Performance of the IEEE 802.15.4a UWB System using Two Pulse Shaping Techniques in Presence of Single and Double Narrowband Interferences

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Abstract

In Cognitive radio (CR) applications Ultra-wideband (UWB) impulse radio (IR) signals can be designed such as they can co-exist with licensed primary users. The pulse shape should be adjusted such that the power spectral characteristics not only meet the Federal Communications Commission (FCC) constrains, but also mitigate multiple narrow-band interference at the locations of existing primary users. In this paper, the Parks-McClellan (PM) Algorithm and the Eigen Value Decomposition (EVD) approach for UWB impulse radio waveform shaping are considered. The power spectral density (PSD) and the bit-error-rate (BER) performance of the two methods are compared in the presence of single and double narrow-band interference (NBI). The interference rejection capabilities of the two methods are evaluated and compared for different interference and additive noise levels. In particular, the simulations consider the coexistence of practical IEEE 802.15.4a UWB systems with both IEEE 802.11 wireless LAN systems operating at 5.2 GHz and radio location services operating at 8.5 GHz.

Key words; *Cognitive Radio, UWB, Impulse Radio, Interference Rejection, IEEE 802.15.4a, Parks-McClellanAlgorithm, Eigen Value Decomposition.*

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.

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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 [6] 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 [7] and modified Hermite orthogonal polynomials [8] 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, two 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 [9,10], the Eigen Value Decomposition (EVD) approach [11,12].

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 gives a comparison between the PSD of the EVD approach and the PM pulse design method. Simulations will be done for both single and double NBI. Section V evaluates and compares the bit error rate (BER) performance of both systems in case of single and NBI. 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[13]is used to suppress the narrowband interference, as well as satisfying the FCC indoor spectral mask.

The PM Algorithm[9,10] was published by James McClellan and Thomas Parks in 1972 as an iterative algorithm for finding the optimal Chebyshevfinite 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[9], with the change that it is specifically designed for FIR filters and has become a standard method for FIR filter design.

The use of PM method to design UWB pulses with single or double notches at the narrow band interference frequency was considered in [14]. The spectrum of the adaptive pulse, $S(f)$, can be expressed as:

$$S(f) = \bar{H}(f) - N_n(f) \tag{1}$$

Where $\overline{H}(f)$ and $N_n(f)$ are the spectra of the UWB needed to satisfy the FCC mask and the narrowband interference spectrum to be cancelled. 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, $\boldsymbol{\gamma(f)}$, is a suitable weighting function. The remez(..) function in MATLAB can then be used to get the solution that minimizes the error.

B. Simulation Results of Pulse Design:

iSingle Narrowband Interference:The adaptive pulse, the normalized spectrum and the resultant designed spectrum are shown in Fig. 1. 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:

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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].
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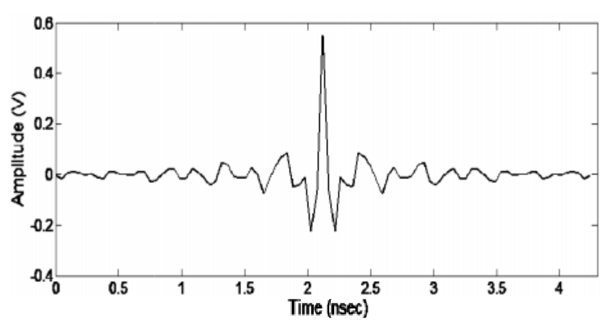
The NB interference is assumed at 5.2 GHz. It is clear from Fig. 1 that the spectrum fit the normalized FCC mask while the narrowband interference at *5.2 GHz* is suppressed.

