http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (13): 2103-2111, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.2103.2111

A Design Method of UWB Signal Waveform based on SSA

[1]Pingyan Shi, [1]Xiaofeng Tao, [1]Jianchao Ji, [2]Xiaohui Liu and [2]Kai Cui
[1]China Academy of Space Technology (Xi'an), Xi'an, Shanxi, 710100, China
[2]School of Electronics and Information Technology, Harbin Institute of Technology, Harbin, Heilongjiang, 150001, China

---

Abstract: Ultra Wideband (UWB) wireless communication has become the hot spot of the new generation ultra-high speed wireless communications in short-range. DS-UWB is one of the most important work patterns which can be applied to high speed wireless communications in dense indoor multipath environment. DS-UWB has various inherent advantages, one is that it can make full use of the radio frequency spectrum resources, but it also brings the problem of interference to existing radio systems. According to the particularity of confined spaces, it is needed a new analytical design method of UWB signal waveform which has the diffraction and penetration ability, so as to match the requirement. The UWB systems can coexist with other radio systems in confined spaces by using the specific waveform designed before. In this study, a waveform design method based on Soft Spectrum Adaptation (SSA) is proposed for UWB systems in confined spaces and it is evaluated through both theoretic analysis and computer simulation. In order to decrease or avoid the influence of spectrum aliasing on other narrowband radio systems, a design scheme for pulse waveform optimization based on Prolate Spheroidal Wave Functions (PSWF) has been investigated for producing the expected pulse waveform while matching with the required spectrum mask.

Key words: UWB, waveform design, SSA, PSWF

INTRODUCTION

Ultra Wideband (UWB) has been seen as one promising technology for the high data rate indoor wireless multimedia transmission and it attracted increasing interest in academic and industrial bodies in the past few years (Lee and Scholtz, 2002; Choi *et al*., 2004; Kilic *et al*., 2014). In order to facilitate this technology, the Federal Communications Commission (FCC) agreed to allocate 7500 MHz of spectrum for unlicensed use of UWB devices for communication applications in the 3.1-10.6 GHz frequency band. According to the description on cognitive radio in FCC (2002), especially relevant to the CR scenario is the UWB wireless technology and its application. Since, UWB pulse waveforms are generally spread over very large bandwidths, they will unavoidably overlap with the existing and planned narrowband radio systems so that coexistence and compatibility become a critical issue. UWB signals have effect on most of the existing radio systems due to its ultra wideband, so it's necessary to solve the coexistence problem between UWB and other narrow band signals. SSA is such a technology which can achieve flexible and scalable waveform designs by choosing different wavelet basis and combination according to the cognitive radio theory (Zhang and Kohno, 2003). And it can produce the expected spectral notches to limit interference at the same time.

For the part of UWB pulse choice, there are many pulse waveforms have been proposed and analyzed in the literature (Rius *et al*., 2014; Mirshafiei *et al*., 2012). Early ultra wideband waveform is sampled Gaussian pulse waveform. Win and Scholtz (2000) in the literature using the second derivative of the Gaussian pulse as a the pulse waveform of the radio system to overcome the high DC component and the low radiation efficiency of Gaussian pulse, the pulse is called ScholtZ pulse subsequently been widely adopted. Ghavami *et al*. (2002) proposed the use of novel modified Hermite pulse shapes for UWB communication system, by constructing a set of orthogonal waveforms an M-ary signaling set can be constructed, allowing higher data rates, or alternatively in a multi user system, the orthogonal pulses can be assigned to different users. Subsequently a number of researchers have proposed for Hermite pulses improvement, in order to different order Hermite pulse duration and bandwidth tends to be uniform (Harada *et al*., 2004; Hu and Zheng, 2005). Parr *et al*.

Corresponding Author: Pingyan Shi, China Academy of Space Technology (Xi'an), Xi'an, Shanxi, 710100, China

(2003) proposed an algorithm which numerically generates pulses whose power spectra fit a desired frequency mask.

Following this kind of signal waveforms adaptation approach in the cognitive UWB radio, a method of pulse waveform optimization based on the linear combination of orthogonal basis functions have investigated, in which Prolate Spheroidal Wave Functions (PSWF) are utilized (Kong and Rokhlin, 2012; Osipov, 2013).

MATERIALS AND METHODS

System model: In the following discussion, a brief description of SSA method is provided and its mechanism of adaptive interference avoidance. First, the whole bandwidth for UWB communication systems can be divided into several multiple sub-bands. The existence of narrow-band signals in some sub-bands should be utilized to determine whether we should give up these sub-bands in combination while taking care of the interference with existing narrow-band system. SSA method has many advantages. One is that can get feasible solution of flexible and adaptive UWB spectrum when spectral masks have been given. Moreover, it maintains exchange ability among various existing or forthcoming UWB systems and it still keeps the pulse duration in the order of nanosecond for higher data rate, also it gives spectrum freedom based on flexibility and scalability.

It's significant to optimize the pulse waveform when designing for UWB communication systems in confined spaces. There're few rules should be followed:

- The pulse spectrum should be contained in the desired frequency band to satisfy the spectral mask, namely being bandwidth-limited
- The pulses should be limited to short duration with energy concentration, namely being time-limited
- The pulse set could be flexibly combined or extended to fit any further spectral mask change

Starting from these prerequisites, a design scheme for pulse waveform optimization based on PSWF (Prolate Spheroidal Wave Functions) has been investigated for producing the expected pulse waveform in our project (Fig. 1). The expected pulse can produced by combining the wavelet basis of PSWF.

