Pulse Shaping for Impulse Radio UWB

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1. Introduction

There are many ways how to increase quality of service (QOS) or the number of wireless users in the shared spectrum of modern wireless communication. It is possible to use better modulation schemes or multiplexes, but all of these techniques do not constitute a dynamic solution. A more intelligent solution of the spectrum access gives us the potential to solve these spectrum problems. Cognitive systems recognize other services and they are able to change their radio parameters in order to communicate with other cognitive nodes. This idea was well described in [1]. Ultra Wideband (UWB) technology serves as a powerful technology for the physical layer of wireless communication systems. The large bandwidth (7.5 GHz [2]) of UWB could also be used as the physical layer for the most common services. Wimedia Alliance has developed MB-OFDM UWB [3] (Multi Band Orthogonal frequency Multiplex) systems for Wireless USB and other hi-speed applications such as video streaming. This technology uses several bands with a width of 528 MHz within the FCC spectral mask [2]. The cognitive technology principles have already been presented for the MB-OFDM UWB by channel cancelation.

In this paper, we focus on pulse UWB where the basic modulations such as OOK and basic amplitude detection are supposed. The biggest disadvantage of the pulse system is the fact that it is not possible to use classic narrowband detection (super heterodyne receiver) because it is very difficult to use down conversion in pulse systems. These systems use different techniques to access the physical layer which are corresponding to optics principles or radar techniques. The power spreads into the wide bandwidth of the pulse where data are modulated directly, and the pulse is processed as a carrierless signal in the baseband.

There are several shaping techniques presented in [4]. In this paper another principle of shaping technique is presented. The basic Gaussian pulse is directly shaped in the time domain so that the frequency spectrum of this pulse is shifted to an appropriate frequency. Measured data from the simplified system model are presented in chapter 3.

This paper is organized as follows. Following this introduction, the frequency spectral mask shaping and the system model are explained. Measurements are then presented in part four, followed by the conclusion at the end.

2. Frequency mask shaping

Usually, the pulse is shaped in one of two basic ways. First, it is possible to use specially designed filters to compensate for channel pulse distortions [5]. Or, the pulse could be modulated by harmonic function. This modulation does not ensure a higher transfer speed but it does guarantee better spectral properties. Moreover it is possible to shape the spectral shape of the pulse with this modulation technique:

$$\begin{aligned} g_s(t) &= g(t)A\cos(2\pi f_s t) \\ g(t) &= Ce^{-\left(\frac{t}{\tau}\right)^2}, \end{aligned} \tag{1}$$

where $g_s(t)$ is the shaped Gaussian pulse, $g(t)$ represents the standard well-known Gaussian pulse, A and C are the energy constants, τ is a time-scaling factor and f_s stands for the shifting frequency.

We used the effect of modulation on UWB pulse to find a mechanism that shapes UWB pulses to accomplish various shapes of spectral masks. Moreover, it would seem to be possible to add it to the signal required energy level through harmonic signal. The creation of the Gaussian pulse could be done in many ways [6], but there is a great deal of influence in the power of the parts of the UWB pulse [7].

However, the simple multiplication of the UWB pulse with the harmonic function is not acceptable for the real system. The pulse should be shaped with higher dynamicity which could be created by the multiplication of several harmonic pulses (2).

$$g_{shifted}(t) = g(t)\sum_{i=1}^{N} D\cos(2\pi f_{s,i} t), \tag{2}$$

where N is number of shifting frequencies and each frequency component has the frequency $f_{s,i}$ with amplitude D.

When creating a complex system for pulse shaping we need to have the opportunity to control power in each of these sub-bands. The simulation of this cancelation is presented in Figure 1 based on (3). It is possible to optimize the pulse shape and number of pulses to reach maximal usage of available band.

$$\begin{gathered} g_{shifted} = g(t)\sum_{i=1}^{4} D_i \cos(2\pi f_{s,i} t) \\ f_{s,i} = \{4.5, 6, 7.5, 9\}\ GHz, \\ D_i = \{1, 0, 0.3, 0.75\} \end{gathered} \tag{3}$$

where $f_{s,i}$ is the vector of shifting frequencies and D_i stands for the energy coefficients of the gain control of each f_s.

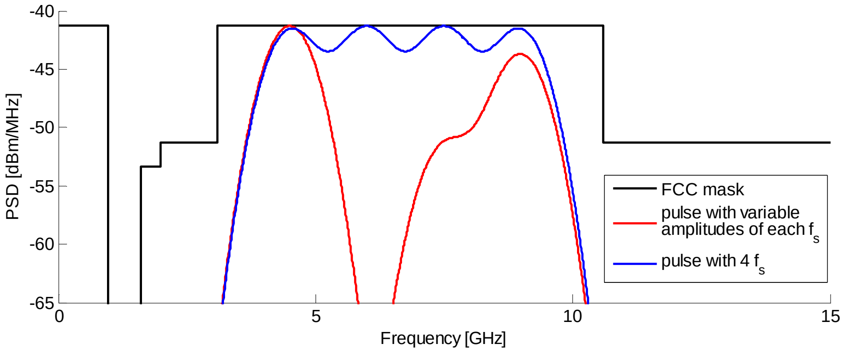

Figure 1: Simulation of shifted pulse contains 4 shifting frequencies f_s (blue line) and the pulse with variable energy coefficients of shifting frequencies (red line)

3. System model

A model of the system is depicted in Figure 2, where the main parts of our proposed system are highlighted. Each generator of harmonic frequency contains an amplifier because it is easier to create an amplifier of one single frequency rather than a wideband amplifier with constant gain through the whole UWB band. The fast controllable switches are necessary for successful band cancelation and pulse shaping. These switches are managed by a control unit which has to change according to input cognitive data. This cognitive unit needs to change based on input values from another part of the cognitive radio, namely its radio parameters, and designates the current spectral limitation which needs to be filled. Clearly, the control unit of this radio is the most essential aspect of it.