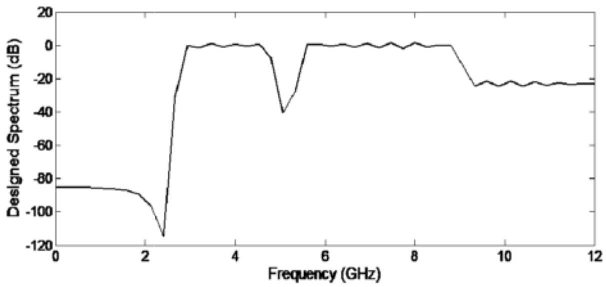
ii. Double Narrow-band Interference:Now we assume *t*wo NBI signals interfering with the UWB band centered at frequencies *5.2* and *8.5* GHz. Using the same pre-described remez function, the generated pulse in this case and its PSD are obtained as shown in Fig. 2.

III. Eigen-Value Decomposition (EVD) Approach

Another pulse design method based on Eigen-value decomposition [11,12]is considered in this paper as another method to suppress single or multiple narrow-band interferences located in the UWB band.

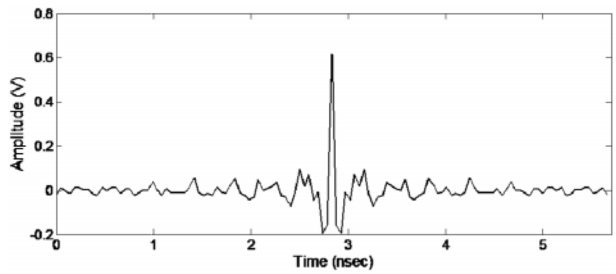


(a)

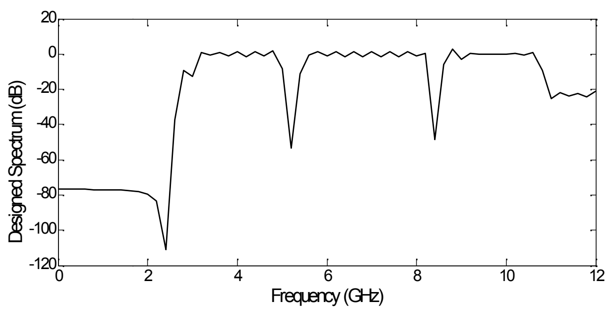


(b)

Fig. 1. Adaptive Generated Pulse for Single NBI Rejection using the PM Algorithm
a) Pulse shape b) Normalized PSD of generated pulse.



(a)



(b)

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

The time response s(t) of the ideal pulse covering the frequency ban$d f_L \leq f \leq f_H$, where: f_L=3.1GHz, f_H=10.6GHz is obtained by the inverse Fourier transform of the FCC ideal mask *H(f)* as,

$$h(t) = 2f_H \mathrm{sinc}(2f_H t) - 2f_L \mathrm{sinc}(2f_L t) \quad (4)$$

where, sinc(x)=sin(x)/ x. The UWB pulses *s*(*t*) can thus be generated by convolution:

$$\lambda s(t) = \int_{-\infty}^{\infty} s(\tau) h(t-\tau) d\tau \quad (5)$$

where, λ is a constant (Eigen value). By sampling at a rate of *N* samples per pulse period T_m, , equation (5) can be expressed as an Eigen Value Problem, namely,

$$\lambda . \boldsymbol{s} = \boldsymbol{H} . \boldsymbol{s} \quad (6)$$

where, the vector *s* represents the samples of discretized UWB pulse, *H* is a Hermitian matrix constructed by the discrete samples of h(t).

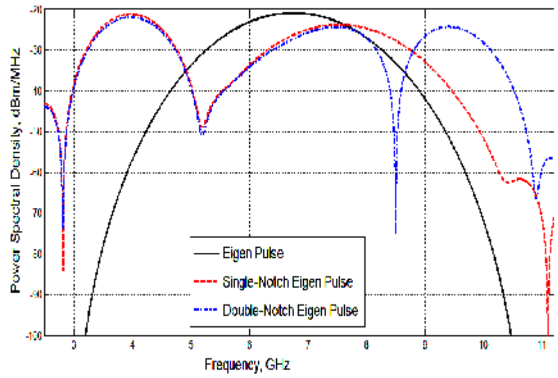


Fig. 3. PSD of the Eigen pulse in absence of an Interferer, and compared to that of the Designed Single and Double Notch Eigen Pulse

The extension of the designed Eigen pulses to affect nulls at the frequencies of narrowband interference was discussed in [15]. Comparison between the obtained spectra of the ideal pulse, the pulse needed to mitigate single narrowband interference of the IEEE 802.11 wireless LAN systems operating at 5.2 GHzand the pulse needed to mitigate double narrow band interferences of the radio location services operating at 8.5 GHz are shown in Fig. 3 [15].

