# Image Transmission using Hermite based UWB Communication with Simple Receiver

Joanne Gomes[1], B K Mishra[2]
*Research Scholar*

[1]*St Francis Inst. of Technology, Mumbai, India*
*jngomes@ieee.org*

[2]*Thakur college of Engg. and Technology, Mumbai, India*
*drbk.mishra@thakureducation.org*

***Abstract***

*Use of Ultra-wideband (UWB) for wireless communication in home networking requires cost effective technical solutions with high quality. This paper investigates the performance of simple receiver with zero forcing equalizer in place of rake receiver for hermite based UWB communication. The UWB system with simple receiver is simulated for the application of image transmission over IEEE UWB channels CM1-CM4 modeled for indoor communication. Image to be transmitted is compressed by using JPEG lossless compression. The Double error correcting block code has been used to improve the BER performance of the system. The received image quality is tested using PSNR and its Structural Similarity and Image Quality (SSIM) index.*

***Keywords:*** *Hermite-pulse-shape-modulation, Image-PSNR,, Image-SSIM, Simple-receiver, UWB-Communication*

## 1. Introduction

With the advent of novel technologies in home networking, UWB (Ultra-wideband) has gained tremendous popularity for short distance indoor communication. The transmission of multimedia content over indoor communication link, such as wireless Universal Serial Bus (USB), demands wide bandwidth. This wide bandwidth can be harnessed from Ultra wideband (UWB) so called Impulse Radio. The extremely short and impulsive base band pulses used in UWB result in bandwidths ranging from 1 GHz to several GHz allowing high data rate wireless communications [1][2]. Absence of Carrier signal makes the design of UWB system simple and cheaper. Derivatives of Gaussian pulse that are FCC (Federal Communications Commission) compliant are considered to be suitable pulses for UWB communication [1]. Recently orthogonal hermite pulses have been proposed [3] for short distance M-ary UWB communication in order to achieve high data rates. Time Hopping Pulse Position Modulation (TH- PPM), TH-Pulse Amplitude Modulation (TH-PAM), and TH-Binary Phase Shift Keying (TH-BPSK) are some of the commonly used modulation techniques for UWB communication [2]. Hermite pulse based modulation called as Pulse Shape Modulation (PSM) was introduced in [3][4]. Orthogonal hermite pulses tend to lose their orthogonality at the receiver end over the multipath UWB channel hence PSM has higher Bit-Error-Rate (BER) as compared to PPM or BPSK modulation [5].

Generally rake receiver with multiple fingers (bank of correlators) is preferred for UWB systems to improve BER of the system over frequency selective channel. The transmitted signal undergoes reflection, refraction and scattering over the multipath UWB channel. Rake receiver fingers gather the energy of the transmitted signal received from multiple paths. This increases the probability of correct symbol detection. Rake receivers need to use channel estimation filters with number of taps in order to estimate gains and delays of different channel paths. Number of different filters used in rake receiver does not make it less complex solution for UWB system. To simplify the UWB system and to make it cost effective this paper suggests the use of a simple receiver structure using a channel equalizer and a multiplier with adder. A multiplier with adder is equivalent to a single rake finger and it saves on the cost of multiple finger rake. The objective of this paper is to provide a low cost single user UWB system for short distance (< 10m), point to point high speed wireless link using 2-dimensional hermite based pulse shape modulation. The performance of UWB system using 2-dimensional hermite modulation has been evaluated in [6][8] for the application of lossless image transmission without using channel equalizer. In hermite based UWB communication data is modulated over orthogonal hermite pulses using pulse shape modulation technique. This paper investigates the performance of the simple receiver for the application of image transmission, over IEEE UWB channel models CM1, CM2, CM3 and CM4 to simulate the high speed wireless USB link between two devices in home network. Simulations are performed using MATLAB simulink software. A simulink model of UWB system with 2d PSM is presented here along with channel coding. The ¼ rate (8 2 5) double error correcting block code designed in [7][8] has been used to further improve the BER of the UWB system, which protects the data against the channel imparities. The performance degradation due to synchronization errors and multiuser interference is not considered in this paper. It is observed that with proper channel equalization a simple multiplier can achieve BER of 10e-5 at symbol SNR of 13dB without ECC and 7dB with ECC. Thus an image is received with its original transmitted quality over the transmission distance of 4m at symbol SNR of 7dB with ECC and with the speed of 333MBps.

This paper is organized as follows: Section-II briefs about related work. Introduction to IEEE UWB channel models has been given in Section-III. Section-IV reviews hermite pulse basics and the pulse shape Modulation (PSM) technique. Section-V presents the Simulink model of UWB system with simple decoder used for simulations. Section-VI assimilates the results. Section-VII provides the observations and comparisons. Section-VIII concludes the paper.

