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Ultra-wide band (UWB) pulse design and channel modeling

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Abstract

Ultra-wideband technology is a new wireless technology. The advantages of ultra-wide and technology are high bandwidth, high data rate, and low cost and low power consumption. A conventional type of UWB communication is impulse radio and other different types of UWB systems are available. They act as an overlay system with other existing narrowband (NB) radio systems overlapping with their bands. The issue of coexistence and interference of UWB systems with current indoor wireless systems must be considered for a robust communication link. Designing of an optimized interference mitigation technique for UWB channel is main concern here. As a part of this goal here we are presenting detail study of UWB pulse in time and frequency domain along with the simulated model of UWB channel.

Keywords: *FCC, PSD, UWB, NBI, ISI*

INTRODUCTION

Federal communication commission (FCC) has approved the operation and production of unlicensed ultra-wide band devices (UWB) since 2002. Ultra-wideband (UWB) is a technology for transmitting large amounts of digital data over a broad frequency spectrum using short-pulse, low powered radio signals [1]. UWB has gain importance because of its very high data rate along with low cost hardware and low power consumption. The two task groups (TGs) that are based on UWB technology are IEEE 802.15.3a and IEEE 802.15.4a. In the year 1960 UWB technology was mainly used for radar and military applications. The IEEE 802.11a and IEEE 802.11b operate at 5 GHz and 2.4 GHz which used for high data rate WLANs and long range applications respectively [2]. In this research work we have generated different types of UWB pulses. For interference evaluation the characterization of wireless channel parameter are important. Channel parameters such as path loss, signal attenuation, signal fading margin etc. Different interference mitigation techniques are as follows- NBI as a single tone [3], NBI reduction in IR UWB communication systems using Rake receiver[4-6], Transmitted reference (TR) signaling in conjunction with an autocorrelation receiver (AcR) [7-9], NBI mitigation technique using multiple receive antennas [10], channel equalization [11]. During the process of transmission, the signals get distorted due to various condition causing inter symbol interference (ISI). To eliminate this channel equalizer is required. In this work we have used neural network for channel equalization. When the system is time variant, neural network has the adaptability to perform well [12].

UWB PULSE ANALYSIS

Different types of UWB pulses includes “impulse,” “short-pulse,” “no sinusoidal,” “carrier-less,” “time domain,” “super wideband,” “fast frequency chirp,” and “monopoles”. UWB spectrum results from utilization of short pulse transmission from impulse radio communications systems and impulse radars. According to FCC, UWB is the transmission of ultra-short duration pulses, with bandwidth in the gigahertz range. UWB consists of narrow time signals that occupy a wide portion of spectrum; as the PSD is low therefore it results in low interference with existing narrowband services [13]. Because of sharp rise and fall of the pulse, such pulses provide spreading of energy over a large bandwidth. There are three types of UWB pulses usually referred as Gaussian pulse, Gaussian pulse of first derivative or Gaussian monocycle and Gaussian pulse of second derivative or Gaussian doublet. The Gaussian pulse for UWB system is defined as:

$$p(t) = A\, exp\left(-\frac{(t-t_0)^2}{2\tau^2}\right) \qquad (1)$$

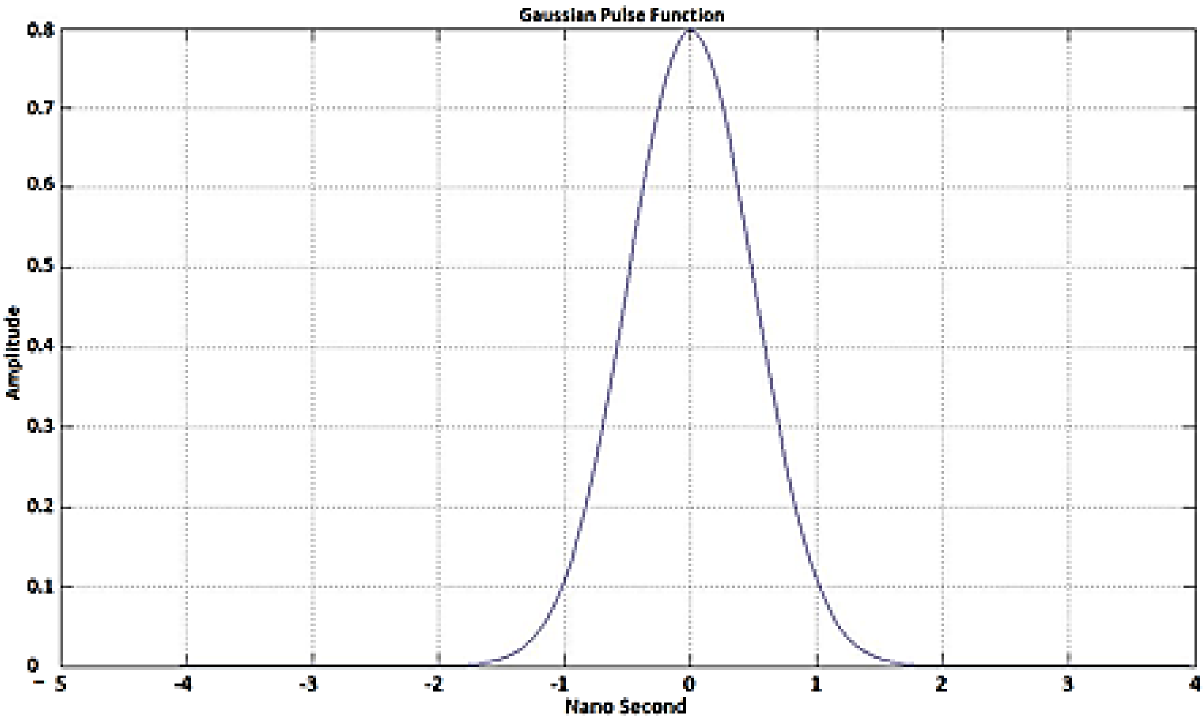
Where 'A' and 't_0' provides the amplitude and time offset respectively and 'τ ' is the time constant gives the width of the pulse in seconds. The Gaussian monocycle is defined as:

$$\frac{d}{dt}p(t) = A\frac{1}{\tau^2}exp\left(-\frac{1}{2}\left(\left(\frac{t-t_0}{\tau}\right)^2\right)\right) \qquad (2)$$

The Gaussian doublet is defined as:

$$\frac{d^2}{dt^2}p(t) = A\left[\frac{1}{\tau^2}exp\left(-\frac{1}{2}\left(\left(\frac{t-t_0}{\tau}\right)^2\right)\right) - \frac{t^2}{\tau^4}exp\left(-\frac{1}{2}\left(\left(\frac{t-t_0}{\tau}\right)^2\right)\right)\right] \qquad (3)$$

Figure 1 shows the Gaussian, Figure 2 shows the Gaussian monopoles and Figure 3 shows the doublet pulse respectively when we implemented from the above three equations. There are different approaches to the implementation of UWB employed by companies for a variety of applications like chirp, wavelet and raised cosine pulses.



`***Fig1.*** *Gaussian pulse*

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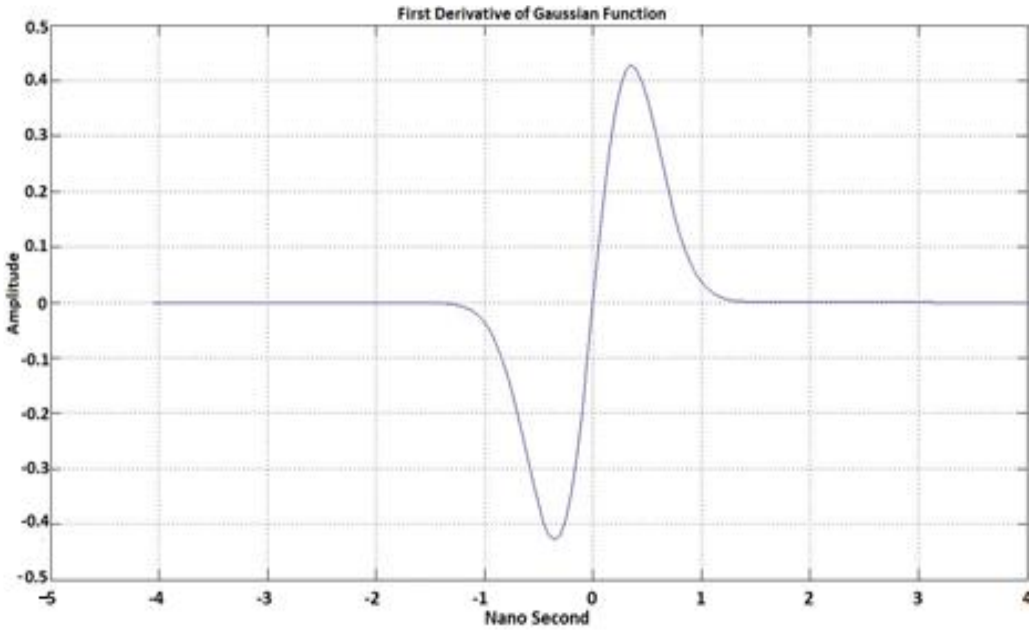


