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Optimized Pulse Shaping for Efficient UWB Communication

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ABSTRACT

Federal Communications Commission (FCC) guidelines on UWB spectral mask, suitable design of pulses is required to minimize the interference on other existing narrowband services due to UWB systems and vice versa. In this work, we attempt a pulse shaping method, considering the channel as a raised-cosine filter and futher optimized using genetic algorithm (GA). The pulses designed are not only meet the constraints of FCC for UWB, but also spectrally efficient. Pulses generated have a very short duration to reduce multipath interference and are mutually orthogonal. Average bit error rate (ABER) performance of time-hopping binary phase shift keying (TH-BPSK) UWB systems has been evaluated in presence of multiple access interference (MAI) and additive white Gaussian noise (AWGN) for variety of different scenarios, such as, number of users, number of slots per frame and modulation types.

Keywords : Ultra Wide Band, Impulse Radio, Pulse Shaping, GA, UWB Multiuser, Average Bit Error Rate.

I. INTRODUCTION

UWB technology has gained popularity worldwide due to its promise of providing very high bit rates in indoor wireless multimedia transmission with low complexity and low power consumption. The FCC has defined UWB communication as, any wireless scheme that occupies a fractional bandwidth greater than 0.2 or have an absolute bandwidth (-10 dB band-width) more than 500 MHz. In 2002 the FCC has introduced restrictions that the UWB systems must operate with their - 10(-20) dB bandwidth of the spectrum (the bandwidth measured between the 10 (20) dB down points of the spectrum) for indoor (outdoor) communications, exciting a maximum power spectral density (PSD) of -41.3 dBm/MHz in the range of 3.1 GHz to 10.6 GHz (FCC Document 00-163,2002). This new constraint of FCC motivates, that make an investigation into pulse shaping for UWB communication systems. In UWB systems, a train of very narrow pulses of nanosecond or 100s of picosecond is used for data transmission, whose PSD covers the entire available frequency band 3.1-10.6 GHz, for which it is also called impulse-radio(IR) system. UWB system shares the frequency band, where other co-exist narrow-band systems like GPS, PCS, Bluetooth, Wireless LAN (IEEE 802.11a) are already operating. In order to avoid interference to, and from, these co-existing narrow-band services, multi-band or-thogonal frequency division multiplexing (MB-OFDM) can be approached (Zhang, D., Fan, P. and Z. Cao, 2004). But in case of IR-UWB spectral notching is another method that can be used to limit the interference by keeping the PSD of the UWB pulse very low at the NBI occurrence frequencies (Wang, Y., Dong, X. and Fair, J., 2007; Noorodin K .S., Saeed, H., Hamidi, M. and Omali, M. G., 2010).

The PSD of commonly used Gaussian pulse violates the FCC constraints for UWB. In order to meet the FCC requirements, it requires frequency shift, which in turn increases the circuit complexity. Several pulse shaping methods include the combination of Gaussian pulse (Liu, X. , Premkumar, A. and Madhukumar, A. ,2008), modified Hermite pulse (Fan, K., Zhang, S. and Liu, X., 2008; Wenke, L., Hongsheng, S. and Gaoming, L. ,2009) and Optimal pulses (Luo,X., Yang,L. and Giannakis, G. ,2003; Rezaii, M.,2010) have been proposed for UWB communication whose spectrum fits closely to the FCC UWB spectral mask. M. Rezaii (2010) a digital FIR filter approach is proposed for synthesizing UWB pulses that satisfy the spectral mask. B. Parr *et.al* proposed a method using prolate spheroidal wave function (PSWF), which generates a set of orthogonal spectrally compliant pulses. In this work, we used the method proposed in (Parr, B., Cho, B., Wallace, K. and Ding, Z., 2003) and treating the channel as a raised-cosine filter a set of orthogonal pulses are generated. Utilizing this pulse shape, ABER performance of TH-BPSK system is evaluated.

The remaining content of this paper is organized as follows. In Section 2, we present the pulse shaping method, which generates a set of spectrally efficient and orthogonal pulses. The ABER performance evaluation is discussed in Section 3. In Section 4 simulation results are presented. Finally, the conclusions drawn from this work are presented in Section 5.