## 2. Related Work

Most performances of the UWB system simulated so far are obtained using the rake receivers. The more the fingers of the rake more the energy is captured from the multipath received signal. Thus the complexity of the rake receiver increases with the performance improvement. For example BER performance of A-Rake (All rake) P-Rake (Partial combining) and S-Rake (selective combining) over UWB channels is analyzed in [9]. Authors of [9] show that for indoor communication over a distance of 6-14 meters, using 2 to 64 fingers of rake, SNR of almost 30 dB or more is required for UWB system to achieve BER of 10E-5. In [10] based on experimental results it is proved that using different types of rake receivers (A, P and S) up to 120 correlators, SNR of approx. 30 dB is required to achieve BER of 10E-5. Equal Gain Combining (EGC) rake and MRC rake were compared in [11] for their performances over UWB channel. Here the results show that for the rake of 60 taps, SNR of 15 dB is required to achieve BER of 10E-5. A receiver based on Maximum Ratio Combining (MRC) along with LDPC codes with code rates ½ to ¼ is used in Wi-Media PHY layer for UWB communication over UWB channel CM1 in [12]. The results show that there is great improvement of 4 to 5 dB in BER of the system on application of error correcting codes like LDPC. Performance of the suboptimal receivers (i.e. rake receivers with various diversity combining schemes and an autocorrelation receiver) is evaluated in [13] using transmitted reference (TR) signaling. TR communication systems operate by transmitting a pair of unmodulated and modulated signals and employing the former to demodulate the latter. Using TR signaling system the performance of UWB system improves but with the increased overhead and reduced data rate.

In the current paper a multiplier followed by a summer is used in the receiver along with a zero forcing equalizer. The paper analyses the performance of this simple receiver over IEEE UWB channel models CM1, CM2, CM3 and CM4 for image transmission application. Along with the BER performance, the quality of the received image is tested here using two different measures PSNR and SSIM.

## 3. IEEE UWB Channels

IEEE 802.15.3a standard for wireless personal area network specifies UWB channel models (CM1 to CM4) for indoor wireless communication based on the work of Saleh-Valenzuela (SV) [14].

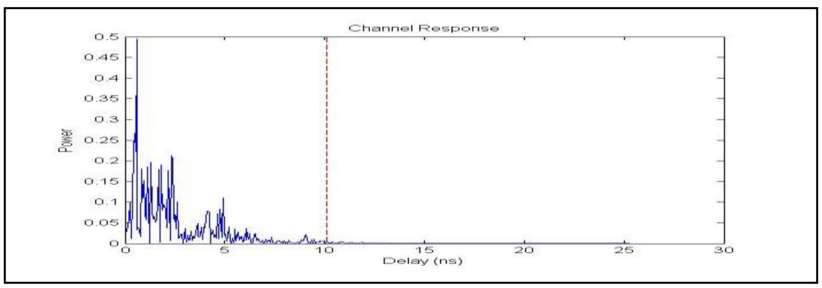


**Figure 1. Impulse response of UWB channel-CM1**

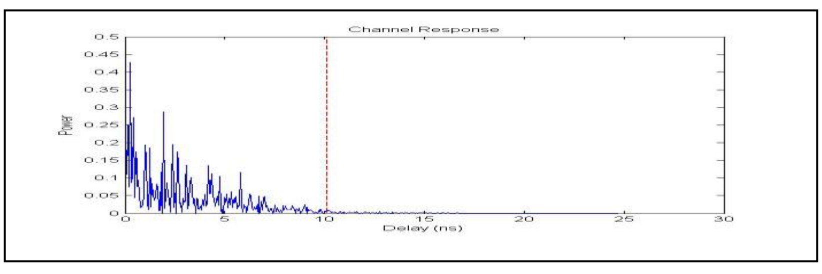


**Figure 2. Impulse response of UWB channel-CM2**

The UWB channel is frequency selective and is represented by multiple paths/rays, having real positive gains $\{\alpha_k\}$, propagation delays $\{\theta_k\}$, and associated phase shifts $\{\tau_k\}$, where $k$ is the path index; in principle, $k$ extends from 0 to ∞. These rays usually arrive in clusters. If $T_l$ is the arrival time of $l^{th}$ cluster then for the $k^{th}$ ray of the $l^{th}$ cluster, the complex, low-pass impulse response of the UWB channel is given by eq.1.

$$h(t) = X \sum_{l=0}^{L} \sum_{k=o}^{K} \alpha_{k,l} \, \delta(t - T_l - \tau_{k,l}) \quad (1)$$

The four UWB channel models CM1, CM2, CM3 and CM4 are shown in figs-1, 2, 3 and 4 respectively.

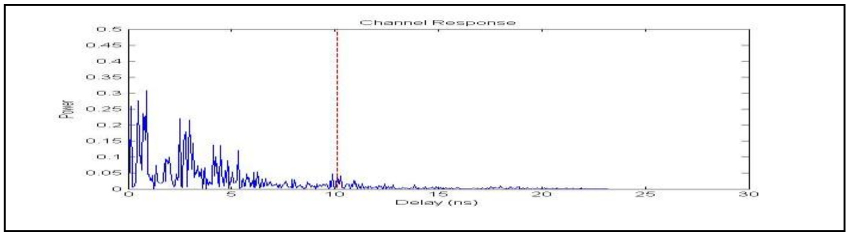


**Figure 3. Impulse response of UWB channel-CM3**

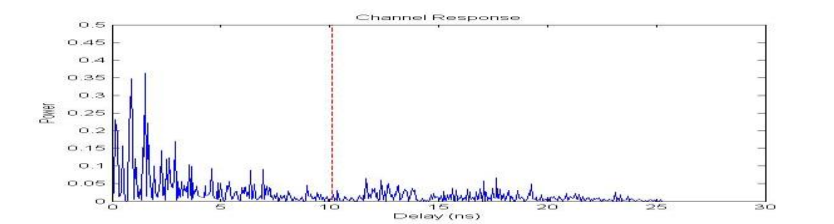


**Figure 4. Impulse response of UWB channel-CM4**

The channel characteristics for CM1 to CM4 have been listed in table-1. As shown in table-1 channel CM1 is modelled for indoor Line-of-sight (LOS) wireless communication of short distance of 4 meters. CM2 is modelled for no-Line-of-sight (NLOS), short distance communication of 4 meters. CM3 and CM4 are modelled for NLOS communication for a distance of 10 meters. For each type of channel mentioned above 100 different sample impulse responses can be derived.

