

# Investigation of the influence of signal parameters on ultra-wideband (UWB) impulse radio systems

Abubakkar bin Nasar Janjua  
Department of Electrical Engineering  
COMSATS Institute of Information Technology (CIIT)  
Islamabad, Pakistan

Rafae Shamail  
Department of Electrical Engineering  
COMSATS Institute of Information Technology (CIIT)  
Islamabad, Pakistan

Mamoon Raja  
Department of Electrical Engineering  
COMSATS Institute of Information Technology (CIIT)  
Islamabad, Pakistan

Bushra Ghouri  
Department of Physics  
COMSATS Institute of Information Technology (CIIT)  
Islamabad, Pakistan

**Abstract**— this project investigates the effect of different pulse shaping techniques on spectra of transmitted signal of an Ultra Wide Band communication systems, the target is to achieve high spectral efficiency by finding optimum parameters for pulse shaping filter. Another target is to achieve best bit error performances for different channel environments (AWGN channel and IEEE 802.15.3a UWB channel) for both single user and multi-user systems; to attain this goal different channel coding schemes have been used. MATLAB® simulations are used to show the efficacy of used methodologies in achieving higher spectral efficiency and better error rate performance. In this project UWB technology, transmission of UWB, properties of a wireless channel, Correlator Receiver and Rake receiver is discussed in detail.

## I INTRODUCTION

The rapid growth in technology and placement of wireless systems are considerably affecting our daily lives. Wireless mobile radio systems allow the comfort of flexible data rates to user and provide services to as many users as possible. Ultra wideband Impulse radio communications is different from other wireless techniques because it is implemented by communicating short duration pulses between transmitter and receiver, which generates a wideband signal and provides many advantages. Ultra-wideband communications is not a new technology. Inventor of the radio communication Guglielmo Marconi was the first one who employed this technology in 1901 to transmit Morse code sequence. However, the benefits of the technology were unknown at that time. A Nobel Prize was awarded to him in 1909 for his services [1].

After Marconi for a long period no major work was done on this technology, but between 1969 and 1984 Hurmuth exposed different papers and books to the world with the basics of UWB transmitters and receivers [2], but the problem in Hurmuth's work is that receiver is not sensitive. In 1972 the

invention of short impulse receiver by Robbins was the turning point in the UWB communications [2]. In 1980's it was also known as carrier less, baseband or impulse technology. In the year 2002 Federal communication commission allows the unlicensed use of ultra-wideband. Figure 1 summarizes the history of ultra-wideband communication

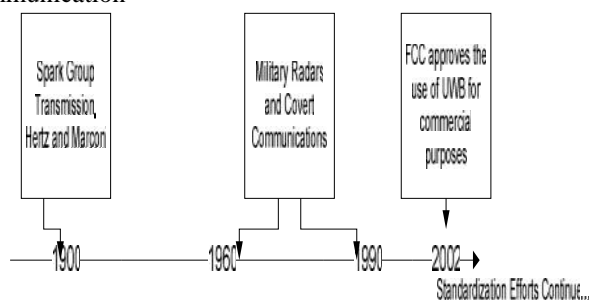


Figure 1 History of UWB developments [1]

## II ULTRA WIDEBAND

Ultra wideband radio communication also known as UWB radio communication consist on radiating the waveforms formed by pulses having duration of hundreds of Pico seconds, transmission is digital so the information is transferred into bits and each bit is represented by a pulse or pulses.

According to the federal communication commission (FCC) a signal lies in classification of UWB, if it meets any of the following criteria [3]:

Fractional signal bandwidth  $>20\%$  or  
Total signal bandwidth  $>500$  MHz

Fractional bandwidth of a signal is the ratio of bandwidth at  $-10$ dB emission point to the center frequency [1]. Mathematically it can be written as:

$$f_B = \frac{B}{f_c} = \frac{(f_H - f_L)}{(f_H + f_L)} \cdot 2$$

Where,  $f_H$  and  $f_L$  are the upper frequency and lower frequency at the -10 dB emission points.

*Characteristics of UWB*

*Low Power Spectral Density*

UWB communication systems have large bandwidth, as the bandwidth of the UWB signal is at least 1/4 of the center frequency. Thus if center frequency of signal is 4 GHz, it would have minimum bandwidth of 1GHz or if a signal will have center frequency of 5 GHz, then the minimum bandwidth of the signal is 1.25 GHz. As the ruling committee of communication in USA i.e. FCC restricted to use UWB only in the spectrum of 3.1 GHz to 10.6 GHz which means for a signal to be UWB its center frequency must lie in the given spectrum with certain power limits that is -41.5 dBm, power limit is for the control of interference due to UWB on the other operation Communication channels in the given spectrum. Figure 2 and Figure 3 represents the above discussion graphically:

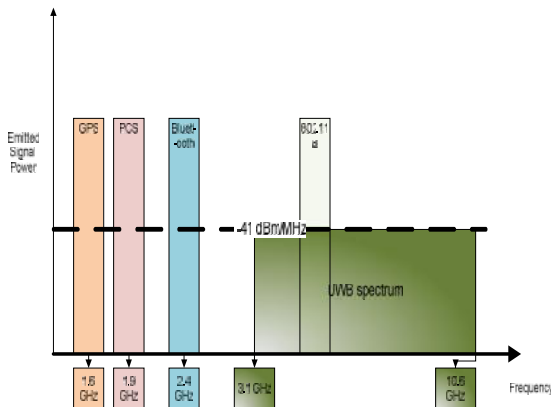


Figure 2 Existence of UWB in presence of other operating bands [9]

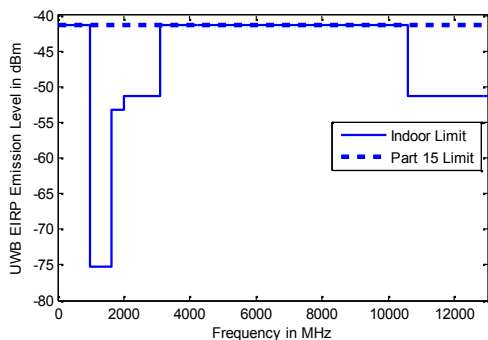


Figure 3 FCC indoor emission mask for UWB devices (FCC, 2002)[16]

*Very short pulses*

Huge bandwidth is the well-known feature of UWB signals. Bandwidth of the UWB signals have indirect relation with the pulses used in the time domain for the representation of information bits, smaller the duration of a pulse wider the band is. As discussed earlier for the generation of UWB signals the pulses with the duration of hundreds of Pico seconds are used. This relation is depicted in Figure 4.

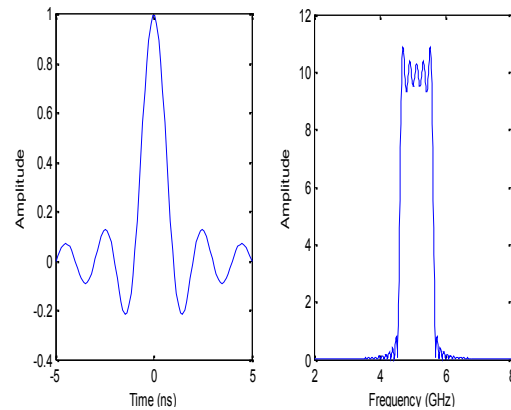


Figure 4 Time domain and frequency domain behavior of UWB pulse [9]

*Multipath Immunity*

When a modulated signal arrives at the receiving antenna from different paths with different delays, when it combines it cancel the effect of each other or get distorted and in the end our information is lost. But that's not the case in UWB signals, in this signal arriving from different paths arrives at the receiving antenna with different delays which can be individually identified by the receiver due to the fine delay resolution (large bandwidth) and consequently processed for reliable detection.

