INTERNATIONAL JOURNAL OF RECENT TRENDS IN ENGINEERING & RESEARCH
Impact Factor 4.101 ISSN -2455-1457
RECENT ADVANCES IN ELECTRONICS & COMMUNICATION ENGINEERING (RAECE-2K17)

A Novel M-Ary Pulse Shape Modulation (PSM) Scheme For UWB Communication Technology In Wireless Sensor Applications

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Abstract: With technological advances in the field of communication, the need for reliable high-speed data transfer is increasing. The deployment of large number of wireless sensors for remote monitoring and control and streaming of high definition video, voice and image data, etc. are imposing a challenge to the existing network bandwidth allocation for reliable communication. Two novel schemes for ultra-wide band (UWB) communication technology have been proposed in this paper with the key objective of intensifying the data rate by taking advantage of the orthogonal properties of the modified Hermite pulse (MHP). In the first scheme, a composite pulse is transmitted and in the second scheme, a sequence of multi-order orthogonal pulses is transmitted in the place of a single UWB pulse. The MHP pulses exhibit a mutually orthogonal property between different ordered pulses and due to this property, simultaneous transmission is achieved without collision in the UWB system, resulting in an increase in transmission capacity or improved bit error rate. The proposed schemes for enhanced data rate will offer high volume data monitoring, assessment, and control of wireless devices without overburdening the network bandwidth and pave the way for new platforms for future high-speed wireless sensor applications.

Keywords: UWB; modified hermite pulse; orthogonal pulse; correlation; bit error rate

1. Introduction

In recent times, ultra-wide band (UWB) communication technology has become widely used in wireless sensing applications such as structural health monitoring, patient health care monitoring, military surveillance, and smart homes, etc. Owing to its attractive features like lower power consumption, its power spectrum below the noise floor, and its consistency with preexisting wireless technologies, there is a shift of interest among researchers towards the pulse-based UWB communication since narrow-band communication for WSN is afflicted with channel impairments and bandwidth constraints. In a UWB system, the narrow-band signal is a major interferer; however, a significant number of articles have been reported to mitigate these problems [1–5].

A lot of work has been put in towards developing innovative techniques for pulse set generation and modulation for UWB systems. Pulse-position amplitude modulation (PPAM) [6], biorthogonal-pulse position modulation (BPPM) [7], and OOK-PSM [8] are proposed in several works in the literature to achieve better system performance using combined modulation techniques with higher data rates, less complex receivers, and lower power consumption. The Federal Communications

Commission (FCC) defines the regulation of pulse power and spectrum [9]. Different types of pulse shapes are used to obtain desired power and spectral ranges [10,11].

One of the main drawbacks of the UWB system is the generation of proper orthogonal practice of employing orthogonal pulse to increase the data rate in the prevailing UWB communication systems. The authors of [14] used different pulse in different positions to increase the number of information bits to be transmitted, whereas the authors of [13] utilized an orthogonal pulse sequence to encode the information bits. The orthogonal pulses can be added in time and transmitted as a composite pulse to the receiver end. These orthogonal pulses are then put through a correlator which in turn decodes the composition of the symbols.

2. composite Pulse Generation

Traditional Hermite polynomials have been defined by the authors of [22]. For the purpose of generating orthogonal pulses for UWB communications, MHPs have been proposed by pioneering researchers [23,24]; which permit one particular dynamic system to generate another MHP. Since orthogonal pulses can be transmitted simultaneously without mutual interference, orthogonal pulse set-based IR-UWB systems have the potential to achieve a higher data rate than the conventional IR-UWB systems [25–54]. Most of the mathematical functions for the design of orthogonal UWB pulses such as the Haar function [55], the modified Hermite polynomial (MHP) function [22–24,56], and the prolate spheroidal wave function (PSWF) [57,58], etc. involve complicated math models and power hungry hardware implementation [59]. MHP pulses, which have lower computational complexity than PSWF-based pulses, possess the properties of orthogonality and nearly-constant pulse widths irrespective of the pulse orders.

