CHAPTER 4

PERFORMANCE COMPARISON OF IR-UWB SIGNAL GENERATORS

4.1 IR-UWB SYSTEM MODEL

The final objective of this research is to evolve a power efficient wireless solution for the efficient communication from an on–body sensor node to BCU in a WBAN environment. Some proposals are suggested in this thesis for the transmit signal design to improve the wireless communication efficiency in WBAN, and their salient features discussed in the previous chapters. The complete IR-UWB wireless system includes a transmitter with proper wave shaping, an appropriate wireless channel for signal propagation and an error free decoding logic for recovering the transmitted information. The sub-nano second pulse generator is required not only for generating an accurate pulse for FCC compliance, but also should offer low-cost, low-power and low-complexity features. There are several approaches for IR-UWB signal generation as discussed in previous chapters. It has been shown that higher order Gaussian pulses will satisfy the spectrum mask as per the requirement of FCC and their performance for higher data rate transmissions over multipath environment needs to be studied. Most of the reported research works on UWB channel characterization suggests the superiority of the MSV model for the same. The four categories of MSV channel models are Line Of Sight within 4m distance, None line Of Sight (NLOS) within 4m distance, NLOS with more than 4m distance and NLOS with maximum value of attenuation constant value, (Saleh & Valenzuela 1987). In this part of the thesis, the BER performance of the sixth derivative BPSK modulated
Gaussian signal and the previously generated Gaussian monocycle, triangular wave shaped multicycle and wavelet based IR-UWB signals are obtained and compared for transmission over the different channel scenarios defined in the Modified Saleh-Valenzuela (MSV) model. The received signal is demodulated using correlation receiver with the help of a template signal. The decoded signal is processed with the threshold detecting logic for getting the estimated information signal. The maximum possible data rate supported over the different channel types are determined for the transmission of higher order shaped pulses. The system performance is also evaluated and compared for the different IR-UWB signal generators proposed and studied in this thesis for their transmission over the four MSV channel types. The comparisons are done only for the proposed transmit signals since such data is not available for the signals reported in the literature.

4.2 SIXTH DERIVATIVE GAUSSIAN IR-UWB SYSTEM MODEL

A sixth derivative Gaussian pulse has been simulated to start with and used for validating the IR-UWB system performance with indoor channel models. Adoption of a suitable modulation scheme provides better periodicity and spectral efficiency. The most generally used BPSK method offers comparatively good performance in multipath environment and offers a 3dB advantage in SNR over PPM, (Wentzloff 2005). Channel models are adopted for validating the multipath environment under realistic conditions. The MSV Channel Model is considered a better approximation for hospital environment based WBAN application. The model specifies four types of channels including LOS (Line-of-sight) and NLOS (Non-Line-of-sight) channels. The simulated sixth derivative Gaussian pulses with BPSK modulation are transmitted through the simulated channel models and then finally decoded. The BER is calculated for different bit rates correspondingly for the four
types of channels and performance compared. The IR-UWB transceiver module is realized using a simple impulse transmitter and an energy efficient receiver with a special template based decoding logic. Figure 4.1 describes the system level diagram of the transmitter, which includes the wave shaping block. The sixth derivative Gaussian model is selected for better performance. The sixth-derivative Gaussian pulse is an accumulation of five delayed monopulse signals. Equation 4.1 gives the mathematical general expression of the $n^{th}$ derivative of Gaussian impulse. Power Spectral Density (PSD) of sixth derivative Gaussian pulse complies perfectly with the FCC spectrum mask. 

$$x^{(n)}(t) = \frac{d^n}{dt^n} \left( \frac{At}{\sqrt{2\pi\sigma}} e^{-t^2/2\sigma^2} \right)$$  

The spectrum of BPSK modulated pulses are free from spectral lines, so the complete spectrum will be fitting under the FCC for maximizing the transmit power. A PPM spectrum does not provide sufficient periodicity, hence contains spectral lines even when modulated with random data. The binary PPM spectrum and BPSK spectrum are compared in Figure 4.2, and it can be seen that the lines in the binary PPM spectrum are $10\log(\text{PRF}/1\text{MHz})$ dB above the BPSK spectrum (Wentzloff 2005). Therefore, higher-order PPM or BPSK scrambling in addition to PPM is used to eliminate these tones and thus the need to reduce the transmission power in case of PPM. The BPSK decouples the scrambling problem from the modulation, which is preferred over higher-order PPM also. But the BPSK system increases the hardware complexity at the receiver and requires synchronization to be implemented. The BPSK modulation is the most robust of all the PSK schemes, since it withstands the highest level of noise or distortion to make the demodulator reach an incorrect decision.

