ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

UWB Impulse Radio Waveform Shaping Techniques for Narrow-Band Interference Rejection

Rasha El-Khamy#, Shawky Shaaban*, Ibrahim Ghaleb*, Hassan Nadir Kheirallah*
#Alexandria Higher Institute of Engineering and Technology, Alexandria, Egypt
* Dept. of Electrical Engineering, Faculty of Engineering, Alexandria Univ., Alexandria 21544, Egypt

Abstract:-In ultra-wideband (UWB) impulse radio (IR) technology, it is important that the pulse shape be adjusted such that the power spectral characteristics not only satisfy the standard limits, but also be characterized by deep nulls at the locations of existing narrowband primary users. Cognitive Radio Technology (CR) is presented as a viable solution for UWB systems for narrow- band interference suppression. In this paper, we present and compare several ultra-wideband (UWB) impulse radio waveform shaping techniques for narrow-band interference (NBI) rejection. The generated UWB pulses not only meet the Federal Communications Commission (FCC), but also mitigate single and multiple narrow-band interference.

I. INTRODUCTION

Ultra-wideband radio is a promising technology for high data rate short-range wireless communication. Compared with the conventional narrowband (NB) communication systems, UWB systems have many advantages, e.g. reduced complexity, low power consumption, immunity to multipath fading, high security, etc. [1]-[3]. Since UWB systems transfer information data by using extremely short duration pulses, they have considerably large bandwidth. FCC regulates UWB systems can exploit the frequencies from 3.1 GHz to 10.6 GHz [4]. From Shannon channel capacity [5], it is evident that UWB systems can achieve higher capacity than any other current wireless communication systems. However, in order to reduce the interference between UWB systems and the existing NB systems, FCC presents a UWB spectral mask to restrict the power spectrum of UWB systems. Cognitive radio (CR) aims at a very efficient spectrum utilization employing smart wireless devices with awareness, sensing, learning, and adaptation capabilities [6-8]. As a solution for the spectrum scarcity problem, cognitive radio proposes an opportunistic spectrum usage approach [7], in which frequency bands that are not being used by their primary (licensed) users are utilized by cognitive radios. Thus, CR technology is presented as a viable solution for UWB systems for narrow-band interference suppression. The spectrum of a transmitted signal is influenced by the modulation format, the multiple access schemes, and most critically by the spectral shape of the underlying UWB pulse. The choice of the pulse shape is thus a key design decision in UWB systems. Several pulse design methods of UWB signals have been proposed to let them match with the FCC spectral mask. The simple Gaussian monocycle pulses need to be filtered to meet the FCC spectral mask. This leads that the time duration of the corresponding pulses becomes too long. On the other hand, Gaussian derivatives pulses [9] have fixed features, i.e.; their spectrums are unchangeable once they have been built, making them unable to adjust and adapt their frequency components to avoid frequency colliding. Prolate spherical wave functions [10] and modified Hermite orthogonal polynomials [11] are also used to generate mutually orthogonal pulses that can be used in multiple access schemes. These pulses fit frequency masks with multiple pass-bands. However, they require a high sampling rate that could lead to implementation difficulties. In this paper, three pulse design methods are discussed and compared as methods of NBI suppression and at the same time overcoming the short-comes of the previously mentioned pulses shapes. The methods give a chance of increasing the UWB transmitted power and enlarging the application range of UWB systems, while meeting the FCC spectral mask. The considered pulse design methods are the Parks-McClellan (PM) Algorithm [12,13], the Eigen Value Decomposition (EVD) approach [14,15], and Semi-definite Programming (SDP) scheme [16-20]. The paper is organized as follows. Section II presents a filter design method using the PM filter design algorithm. Simulation results of the pulse design for single and double narrowband interference are illustrated. Section III presents the EVD approach for pulse design and shows by simulation how it mitigates multiple NBI. Section IV presents the third pulse design method based on SDP. Simulation results of multiple NBI suppression will be also shown. In section V evaluates compares the bit error rate (BER) performance of the system with and without introducing NBI suppression. Section VI draws the conclusion.

