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Performance Evaluation of UWB Wireless Link

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ABSTRACT

An Ultra wideband technology played an important role in home networks to facilitate the transmission of multimedia contents between two consumer devices using wireless USB. This paper investigated the performance of UWB Transmitter-Receiver system, based on 2-dimensional hermite modulation, in view of its practical implementation. Performance of the UWB system was evaluated here with a cost effective and simple receiver structure, for short distance communication of 4 meters, by limiting the transmitter power, to maintain the Effective Isotropic Radiated Power (EIRP) of -41.3dBm/MHz as per FCC rule for UWB radio. The performance of the said system was also analyzed for different data rates using different sampling frequencies over multipath UWB channel, with and without the use of error correcting code. Simulations were performed in MatLAb Simulink for single user, for the image transmission application, as an extension to the previous work. System BER of 10e-5 was required to receive an image with 100% accuracy at the receiver end. It was observed that over UWB channel, at 10 GHz sampling rate, with 1.5 ns pulse width and with 10dBm transmission power, an image was received accurately at symbol SNR of 35dB without ECC and that of 12dB with (8 2 5) double error correcting code, of ¼ code rate designed in earlier work. The simulation results presented in this paper support the future implementation of UWB system that is cheaper and simpler for better performance.

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1. INTRODUCTION

In home networks, the wireless communication, between different consumer devices such as PC and its peripherals or between devices used in TV entertainment network, is currently possible due to Bluetooth technology. Invention of high speed 480 Mbps Universal Serial Bus (USB) facilitated the wired transfer of the multimedia traffic that needed higher bandwidth such as audio and video. To implement high speed wireless USB, the Ultra wideband (UWB) technology is proved to be ultimate solution for short distance indoor wireless communication of 4 to 10 meter. This has widened research opportunities in designing cost effective and reliable UWB Tx-Rx system. The wide bandwidth required for multimedia traffic, can be harnessed from UWB, so called Impulse Radio, by modulating the data on the extremely short and impulsive base band pulses resulting in bandwidths ranging from 1 GHz to several GHz. Absence of Carrier signal makes the design of UWB system simpler and cheaper. UWB is defined as any signal whose fractional bandwidth is equal to or greater than 20% of the center frequency or that occupies bandwidth equal to or greater than 500 MHz [1][2].

This paper relates to physical layer design aspects of UWB wireless link such as modulation and error correcting techniques, for single user, for point to point high speed and reliable communication. In early research work the derivatives of Gaussian pulse, those are FCC (Federal Communications Commission) compliant were considered to be suitable pulses for UWB wireless communication. Different modulation schemes based on Gaussian pulse such as Time Hopping Pulse Position Modulation (TH- PPM), TH-Pulse Amplitude Modulation (TH-PAM), and TH-Binary Phase Shift Keying (TH-BPSK) had been proposed for UWB communication. The performance of these modulation techniques was simulated in [2]. The main drawback of these techniques was they were not suitable for high data rate multimedia transmission. Recently the research has been focused on the use of hermite pulses that are orthogonal in time domain, for implementation of high speed modulation techniques. Orthogonal hermite pulses have been proposed in [3] for short distance M-ary UWB communication where multiple data bits can be transmitted in parallel, in order to achieve high data rates. Hermite pulse based modulation called as Pulse Shape Modulation (PSM) was introduced in [3], [4].

In PSM the information bits are modulated in the shape of the waveform so that many data bits can be simultaneously transmitted using different orthogonal wave shapes (hermites) that overlap in time domain. Though PSM modulation can achieve higher data transmission rates it has higher Bit-Error-Rate (BER) compared to PPM or BPSK modulation this is because the transmitted signal undergoes reflection, refraction and scattering over the multipath UWB channel, as a result of this, for one transmitted pulse from UWB transmitter (Tx), multiple delayed pulses are received by the UWB receiver (Rx) from multiple paths. Due to this multipath interference orthogonal hermite pulses tend to lose their orthogonality at the receiver end [5]. In order to take advantage of PSM technique for higher data rate, suitable error correcting codes are required to be implemented to improve BER of the system. Typically the rake receiver with multiple fingers is preferred for UWB communication to dampen the effect of multipath interference, where each finger will gather energy from the pulse received from one of the multiple paths and will contribute in decision making to guess which symbol was transmitted [6].

The choice of the modulation scheme and values of the associated parameters is important in the system design because this determines important figures of merit, such as spectral efficiency, power efficiency and required level of transmit power, required coding overhead, and system complexity. The performance of the UWB system, using 2-dimensional (2d) hermite based PSM technique was evaluated in [7], [9] for the application of lossless image transmission without using the channel equalizer. To simplify the UWB system and to make it cost effective our earlier work [10] implemented a low cost, high speed UWB Tx-Rx wireless link for a single user and proposed the use of a simple receiver structure using a channel equalizer and a multiplier where a multiplier is equivalent to a single rake finger and use of it saved on the cost of the system as against the use of multiple finger rake. The paper [10] investigated the possible use of simple receiver in the UWB system with channel equalization and evaluated its performance over IEEE UWB channel models CM1 to CM4 for communication distance of 4 and 10 meters, for transmission of lossy, JPEG compressed image. To improve the BER of the UWB system in multipath environment, the double error correcting (ECC), systematic cyclic code (8 2 5), with ¼ code rate, designed in [8] was used, which protected the data against the channel imparities. This code corrects both the bits transmitted with 2d PSM modulation. Due to its cyclic nature the code was simple to implement using shift registers.

