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Comparing PSWF, Hermite Pulses For High Speed Communication Using *N*-PSM

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ABSTRACT

Wireless technologies provide quick and easy access to information. Data rate/throughput is very important for multimedia communication. High-speed communication is recently achieved by using technologies such as UWB, OFDM etc. N-Dimensional Pulse Shape Modulation (N-PSM) is one of the modulation technique used to achieve high data rate based on the family of orthogonal pulses e.g. Prolate Spheroidal Wave Function (PSWF) and Hermite waveforms. Transceiver system based on N-PSM using PSWF and Hermite has been implemented in MATLAB and compared in this paper. Performance evaluation of the N-PSM is carried out over Additive White Gaussian Noise (AWGN) channel for different values of N to measure Bit Error Rate (BER). It has been found that a combination of PSWF and Hermite pulses can be used for high-speed modulation if these pulses are orthogonal to each other since both the types of pulses achieve same bit error rate over AWGN.

Keywords: *N-PSM Technique, Transceiver, PSWF, Hermite, Correlation*.

1 INTRODUCTION

Wireless communication systems demand transmission with large data, fast rate and to many users at once. So, rapid growth in wireless communication, allowing us to use applications such as multimedia communication, video tele-conferencing, military application etc [1]. Modulation performs main role in communication. There are some traditional modulation techniques like Amplitude Shift Keying (ASK), Phase shift keying (PSK), Frequency Shift Keying (FSK), and Pulse Position Modulation (PPM), These techniques are not suitable for high data rate communication. Some recent modulation techniques which give high data rate include *N*-PSM modulation [2]. In this research work *N*-PSM system is implemented which makes a use of orthogonal waveforms such as PSWF [3] and Hermite [4]. These pulses are orthogonal to each other, orthogonality between waveforms allows transmitting waveforms simultaneously in one symbol period and transmitted bits can be recovered at receiver side.

In [5] author has represented the hybrid *MN*-ary hybrid Amplitude Shape Modulation (h-ASM) scheme based on Hermite orthogonal pulses. *MN*-ary h-ASM waveform consists of *N* orthogonal signals with *M* amplitude levels for each signal, BER over AWGN channel. In [6], authors discussed *M*-ary PSM scheme, and high bit rate wireless connectivity for multiple devices, a new metric decision factor (*Df*) was introduced to determine the tolerance to timing jitter for both the pulse shapes. In [7], "modified triangular" pulse was implemented using a current steering Digital to Analog Converter. "Modified-triangular" shape consists of combining two triangular pulses, first is characterized by positive amplitude (A_1) and duration (T_1) while the second have negative amplitude (A_2) and duration T_2, value A_1 and T_1 are greater than A_2 and T_2. In paper [8] author presented the performance of pulse-based UWB *M*-ary *N*-orthogonal PPM (OPPM) signals, analyzed the symbol error rate (SER), and the capacity over both the AWGN and multipath channels. PSWF-based pulse waveform shaping is applied to *M*-ary signaling in [9].

Most of the papers have worked on *M*-ary system, where only one symbol is transmitted at one time. Each of this symbol carries $log_2^{(k)}$ no of data bits. So, overall to transmit *M*-symbol *M*-orthogonal symbols are required. However higher order *M*-ary cannot be used due to the limited auto correlation properties of higher order orthogonal pulses, the system complexity at receiver increases linearly. To address this problem, in this work *N*-dimension system has been implemented. Also, all the communication systems simulated so far have used either Prolate or Hermite pulses for data modulation, however this work uses both the types of pulses together, for data modulation to find out bit error rate.

This paper compares and analyses the use of PSWF and Hermite pulses for high speed modulation. The BER performance is obtained over AWGN with *N*-PSM modulation technique in MATLAB.

The paper is organized as follows: Section-2 briefs about properties of PSWF & Hermite, Section-3 discusses the correlation between respective pulses, Section-4 discusses Transceiver system using *N*-PSM based on Hermite & PSWF system, Section-5 discusses simulation results and Section-6 concludes this paper.

2 PSWF AND HERMITE

This section briefs about the PSWF and Hermite pulses along with their mathematical equations.

2.1. *PSWF Function*

PSWF is waveform denoted by $\phi_n(t)$.