**Table 1. IEEE UWB Channel Model Specifications**

| | CM1 | CM2 | CM3 | CM4 |
|---|---|---|---|---|
| | LOS | NLOS | NLOS | NLOS |
| Distance | 0-4 m | 0-4 m | 4-10 m | --- |
| Mean Access Delay | 5.05 ns | 10.38 ns | 14.18 ns | --- |
| RMS Delay Spread | 5.28 ns | 8.03 ns | 14.28 ns | 25 ns |

In this paper the performance of UWB system with simple receiver is evaluated over these four UWB channels CM1 to CM4.

## 3. Hermite Pulse Shape Modulation

This section gives overview of hermite modulation. Recently hermite-polynomial based orthogonal pulses, also known as Hermite pulses were proposed in [3][4] for pulse shape modulation (PSM). Hermite pulses are overlapped and have the same duration in time as well as in frequency domain. They are orthogonal to one another and individual spectra of Hermite pulses are not identical. Due to these advantages of Hermite pulse its use in multidimensional communication system can help in enhancing data rates by reducing requirement of bandwidth. First order Hermite functions are given by eq. 2.

$$\psi_n(t) = \frac{H_n(t)\, e^{-t^2/2}}{\sqrt{2^n n! \sqrt{\pi}}} \tag{2}$$

$$\begin{aligned} H_0(t) &= 1 \\ H_1(t) &= 2t \\ H_2(t) &= 4t^2 - 2 \\ H_n(t) &= 2tH_n(t) - 2nH_{n-1}(t) \qquad n \geq 1 \end{aligned} \tag{3}$$

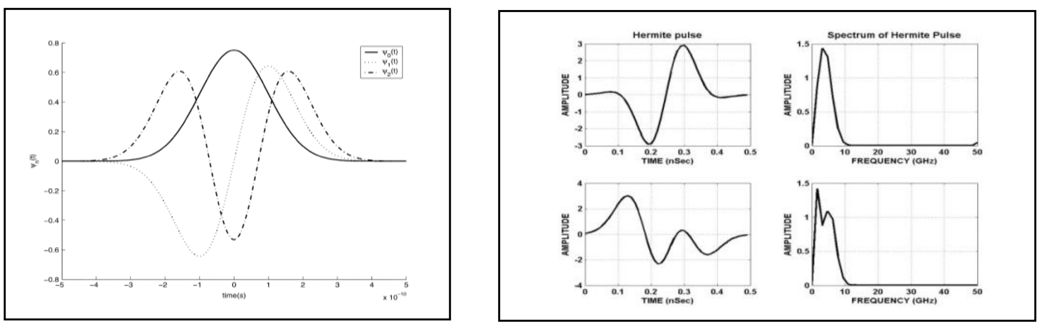


**Figure 5. Hermite pulses of first order and their spectrum**

The hermite polynomials, $H_n(t)$ can be recursively obtained by the formula given by eq. 3. Fig-5 shows the first three hermite pulses of infinite duration and fig-5 shows the spectrum of 0.5 nanosecond hermite pulses used for UWB communication. The hermite pulses shown in fig. 6 are used for the simulations presented in this paper.

$$\psi_0(t) = \frac{H_0(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \tag{4}$$

$$\psi_1(t) = \frac{H_1(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{2t\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \tag{5}$$

$$\psi_2(t) = \frac{H_2(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{(4t^2 - 2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \tag{6}$$

$$\psi_3(t) = \frac{H_3(t)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} = \frac{(4t^2 - 2)\, e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \tag{7}$$

First four basic hermite pulses of first order are given by eq. 4 to 7. As mentioned earlier hermite pulses are orthogonal to each other and can be overlapped in time domain. It means the information carried by one pulse does not interfere with the information carried by another pulse. This facilitates the pulse shape modulation technique which could be multidimensional. In single dimension PSM, information is modulated in the shape of the pulse e.g. bit '0' can be represented by pulse shape Ψ1(t) and bit'1' can be represented by pulse shape Ψ2(t) where both Ψ1(t) and Ψ2(t) are orthogonal to each other. In two-dimensional (2D) PSM technique each symbol of two bits is transmitted at a time. This doubles the data rate but at the cost of increase in BER of the system. Using PSM, a symbol of two bits can be transmitted in three ways.

**Table 2. 2D PSM (Bidirectinal orthogonal) signal waveforms**

| 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 | $-\psi_1(t)-\psi_2(t)=-\frac{2t\,e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}-\frac{(4t^2-2)\,e^{-t^2/2}}{\sqrt{\sqrt{\pi}}}$ |

In the first case the input bit stream can be divided into even and odd bit stream. Even bit stream can be modulated on the pulse-1 as ±Ψ1 (t) and odd bit stream can be modulated on the pulse-2 as ±Ψ2 (t). Final symbol will be combination of two waveforms Ψ1(t) and Ψ2(t). This scheme is called as bidirectional orthogonal or two-dimensional modulation technique. If each pulse has unit energy then the energy of the transmitted symbol will be double than that of single pulse energy. In 2D technique the transmitted symbol could be one of the four composite signals given in table 2.

