

Reduction of UWB interference at NB systems based on a generalized pulse waveform

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Abstract: This work proposes a pulse waveform to reduce UWB interference at narrowband (NB) systems. The pulse waveform is represented as a generalized form of Gaussian pulse family which can be used in ultra wideband (UWB) impulse radio systems. It is obtained by combining two higher order derivatives of Gaussian pulses. The pulse waveform reduces UWB interference power at NB systems by introducing spectral notches at the center frequency of NB systems.

Keywords: ultra wideband radio, generalized pulse waveform, interference and coexistence of UWB systems

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Minimization of interference power of ultra wideband (UWB) radio signal is one of the primary concerns for heterogeneous radio environment where UWB radio system has to coexist with other narrowband (NB) systems. In general, UWB radio is proposed for a large band of unlicensed spectrum. Different regulatory boards have defined UWB spectral mask in different ways [1]. For example, FCC has approved a large frequency band (3.1–10.6 GHz) with maximum effective isotropic radiated power (EIRP) of -41.3 dBm/MHz. As a result, UWB degrades the performance of the systems which operate in the same or nearby frequency bands. A typical example of NB system is 802.11a down-link receiver. Close proximity of UWB transmitter and 802.11a down-link receiver degrades the performance of 802.11a down-link receiver [2]. The free-verse type of soft spectrum adaption (SSA) approach contributes a significant work to avoid UWB interference at NB systems [3]. The performance of such NB systems can be improved by using some interference models [4]. However, UWB system has to lose data rate by giving long pulse repetition intervals [5].

Extensive studies have shown that the UWB interference depends on pulses, width of pulses, pulse repetition frequency, center frequency of UWB systems, power spectral density and modulation schemes of UWB systems [6]. The pulse waveforms of UWB systems are an important design consideration which offer better coexistence with other radio communication systems. Different types of pulses are used in UWB systems for different purposes [7]. For example, the Gaussian pulse family, consisting of Gaussian pulse, Gaussian monopulse, Gaussian doublet, doublet and dualcycle can be used for UWB impulse radio systems [7, 8]. However, these pulse waveforms do not satisfy the allowed spectral mask without carrier signals.

This letter discusses a mathematical model for UWB interference from the perspective of pulse waveform. It also describes a combination of higher order derivative of Gaussian pulses, which can be used to represent the gen-

eralized pulse waveform of Gaussian pulse family [3, 7]. This generalized pulse satisfies the spectral mask without using the carrier signals (although it is not necessary condition), which has higher robustness in multipath interference [5]. Moreover, this work shows how this pulse can reduce UWB interference on NB systems by creating null (spectral notch) point at the center frequency of NB systems. It is demonstrated by analyzing the UWB interference power on 802.11a systems. The simulation results show that the performance of 802.11a device can be improved in the presence of interfering UWB device when the UWB device uses the proposed pulse waveform. However, this performance improvement is traded off with allowable data rate of the UWB device.

2 Generalized Pulse Waveform of Gaussian Pulse Family for UWB Systems

The generalized pulse waveform is represented as a combination of two higher order derivatives of Gaussian pulses and can be expressed as

$$p(t) = ay^{(n-1)}(t) + by^{(n-1)}(t - t_w) \quad (1)$$

where $a, b \in [-1, 1]$, n is any positive integer, the superscript indicates order of the derivative and t_w represents the time gap between two pulses. The simple Gaussian pulse $y(t)$ is given by [9]

$$y(t) = \frac{A}{\sqrt{2\pi}\sigma} \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (2)$$

where A denotes the amplitude and σ is the time scaling parameter which decides width of the pulse waveform. Assuming constant aperture transmitter antenna with ideal characteristics, transmitted pulse waveform can be represent as follows

$$p^{(1)}(t) = ay^{(n)}(t) + by^{(n)}(t - t_w) \quad (3)$$

where $y^{(n)}$ is the n^{th} order derivative of Eq. (2) and can be written as

$$y^{(n)}(t) = -\frac{n-1}{\sigma^2}y^{(n-1)}(t) - \frac{t}{\sigma^2}y^{(n-1)}(t). \quad (4)$$

From Eq. (1), it is possible to obtain the expressions of conventional Gaussian pulse family by changing the parameters a , b , and n . Table I shows the various pulse waveforms with different values of parameters. It indicates that the proposed pulse waveforms behave like a generalized pulse waveform.