II. PULSE DESIGN METHOD USING THE PARKS-MCCLELLAN (PM) FILTER DESIGN ALGORITHM

A. The PM Algorithm

In this approach the UWB pulses are designed using an adaptive filter design method based on the PM Algorithm. CR Technology [8] is used to suppress the narrowband interference, as well as satisfying the FCC indoor spectral mask. The PM Algorithm [12,13] was published by James McClellan and Thomas Parks in 1972 as an iterative algorithm for finding the optimal Chebyshev finite impulse response (FIR) filter. The PM Algorithm is utilized to design and implement efficient and optimal FIR filters. It uses an indirect method for finding the optimal filter coefficients. The goal of the algorithm is to minimize the error in the pass and stop bands by utilizing the Chebyshev approximation. The PM Algorithm is a variation of the Remez Algorithm [12], with the change that it is specifically designed for FIR filters

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

and has become a standard method for FIR filter design. Consider NB interference that is present within the UWB spectrum as shown in Fig.1. The transfer function of the equivalent FIR filter is obtained by subtracting the interference window, $N_n(f)$, from the UWB mask $\overline{H}(f)$. Therefore, the spectrum of the adaptive pulse, $S(f)$, can be obtained as follows:

$$S(f) = \overline{H}(f) - N_n(f) \quad (1)$$

The estimated optimal pulse spectrum, $\tilde{S}(f)$ can be expressed as a polynomial of order R:

$$\tilde{S}(f) = \sum_{i=0}^{R} a_i f^i \quad (2)$$

The observational error is defined as:

$$e(f) = \gamma(f)[S(f) - \tilde{S}(f)] \quad (3)$$

Where, $\gamma(f)$, is a suitable weighting function?
The remez(..) function in MATLAB can then be used to get the solution that minimizes the error.

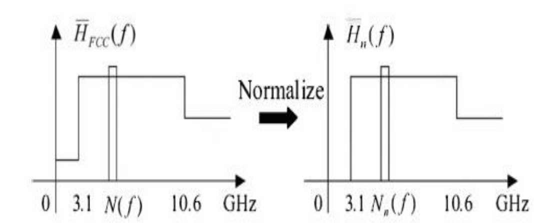


Fig. 1 Desired Spectrum and its Normalized Spectrum.

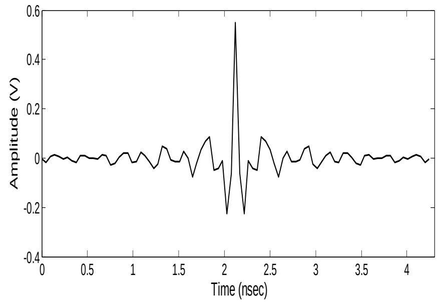
B. Simulation Results of Pulse Design:

1 .Single Narrowband Interference: The adaptive pulse, the normalized spectrum and the resultant designed spectrum are shown in Fig. 2. It was generated by setting the remez(N,F,M,W) function with N=90 sample points. The frequency vector *F*, its corresponding amplitude value *M*, and the weight vector *W* are as follows:

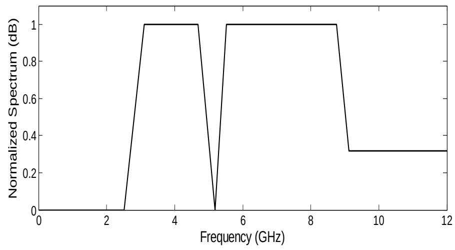
```
F1=[0,0.21,0.2583,0.39,0.432,0.46,0.48,
0.73,0.76,1];
M1= [0,0,1,1,0,1,1,1,0.316,0.316];
W1=[6,1,6,1,3].
```

The NB interference is assumed at 5.2 GHz. It is clear from Fig. 2 that the spectrum fit the normalized FCC mask while the narrowband interference at *5.2 GHz* is suppressed.

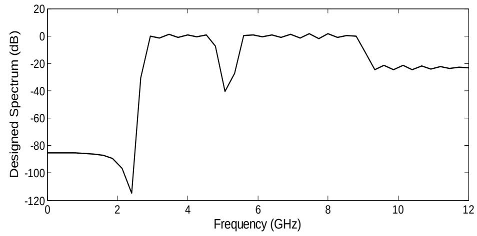
2. Double Narrow-band Interference: Now we assume *two* NBI signals interfering with the UWB band centered at frequencies *5.2* and *8.5* GHz. Using the same pre-described remez function, the generated pulse in this case and its PSD are obtained as shown in Fig. 3.