**Table 3. 4-ary case II waveforms.**

| Odd bit | Even bit | 4-ary symbol |
|---|---|---|
| 0 | 0 | $\psi_0(t)$ |
| 0 | 1 | $\psi_1(t)$ |
| 1 | 0 | $\psi_2(t)$ |
| 1 | 1 | $\psi_3(t)$ |

**Table 4. 4-ary case III waveforms**

| Odd bit | Even bit | 4-ary symbol |
|---|---|---|
| 0 | 0 | $\psi_0(t)$ |
| 0 | 1 | $\psi_1(t)$ |
| 1 | 0 | $\psi_2(t)$ |
| 1 | 1 | $\psi_3(t)$ |

In case-II each symbol of two bits can be represented by a single hermite pulse and can be called as orthogonal or 4-ary modulation technique. Here four orthogonal hermite pulses are required to represent four symbols as given in table-3. In case-III four symbols can be represented by only two pulses along with their inverted versions using PSM-BPSK hybrid modulation as given in table-4. This technique can be called as hybrid 4-ary modulation. Considering normalized hermite pulses with unit energy as mentioned earlier, case-I symbol is transmitted with double energy (combination of two pulses) in one symbol period compared to other two cases. Due to the higher energy of the transmitted symbol, BER of 2D system is better than other two cases discussed below. Also in case-I each hermite pulse represents an even or odd bit where as in case-III each hermite pulse represents a symbol of two bits. The advantage of the later case is that the energy of only one pulse is transmitted in one symbol period making it an energy efficient technique but the disadvantage of this technique is that if at the receiver detection of correct pulse fails then at a time two received bits could be in error. On the contrary in case-I the energy of two pulses is transmitted in one symbol interval and the advantage is that at a given time any one of the received bits could be in error. The BER using these three schemes is evaluated in the following section.

Above concept can be extended to three, four or multidimensional modulation systems. Bit Error Rate (BER) of multidimensional hermite based system is usually high due the fact that the orthogonality between the pulses is lost at the receiver end due the effect of frequency selective multi-path channels. The simulations performed in the paper [5] show that BER of PSM is higher than that of PPM or BPSK over UWB (SV) channel. But the advantage of PSM is, it facilitates increased data rate. Many other modified versions of hermite pulses have been suggested in the literature but in this paper basic hermite pulses of first order are used to simulate the performance of the UWB system using hermite based 2D modulation at the transmitter.

BER of PSM based UWB systems can be reduced by the choice of receiver structure, use of the equalizer at the receiver and the error correcting codes. For UWB communication, rake-receiver with multiple fingers has been a common choice on the receiver side [9] [11]. This improves the detection of transmitted symbol and improves the BER of the system. If a simple multiplier with the adder is used in the receiver it will be unable to detect the transmitted pulse due to the fact that the transmitted pulse will be smeared and delayed at the receiver end as an effect of multipath UWB channel.

This paper proposes the use of multiplier along with an equalizer on the receiver side in place of correlators. The zero forcing equalizer is used here to nullify the effect of UWB multipath channel over which the data is transmitted. To make the multidimensional PSM system more robust and to improve the BER of the system the double error-correcting-code (ECC) devised in [7] is used along with 2D PSM system. Double error correcting long code (8 2 5) is 100% data correction long code which corrects all the two transmitted data bits (k=2) on the receiver side provided that only two bits go in error (t=2) on the receiver side. This code is called as long code because of its low code rate of ¼. It encodes two data bits in to a codeword of 8 bits by using the generator matrix of double ECC given by eq. 8. This code is used here to improve the BER performance of the UWB system for the transmission of JPEG image.

## 5. Simulink Model of UWB System

This section elaborates on simulink model that is designed based on 2-dimensional Hermite pulse shape modulation and a simple receiver as shown in fig. 6. The Image to be transmitted has resolution of 128x128 pixels. It is fed to source encoder block shown in fig. 8 which outputs the compressed image. JPEG lossy compression algorithm shown in fig 7 is used here to compress the image [17].

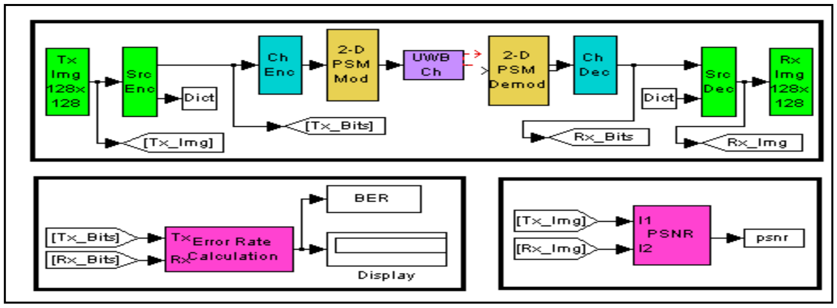


**Figure 6. Simulink Model of UWB system**

Here the 'Cameraman' image of size 128x128 pixels is JPEG compressed to get total 4501 coefficients. These coefficients are encoded into 16351 bits by using Huffman code. Image thus compressed has PSNR of 30.81 dB. Channel encoder block shown in fig 8 adds controlled redundancy to protect the data bits to be transmitted against the channel noise using linear encoder block of simulink. It takes 16351 bits from source coder and encodes them using double error correcting code (8 2 5) explained in [7] with generator matrix as given by eq. 8.