First, choose a set of pulse waveforms that are band-limited as well as time-limited. Let us first start from one arbitrary sub-band (e.g., kth pass-band) located in S-band (2-4 GHz) as shown in Fig. 2 which can be given in frequency domain and time domain as:

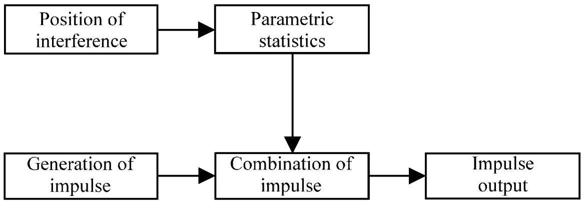

Fig. 1: Block diagram of pulse design principles

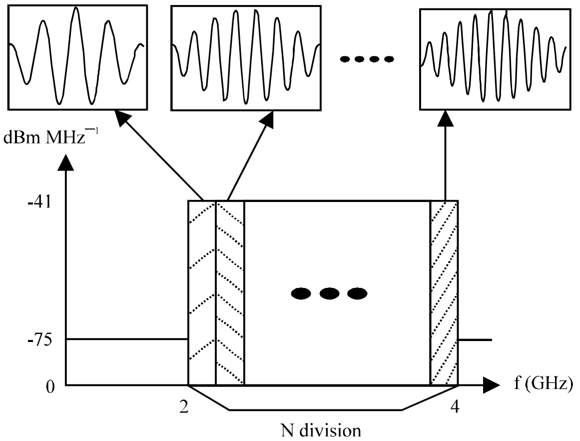

Fig. 2: Multi-bands pulse combination based on bandwidth division in S-band

$$h_k(t) = 2f_{k,H}\sin c(2f_{k,H}t)-2f_{k,L}\sin c(2f_{k,L}t) \quad (1)$$

$$H_k(f)=\begin{cases}1, & f_{k,L}\le f\le f_{k,H}\\ 0, & \text{otherwise}\end{cases} \quad (2)$$

where, $f_{k,H}$ and $f_{k,L}$ denote the high and the low frequency of the Kth sub-band, respectively. To design the basic pulse waveform of the sub-band, each sub-band can be considered as a filter with pulse response $h_k(t)$. First send an arbitrary kernel pulse $\phi_k(t)$ through the filter $h_k(t)$ and let the filter output be $\lambda_k\phi_k(t)$ in which λ_k is an arbitrary constant factor. The output can be expressed as follows when $h_k(t)$ is assumed to be ideal filter:

$$\lambda_k\phi_k(t)=\int_{-\infty}^{\infty}\phi_k(\tau)h_k(t-\tau)d\tau \quad (3)$$

where, $\phi_k(t)$ coincides with the required pass-band (the Kth sub-band) and has the following time-limited quality:

$$\phi_k(t)=\begin{cases}p_k(t), & |t|\le T_p/2\\ 0, & \text{otherwise}\end{cases} \quad (4)$$

where, T_p is the width of the pulse, $p_k(t)$ is the target pulse waveform. Since, $\phi_k(t)$ is time-limited and energy-concentrated over $[-T_p/2,\ T_p/2]$, Eq. 3 can be given as:

$$\lambda_k\phi_k(t)=\int_{-T_p/2}^{T_p/2}\phi_k(\tau)h_k(t-\tau)d\tau \qquad (5)$$

Then, the obtained sub-band wavelet can be further combined to form a more complex wavelet corresponding to arbitrary multiple sub-bands system including dual, triple and multiband architecture, as illustrated in Fig. 2. The waveform expression for the multiband combination can be written as follows:

$$\phi_{mul}(t)=\sum_{k=1}^{N}\phi_k(t) \qquad (6)$$

As mentioned above, the basic philosophy in our SSA-UWB pulse waveform design is contrary to the conventional Gaussian approach, namely, not just trying to construct a pulse waveform in order to satisfy the spectral mask, on the contrary, first starting from considering a required spectral mask in frequency domain (band-limited) and then inversely finding its corresponding wavelet in time-domain (time-limited). Designing time-limited and band-limited functions by predecessors has given rise to the discovery and usage of Prolate Spheroidal Wave Functions (PSWF). Comparing with the equivalent case of Eq. 5, the PSWFs are the solutions of:

$$\lambda_k\phi_k(t)=\int_{-T_p/2}^{T_p/2}\phi_k(\tau)\frac{\sin W_k(t-\tau)}{t-\tau}\,d\tau \qquad (7)$$

Also they are solutions of a second-order differential equation eigenvalue problem:

$$\frac{d}{dt}\Big[(1-t^2)\frac{d\phi_k}{dt}\Big]+(\chi_k-c_k^2t_k^2)\phi_k=0 \qquad (8)$$

The closed-form solution of Eq. 8 is difficult to find, a discrete solution is proposed in Eq. 5 by sampling at a rate of N samples per pulse duration. The problem described in Eq. 5 then becomes:

$$\lambda_k\phi_k[n]=\sum_{m=-N/2}^{N/2}\phi_k[m]h_k[n-m],n=-N/2,\cdots,N/2 \qquad (9)$$