(a)

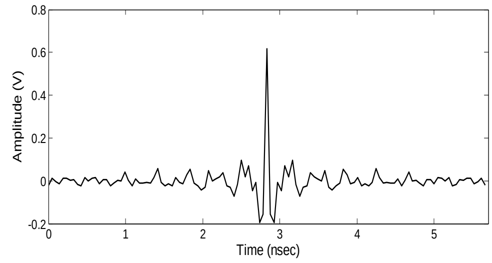


(b)

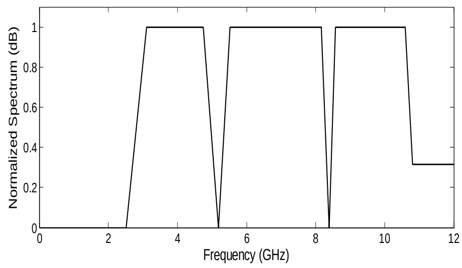


(c)

Fig. 2. Adaptive Generated Pulse for Single NBI Rejection using the PM Algorithm a) Pulse shape b) PSD of generated pulse. c) Normalized spectrum.

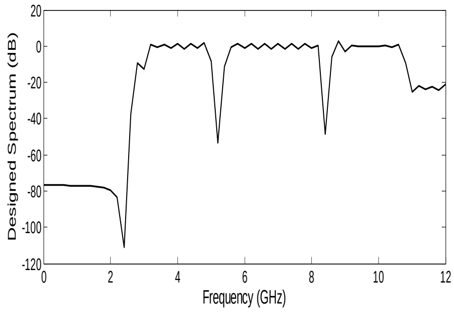


(a)



(b)

IJEIT
ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013



(c)

Fig. 3 Adaptive Generated Pulse for Multiple NBI Rejection using the PM Algorithm: a) PSD of generated pulse. b) Pulse shape. c) Normalized spectrum

III. EIGEN-VALUE DECOMPOSITION (EVD) APPROACH

Another pulse design method based on Eigen-value decomposition [14, 15] is considered in this paper as another method to suppress single or multiple narrow-band interferences located in the UWB band.

A. *The EVD Method for Pulse Shape Design*

The design of the time-limited UWB pulse, *s(t)*, is chosen such that it occupies a short time duration, T_m, i.e.

$$s(t) = 0, \quad |t| > T_m/2 \tag{4}$$

An ideal desired UWB frequency mask *H(f)* is assumed on the form:

$$H(f) = \begin{cases} 1 & f_L \le f \le f_H \\ 0 & \text{elsewere} \end{cases} \tag{5}$$

Where: f_L =3.1GHz , f_H=10.6GHz.

This mask is equivalent to a frequency response of a filter. The simple way to investigate the frequency response of s(t) is to get the inverse Fourier transform of *H(f)*, namely,

$$h(t) = 2f_H \operatorname{sinc}(2f_H t) - 2f_L \operatorname{sinc}(2f_L t) \tag{6}$$

Where, sinc(x)=sin(x)/ x. So, the UWB pulses *s*(*t*) can be generated by convolution:

$$\lambda\, s(t) = \int_{-\infty}^{\infty} s(\tau) h(t-\tau) d\tau \tag{7}$$

Where, λ is a constant (Eigen value).

By sampling at a rate of *N* samples per pulse period T_m, can be expressed as follows:

$$\lambda\, s[n] = \sum_{m=-N/2}^{N/2} s[m] h[n-m], \quad n = -\frac{N}{2} \dots \frac{N}{2} \tag{8}$$

In vector form, the problem is equivalent to an Eigen Value Problem

$$\lambda\, .\boldsymbol{s} \;\; = \boldsymbol{H}.\boldsymbol{s} \tag{9}$$

Where, the vector *s* represents the discretized UWB pulse, *H* is a Hermitian matrix:

$$H = \begin{pmatrix} h[0] & h[-1] & \cdots & h[-N] \\ h[1] & h[0] & \cdots & h[-N+1] \\ \vdots & \vdots & & \vdots \\ h[N] & h[N-1] & \cdots & h[0] \end{pmatrix} \tag{10}$$

The obtained UWB pulse waveform is shown in Fig. 4a and the corresponding power spectral density, PSD = $|S(f)^2|$ is shown in Fig. 4b.