$\phi_n(t), = 0,2,4,8 \ldots.\ even\ ordered\ pulse$ &

$\phi_n(t), n = 1,3,5,7 \ldots odd\ ordered\ pulse.$

$\phi_n(t)$ is evaluated by using following eq.

$$\phi_n(t) = \sum_{m=0,2}^{\infty} d_m^n P_{m(t)} \quad (1)$$

$$\phi_n(t) = \sum_{m=1,3}^{\infty} d_m^n P_{m(t)} \quad (2)$$

Where, P_r – Legendre polynomial,

If m is even then $d_m^n = [d_0^n, d_2^n, d_4^n \ldots]^T$ and if m is odd then $d_m^n = [d_1^n, d_3^n, d_5^n \ldots]^T$.

Calculation of d^n is very complex and is evaluated by using eigen vector symmetric tridiagonal matrix [3].

2.2 *Hermite*

Hermite waveform is denoted by w_n. It is generated by multiplication of hermite polynomial and respective exponential factor [4].

n^{th} Hermite pulse is evaluated by,

$$w_n = N_n H_n(t) e^{-t^2/a} \quad (3)$$

Where N_n and H_n is evaluated by using following eqns.

$$N_n = \sqrt{2^n n! \sqrt{\pi}} \quad (4)$$

$$H_n(t) = 2tH_n(t) - 2nH_{n-1}(t) \quad (5)$$

$$w_0 = \frac{H_0(t)e^{-t^2/2}}{\sqrt{2^0 0! \sqrt{\pi}}} = \frac{e^{-t^2/2}}{\sqrt{\sqrt{\pi}}} \quad (6)$$

$$w_1 = \frac{H_1(t)e^{-t^2/2}}{\sqrt{2^1 1! \sqrt{\pi}}} = \frac{2te^{-t^2/2}}{\sqrt{2\sqrt{\pi}}} \quad (7)$$

Fig.1 shows first four PSWF and Hermite waveforms in time and frequency domain.

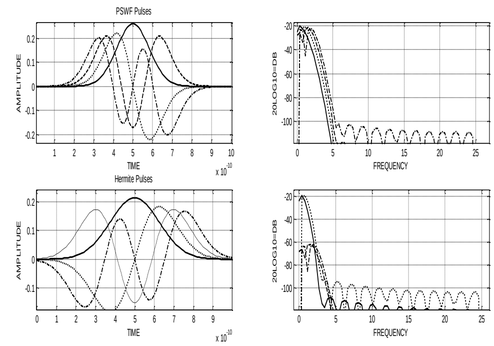

Fig. 1. PSWF/Hermite in time and freq. domain

3 CORRELATION BETWEEN PULSES

Correlation gives information about similarity between two waveforms. Correlation coefficient ($C_{coeff.}$) value between two waveforms plays a very important role for selection of orthogonal pulses. If $C_{coeff.}$ is '1' then waveforms are strongly like each other. If C_{coeff} value is '0' then waveforms are distinct and independent to each other. In *N*-PSM modulation, more than one pulses represent a symbol, they all are overlapping in one symbol period and finally all the pulses are combine. If the correlation is low then pulses do not mix with each other so at receiver it is easy to separate them for guessing the transmitted bits.

Tables 1, 2, 3, 4and 5 lists the C_{coeff} between Even-Even (E-E) order PSWF pulses, Odd-Odd (O-O) order PSWF pulses, Even-Odd (E-O) PSWF pulses, Hermite waveforms and between PSWF and Hermite pulses respectively.

Table 1: $C_{coeff.}$ between E-E order PSWF

$C_{coeff.}$	Φ_0	Φ_2	Φ_4
Φ_0	1	-0.2658	-0.2846
Φ_2	-0.2658	1	-0.1238
Φ_4	-0.2846	-0.1238	1

Table 2: $C_{coeff.}$ between O-O order PSWF

$C_{coeff.}$	Φ_1	Φ_3	Φ_5
Φ_1	1	0.0487	0.0020
Φ_3	0.0487	1	0.0911
Φ_5	0.0020	0.0911	1

Table 3: C_{coeff} between E-O order PSWF

$C_{coeff.}$	**Φ_1**	**Φ_3**	**Φ_5**
Φ_0	0	0	0
Φ_2	0	0	0
Φ_4	0	0	0

Table 4: C_{coeff} between Hermite waveform

$C_{coeff.}$	**W_0**	**W_1**	**W_2**	**W_3**
W_0	1	0	-0.4675	0
W_1	0	1	0	0
W_2	-0.4675	0	1	0
W_3	0	0	0	1

Table 5: $C_{coeff.}$ between PSWF-Hermite

$C_{coeff.}$	**W_0**	**W_1**	**W_2**	**W_3**
Φ_0	0.9568	0	-0.6890	0
Φ_1	0	-0.8905	0	0.4010
Φ_2	0.0150	0	0.7193	0
Φ_3	0	-0.4570	0	0.6163

Table 3 shows that correlation coefficients between even-odd order PSWF are 0, so they can be selected for *N*-PSM modulation. Selection of even-odd order PSWF waveforms gives better BER performances than other combinations like E-E and O-O PSWF pulses as mention in Table 1 and 2. Table 4 shows the coefficients of Hermite pulses. Correlation coefficients of PSWF are smaller than Hermite. Table 5 show that correlation between PSWF-Hermite pulses. It is found that E-O pair of PSWF-Hermite pulses having low correlation.

