Abstract
Efficient pulse shaping techniques are required in UWB communication systems to fit the Federal Communication Commission (FCC) mask with reduced interference with other narrow band systems. We propose a pulse shaping technique to fit the FCC mask efficiently by employing our proposed band pass filter. The UWB pulse shape is spectrally modified and analyzed to prove its ability in achieving higher spectral utilization efficiency without employing any optimization techniques as in literature. The proposed band pass filter for pulse shaping has features of sharp transition, desired stop band attenuation and expression for filter coefficients which enables flexible spectral shaping to fit any FCC mask efficiently.

Keywords
Impulse Radio, Monopulse, Spectral Pulse Shaping, Power Efficiency, Power Spectral Density.

Introduction
Ultra-wide band systems have a fractional bandwidth exceeding 0.20 or an absolute bandwidth exceeding 500 MHz as defined by FCC (Y.Rahayu et al., 2008; R.K.Dokania et al., 2011; HaoluXie et al., 2008; Hyunseok Kim et al., 2005). The FCC has standardized the spectral shape and mandated power spectral density (PSD) of -41dBm / MHz for UWB devices for preventing interference with other communication technologies. For UWB communication schemes, efficient pulse shapers are needed for the spectrum of UWB pulses within the FCC mask and high energy effectiveness with negligible interference with other narrow band systems. The pulse shaper designs should be such that the bandwidth and power permitted by the spectral mask of the FCC should be used optimally. The baseband UWB systems can be single-band or multi-band. UWB radio systems transmitter and receiver use single-band or multi-band pulses. In single-band (SB) UWB systems, only one transmission frequency band is used and two or more frequency bands are used in multi-band (MB) UWB systems, each with a bandwidth of at least 500 MHz (Y.Rahayu et al., 2008; G.Zhang et al., 2011). The SB-based UWB systems are also referred to as carrier-free or Impulse Radio (IR) UWB communication systems as the signal generated is very short, low duty cycle, baseband pulse of required shape and duration (M.Z.Win et al., 1998; S.M.Ekome et al., 2011; B.A. Lagovsky et al., 2016). These pulses have quick rise and fall times, resulting in wideband spectra. Then such systems have low system complexity, reduced expenses due to direct transmission and reception of pulsed signals and also owing to the need for the least radio frequency equipment at their front ends as compared to standard narrowband radio systems (B.Parr et al., 2013; L.Li et al., 2011). MB UWB systems implementation can be carrier less or carrier based (Hongsan Sheng et al., 2003; M.Sablatash et al., 2006). The carrier-based UWB scheme is known as multiplexing UWB orthogonal frequency division (UWB-OFDM) where communication methods are used to divide the bandwidth into sub-bands. The ultra-short pulses employed in UWB systems have the advantages of high data rates, superior localization properties, low complexity receivers, multi-path immunity, jamming resistant, and very excellent time-domain resolution that are crucial for location and tracking applications (I.I.Immoreev et al., 2002; H.Werfelli et al., 2013). UWB transmitter does not require mixing stage for the signal propagation since they produce very short time-domain pulses of nanosecond duration unlike narrowband. Since the permissible power for data transmission is very low these pulses are designed with very low energy. The UWB has applications in wireless communications, radar imaging, vehicle radar, high-data communications, automotive radar, ground penetrating radar, radio frequency identification, in-wall imaging, consumer electronics and PCs as well as wireless sensor networks.

The contents of this paper include review of UWB pulse shaping techniques, expression of filter coefficients of a novel FIR filter for UWB pulse shaping, simulations and results of UWB pulse shaper and conclusion.