Equation 9 can be written in the matrix form and it is can be find that the approximate solution by means of eigenvalue decomposition. Equation $\lambda_k\psi_k = H\phi_k$ can be expressed in matrix form as follows:

$$\lambda_k\begin{bmatrix}\phi[-\frac{N}{2}]\\ \phi[-\frac{N}{2}+1]\\ \cdots\\ \phi[0]\\ \cdots\\ \phi[\frac{N}{2}]\end{bmatrix}=\begin{bmatrix}h[0] & h[-1] & \cdots & h[-N]\\ h[1] & h[0] & \cdots & h[-N+1]\\ \cdots & \cdots & \cdots & \cdots\\ h[\frac{N}{2}] & h[\frac{N}{2}-1] & \cdots & h[-\frac{N}{2}]\\ \cdots & \cdots & \cdots & \cdots\\ h[N] & h[N-1] & \cdots & h[0]\end{bmatrix}\begin{bmatrix}\phi[-\frac{N}{2}]\\ \phi[-\frac{N}{2}+1]\\ \cdots\\ \phi[0]\\ \cdots\\ \phi[\frac{N}{2}]\end{bmatrix} \qquad (10)$$

where, ψ_k is the eigenvector of matrix H. Therefore, defined ψ_k as $\varphi_1, \varphi_2,\ldots, \varphi_k$ and λ_k as $\lambda_1, \lambda_2,\ldots, \lambda_k$, where, eigenvalues are arranged in descending order, i.e., $\lambda_1>\lambda_2>\lambda_3>\cdots>\lambda_i$.

According to the Eq. 7-10, it can be further concluded that the pulse waveform designs based on PSWFs possess a number of characteristics, namely:

- The pulse waveforms are doubly orthogonal to each other
- Pulse-width and bandwidth can be simultaneously controlled to match with arbitrary spectral mask adaptively
- Pulse-width and Pulse bandwidth can be kept same for all orders of i

When the order of the matrix is a huge number, it will take a long time to calculate all the eigenvalues and corresponding eigenvectors using conventional method, but it's unnecessary to calculate all of them. According to Slepian (1978), the eigenvalues represent the amount of energy inside the band defined by the kernel function, so it is desired to calculate the maximum eigenvalue and corresponding eigenvector.

RESULTS AND DISCUSSION

Simulation results: To take a further study in characteristics of PSWF, computer simulations are carried out to evaluate the influence of simulation parameters and conditions, including order, bandwidth, center frequency and pulse duration.

Get that the simulation result of PSWF pulse in both time and frequency domain with parameters f_H = 5 GHz, f_L = 4 GHz, bandwidth B = 1 GHz, pulse duration T = 6 nsec and order of 0-3, as showing in Fig. 3 and 4.

As indicated in Fig. 3, there isn't DC component in PSWF pulses in time domain and find that the pulse expands along with the order of pulse increasing. Based on the result in Fig. 4, it is can be seen that, the PSD of main lobe over $[f_L,f_H]$ decreases but the side lobe increases in frequency domain when the order get higher. Therefore, it's necessary to choose pulses with low order as basis.

Then, select the PSWF pulse with parameters of pulse duration T = 6 nsec, center frequency = 6 GHz

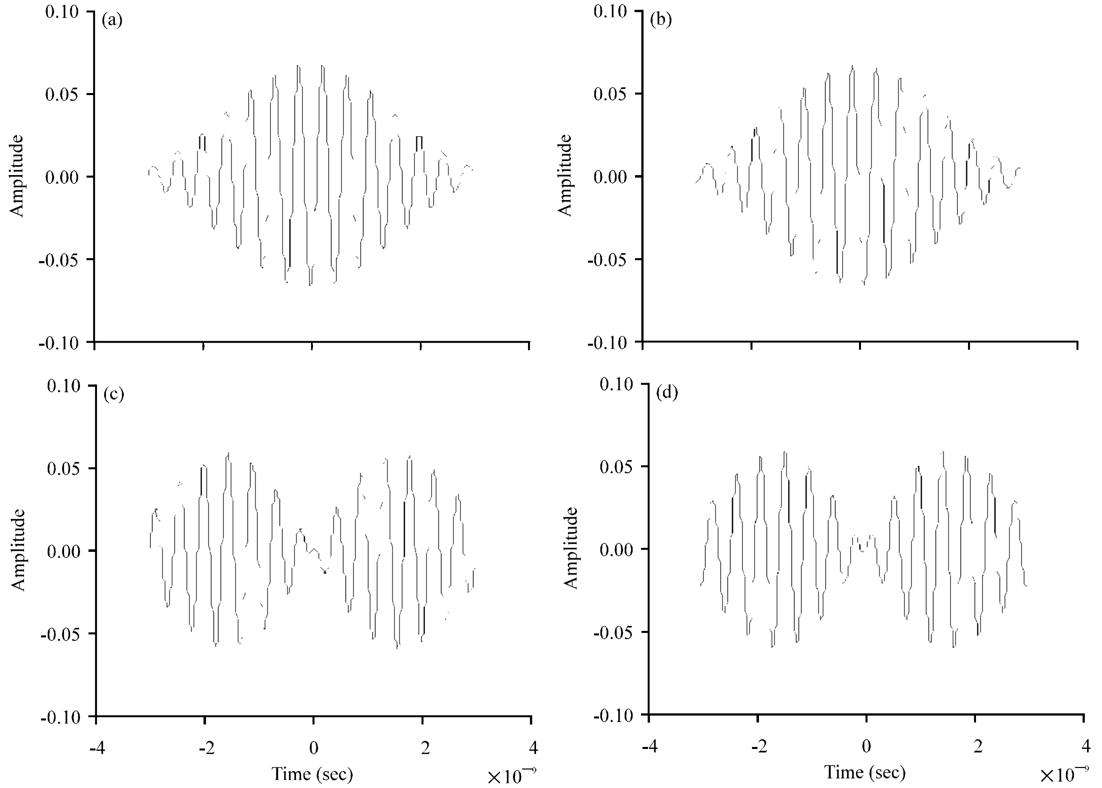

Fig. 3(a-d): PSWF in time domain with order of 0-3, (a) n = 0, (b) n = 1, (c) n = 2 and (d) n = 3