An efficient mathematical model for MHP set generation has been presented in [12], where the pulses and their higher derivatives.A modified Hermite pulse (MHP) set generator has been presented in [12] which uses an efficient technique to generate orthogonal pulses. Similarly, the authors of [13,14] endorsed the

*n*th order derivatives of the MHP are given as

$$\tau \dot{h}_n(t) = -\frac{t}{2\tau} h_n(t) + n h_{n-1}(t)$$

$$\tau \dot{h}_{n-1}(t) = \frac{t}{2\tau} h_{n-1}(t) - h_n(t)$$

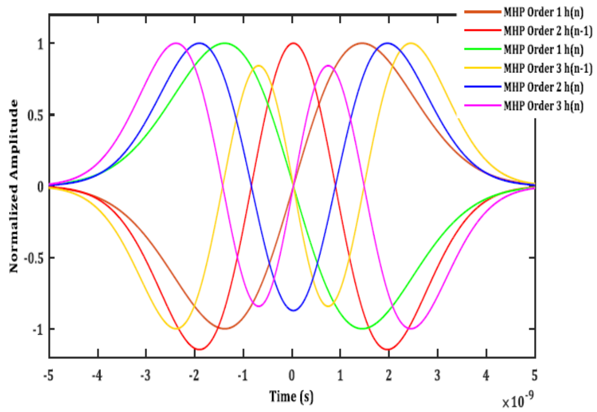


Figure 1. Combined plots of modified Hermite polynomial (MHP) order 0, 1, 2 and 3 from the generator circuit (pulse width = 10 ns).

Table 1. Correlation coefficient between the orthogonal pulses (6 ns).

	MHP_0 $h(n)$	MHP_1 $h(n)$	MHP_1 $h(n-1)$	MHP_2 $h(n)$	MHP_2 $h(n-1)$	MHP_3 $h(n)$	MHP_3 $h(n-1)$
$MHP_0\,h(n)$	1	0	0	0.3409	−0.3208	0	0
$MHP_1\,h(n)$	0	1	−1	0	0	0.1743	−0.1913
$MHP_1\,h(n-1)$	0	−1	1	0	0	−0.1363	0.1538
$MHP_2\,h(n)$	0.3409	0	0	1	−1	0	0
$MHP_2\,h(n-1)$	−0.3208	0	0	−1	1	0	0
$MHP_3\,h(n)$	0	0.1743	−0.1363	0	0	1	−1
$MHP_3\,h(n-1)$	0	−0.1913	0.1538	0	0	−1	1

Table 2. Correlation coefficient between the orthogonal pulses (10 ns).

	MHP_0 $h(n)$	MHP_1 $h(n)$	MHP_1 $h(n-1)$	MHP_2 $h(n)$	MHP_2 $h(n-1)$	MHP_3 $h(n)$	MHP_3 $h(n-1)$
$MHP_0\,h(n)$	1	0	0	0.2507	−0.2507	0	0
$MHP_1\,h(n)$	0	1	−1	0	0	0.2507	−0.2507
$MHP_1\,h(n-1)$	0	−1	1	0	0	−0.2507	0.2507
$MHP_2\,h(n)$	0.2507	0	0	1	−1	0	0
$MHP_2\,h(n-1)$	−0.2507	0	0	−1	1	0	0
$MHP_3\,h(n)$	0	0.2507	−0.2507	0	0	1	−1
$MHP_3\,h(n-1)$	0	−0.2507	0.2507	0	0	−1	1

Table 3. Correlation coefficient between the orthogonal pulses (18 ns).

	MHP_0 $h(n)$	MHP_1 $h(n)$	MHP_1 $h(n-1)$	MHP_2 $h(n)$	MHP_2 $h(n-1)$	MHP_3 $h(n)$	MHP_3 $h(n-1)$
$MHP_0\,h(n)$	1	0	0	0.2541	−0.2541	0	0
$MHP_1\,h(n)$	0	1	−1	0	0	0.1968	−0.1968
$MHP_1\,h(n-1)$	0	−1	1	0	0	−0.1968	0.1968
$MHP_2\,h(n)$	0.2541	0	0	1	−1	0	0
$MHP_2\,h(n-1)$	−0.2541	0	0	−1	1	0	0
$MHP_3\,h(n)$	0	0.1968	−0.1968	0	0	1	−1
$MHP_3\,h(n-1)$	0	−0.1968	0.1968	0	0	−1	1