Review of UWB Pulse Shaping Techniques
The UWB pulse waveform is a function which should meet the spectral mask regulatory requirements. Since the transmission power spectrum in UWB devices is strictly restricted by the statutory FCC spectral mask, the pulse
filters is influenced by the selection of pulse form, recipient bandwidth selection, bit error rate and efficiency in decrease power distribution interference in a frequency band from 3.1 GHz to 10.6 GHz. The design of the duration reduce the data rate and system ability. The challenge is therefore to design short-term pulses to reduce the energy consumption and interference. The proposed method is not an optimal solution. The semi-definite programming (SDP) method is used in (E.Baccarelli et al, 2003) .The designed pulses have higher flexibility and FCC spectral mask compliance attained employing the Parks-McClellan algorithm (E.Baccarelli et al, 2009). The produced pulses have a flexible property for preventing interference and thus guarantee negligible interference with other existing narrow band (NB) schemes. They also meet the mask criteria of the FCC Power Spectral Density (PSD). An approximate sinc function using Gaussian pulse as the basic function is shown in the pulse shaping technique discussed in (X.Liu et al, 2008). The produced pulse has appealing characteristics such as high spectrum utilization efficiency (SUE), FCC mask compliance, flexible interference prevention, flexible pulse duration to fulfill various data rate demands and very excellent jitter resistant property particularly when timing jitter is comparatively high in multipath setting. Hamming and Hann windowed pulses (N.C. Beaulieu et al, 2006) and sinc based monocycles (N.C. Beaulieu et al, 2008) are the widely used technologies for generating orthogonal UWB pulses in multiple access applications to decrease bit error rates. Under different channel circumstances, the spectrum feature and the bit error rate of the pulse waveforms are discussed in (J.Joe et al, 2003) . Considering additive white Gaussian noise channels, multiple access interference channels and fading multi-path channels, the different channel conditions are realized. The algorithm provided in (Lu Yin et al, 2005) is flexible in developing ultra-wideband pulses that meet the demands of the FCC spectral mask and has superior bit error rate performance. A novel pulse design is suggested based on Hermite functions in (M.Ghavami et al, 2003). The pulse shapes meet the multi-access FCC emission boundaries and the appropriate pulses have excellent orthogonality. AWGN noise performance assessment demonstrates that these pulses are robust to pulse jitter and deliver outstanding BER output. (Bo Hu et al, 2005) introduces an algorithm designing two powerful orthogonal pulses restricted to a short time. These pulses power spectra fit the desired frequency mask. Prolate Spheroidal wave functions are another widely employed FCC-compliant orthogonal pulses. The pulse response generated employing pulse shapers can be approximated to the least square sense of Prolate Spheroidal pulses (B.Parr et al, 2003) . Other transfer functions that provide highly extremely impulse responses which are FCC compliant are also presented. The PSD is minimized by distributing energy in frequency range and thus reducing the interference probability with other user systems. Modified Hermitean and Prolate Spheroidal pulses are commonly used in multi-access UWB communications using orthogonal pulses. FIR filter techniques are extensively employed for pulse shaping. Spatial filters also extensively use FIR filters in antenna array beamforming to obtain a highly directive beam (L.J.Gudino et al, 2008; L.J.Gudino et al, 2009) . The designed pulses have higher flexibility and FCC spectral mask compliance attained employing the Parks-McClellan algorithm (E.Baccarelli et al, 2008). However, since the length of the filter and therefore the pulse length is very large, this can lead to overlapping pulses, increased energy consumption, interference and therefore the proposed method is not an optimal solution. The semi-definite programming (SDP) method is used in (M.Rezaii et al, 2010) to reduce the filter length as well as to meet FCC spectral mask specifications. Pulse shaping is done with pulse shapers called band pass filters. But the filtering methods that extend the pulse duration reduce the data rate and system ability. The challenge is therefore to design short-term pulses to decrease power distribution interference in a frequency band from 3.1 GHz to 10.6 GHz. The design of the filters is influenced by the selection of pulse form, recipient bandwidth selection, bit error rate and efficiency in...
multi-path propagation settings. In this paper, we described the design of an FIR filter in order to achieve a pulse with optimal power efficiency. We discussed an approach to formulate the magnitude constraint. We applied this approach for shaping monocyte pulse using filters of different length for compliance with required FCC mask spectral emission constraints.

In this paper, a UWB pulse shaping technique is introduced using a FIR band pass filter. This technique is flexible to fit into any FCC mask with good spectral utilization efficiency. A Closed form expression is obtained as a shaping function for this purpose.

Expression for Filter Coefficients

In this section, an expression for filter coefficients of band pass filter is proposed for spectral shaping of the UWB pulse. The proposed filter possesses sharp transition, low pass band ripple and good stop band attenuation to fit the FCC mask regulations. Its magnitude response can be tailored made to fit any FCC mask requirements. The magnitude response H(\(f\)) of the filter is modelled with well behaved trigonometric functions of frequency. Applying the cosine transformation (L.J.Gudino et al., 2008) to the magnitude function H(\(f\)), we obtain an expression for filter coefficients of the band pass filter as:

\[
\begin{align*}
h(n) &= \frac{A\delta_p \cos k f_p}{\pi \left(U_{pb}^2 - k^2\right)} \left[ U_{pb} \sin U_{pb} f_p \cos k f_p - k \cos U_{pb} f_p \sin k f_p \right] \\
+ \frac{A \delta_p U_{pb}}{2\pi \left(U_{pb}^2 - k^2\right)} \left[ \cos U_{pb} (f_s - f_z) - \cos k (f_s - f_z) \right] \\
+ \frac{A}{k^2 \pi (f_z - f_p)} \left[ \cos k (f_z - f_p) - \cos k (f_z - f_p) + k (f_z - f_p) \sin k (f_z - f_p) \right] \\
+ \frac{A}{k^2 \pi (f_z - f_p)} \left[ \cos k (f_z + f_p) - \cos k (f_z + f_p) - k (f_z - f_p) \sin k (f_z + f_p) \right] \\
+ \frac{A \delta_z}{2\pi \left(U_{pb}^2 - k^2\right)} \left[ U_{pb} \cos U_{pb} (\pi - (f_z + f_p)) \cos k \pi - U_{pb} \cos k (f_z + f_p) \right] \\
+ k \sin U_{pb} (\pi - (f_z + f_p)) \sin k \pi + \frac{2A}{k \pi} \cos k f_p \sin k f_p \\
\end{align*}
\]

where, \(n = 0, 1, \ldots, (L/2)-1\) for \(L\) even, \(n = 0, 1, \ldots, L-(1/2)\), for \(L\) odd and \(k = \{(L-1)/2\} - n\).

