's emission. Producing emissions with flat & wide PSDs requires extremely accurate pulse designs. Although most UWB developments are still in the laboratory due to regulatory issues, already some pioneering work has been undertaken by a number of companies. Common approaches include using avalanche transistors, tunnel diodes, mercury switches and other exotic devices.

The technology developed by Time Domain Corporation is called Time Modulated UWB (TM-UWB). The TM-UWB transmitters emit ultra-short "Gaussian" monocycles with tightly controlled pulse-to-pulse intervals, commonly known as Pulse Repetition Interval (PRI). Typical pulse widths are between 0.2 & 1.5 nanoseconds and the PRI is in the range of 25-1000 nanoseconds. PRI is varied on a pulse-by-pulse basis in accordance with two components: an information signal and a channel code that is a pseudo-random noise (PN) sequence.

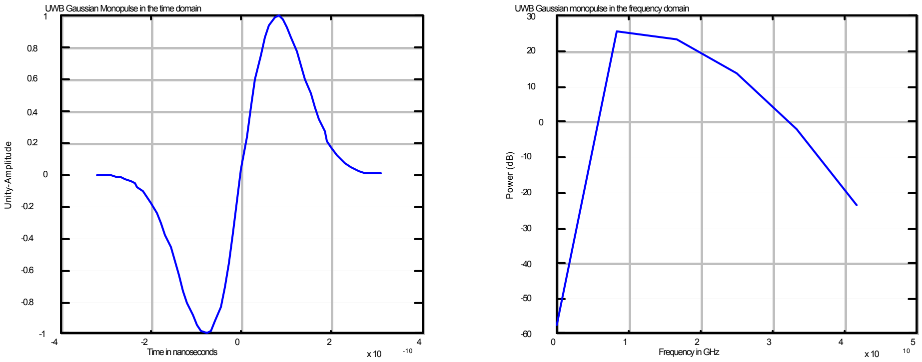

Figure 2. UWB monocycle pulse both in the Time & Frequency domains

New functions, **gmonopuls.mat** and **gpolycycle.mat** have been written in the Matlab (See Appendix 1) to facilitate the study of UWB signals and systems. Figure 2 is simulated using **gmonopuls.mat**.'The UWB monocycle is a wide bandwidth signal, with the centre frequency and the bandwidth completely dependent upon the monocycle's width. In the time domain, the Gaussian monocycle is mathematically similar to the first derivative of the Gaussian function. It has the form:

$$v(t) = (t/\tau)e^{-(t/\tau)2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where τ is a time decay constant that determines the monocycle's duration and t is time. In the frequency domain, a Gaussian monocycle's spectrum is of the form:

$$V(f) = -j f \tau^2 e^{(-f\tau)2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The centre frequency (**fc**) of a monocycle is the reciprocal of the monocycle's duration, $\mathbf{fc} \propto \mathbf{1}/ t$**.** and the Bandwidth is 116% of the monocycle's centre frequency. [1] Thus, for the 0.5 ns monocycle shown in Figure 2, the centre frequency is 2 GHz and the half power bandwidth is approximately 2.3 GHz .

Figure 3 below shows unmodulated monocycle pulse train (a polycycle) both in the Time and Frequency domains, simulated using **gpolycycle.mat**.
UWB systems use long sequences of monocycles for communications, not single monocycles. It can be observed in the Frequency domain of figure 3 that this highly regular monocycle pulse trains produces energy spikes as "comb lines" at regular intervals. The already low power spectral density is spread further among the comb lines, reducing the peaks in the PSD. Of course, a simple monocycle pulse train does not carry information and further, given the regularity of the energy spikes, might interfere with conventional radio systems. It has been noted that varying the pulse-to-pulse time interval (PRI) can eliminate these comb lines.