Figure 4.3 gives the systematic architecture of a correlation receiver for IR-UWB reception. The simulation is carried out in baseband and hence
the front end of a wireless communication receiver namely the Low Noise Amplifier (LNA) and Variable Gain Amplifier (VGA) are neglected.

Figure 4.1 UWB Transmitter block diagram (Courtesy: Maria-Gabriella 2006)

![UWB Transmitter block diagram](image)

Figure 4.2 Comparison of PPM and BPSK spectra for equal power (Courtesy: Wentzloff 2005)

![PPM and BPSK spectra comparison](image)

The correlation receiver concept has been adapted for good performance and easy realization. The correlation receiver should be equipped with a template signal generator for correlating with the received signal. The product of the input received signal and the template signal is integrated for
generating a robust signal level with relatively low frequency content. For faithful recovery of the transmitted data, the system clock synchronization should be performed at the receiver side and is assumed to be perfectly done in the simulation. The ADC section regenerates the estimate of the original data sequence from the integrated signal. The system performance is validated with the help of BER metric.

![Impulse UWB receiver block diagram](image)

**Figure 4.3** Impulse UWB receiver block diagram (Courtesy: Maria-Gabriella 2006)

### 4.3 CHANNEL MODEL FOR INDOOR UWB TRANSMISSION

The wireless communication channels generate multipath effect in between transmitter and receiver, causing delayed and damped signals at the receiver. The application environment decides the transmission performance of a wireless communication system, and hence a suitable channel model computation is very crucial. The channel characteristics should include both the path loss and the multipath fading aspects. As indicated earlier, the MSV channel types are used in the present IR-UWB system performance characterization.
**SV Channel Model:-** The SV channel model is described for short range wireless communication channels and is universally accepted as the channel model for all types of indoor and outdoor short range wireless communications. The transmission channel model for UWB is also initially characterized using the SV channel model. The SV channel model defines two absolute Poisson processes (double exponential model) for describing the complete channel model (Taparugssanagorn 2010). The self-governed Poisson processes (dual exponent models) describe the arrival of cluster (the 1st path) and inner multipath for implementing S-V model (Molisch 2003). The individual path amplitude of the channel is modeled by Rayleigh distribution. The impulse response of such model can be mathematically described with using Equation (4.2),

\[
h(t) = \sum_{l=0}^{L} \sum_{K=0}^{K} \beta_{kl} \delta(t - T_l - \tau_{k,l})
\]  

(4.2)

where, \(L\) = cluster number, \(K\) = ray number, \(T_l\) = the arrival time of the first path of the \(l^{th}\) cluster, \(\tau_{k,l}\) = the time delay of the \(k^{th}\) path in the \(l^{th}\) cluster relative to first path arrival time. The component \(\beta_{kl}\) can be described as,

\[
\overline{\beta_{k,l}^2} = \beta_{0,0}^2 \exp\left(-\frac{T_l}{\Gamma}\right) \exp\left(-\frac{\tau_{k,l}}{\gamma}\right)
\]  

(4.3)

where, \(\beta_{0,0}\) is the average power of the first path within first cluster, \(\Gamma\) and \(\gamma\) are power attenuation coefficients of cluster and multipath component. The arrival of clusters in multipath signals are described with first Poisson process with an arriving rate of ‘\(\Lambda\)’, and the second Poisson process explains the ray arrival process with arrival rate of ‘\(\lambda\)’. The first arriving process is described by Equation (4.4),

\[
p\left(T_l/T_{l-1}\right) = \Lambda e^{-\Lambda(T_l-T_{l-1})} \quad l > 0
\]  

(4.4)
The successive multipath components arrive with the second poison distribution with velocity of ‘λ’ and described by the Equation (4.5).

\[ p \left( \frac{\tau_{kl}}{\tau_{(k-1)l}} \right) = \lambda e^{-\lambda (\tau_{kl} - \tau_{(k-1)l})} \quad k > 0, l > 0 \] (4.5)

The above mentioned SV model however does represent the indoor specific LOS channel environments accurately. The bandwidth of the UWB waveforms is high and the objects generate several multipath components as part of one cluster. Especially the IR-UWB channels depict a multipath rich profile and non-Rayleigh fading amplitude characteristics. The MSV channel model has evolved to suit such characteristics.

