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Original scientific paper

NEW APPROACH TO A DS-CDMA-UWB SYSTEM USING A PSEUDO ORTHOGONAL CODE (POC)

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Abstract. *Ultra-Wideband Direct Sequences Code Division Multiple Access (DS-DMA) plays an important role in the case of multi-terminal multi-application communications of UWB devices. In the case of UWB systems that exploit the injection of the pulse itself directly to the antenna hence the very wide bandwidth, generation of suitable DS-CDMA codes poses a real challenge. In this paper we will describe our novel UWB transmission which uses pseudo-orthogonal time code (POC) as DS-CDMA sequences. The suggested codes are unipolar sequences with chips that may be dynamically modified to target a certain number of users or applications. Our approach bypasses the modulations schemes commonly used on UWB systems. Moreover, as perspectives to our work, it would be very interesting to realize our new approach based on an FPGA circuit.*

Key words: *UWB systems, pseudo-orthogonal code (POC), direct sequence-CDMA*

1. INTRODUCTION

The ultra-wideband (UWB) technology can be integrated into many applications such as Personal Area Networks (WPAN) [1-3] and mobile telecommunications (5G today) [4-6]. The UWB system is a rapidly developing technology that uses short range with very low power consumption, to transmit information over a majority of the radio spectrum to occupy a bandwidth greater than or equal to 25% of the center frequency or 1.5 GHz [7]. The UWB transmitters use very short-in-time pulses instead of carrier signals modulation. The most used pulses models are Gaussian second derivatives, whose representation in the time domain is described by (1):

$$U(t) = \left(1 - 4\pi\left(\frac{t}{\vartheta}\right)^2\right) e^{-2\pi\left(\frac{t}{\vartheta}\right)^2} \tag{1}$$

Where ϑ represents a time normalization factor.

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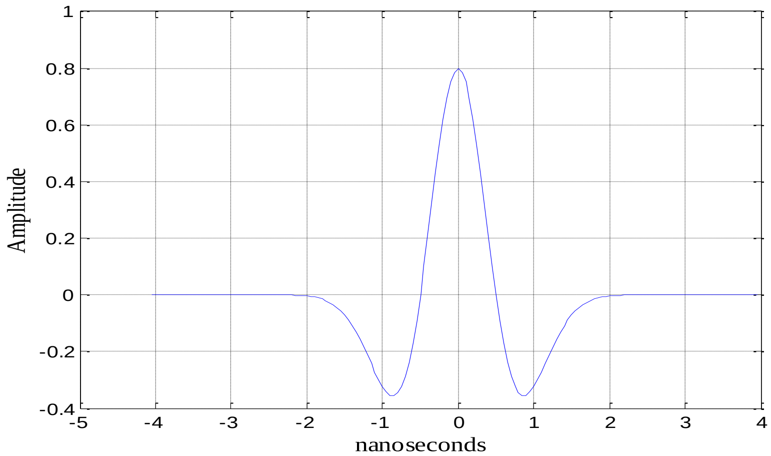

Fig. 1 Second derivative of a Gaussian pulse

Especially for wireless communications, the United States Federal Communications Commission has set the power level to a very low level (lower than -41.3 dBm) [8] allowing UWB technology to share spectrum with other users without interference. To get the required spreading, various techniques can be used such as Direct Sequence (DS) and Time-Hopping (TH) [9]. User data is allotted to time frames in the TH-UWB systems, and pulse position modulation (PPM) is employed to eliminate overlap in multiple access networks [10-11]. On the other hand, time spreading codes are used in DS-UWB techniques [12] in the same way as they are in traditional direct sequence code access (DS-CDMA) technique, so they have the same advantages than direct sequence spread spectrum (DSSS) [13-14]. In this paper we propose a transceiver model suitable for a new approach to direct sequence digital transmission, for an ultra-wideband application (DS-UWB), using a pseudo-orthogonal time code (POC). The proposed codes are composed of unipolar sequences characterized by a length L, constituted of N elements called "chips", a predefined number of users, and the weight of the code; chips with level "1". Moreover, to enhance the synchronization between transmitters and receivers, this new proposed spreading schema makes it possible to separately code high-level bits '1' and low-level bits '0' of the data stream by two different codes; the doublet code sequence is unique for each user. The proposed study aims to transmit DS-CDMA-UWB without using classical modulations associated with UWB systems. Our new model, based on pseudo orthogonal codes, build a DS-CDMA-UWB system for both sides receiver and emitter. Direct sequences for UWB systems are explained in section 2. Section 3 will introduce the classic modulation schema used on UWB systems. Sections 4 detail the POC mechanisms. The UWB DS-CDMA emitter is detailed in section 5. Sections 6 and 7 highlight the emitter signals generation; simulation and results for the propagation and signal acquisition at the receiver level that we present in section 8. Section 9 concludes this paper.