The band pass filter design parameters are \(A\) the peak gain, \(U_{pb}\) controls the shape of magnitude function \(H(f)\) in the pass band, \(f_p\) is the pass band frequency, \(H(f)=0\) at frequency \(f_s\), for the filter design model, \(f_b\) is the centre frequency, \(\delta_p\) is the pass band ripple, \(\delta_z\) is the stop band attenuation and \(L\) is the length of the filter.

Simulations and Results

A UWB band pass filter for pulse shaping is synthesized to fit the FCC mask of 3.1GHz to 10.6 GHz. The designed band pass filter is employed to shape the Gaussian monocyte pulse to obtain a modified pulse with good power efficiency employing filters having length \(L\) of 21 and 37. The filter normalized specifications to fit the FCC mask are centre frequency \(f_c\) of 0.6\(\pi\), lower cut-off frequency \(f_l\) of 0.2575 \(\pi\), upper cut-off frequency of \(f_u\) of 0.9425 \(\pi\) and transition band of 0.018\(\pi\). The sampling frequency \(F_s\) is 22GHz. We consider a UWB Gaussian monopulse with Tg of 0.186ns. Fig.1 and Fig.2 respectively shows the FCC mask and PSD of the proposed pulse shaping bandpass FIR filter with \(L\) of 37 and \(L\) of 21. Its impulse response \(h(n)\) is shown in Fig.3. For \(L\) of 21, it is observed in Fig.2 that side lobe level (SLL) and power efficiency deteriorates. The obtained PSD very closely matches the FCC spectrum and power efficiency of 91.2% is achieved for \(L\) of 37. The Power efficiency of the proposed method is compared with other methods as shown Table 1. An improvement of 7.2% in power efficiency is achieved for \(L\) of 37 compared to \(L\) of 21. It is observed that for the same power efficiency, the length of UWB pulses required for our proposed method is lesser than some methods as inferred from Table 1. In addition, the suggested technique does not use computationally intensive optimization techniques. It is observed from Fig.1 that the proposed FIR filter has tapering frequency response characteristics which fits into the FCC mask efficiently. It possesses good first null to last null ratio of 0.852 and flat pass band is achieved that increases spectral utilization efficiency. Other advantages of the proposed pulse shaping filter has an adjustable centre frequency and pass band, sharp transition with low side lobe level to fit into any FCC mask with least filter length compared to some of the existing techniques which employ optimization techniques (M.Rezaii et al., 2010).
Fig. 1: Regulatory FCC Spectral Mask for UWB Band of 3.1 to 10.6 GHz and PSD of Proposed Band Pass Filter for Pulse Shaping with L=37.

Fig. 2: PSD of Proposed Band Pass Filter for Pulse Shaping with L=21

Fig. 3: Proposed Pulse Shaper Impulse Response h(n). Shaping with L=37

Table 1: Power Efficiency of Proposed Pulse Shaping Method for Filter Lengths L=37 and L=21 and Other Methods.

| Design Technique              | Filter lengths L | Power Efficiency |
|------------------------------|------------------|------------------|
| Proposed pulse shaping       | 37               | 91.2%            |
| Proposed pulse shaping       | 21               | 84%              |
| Parks-McClellan (E. Baccarelli et al., 2008) | 37 | 85.47% |
| SDP-Non Constant PSD (M. Rezaii et al., 2010) | 37 | 92.7% |
| SDP-Non Constant PSD (M. Rezaii et al., 2010) | 21 | 87.8% |

Conclusion
To avoid interference problems, the FCC has specified the spectral shape for UWB pulse communications. The proposed band pass filter spectrally modifies the UWB pulse to be transmitted. It possesses features of sharp transition to fit the requirements of FCC mask, good stop band attenuation and a simple design procedure without optimization. The pulse shaping filter is adaptable to any change in centre frequency, transition width and pass band width to fit any FCC mask. Expressions for the impulse response are derived, its coefficients are obtained and simulation of pulse shaping band pass filter is carried out. Obtained PSD closely matches with FCC mask and power efficiency of 91.2 % is achieved. The performance using different pulse shaping techniques is examined and compared with the proposed method.
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