**Modified SV Channel Model :-** The Modified Saleh-Valenzuela (MS-V) model was adopted as a channel model for IR-UWB wireless communication for WBAN applications in indoor scenarios (Hamalainen 2009). The channel model statistics for WBAN are adopted based on the measurement of indoor propagation environment, particularly hospital environment. The multipath components of UWB transmitted signals are sensed as clusters at the receiver. Each cluster is represented as multiple subsequent arrivals of rays (Sun 2009). The time-of-arrival statistics for the Saleh-Valenzuela (S-V) model is decided by the characteristics of multipath components in clusters and rays. Due to the short duration of UWB pulses, a few multipath components overlap with each resolvable delay bins. Hence the model violates the ‘central limit theorem’ and hence the amplitude fading statistics do not follow the Rayleigh. The amplitude fading statistics in the modified S-V channel model is realized by log-normal distribution in place of the Rayleigh amplitude fading statistics. The impulse response of such model can be pictorially represented as in Figure 4.4.
Equation (4.6) is used for mathematically describing the impulse response of the channel model, which is correlated with the time-of-arrival and angle-of-arrival,

$$h(t, \theta) = \sum_{l=0}^{L} \sum_{k=0}^{K} \beta_{kl} e^{j\theta_{kl}} \delta(t - T_l - \tau_{k,l})$$  \hspace{1cm} (4.6)

The arrival time and arrival angle of the multipath components generates cluster mean square angle. The arrival time and angle-of-arrival are relatively independent quantities and offers minimum time delay. So the above equation can be reframed as,

$$h(t, \theta) = h(t)h(\theta)$$  \hspace{1cm} (4.7)

where $h(\theta)$ is an independent angle impulse response, that has channel characteristics similar to the channel time impulse response, and hence is described by,

$$h(\theta) = \sum_{l=0}^{L} \sum_{k=0}^{K} \delta(t - \omega_{kl})$$  \hspace{1cm} (4.8)

where $\omega_{kl}$ is the arrival angle of the $k^{th}$ path within $l^{th}$ cluster. The temporal changes deteriorate the signal amplitude and fading may force the amplitude...
to zero. Therefore, $\omega_{kl}$ obeys Laplacian distribution and the model characteristic perfectly fits the channel model. The mean value of $\omega_{kl}$ is zero, the standard deviation is $\sigma$, its probability density is described as,

$$p(\omega) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{\omega^2}{2\sigma}}$$ \hspace{1cm} (4.9)$$

$h(\theta)$ is absolutely independent according to the Equation (4.7). So, the channel impulse response of the Modified SV is depicted as,

$$h(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} \beta_{kl} \delta(t - T_l - \tau_{kl})$$ \hspace{1cm} (4.10)$$

where the component $\beta_{kl}$ can be described as in Equation (4.3) and the variables are described as, $\Gamma$ = cluster decay factor, $\gamma$ = ray decay factor, $\sigma =$standard deviation of log-normal fading term(dB). Different indoor short channel models are also proposed for assessing various UWB system schemes. The Modified SV channel model design parameters are specified by IEEE 802.15 task group and the same values are adopted for the proposed system simulation. The Table 4.1 gives the channel parameters for the four channel types, namely (i) Line Of Sight –CH1 (ii) None Line of Sight Channel (NLOC)–CH2 (iii) NLOS (4-10 mtrs)- CH3 and (iv) NLOS (4-10mtrs) Channel with maximum attenuation factor-CH4, respectively.
Table 4.1  Channel environment characteristics and model parameters  
(Courtesy: Jadhavar 2011)