Fig2. *Gaussian monocycle*

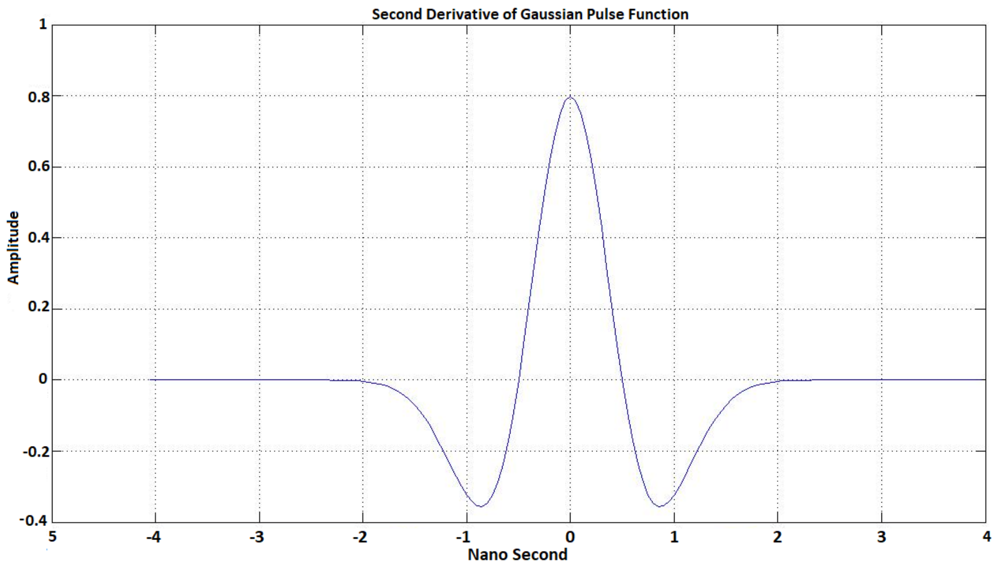
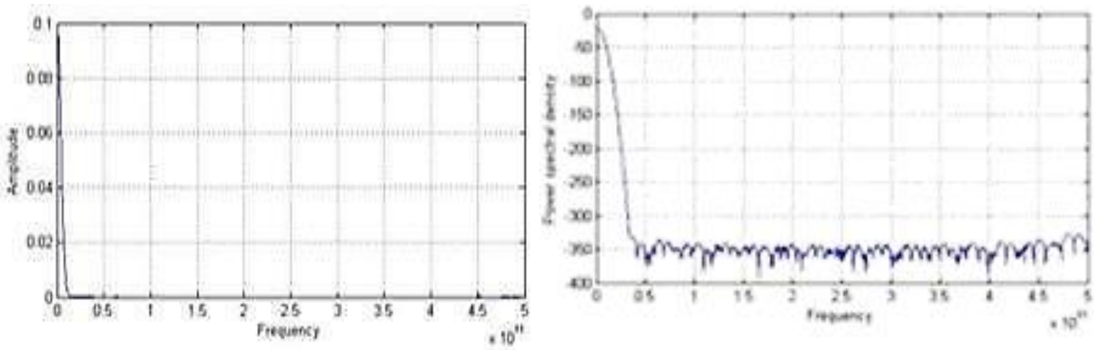