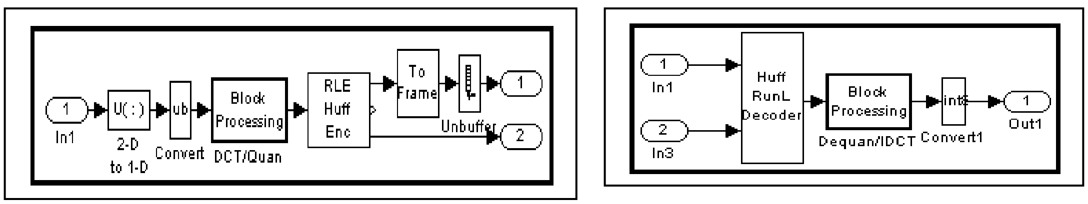


**Figure 7. Source Encoder and decoder**

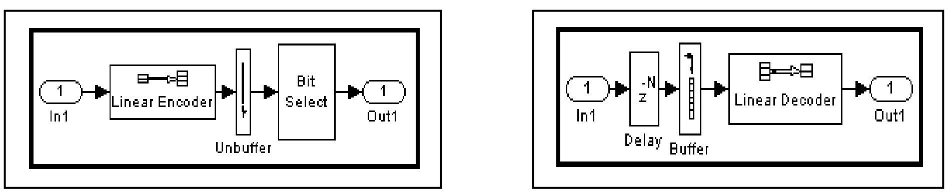


**Figure 8. Channel Encoder and decoder**

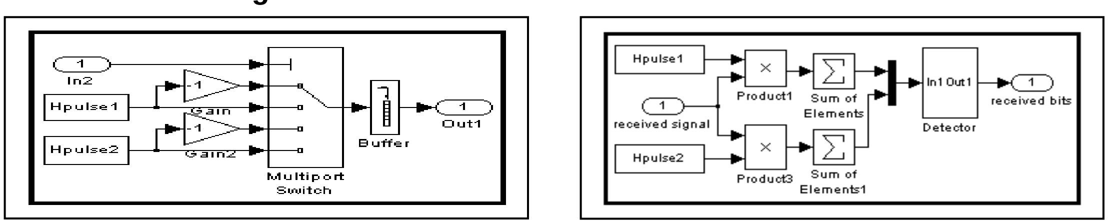


**Figure 9. Hermite modulator and demoulator using multiplier**

Hermite Modulator of fig-9 uses two orthogonal Hermite waveforms Hpulse1 and Hpulse2, each with width of 0.5 nanoseconds. Here case-I 2d modulation scheme is employed as explained in the previous section. Modulated waveforms are then transmitted over UWB multipath channels CM1 to CM4 meant for indoor communication over the distance of 4 to 10 meters. The UWB channel block is shown in fig-10. It implements AWGN channel plus UWB multipath (SV) channel CM1 which was originally modeled in [14]. Its impulse response is indicated in fig-1. UWB channel block model used in simulink as shown in fig. 10 is taken from [15].

$$G_{(k,n)} = \left[ I_k \vdots P_{(k,n-k)} \right] = \begin{pmatrix} 1 & 0 & \vdots & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & \vdots & 0 & 1 & 1 & 1 & 0 & 1 \end{pmatrix} \quad (8)$$

Each pair of bits (k=2) is encoded to eight bit long code vector (n=8) achieving code rate of 0.25 (¼). Thus 16351 bits from source encoder are encoded in to ((16351/2)*8) approx. 65404 bits by channel encoder. This is done to preserve the PSNR of JPEG compressed image to 30.81dB during the wireless transmission. At the receiver two types of demodulators were employed for simulations. Single correlator as a demodulator is shown in fig. 10 whereas simple multiplier based demodulator is shown in fig. 9. It uses masks of waveforms Hpulse1 and Hpulse2 to help the detector to recover the symbol transmitted.

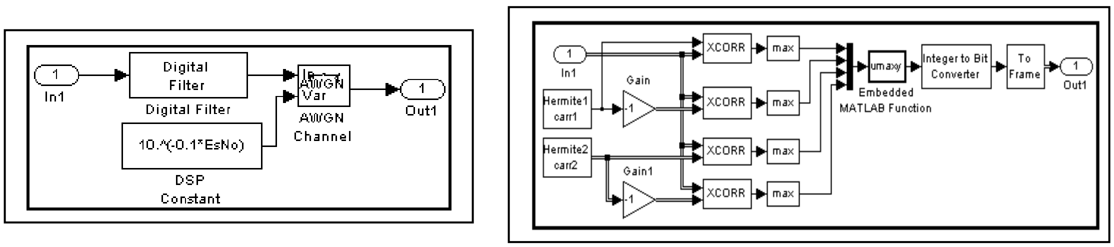


**Figure 10. UWB with AWGN Channel block and correlator Receiver**

Demodulator is followed by detector. Detected bits in a group of 8 (for double ECC) are then fed to channel decoder of fig.8 to remove the redundancy added. Finally source decoder of fig.7 performs 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. Image thus received is compared with transmitted image to calculate PSNR. Error calculation block is inserted to evaluate the BER performance of the given system. The experiment was repeated for transmission of two different images.