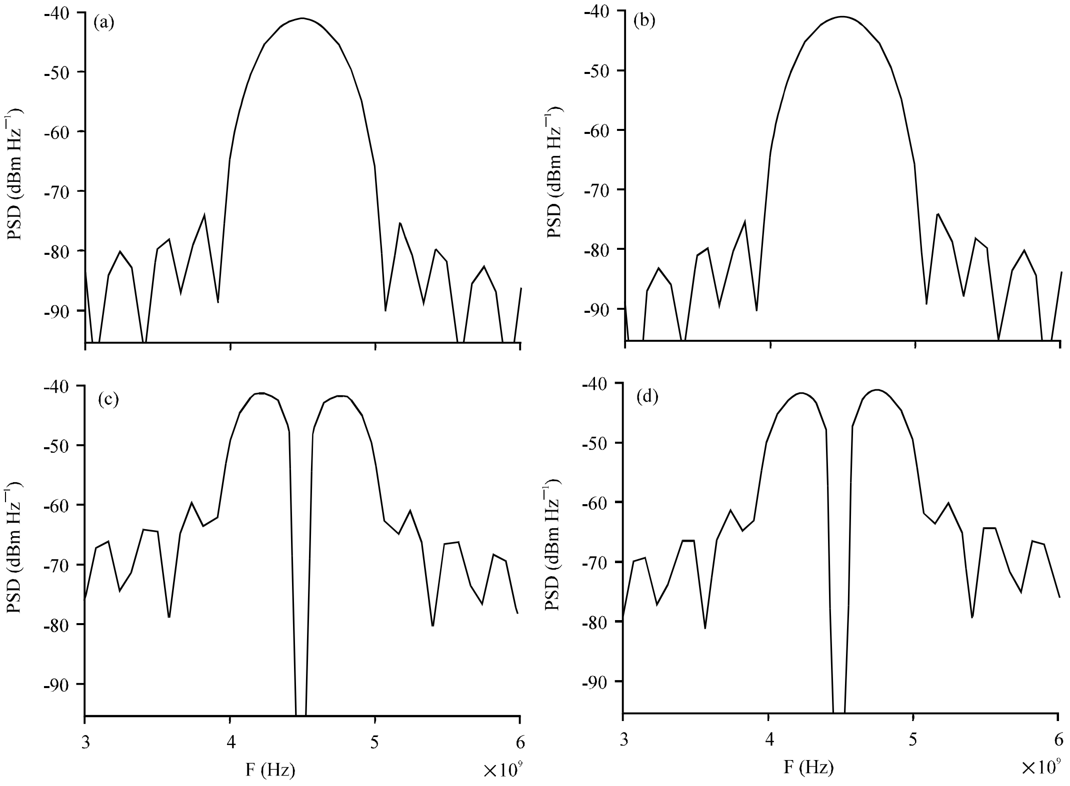

Fig. 4(a-d): PSD of PSWF with order of 0-3, (a) n = 0, (b) n = 1, (c) n = 2 and (d) n = 3