As an extension to the work presented in [10], the current paper analyses the BER performance of UWB Transmitter (Tx) – Receiver (Rx) system in a view of its practical implementation with simple receiver that was proposed. While targeting a particular data rate in few MHz, at physical layer, one needs to choose width of the transmitter pulse in nanoseconds and hence the sampling frequency is in GHz. Practically it is difficult to get ADCs working at higher GHz frequencies. This paper investigated the performance of UWB system using lower sampling frequencies such as 5 and 10 GHz since the devices like DSPs, operating at these frequencies are now available. The BER performance was evaluated for different pulse widths viz. 1.5ns, 2.5ns and 5ns to achieve different data rates. FCC has approved the use of 7500 MHz of spectrum, for UWB devices, for communications applications in the 3.1 GHz to 10.6 GHz frequency band. Different system design approaches are implemented to use this 7500 MHz band that is allocated for UWB spectrum. These approaches include single-band UWB (uses the entire 7500 MHz), and multiband UWB, which divides the 7500 MHz into 15 sub-bands (500 MHz each). The current work implemented the single band UWB system. As UWB works in Industrial, scientific and medical (ISM) frequency band which is license free, the FCC has set the limit on the transmission power of UWB system in order to avoid its interference to other coexisting wireless technologies in same frequency band, such as WLAN and Bluetooth. As per current FCC rule, the max allowed Effective Isotropic Radiated Power (EIRP) for UWB signal is set to -41.3 dBm/ MHz where EIRP indicates the product of max power that the transmitter can transfer to the transmitting antenna and the gain of the transmitting antenna [2]. In this regard the effect of transmission power on the performance of the UWB system with 10 GHz sampling frequency, with and without ECC was also analysed. With -41.3 dBm/MHz EIRP limit of FCC and BW of 12000 MHz (for pulse width of 1.5ns), max allowable transmission power is approximately 0 dBm (-0.5dBm) It was observed that at 10 dBm transmission power over UWB channel CM1 (modeled for 4 meter distance), with 10GHz sampling frequency and 1.5 ns pulse width, BER of 10e-5 was targeted at symbol SNR of 35dB without ECC to achieve data rate of 667 Mbps and at symbol SNR of 12 dB, with ¼ rate ECC to achieve the data rate of 165 Mbps.

This paper is organized as follows: The hermite based UWB wireless Tx-Rx system designed in the previous work has been introduced in section-II. Section-III assimilates the simulation results for various scenarios of practical aspects. Section IV presents observations and comparative study. Section-V concludes the paper.

2. UWB Tx-Rx SYSTEM

UWB Tx-Rx system for high speed wireless link based on 2-d Hermite pulse shape modulation and a simple receiver was simulated using MatLab Simulink model as shown in fig. 1.

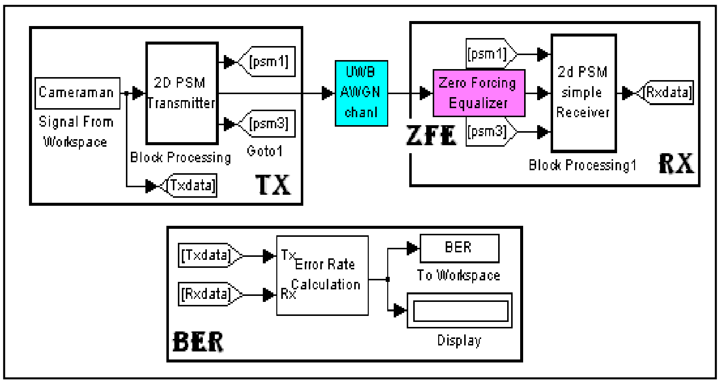

Figure 1. UWB System [10]

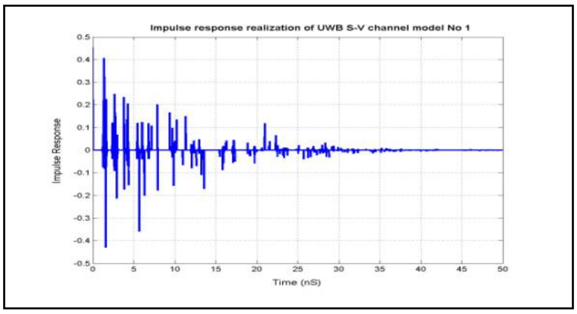

Figure 2. Impulse Response of IEEE UWB Channel model CM1 [11]

The UWB transmitter consisted of a source encoder, a channel encoder and a modulator that implemented the pulse shape modulation (PSM) based on hermite pulse. Encoded and modulated signal was transmitted over UWB channel that was simulated using IEEE UWB channel model CM1 [11] shown in fig 2. Received signal was passed through an equalizer to undo the effects of channel imparities. The receiver consisted of demodulator, channel and source decoder. The demodulator was a simple multiplier unit.