A. *Extension of the EVD Method to Mitigate Narrowband Interference (NBI)*

1. Single NBI Mitigation: The idea of the scheme used here is to form a zero point in the PSD of the UWB pulse at the frequency of interference (f_0) as follows:

1-Divide the UWB band into two bands: (f_L, f_M) & (f_N, f_H) on condition that f_N>f_M .

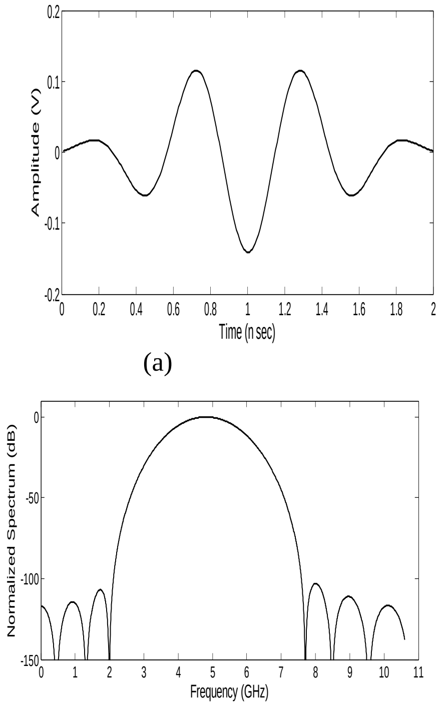
2-Use the EVD method in each band to obtain two sub-pulses; $s_1(t)$ and $s_2(t)$.

3-Adjust f_m and f_n in a way that $S_1(f_0)$= - $S_2(f_0)$, where $S_1(f_0)$ and $S_2(f_0)$ are the spectrums of $s_1(t)$ $s_2(t)$.

4-Add the two sub-pulses to generate the required UWB pulse. The PSD of the obtained UWB pulse will have a zero point at f_0; the point of interference.

Fig. 5 shows PSD of an UWB pulse cancelling single interference at 5.2 GHz.

2. Multiple NBI Rejection: The design method is extended to suppress more than one NBI point. *2* NBI points are assumed. Fig. 6. Shows PSD of a designed UWB pulse cancelling double interference at 5.2 and 8.5 GHz.



(b)

Fig. 4 UWB Pulse obtained from EVD Method: a) Pulse shape. b) PSD.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

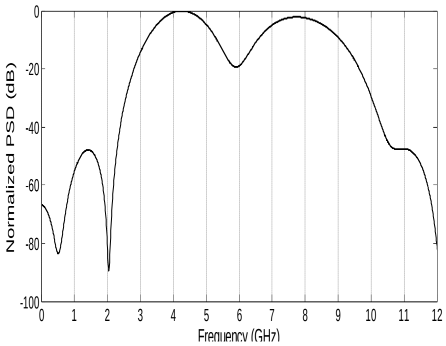


Fig. 5 PSD of UWB Pulse mitigating Single NBI.

IV. PULSE DESIGN METHOD BASED ON SEMI-DEFINITE PROGRAMMING (SDP)

A. The SDP Approach

A pulse design method based on semi-definite programming *(SDP)* [16-20] is introduced to achieve the most efficient spectral utilization at a relatively low sampling rate. This pulse design framework capitalizes on the fact that many of the desired properties of a waveform, including the optimum spectral utilization, can be expressed as properties of the auto-correlation of the waveform [17].