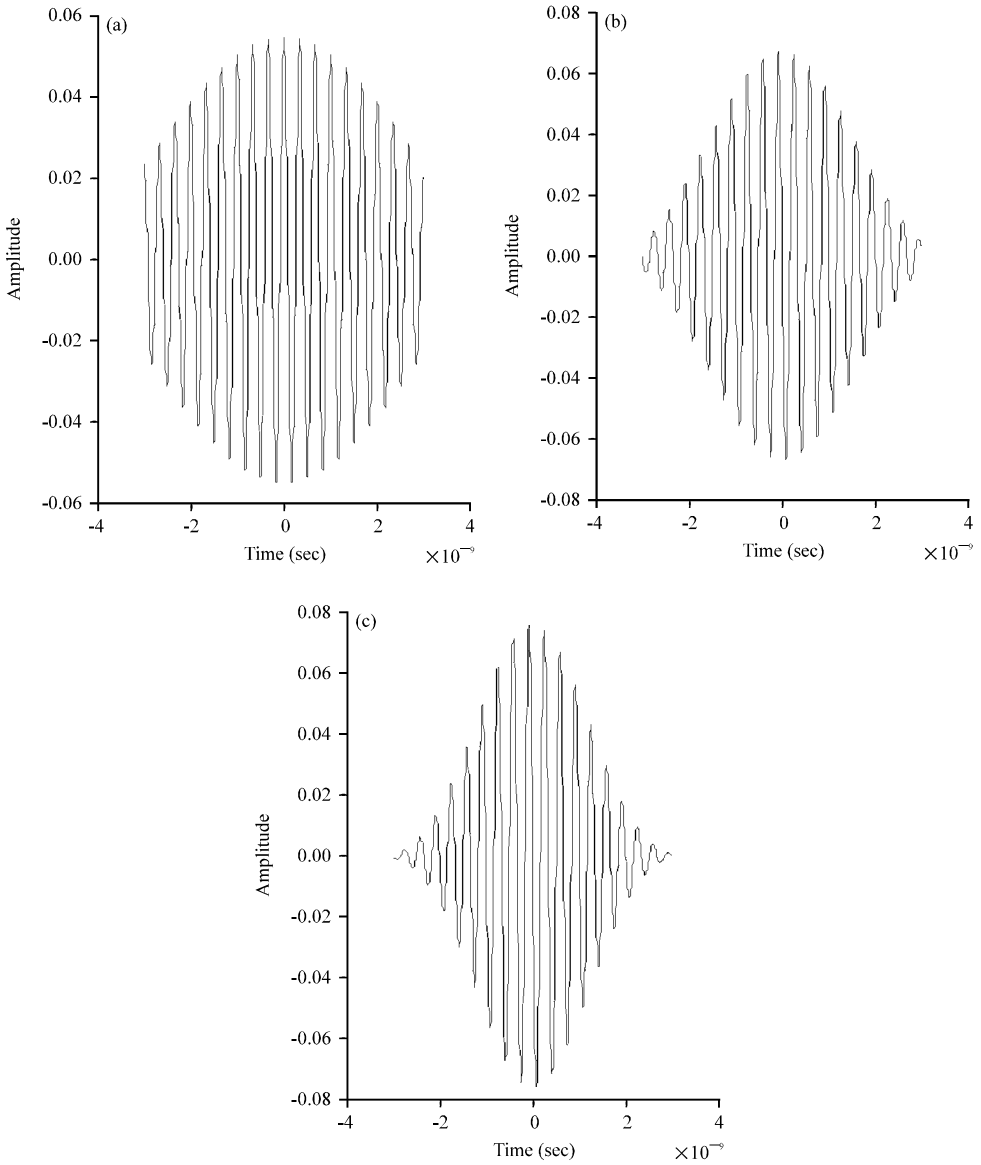

Fig. 5(a-c): Waveform in time domain with different bandwidth, (a) B = 0.5 GHz, (b) B = 1.0 GHz and (c) B = 1.5 GHz

and order of 0, bandwidth B = 0.5, 1 and 1.5 GHz, the results in time and frequency domain show in Fig. 5 and 6.

As we can see in Fig. 5 and 6, the wider of the bandwidth is, the faster convergence rate of amplitude would be in time domain and more effective the side-lobe suppression would be in frequency domain. But spectrum utilization decrease at the same time. Therefore, it's necessary to consider both side-lobe suppression and spectrum utilization when the bandwidth is chose.

Next, get the result in time and frequency domain with the parameters of pulse duration T = 6 nsec, bandwidth B = 1 GHz, center frequency = 4, 5 and 6 GHz and order of 0, the simulation result can be given in Fig. 7 and 8.

From Fig. 7, it is can be seen that there is a positive correlation between center frequency and oscillating frequency. But it also can be observed that the shape of PSD has nothing to do with the center frequency in Fig. 8.

Finally, remain the bandwidth B = 0.5 GHz, center frequency = 6 GHz, order of 0, change the pulse duration of 6, 8 and 10 the results are presented in Fig. 9 and 10.

Based on the result in Fig. 9 and 10, it can be seen that choosing different pulse duration is equivalent to limit the pulse in time domain. Also can see that the longer the pulse duration is, the more concentrative the PSD would be, the lower side-lobe would be. Choose

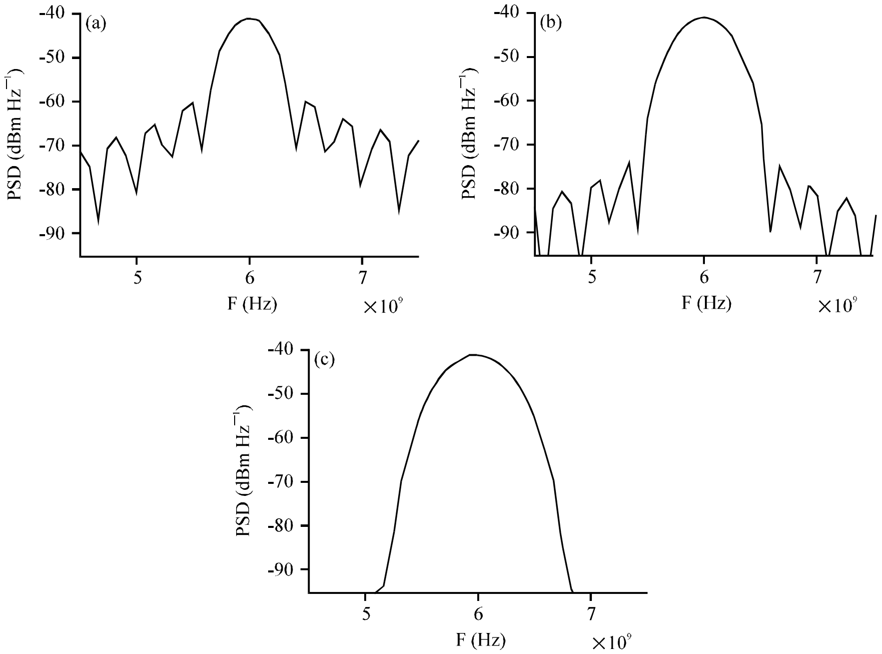

Fig. 6(a-c): PSD of pulse with different bandwidth, (a) B = 0.5 GHz, (b) B = 1.0 GHz and (c) 1.5 GHz