II. UWB PULSE SHAPING

For any designed pulse, we require its power to concentrate in the 3.1-10.6 GHz frequency band, for an efficient spectrum utilization. Specifically we wish to design a pulse $\Psi(t)$ that is time limited to T_m seconds while exhibiting minimal distortion as it pass through the filter with impulse response $h(t)$. $H(f)$ is a desired frequency mask, it's corresponding impulse response is $h(t)$. The output of the filter is the convolution of $\Psi(t)$ and $h(t)$, i.e.

$$\lambda\Psi(t) = \int_{-\infty}^{\infty}\psi(\tau)h(t-\tau)d\tau = \int_{-T_m/2}^{T_m/2}\psi(\tau)h(t-\tau)d\tau$$

Where λ is the attenuation factor. A discretization of the above equation by sampling N times in pulse duration T_m can be expressed as

$$\lambda\Psi(n) = \sum_{m=-N/2}^{N/2}\psi[m]h[n-m], n = -\frac{N}{2}.......\frac{N}{2}$$

where n and m take on integer values only and can be written in matrix form as

$$\lambda\Psi = H\Psi$$

where

$$H = \begin{pmatrix} h[0] & h[-1] & \cdots & h[-N] \\ h[1] & h[0] & \cdots & h[-N+1] \\ \vdots & \vdots & \cdots & \vdots \\ h\left[\frac{N}{2}\right] & h\left[\frac{N}{2}-1\right] & \cdots & h\left[-\frac{N}{2}\right] \\ \vdots & \vdots & \cdots & \vdots \\ h[N] & h[N-1] & \cdots & h[0] \end{pmatrix}$$

and

$$\Psi = \begin{pmatrix} \psi\left[-\frac{N}{2}\right] \\ \psi\left[-\frac{N}{2}+1\right] \\ \vdots \\ \psi[0] \\ \vdots \\ \psi\left[\frac{N}{2}\right] \end{pmatrix}$$

From the above equation, it is clear that Ψ is an eigenvector of H.

So every solution of $\lambda\Psi(t)$ can be found by means of the eigenvalue decomposition of $\lambda\psi$. The greater the eigenvalue, the better the power spectrum fits inside the desired frequency mask $H(f)$. Therefore, only the eigenvectors corresponding to large eigenvalues should be taken as pulse design. For the case when, $h[k]=h[-k]$ and is real for all k, then H is a Hermitian matrix. The eigenvalues of a Hermitian matrix are real, and the corresponding eigenvectors of distinct eigenvalues are orthogonal. So a set of orthogonal pulses can be generated. These multiple orthogonal pulses provides PSM for the multiple user access without interference.

B. Parr *et.al.* have taken the filter $H(f)$ as a ideal band-pass filter having a pass band between 3.1-10.6 GHz (Parr, B., Cho, B., Wallace, K. and Ding, Z., 2003). But instead of considering the channel as an ideal band-pass filter, we consider it as a raised-cosine pulse shaping filter, which is more practical. The impulse response and transfer function of the raised-cosine filter are expressed as:

$$h_{R.C}(t)=\sin c\left(\frac{\pi t}{T_m}\right)\frac{\cos\left(\frac{\pi\alpha t}{T_m}\right)}{1-\frac{4\alpha^2t^2}{T_m{}^2}},$$

$$H_{R.C}(f)=\begin{cases} T_m, & |f|\le f_l \\ \frac{T_m}{2}\left[1+\cos\frac{\pi T_m}{\alpha}\left(|f|-f_l\right)\right], & f_l<|f|\le f_h \\ 0, & f_h<|f| \end{cases}$$

where $f_l=\frac{1-\alpha}{2T_m}$, $f_h=\frac{1+\alpha}{2T_m}$ and α is the excess bandwidth parameter, it takes values from 0 to 1.

