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Performance Study of UWB System at Various Signal Parameters

KEYWORDS
DS-UWB System, Monocycle Pulses, S-V Channel Model

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ABSTRACT *Direct-sequence Ultra Wide Band (DS-UWB) transmission is a strong competitor for the physical layer of high data-rate short-range UWB systems. In DS-UWB the Monocycle pulses have a big role in band spreading and performance evaluation. In this paper the impact of Monocycle pulse parameters as pulse width and time scaling factor are investigated. The requirements of the FCC spectral mask and DS-UWB intended bandwidth are considered. The values of time scaling factor and Pulse width (have been found in the range 56*10-9 to 125*10-9 and 0.3 ns to 0.8 ns, respectively. Optimum values are found that satisfy the indoor FCC spectral mask. The performance of DS-UWD system is showed due to the analyzed values of pulses.*

I. INTRODUCTION

Ultra wideband (UWB) is based on the transmission of short pulses on the order of nanoseconds. It has been emerged as a solution to provide low complexity, low cost, low power consumption, and high-data-rate wireless applications. Owing to the short duration of the pulses, the bandwidth of such transmissions is much larger than any conventional communication signal [1].

In February 2002, the Federal Communications Commission (FCC) allocated a spectrum from 3.1 GHz to 10.6 GHz for unlicensed indoor use of UWB devices. It imposed power mask of -41.3 dBm/MHz combined with huge bandwidth makes UWB technology became a viable solution for short-range indoor wireless network. The IEEE 802.15 Task Group 3a has been developing a physical layer standard for UWB technologies to support high data rates for Wireless Personal Area Networks (WPANs) [2].

The two merged technical proposals, referred to as Multi-Band Orthogonal Frequency Division Multiplexing (MBOFDM) and Direct-Sequence Ultra-Wideband (DS-UWB), are considered as strong candidates for the final high-speed WPAN standard [3].

In this work DS-UWB is considered, where each data symbol is spread by a specific spreading code to form a transmit chip sequence [3]. Single short pulse generation is the traditional and fundamental approach for generating UWB waveforms. By varying the pulse characteristics, the spectral energy density in the frequency domain can be controlled. Generally, there are three needs of interest when defining the spectral density properties to ensure a minimum interference with other systems and efficient channel utilization [4]:

- The intended bandwidth of the transmitted energy should be carefully defined and considered.
- The available energy should be confined within the specified UWB frequency band;
- Most of the generated energy should be concentrated around the interested band of frequencies.

The monocycle pulses are used for generating DS-UWB transmitted signal. The most important parameters in these pulses are the time scaling factor (ρ), which has a direct relation with the pulse width (τ), center frequency, and distribution of signal energy in the band. Therefore, determining optimum value for ρ is very important for the system design. As well as, there is no specific value for pulse width in the literatures. The reported values of τ are varied between 0.1ns to 1ns [5] [6] [7]. In most studies, the impact of τ and ρ are neglected. Different values of pulse width were used in literatures with no explanation. A pulse width of 0.17ns and 0.182ns have been used in [8] while in [9], the pulse width is 0.5ns for DS-UWB and TH-PAM UWB. Öztürk & Yılmaz [8] showed that the Power Spectral Density (PSD) of the first five derivatives of the Gauss pulse (p1, p2, p3, p4 and p5). It is Showed that the PSD of p4 and p5 Gauss pulses comply with the FCC UWB rule, while the study didn't investigate the role of relation between τ and ρ, and their effects on the PSD. Furthermore, the effect of time scaling factor (ρ) on the signal shape has not been investigated too.

Also, some studies didn't mention the role of the pulse parameters on spectrum shaping and performance evaluation [10].

In this paper, the parameters of Monocycle pulses; time scaling factor (ρ) and pulse width (τ) are investigated and proper values are found for both. The dependency between ρ, τ, and center frequency (f_c) are studied in order to satisfy an optimum case.

$$\sum_{k=1}^{M} h_{ik}h_{jk} = M \text{ , for i=j, and 0 other wise} \quad (1)$$

Where h_{ik} is row elements of the matrix and h_{jk} is column elements of the matrix.