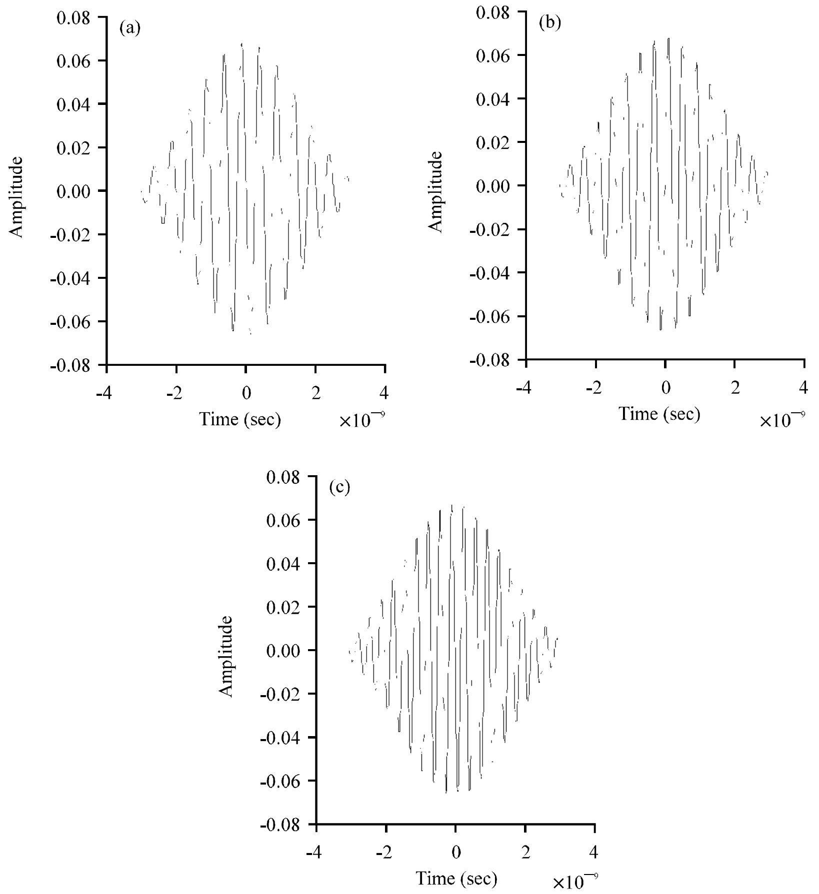

Fig. 7(a-c): Pulse in time domain with different center frequency, (a) f0 = 4 GHz, (b) f0 = 5 GHz and (c) f0 = 6 GHz

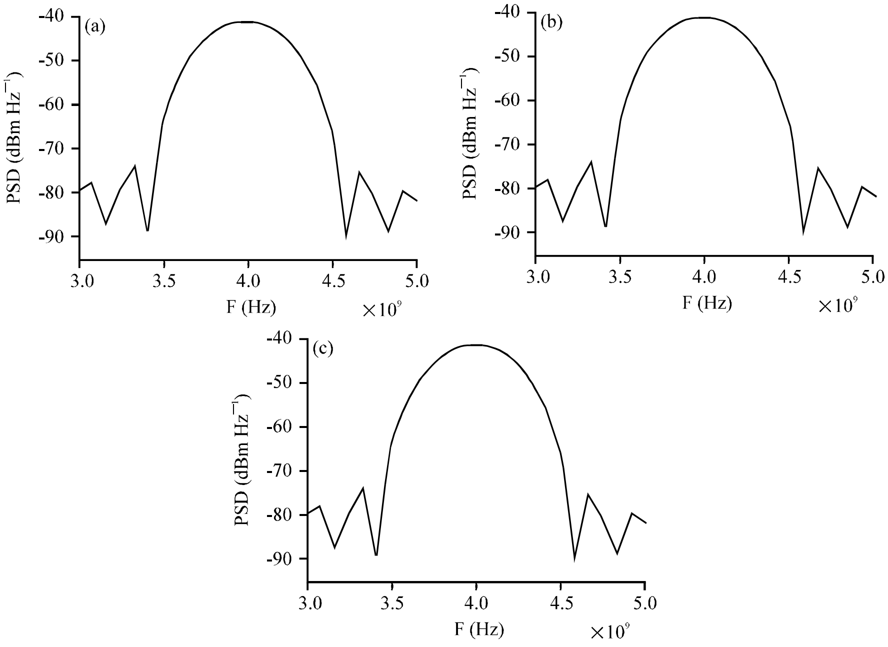

Fig. 8(a-c): PSD of pulse with different center frequency, (a) f0 = 4 GHz, f0 = 5 GHz and (c) f0 = 6 GHz