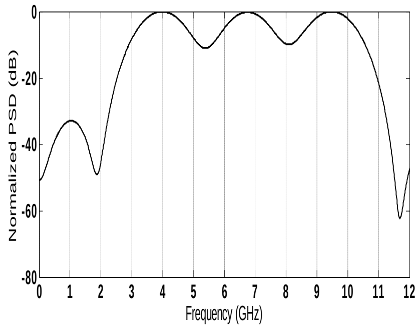


Fig. 6 PSD of UWB Pulse mitigating Double NBI

By reformulating the pulse design problem in terms of the autocorrelation sequence of the "pulse-shaping" filter, many of the design constraints such as the spectral mask constraints become linear; hence the design problems become linearly constrained convex optimization problems [20]. The objective of the pulse design problem [16] in this method is to find *P(f)*; the spectrum of the UWB pulse *p(t)*; that maximizes the normalized effective signal power (NESP) ψ under the spectral mask, *S(f)* and *covers the* pass-band Fp, namely,

$$\psi = \frac{\int_{F_p} |P(f)|^2 df}{\int_{F_p} S(f) df} * 100\% \qquad (11)$$

Where,

$$Fp = \{f \ / f \in \{[3.1, 10.6] GHz\}\ \}, \qquad (12)$$

This can be mathematically formulated as follows:

$$\underset{p(t)}{Max}\ (\psi) \text{ subject to } |P(f)|^2 \leq S(f), \forall f \qquad (13)$$

The pulse *p(t)* can be expressed as the train of pulses :

$$p(t) = \sum_{i=0}^{L-1} g_i\ q(t - iT_q) \qquad (14)$$

Where: T_q is the sampling period, and the set $\{g_i\}_{i=0}^{L-1}$ contains L pulse coefficients to be designed by (13).

The corresponding power spectral density of *p(t)*, $S_p(f)$ is

$$S_p(f) = |Q(f)|^2 \left|\sum_{i=0}^{L-1} g_i\, e^{-j2\pi i f T_q}\right|^2 \approx \left|\sum_{i=0}^{L-1} g_i\, e^{-j2\pi i f T_q}\right|^2 \qquad (15)$$

Where, $Q(f)$, the Fourier transform of $q(t)$ is assumed almost flat over the UWB pulse, sampling frequency $F_q = 1/T_q$, pulse duration T_p of *p(t)* is $T_p = LT_p$.

The pulse design problem in (13) is not convex in $\boldsymbol{g}^{\rightarrow}$ and hence it has been transformed to a semi-definite programming problem (SDP) over the autocorrelation of the pulse shape. An autocorrelation sequence, $\boldsymbol{r}^{\rightarrow} = (r_0, r_1, \ldots, r_{L-1})$ of $\boldsymbol{g}^{\rightarrow}$ is defined as:

$$r_k = \sum_{i=0}^{L-1} g_i\ g_{i+k}, k = 0,1,..L1 \qquad (16)$$

with $r_{-k} = r_k$.

Therefore, $S_p(f)$ becomes a linear function of $\boldsymbol{r}^{\rightarrow}$, namely,

$$S_P(f) = r_0 + 2\sum_{K=1}^{L-1} r_k\ \cos(2\pi k f) \qquad (17)$$

The corresponding expression of the NESP ψ can be written as:

$$\psi = r_0 + 2\sum_{K=1}^{L-1} \frac{\sin(2\pi k\beta) - \sin(2\pi k\alpha)}{k\pi(\beta - \alpha)} r_k \qquad (18)$$

where: $\alpha = Tq \cdot 3.1GHz$, $\beta = Tq \cdot 10.6GHz$.

The metric in (18) is linear in $\boldsymbol{r}^{\rightarrow}$. The coefficients form a metric vector $\boldsymbol{w}^{\rightarrow} := (w_0, w_1, \ldots, w_{L-1})T$,

where:

$w_0 := -1$,

$$w_i := -\frac{\sin(2\pi k\beta) - \sin(2\pi k\alpha)}{k\pi(\beta - \alpha)}, 1 \leq i \leq L - 1 \qquad (19)$$

A new tighter normalized mask $P_\alpha(f)$ is imposed in the stop band to reduce interference of other systems operating in the band. The new bounds on $P_\alpha(f)$ are -70dB for f ≤0.96 GHz, -40dB for 0.96 <f ≤3.1 GHz, -15 dB for f ≥10.6GHz, while satisfying 0dB for the main pass-band: 3.1GHz <f ≤10.6GHz.