2. DIRECT SEQUENCE UWB (DS-UWB)

Direct sequence spread spectrum systems appear easier to implement since all the pulses are spaced at the same period, which imposes fewer constraints on the components of the transmission chain. Indeed, our built DS-UWB transmitter scheme uses orthogonal pseudo-random codes (PN) [15] as spreading sequences to encode each bit of information, and the bandwidth of the transmitted pulse is much greater than that used by the transmitted binary stream. Figure 2illustrates a block diagram of the DS-UWB signal generator.

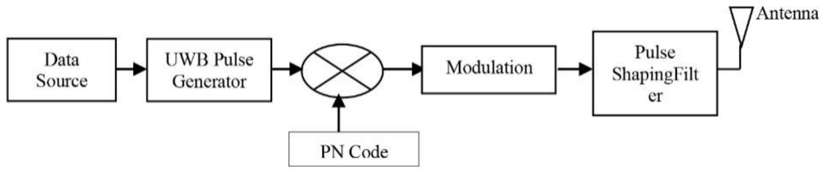

Fig. 2 Block diagram of a DS-UWB signal generator

3. MODULATIONS ASSOCIATED WITH UWB SYSTEMS

There are mainly modulation methods for UWB communications, such as PPM (Pulse Position Modulation), OOK (On-Off Keying) and PAM (Pulse Position amplitude modulation) [16-17].

- PPM modulation: The information is encoded according to the position of the time-spaced pulse; bit '0' is defined by a time-shifted pulse from a reference pulse that matches bit '1'.
- OOK modulation: Corresponds to the presence of a pulse representing the "1" bit and the "0" results in the absence of a pulse.
- PAM modulation: is an access method based on the property of orthogonality of pulses.

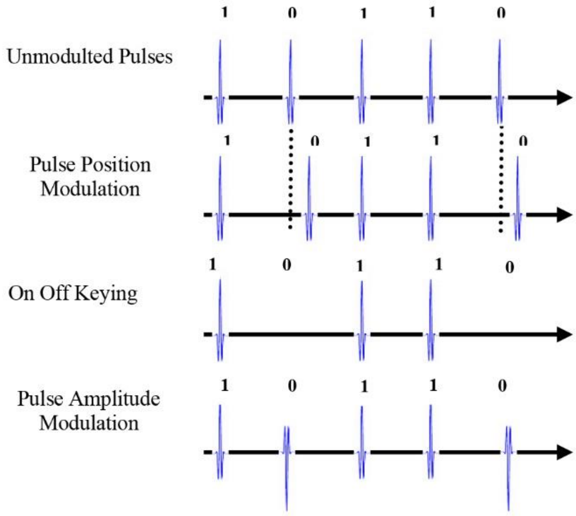

Fig. 3 Modulations associated with UWB systems

4. PSEUDO-ORTHOGONAL CODES (POC)

J. A. Salhi developed the POC codes in 1989 [18], these codes are composed of unipolar sequences c = {c j} defined by the following parameters:

- L represents the code length POC
- W stands for the code's weight, which denotes the number of chips at "1."
- The auto and inter-correlation constraints are represented by λ_a and λ_c respectively.