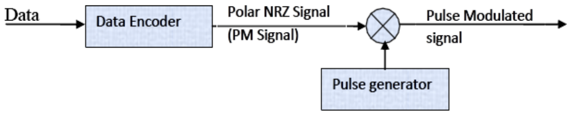

Fig.1 Phase Modulation & Pulse Modulation

II. Monocycle Pulses

The UWB pulse shape design's aim is to obtain a pulse waveform that complies with the FCC mask as closely as possible. UWB signal can be any of a variety of wideband signals, such as Gaussian, chirp, wavelet, or Hermite-based short duration pulses which are typically of nanosecond or picosecond order [15]. However, the good candidate shapes for UWB signal are the group of Gaussian pulses which are called Monocycle pulses. Monocycle pulses contain the Gaussian pulse and the other pulses that can be created by high-pass filtering a Gaussian pulse [16].The Gaussian pulse is defined as [4]:

$$y(t) = Ee^{-\left(\frac{t}{\rho}\right)^2} \qquad (2)$$

where$-\infty < t < \infty$,ρ is the time-scaling factor, E is a constant.

The monocycle, doublet, and fifth order Gaussian pulses are the first derivative, second derivative and fifth derivative of Gaussian pulse, respectively, as shown in Eq. 3, 4 & 5. The Monocycle pulses which are used in this work are shown in figure 2 with a pulse width of 0.45 ns.

$$y^{(1)}(t) = E_1 \frac{-2t}{\rho^2} e^{-(t/\rho)^2} \qquad (3)$$

$$y^{(2)}(t) = E_2 \frac{-2}{\rho^2}\left(1 - \frac{2t^2}{\rho^2}\right) e^{-(t/\rho)^2} \qquad (4)$$

$$y^{(5)}(t) = E_5\left[\frac{-120}{\rho^6}t + \frac{160}{\rho^8}t^3 - \frac{32}{\rho^{10}}\right] e^{-(t/\rho)^2} \qquad (5)$$

where $-\infty < t < \infty$, and E_i are constants.

III. DS-UWB Transmitted Signal

In DS-UWB, one bit duration T_b is divided into number of frames N_f each with duration T_f such that $T_b = N_f \cdot T_f$.During each frame an UWB pulse is transmitted. In Multiuser environment DS-UWB signal is represented as [27];

$$S^{(u)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} b_i^{(u)} c_i^{(u)} w(t - jT_f) \qquad (6)$$

Where u=1, 2, 3… U. $S^{(u)}$ is the signal of the u^{th} user, and $b_i^{(u)}$ is the u^{th} user bipolar data, where $b=2d-1$ and d denotes the unipolar data. For example, when d=0and 1, then b= -1 and 1 respectively. $c_i^{(u)}$is the PN code for u^{th} user which is equal ±1, and N_f is the number of frames or pulses per bit. $w(.)$ is the UWB pulse shape.

The ratio of the T_b/T_f which is N_f is called processing gain G_P, which is usually not large due to the high data rate transmission.

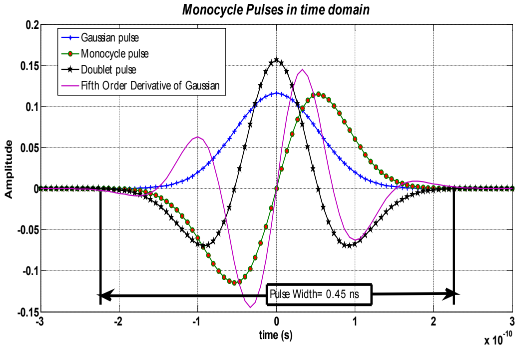

Fig.2 Four types of Monocycle Pulses

IV. Multipath Channel

The IEEE802.15.3a channel model [12] is used, which is depends on the S-V channel model that matches with the measured channel characteristics. In addition, the log-normal distribution was proposed to model the amplitude distribution.