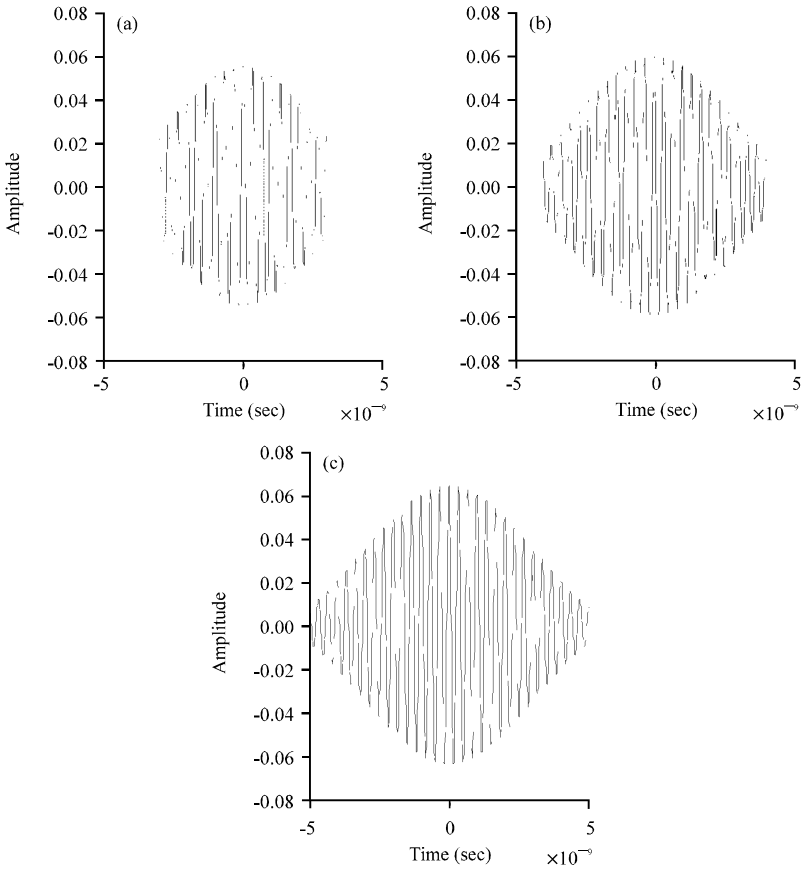

Fig. 9(a-c): Pulse in time domain with different pulse duration, (a) T = 6 nsec, (b) T = 7 nsec and (c) T = 10 nsec

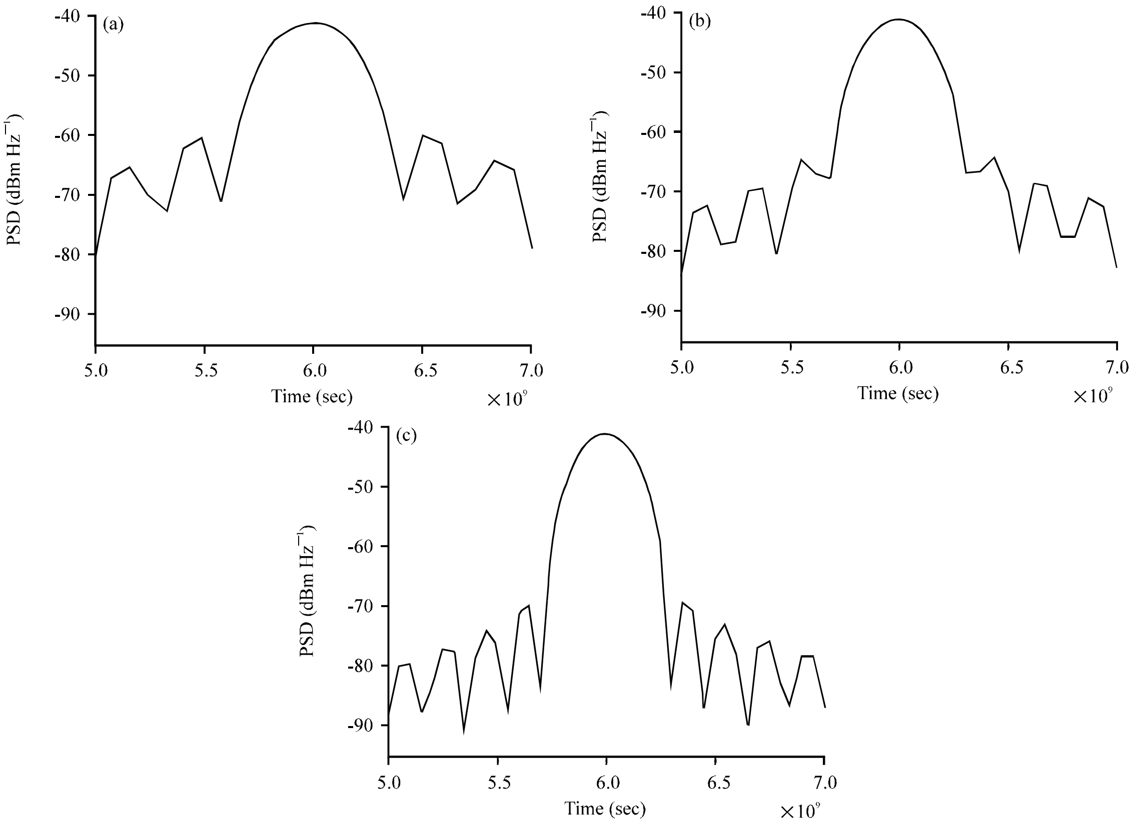

Fig. 10(a-c): PSD of pulse with different pulse duration, (a) T = 6 nsec, (b) T = 8 nsec and (c) T = 10 nsec

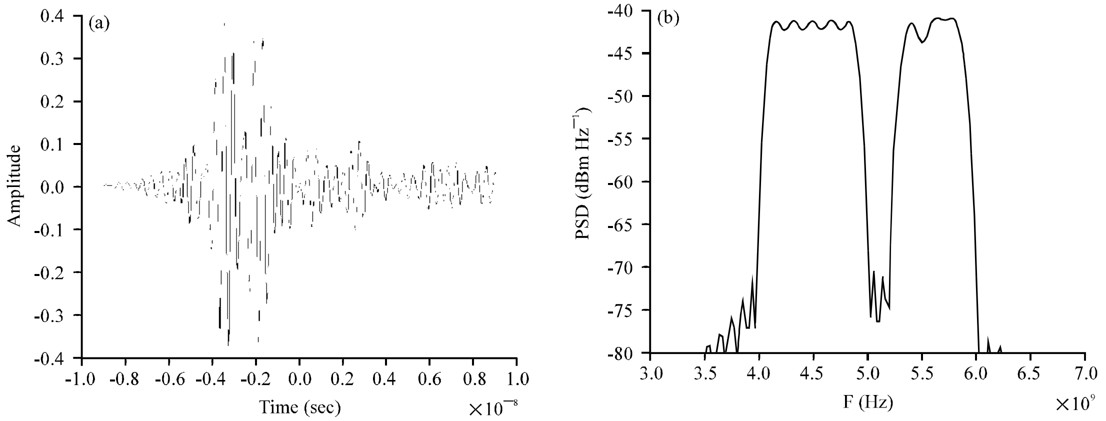

Fig. 11(a-b): Waveform in (a) Time and (b) Frequency domain designed by using SSA