4.1. Numbers of user

In the event that $\lambda_a = \lambda_c = 1$, various works [18-19] have shown that the number of possible users of a POC code sequence is limited by the relation (2):

$$N(L, W, 1, 1) \leq \left\lfloor \frac{L-1}{w(w-1)} \right\rfloor \tag{2}$$

- N: Number of User.
- L, W: represents the code length POC and the code's weight respectively.

4.2. Construction of codes

The BIBD (Balanced Incomplete Block Design) method [20] allows us to generate OC (L, W) code sequences when the desired spread length is a prime number. It is mathematical method based on properties related to primitive roots from a Galois field; it is a simpler and faster method.

We consider the primitive root α of L, we can get the positions of the chips at 1 of the i[th] sequence $C_i = [P_{i,0} ; P_{i,1};\ldots; P_{i,W-1}]$ for each code according to the parity of W [21] :

$$-if\ W\ is\ even(W = 2m): \begin{cases} P_{i,0} = 0 \\ P_{i,j} = \propto^{(m\times i)+(j\times k)} \end{cases} \tag{3}$$

$$with: i \in [0, N-1]; j \in [0, W-2]\ et\ k = 2 \times m \times N$$

$$-if\ \ W\ is\ odd(W = (2\times m) + 1): \{P_{i,j} = \alpha^{(m\times i)+(j\times k)} \tag{4}$$

$$with: i \in [0, N-1]; j \in [0, W-1]\ et\ k = 2 \times m \times N$$

- α is the primitive root of L.
- is the P_{ci} is the position of chips at 1 for i[th] Code sequence

$$C_i = \left[P_{i,0}; P_{i,1}; \ldots; P_{i,W-1}\right]$$

Table 1 shows the code positions used in our study according to the BIBD method.

In the following figure 4, we present the positions of the chips at "1" of the POC code (73, 4) according to number of users N=6andthe length of the code L=73.

Table 1 The different positions of (73, 4, 1, 1) code according to the BIBD method

			First chips	j		
				0	1	2
Code		0 (C_1)	0	1	8	64
(73,4,1,1)		1 (C_2)	0	25	54	67
N = 6	i	2 (C_3)	0	36	41	69
		3 (C_4)	0	3	24	46
		4 (C_5)	0	2	16	55
		5 (C_6)	0	35	50	61

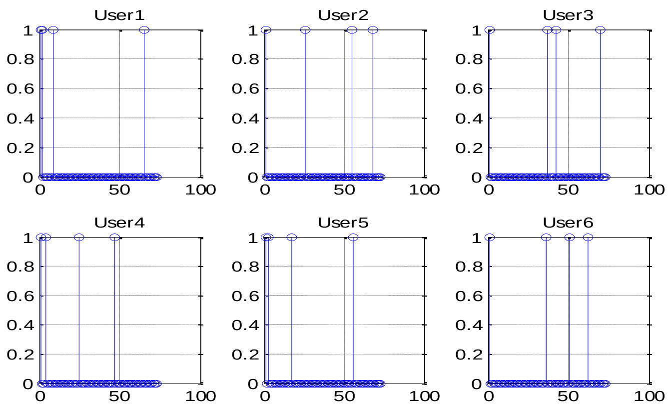

Fig. 4 Positions of chips at "1" of the code POC (73,4)

5. New Model of DS-CDMA-UWB Emitter

For our proposed model, the bit flow equal to "1" is convoluted by the chips of a user's POC code and the bit flow equal to "0" bit by another user code, which gives an increased bandwidth to the signal by emitting low-energy Gaussian-shaped pulses that are coherent on reception as explained by Figure 5.