UWB communication system is an unlicensed system; the only limitation on its operation is the transmitted power that is for the control of interference on the other operating channels. Regulatory bodies control the transmitted power of the transmitted signal to be very low so that it cannot interfere other bands [4]. The power limits used by the FCC is -41 dBm/MHz.

One of the main advantaged of UWB systems is its coexistence with other bands radio communication systems operating with a negligible amount of interference due to UWB radio system. Figure 2 [9] gives the little bit clear idea of the coexistence of UWB with other operating channels. Another major advantage of the system due to its huge bandwidth is data rate. Bandwidths have a direct relation with data rate or channel capacity. As bandwidth increases data rate or channel capacity also increases. We can prove our statement with the help of Shannon's equation of capacity i.e.

$$C = B \log_2(1 + SNR)$$

Where,

C= Channel Capacity or Data Rate

B=Bandwidth of the system, SNR=Signal to Noise ratio

This system provides high data rate of 1Gbps over a distance of 1m whereas 200Mbps over a distance of 10m [4]. UWB system occupy a wide range of frequencies having low frequencies in its spectrum too due to which UWB signals can penetrate through walls or different materials. Other advantages of this technology are the low cost of the devices, hardware simplicity and its robustness [4].

### III. GENERATION OF UWB

UWB communication has gained the world's attention due to its relatively higher capacity, very high data rates, and robustness against multipath fading, lower level of power consumption, cost effectiveness and minimal complexity. Research has been done to find the modulation schemes for UWB systems. The selection of modulation scheme depends on the type of application, its design specifications, data rates, transmitter & receiver power and many other factors. So selecting best modulation technique for UWB system still a problem. The modulation schemes or mapping options mostly used in these systems are BPSK, QPSK, PAM, OOK, PPM, PIM and PCM [4]. The most popular modulation scheme is BPSK because of its smooth power spectrum and better bit error rate (BER) performance. Different generation techniques used for UWB signals are:

Impulse Radio

Multicarrier Modulation (OFDM)

#### Impulse Radio

We have generated UWB signals using impulse radio in which pulses having duration of hundreds of nanoseconds are transmitted having wide spectrum, these pulses have low power and energies so multiple pulses are used to encode one information bit[7]. For the transmission of information bits pulses are used, so we can use different pulse shapes that have different effects. Conventional modulation techniques cannot be applied to UWB-IR systems due to its huge bandwidth. Pulse Position modulation is mostly used in IR while considering the transmission over multiple access schemes like Time Hopping and Direct sequence. The advantage of using the impulse radio is that it is baseband technique. The modulation schemes used for data mapping studied with UWB-IR [8] is shown below.

Modulation Schemes

The most commonly modulation technique used with IR is pulse position modulation in which the position of the pulse is shifted with respect to the information bit. Assume the signal  $y(t)$  be the modulated generally it can be written as:

$$y(t) = x(t - \tau)$$

Where  $x(t)$  is the un-modulated signal represented by waveform and  $\tau$  is the time shift with respect to the input information bit.

The next modulation scheme is Bi Phase Modulation in which the polarity of the pulse is inverted with respect to the binary information bits. Generally it can be expressed as

$$y(t) = ax(t)$$

Where  $a$  is known as pulse weight and its value is 1 or -1. Now the graphical demonstration of the above discussed modulation schemes are shown in figure 5.

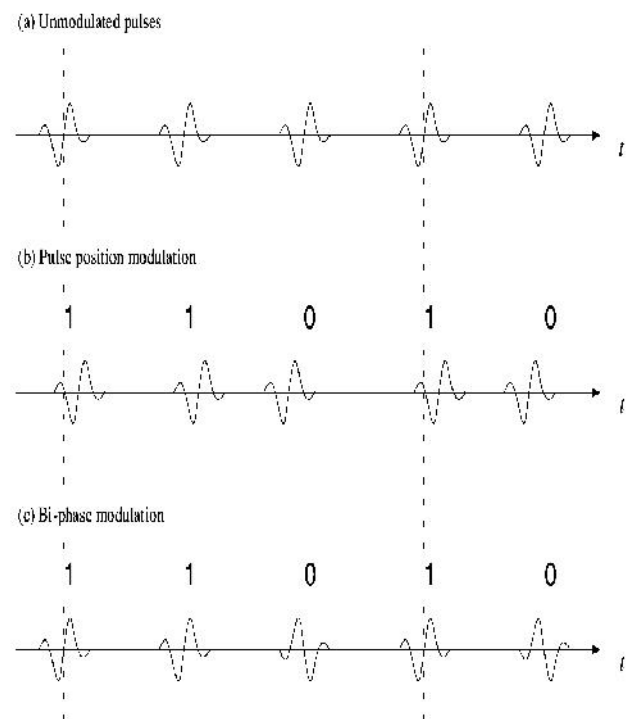


Figure 5 PPM and BPM modulation [8]

BPM is more efficient than PPM. BPM is an antipodal modulation scheme whereas PPM is an orthogonal modulation scheme. If the delay in PPM is equal to single width of pulse then BPM can send double information within that delay and twice number of pulses. Pulse amplitude modulation is the technique in which the amplitude of the pulse or waveform is changed with respect to binary inputs. It can be expressed as

$$y(t) = ax(t)$$

Where  $a$  is the weight of the pulse and it must be greater than zero. PAM is not a very wise choice for modulation scheme in case of short range transmission.

On Off Keying is a modulation scheme which is defined by the presence or the absence of pulse.

$$y(t) = ax(t)$$

Where defines OOK as binary modulation scheme, its value is 0 or 1. Graphical representation of OOK, PAM and Orthogonal Pulse modulation is shown figure 6.

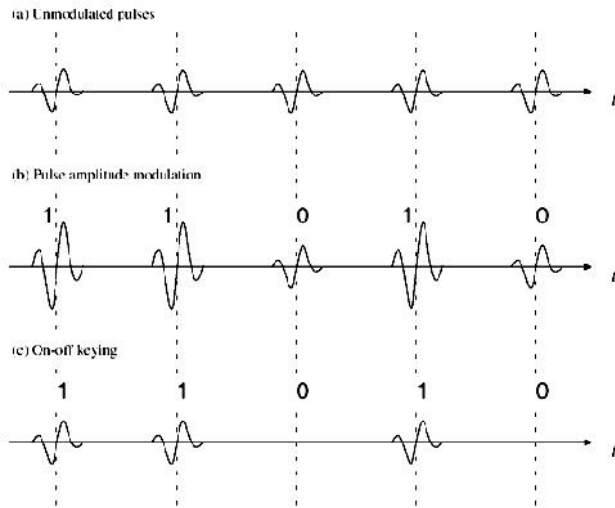
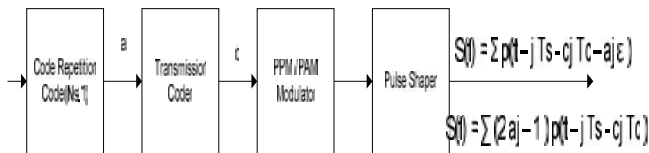


Figure 6 Representations of OOK, PAM and OPM [8]

In the next section we will learn about the multiple access schemes used in IR [3].