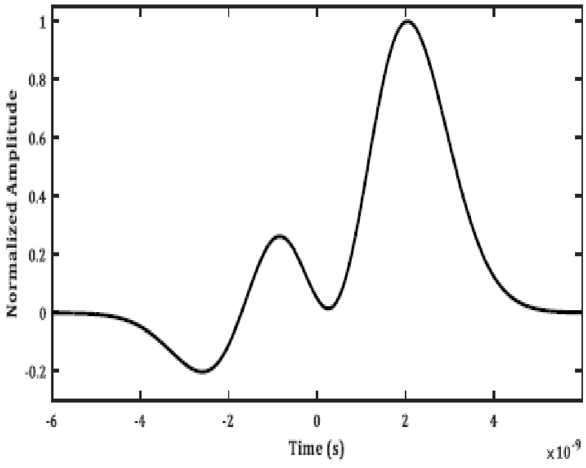
The correlation values between the selected orthogonal pulses and all possible combinations of 2, 3, and 4 orthogonal pulses are shown in Tables 4 and 5. The correlation coefficient values show how closely the two signals under consideration resemble each other. Hence, it can be interpreted as a conviction factor for the given MHP to be present in the composite pulse under inspection. For instance, for 57% confidence it can occur that $MHP0$ is present in the composite pulse of $MHP0,1$ (Table 4: second row, second column).

Table 4. Correlation coefficient values for selected pulses and all possible combinations of 2 orthogonal pulses.

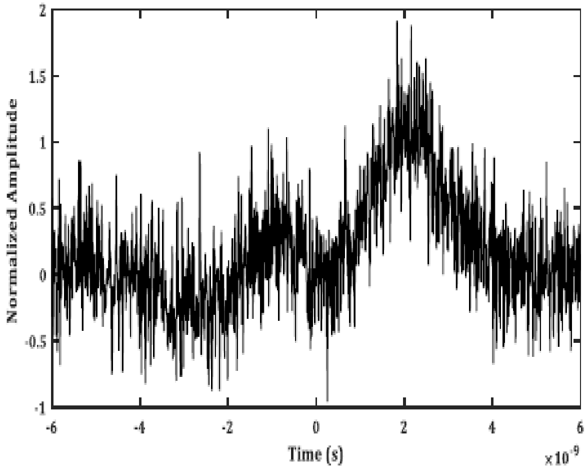
	$MHP_{0,1}$	$MHP_{0,2}$	$MHP_{0,3}$	$MHP_{1,2}$	$MHP_{1,3}$	$MHP_{2,3}$
MHP_0	0.5698	0.4454	0.5664	−0.1744	0	−0.1736
MHP_1	0.8218	0	0.1622	0.7275	0.7713	0.1438
MHP_2	−0.1448	0.7528	−0.1440	0.6861	0	0.6829
MHP_3	0.1617	0	0.8241	0.1432	0.7759	0.7305

Table 5. Correlation coefficient values for elected pulses and all possible combinations of 3 and 4 orthogonal pulses.

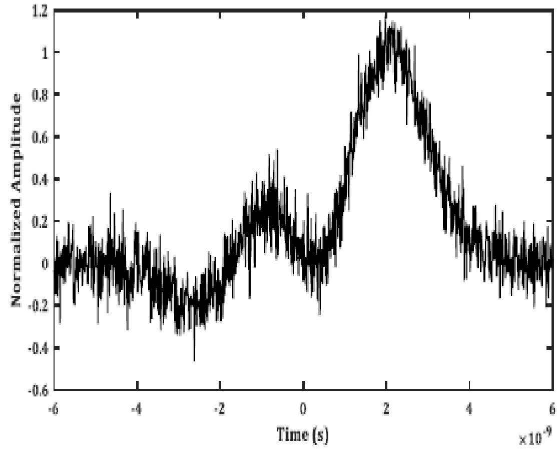
	$MHP_{1,2,3}$	$MHP_{0,2,3}$	$MHP_{0,1,3}$	$MHP_{0,1,2}$	$MHP_{0,1,2,3}$
MHP_0	0.1319	0.3165	0.4075	0.3178	0.2442
MHP_1	0.6594	0.1385	0.7043	0.7005	0.6450
MHP_2	0.5188	0.5349	-0.1036	0.5372	0.4127
MHP_3	0.6633	0.7037	0.7085	0.1379	0.6489



(a)



(b)



(c)

Figure 2. Composite pulse (**a**) without noise (**b**) with signal-to-noise ratio (SNR) 10 dB (**c**) with SNR 20 dB.