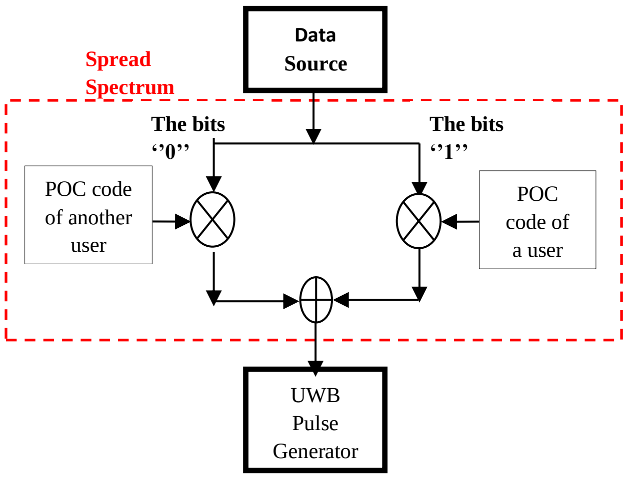

Fig. 5 DS-CDMA-UWB emitter

The DS-CDMA-UWB signal transmitted to a user can be expressed as follows:

$$S_{POCcode}(t) = \left[\sum_{k=-\infty}^{\infty} b_1^k \sum_{j=0}^{N_c-1} C_j^U + \sum_{i=-\infty}^{\infty} b_0^k \sum_{j=0}^{N_c-1} C_j^{U^{\sim}}\right] \oplus W(t - iT_s - jT_c) \qquad (5)$$

- b_0^k, b_1^k : is the 0 and the 1 bit respectively of binary data sent by the k[th] source
- W is the pulse waveform
- T_c, T_s are chip and symbol duration respectively
- N_c is the number of chips
- $C_j^U, C_j^{U^\sim}$ is a code of two different users which only takes chips 1 or 0 up to N the number of users.

6. Emitter Simulation

We first consider a random sequence of 8 bits modeling the useful information as limited bit stream. Then we use two selected POC codes to spread the spectrum, which is completely independent of the random data sequences [20], this data transmission method uses more bandwidth than necessary to traditional transfer. For this paper purpose we have selected as an example the 4th and 6th POC sequences (73,4) for our user (all other codes use the same principle), i.e. the bit flow equal to "1" is convolved by 73 chips of code #4 and the bit flow equal to "0" convolved by 73 chips of code #6.

$$S_{(73,4)}(t) = [(\sum_{k=-\infty}^{\infty} b_1^k \sum_{j=0}^{73-1} C_j^4) + (\sum_{i=-\infty}^{\infty} b_0^k \sum_{j=0}^{73-1} C_j^6)] \oplus W(t - iT_s - jT_c) \qquad (6)$$

The spread of the spectrum as represented in Figure 6 modulates a sequence of data “10011011” by means of two pseudo-random POC codes chosen at a bit rate much higher than that of the information signal to be transmitted. That is to say the convolution is done once between the 73 code chips of user #4 with bits equal to and the 73 code chips of user #6 with bits equal to 0.

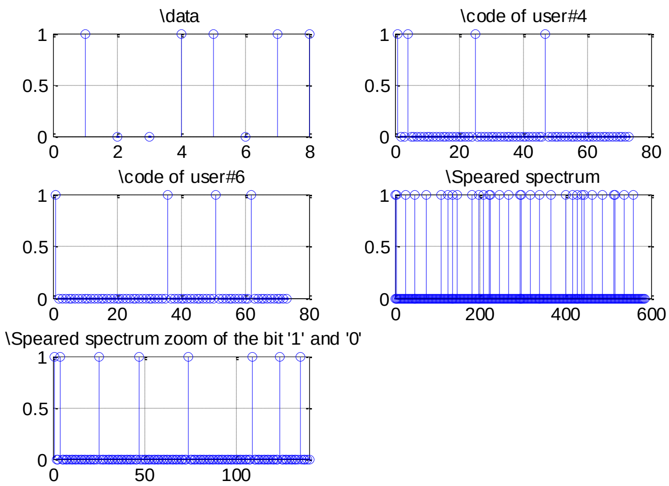

Fig. 6 Spread spectrum phase for the data sequence “10011011”

6.1. Generation of UWB pulses

In this paper, we used the second derivative of the Gaussian generated by equation (1) because of their ease of implementation in UWB systems [19-20]. As shown in the figure 7, the UWB pulse generator receives the spread data to create a second order Gaussian derivative pulse train and output the signal through the antenna [22].