The clustering Channel Impulse Response (CIR) can be expressed as follows [12]:

$$h(t) = \sum_{l=0}^{L} \sum_{k=0}^{K_l} a_{k,l}\,\delta(t - T_l - \tau_{k,l}) \qquad (7)$$

And the multipath gain coefficient of the k^{th} in the l^{th} cluster is :

$$a_{k,l} = p_{k,l}\zeta_l \beta_{k,l} \qquad (8)$$

Where

l is the number of clusters,

K_l denotes the number of Multipath components (MPCs) within the l^{th} cluster. T_l and , $\tau_{k,l}$ denote the delay of the l^{th} cluster and the delay of the k^{th}MPC relative to T_l,respectively.

The ζ_l is the fading associated with the l^{th} cluster. $\beta_{k,l}$ is the fading associated with the k^{th} ray within the l^{th} cluster, and $P_{k,l}$ is equiprobable ±1 to account for signal inversion due to reflections. The channel characteristics are listed in tabel 1.

Table1 IEEE802.15.3a channel specifications[12]

Parameters & characteristics	CM3	Unit
LOS-NLOS	NLOS	---
Distance	4-10	M
Λ	0.0667	1/ns
Γ	2.1	1/ns
Γ	14	---
Λ	7.9	---

V. DS-UWB Received Signal

The correlation receiver is selected [4]. The received signal r(t) consists of the desired signal plus signal produced by the multipath channel and white Gaussian noise n(t). The received signal is given as [17]:

$$r(t) = \int_0^{\infty} h(t)s(t - t_s)d\tau + n(t) \qquad (9)$$

s(t) is the DS-UWB transmitted signal for N users as defined in Eq.(6)

The locally template waveform has the same shape as the transmitted signal and is defined by:

$$p(t) = \sum_{j=0}^{N_f-1} w(t - jT_f) \qquad (10)$$

The correlation receiver output is defined as

$$C = \int_0^{T_b} r(t)p(t)dt \qquad (11)$$

The block diagram of the overall simulated DS-UWB system is shown in Fig.3.

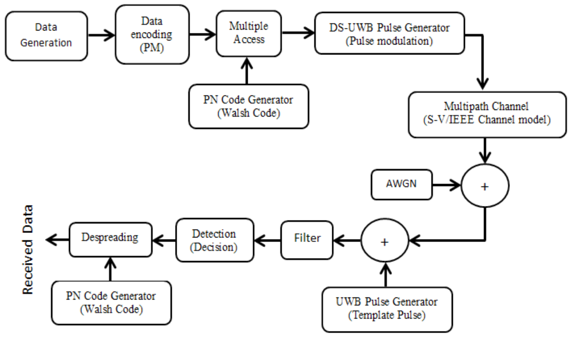

Fig.3 Block diagram of DS-UWB Transceiver.

VI. Results

Fig.4 shows the effect of changing the time scaling factor ρ on the pulse width τ. By increasing ρ, τ gets higher roughly linearly that lead to decrease signal bandwidth. Hereby ρ has an inverse relation with the signal bandwidth. Further, τ increases with the higher order of derivative of the pulse for constant ρ.

Fig.5 shows the inverse relation between ρ and the center frequency of the spectrum. Also, for constant ρ the center frequency shifts up with increasing the order of the pulses derivative. As shown, for $(\rho = 5*10^{-8})$ the center frequency of the monocycle, doublet, and fifth order derivative are 4.5GHz, 6.5GHz, and 10GHz respectively.