4 *N*-DIMENSIONAL PSM TRANSCEIVER

Designing details of *N*-PSM transceiver are discussed in this section. *N*-Dimensional transceiver system uses PSM scheme to transmit *N* orthogonal pulses simultaneously in one symbol period where *N* is number of bits per data symbol.

In *M*-ary system $M=2^N$ symbols are generated, where *N* is no of bits. For *N*=2 four different pulses are required, for *N*=3 and *N*=5 total 8 (8-ary) and 32 (32-ary) pulses are required respectively. In *N*-PSM, *N*=2 two different pulses required where information is modulated in the two-different pulse shapes on two-parallel branches. For *N*=3, 3 pulses (3-PSM), and for *N*=5, 5 pulses (5-PSM) are required. Table 6 shows required no. of pulses for *M*-ary and *N*-PSM technique. It is found that use of *N*-PSM technique reduces required no pulses than *M*-ary communication.

Table 6: M-ary and N-PSM

No. of Bits, No. of symbols	**Required no. of pulses for M-ary**	**Required no. of pulses for N-PSM**
N=2, *M*=4	4	2
N=3, *M*=8	8	3
N=4, *M*=16	16	4
N=5, *M*=64	64	5

Fig. 2 represents the general block diagram of *N*-PSM transceiver (TxRx), data bits are generated from binary bernoulli generator then data is divided into *N* parallel branches such as $D_0, D_1 \ldots D_{N-1}$.

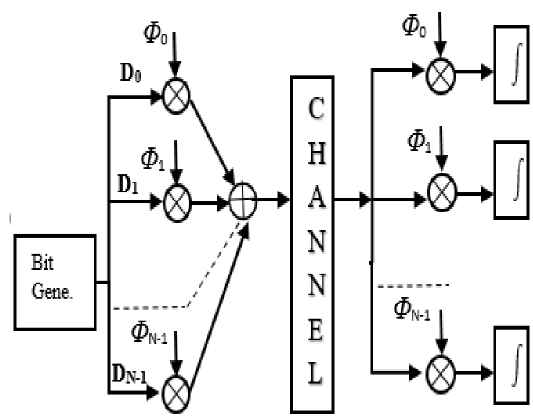

Fig. 2. Block diagram of N-PSM TxRx

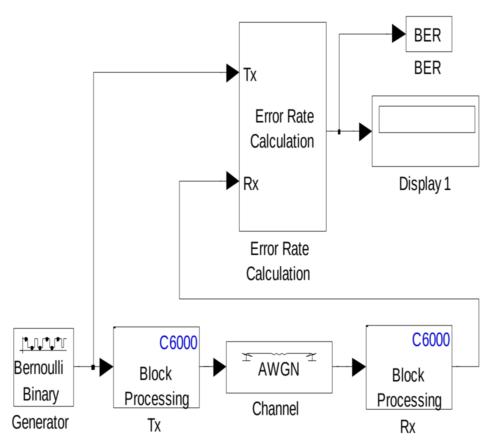

Fig.3. 2-PSM transceiver

The data bits are modulated on orthogonal pulses Φ_0, Φ_1… Φ_{N-1} which are finally added together. AWGN channel is modeled in this system. At the receiver *N* parallel correlators along with detectors take decision about *N* transmitted bits of a symbol.

Up to four-dimension (4-PSM) Transceiver using orthogonal pulses such as PSWF and Hermite have been implemented in this research work. Figs.3, 4 and 5 represent 2-PSM transceiver system, 2-PSM transmitter, and 2-PSM receiver respectively. In 2-PSM, *N*=2, $\Phi_0(t)$ and $\Phi_1(t)$ PSWF pulses are used to generate four symbols as shown in Table 7. Information is modulated in different pulse shapes on each of two-parallel branches as shown in Fig. 4, where first branch is represented by one pulse shape $\Phi_0(t)$ i.e. for bit "0" it is $\Phi_0(t)$ and for bit "1" it is - $\Phi_0(t)$ and second branch is represented by another pulse shape $\Phi_1(t)$ i.e. for bit "0" it is $\Phi_1(t)$ and for bit "1 it is - $\Phi_1(t)$.