## 6. Simulation Results

The UWB system presented in previous section uses Time-hopping spread spectrum technique as a multiple access technique with provision for three users. But the simulation results are currently obtained for a single user data transmission. In a Time Hopping (TH) scheme, the symbol duration $T_s$ is split into N frames with 1 pulse per frame [18]. Within each frame, the pulse can take M equiprobable positions. In addition to modulation, in order to change the shape of the spectrum, data symbols are encoded using pseudorandom (PN) codes introducing time delay in generated pulses, which leads to Time-Hopping UWB. Considering Hermite pulse of width Tm = 0.5 nanosecond for PSM modulation as shown in fig-5, time hopping frame for one pulse is given by Tframe = 1.5 nanosecond (0.5x 3). Within the frame the pulse has unit energy. There is only one pulse per user per Tframe. The sampling frequency used is 100 GHz.

If pulse width = t = 0.5ns, chip time = Tc= 1ns, k=bit 0 or 1, Cj = random time hopping code (e.g. 0, 1, 2 etc) with cardinality, N= number of frames/symbol then using $\psi_n(t)$ of eq. 2 as the carrier pulse [18], TH-BPSK signal (1-dimensional) is given by eq. 9.

$$S_k(t) = \pm\sum_{j=o}^{N}\Psi(t - j*Tc*Nh - Cj*Tc) \qquad (9)$$

Fig.11 shows two Tframes with two different Hermite pulses for pulse shape modulation of 2-dimension. Here each pulse represents even or odd bit. A symbol of two bits is a composite signal and is a combination of two pulses thus doubling the data transmission rate. The following eq. 10 represents TH-PSM signal that is transmitted as symbols of 2d PSM scheme.

$$S(t) = \pm\sum_{j=o}^{N}\Psi_1(t - j*Tc*Nh - Cj*Tc) \pm \sum_{j=o}^{N}\Psi_2(t - j*Tc*Nh - Cj*Tc) \qquad (10)$$

Where Ψ1(t) and Ψ2(t) are given by eq. 5 and 6 respectively.

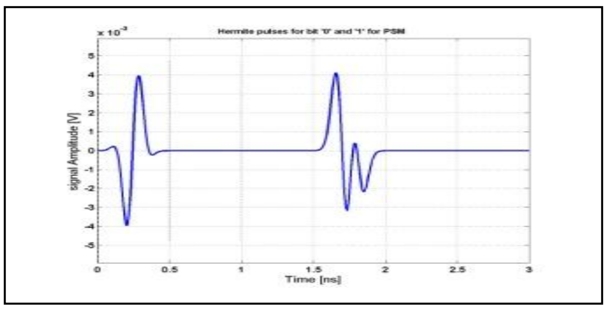


**Figure 11. Time Hopped (TH) Hermite Modulation**

**Table 5. UWB System Parameters**

| Model Parameters | Values |
|---|---|
| Pulse energy | Normalized to unity |
| Pulse width | 0.5 nanoseconds |
| TH-frame width | 1.5 nanoseconds |
| Bit rate | 1/1.5 nanosecond<br>~ 667 MHz, with BPSK<br>~ 1334 MHz, with PSM |
| Image compression | JPEG Lossy Compression |
| Channel coding rate with (8 2 5) long code | ¼ |
| Modulation | PSM (2-Dimensional) |
| Number of pulses / symbol | Two |
| UWB channel | CM1, CM2, CM3 and CM4 |
| Equalization | Zero forcing equalizer |

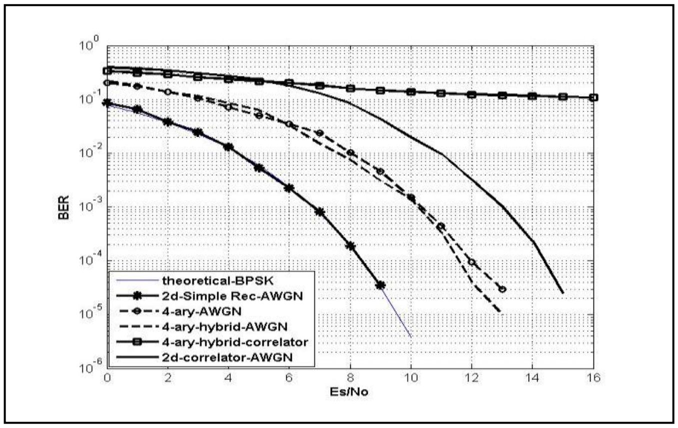


**Figure 12. BER performance 2d and 4-aryUWB system over AWGN**

The table 5 summarizes the simulation parameters set for UWB system represented by fig. 6. Fig.-12 shows BER performance of UWB system over AWGN channel with 2d, 4-ary and hybrid 4-ary modulation schemes, using multiplier as well as correlator at the receiver end. It is observed that multiplier performance is better than the correlator over AWGN. 2d modulation scheme with multiplier, has less BER as compared to system with correlator and is similar to that of theoretical BPSK. Fig. 13 shows BER performance of the 2d UWB system over UWB channel CM1 with simple receiver (multiplier) and correlator.