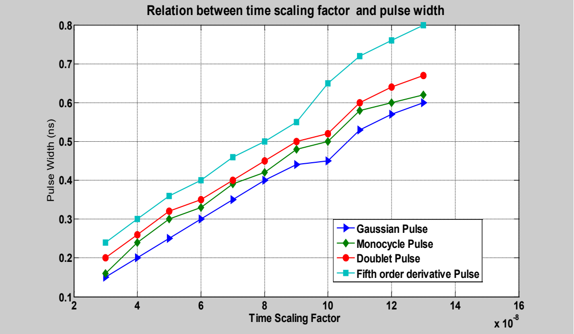

Fig.4 The time scaling factor versus the pulse width

The spectrum of the Gaussian pulse has some different behaviours compared to other three pulses. The maximum energy is always confined in the low frequencies for different values of ρ as shown in fig. 6. It is seen that decreasing ρ in Gaussian pulse deepens the spectrum nulls, which reduces the harmonic interferences with the neighboringsystems. To minimize the inter-pulse interference the proper spectrum shape for the Gaussian pulse is when the ρ and τ are $60*10^{-9}$ and 0.3ns respectively.

The values shown in Table 2 are optimal values for DS-UWB system with center frequency of 4 GHZ.

Regarding the energy and the center frequency of the band, the best choice would be the fifth order derivative Gaussian pulse as shown in Fig.7. However, if inter-pulse interference is mainly concerned the Gaussian pulse is the best choice since it has minimum τ compared to the three other pulses.

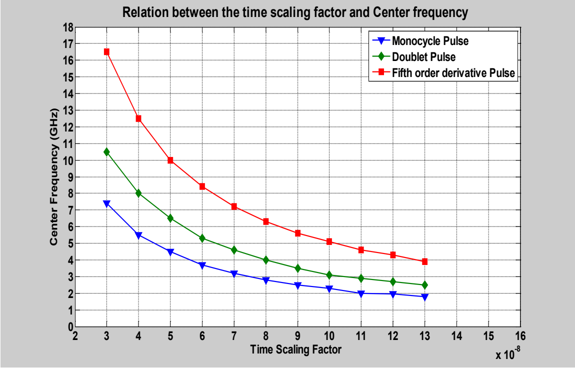

Fig.5 Relation between ρ and fc

Furthermore, the value of ρ affects all pulse amplitude except the Gaussian pulse. Therefore, the constants coefficients of the pulses E1, E2, and E3 must be adjusted for any new value of ρ. System parameters in table 3 are used to calculate the performance of DS-UWB over the AWGN & multipath channel.

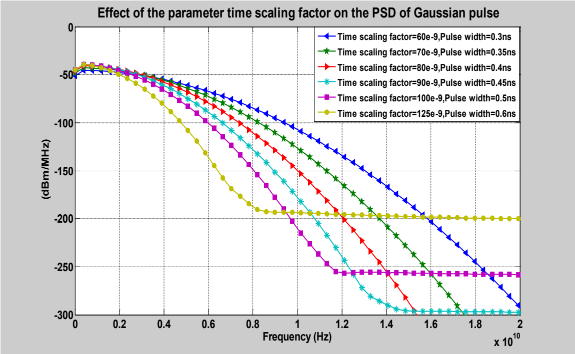

Fig.6 Effect of ρ on the PSD of Gaussian pulse

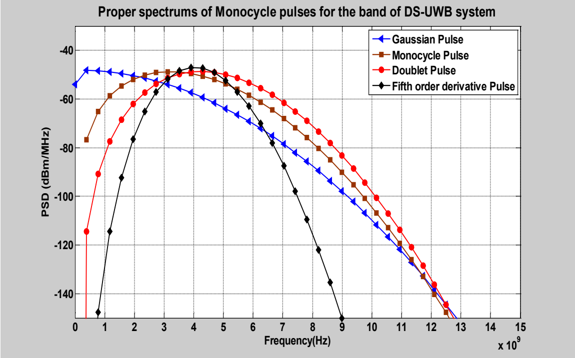

Fig.7 Modified spectrums for lower band of DS-UWB system for four pulses

Fig. 8 shows the performance of the DS-UWB for the four Monocycle pulses over AWGN channel. It is seen that the performance of the pulses are good in low SNR due to the ability of the correlation at the receiver side to maximize signal to noise ratio. The decision level has substantial effect on the system's performance due to low transmission power. The optimum decision level which is found is -200 dB. It is found that the performance is independent on the τ for the given pulse rate because there is no overlapping between adjacent pulses in all types.