3. Single User UWB System

With 4 orthogonal pulses, this scheme can represent 4 bits of data using 16 unique composite pulses. Each composite pulse can represent 4 bits of information. Table 10 shows the 4 bits of data and the corresponding composite pulses that can be used to represent them in a single time slot. In the receiving section, a correlator block can decode the composition of the received composite pulses and determine the transmitted 4 bits of data by analyzing the composition of the received pulses. This scheme will increase the data rate by 4 folds compared to the simple on–off keying (OOK)-based UWB communication system as a 300% gain is achieved.

Table 10. Proposed scheme for data transmission using 4 orthogonal pulses in a single-user scenario.

S.N	Dat	Pulse
1.	000	No pulse
2.	000	*MHP*0
3.	001	*MHP*1
4.	001	*MHP*2
5.	010	*MHP*3
6.	010	*MHP*0.1
7.	011	*MHP*0,2
8.	011	*MHP*0,3
9.	100	*MHP*1.2
10.	100	*MHP*1.3
11.	101	*MHP*2,3
12.	101	*MHP*0,1,2
13.	110	*MHP*0,1,3
14.	110	*MHP*0,2,3
15.	111	*MHP*1,2,3
16.	111	*MHP*0,1,2,3

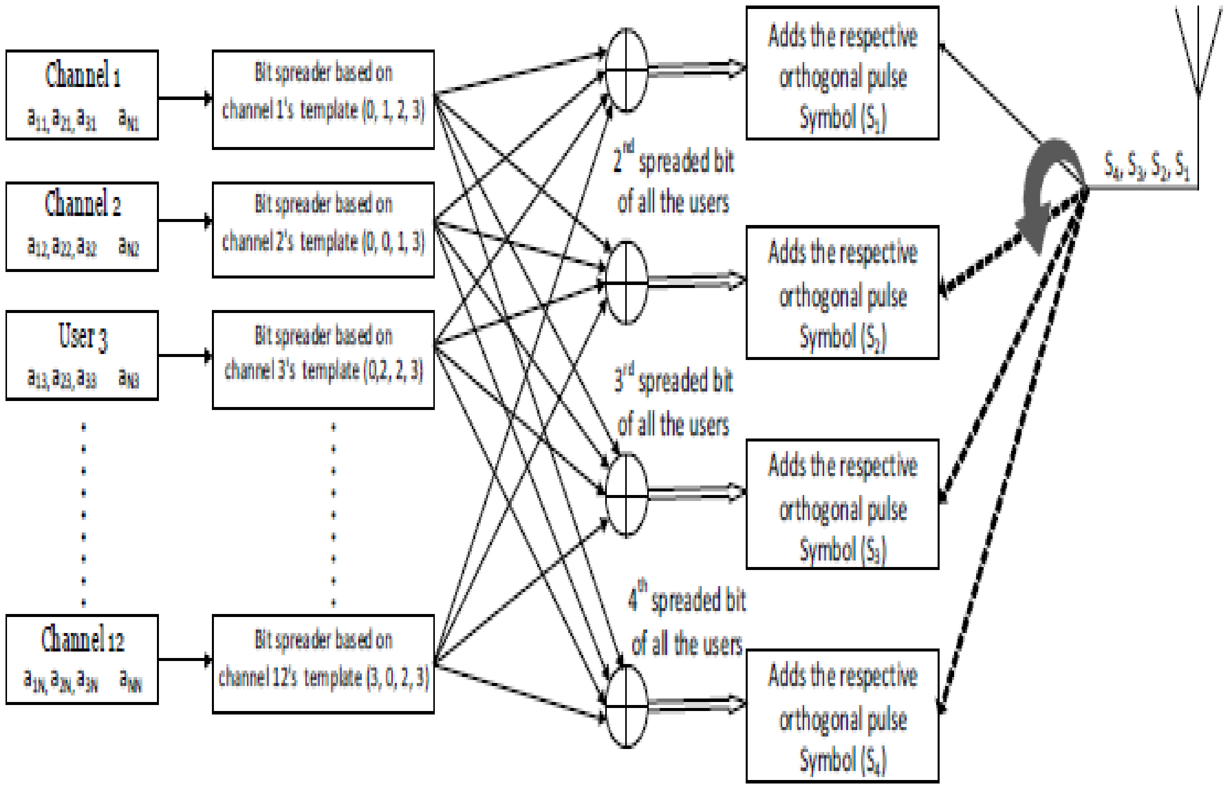


Figure 3. Proposed transmitter architecture for the ultra-wide band (UWB) system using pulse shape modulation (PSM).