2.1. Source and Channel Encoder

The Image to be transmitted was compressed by source encoder using JPEG lossy compression algorithm. The transmitted image had PSNR of 30.81dB. Here ‘Cameraman’ image shown in fig 3, with resolution of 128x128 pixels was compressed to 4501 coefficients. These coefficients were encoded into 16351 binary bits by using Huffman code. The channel encoder used Double error correcting code (8 2 5) of ¼ code rate [8] with generator matrix given by eq. 1 to encode 16351 bits from source coder into 65404 bits.

$$G_{(k,n)} = \left[I_k \vdots P_{(k,n-k)} \right] = \begin{pmatrix} 1 & 0 & \vdots & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & \vdots & 0 & 1 & 1 & 1 & 0 & 1 \end{pmatrix} \qquad (1)$$

2.2. PSM Modulator

The modulator implemented 2-dimensional (2d) pulse shape modulation technique where two bits carried by two hermite pulses were transmitted simultaneously in one bit period. The input bit stream was divided into even and odd bit stream. The hermite pulses of first order, Ψ1 (t) (Hpulse1) and Ψ2 (t) (Hpulse2) are given by the eq. 2. Even bit stream was modulated on the pulse-1 as ±Ψ1 (t) and odd bit stream was modulated on the pulse-2 as ±Ψ2 (t). This doubled the data rate but at the cost of increase in BER of the system.

$$\begin{aligned}\psi_1(t) &= \frac{H_1(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{2t\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \\ \psi_2(t) &= \frac{H_2(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{(4t^2-2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}\end{aligned} \tag{2}$$

Final transmitted symbol was combination of two waveforms Ψ1(t) and Ψ2(t). Considering each pulse had unit energy then the energy of the transmitted symbol was double than that of single pulse energy. In 2d PSM technique the transmitted symbol was one of the four composite signals given in table 1.

Table 1. The 2d PSM Signals

Odd bit	Even bit	Composite signal (2-dimensinal symbol)
0	0	$\psi_1(t)+\psi_2(t) = \frac{2t e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} + \frac{(4t^2-2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}$
0	1	$\psi_1(t)-\psi_2(t) = \frac{2t e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} - \frac{(4t^2-2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}$
1	0	$-\psi_1(t)+\psi_2(t) = -\frac{2t e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} + \frac{(4t^2-2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}$
1	1	$-\psi_1(t)-\psi_2(t) = -\frac{2t e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} - \frac{(4t^2-2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}$

As mentioned earlier for UWB communication, rake-receiver with multiple fingers has been a common choice on the receiver side [6]. Each finger of rake gathers energy from delayed versions of transmitted signal. Though this improves the detection of transmitted symbol and improves the BER of the system. it is a complex and costly receiver structure. In the proposed work the BER of PSM based UWB system was improved by the choice of receiver structure, use of the equalizer at the receiver and the error correcting code. When a simple multiplier (equivalent to the single finger rake) as shown in fig 3 was used in the receiver, it was unable to detect the transmitted pulse due to the fact that the transmitted pulse was smeared and delayed at the receiver as an effect of multipath UWB channel. This problem was solved by adding channel equalizer along with the multiplier. The zero forcing equalizer reduced the unwanted effect of UWB multipath channel and improved the transmitted symbol detection just using a product demodulator.

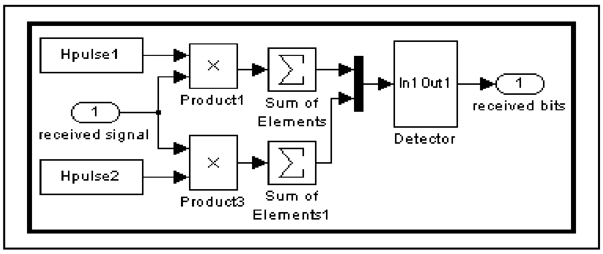

Figure 3. The Simple Receiver [10]

The hermite modulated waveforms were then transmitted over UWB multipath channel, simulated using IEEE UWB channel model CM1, meant for Line of sight indoor communication over the distance of 4 meters [10]. The AWGN channel plus UWB multipath (SV) channel model (CM1) was implemented here using UWB channel block, as shown in fig 1, and it was taken from paper [12].

2.3. The Simple Receiver

At the receiver, Hpulse1 and Hpulse2 helped the detector to recover the symbol transmitted. Demodulator was followed by the detector. Detected bits in a group of 8 (double ECC) were then fed to channel decoder to remove the redundancy added. Finally source decoder performed the inverse actions corresponding to each step that was implemented in JPEG algorithm such as Huffman decoding, run length decoding, inverse zigzag, de-quantization and inverse DCT etc. The received image was compared with transmitted image to compare PSNR for its quality measurement.

Error calculation block was inserted to evaluate the BER performance of the given system. The UWB system was simulated, to evaluate the effect of pulse width, sampling frequency and transmission power on BER performance of the UWB system, as these factors decide the feasibility of the said system. The next section reflects upon the results of various simulation scenarios.

3. SIMULATION RESULTS

The UWB Tx-Rx system presented in previous section used Time-hopping (TH) spread spectrum technique as a multiple access technique. It transmitted data in multiple TH frames. Each TH frame carried data of multiple users. The symbol duration T_s was split into N frames with 1 pulse per user per frame. Within each TH frame, the pulse could take M equi-probable positions. Fig 4 shows TH frame with width (Tf) of 6 nanosecond having two user slots of 2.5 nanoseconds each. It means transmitted hermite pulse (chip) has width of Tc=2.5ns. The simulation results were obtained here for a single user data transmission i.e with single symbol waveform (composite pulse) per frame (N=1).