appropriate pulse duration by taking both side-lobe suppression and duty cycle of UWB signals into account.

In summary, in order to meet different requirements when designing UWB pulse waveforms based on SSA and PSWF, can adjust several parameters such as order, pulse duration, center frequency and bandwidth to shape the waveform to be expected.

As to spectral notches, can first design pulse waveforms corresponding to different bands and then achieve spectral notches by combining them together. For example, the requirement of designing is $f_H = 6$ GHz, $f_L = 4$ GHz, B = 2 GHz, we want to achieve spectral notches over 5.0-5.3 GHz with 30 dB. So, design two waveforms with band 4.0-5.0 GHz and 5.3-6.0 GHz, respectively and the required waveform will be obtained by combining them together, just as Fig. 11.

Based on the result in Fig. 11, it is can be seen that the waveform designed by using SSA method based on

PSWF can meet the requirements which can be used as SSA pulse in UWB communication systems.

CONCLUSION

In this study, we have proposed an algorithm which numerically generates pulses whose power spectra fit a desired frequency mask. SSA-UWB wireless system has been analyzed for co-existence, interference avoidance, matching with regulatory spectral mask (e.g., FCC spectral mask) and large volume multimedia rich data. With respect to the SSA-UWB proposal with adaptive multi-band pulse waveform shaping, the design scheme for pulse waveform optimization based on Prolate Spheroidal Wave Functions have investigated.

We have also shown that our proposed algorithm has the following advantages over the commonly used Gaussian monocycle. The resulting spectrum has been shown to fit the FCC spectrum mask and our proposed algorithm provides the flexibility of designing pulses to fit frequency masks with multiple pass bands.

REFERENCES

Choi, S.H., J.K. Park, S.K. Kim and J.Y. Park, 2004. A new ultra-wideband antenna for UWB applications. Microw. Opt. Technol. Lett., 40: 399-401.

FCC, 2002. Revision of part 15 of commission's rules regarding ultra-Wideband transmission systems: First report and order. Technical Report FCC 02-48, April 22, 2002.

Ghavami, M., L.B. Michael, S. Haruyama and R. Kohno, 2002. A novel UWB pulse shape modulation system. Wireless Pers. Commun., 23: 105-120.

Harada, H., K. Ikemoto and R. Kohno, 2004. Modulation and hopping using modified Hermite pulses for UWB communications. Proceedings of the International Workshop on Ultra Wideband Systems, Joint with Conference on Ultra Wideband Systems and Technologies, May 18-21, 2004, Kyoto, Japan, pp: 336-340.

Hu, W. and G. Zheng, 2005. Orthogonal Hermite pulses used for UWB M-ary communication. Proceedings of the International Conference on Information Technology: Coding and Computing, Volume 1, April 4-6, 2005, Las Vegas, Nevada, USA., pp: 97-101.

Kilic, Y., H. Wymeersch, A. Meijerink, M.J. Bentum and W.G. Scanlon, 2014. Device-free person detection and ranging in UWB networks. Sel. Top. Signal Process. J., 8: 43-54.

Kong, W.Y. and V. Rokhlin, 2012. A new class of highly accurate differentiation schemes based on the prolate spheroidal wave functions. Applied Comput. Harmon. Anal., 33: 226-260.

Lee, J.Y. and R.A. Scholtz, 2002. Ranging in a dense multipath environment using an UWB radio link. IEEE J. Sel. Areas Commun., 20: 1677-1683.

Mirshafiei, M., M. Abtahi and L.A. Rusch, 2012. Ultra-wideband pulse shaping: Bypassing the inherent limitations of the Gaussian monocycle. Commun. IET, 6: 1068-1074.

Osipov, A., 2013. Certain inequalities involving prolate spheroidal wave functions and associated quantities. Applied Comput. Harmon. Anal., 35: 359-393.

Parr, B., B. Cho, K. Wallace and Z. Ding, 2003. A novel ultra-wideband pulse design algorithm. IEEE Commun. Lett., 7: 219-221.

Rius, M., M. Bolea, J. Mora, B. Ortega and J. Capmany, 2014. Multiband-UWB signals generation based on incoherent microwave photonic filters. Photonics Technol. Lett., 26: 142-145.

Slepian, D., 1978. Prolate spheroidal wave functions, Fourier analysis and uncertainty-V: The discrete case. Bell Syst. Technol. J., 57: 1371-1430.

Win, M.Z. and R.A. Scholtz, 2000. Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications. IEEE Trans. Commun., 48: 679-689.

Zhang, H. and R. Kohno, 2003. Soft-spectrum adaptation in UWB impulse radio. Proceedings of the 14th IEEE Personal, Indoor and Mobile Radio Communications, Volume 1, September 7-10, 2003, Bejing, China, pp: 289-293.