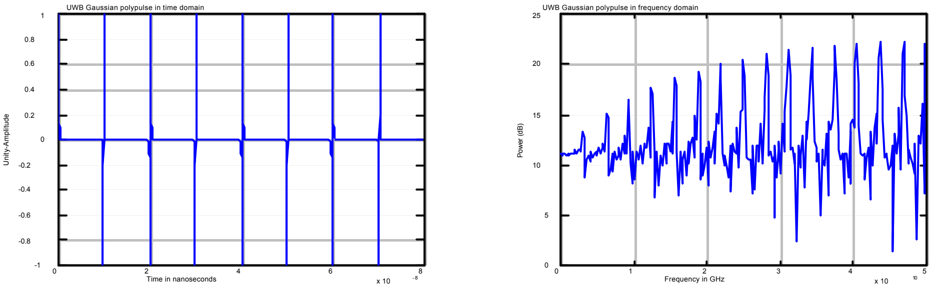

Figure 3. Unmodulated UWB polycycle in the Time & Frequency domains.

In order to convey information, some form of modulation is required. One approach is to use (ptm) pulse time modulation. Ptm is used to adjust the timing of a series of monocycles. A single data symbol spans many monocycles, with group of monocycles known as Polycycle. For example, for a data symbol of logical "1", a small time shift may be added to the monocycles, with no time shift applied to a data symbol of logical "0". This data modulation also helps to 'smooth' the spectral spikes associated with the unmodulated pulse train as noted above.[2]

2.2 Pulse time modulation & channelisation

The format pulse time modulation (ptm) is used in the Matlab simulation package, but in fact it corresponds to a form of pulse position modulation (PPM). Pulse time modulation distributes the RF energy more uniformly across the band in the frequency domain, making the system less detectable.
By shifting each monocycle's actual transmission time over a large time frame in accordance with a code, a pulse train can be channellised. In a multiple access system, each user would have a unique PN code sequence. Only a receiver operating with the same PN code sequence can decode the transmission. In the frequency domain, this pseudo-random time modulation makes a TM-UWB signal appear indistinguishable from white noise (as shown in Figure 4).

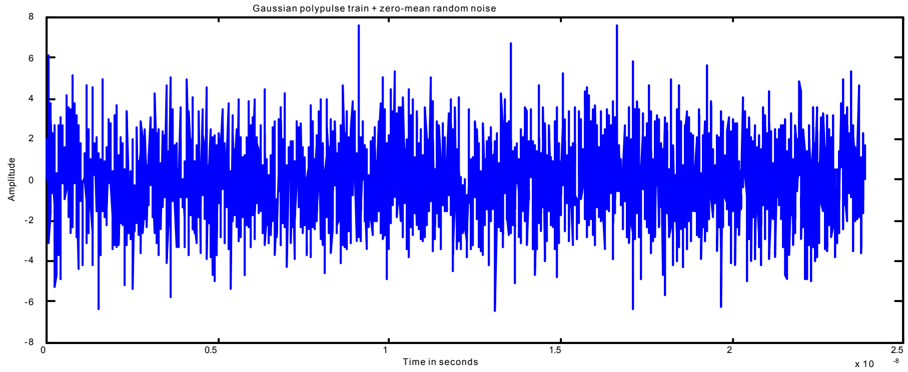

Figure 4.UWB Gaussian polypulse with zero mean random noise, indistinguishable from white noise.

2.3 Detection & Performance in the presence of noise and interference

Most UWB receivers have direct conversion (also referred to as homodyne or zero-IF) architecture rather than that of a hetrodyne (or superhetrodyne) receiver. The UWB direct conversion receiver avoids the multiple RF & IF stages, local oscillators & mixers. Synchronisation of a carrier is also not required.
'Having generated a signal with minimal spectral features, it is also necessary to have an optimal receiving system. The optimal receive technique, and the technique used in TM-UWB, is a correlation receiver ("correlator"). A correlator multiplies the received RF signal with a "template" waveform and then integrates the output of that process to yield a single DC voltage. This multiply-and-integrate process occurs over the duration of the pulse and is performed in less than a nanosecond. With the proper template waveform, the output of the correlator is a measure of the relative time positions of the received monocycle and the template.' [1]

3. Concluding remarks

This paper has introduced the principles of UWB, and detailed the basic simulation platform developed to facilitate system studies. Illustrative signal waveform and spectra have been presented. Work is continuing on the development of the simulation platform for the realisation of ptm modulation & correlator reception.