Fig3.*Gaussian doublet*

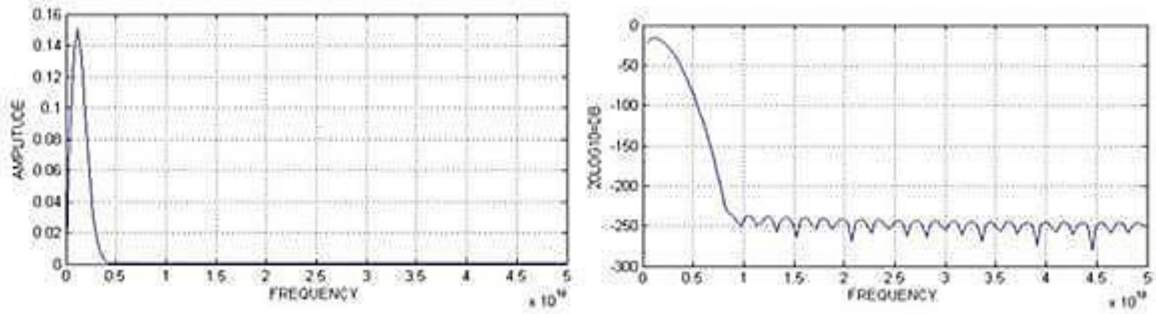
TIME, FREQUENCYAND POWER SPECTRAL DENSITY (PSD) ANALYSIS OF DIFFERENT UWB PULSES

A typical UWB pulse ranges between 0.2 and 0.5 nanosecond. In the initial simulation, a UWB mathematical model based on Gaussian pulse train, Gaussian monocycle, Gaussian doublet pulses in time, frequency domain and power spectral density were made which are shown in Figure 4, 5 and 6 respectively. By changing the duration of the pulses we examined the effect on the spectrum. Time domain pulse rate is directly proportional to Frequency domain magnitude i.e. the magnitude of the spectrum is influenced by the pulse rate. Spectral width is inversely proportional to the pulse duration in the time domain, i.e. the pulse duration helps one to determine the spectral width. It is seen that the 1^{st} and 2^{nd} derivative pulses will meet the FCC spectral mask with reducing the transmitter power.



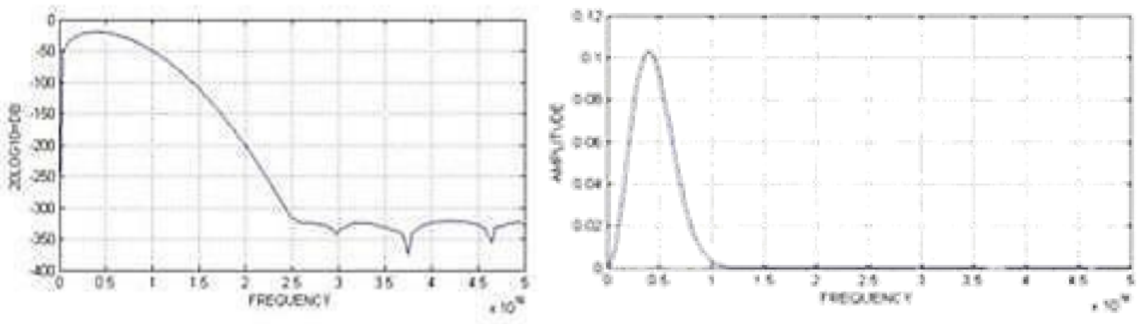
(a) Gaussian Pulse in Frequency Domain (b) Magnitude Spectrum of Gaussian Pulse

Fig 4. *Gaussian Pulse in frequency domain and magnitude Spectrum*



(a) Gaussian Monocycle in Frequency Domain (b) Magnitude Spectrum of Gaussian Monocycle

Fig5. *Gaussian monocycle in frequency domain and magnitude Spectrum*



(a) Gaussian Doublet in Frequency Domain (b) Magnitude Spectrum of Gaussian Doublet