IV. PSD Comparison between (EVD) Method and (PM) Filter Design Algorithm

A- Single Narrowband Interference:

The PSD of Single Notch Modified Eigen Pulse is compared to the PSD of a Single Notch adaptive PM Pulse in Fig. 4. The NB interference is assumed at *5.2 GHz.*

The used design parameters for the generation of the Single Notch Eigen Pulse are: sampling frequency f_s=120 GHz, f_L=3.1GHz, f_M=4.9GHz, f_N=4 GHz, and f_H=11.1 GHz.

The PSD of adaptive PM pulse is generated as seen in Fig. 4 by setting the remez (N,F,M,W) function with N=90 sample points, sampling frequency of 30 GHz, frequency vector *F*, its corresponding amplitude value *M*, and the weight vector *W* are as follows:
F1= [0 0.168 0.20664 0.33 0.35 0.37 0.384 0.68667 0.70667 1] ;
M=[0 0 1 1 0 1 1 1 0 0]

B- Double Narrowband Interference:

The PSD of Double Notch Eigen Pulse iscompared to the PSD of a Double Notch adaptive PM Pulse as shown in Fig. 5. The NB interference is assumed at *5.2 GHz* and *8.5 GHz.*

The used design parameters for the generation of the Double Notch Eigen Pulse are: fs=120GHz, f_{L1}=3.1GHz, f_{H1}=4.9GHz, f_{L2}=4GHz, f_{H2}=11.1 GHz, f_{L3}= 7.9 GHz, f_{H3}=10.7 GHz.

The PSD of adaptive PM pulse is generated as seen in Fig.5 by setting the remez (N,F,M,W) function with N=90 sample points, sampling frequency of 30 GHz, frequency vector F, its corresponding amplitude value M, and the weight vector W are as follows:

F1= [0 0.168 0.20664 0.33 0.35 0.368 0.384 0.55 0.56667 0.59 0.6 0.68667 0.70667]

M = [0 0 1 1 0 1 1 1 0 0]

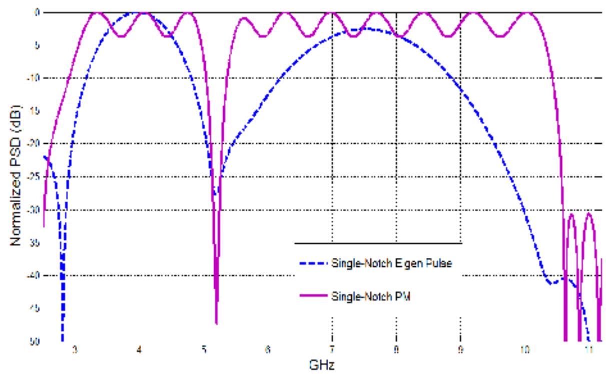


Fig. 4.PSD of Single Notch Adaptive PM Pulse, and compared to PSD of Single Notch EigenPulse

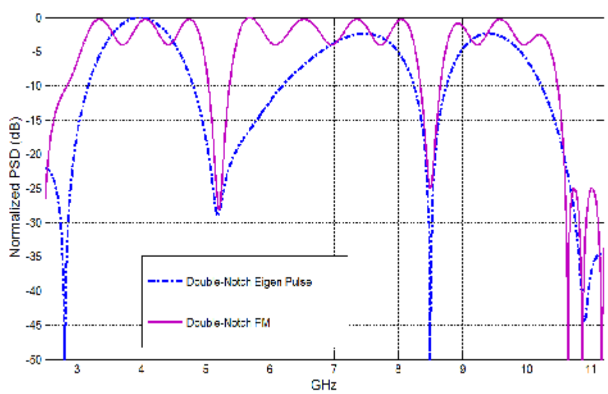


Fig. 5.PSD of Double Notch Adaptive PM Pulse, and compared to PSD of Double Notch Eigen Pulse