Appendix 1

```
% gmonopuls.mat a new function program written in Matlab for a 2GHz gaussian monopulse both in
% the Time & Frequency domains
N=12; fc=2E9; fs=100E9; n=0:N-1;
%2GHz UWB Gaussian monopulse in the time domain sampled at a rate of 100 GHz.
tc=gmonopuls ('cutoff',fc);            %width of each pulse (0.5nS)
t =-2*tc: 1/fs: 2*tc;                  %signal evaluation time
y= gmonopuls (t,fc);
figure(1); subplot (1,1,1); subplot (1,2,1);
plot(t,y); grid; title ('UWB Gaussian Monopulse in the time domain');
xlabel ('Time in nanoseconds'); ylabel ('Unity-Amplitude');
%spectrum of a 2GHz G.monopulse
tc=gmonopuls('cutoff',fc);             %width of each pulse(0.5nS)
t=-2*tc: 1/fs: 2*tc;                   %signal evaluation time
y=gmonopuls(t,fc); Y=fft(y); magY=abs(Y);
fy=0:(N/2)-1;                          %first make a vector f=0,1,2,...(N/2)-1
fy=(fy*fs)/N;                          %scale frequencies in Hertz
subplot (1,2,2); plot(fy,20*log10(magY(1:N/2))); grid;
title ('UWB Gaussian monopulse in the frequency domain');
xlabel('Frequency in GHz'); ylabel('Unity-Amplitude');
```

```
% gpolycycle.mat a new function program written in Matlab for a 2GHz gaussian ploycycle both in
% the Time & Frequency domains
N =12; n= 0:N-1; fc=2E9; fs=100E9;
%2GHz UWB G.polypulses trains in the time domain with pulse intervals (PRI) of 100nS.
D  = [0 1 2 3 4 5 6 7 8 9 ]' * 1e-7;          %Pulse delay time (100nS)
tc = gmonopuls ('cutoff',fc);                   %width of each pulse(0.5nS)
t  = 0 : 1/fs : 800*tc;                         %signal evaluation time
yp  = pulstran (t,D,'gmonopuls',fc);
figure(1); subplot(1,1,1); subplot (1,2,1); plot(t,yp); grid;
title ('UWB Gaussian polypulse in the time domain');
xlabel ('Time in nanoseconds'); ylabel('Unity-Amplitude');
%2GHz G.poly-pulses in Frequency domain
D  = [0 1 2 3 4 5 6 7 8 9 ]' * 1e-7             %Pulse delay time (100nS)
tc = gmonopuls('cutoff',fc);                    %width of each pulse(0.5nS)
t  = 0 : 1/fs : 800*tc;                         %signal evaluation time
yp  = pulstran (t,D,'gmonopuls',fc);  YP = fft(yp);
magYP=abs(YP); fyp=0:(N/2)-1; fyp=(fyp*fs)/N;
subplot (1,2,2); plot(fyp,20*log10(magYP(1:N/2))); grid;
title ('UWB Gaussian polypulse in the frequency domain');
xlabel('Frequency in GHz'); ylabel ('Power (dB)');
```

References:

1. www.time-domain.com technical papers,"PulsON-Time Modulated Ultra-Wideband for Wireless Applications.
2. "Broad is the way" by Terry Mitchell, IEE Review January 2001.
3. http://www.mathworks.com
4. The Matlab Handbook, by Eva Port-Enander, Andres Sjoberg, Bo Melin, Pernilla Isaksson, ISBN: 0-201-877570, Addison - Wesley Longman, 1996