**Time Hopping  
Direct Sequence Spread Spectrum (DS-SS)**

*Generation of Time Hopping-UWB*



$$R_a = 1/T_c \text{ (bits/sec)} \quad R_b = N_s/T_b \text{ (bits/sec)} \quad R_c = N_s/T_b \text{ (symbols/sec)} \quad R_p = N_s/T_b \text{ (Pulses/sec)}$$

Figure 7 Transmission of a TH-UWB signal [3].

Figure 7 shows the block diagram for the transmission of TH-UWB signals. The first block is code repetition coder i.e. used to introduce redundancy by repeating the input sequence  $b$  to  $N_s$  times, by using repetition code we can achieve error free communication and here it generates a sequence  $a$ , where rate  $R_{cb}$  of  $a$  is :

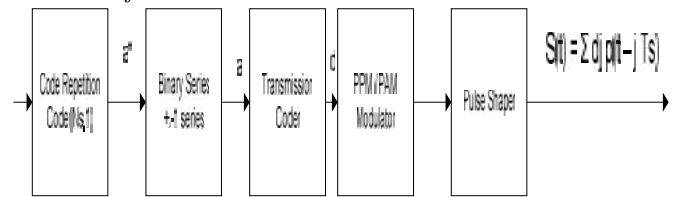
$$R_{cb} = \frac{N_s}{T_b} = \frac{1}{T_s}$$

Where  $N_s$  represent bit repetition and  $\frac{1}{T_b}$  are the rate of the input sequence  $B$ . Then transmission coder assigned an integer

value code to the sequence 'a' which results in sequence 'd'. The transmission coder is usually periodic with time period  $N_p$ . The elements of the resulting sequence 'd' are  $c_j T_c$  with  $c_j T_c < T_s$ . We assume the transmission coder code to be pseudorandom. Basically the effect code  $c$  is to generate time hopping on the generated pulses. The transmission coder is also used to shape the spectra of the transmitted signal. It also play very important role in multiuser environment where different users assigns different codes that is known as code division coder. The task of modulator is to assign Dirac pulses to sequence 'd' These pulses are located at  $kT_s + DkT_c$ . In the modulator block either PPM or PAM is used. If pulse position modulation is used for all the information bits that are 1, pulses have assigned a shift of  $\epsilon$  while no shift in case of 0 bit. And in case of PAM the amplitude of the information bit remains unchanged for 1 and for the bit 0 the amplitude of the bit inverts. The last block in the transmission scheme is pulse shaper filter with impulse response  $p(t)$ . The output of the above transmission scheme is  $s(t)$  and in case of PPM it is written as:

$$S(t) = \sum_{j=-\infty}^{\infty} p(t - jT_s - c_j T_c - \epsilon \cdot a_j)$$

*Generation of DS-SS UWB*



$$R_b = 1/T_b \text{ (bits/sec)} \quad R_{cb} = N_s/T_b \text{ (bits/sec)} \quad R_{cd} = N_s/T_b \text{ (symbols/sec)} \quad R_c = N_s/T_b \text{ (symbols/sec)} \quad R_p = N_s/T_b \text{ (Pulses/sec)}$$

Figure 8 Transmission of DS-UWB signal

Another method use for generation of UWB signal is direct sequence –spread spectrum technique. The above figure [3] is the transmission scheme for the generation of DS-UWB signals.

Given is the binary input source  $b$  to the first system that is  $(N_s, 1)$  code repetition coder and each of the input sequence bit is repeated  $N_s$  times and generates bit sequence 'a' at the rate of  $R_{cb}$ .

$$R_{cb} = \frac{N_s}{T_b} = \frac{1}{T_s}$$

The second system represents the binary sequencer where the sequence  $a$  is transformed to positive and negative valued sequence  $d = (\dots, a_0, a_1, \dots, a_k, a_{k+1}, \dots)$ . The transmission coder is applied to the sequence  $a$ , the code  $c$  is binary code that is of + or -1. The result of the system is a new sequence  $d = a \cdot c$ . It is to be noted that sequence 'd' is of  $\pm 1$  as is the sequence 'a' and is generated at a



rate  $R_{cb} = (\frac{1}{T_s})$  bits/sec. Then the sequence is passed through the system that is BAM modulator where the Dirac pulses are generated at rate  $R_p = \frac{1}{T_s}$  pulses/Sec. And the last system of transmission scheme is pulse shaper filter with impulse response  $p(t)$ . The output of the pulse shaper is the result of the system i.e.  $s(t)$  and expressed as

$$s(t) = \sum_{j=-\infty}^{\infty} p(t - jT_s)$$

#### Factors affecting UWB Signal Design

Factors that affect the transmission of UWB signal.

- Gaussian Derivative
- Pulse Duration

#### Pulse Shaping

The pulse shape which can be generated in the easiest way is a Gaussian pulse, as shown in Fig2.5 [3] and one can write as

$$p(t) = \sqrt{2/\alpha} e^{-\frac{2\pi t^2}{\alpha^2}}$$

The reason behind using Gaussian pulse is that it gives optimum relationship between maximum energy transmitted and a minimum time-bandwidth product. In figure 2.5, graphical representation of Gaussian pulse is given and also the graphical representation of its power spectral density is given.

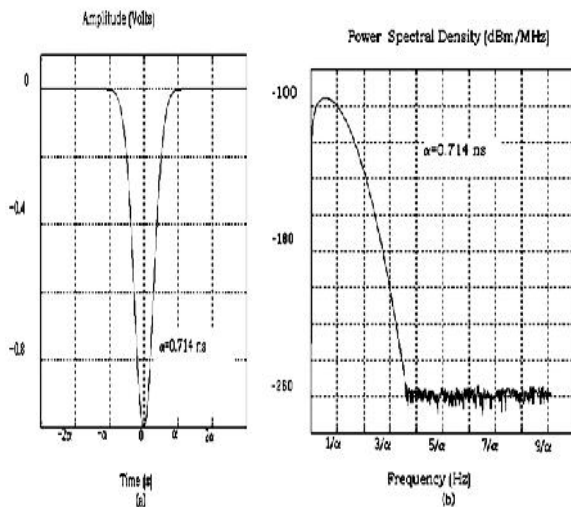


Figure 9 (a) Gaussian pulse (b) PSD of Gaussian pulse [3]

#### Gaussian derivative

By taking the derivative of our Gaussian transmitted pulse we can affect the spectral occupancy of signal. As the order of the derivative increases, peak frequency of the signal increases (i.e. main lobe of frequency spectrum moves to higher frequency) but the spectral occupancy of signal also decreases.

#### Pulse duration

Pulse duration can be controlled by “ ” and that “ ” affects the power spectrum of density, this phenomenon is shown in figure 10 as the “ ” increases bandwidth of signal decreases.