With $\alpha=0$, the raised cosine filter reduces to the classical Nyquist filter with zero excess bandwidth outside $\frac{1}{T_m}$. But in order to keep the power spectral density of the pulse zero outside the band 3.1- 10.6 GHz for different value of α, the corresponding impulse response of the raised cosine filter will be

$$h_{R.C}(t)=W\sin c(Wt)\frac{\cos(\pi\alpha Wt)}{1-(2\alpha Wt)^2}e^{j2\pi(6.8\times10^9)t},$$

Where $W=\frac{7.5\times10^9}{1+\alpha}$. The eigenvectors $(\psi_1(t),\psi_2(t))$ corresponding to two highest eigenvalues, by the genetic algorithm based optimization and are plotted in Figure 1 for $\alpha=0$ & $\alpha=0.5$ with N = 64 and $T_m=1n\sec$. The corresponding power spectra are shown in Figure 2, which shows that majority of their power is concentrated in the 3.1-10.6 GHz frequency band. Autocorrelation of $\psi_1(t)$ and the cross-correlation between $\psi_1(t)$ and $\psi_2(t)$ are shown in Figure 3. It shows that at the sampling instant autocorrelation of $\psi_1(t)$ has higher value, where as cross-correlation between $\psi_1(t)$ and $\psi_2(t)$ is zero. It is advantageous in determining multipath energy because of the higher autocorrelation value at the sampling instant. Also the multiuser interference is reduced due to zero crosscorrelation at the sampling instant.

Optimization Using GA

A genetic algorithm works like the genetic evolution process and survival for fittest procedure. The fitness function can be formulated as

O=max [$\square\,\psi_i(t)$]

The optimal eigen values are used in the model for pulse shaping and to reduce the error simultaneously.

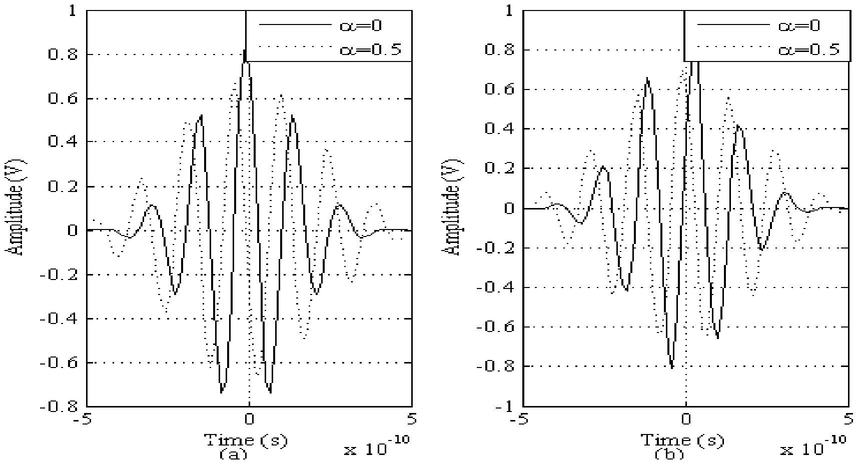

Figure 1. Pulses (a) $\psi_1(t)$ and (b) $\psi_2(t)$ obtained from pulse design method.