<table>
<thead>
<tr>
<th>Channel Type</th>
<th>Distance</th>
<th>Channel Quantity</th>
<th>$\Lambda(1/nS)$</th>
<th>$\lambda(1/nS)$</th>
<th>$\Gamma$</th>
<th>$\Upsilon$</th>
<th>$\sigma_e$</th>
<th>$\sigma_\epsilon$</th>
<th>$\sigma_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS-CH Type 1</td>
<td>0-4 m</td>
<td>1000</td>
<td>0.0233</td>
<td>2.5</td>
<td>7.1</td>
<td>4.3</td>
<td>3.3941</td>
<td>3.3941</td>
<td>3</td>
</tr>
<tr>
<td>NLOS-CH Type 2</td>
<td>0-4 m</td>
<td>1000</td>
<td>0.4</td>
<td>0.5</td>
<td>5.5</td>
<td>6.7</td>
<td>3.3941</td>
<td>3.3941</td>
<td>3</td>
</tr>
<tr>
<td>NLOS-CH Type 3</td>
<td>4-10 m</td>
<td>1000</td>
<td>0.0667</td>
<td>2.1</td>
<td>14</td>
<td>7.9</td>
<td>3.3941</td>
<td>3.3941</td>
<td>3</td>
</tr>
<tr>
<td>Max $\Gamma$ NLOS-CH Type 4</td>
<td>4-10m</td>
<td>1000</td>
<td>0.0667</td>
<td>2.1</td>
<td>24</td>
<td>12</td>
<td>3.3941</td>
<td>3.3941</td>
<td>3</td>
</tr>
</tbody>
</table>

4.4 SIMULATION RESULTS FOR SIXTH DERIVATIVE GAUSSIAN IR-UWB SYSTEM

The simulation of the IR-UWB wireless system has been carried out with the sixth derivative Gaussian impulse signal wherein the bits are transmitted in the form of low energy nano-second pulses. The simulation parameters used are listed in Table 4.2. The simulated sixth derivative Gaussian waveform is as shown in Figure 4.5. For good spectral efficiency, the data is pulse shaped after BPSK modulation. Figure 4.6 shows the spectral density for the BPSK modulated sixth derivative Gaussian pulse for the proposed study.

All simulations are carried out as per the channel parameters provided in Table 4.1 for the four Modified SV channel types and the channel impulse response functions realized. The response of these channels to the BPSK modulated sixth derivative Gaussian transmitted signal is obtained. A
high sensitive energy detection type receiver picks the signal and using the correlation with a template the information is retrieved and the BER evaluated.

**Table 4.2 Simulation parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order of Gaussian Derivative</td>
<td>6th Derivative</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>45 GHz</td>
</tr>
<tr>
<td>Impulse Duration</td>
<td>400ps</td>
</tr>
<tr>
<td>Peak Signal Voltage</td>
<td>370 mV</td>
</tr>
<tr>
<td>Frequency of the cycle</td>
<td>7.53 GHz</td>
</tr>
<tr>
<td>Peak Power</td>
<td>-42.8 dBm/MHz</td>
</tr>
</tbody>
</table>

**Figure 4.5 Generated sixth derivative Gaussian impulse**
4.4.1 Simulation Results of MSV Channel Type 1

The simulation has been conducted for IR-UWB wireless system with sixth derivative Gaussian pulses transmitted over MSV channel type1, which represents an LOS channel with distance less than 4m has adopted as transmission medium. Figure 4.7 presents the impulse response of channel type 1. From the impulse response graph, the first component is identified with highest energy, while the other two component of better transmitting capacity appear at 1.91ns and 4.9ns after the first one. All clusters behave in a similar way and the multipath impulse response of individual clusters may overlap each other, even then the multipath components may fall back by 4ns after the first path for majority of cases. The transmission performance is verified from the demodulated signal analysis. Figure 4.8 shows the correlator output signal, its PSD and the demodulated signal. The performance of the transmission is verified by estimating the BER and in a later section compared for all the four channel types.

Figure 4.6 PSD of the transmitted BPSK modulated signal
4.4.2 Simulation Results of MSV Channel Type 2

The data has been transmitted through the simulated MSV channel type 2 and the results are illustrated in Figures 4.9 and Figure 4.10. Figure 4.9 represents the impulse response of the channel. The maximum amplitude multipath signal has arrived in the third cluster. That is mainly due to the scattering, diffraction and reflection effects of the NLOS channel. The center frequency used is 7.012 GHz. Figure 4.10 represents the correlator output signal, its power spectral density and the demodulated signal.