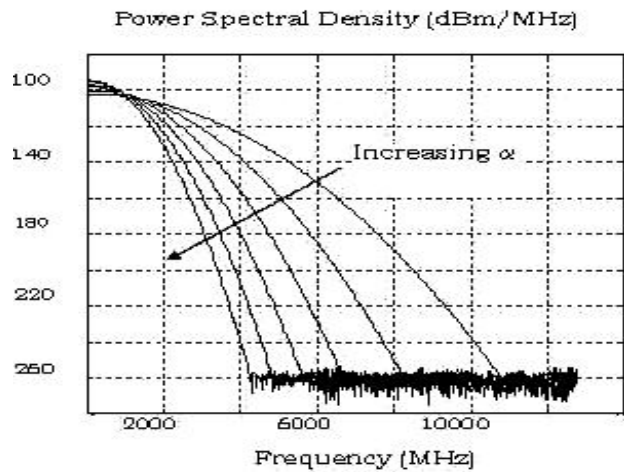


Figure 10 Effect of “ ” on PSD [3]

### IV. IWIRELESS CHANNEL

#### AWGN Channel

Additive white Gaussian noise (AWGN) channel is the ideal channel that adds noise to the signal. There will be no fading, frequency selectivity, interference, non-linearity or dispersion.

#### Types of Fading Channels

##### Small Scale fading

- Multi path Effect
- Flat fading
- Frequency selective fading

##### Large Scale fading

- Path loss
- Shadowing

#### Narrow Band Channel

A channel can be regarded as the narrow band channel if its frequency response can be considered flat. Therefore coherence bandwidth of the channel is greater as compared to the band width of the transmitted signal. This is just an assumption because no channel has flat fading. In terms of fractional bandwidth it should be less than 1 %. The delay of individual multi path components will not impact the performance of the system. These multi path components will interfere at the receiver end.

#### Wideband Channel

A system is described as wideband if the message bandwidth significantly exceeds the channel's coherence bandwidth. Frequency response of the channel is frequency

selective if (coherence bandwidth < bandwidth of the transmitted signal). In terms of fractional bandwidth, fb should be between 1% and 20%. The delay of multi path components will influence the system performance [14].

### Ultra Wideband Channel

The UWB channel model is proposed by IEEE 802.15.3a, which is basically a modified form of S-V model [15]. But S-V model is not specifically for UWB even though S-V model was designed on basis of measurements using low power radar like pulses [16].

The basic observation of S-V model was that the multipath contributions for a pulse will arrive at the receiver in form of clusters, and we can model the time of arrival of clusters using Poisson arrival process. We can assume that every cluster has ‘n’ number of multipath components in it. Several changes has been made in S-V model and a unique set of parameters for UWB channel has been established , we will see parameter setting for IEEE UWB 802.15.3a model in Table 3.2 [16].

Table 1 parameters for IEEE 802.15.3a UWB channel [16]

Scenario	(1/ns)	(1/ns)		‘ ,	dB	dB	g
Case A LOS (0-4) m	0.023 3	2.5	7.1	4.3	3.394 1	3.394 1	3
Case B NLOS (0-4)m	0.4	0.5	5.5	6.7	3.394 1	3.394 1	3
Case C NOLS (4-10)m	0.066 7	2.1	14	7.9	3.394 1	3.394 1	3
Case D Extreme NLOS	0.066 7	2.1	24	12	3.394 1	3.394 1	3

### Interference in UWB

Interference in any communication affects the performance. Similarly in case of UWB systems receivers are challenges due to interference issues.

### Types of interference

- Inter symbol interference (ISI)
- Narrow band interference (NBI)
- Multiple access interference (MAI)

### Inter symbol interference

When the interval between pulses becomes shorter than the maximum excess delay of the channel through which propagation is done, ISI occurs.

### Narrow band interference

Although UWB does not interfere with the legacy narrow band systems due to its low transmit power however, transmitted powers of narrowband systems are well above the threshold of UWB systems; thus interfering with the UWB system severely.

### Multiple access interference

Multiple access interference (MAI) is caused when different users are using the same bandwidth of frequency allocation at the same time. This multiple access interference can present immense problems if the power level of the transmitted signal is less than the power level of the interfering signal.

## V. RECIEVER

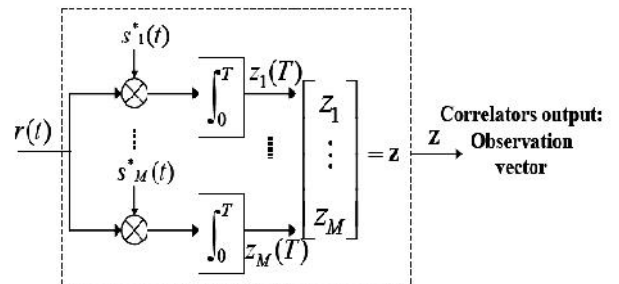
### Correlation Receiver

$$z(T) = h_{opt}(T) * r(T)$$

$$= \int_0^T r(\tau) s_i^*(\tau) d\tau = \langle r(t), s(t) \rangle$$

Correlation receiver and matched receiver are very similar to each other. The difference is only in the use of a switch. In case of correlation receiver multiplication is done first followed by the integration.

### Implementation of Correlation Receiver



$$\mathbf{z} = (z_1(T), z_2(T), \dots, z_M(T)) = (z_1, z_2, \dots, z_M)$$

$$z_i = \int_0^T r(t) s_i^*(t) dt \quad i = 1, \dots, M$$

Figure 11 Structure of Correlator receivers

For digital systems, threshold detector will be used after the integrator where as in case of analog systems envelope detector may be used.

### Rake receiver

Rake receiver is used to overcome the effects of multi path fading. In rake receiver there are several sub-receivers called the fingers used to detect the multi path components. These fingers actually are the different correlators tuned in delay to different arriving multipath components. Each correlator independently receives the components from each path and then these combine to form the resultant which is then detected.

#### *Types of rake receiver*

There are three well known types of rake receivers;

- All Rake Receivers (ARAKE)
- Selective Rake Receivers (SRAKE)
- Partial Rake Receivers (PRAKE)

#### *All Rake Receivers (ARAKE)*

All rake receiver functions in such a way that it combines all the  $N$  multi path components for predicting the information signal sent. This is the ideal case of reception but when considering the power constraints and the design implementations and complexity it is almost impossible to implement design such a receiver.

#### *Selective Rake (SRAKE)*

Selective rake receiver functions in such a way that it picks out the components of the multi path transmitted signal with maximum energy. Suppose there are  $N$  total numbers of multi paths, the selective rake receiver will pick out  $M$  number of best paths and will then use them as the rake fingers to predict the message. There is a possibility of error when we select  $M$  number of path out of  $N$  paths but selective rake is easier to implement as compared to all rake receiver. However this type of receiver is still fairly complex.

#### *Partial Rake Receiver (PRAKE)*

Partial rake receiver works in such a way that it will pick out first  $M$  paths out of  $N$  paths regardless of their energy levels. Due to this it becomes very easy to implement and is less complex but it can have more errors. May be the components it is selecting are so less in energy and most of the energy lies in the upcoming multi path components.

## VI. TRANSMITTER

#### *Ultra Wide Band Transmitter Design*

Traditionally ultra wide band signal is emitted by radiating short duration pulses. The main distinction in ultra wide band system is the bandwidth, which encourages us to generate shorter pulses. Important features of our transmitter

- Code Repetition Coder
- Transmission Coder
- Modulator
- Pulse Shaper

#### *Code Repetition Coder*

Simple  $(N_s, 1)$  Repetition coder is implemented to introduce redundancy by repeating every single bit  $N_s$  times. We simulated our transmitter for  $N_s=1$  and  $N_s=3$ . Implementation of repetition code was an easy task, transmitted bit has been repeated  $N_s$  times and passed on to next block. This task can also be performed by using built in MATLAB functions like `encode()`, for that purpose Generator matrix has to define. If the transmitted bit stream has been generated at a rate of  $1/T_b$  (bits/sec) then, after the Repetition coder rate of generated bits will be  $N_s/T_b$  (bits/sec) [16].