The design problem can now be written as the following convex optimization problem:

$$\underset{\boldsymbol{r}^{\rightarrow}}{\text{Min}}\ (-\psi) \quad \text{such that}$$

$$S_p(f) \geq 0\ \ \forall f \qquad (20a)$$
$$S_p(f) \leq 0dB\ \ \forall f \qquad (20b)$$
$$S_p(f) \leq -15dB,\ \ f > 10.6GHz\ \forall f \qquad (20c)$$
$$S_p(f) \leq -40dB,\ \ 0.96 < f \leq 3.1GHz\ \forall f \qquad (20d)$$
$$S_p(f) \leq -70dB, 0 \leq f \leq 0.96\ GHz\ \forall f \qquad (20e)$$

It is evident from (20) that all the involved mask constraints are linear with respect to the correlation coefficient $\boldsymbol{r}^{\rightarrow}$, and from (18) that the objective is also a linear function of $\boldsymbol{r}^{\rightarrow}$. The pulse shape and its spectrum are generated in Fig.7 using *Sedumi (Self-Dual Minimization)*

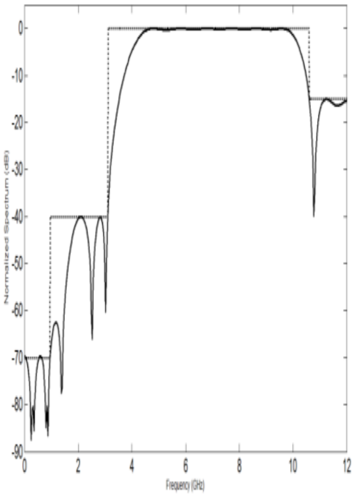
ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

DSP package for MATLAB [19]. The designed spectrum fully satisfies our mask requirements.

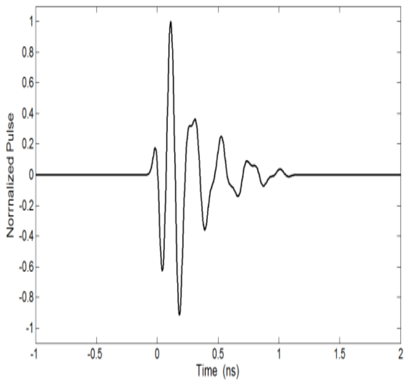
B. Mitigation of Narrowband Interference (NBI)

1. Single NBI Mitigation: Pulse shapes were designed to affect single narrow band interferences and the resultant spectra are shown in Fig. 8 for NBI at 5.2 GHz.

2. ***Multiple NBI Rejection:*** ***U***sing this technique we were able to extend the pulse design to cancel multiple narrow band interferences. The resultant spectrum is shown in Fig. 9 for double NB interference at both 5.2 GHZ and 8.5 GHz.



(a)



(b)

Fig. 7. Generated UWB Pulse Spectrum using SDP Method: a) Spectrum b) Pulse shape.

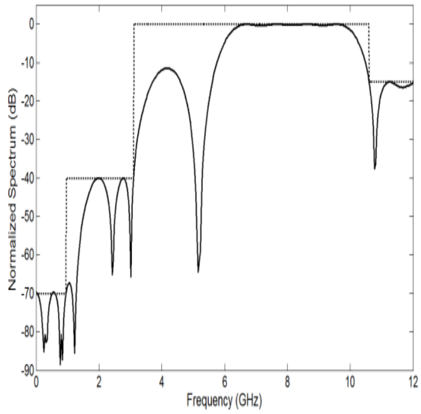
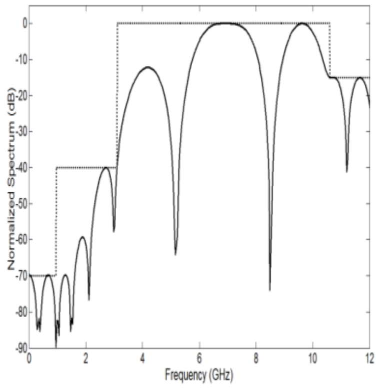
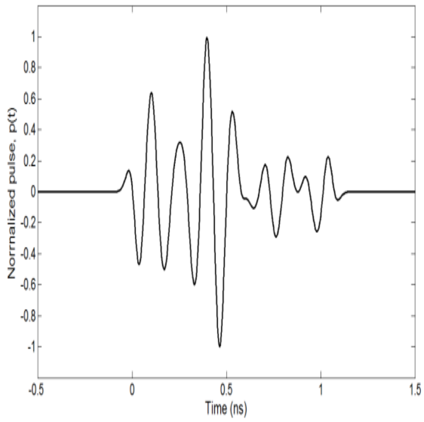


Fig. 8. PSD of UWB Pulse mitigating Single NBI at 5.2 GHz.