Fig 6. *Gaussian Doublet in frequency domain and magnitude Spectrum*

UWB CHANNEL MODELING

As UWB has a very wide bandwidth, different parts of the same object will give rise to several multipath components, all of which would be part of one cluster. Thus, the multipath components arrive at the receiver in clusters. At the receiver part multiple components arrives in the form cluster. Within each cluster, there are multiple subsequent arrivals called rays. Therefore to model Saleh-Valenzuela (S-V) model cluster arrival rate and ray arrival rate parameters are required. It obtains a non-Rayleigh fading characteristic as it uses very short pulses. In case of S-V modeling log normal distribution is used to denote the non-Rayleigh amplitude characteristics. Arrival rate of path within each cluster is known as ray arrival rate. The ray arrival rate is always bigger than the cluster arrival rate. The amplitude statistics in S–V model are based on lognormal distribution, the power of which is controlled by the cluster and ray decay factor. Cluster arrival rate, cluster decay factor, ray arrival rate and decay factor, standard deviation of ray lognormal fading term, standard deviation of cluster lognormal fading term, standard deviation of lognormal shadowing term describes the indoor channel environments. Depending upon different types of channel environmental condition, channel environments are classified as- CM1, CM2, CM3, CM4. Line of sight (LOS) scenario with a distance of less than 4m and more than 10m respectively between transmitter and receiver is described by CM1 and CM4. CM2 and CM3 describes NLOS scenario with a distance of less than 4m and between 4-10m respectively. In wireless transmission, the characteristics of the signal changes as it travel from the transmitter to the receiver. The reason for different types of propagation condition: 1) existence of line of sight path between the antennas, 2) reflection, refraction and diffraction of the signal, 3) The relative motion between the transmitter and receiver and the objects in between them, 4) The signal attenuation as it travels through the medium, 5) Noise. If we can accurately model the channel in between the antennas, the received signal can be obtained from the transmitted signal. It is quite difficult to model the real world environment. The location of scattering objects is dependent on the response of UWB channel which is characterized by a few spikes separated by a time during which no significant energy arrives. In UWB communication systems fundamentals of UWB propagation are multipath propagation, path gain and large scale fading. Because of the multipath propagation signal can be transmit through transmitter to receiver. As a sum of components the transmitter emits electromagnetic field which propagates in space and might be reflected, diffracted or scattered by objects in the environments.Thus the components gets change and some interactions like diffraction even spilt up the components into multiple new components. Path gain and large scale fading are two important phenomenons in wireless propagation. Large scale fading means that strength of a multiple components show variations as the transmitter (receiver) moves over distances that are larger than small scale averaging area. The path gain describes the ratio of received power to the transmitted power, averaged over both small scale and large scale fading. The modeling of UWB propagation channel is fully based on the proposed IEEE 802.15.3a standard model [14]. The impulse response of modified Saleh-Valenzuela model may be represented as:

$$\boldsymbol{h(t) = X\sum_{l=0}^{L-1}\sum_{k=0}^{K-1}\alpha_{k,l}\delta\left(t - T_l - \tau_{k,l}\right)} \qquad (4)$$

Where$\{\boldsymbol{\alpha_{k,l}}\}$is the multipath gain coefficient of k^{th} ray related to l^{th} cluster, $\{T_l\}$ is the delay or arrival time of first path of the l^{th} cluster, $\{\boldsymbol{\tau_{k,l}}\}$ is the delay of the k^{th}multipath component within the l^{th} cluster relative to arrival time $\{T_l\}$, $\{X\}$ represents the lognormal shadowing term.

The multipath components are defined in cluster and rays cluster arrivals are Poisson distributed with rate $\boldsymbol{\Lambda}$ (cluster arrival rate). The definition assumes that within a cluster, the first ray arrives at with no delay. The distribution of cluster arrival time and the ray arrival time can be presented by:

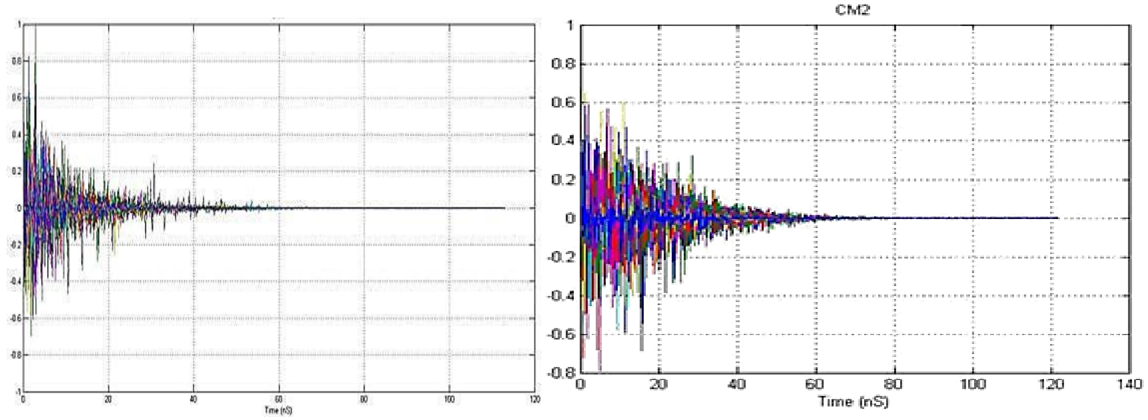
$$p\left(\frac{T_l}{T_{l-1}}\right) = \boldsymbol{\Lambda}\mathbf{exp}[-\boldsymbol{\Lambda}(\boldsymbol{T_l} - \boldsymbol{T_{l-1}})] \qquad (5)$$

$$\boldsymbol{p\left(\frac{\tau_{k,l}}{\tau_{(k-1),l}}\right) = \lambda exp[-\lambda(\tau_{k,l} - \tau_{(k-1),l})]} \qquad (6)$$