4.4.3 Simulation Results of MSV Channel Type 3

The MSV channel type 3 is a Non Line Of Sight Channel (NLOS) with a transmission range of 4-10 meters. It has been simulated with a sixth order Gaussian impulse as transmitted signal. Figure 4.11 depicts the impulse response of the Channel type 3 and it is observed that, the highest amplitude cluster position is away from the origin. It is mainly due to the high multipath effect of NLOS channel with highest transmission distance. Figure 4.12 plots the correlator output waveform, PSD of the received signal and the decoded information data. The error performance of the channel is discussed in the next section and the NLOS channel model shows a degraded error performance.

4.4.4 Simulation Results of MSV Channel Type 4

The MSV Channel type 4 is also an NLOS channel model with the transmission range of 4-10 meters and maximum value of attenuation factor ‘Γ’. Figure 4.13 represents the impulse response of the type 4 channel and Figure 4.14 describes the receiver performance for the same channel model. The observed center frequency is same as the case of type 3 channel. Figure 4.13 shows maximum number of multipath components and shows a
Figure 4.7 Impulse response for MSV Channel type 1

Figure 4.8 Correlator Output Signal at Receiver, PSD and the Demodulated Signal for MSV Channel type 1
Figure 4.9 Impulse response for MSV Channel type 2

Figure 4.10 Correlator Output Signal at Receiver, PSD and the Demodulated Signal for MSV Channel type 2
Figure 4.11 Impulse response for MSV Channel type 3

Figure 4.12 Correlator Output Signal at Receiver, PSD and the Demodulated Signal for MSV Channel type 3
Figure 4.13 Impulse response for MSV Channel type 4

Figure 4.14 Correlator Output Signal at Receiver, PSD and the Demodulated Signal for MSV Channel type 4
good amount of clustering effects. The maximum amplitude multipath components are away from the origin and the first cluster. The reflection coefficient has the maximum value and total number of multipath components is increased. The channel shows very good clustering effect. Figure 4.14 gives the receiver characteristics like correlator output signal, PSD of the same wave form and the decoded information signal. The information bits were decoded using a bit comparator logic.

4.4.5 BER Comparison and Data Rate Optimization for MSV Channel Types

The BER results from the simulation are evaluated and the maximum possible data rates that is supported with least BER for the different channel types are obtained. The Bit Error Rate (BER) is defined as the number of erroneously decoded bits divided by the total number of bits transferred during a studied time interval. The simulation has computed the BER value by transmitting 500 bits through the MSV channel models using BPSK modulated higher order Gaussian impulse and comparing the decoded data at the receiver with the transmitted original data. The BER vs bit rate plot obtained for the four types of channel environments are shown in Figure 4.15 (a), (b), (c) and (d) respectively.

The simulation results suggest that, when a sixth derivative gaussian impulse UWB signal is used, channel type 1 can support up to 800 Mbps, Channel type 2 can support up to 80Mbps, Channel type 3 can support up to 20Mbps and channel type 4 can support up to 10 Mbps data rate. In other words a data rate of 800 Mbps is possible over a short distance LOS channel environment, however it becomes less than 100 Mbps for NLOS channel environment. The highly clustered multipath effect significantly deteriorates the channel performance.
Figure 4.15 (a) BER vs Bit Rate for MSV Channel type 1

Figure 4.15 (b) BER vs Bit Rate for MSV Channel type 2
Figure 4.15 (c) BER vs Bit Rate for MSV Channel type 3

Figure 4.15 (d) BER vs Bit Rate for MSV Channel type 4
In a WBAN environment smooth wireless transmission of real time images using IR-UWB is possible only if the channel is a short distance LOS type. However if the requirement is only to transmit low data rate vital biological parameters then any of the four channel types can support the transmission with reasonable reliability. The system model has verified the performance of sixth derivative Gaussian IR-UWB signal over four types of channel models and measured the maximum allowable data rate with minimum error.