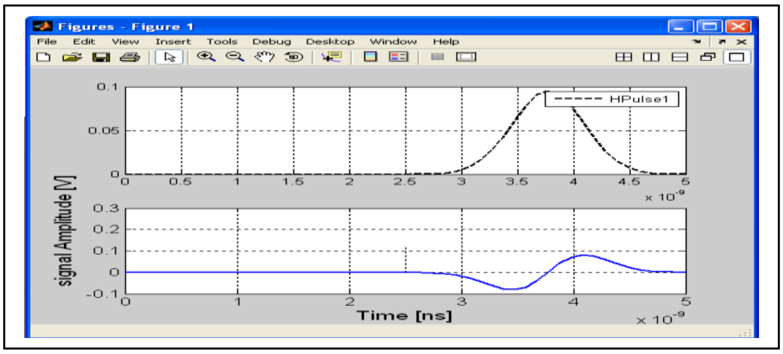

Figure 4. The Time Hopped hermite Pulse

Cosidering ψ1(t) and ψ2(t) indicate carrier pulses of eq 2 with pulse (chip) width = Tc = 2.5ns, Cj is random time hopping code (e.g. 0, 1) with cardinality Nh = 2 and if N= number of frames/symbol then TH-2d PSM signal for each transmitted symbol (2 bits) is given by eq 3.

$$S(t) = \pm\sum_{j=o}^{N} \Psi_1(t - j * Tc * Nh - Cj * Tc) \pm \sum_{j=o}^{N} \Psi_2(t - j * Tc * Nh - Cj * Tc) \quad (3)$$

Table 2. The UWB System Simulation Parameters

Model Parameters	Values
Image compression	JPEG Lossy Compression
Modulation	PSM (2-Dimensional)
Channel coding	¼ rate (8 2 5) Double error correcting quasi-cyclic code
UWB channel model	CM1, LOS distance - 4 m
Channel Equalization	Zero forcing equalizer 25 taps (for CM1)
Hermite Pulse widths	1.5, 2.5 and 5 nanoseconds
TH frame widths	3, 5, and 10 nanoseconds
No. of pulses / symbol	Two
No. of TH frames / symbol	One
Sampling Frequencies Fs	5, 10, 50 and 100 GHz
Average max Transmitted power Ptx	-30, 0 and 12 dBm
Bit rate without ECC	667, 400 and 200 MBps

Simulations were carried out for three different scenarios of practical importance. In scenario-1 three different pulse widths were chosen to study system performance, viz 1.5ns, 2.5ns and 5ns to target data rates of 667MHz, 400MHz and 200MHz. Data rate was calculated as n*(1/Tf) where n was dimension (bits/symbol) of a modulation technique used. Here for 2d PSM modulation n was 2. In scenario-2 the system performance was evaluated for three different sampling frequencies as 5GHz, 10GHz, 50 and 100GHz. The third scenario considered the effect of transmission power on system performance with three transmitter power levels such as -30dBm, 0dBm and 12dBm. These power (energy) levels were set per hermite pulse. It means with 2d PSM, the transmitted power per symbol was double than that of power level set per hermite pulse. Table 2 shows common simulation parameters that were set for the performance evaluation of hermite based UWB system for image transmission application.

3.1. Simulation Results with Different Pulse Widths

In the first scenario, the BER performance of the said system was simulated for a set of three different hermite pulse widths of measure 1.5ns, 2.5ns and 5ns, the results of which are tabulated in table 3. For example with pulse width = Tc= 1.5ns, TH frame width was Tf=3ns. The duration of a single symbol was Ts = Ns x Tf where Ns= number of pulses used to represent one symbol. Since only one composite pulse was used to represent one symbol, Ts=Tf=3ns.