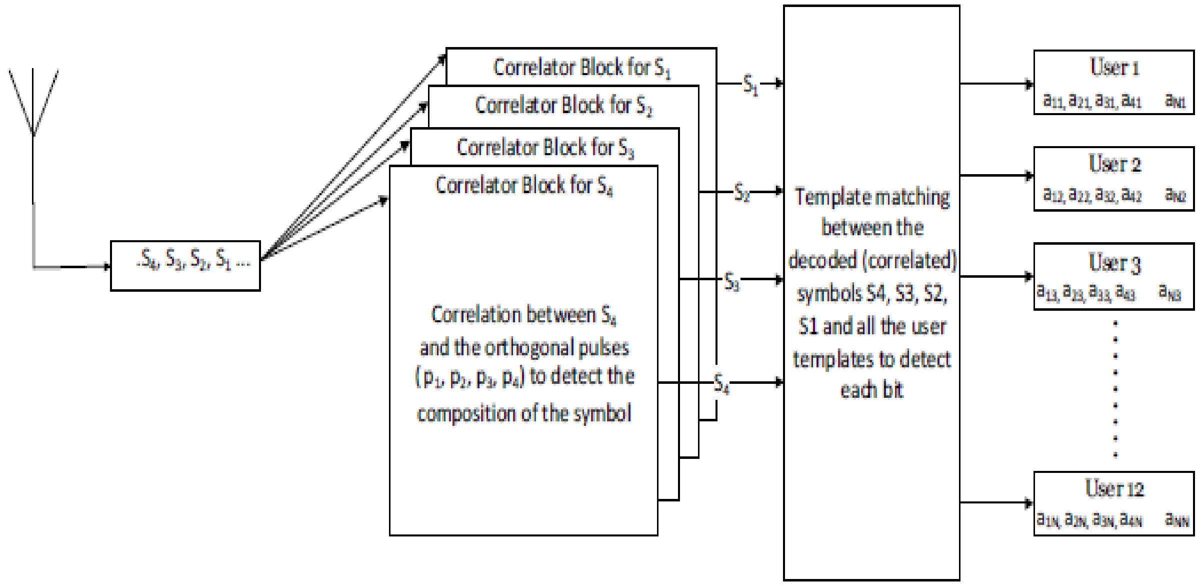


Figure 4. Proposed receiver architecture for the UWB system using PSM.

4. Conclusions

Two novel schemes for data rate enhancement in UWB communication technology have been presented through the course of this paper. The proposed schemes use orthogonal pulses to transmit data in both single user and multiple user scenarios. Instead of transmitting individual orthogonal pulses, this scheme transmits composite pulse of 4 orthogonal pulses and by doing such it manages to increase the data rate in single-user scenario by 4 folds and at the same time accommodates 12 channels for simultaneous data transmission. The correlation properties of the MHP are analyzed through MATLAB simulations as it also validates that the composite pulse can be decoded in the receiver end with a threshold value calculated from the correlation analysis of MHPs with a 10-ns pulse width. The carefully chosen threshold level of 21% satisfies both the low and high ends of the SNR values. One of the major gains in employing the proposed scheme is its capability to work with the existing pulse-based UWB system due to the similarities in features such as the pulse width, pulse repetition interval (PRI), and energy with that of the single orthogonal pulse-based system. Since the difference exists exclusively in the shape of the pulse, it will not affect the transmission and the synchronization; as a result the proposed scheme can be readily incorporated with the existing UWB system with minimal change. The proposed scheme's competence in enhancing number of channels for simultaneous data transmission along with the rate of data being transmitted in sub-GHz UWB communication makes it a leading alternative for future wireless sensing applications.

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