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Table 2 Proposed values for ρ and τ of different pulses for lower band of DS-UWB

Pulse Type	ρ	Pulse width(ns)
Gaussian pulse	$60*10^{-9}$	0.3
Monocycle pulse	$56*10^{-9}$	0.32
Doublet pulse	$80*10^{-9}$	0.45
Fifth order derivative of Gaussian pulse	$125*10^{-9}$	0.8

The results also demonstrate that the type of the pulses has no significant effect on the system performance in AWGN channel. The role of the pulse type on the performance appears clearly in multipath channel as shown in Fig.9 which is the performance study at CM3 in multipath channel.

Table (3) DS-UWB system parameters

parameters	Values and types
Channel scenario	AWGN /Multipath(CM1,3)
Number users	4
Code length	4 chips (Walsh code)
Data rate	100Mbps
Power transmit	-9.9 dBm
Pulse	Gaussian, monocycle, doublet, and fifth order derivative pulses

Over CM3 multipath channel scenario the results show that the Gaussian pulse has 5 dB gains over the fifth order derivative pulse as shown in fig. 9

Further, the results demonstrate that the Gaussian pulse has better performance and fifth order derivative pulse is the worst. This could be explained as results of pulse width effects on inter pulse interference (IPI): the higher τ the larger is the IPI and hence higher BER.

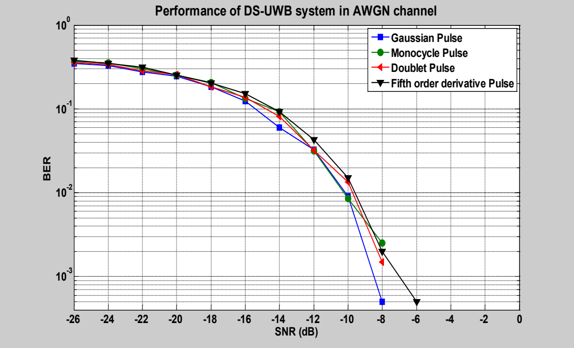

Fig.8 Performance of DS-UWB over AWGN channel.

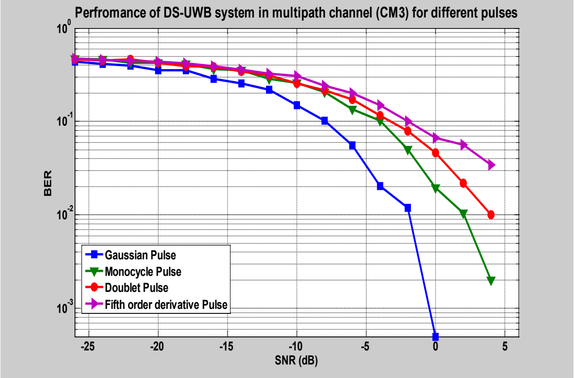

Fig.9 Performance of DS-UWB over multipath channel CM3

VII. Conclusions

In this work the Monocycle pulse parameters are investigated in the DS-UWB pulse shaping and performance evaluation. Proper values for time scaling factor and pulse width are suggested for the Gaussian pulse, monocycle pulse, doublet pulse, and fifth derivative of Gaussian pulse. The PSD of each pulse is investigated due to the suggested values of time scaling factor and pulse width under the FCC regulations for indoor emission. The obtained results of PSD are optimum because most the energy of the signal is inside the intended band. Also, the first nulls of the spectrums are deep too much which is avoid harmonic interference to the near bands.

Also, the performance of DS-UWB is evaluated over the AWGN and multipath channel using suggested values of τ and ρ. The performance of the system over AWGN are similar for all four types of pulses, while in this case the decision level in the signal detection is important due to sensitive and low level power.

The performance over multipath channel is evaluated, and the performance of system is better for Gaussian pulse compared to the other three pulses because it has minimum pulse width. However, the fifth derivative of Gaussian pulse is the worst one because the pulse width of the pulse is wide.

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