4.5 SYSTEM PERFORMANCE VALIDATION OF IR-UWB TRANSMIT SIGNAL DESIGNS

The system BER performance is evaluated and compared in this section for the IR-UWB transmit signal designs studied in the previous chapter. Their transmission over the four MSV channel types is analyzed. The signal generators considered are the CMOS based Gaussian monocycle, the Triangular shaped multicycle generators and the wavelet based Gaussian sixth derivative signal generator. The generated signal performance is validated by transmitting through the MSV channel types after BPSK modulation.

4.5.1 Transmission Performance of Gaussian Monocycle IR-UWB Signal

The Gaussian monocycle generated on CMOS with a VCDL circuit driven with a PRF of 100MHz pulse signal is considered with BPSK modulation. The link transmission rate is dictated by the PRF and hence this generator can support a maximum rate of 100Mbps. The template of the Gaussian shaped monocycle signal with a cycle time period of 285ps with 223mV peak to peak amplitude voltage is generated at the circuit level is saved as a data file and this is used in the MATLAB based complete
IR-UWB transmission and reception setup for validating the performance over the MSV channel models. The four MSV channel types are considered as in the previous section and link BER estimated for a transmission of 1000 bits. The total bit duration is 10ns but the impulse transmission occurs only for the time period of 285ps with BPSK modulation. From the transmitted signal spectrum, it is observed that the centre frequency is 2.66 GHz with a -10dB bandwidth of 4.96 GHz. The performance of the system can be verified from the simulation results. Figure 4.16 shows the transmitted Gaussian monocycle shaped BPSK modulated signal, Figure 4.17 shows the PSD of transmitted signal, Figure 4.18 shows the channel impulse response, Figure 4.19 shows the signal at the frontend of the receiver and Figure 4.20 shows the processed signals at the receiver output, respectively.

Figure 4.16 BPSK modulated Gaussian monocycle signal
Figure 4.17 PSD of Transmitted signal

Figure 4.18 Channel Impulse Response
Figure 4.19 Received signal at frontend

Figure 4.20 Receiver output signal
The system performance simulation is similarly carried out for all the four MSV channel types: 0-4m distance LOS (Ch 1), 0-4m distance with NLOS (Ch 2), 4-10m distance with NLOS (Ch 3), 4-10m distance with max. value of attenuation factor (Ch 4). Figure 4.21 shows the BER Vs SNR plot for the four cases with BPSK modulated Gaussian monocycle signal for validating the transmission performance of the generated Gaussian monocycle signal.

![BER Vs SNR curve for Gaussian Monocycle with 100Mbps](image)

**Figure 4.21 BER Vs SNR graph for Gaussian Monocycle transmission**

Based on the link BER it is seen that the overall error performance of Gaussian monocycle IR-UWB signal is not good enough due to its reduced transmitted signal amplitude. There is no similar reported data for comparison since the generated signal is unique and novel.
4.5.2 Transmission Performance of Triangular Multicycle IR-UWB Signal

The Triangular Multicycle signal is generated in this thesis with CMOS gates and passive variable attenuator. The VCDL circuit was driven with a pulse signal of 50MHz PRF which limits the maximum link transmission rate to 50Mbps. The entire pulse cycle of period 20ns is considered saved as data file and exported to MATLAB environment for system level validation. The regenerated Triangular Multicycle signal amplitude is only 3.9mV and with this amplitude, the distance of transmission will not be greater than 10cm. But the MSV channel models requires a minimum distance coverage of 4m and it can be satisfied with only higher amplitude signals. So the generated signal is amplified with a fixed gain constant and the signal level is enhanced to 273 mV. This signal is transmitted over the four channel types and the observed results are plotted.

The transmitted signal spectrum shows the centre frequency as 3.57GHz with a -10dB bandwidth of 900MHz. The performance of the BPSK modulated Triangular Multicycle signal over the MSV channel types is validated with a simulation set up and the performance analysed from the output plots. Figure 4.22 shows the BPSK Modulated multi cycle triangular signal, Figure 4.23 shows the PSD of the transmitted signal, Figure 4.24 shows the channel impulse response, Figure 4.25 shows the signal at the frontend of the receiver and Figure 4.26 shows the demodulated signal at the decoder stage.
Figure 4.22 BPSK modulated Transmitted Triangular Multicycle Signal

Figure 4.23 PSD of Transmitted signal
Figure 4.24 Channel Impulse Response

Figure 4.25 Signal at receiver Frontend
Figure 4.27 shows the BER Vs SNR performance for the four types of MSV channel models with BPSK modulated triangular multicycle signal. The channel type I link offers a comparatively better BER performance than the other three channel types.