3 Analysis in Frequency Domain

The frequency domain (FD) characteristics of the proposed pulse waveforms are analyzed extensively to find the suitability of using those in the available bandwidth. The Fourier transform (FT) of Eq. (3) can be expressed as

$$P(f) = aY_n(f) + bY_n(f) \exp(-j2\pi ft_w). \quad (5)$$

Table I. Parameters for different pulse waveforms

Parameters			Types of pulse waveforms
n	a	b	
1	1	0	Gaussian pulse
2	1	0	Gaussian monopulse
3	1	0	Gaussian doublet
3	1	1	Dualcycle
1	1	−1	Doublet
> 3	1	0	Higher order Gaussian pulse
≥ 3	±1	±1	Higher order Doublet

where $P(f)$ is the FT of Eq. (3). The energy spectral density (ESD) of the pulse waveform in radio channel can be expressed as

$$E(f) = A^2(2\pi f)^{2n} \exp(-(2\pi f\sigma)^2) ((a+b)^2 \cos^2(\pi f t_w) + (a-b)^2 \sin^2(\pi f t_w)) \quad (6)$$

The transmitted power $P_{tu}(f)$ for UWB devices defined as follows:

$$\begin{aligned} P_{tu}(f) &\cong A_{max} \frac{|P(f)|^2}{|P(f_M)|^2} \\ &= A_{max} \left(\frac{f}{f_M}\right)^{2n} \exp\left(-(2\pi\sigma(f-f_M))^2\right) \psi(f) \end{aligned} \quad (7)$$

where A_{max} is maximum effective isotropic radiation power spectral density (EIRPSD) [9], f_M is the frequency which maximizes $|P(f)|$ and $\psi(f)$ can be expressed as

$$\psi(f) = \frac{(a+b)^2 \cos^2(\pi f t_w) + (a-b)^2 \sin^2(\pi f t_w)}{(a+b)^2 \cos^2(\pi f_M t_w) + (a-b)^2 \sin^2(\pi f_M t_w)} \quad (8)$$

In order to satisfy the spectral mask, fix the upper frequency f to 10.6 GHz (FCC corner point at −10 dB for indoor systems). It is done by using the bisection method and then by obtaining the value of σ (shown in Fig. 2(b)) for each value of n [9]. The value of n is determined based on the spectral mask. Since increase in n , increases the peak power position of ESD, this generalized pulse waveform satisfies the spectral mask without multiplying the carrier signals for $n \geq 5$, as shown in Fig. 1.

For unit power and unit values of a and b including dualcycle [8] Eq. (6) gives the nulls in ESD at the points $f = (k/t_w)$ for $k = 1, 2, \dots, M$, as shown in Fig. 1. These points can be shifted by changing the value of t_w and one null point can be placed at the center frequency of 802.11a systems for $t_w = 0.189$ ns. Values of a and b are chosen by trial and error method to get optimal notch. For unit values of a and b , these null spectral points are created below −70 dB power level and in normalized form below −35 dB power level (deep nulls) as shown in Fig. 1. For fractional values of a and b , the spectral notch points can be created at power level greater than −35 dB, which is approximately the same as normalized noise power level. Due to

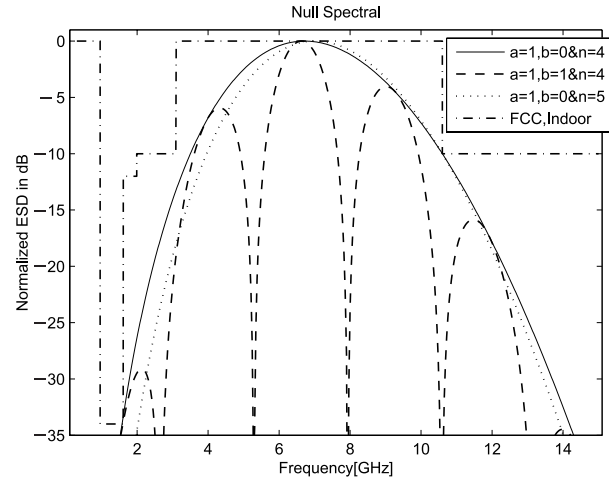


Fig. 1. Normalized ESD of 4th and 5th order derivatives of the proposed pulse waveform for different values of a , b , n , and $t_w = 0.189$ ns.

the presence of noise, fractional values of a and b can also reduce the same amount of UWB interference power at NB systems without creating deep nulls. But comparing with unit values it gives relatively smaller spectral spikes in the PSD which gives lower UWB interference [6]. It indicates that the proposed pulse waveforms can be used adaptively in the UWB systems from different perspective. The free-verse SSA approach [3] can view as a particular case of this approach.