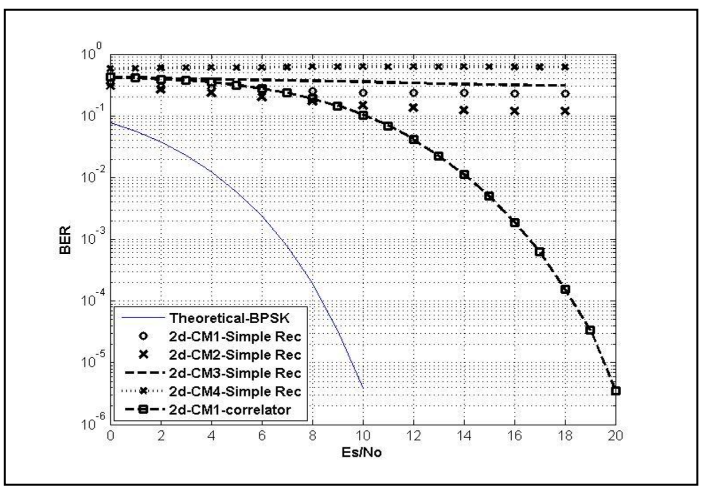


**Figure 13. BER of UWB system over CM1 with simple receiver and correlator receiver**

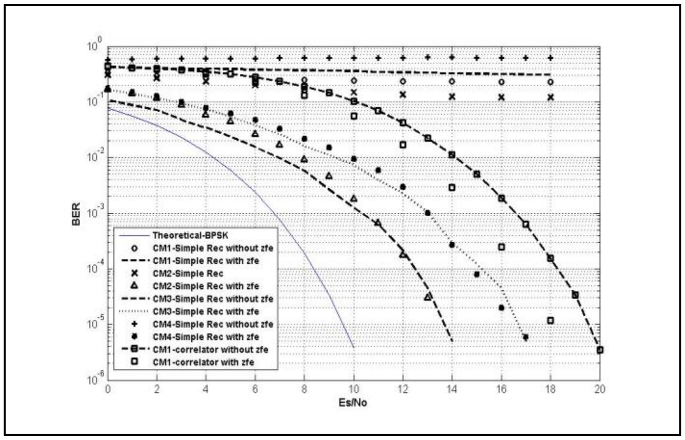


**Figure 14. BER of 2d UWB system with simple rec over CM1-CM4 with and without zero forcing equalizer**

UWB channel CM1 is meant for LOS communication over the short distance of 4 meters. Therefore received pulse delay is small and BER of 10E-5 can be achieved with correlator receiver at symbol SNR of 19 approx. But BER with simple receiver over CM1 to CM4 is worst and almost constant at 0.4 BER. Therefore channel equalization is necessary for simple receiver to perform better, over UWB channels. Receiver with correlator also needs equalizer over channels CM2-CM4. Fig. 14 presents BER of 2d UWB system with simple receiver over UWB channels CM1-CM4 with and without zero forcing equalizer (zfe). Here the zfe of 9 taps is used to equalize CM1, zfe of 5 taps is used to equalize CM2, zfe 0f 19 taps have been used to equalize channel CM3 and CM4. BER performance of the UWB system with simple receiver over UWB channel is further improved by using double ECC as shown in fig. 15.

The JPEG compressed image that is transmitted over UWB channels has PSNR of 30.8021 with respect to. the original uncompressed image Cameraman.tiff. Fig. 21 shows the PSNR of received image over channels CM1 (LOS 4 meters communication distance) and CM3 (NLOS 10 meters communication distance) with and without using error correcting codes.

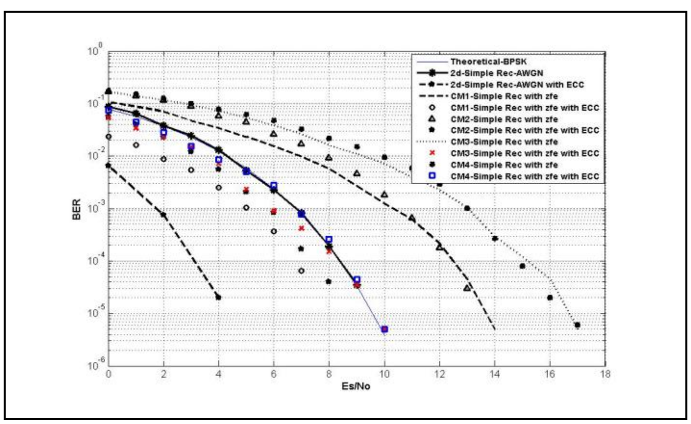


**Figure 15. BER of system with simple rec over CM1- CM4 with equalizer and double ECC**

Recently it has been proved that PSNR may not be a good measure of quality of image or video. This measure does not always correspond well with human judgments of quality. The Structural Similarity and Image Quality (SSIM) (Wang et al., 2004) is based on the idea that natural images are highly "structured". In other words, image signals have strong relationships amongst themselves, which carry information about the structures of the objects in the scene. The general formula of the SSIM metric is given by

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}. \tag{11}$$

The SSIM has a range of values varying between '0' and '1', with '1' being the best value possible [16]. The following table 6 shows the SSIM between received image and transmitted image over channels CM1 and CM2.