**Figure 4.27 BER Vs SNR curve for multicycle 50Mbps**

The BER value for each channel type is as follows:
- Channel I
- Channel II
- Channel III
- Channel IV
4.5.3 Transmission Performance of Wavelet based Gaussian Sixth Derivative Signal

The wave shape optimized Gaussian sixth derivative signal generated using the wavelet transform method is then used for system performance evaluation at a link transmission rate of 200Mbps with BPSK modulation system. The sixth derivative Gaussian signal has a cycle time period of 688ps with a 700mV peak to peak amplitude. Figure 4.29 gives the spectrum of the corresponding BPSK modulated transmitting signal, which shows a transmission frequency of 4.31GHz at peak amplitude of -6dBm/Hz with -10dB bandwidth of 2.25 GHz. The PSD is seen to exactly follow the FCC mask. The total bit duration considered is 5ns in which the impulse transmission occurs only for the time period of 688ps with BPSK modulation. The simulation results are observed and analysed. Figure 4.28 shows the BPSK modulated wavelet transform based sixth derivative Gaussian signal, Figure 4.29 shows the PSD of transmitted signal, Figure 4.30 shows the channel impulse response, Figure 4.31 shows the signal at the frontend of the receiver and Figure 4.32 shows the demodulated signal at the decoder stage. The performance of this signal observed for all the four channel types is seen to be better than the Gaussian monocycle and the triangular multicycle waveform signals.
Figure 4.28 BPSK modulated transmitted Signal

Figure 4.29 PSD of Transmitted signal
Figure 4.30 Impulse Response

Figure 4.31 Signal at receiver frontend
Figure 4.33 shows the BER Vs SNR performance of the transmission of BPSK modulated wavelet transformed sixth derivative Gaussian signal over the four types of MSV channel models. The performance of wavelet based sixth derivative Gaussian signal over Channel Type I is better than the other channel scenarios. The overall link error performance of wavelet transform based sixth derivative Gaussian UWB signal is noted to be better than the previous signal designs.

Figure 4.32 Decoded receiver output signal
4.5.4 Performance Comparison

The proposed research has different transmit signal design options for a UWB impulse generator and their performances is validated by transmitting these signals through the MSV channels after BPSK modulation. The proposed impulse signals are observed to have different pulse duration, bit duration and bandwidth occupation. A straightforward comparison of the link BER achieved for transmission over the MSV channels is not a fair comparison. The channel transmission rate is dictated by the signal which is not the same in the three cases. Hence in carrying out the comparison, the effective data rate is fixed at 1Mbps and it is assumed that the link transmission rate is realized by appropriate coding. In the present case the Repetition Code is considered. The repetition rate depends on the link rate possible in relation to 1Mbps data rate. The coded bit error rate $P_{ce}$, is then
evaluated quasi-analytically using Equation (4.11), where $P_e$ is the uncoded link BER obtained from the simulation and the majority logic decoding is used.

$$P_{ce} = \sum_{i=\left\lceil \frac{n}{2} \right\rceil}^{n} nC_i P_e^i (1 - P_e)^{n-i}; if \ n \ is \ odd$$

$$= \sum_{i=\left\lceil \frac{n}{2} \right\rceil + 1}^{n} nC_i P_e^i (1 - P_e)^{n-i} + \frac{1}{2} nC_{n/2} P_e^{n/2} (1 - P_e)^{n/2}; if \ n \ is \ even$$

The bit energy to noise density ratio ($E_b/N_o$), is fixed at 30 dB for all schemes and the corresponding SNR is evaluated using the following relationship,

$$\frac{S}{N} = \frac{E_b}{N_o} \cdot \frac{f_b}{BW}$$

where $f_b$ is the link transmission rate and $BW$ is the -10 dB bandwidth occupied by the pulse. The Table 4.3 describes the different parameter values for finding the coded link BER performance with 1Mbps user data rate, the uncoded link BER obtained from the respective graphs of Figure 4.21, Figure 4.27 and Figure 4.33. From the parameters listed in the table, the error performance of wavelet based IR-UWB signal generation and transmission is seen to show good error performance compared to the other two methods. The performance of Gaussian monocycle is seen to be the worst, due to the nature of wave shape and the lower signal amplitude. The Gaussian monocycle is observed to perform with reasonable reliability only for the MSV channel type1, that is LOS (0-4m) and is not suitable over other channel conditions.
Table 4.3  BER Comparison for different transmit signal designs at $E_b/N_o$ of 30dB and effective Data Rate of 1Mbps