V.Bit Error Rate (BER) Performance Comparison between(EVD) Method and (PM) Filter Design Algorithm

The BER performance of the IEEE 802.15.4a UWB system transmitting on IEEE 802.15.4a channel is evaluated. The IEEE 802.15.4a UWB channel model is deployed[16].The IEEE 802.15.4a UWB channel model is deployed. The UWB channel model is a Saleh-Valenzuela (SV) model modified to take into account different measurement and simulation parameters [23]. Our simulations in this paper assume the residential LOS model CM1, with parameters as given in Table I of [23].

The IEEE 802.15.4a transmitter is specified by the standard and is explained in details in [16-23]. The receiver deployed is a coherent detector assuming perfect UWB channel estimation available at the receiver [21].

A- Single Narrowband Interference:

We consider the coexistence of practical IEEE 802.15.4a UWB systems with IEEE 802.11 wireless LAN systems operating at 5.2 GHz.

In Fig. 6, BER performance is evaluated for each of the ideal Eigen Pulse (in absence of interference), Single Notch Eigen Pulse and the Single Notch adaptive PM Pulse. The BER performance is compared versus the SIR, and at Signal to Noise Ratio (SNR) fixed at E_b/N_0 of 9 dB.It is clear from the figure that the Single Notch adaptive PM Pulse outperforms the Eigen-Value pulse whether there is a single- notch interference or in its absence.

In Fig. 7, BER performance evaluation is repeated. This time, the BER performance is simulated versus the SNR and at Signal to Interference Ratio (SIR) fixed at 5 dB. The same results appear here also; i.e: the BER of the Single Notch adaptive PM Pulse is the least among the three methods at any SNR value

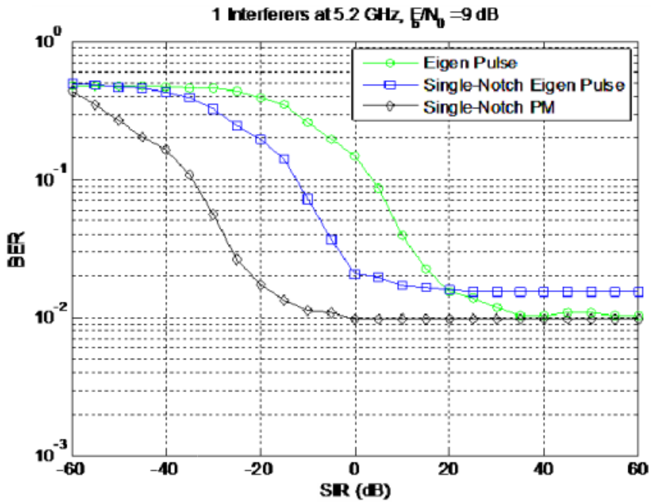


Fig.6.BER vs SIR at E_b/N_0 of 9 dB in the presense of a single narrow band interference

B- Double Narrowband Interference:

Here, the coexistence of practical IEEE 802.15.4a UWB systems is considered with both IEEE 802.11 wireless LAN systems operating at 5.2 GHz and radio location services operating at 8.5 GHz.

Simulations are repeated in Fig. 8 but comparisons are extended to include Double NBI at 8.5 GHz. BER performance is evaluated for each of the ideal Eigen Pulse (in absence of interference), Double Notch Eigen Pulse and the Double Notch adaptive PM Pulse. The BER performance is compared versus the SIR. The Signal to Noise Ratio (SNR) is fixed at E_b/N_0 of 3dB. Results show that the Double Notch Eigen Pulse outperforms the Double Notch adaptive PM Pulse at any SIR value.