## 7. Observations and Comparisons

The jpeg compressed 'cameraman' image is transmitted with PSNR of 30.81. The image can be received with 100% accuracy (received PSNR = transmitted PSNR = 30.81) when BER of the UWB system is 10e-5. It is observed from the 5, with 2D PSM is obtained at symbol SNR (EsNo) of 13dB over CM1 (LOS communication over 4 meters) and 16dB over CM3 channel (NLOS communication over 10 meters). From fig. 15 BER of 10e-5 can be achieved using double ECC at symbol SNR of 7dB over CM1 and 10dB over CM3 channel. Thus the simple receiver with equalizer performs better compared to single correlator with equalizer.

**Table 6. Simulation Results**

| UWB Channel | EsNo dB | BER | PSNR of received Image w.r.t. original un-compressed image | SSIM of Image w.r.t. transmitted compressed image | Data Rate Mbps |
|---|---|---|---|---|---|
| CM1 Without ECC (LOS-4 meters) | 8 | >10E-2 | 12.1289 | 0.251 | 1334 |
| | 10 | ~10E-3 | 14.8692 | 0.5752 | |
| | 11 | >10E-3 | 18.2267 | 0.7356 | |
| | 12 | 10E-4 | 30.5287 | 0.9989 | |
| | 13 | 10E-5 | 30.8021 | 1 | |
| | | | | | |
| With double ECC over CM1 | 3 | >10E-2 | 12.1563 | 0.2686 | 1334/4=333 |
| | 4 | ~10E-3 | 12.8061 | 0.3098 | |
| | 5 | >10E-3 | 17.3748 | 0.6552 | |
| | 6 | ~10E-4 | 30.3780 | 0.9947 | |
| | 7 | ~10E-5 | 30.8021 | 1 | |
| | | | | | |
| CM3 Without ECC (NLOS-10 meters) | 12 | >10E-2 | 12.9945 | 0.323 | 1334 |
| | 13 | ~10E-3 | 12.9945 | 0.323 | |
| | 14 | ~10E-4 | 13.6681 | 0.475 | |
| | 15 | >10E-4 | 30.8021 | 1 | |

| | | | | | |
|---|---|---|---|---|---|
| With double ECC over CM3 | 6 | ~10E-3 | 17.2543 | 0.6314 | 333 |
| | 8 | ~10E-4 | 23.2633 | 0.8234 | |
| | 9 | ~10E-5 | 24.8773 | 0.8951 | |
| | 10 | ~10E-6 | 30.8021 | 1 | |

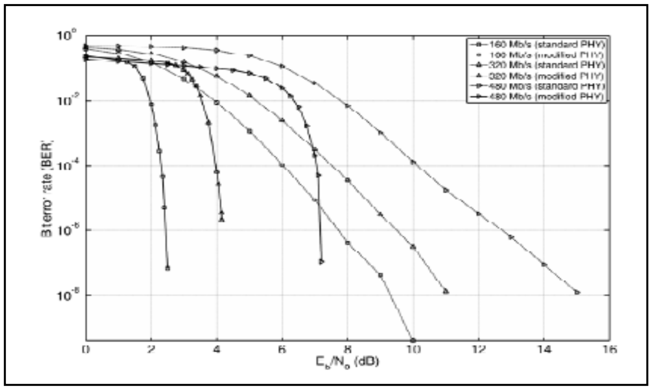

**Figure 16. BER of modified PHY for CM1as given in [10]**

The double ECC furthers the improvement of BER by approximately 6dB. The performance parameters of UWB system with 2D PSM and simple receiver with equalizer for application of image transmission are listed in table 6 based on the observations made from above simulation results. Fig. 16 shows the result obtained in paper [10] for purpose of comparison.Comparing the results obtained in this work with the results of paper [10], it is observed that in [10] using OFDM technology, rake receiver and LDPC code, the BER of ~10e-6 was achieved at the data rate of 480Mbps and at SNR of 7dB. In this paper using very simple transmitter (based on hermite pulse shape modulation) and a cost effective receiver (multiplier and equalizer) along with a very simple to decode double error correcting code, BER of > 10e-5 can be achieved at the data rate of 333 Mbps and at symbol SNR of 7dB.

## 8. Conclusion

The 2-dimensional PSM at the transmitter of UWB system doubles the data rate. A simple and economical receiver presented here performs better when used with a channel equalizer. The double error correcting block code with code rate ¼ reduces the data rate from 1334 Mbps to 333 Mbps but achieves the BER of 10e-5 at symbol SNR of 7dB over channel CM1 for the LOS communication distance of 4 meters. Over channel CM3 for NLOS communication of 10 meters BER of 10e-5 can be achieved at symbol SNR of 9 to 10dB. The simple receiver presented here gives improvement of about 3dB over the use of single correlator as a receiver. The further improvement of 5-6dB is provided by Double ECC. Over UWB channels CM1 and CM3 the image (of 16351 bits) could be received with 100% accuracy with original PSNR of 30.81, above the BER of 10e-5. Thus hermite based PSM helps in increasing speed of the transmission and double ECC helps to achieve energy efficient wireless communication.

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## Authors

**B K Mishra** was awarded PhD degree from Birla institute of technology in 1998.He has 22years of teaching experience. His present research interest focuses on device modeling of optical sensors.

**Joanne Gomes** completed ME in Electronics and Telecom engineering, from Mumbai University of, India, in 2005. She has 13 years of industrial and 9 years of teaching experience. She is presently pursuing her PhD. Her present research area is UWB wireless communication for home networking.