<table>
<thead>
<tr>
<th>Wave Shape Parameters</th>
<th>Gaussian Mono Cycle</th>
<th>Triangular Multicycle</th>
<th>Wavelet based Gaussian 6th Derivative</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_b/N_o$</td>
<td>20 dB</td>
<td>20 dB</td>
<td>20 dB</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1 Mbps</td>
<td>1 Mbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Link Rate</td>
<td>100 Mbps</td>
<td>50 Mbps</td>
<td>200 Mbps</td>
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<tr>
<td>Repetition Rate n</td>
<td>100</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>-10 dB BW</td>
<td>4.96 GHz</td>
<td>900 MHz</td>
<td>2.25 GHz</td>
</tr>
<tr>
<td>$f_{BW}$</td>
<td>0.0202</td>
<td>0.0556</td>
<td>0.0889</td>
</tr>
<tr>
<td>SNR</td>
<td>13.05 dB</td>
<td>17.45 dB</td>
<td>19.49 dB</td>
</tr>
<tr>
<td>Uncoded BER over Channel 1</td>
<td>0.3202</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Uncoded BER over Channel 2</td>
<td>0.4079</td>
<td>0.5</td>
<td>0.09011</td>
</tr>
<tr>
<td>Uncoded BER over Channel 3</td>
<td>0.4715</td>
<td>0.2</td>
<td>0.2727</td>
</tr>
<tr>
<td>Uncoded BER over Channel 4</td>
<td>0.4079</td>
<td>0.23</td>
<td>0.3333</td>
</tr>
<tr>
<td>Coded BER over Channel 1</td>
<td>$6.36 \times 10^{-5}$</td>
<td>$9.636 \times 10^{-39}$</td>
<td>$3.348 \times 10^{-144}$</td>
</tr>
<tr>
<td>Coded BER over Channel 2</td>
<td>$2.484 \times 10^{-2}$</td>
<td>$4.44 \times 10^{-1}$</td>
<td>$2.33 \times 10^{-51}$</td>
</tr>
<tr>
<td>Coded BER over Channel 3</td>
<td>$2.51 \times 10^{-1}$</td>
<td>$4.92 \times 10^{-7}$</td>
<td>$2.8854 \times 10^{-12}$</td>
</tr>
<tr>
<td>Coded BER over Channel 4</td>
<td>$2.48 \times 10^{-2}$</td>
<td>$7.86 \times 10^{-6}$</td>
<td>$3.87 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

The performance of triangular multicycle signal performance is better than monocycle, even with low amplitude signal levels. The superior performance is mainly due to its multicycle wave shape. If the center frequency is
translated to higher values and amplitude increased to the level of -41.3 dBm/MHz, its performance can be further improved. Higher order wave shapes are seen to perform reasonable well for all channel types. Comparing the different channel performances, it is noted that all the three methods of signal generation are suited for channel type 1 and hence are suited to low data rate short range LOS wireless transmission scenarios and hence can be adopted for WBAN transmission.

4.6 SUMMARY

The validation of a complete IR-UWB transmission system over realistic channel scenarios is carried out in this chapter by simulation. The different channel scenarios defined by the MSV model are simulated and the BER performance of a sixth derivative BPSK modulated Gaussian signal and that of the previously generated Gaussian monocycle, Triangular wave shaped Multicycle and Wavelet based IR-UWB signals are obtained and compared. The validation has concluded that, higher order wave-shaped signals perform reasonably well in all the channel scenarios. However, comparing the different channel performances, it is concluded that all the methods of signal generation considered in the thesis are suited for channel type 1 with reasonable reliability. Hence the proposed IR-UWB signal generators are suited for low data rate short range LOS wireless transmission of biological parameters in a WBAN application.