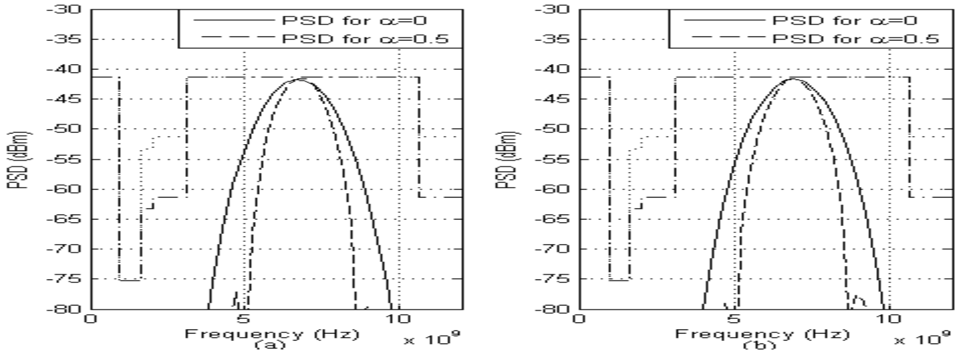

Figure 2. PSD of pulse shapes (a) $\psi_1(t)$ and (b) $\psi_2(t)$

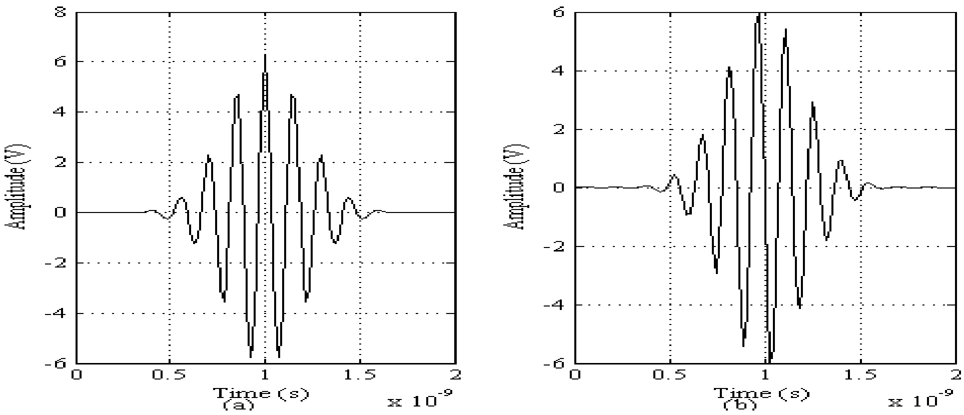

Figure 3. (a) Autocorrélation of $\psi_1(t)$ and (b) Cross-corrélation between $\psi_1(t)$ and $\psi_2(t)$

III. PERFORMANCE EVALUATION

In this section we analyzed the ABER performance for TH-BPSK UWB system, utilizing the designed pulse. The transmitted signal corresponding to the i^{th} data bit of the k^{th} user using TH-BPSK is given by (Hu, B. and Beaulieu, N. C., 2004).

$$s_{bpsk}^{(k)}(t,i) = \sqrt{\frac{E_b}{N_h}} \sum_{j=iN_h}^{(i+1)N_h-1} (-1)^{d_i^{(k)}} p\left(t - jT_f - c_j^{(k)} T_c\right),$$

Where

- $p(t)$ is the reference pulse with pulse width T_m, defined in $-T_m/2 < t \le T_m/2$ and normalized so that $\int_{-\infty}^{\infty} p^2(t)dt = 1$,
- E_b is the bit energy common to all signals,
- N_h is the number of pulses required to transmit a single data bit, called the length of the repetition code,
- T_f is the time duration of a frame and thus the bit duration $T_b = N_s T_f$,
- $\left\{c_j^{(k)}\right\}$ represents the pseudorandom TH code for k^{th} source whose elements take an integer value in the range $0 \le c_j^{(k)} < N_s$ where N_s is the number of hopes,
- T_c is the chip width and satisfies $N_s T_c \le T_f$,
- $d_i^{(k)} \in \{0,1\}$ represents the i^{th} binary data bit transmitted by the k^{th} source and different bits are assumed to be equiprobable,

Assuming N_u cochannel users are transmitting asynchronously in an AWGN channel, the received signal at the receiver input is given as

$$r(t) = \sum_{k=1}^{N_u} A_k s^{(k)}(t - \tau_k) + n(t),$$

Where

- $n(t)$ is the Gaussian noise (AWGN) with two-sided PSD $N_0/2$,
- $\{A_k\}_{k=1}^{N_u}$ is the channel attenuation suffered by the k^{th} user signal,
- $\{T_k\}_{k=1}^{N_u}$ is the time shift which represents user asynchronism.