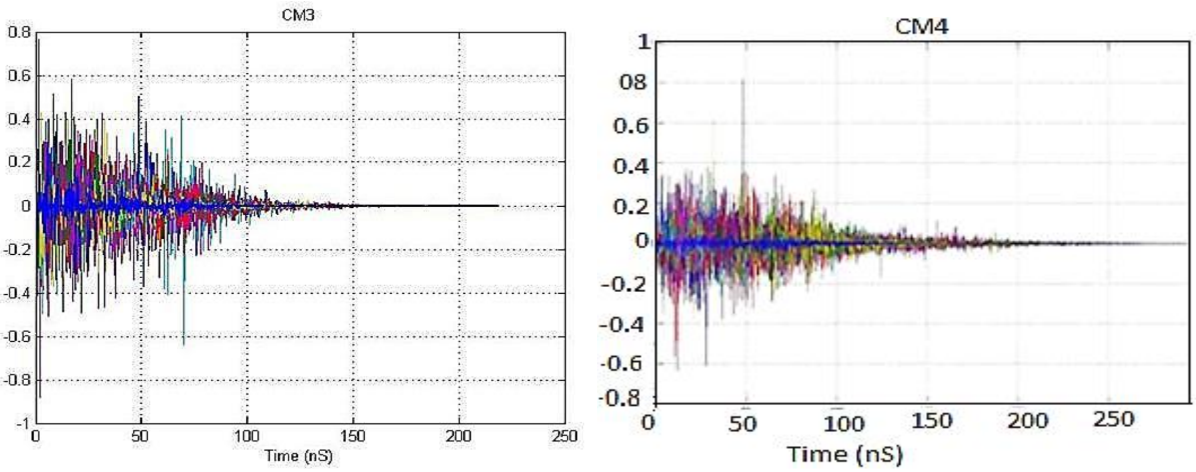
The shadowing term is characterized by:

$$\boldsymbol{20\log_{10} X \infty Normal(0, \sigma_X^2)}$$

To study the delay characteristics of the modified S-V channel under UWB, we calculate the impulse response of equation (4) using MATLAB. The following result is obtained. Four different channel modeling is done by considering the standard parameters. The impulse responses of the four different modified S-V models are shown in Figure 7. It is seen that gains of paths in CM3 and CM4 decay faster as compare to CM1 and CM2



(a) Impulse response realization of CM1 (b) Impulse response realization of CM2



(c) Impulse response realization of CM3 (d) Impulse response realization of CM4
Fig 7.*Impulse response realization for four different channel environments*

IMPLEMENTATION OF UWB COMMUNICATION SETP WITH THE UWB CHANNEL

Because of high data rate transmission capability and the ability to deal with the delays Orthogonal Frequency Division Multiplexing (OFDM) is used. In the IEEE802.15.3a standard UWB-OFDM is used. Future wireless communication systems requires high data-rate and reliable transmissions with bandwidth efficiency

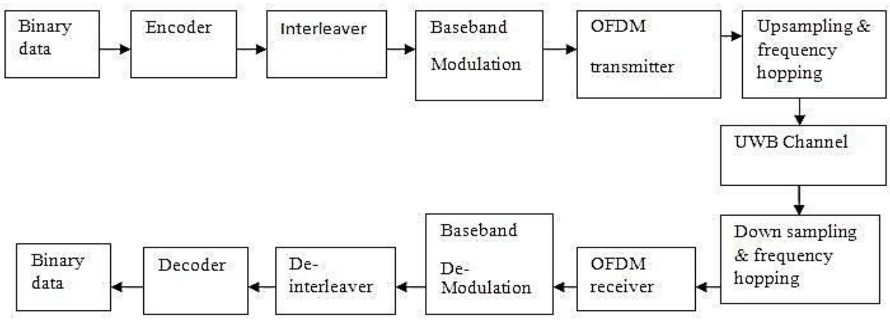


Fig 8. *Block diagram of UWB OFDM system [15]*

In this work a random binary number is taken. In the encoder part, convolution and puncture is done. In this work 5/8 encoder is used. The interleaver increases the resistance to fading. The interleaving is used on OFDM is to attempt to spread the errors out, as when there is high concentration of errors the decoder is unable to correct all the bit errors and a burst of uncorrected errors occurs. Then the QPSK modulation is done. For the transmission purpose OFDM transmitter is used. After doing the frequency hopping and filtering, it is passed through the UWB channel. In this case CM4 channel model is considered. Then the frequency de hopping and filtering is done. Then the OFDM receiver is used. After that QPSK demodulation, deinterleaver and decoing are performed. BER between the transmitted and received data is obtained. The BER is of 0.5074. All of the work has been done by using Simulink model which is shown in Figure 9.