#### *Transmission Coder*

Transmission coder is used to assign code-division code in case of multiuser environment, and this code also introduces time hopping (TH) to our bit sequence. We use TH-SS because it has ability to highly resolve multipath [17] and available technology has relatively less complexity. This technique has been used in our code even if we are simulating for single user environment, but main reason was to investigate the multi user environment and after getting desired results for the single user environment, the simulations for multi user environment were also held. The chip time  $T_c$  for our code was  $1e-11$ s which was smaller than the bit time.

In case of multiuser environment the code  $c$  was generated by using `rand()` function, the same code was also known at receiver. We used an approach in which multiuser interferences were added to the transmitted signal. For multiuser environment SGA hypothesis was used. The analysis used to evaluate multi-user UWB IR performance was done under following hypothesis:

- Binary sequences are formed by independent and identically distributed random variables.
- Pulse repetition frequency of all sources is same i.e.  $1/T_s$
- Each code corresponds to a PN sequence.
- For every Tx / Rx pair, specific code is used which is known at receiver.
- Pulse will have a symmetrical shape around its center value.
- Channel must be considered as a multi-path-free channel.
- The receiver use single-user coherent correlation structure and soft decision detection and a ML detector.
- Transmitter and Receiver are supposed to be perfectly synchronized.

#### *Modulator*

Now, about the modulation schemes used in our system. There are several options available when we consider modulation schemes. Our leading contenders were binary PAM and binary PPM, binary PAM is easier to implement and provide better bit error performance. But PPM has an advantage that it requires constant transmitted power, because

the amplitude and pulse width is always same. Another trade off we encounter was that better synchronization and tracking at both receiver and transmitter is required for pulse position modulation.

The time shift that was introduced by the modulator to the transmitted pulse is 0.5ns. If the bit is one, pulse will be shift 0.5ns in time domain and if the bit is zero there will be no shift in position of pulse.

*Pulse Shaper*

Next step in our transmitter design is pulse shaping. We used Gaussian pulse shaping in our transmitter design. The amplitude of the pulse is set in such a way that the pulse energy will be 1, the formula used for Gaussian pulse shaping was

$$p(t) = \pm \frac{\sqrt{2}}{\alpha} e^{-\frac{2\pi t^2}{\alpha^2}}$$

The effect of transmitter on a transmitted bit is explained by the following equation

$$s(t) = p(t - T_s - c * T_c - x * s)$$

The value of  $\alpha$  used was 0.6ns, where bit time was  $2 * T_c$ . The code repetition produces a shift of 'Ts', transmission coder adds a shift of 'c\* $T_c$ ', and modulator added a shift 's', where 'x' is the transmitted bit.

Observation of transmitter will transmit the bit stream of test data provided by user in graphical form. The different values used in this specific simulation are

- Bit stream = 0, 0,0,0,0
- = 0.4ns
- Sampling frequency = 50/
- PPM shift s = 0.5 ns
- TH shift  $T_c = 0.1$  ns

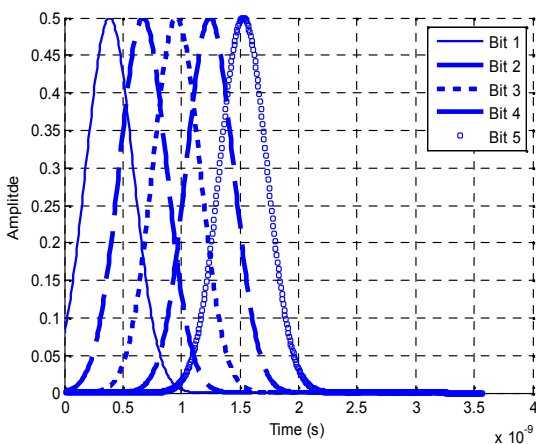


Figure 12 Representation of transmitted bit stream

We have sent another bit stream [1, 0, 1, 0, and 0] using our transmitter by keeping all other values of transmitter parameters same.

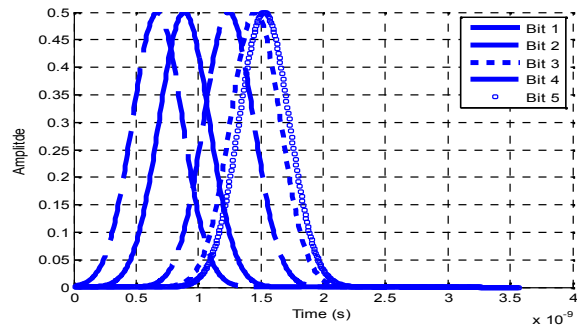


Figure 13 Representation of transmitted bit stream - case 2

As in figure 13 the demonstration of Pulse Position Modulation in our code, as the first bit is 1 so is the shift of 0.5ns in the corresponding pulse. Same is the case for 3<sup>rd</sup> bit, as it is shifted to the end of train of pulses.

*Channel Implementation*

After the successful implementation of transmitter, next step in our quest to design and implement a fully functioning ultra wide band communication system is to design and implement the channel model. There are two channel models that we will use in our simulations,

- AWGN channel model
- IEEE 802.15.3a UWB channel model

*AWGN channel model*

Additive white noise Gaussian channel is the simplest channel model available. Absence of nonlinearity, dispersion and other multipath channel impairments means that the noise added to transmitted waveform is simply an additive random noise. The simplest way to implement an AWGN channel is to create random Gaussian distributed noise and multiply it with standard deviation of our transmitted signal. Relationship for standard deviation ( $\sigma$ ) is given below

$$Eb/No = 10^{EbNo_{db}/10}$$

Now,

$$\sigma = \sqrt{\frac{No}{2}}$$

Where,

$$No = \frac{E_t}{Eb/No}$$

Where  $E_t$  is the energy of waveform transmitted, now we will observe how the transmitted pulse is affected by channel noise in case of AWGN with the help of a graphical description.



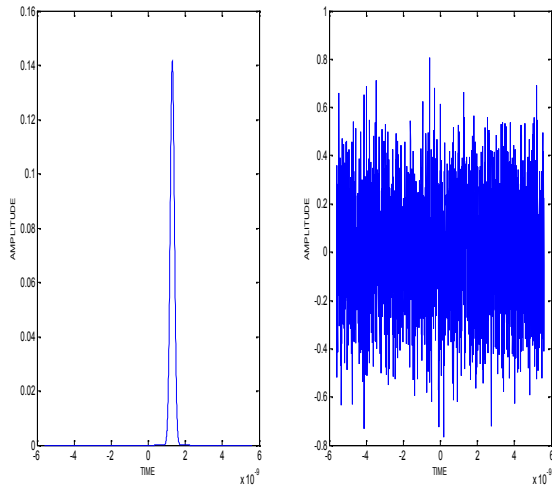


Figure 14 Transmitted pulse a) at transmitter b) at receiver [ for Eb/No=10dB]