(a)



(b)

Fig. 9 UWB Pulse mitigating Double NBI at 5.2 GHz and 8.5 GHz. a) PSD. b) UWB Pulse shape.

V. BIT ERROR RATE (BER) PERFORMANCE

The BER performance is illustrated in this section as a comparison between the performance of the system with and without introducing NBI suppression. The effect of mitigating single interference will be also compared with that in case of double interference. The BER performance of the IEEE 802.15.4a UWB system transmitting on IEEE 802.15.4a channel is evaluated [21]. Among the three previously studied

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

pulse design methods for interference suppression, the EVD approach is chosen as an example for performance evaluation In Fig. 10, the performance of the ideal Eigen-value pulse (in absence of any interference) is compared with that in presence of interference (no NBI mitigation). With interference, its performance is very bad in comparison with the ideal case. The Eigen pulse designed with a single notch at 5.2 GHZ (single NBI suppression) is compared and shown to be much better than that with no notch in presence of interference. In Fig. 11, comparison is extended to include double NBI. It is clear from the figure that eliminating two points of interferences at 5.2GHz, and at 8.5GHz decreases the BER than in case of single NBI. The doule-notch curve nearly meets that of the ideal case where no interference exists.

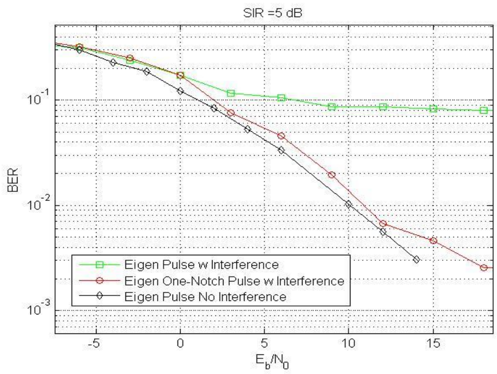


Fig. 10 BER Performance for Single NBI

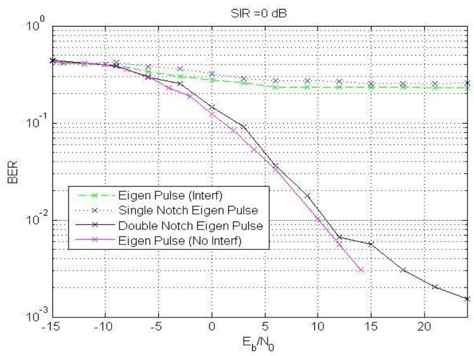


Fig. 11 BER Performance for Double NBI

VI. CONCLUSION

In this paper three methods are presented to suppress NBI located in the UWB band without the need of lowering the UWB pulse PSD. These methods not only give a solution to the co-existence between UWB systems and existing narrowband systems, but also give a chance of increasing the UWB transmitted power and enlarging the application range of UWB systems, while meeting the FCC spectral mask. Finally, BER comparison for the EVD approach between single and double NBI is evaluated to show how the system performance deteriorates in presence of interference and how it gets much better at interference mitigation.

REFERENCES

[1] Intel White Paper, "Ultra-wideband (UWB) Technology: Enabling high-speed wireless personal area networks," 2004.Online].Available:http://www.intel.com/technology/comms/uwb.

[2] C-C. Chong, F. Watanabe, and H. Inamura , "Potential of UWB Technology for the Next Generation Wireless Communications (Invited Paper)", IEEE Ninth International Symposium on Spread Spectrum Techniques and Applications, pp.442-49, 2006.

[3] A. Chen and Di Benedetto, "Ultra Wideband Wireless Communication", John Wiley & Sons, Inc., 2006.