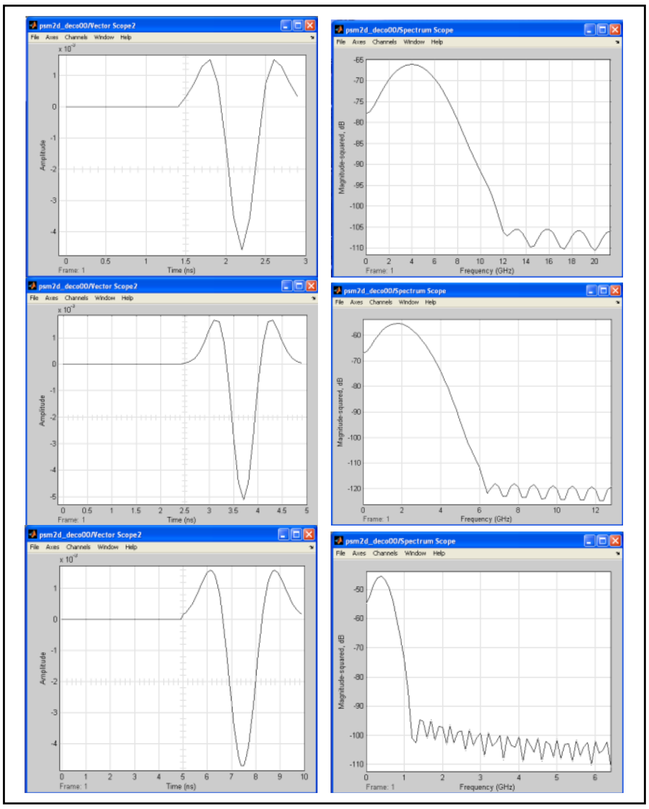

Figure 5. The Time Hopped hermite Pulse with its Spectrum

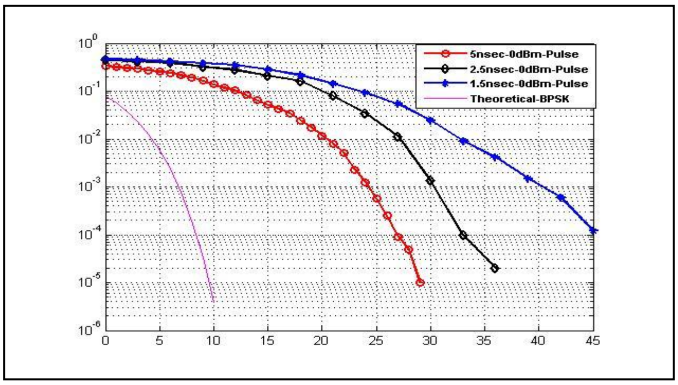

Figure 6. BER without ECC with different pulse widths

The transmitter power Ptx was set to 0 dBm (1000 milli-Watts) by multiplying the normalized hremite pulse with Energy =Tf x Ptx = 3e-6 J. The sampling frequency Fs was chosen to be 10 GHz as the use of DSP is possible at this sampling frequency. One composite pulse per user was transmitted in one TH frame and each pulse carried a data symbol of 2 bits doubling the data rate. Therefore the data rate was calculated as 2 x 1/Tf = 2 x 1/3 = 667 MBps. Image data received at the receiver with this set up was compared with transmitted image to compute PSNR and Structural Similarity and Image Quality (SSIM) [13]. The fig 5 shows actual transmitted hermite pulses on vector scope and their spectra on the spectrum analyser.

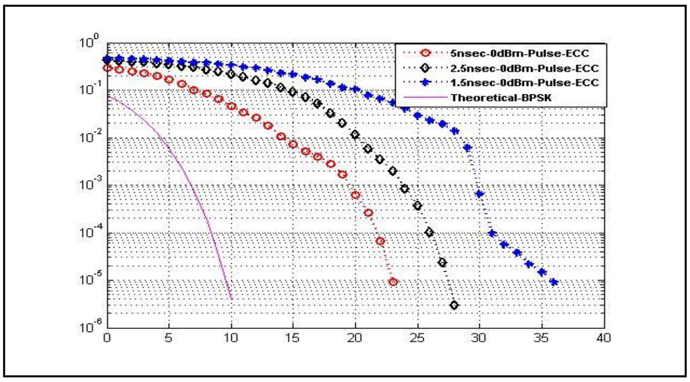

Figure 7. BER with ECC with different pulse widths

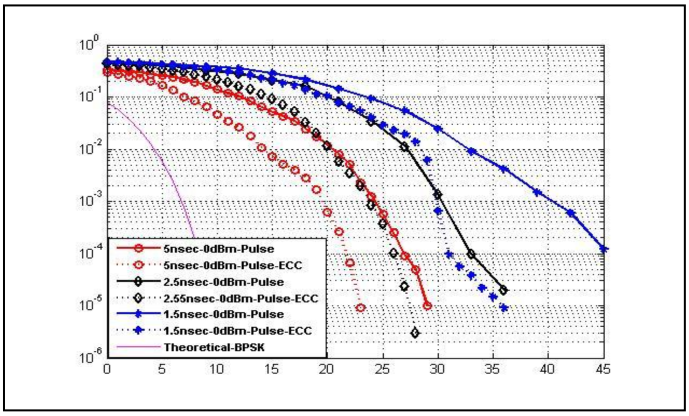

Figure 8. BER with and without ECC with different pulse widths

Simulations were also performed for pulse widths of 2.5ns (Tf=5ns) and 5ns (Tf=10ns) with sampling frequency of 10GHz ad transmission power set to 0dBm as mentioned earlier, over multipath IEEE UWB channel model CM1 modeled for 4 meters of Indoor communication distance. The BER simulations using hermite pulses of different widths without the use of ECC are shown in fig 6 whereas, with ECC are shown in fig 7. Fig 8 compares both these results. Table 3 assimilates the results for this scenario.