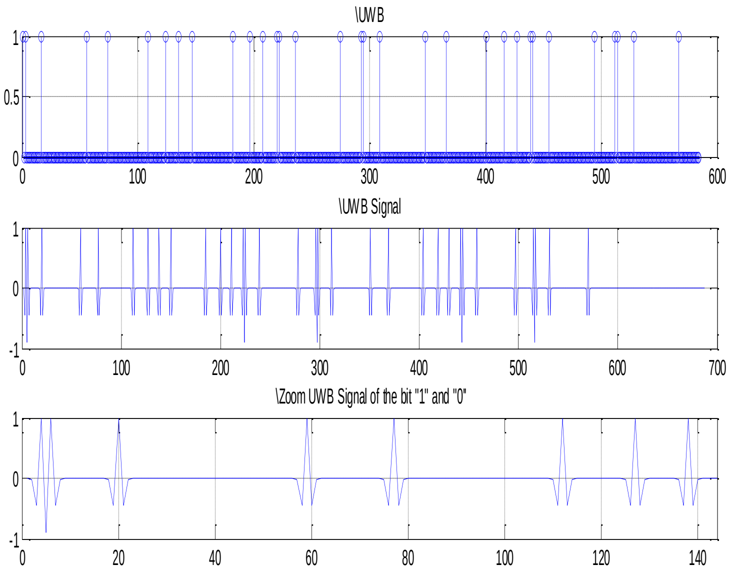

Fig. 7 UWB pulses

To comply with the regulatory agency's recommendations, the frequency band allocated for UWB transmissions has been grouped into two parts, a so-called "low band", comprising between 3 and 5 GHz, and the other called "high band", include between 6 and 10 GHz [23]. Our transmitted DS-UWB signal is included in low band according to figure 8 which shows UWB signal spectrum and power spectral.

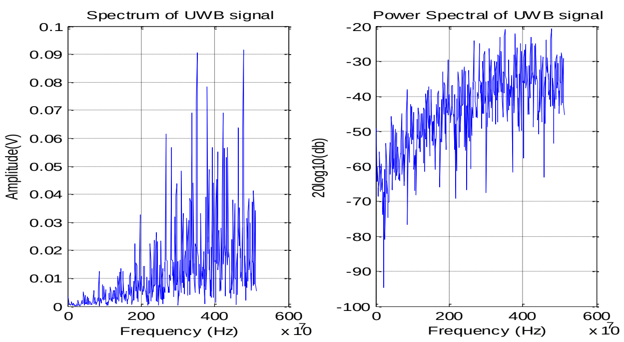

Fig. 8 The spectrum and the power spectral of UWB signal

7. Transmission Channel

In our work, we did not examine multi-user interference (MUI) [24] and intersymbol interference (ISI) [25] since these phenomena are not predominant. In our work, the only phenomenon which imperfects our system is the noise AWGN the received signal can be described by $r(t) = s(t) + n(t)$ where $s(t)$ is the signal generated by the transmitter and $n(t)$ denotes the additive Gaussian noise [26-27-28]. Figure 9 shows the noise signal based on the AWGN channel model.

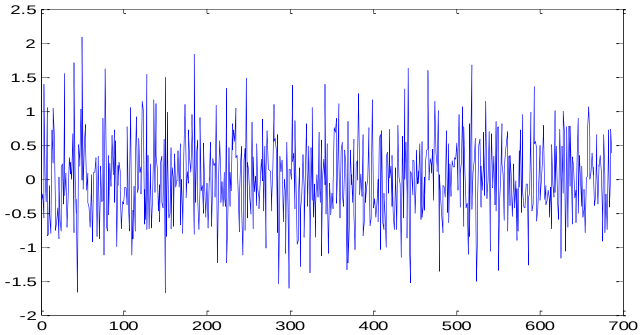

Fig. 9 AWGN Channel output, where Eb/No=2dB

8. The Correlation Receiver

Gaussian white additive noise (AWGN) channel the correlation receiver as shown in the figure 10 is the most optimal of a DS-CDMA-UWB chain by adding a filter adapted to the received signal, it uses a correlation device, it breaks down into three steps main [29]:

- Multiplication of the received signalr(t) by the POC code users #4 and #6 with the pulse generator UWB:

$$R_{corr}(t) = r(t) * [(\sum_{k=-\infty}^{\infty} b_1^k \sum_{j=0}^{73-1} C_j^4) + (\sum_{i=-\infty}^{\infty} b_0^k \sum_{j=0}^{73-1} C_j^6)\ ] \oplus W(t - jT_c)] \quad (7)$$

- Integration of the correlated signal over the bit time

$$Z_1^{(i)} = \int_0^{T_b} r_{corr}(t)dt \quad (8)$$

- Decision making by comparison to a threshold knowing that user POC code #4 and #6 indicates bit '1' , '0' respectively.

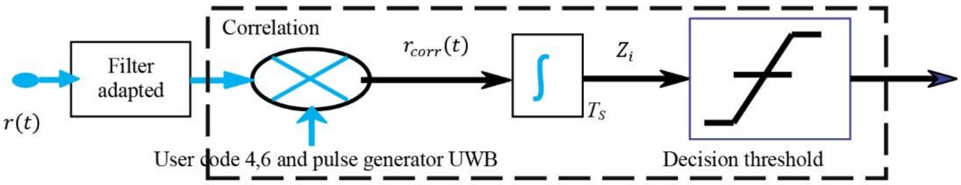

Fig. 10 Correlation Receiver

At the reception, it suffices to compare the correlator signal with the possibly generated POC sequence to recover the transmitted signal. Figure 11 illustrates the correlator output signal with its power spectral, the spectrum of the correlator output signal and recovered data.

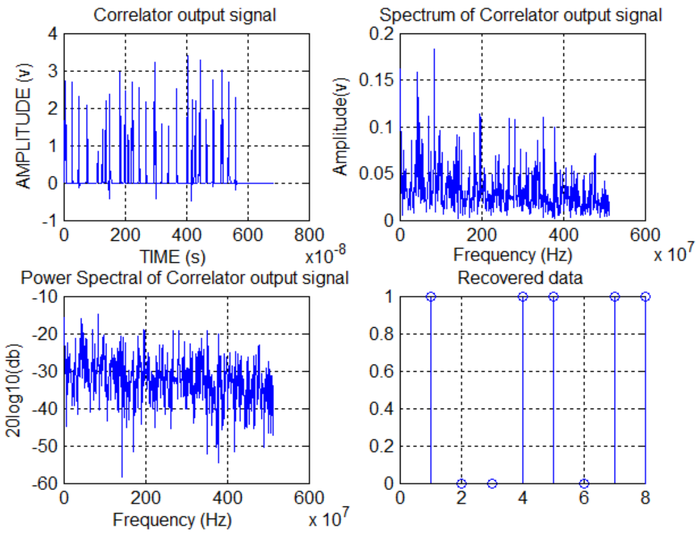

Fig. 11 The correlator output signal with its power spectral, the spectrum and the data recovered

The new DS-UWB system based on POC orthogonal unipolar codes without modulation was analyzed. Only the end-to-end DS-UWB transmission chain we are interested in. We removed the modulation part on our new approach. POC codes are preconfigured (calculated in advance). Our perspective is to realize our new DS-UWB approach based on components such as FPGA [30-31-32], SoC [33]… because nowadays it is easy to build a transceiver.

9. Conclusion

In this work, we suggested a new approach to a multi-users DS-CDMA-UWB system using a family of pseudo-orthogonal codes POC on an AWGN channel for a correlation receiver. Applying POC code offered a whole new and different approach than any other used before in literature with the ultra-broadband system. We have given a complete description of the DS-CDMA-UWB system, including the transmission and reception formalism. This work allowed us to present and analyze new emission reception approach based on DS-CDMA-UWB signal.

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