Table 7: 2-PSM scheme

Symbol	**1st pulse**	**2nd pulse**
00	- Φ_0	- Φ_1
01	- Φ_0	Φ_1
10	Φ_0	- Φ_1
11	Φ_0	Φ_1

Modulated signal is mapped to the signal template by the receiver to recover binary bits. A correlator multiplies the received signal by a template pulse and then integrates the output of that process to yield a single value DC voltage.

Multiply-and-integrate process goes throughout

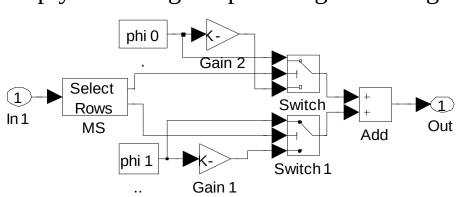

Fig.4: 2-PSM transmitter

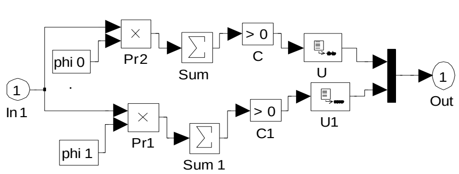

Fig.5. 2-PSM receiver

duration of the respective pulse.

Similarly, *3*-PSM and *4*-PSM schemes are designed using the following cases for 1ns,

case-I even-odd order of PSWF waveforms ($\Phi_0(t)$, $\Phi_1(t)$, $\Phi_2(t)$, $\Phi_3(t)$).

case-II Hermite waveforms W_1, W_2, W_3, W_4.

case-III combination of PSWF and Hermite (W_1, $\Phi_2(t)$, W_3, $\Phi_3(t)$).

5 SIMULATION RESULTS

In this paper, the BER performance of *N*-PSM scheme based on PSWF, Hermite and combinations of both over AWGN has been evaluated in Monte Carlo simulation. Table 8 gives details of simulation parameters.

Table 8: Simulation Parameters

Type of pulse	Hermite, PSWF
Pulse Width	1ns
Total no. of transmitted bits	1e5
No. of bits per symbol	2, 3, 4
Energy of Normalized pulse	1
Channel model	AWGN
Modulation Techniques	2-PSM, 3-PSM, 4-PSM

In transmission, the bit error rate (BER) is the number of bits in error divided by the total number of transmitted data bits.

Fig. 6, shows BER performance of 3-PSM system using Even-Even-Even (E-E-E), Odd-Odd-Odd (O-O-O) and Even-Odd-Even (E-O-E) PSWF pulses. Table 9 lists down BER values of the same. It is observed that the combination of E-O-E PSWF pulses shows a better BER performance than E-E-E and O-O-O PSWF pulses. This is because the correlation between E-O PSWF pulses is less than correlation between E-E and O-O PSWF pulses. Hence for case-I, case-II and case-III E-O pulses are selected for finding performance of *N*-PSM system.

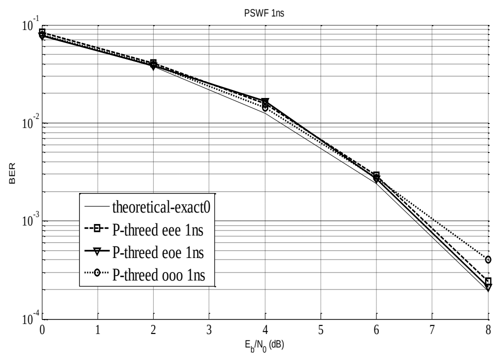

Fig. 6. shows BER performance of 3-PSM using different combinations of PSWF pulses

Table 9. BER performance for different PSWF pulses

$E_b N_0$	E-E-E	O-O-O	E-O-E
0	0.0833	0.0778	0.00788
2	0.0396	0.0384	0.0391
4	0.0120	0.0167	0.0142
6	0.0024	0.0026	0.0027
8	2.8 E-4	2.41 E-4	3.99 E-4

The BER performance of BPSK, 2-PSM, 3-PSM, and 4-PSM scheme for PSWF, for Hermite waveform, and combined pulses of Hermite-PSWF over AWGN channel is shown in following Figs.7, 8, 9, 10.

Fig. 7 shows BER performance of 2-PSM, 3-PSM and 4-PSM transceiver system for case-I using even-odd PSWF pulses. Fig. 8 shows BER performance of 2-PSM, 3-PSM and 4-PSM transceiver system for case-II using Hermite pulses. Fig. 9 shows BER performance of 2-PSM, 3-PSM and 4-PSM transceiver system for case-III using combination of E-O PSWF and Hermite pulses.