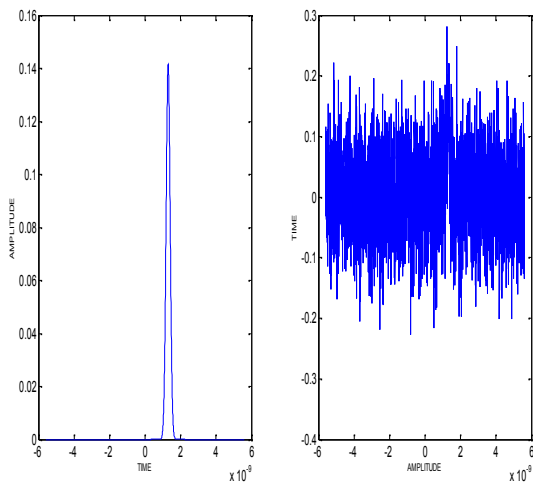


Figure 15 Transmitted pulse a) at transmitter b) at receiver [ for Eb/No=20dB]

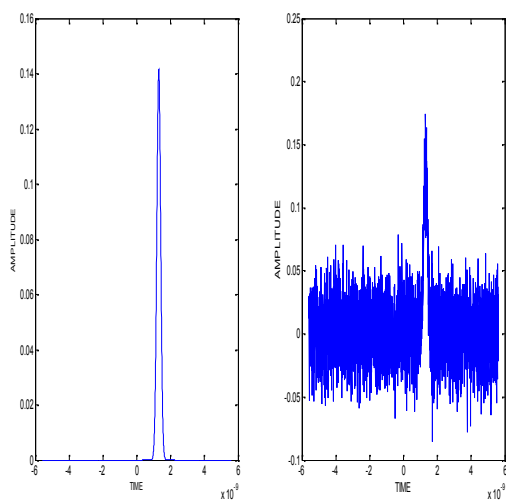


Figure 16 Transmitted pulse a) at transmitter b) at receiver [ for Eb/No=30dB]

The effect of AWGN channel on transmitted waveform has been shown in figure 14, figure 15 and figure 16. We can see that as the value of Eb/No is increased, the channel has lesser effect on the transmitted pulse.

*IEEE 802.15.3a UWB channel model*

After the successful implementation of AWGN channel, we have considered a multipath affected environment. There are certain multipath channel models available, we will use IEEE802.15.3a. It has been specifically designed for ultra wide band communications. Our received signal at receiver input should be as in equation below

$$r(t) = h(t) * s(t) + n(t)$$

Where, channel response of the signal is modeled by  $h(t)$ , our module is specifically designed to generate the impulse response for desired environment. We will use case A and case D from table 1.

Now let us observe what type of impulse response we will have from our channel model. Factors affecting the channel impulse response are

- Observation time
- Bin duration
- Sampling frequency
- Channel parameters selected from table 1

We will check our channel for test values of these parameters. Let us have observation time of 100ns, bin duration of 0.1ns, sampling frequency 100/a where a=0.5ns and case A is selected.

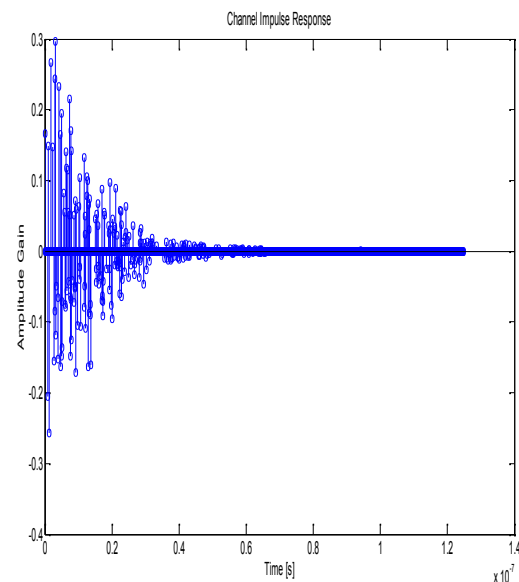


Figure 17 Channel response of IEEE UWB channel (ts=0.1ns) Now, let us have bin duration of 1ns

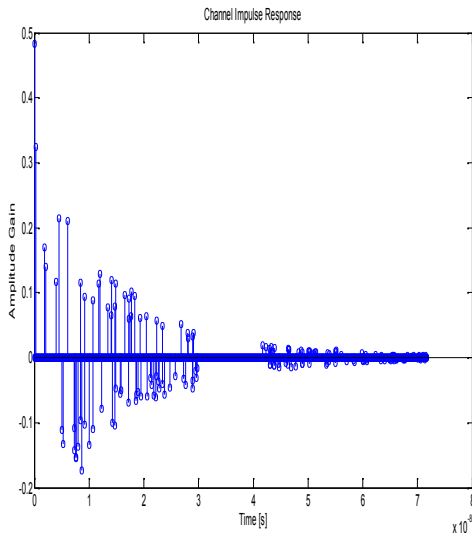


Figure 18 Channel response of IEEE UWB channel (ts=1ns)

We can see that as the bin duration increases, no of components in channel response decreases which decrease the performance of channel. Now we will observe the power delay profile of our channel response. It gives us graphical representation between arrival times of different contributions and power. This is shown in figure 19.

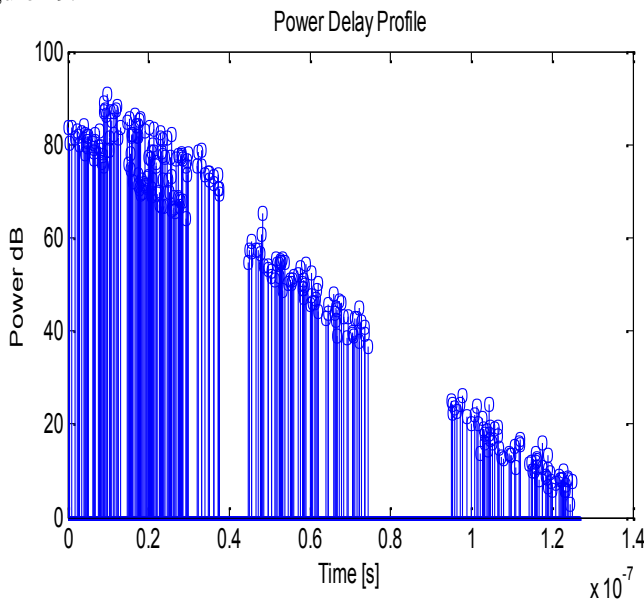


Figure 19 PDP of channel response

### VII. SIMULATION AND RESULTS

Different simulations are performed using our transmitter, channel and receiver modules. We investigated the different factors affecting the transmission of UWB IR system.

#### Influence of signal parameters on UWB IR signal

We will simulate our transmitted pulse and discuss the effect of different parameters on the spectral properties of that signal.

#### Pulse Shaping

First we will discuss the effect of pulse shaping on UWB IR; we will transmit a bit and transmit it as Gaussian pulse and truncated sinusoid waveform. These two techniques of pulse shaping are tested to see whether which one of following technique provides better spectrum efficiency. The results showed in figure 20 and figure 21 shows that Gaussian pulse shaping provides better spectral occupancy. The sinusoid's PSD provides a very narrow pulse at target frequency

$$p(t) = \sqrt{2/a} e^{-\frac{2\pi t^2}{a^2}}$$

Where 'a' is a scale parameter. In this simulation a=0.6ns, sampling frequency was 100/a and plots are generated for one sided spectrum. We generated the sinusoid of higher frequency i.e.2GHz for sinusoid waveform i.e.  $p(g) = \sin(2 * \pi * 2e9 * g)$ . We can see that a Gaussian pulse with pulse width of 1.2ns can provide a spectrum of 7GHz. whereas spectral width for sinusoid is very narrow. We can also see that spectrum of sinusoid waveform is centered on Centre Frequency i.e. 2GHz, Whereas for Gaussian pulse spectrum is not shifted, so use of Gaussian pulse fits better for UWB IR because it has better spectral occupancy.