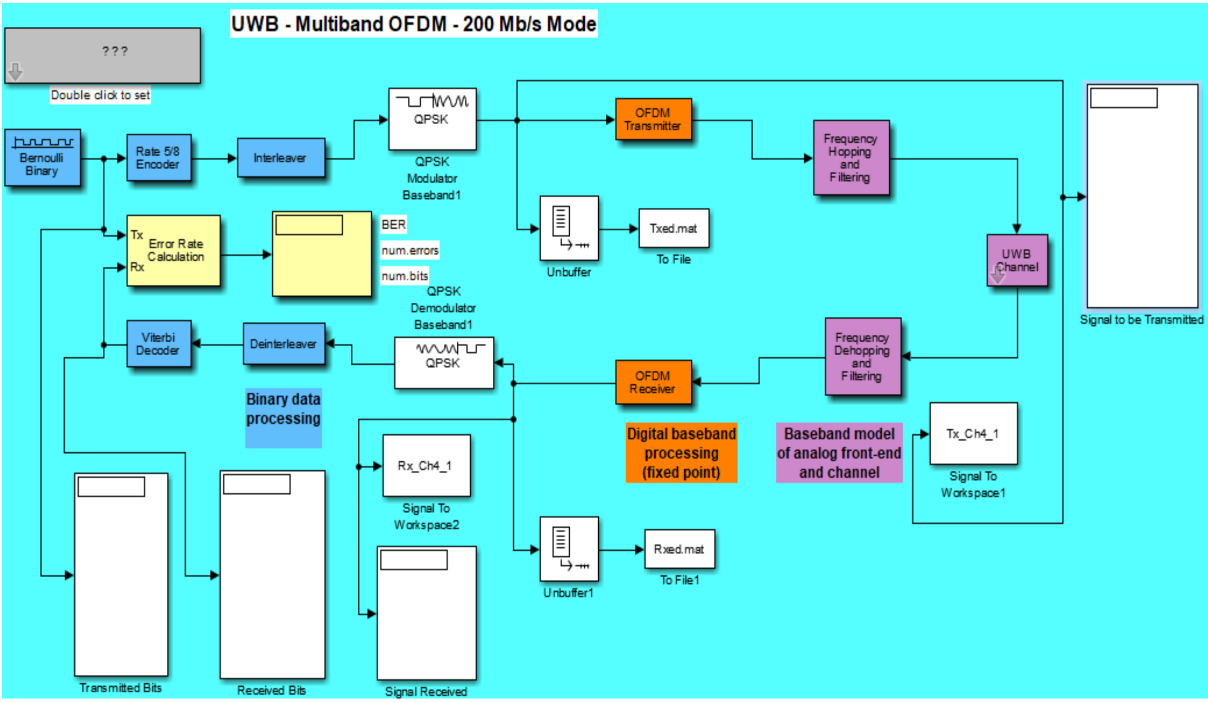


Fig 9. *UWB OFDM simulink model implemented in MATLAB*

CONCLUSION

We first needed to define a pulse shape to generate a UWB channel. We generated different types of pulse shape to compare the result. It is seen that the first and second derivative pulses will not meet the FCC spectral mask without reducing the transmitter power. Without a reduction in power the fifth order derivative is able to meet the FCC mask. The bandwidth is of 3-10 dB wide. Because of different cluster arrival rate, in paths CM3 and CM4 the clusters and delays are more as compare to the path of CM1 and CM2. This is due to their different cluster arrival rates. Due to longer path the path gains of CM3 and CM4 decay faster. As bit error rate (BER) of CM4 is less therefore in my case I have used the CM4 channel model. Through the implementation and the performance analysis, we have obtained a good understanding about the architecture and the performance of the MB-OFDM UWB system. The understanding would help us improving the system in the future.

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