The received signal can be viewed as the desired user's signal plus interference and noise. Considering $s^{(1)}(t)$ to be the desired signal, the interference signal is due to $(N_u - 1)$ users.

$$\tau(t) = A_1 s^{(1)}(t - \tau_1) + \sum_{k=2}^{N_u} A_k s^{(k)}(t - \tau_k) + n(t)$$

A correlator receiver is used for the demodulation. In this demodulation method, correlator multiplies the received signal by a template pulse shape and integrates the output over the duration of the pulse. The output of the correlator is a measure of the relative time position and polarity of the received pulse and the template pulse. The output of the correlator is passed to sample and hold circuit, which produces the decision variable $Z(iT_f)$, which is the energy collected over N_h frames and is given as

$$Z(iT_f) = \sum_{j=1}^{N_h} y(jT_f),$$

Where $y(jT_f)$ is the output of the ideal correlator receiver for j^{th} frame and can be represented as

$$y(jT_f) = \int_{jT_f + c_j^{(1)}T_c + \tau_1}^{jT_f + c_j^{(1)}T_c + \tau_1 + T_c} r(t)\upsilon\left(t - jT_f - c_j^{(1)}T_c - \tau_1\right)dt$$
$$= y_s(jT_f) + y_{\text{int}}(jT_f) + n,$$

where $\upsilon(t)$ is the template pulse used for correlation for BPSK it is same as the pulse $p(t)$. Note that $p(t)$ is the transmitted pulse shape $\psi_1(t)$. $y_s(jT_f)$ is output of the matched filter without any noise and interference signal, $y_{\text{int}}(jT_f)$ is the total MAI due to all $(N_u - 1)$ interfering signals.

The decision block takes the decision on received symbol using the decision rule defined below. Where $\hat{d}_i^{(1)}$ is the estimate of the i^{th} information symbol sent by user 1 $d_i^{(1)}$.

$$\hat{d}_i^{(1)} = \begin{cases} 0, & Z(iT_f) > 0 \\ 1, & Z(iT_f) < 0 \end{cases}$$

Then the probability of error is

$$p(e) = \frac{1}{2} p\left(Z_n(iT_f) < -Z_s(iT_f) \middle| d_i^{(1)} = 0\right)$$

$$+\frac{1}{2}p\left(Z_n(iT_f) > -Z_s(iT_f)\middle| d_i^{(1)} = 1\right).$$

IV. SIMULATION RESULTS AND DISCUSSIONS

We generate a random message using MATLAB, which is used to modulate the pulse shape $\psi_1(t)$. Then a randomly generated $N_u - 1$ interfering pulses of equal amplitude randomly started over the frame duration is added with the desired signal along with a AWGN of proper variance. This received mixed signal is used at the correlator receiver for detection. This process has repeated for various combinations of SNR values, number of users, number of slots per frame and modulation types. The parameters used for performance evaluation are listed in Table I. For a variety of different scenarios, the ABER results are given in Figure 6 and Figure 7.

From the ABER plots it is observed that, as N_u increases, ABER also increases and the rate of increase of ABER slows down for higher values of N_u. In other words, increasing the number of users in the system has a greater impact on the system with a smaller N_u.

It is observed that, ABER is decreasing with increasing number of slots N_s. So this increases the range of SNR values unaffected by multiuser interference i.e. multiuser ABER gets very close to the single-user ABER for higher SNR values. Looking into the relation between the SNR and multiuser interference, when SNR is low, the ABER curves are packed closely together; it indicates that, multiuser interference has little effect for lower SNR values. But with increase of SNR the impact of AWGN on system performance decreases, and multiuser interference becomes more dominant on system performance. The multiuser ABER reaches a floor which is determined by the number of users and the number of slots per frame in the system. So N_s should be carefully selected to provide an acceptable ABER for the maximum number of users in the system.