Table 3. The Simulation Results with Different Pulse Widths

Frame/ Pulse width **Tx-Power**=PTx= 0 dBm Fs=10 GHz	ECC over UWB channel CM1	EsNo dB	BER	PSNR /SSIM	Data Rate (1/Tf)x2 Mbps
Tf =3 ns Tp=1.5ns	**without** ECC	46	~10E-5	30.80/ 1	1/3 x2 =667
	with double ECC	35			667/4 =166.5
Tf = 5 ns Tp =2.5ns	**without** ECC	37	~10E-5	30.80/ 1	1/5 x2 =400
	with double ECC	27			400/4 = 100
Tf = 10 ns Tp =5ns	**without** ECC	29	~10E-5	30.80/ 1	1/10 x2 =200
	with ECC	23			200/4 =50

3.2. Simulation Results with Different Sampling Frequencies

In second scenario the effect of sampling frequency (Fs) on BER performance of the UWB system was observed without the use of ECC. Four sampling frequencies viz. 5GHz, 10GHz, 50GHz and 100GHz were used during data transmission over an additive white Gaussian noise (AWGN) and UWB channel CH1. Pulse width was set to Tc = 2.5 nanoseconds (Tf = 5 nsec) and transmission power was set to 0dBm

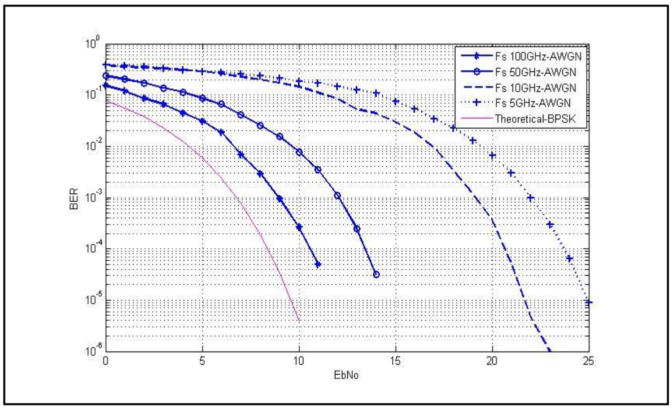

Figure 9. BER over AWGN channel without ECC with different sample frequencies

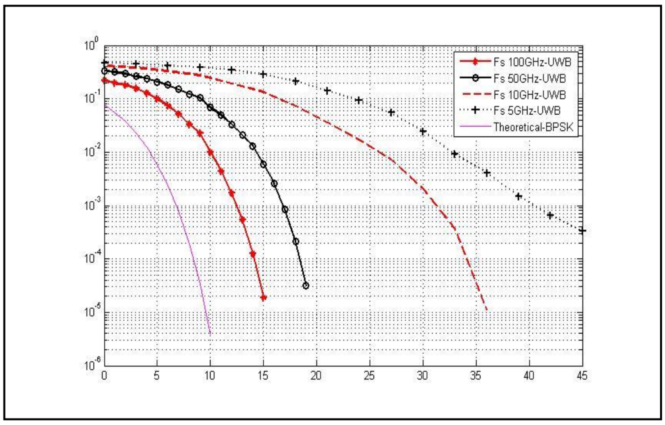

Figure 10. BER UWB channel CM1 without ECC with different sample frequencies

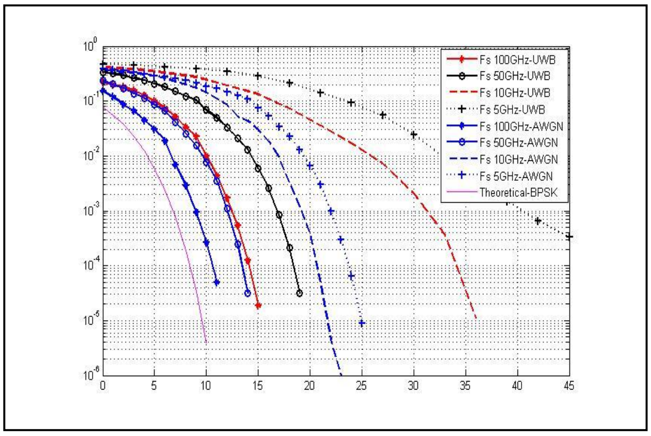

Figure 11. BER over AWGN and UWB with different sample frequencies

Fig 9 shows BER simulations obtained over AWGN channel with different sampling frequencies whereas fig 10 shows BER simulations obtained over UWB channel CM1 and fig 11 compares both the results. As per FCC rule the total allowable average EIRP from a UWB device in the frequency range 3100 to 10600 MHz is -41dBm/MHz. Therefore the maximum allowed total power at the transmitter for entire single UWB band of 7500 MHz will be

Pmax required =EIRP in dBm +10 log10 (Bandwidth)
= -41.3 + 10 log10 (7500)
= -41.3 + 38.75
= -2.5dBm or 0.56mW

This is a fraction of power required for communication as compared to many other wireless technologies. The simulation results presented here were obtained for transmission power as low as -30dBm.Table 4 shows SNR required to achieve reasonably good BER with different sampling frequencies.

Table 4. The Simulation Results with Different Sample Frequencies

Sampling Freq GHz	Channel without ECC	EsNo dB	BER	PSNR/ SSIM	Data Rate (1/Tf)x2 Mbps At PTx = 0 dBm
100	AWGN	12	10E-5	30.80/ 1	1/5 x2 = 200 x 2 = 400
	UWB CM1 (LOS)	16			
50	AWGN	15	10E-5	30.80/ 1	400
	UWB CM1 (LOS)	20			
10	AWGN	22	10E-5	30.80/ 1	400
	UWB CM1 (LOS)	36			
5	AWGN	25	10E-5	30.80/ 1	400
	UWB CM1 (LOS)	47			

3.3. Simulation Results with Different transmission Powers

Considering worst case EIRP of -71.3 dBm for single band UWB system with Pulse width of 1.5 ns the bandwidth of the signal (from spectrum analyzer) will be = 12000MHz. Then as shown below the max transmission power of -34 dBm was required to achieve reasonably low BER of the system.