[4] "Revision of Part 15 the Commission's rules regarding ultra-wideband transmission systems", FCC, ET Docket, pp.98-153, 2002.

[5] T. M. Cover and j. a. Thomas, "Elements of Information Theory", New York: Wiley, 1991.

[6] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," IEEE J. Select. Areas Comm., vol. 23, no. 2, pp. 201–220, Feb. 2005.

[7] S. Mangold, Z. Zhong, K. Challapali, and C.-T. Chou, "Spectrum agile radio: radio resource measurements for opportunistic spectrum usage," Proc. IEEE Global Telecomm. Conf. (GLOBECOM), vol. 6, pp. 3467 – 3471, Dallas, TX, Dec. 2004.

[8] V. D. Chakravarthy, A. K. Shaw, and M. A. Temole, "Cognitive radio- An adaptive waveform with spectral sharing capability", IEEE Wireless Communications and Networking Conference, pp.724-729, 2005.

[9] T-A Phan , Vladimir Krizhanovskii , Seok-Kyun Han , and Sang-Gug Lee , and Nae-Soo Kim, "7th Pulse Derivative Gaussian Pulse Generator for Impulse Radio UWB", Auto-ID Labs White Paper.

[10] Y. Lu, H. B. Zhu, "UWB pulse design method based on approximate prolate spheroidal wave function", Journal of Communications, Vol.26, pp. 60-64, 2005.

[11] M. Ghavami, L. B. Michael and R. Kohno, "Hermite function based orthogonal pulses for UWB communication", Proc. Int. Symp. on Wireless Personal Multimedia Communications, pp. 437–440, Aalborg, September 2001.

[12] X. Shi, "Adaptive UWB Pulse Design Method for Multiple Narrowband Interference Suppression", 2010 IEEE International Conference on Intelligent Computing and Intelligent Systems (ICIS), 29-31 Oct. 2010.

[13] X. Luo, L. Yang, and G. B. Giannakis, "Designing optimal pulse-shapers for ultra wideband radios," Journal of Communications and Networks, vol. 5, no. 4, pp. 344–353, December 2003.

[14] B. Das and S. Das, "Interference Cancellation Schemes in UWB Systems used Wireless Personal Area Network based on Wavelet based Pulse Spectral shaping and Transmitted Reference UWB using AWGN Channel Model", International Journal of Computer Applications, Vol. 2 , No.2, pp. 0975 – 8887, May 2010.

[15] A. Taha., K. M. Chugg, "A theoretical study on the effects of interference UWB multiple access impulse radio Signals," Systems and Computers 2002 Conference Record of the Thirty-Sixth Asilomar Conference., Vol.1, pp.728-732, Nov 2002.

[16] X. Wu, Z. Tian, T. N. Davidson, and G. B. Giannakis, "Optimal Waveform Design For UWB Radios", Int. Conf. on Acoustics, Speech and Signals Processing, ICASSP'04, IV – 521-524, 2004.

[17] T. N. Davidson, Z. Q. Luo and J. F. Sturm, " Linear matrix inequality formulation of spectral mask constraints with applications to FIR filter design" , IEEE Transactions on Signal Processing, Vol.50, No.11, pp.2702-2715, Nov.2002.

[18] B. Parr, B. Cho, K. Wallace, and Z. Ding, "A novel ultra-wideband pulse design algorithm,", IEEE Communications Letters, vol. 7, no. 5, pp. 219–221, May 2003.

[19] J. F. Sturm, "Using SeDuMi 1.02, a MATLAB toolbox for optimization over symmetric cones," Optimization Methods and Software, vols. 11–12, pp. 625–653, 1999.

[20] S. Wu, S. Boyd, and L. Vandenberg he, "FIR filter design via spectral factorization and convex optimization," Applied and Computational Control, Signals and Circuits, vol. 1, B. Datta, ed., Birkhauser, Boston, MA, 1999.

[21] M. Flury, R. Merz, J.-Y. Le Boudec, and J. Zory, "Performance evaluation of an IEEE 802.15.4a physical layer with energy detection and multi-user interference," in Proc. IEEE Intl. Conf. Ultra-Wideband (ICUWB), Singapore, Sept. 2007.