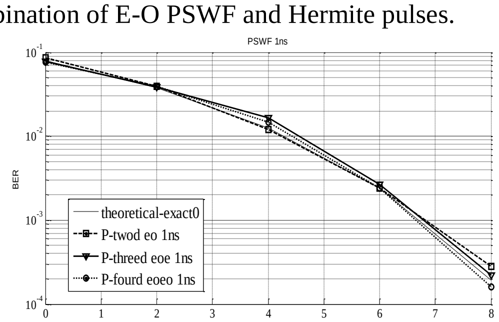

Fig. 7. Performance of 2-PSM, 3-PSM, 4-PSM scheme using PSWF pulses (case-I)

Table 10: BER performance for case-I

$E_b N_0$	2-PSM	3-PSM	4-PSM
0	0.0862	0.0778	0.00755
2	0.0396	0.0384	0.0392
4	0.0120	0.0167	0.0147
6	0.0024	0.0026	0.0024
8	2.8E-4	2.41 E-4	1.6E-4

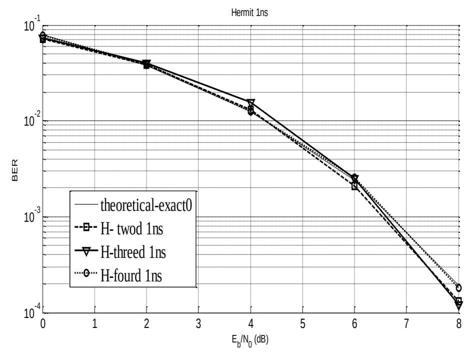

Fig. 8. Performance of 2-PSM, 3-PSM, 4-PSM scheme using Hermite pulses (case-II)

Table 11: BER performance for case-II

$E_b N_0$	2-PSM	3-PSM	4-PSM
0	0.0792	0.0821	0.0816
2	0.0382	0.0402	0.0411
4	0.0131	0.0118	0.0132
6	0.0024	0.0026	0.0025
8	2.1E-4	1.8E-4	1.9E-4

Tables 10, 11, and 12 list the BER at different values of E_bN_0, for case-I, case-II, case-III. Total 1e5 data bits were transmitted for each E_bN_0. BER of 1e-4 was achieved, for 2-PSM, 3-PSM and 4-PSM and it is almost similar.

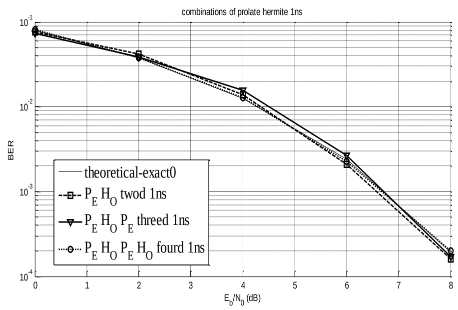

Fig.9 Performance of 2-PSM, 3-PSM, 4-PSM scheme for Combined PSWF-Hermite pulses (case-III)

Table 12: BER performance for case-III

E_b N_0	2-PSM	3-PSM	4-PSM
0	0.0811	0.0801	0.0739
2	0.0351	0.0407	0.0411
4	0.0110	0.166	0.0146
6	0.0024	0.0025	0.0027
8	2.5E-4	1.6E-4	1.4E-4

BER performance E-O PSWF pulses (case-I) for 2-PSM, 3-PSM, 4-PSM is better than E-E and O-O PSWF pulses as correlation between E-O PSWF pulses is less. Hermite pulses also having low correlation so again BER performance for case-II is better. As PSWF and Hermite pulses are orthogonal to each other and having low correlation between them, their combination gives similar kind of BER performance if they would have been used separately.

6 CONCLUSION

In this paper *N*-PSM transceiver system based on orthogonal pulses e.g. PSWF, Hermite and Combination of both has been implemented. Use of *N* -PSM technique reduces no. of pulses required in *M*-ary technique. In BER Performances of *N*-PSM, it is found that E-O PSWF pulses gives better performance than E-E and O-O PSWF pulses. So, E-O PSWF pulses have been selected to evaluate BER performance of 2-PSM, 3-PSM, 4-PSM system. Also Combination of PSWF and Hermite have been used to evaluate BER performance of *N*-PSM system. It is found that whether we use PSWF and Hermite pulses separately or in combination BER performance of *N*-PSM system remains same.

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