Pmax = EIRP in dBm +10 log10 (Bandwidth)
= -75.3 + 10 log10 (12000)
= -75.3 + 40.79
= -34.3dBm

Considering EIRP of -41.3 dBm for single band UWB system with Pulse width of 1.5 ns and with bandwidth of the signal = 12000MHz, then the max transmission power required to achieve reonably low BER was -0.5dBm.

Pmax = EIRP in dBm +10 log10 (Bandwidth)
= -41.3 + 10 log10 (12000)
= -41.3 + 40.79
= -0.5dBm

The table 5 shows calculation of Max Transmission power required as per value of EIRP set by FCC for UWB radio. It also shows the effect of pulse width on required transmission power.

Table 5. Transmitter Power for different Bandwidths

Pulse Width Tc ns	Frame Width Tf ns	UWB Bandwidth (BW) MHz	10x Log10(BW) (A)	EIRP dBm/ MHz	Average TxPower required Pmax dBm (mW)
1.5	3.0	12000	40.79	-75.3	-34.3 (3.7e-4 mw)
				-41.3	-0.5 (0.89 mw)
2.5	5.0	6000	37.78	-75.3	-37.52 (1.8e-4 mw)
				-41.3	-3.51 (0.45 mw)
5.0	10.0	1300	31.14	-75.3	-44.16 (3.8e-5 mw)
				-41.3	-10.16 (0.096 mw)

Depending on power analysis presented in the table-5, in scenario-3 UWB system performance was evaluated for three different allowable transmission powers viz. -30dBm, 0dBm and 10dBm over AWGN and UWB channel, with or without the use of ECC. Sampling frequency was set to 10 GHz and pulse width selected was 1.5ns.

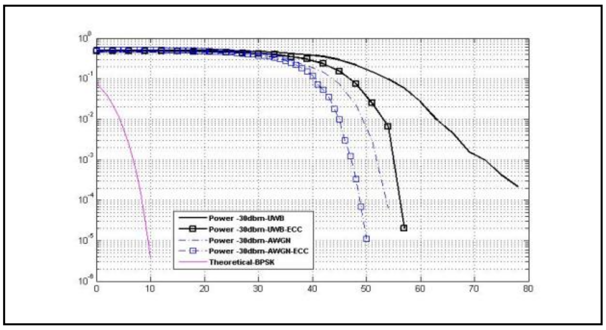

Figure 12. BER over AWGN/UWB channel with/without ECC at PTx= -30dBm

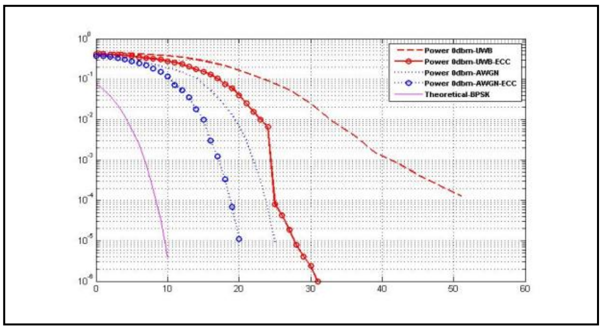

Figure 13. BER over AWGN/UWB channel with/without ECC at PTx= 0dBm

The fig 12 indicates BER simulations with max allowable transmission power of -30dBm, fig 13 indicates BER simulations with max allowable transmission power of 0 dBm and fig 14 indicates BER simulations with max allowable transmission power of 10dBm.

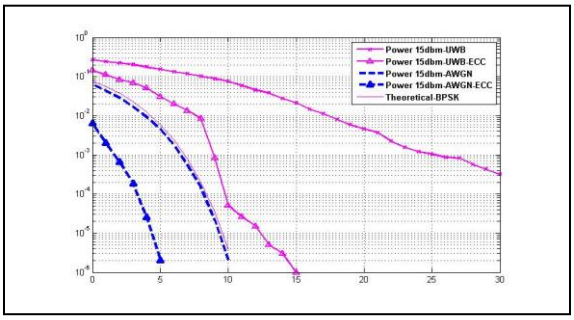

Figure 14. BER over AWGN/UWB channel with/without ECC at PTx= 10dBm

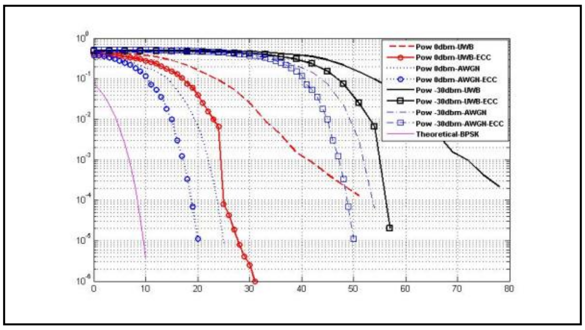

Figure 15. BER over AWGN/UWB channel with/without ECC at PTx= 0/-30dBm

The fig 15 compares simulations results obtained for max allowable UWB transmitter power Ptx = 0 dBm and Ptx= -30 dBm with pulse width of 1.5 ns at 10 GHz sampling frequency. The table-6 below summarizes the simulation results showing effect of transmission power on the BER performance of the UWB system ith simple receiver.