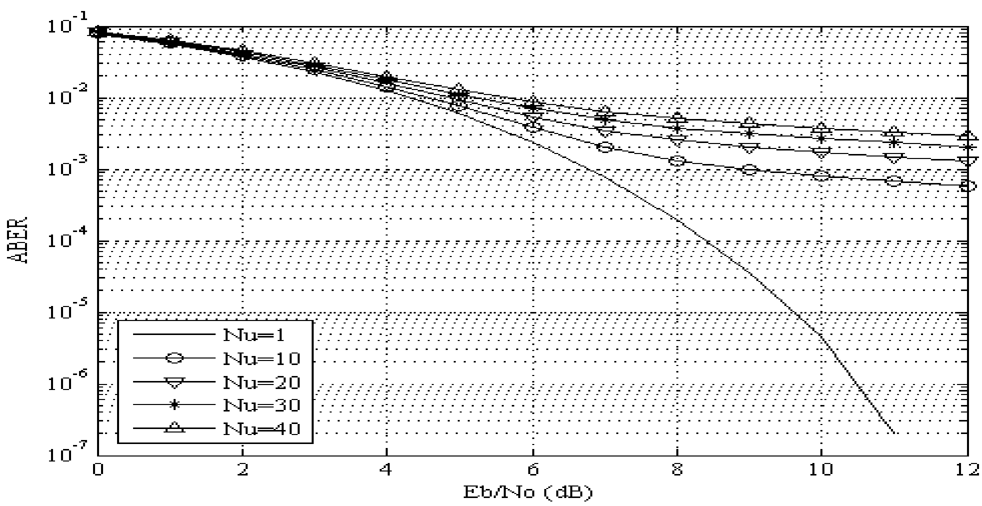

Figure 4. ABER for TH-BPSK UWB system with $N_s = 100$

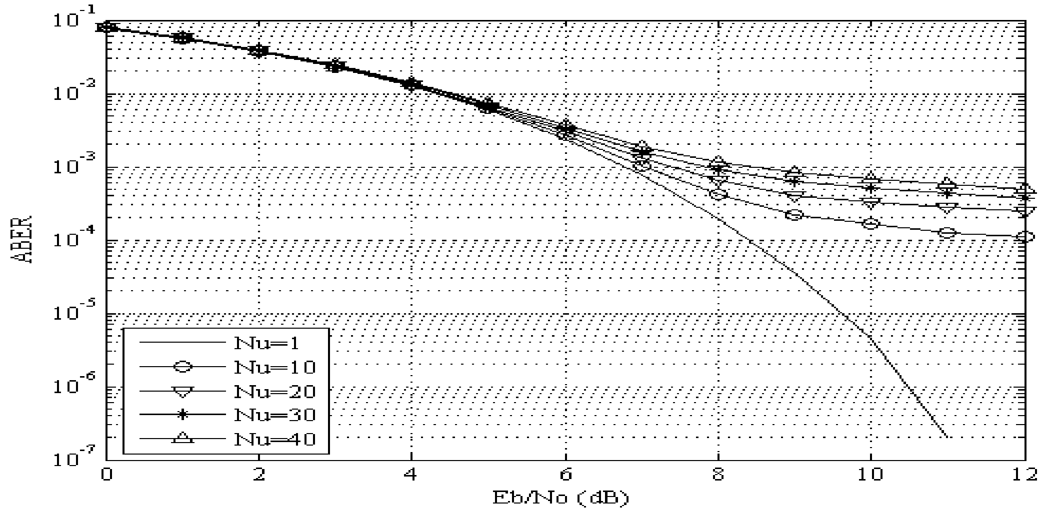

Figure 5. ABER for TH-BPSK UWB system with $N_s = 500$

V. CONCLUSION

In this work we presented a pulse shaping method that generate a set of orthogonal pulses for UWB systems. The power spectra of these pulses shows that the majority of their power is concentrated in the 3.1-10.6 GHz frequency band. The pulse designed by this method has the following advantages over the commonly used Gaussian monocycle. First, the pulses designed are orthogonal and can be used in multiple access schemes. Secondly, the algorithm provides the flexibility of designing pulses to fit frequency masks with multiple pass bands, so that the coexisting narrow band interferences can be avoided.

We presented the performance analysis in-terms of ABER for TH-BPSK multiple access systems, based on different pulse shapes and number of users. It has been observed that the MAI can be reduced by increasing the number of slots per frame at the cost of reduced data rate. This performance analysis method can be extended to any other pulse shapes.

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