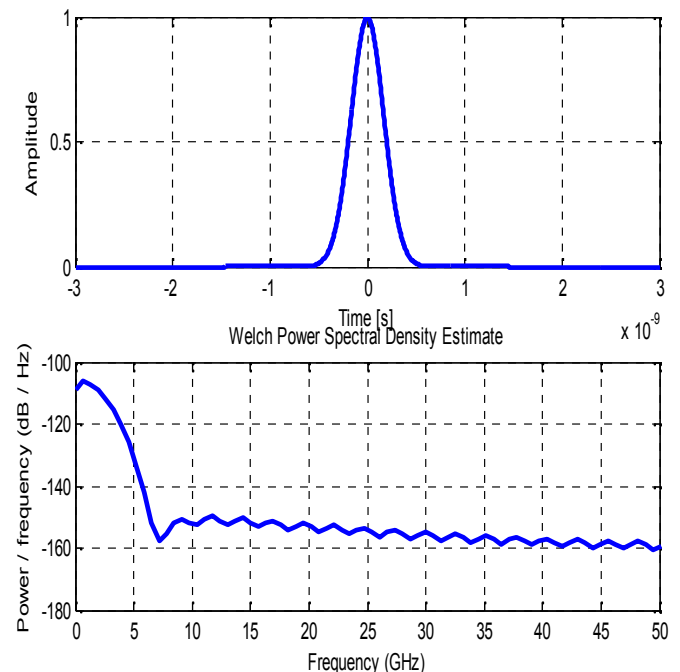


Figure 20 a) Gaussian Pulse b) PSD of Gaussian pulse

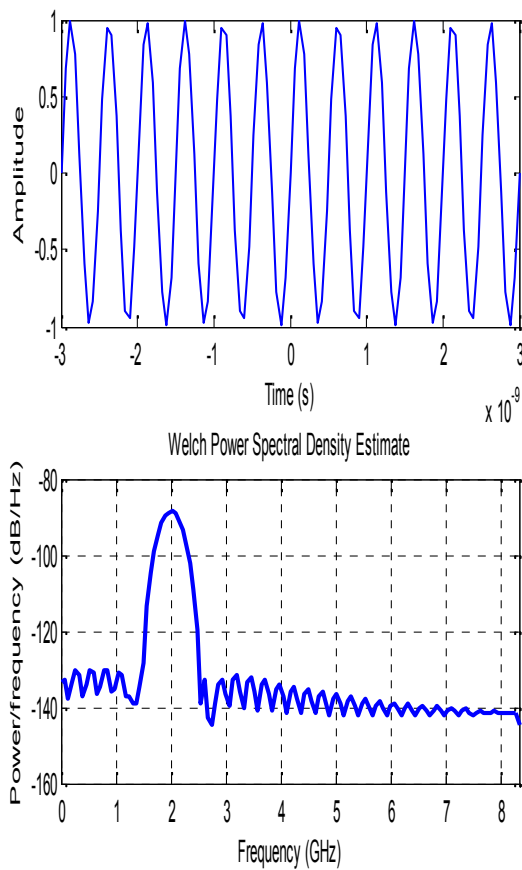


Figure 21 a) sinusoid waveform b) PSD of sinusoid waveform

*Effect of Pulse Width on Spectra of signal*

The Gaussian pulse was observed for different pulse widths, the value of ‘a’ controls our signals pulse width. In figure 20(a) different pulses for different values of ‘a’, we can see that as the value of ‘a’ increase, the pulse width will also increase. Now in figure 20 (b) power spectral densities of these transmitted pulses is shown, we can see that as the value of ‘a’ increases, the spectral occupancy of the signal decreases. So we can conclude that as the pulse width increases, bandwidth of the signal decreases. The sampling frequency used was 100/a.

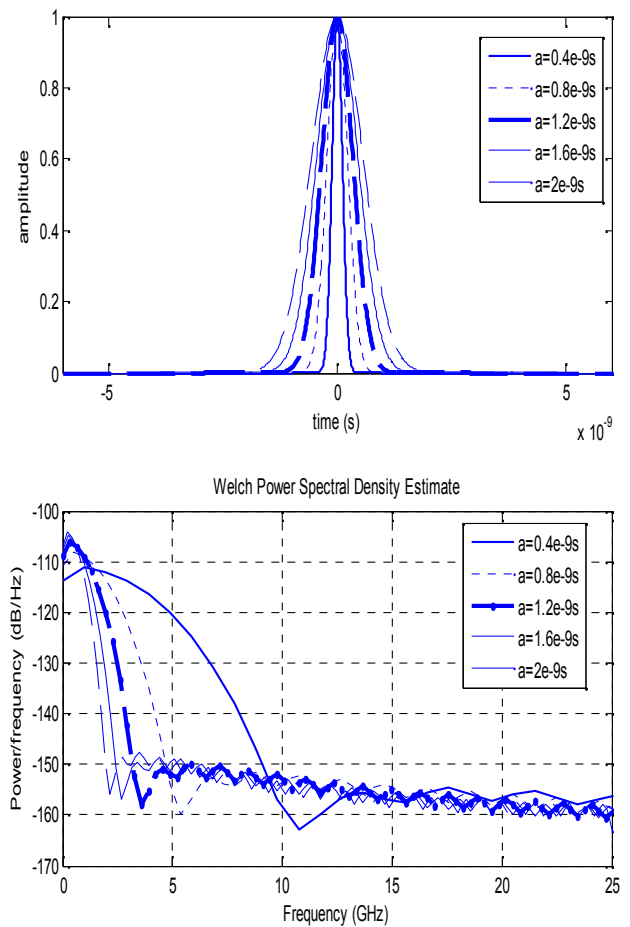


Figure 22 a) different pulses transmitted by changing value of ‘a’ b)Power Spectral Density of transmitted pulse for different pulse widths

*Effect of higher order Gaussian derivative on Spectra of signal*

Higher order derivatives of Gaussian pulse shape will affect signal spectrum. The next plot will show the graphical demonstration of power spectral densities of different derivatives of the Gaussian pulse. As the derivative order increases, peak frequency of power spectral density for the respective derivative also increases. The value of ‘a’ for following simulation was 0.6e-9 and sampling frequency was 100/a.

So we can say that with the increase in the peak frequency, the center frequency of signal is also increased. In this case carrier less transmission of UWB IR has been done, but the spectrum of transmitted signal can be shifted with the help of taking the derivatives of Gaussian pulse and drawback of this method to shift the spectrum is that the bandwidth of signal will also decrease, but that decrease in bandwidth is not very significant.