Table 6. The Simulation Results with Different Transmitter Powers

Ptx dBm	Channel/ECC	EsNo dB	BER	PSNR/ SSIM	Data Rate (1/Tf)x2 Mbps
-30	AWGN without ECC	55	10E-5	30.80/1	1/3x2 = 333x2=667
	AWGN with ECC	50			667/4 =166.5
	CM1 (LOS) without ECC	86			667
	CM1 (LOS) with ECC	58			166.5
0	AWGN without ECC	25	10E-5	30.80/1	667
	AWGN with ECC	20			166.5
	CM1 (LOS) without ECC	57			667
	CM1 (LOS) with ECC	28			166.5
10	AWGN without ECC	9	10E-5	30.80/1	667
	AWGN with ECC	4			166.5
	CM1 (LOS) without ECC	35			667
	CM1 (LOS) with ECC	12			166.5

4. OBSERVATIONS AND COMPARISONS

From figs 6, 7 and 8, it was seen that for fixed sampling frequency, the lower is the pulse width (higher data rate), higher is the BER. Over UWB channel, without ECC, at sampling frequency of 10GHz, with 1.5ns pulse width, SNR of 46dB is required to achieve BER of 10e-5, whereas with pulse width of 5ns, SNR of 29dB is required to achieve BER of 10e-5. Same BER was achieved with ECC at SNR of 35dB with 1.5ns pulse and at SNR of 23dB with 5ns pulse. In second scenario, the effect of sampling frequency over AWGN and UWB channel CM1 was observed from figs 9, 10 and 11. Higher is the sampling frequency, lesser is the BER. Keeping pulse width fixed at 2.5ns and transmitter power at 0dBm, with 100GHz sampling rate, BER of 10e-5 was achieved at SNR of 16dB whereas SNR of 47dB was required to achieve same BER with 5GHz sampling frequency over UWB channel. The effect of transmission power Ptx on BER performance was observed from figs 12, 13, 14 and 15. As expected, lower is the transmission power higher SNR is required to achieve BER of 10e-5. To target BER of 10e-5over UWB channel with pulse width of 1.5ns and sampling frequency of 10GHz, when Ptx is set to -30dBm (in miliwatts), SNR of 58dB was required with ECC and SNR of 86dB was required without ECC, whereas with Ptx set to 10dBm, SNR of 12dB with ECC and SNR of 35dB without ECC was necessary.

The work presented in the paper [14] simulated the performance of UWB wireless link operating at 60 GHz carrier frequency. The authors of the paper have obtained BER simulations of UWB link using OFDM with QPSK modulation without coding and with ¾ rate coding scheme. The results were obtained over a Ricean channel model with *K*-factor of 10 for LOS communication and with *K*-factor of 1 for NLOS communication. As per table 2 in the paper [17] the transmitter power was set to 10dBm for UWB bandwidth of 1.7GHz for data rate of 16Mbps, then BER of 10e-5 was achieved at SNR of 16 dB with un-coded OFDM and at SNR of 14 dB with coded (3/4 rate) OFDM. If we compare the BER results obtained in the current paper then for the transmission power of 10dBm, BER of 10e-5 was obtained at SNR of 12dB with coded (1/4 rate) 2d PSM modulation. Higher SNR of 35 dB was required to achieve same BER with uncoded PSM modulation; this was due to lower sampling frequency of 10 GHz and the performance of channel equalizer at this sampling low sampling frequency.

5. CONCLUSION

This paper investigated the performance of the UWB Tx-Rx system for short distance indoor wireless communication of 4 meter, for different scenarios of practical importance. Choice of the modulation scheme was important in the system design because it determined important figures of merit, such as spectral efficiency, power efficiency, and required level of transmit power, required coding overhead, and system complexity. Use of hermite based 2-dimensional pulse shape modulation technique with (8 2 5) double error correcting systematic cyclic code and a simple receiver, facilitated the design of simple, economical and power efficient UWB system. The Double ECC provided 5-6dB improvement in the BER. It was observed that at lower sampling frequency of 10 GHz, with 0dBm average transmitter power and pulse width of 2.5ns, BER of 10e-5 was achieved at SNR of 22dB over AWGN channel and at SNR of 36dB over UWB channel CM1 (LOS) As the pulse width was reduced from 5ns to 1.5ns, the bandwidth and the data rate was increased thus increasing the required SNR from 22dB to 35dB with ECC to achieve BER of 10e-5 over UWB CH1.

As per FCC rule, with 10GHz sampling frequency, for pulse width of 1.5ns, average max transmission power should be set to 10dBm approximately to avoid interference with coexisting technologies in the same frequency band. With this Tx power BER of 10e-5 was achieved over uncoded UWB channel

CM1 at SNR of 35dB and over coded UWB channel CM1 at SNR of 12dB. Over UWB channel CM1 for LOS communication of 4 meter distance, the BER performance is governed by design of equalizer and hence can be further improved by increasing number of taps in the equalizer in the future scope.

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