4 UWB Interference Power at 802.11a Systems

Performance of a NB system is analyzed in the presence of a single UWB device. This work considers 802.11a as a NB system and UWB device uses the generalized pulse waveform. By using Eq. (7), UWB interference power received by 802.11a down-link receiver within the band $f_{NL} - f_{NH}$ can be defined as

$$\tilde{I}_{UWB} = 10 \log_{10} \left(\frac{G_{tu} G_{ro} c^2}{(4\pi d_{uu})^2} \left(\frac{d_{uu}}{d_{uo}} \right)^{n_u} \int_{f_{NL}}^{f_{NH}} \frac{P_{tu}(f)}{f^2} df \right) \quad (9)$$

where G_{tu} is the UWB transmitter gain, G_{ro} represents gains of 802.11a transceiver, d_{uu} is the UWB transmitter reference distance, d_{uo} is the UWB transmitter and 802.11a receiver distance, n_u is the path loss factor of UWB system, f_{NL} and f_{NH} are the lower and upper band-edges of the 802.11a system. Assuming all other system-linked parameters are constant (say B), and remaining pulse parameters is in $f_1(a, b, n, t_w)$ then the Eq. (9) analytically can be written as

$$\tilde{I}_{UWB} = 10 \log_{10} (B f_1(a, b, n, t_w)) \quad (10)$$

The interference power depends on a and b for creating null point, n for satisfying the spectral mask and t_w for placing null point between f_{NL} and f_{NH} frequency band.

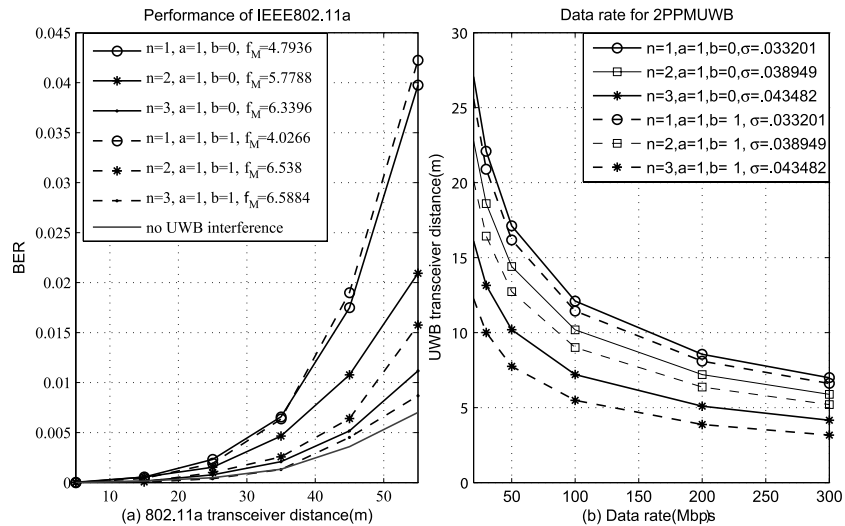


Fig. 2. (a) Performance of 802.11a receiver at different 802.11a transceiver distances. (b) Data rate for UWB system at different UWB transceiver distance, σ is time scaling parameter).

5 Results and Discussions

The performance of 802.11a down-link receiver is analyzed in the presence of a DS-UWB device with the generalized pulse waveform through comprehensive computer simulation studies [6, 7]. The 802.11a device assumes standard system parameters and the studies are conducted in a fading Rayleigh channel for 802.11a device and a Multipath-fading model (CM1) proposed by IEEE802.15.3a study group for UWB systems [11]. The simulation environment for 802.11a system assumes a constant signal to noise ratio of 10 dB.

As seen in the analysis, the proposed pulse waveform has four parameters, a, b, n, t_w , for spectral planning on 802.11a receiver and to satisfy the spectral mask. Computer simulation studies show that this generalized pulse waveform can be effectively used to reduce the UWB interference on 802.11a down-link receiver. Fig. 2(a) shows the performance of the 802.11a device for the proposed pulse waveform for different values of a, b , and n . Peak power point, f_M (shown in Fig. 2(b)), is shifted from the center frequency of 802.11a systems to higher frequency with increase of n [9]. Therefore, performance of 802.11a receiver is improved with the increase of n . From Fig. 2(a), it is evident that the system performance of 802.11a is not affected by the presence of interfering UWB device for some higher values of n . The generalized pulse waveform for $a = 1$ and $b = -1$ gives better performance compared to the Gaussian derivatives, $a = 1$ and $b = 0$, for the same values of n . Fig. 2(b) shows that the data rate of UWB system is reduced with the increase of n because of lower bandwidth of the pulse waveform.

The above discussions lead to the necessity for defining a trade off between interference and data rate for this generalized pulse waveform. Value of n can be decided depending on the system requirements. For less UWB interference power, a larger value of n should be chosen and for high data rate, a smaller

value of n should be chosen, but it should not be less than 5 [9]. For unit values of a and b , these pulse waveforms are efficient for reducing the UWB interference at NB systems. In addition, higher order derivatives of Gaussian pulse do not require carrier signal to step the signal up from the baseband to a frequency band that is well suited for transmission is a distinguishing characteristic of the present method. This technique is efficient, since it reduces the required expensive radio frequency (RF) components in both transmitter and receiver.