In Fig. 9, BER performance evaluation is repeated. This time, the BER performance is simulated versus the SNR. Signal to Interference Ratio (SIR) is fixed at 5 dB . Results show that the performance of Double Notch Eigen Pulse is nearly the same as that of Double Notch adaptive

PM Pulse; BER is nearly the same at any SNR value. However, if the SNR is deeply lowered to -20 dB, results show that the Double Notch Eigen Pulse gives the better performance.

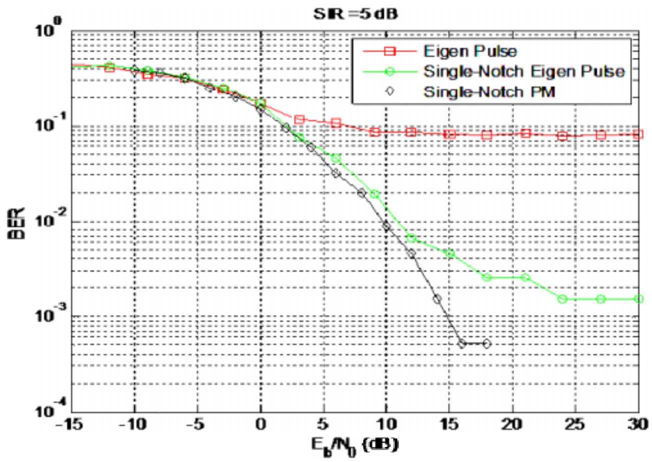


Fig.7. BER vs SNR at fixed SIR of 5 dB

VI. Conclusion

In this paper two 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. The PSD and BER comparisons between both the EVD approach and the PM pulse design algorithm for single and double NBI are evaluated. Results showed that for single NBI, the PM algorithm outperforms the EVD method. While in the case of double NBI, the performance of both methods are nearly the same, except at very low values; SNR= -20dB, performance of the PM algorithm degrades alot.

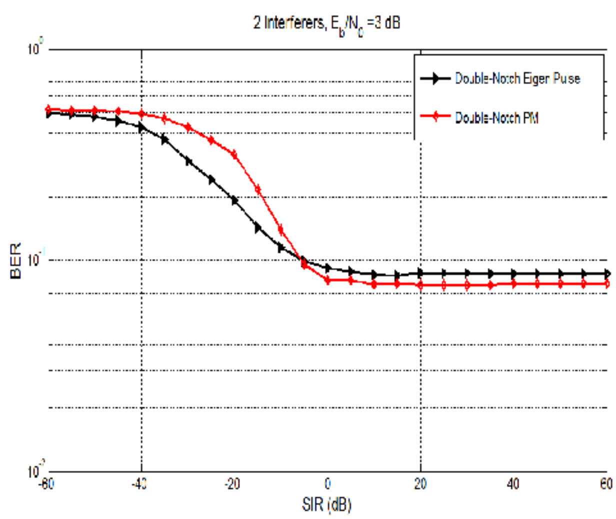


Fig.8.BER vs SIR at atE_b/N_0 of 3 dB

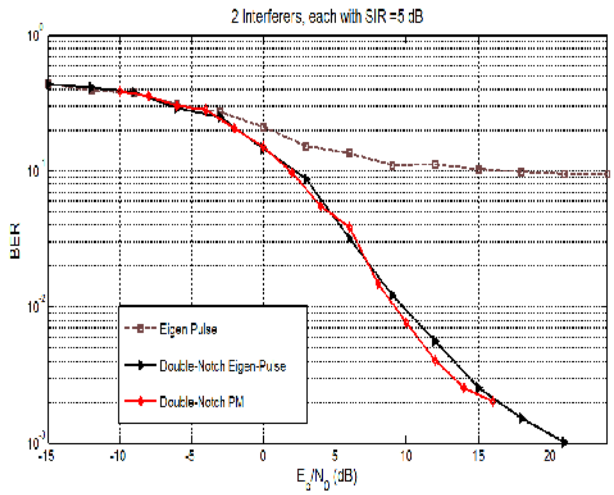


Fig.9.BER vs SNR at fixed SIR of 5 dB

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