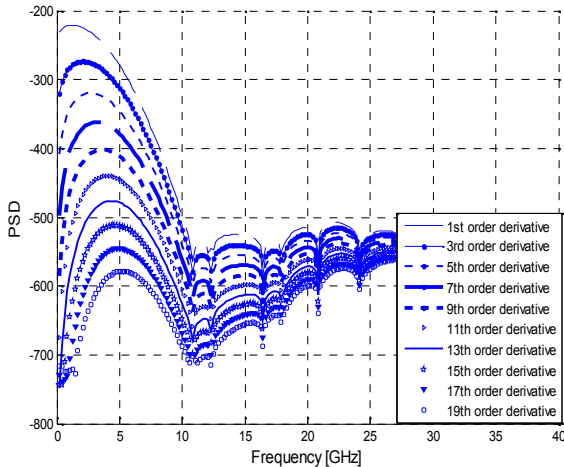


Figure 23 PSD's of different derivatives of Gaussian pulse

**Bit Error Performance evaluation:**

The bit error performance of UWB IR has been evaluated for following cases:

- AWGN channel
- Multi path environment (IEEE UWB 802.15.3.a channel model)
- Multiuser environment

**AWGN channel**

At first, our system has been tested at AWGN channel environment at different values of code repetition coder. We can see in figure24, the effect of code repetition coder on BER performance. Greater the number of repetition bits better the bit error rate performance. We can compare the simulated result versus the theoretical calculations, Figure 24 also shows the plot of theoretical and simulated results, simulations of figure 25 are done for Binary pulse position modulation and time hopping algorithm was also used, also AWGN channel along with correlation receiver were used.

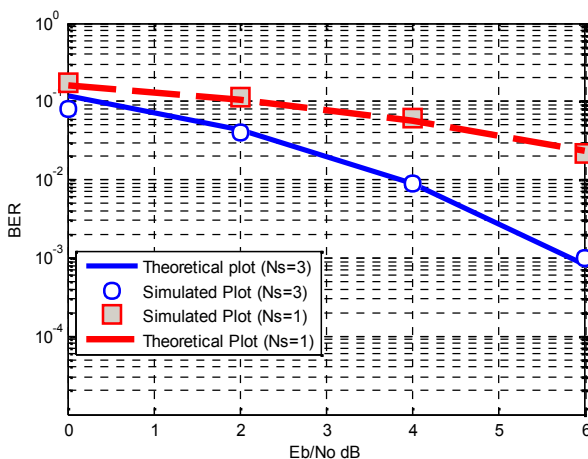


Figure 24 Bit Error Performance of Simulated and Analytical results for AWGN

**Multi Path Environments:**

Now we will use our system in multipath environment. We will first test our system for two cases of IEEE UWB 802.15.3.a channel model i.e. case A and case D. In figure 25, the simulation for case A and case D were done with observation time of 100ns, bin duration of 0.1ns with code repetition value  $N_s=1$ . By keeping other parameters same we will simulate our system for different types of rake receivers for case A, figure 26 shows the result of different types of rake receivers, we can clearly see that ideal rake provide best results and we will get worst performance for Partial rake with 2 branches.

**Multi User Environments:**

Now we will see the results of our system model for multi user environment, time hopping is used for this specific reason. Basic assumption made during simulation was that in multi user environment there will be multi user interferences. Simulation will be done for Binary-PPM, AWGN channel and value of  $N_s=3$  and detection technique used in receiver side was Soft decision detection, used of soft decision was motivated by the fact that Multi user performance for UWB-IR was based on SGA hypothesis which was already discussed in Chapter 5. The value of PPM shift used in simulation was 2.27ns and Multi user delay was 0.6ns, and  $T_s$  was  $2.4*(T_b/N_s)$ , where  $T_b$  was 1.6ns. The error performance of UWB IR in multi user environment for both theoretical and simulated is given in figure 27.

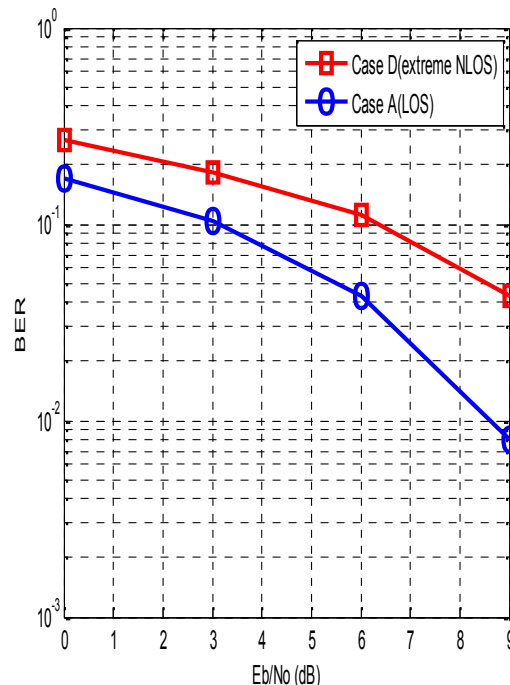


Figure 25 Comparison of BER performance for different multipath environments (IEEE 802.15.3a)

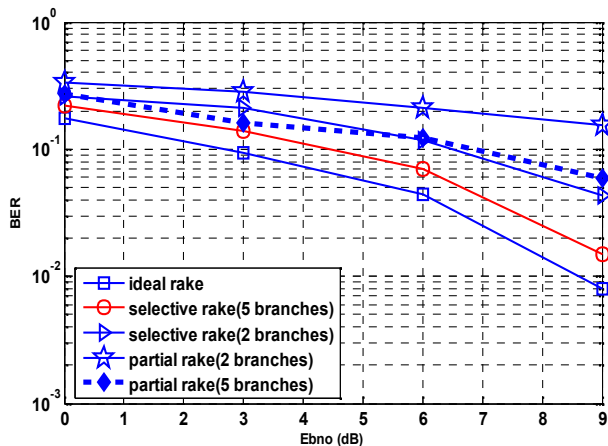


Figure 26 Bit error performance for different types of rake receivers in IEEE 802.15.3a Multipath channel

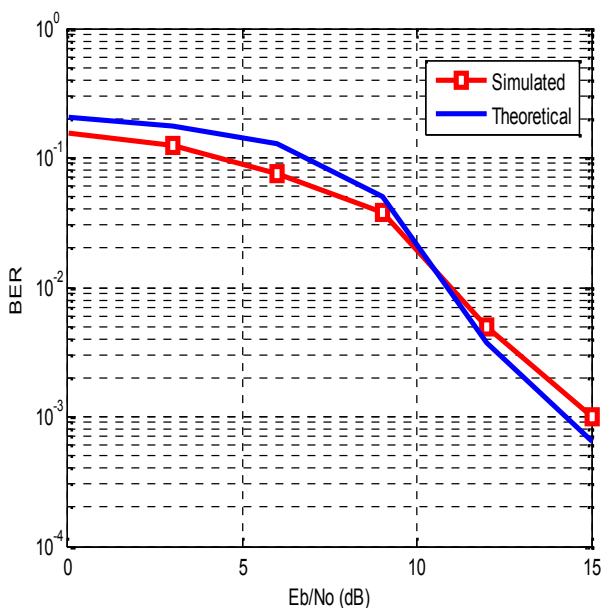


Figure 27 Multi User UWB IR error performances for Simulated and Analytical results

### CONCLUSION

The UWB IR system model was tested with the help of different simulations in different scenarios of modern day communication environments. First different factors affecting the UWB IR transmission were discussed. Then simulated results were supported by the theoretical results; performance of different types of rake receivers was justified. Then performance of system was analyzed for the multi user environment. We would want to implement our UWB IR model for modulation schemes other than PPM that include QPSK, QPAM and PCM. Another interesting perspective that we want to explore is to compare the performance TH-PPM versus the DS-SS at different environments.

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