Firstly, the control unit needs to control the repetition rate of the pulses which take into account the width of the pulse in both time and frequency domains. With the basic calculation using OOK, it is possible to calculate the maximal theoretical bit rate. The transfer speed of this type of communication system is under significant influence of the guard interval in the system. The time scaling factor τ is the main parameter determining the width of the pulse in the time domain and frequency domain. It is necessary to mention, that the higher the τ is, the lower the width the pulse in the frequency domain is (wider pulse in the time domain and lower theoretical bit rate).

Secondly, as was mentioned before, it is better to control the gain of the shifting frequency in order to achieve better amplitude performance of the system. Each of the shifting frequencies needs to have its own controllable amplifier which could control the total power in each sub band in several steps.

Finally, the sub-band cancelation is the main part of the proposed system. For the system to work correctly it is important to use only the demanded frequencies which are necessary and the control unit has to decide how many bands are needed to use with the appropriate parameters such as τ.

4. Measurement

The shifting of the UWB pulse spectrum was proved by measurement. We have started with the basic situation where we used the system model presented in Figure 2 with one shifting frequency (N=1) and without any controlling unit. We used “Gaussian waveform” from one of our pulse generators 1105DLP2 [8] with a high ineligible DC component. The measured configuration is depicted in Figure 2.

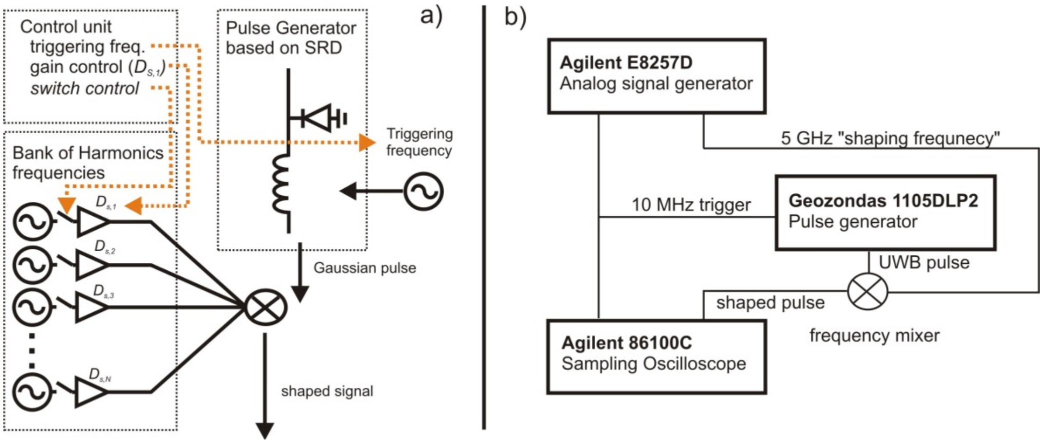

Figure 2: Model of proposed system a) and the measured configuration b)

A 10 MHz trigger was used to synchronize all measuring devices. The pulse generator, 1105DLP2, is able to produce several widths of the pulse in the time domain; both examples are presented in Figure 3. Finally, a 5 GHz harmonic wave was used as the shifting frequency, which was multiplied with the UWB pulse by a typical frequency mixer [9]. This frequency was chosen because of its location in the middle of the UWB band and it is far enough from the generated Gaussian pulse. The results were sampled by a sampling oscilloscope directly in the time domain. The shaped spectrum is symmetric and the harmonic frequency is not dominant in the moved spectrum.

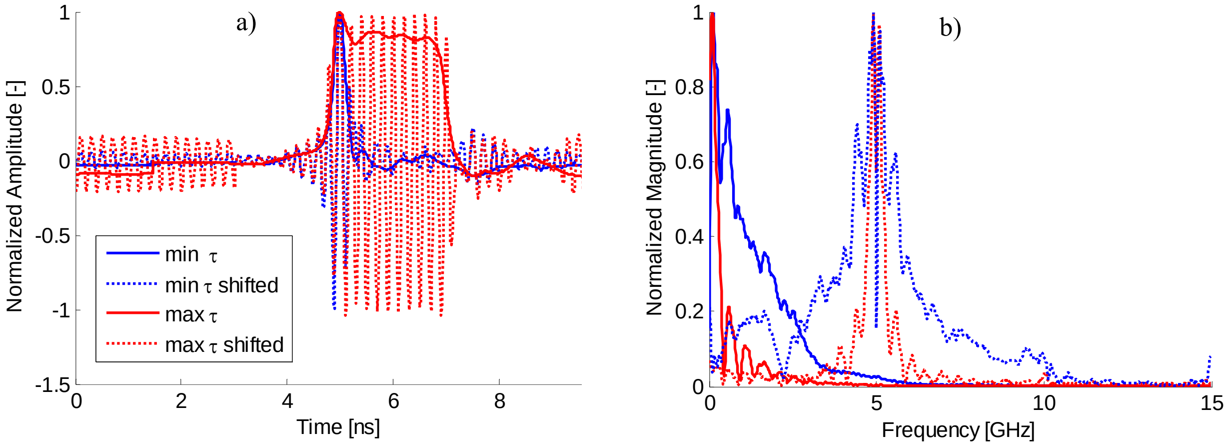

Figure 3: Measured data for UWB pulse with minimal width (red line) and maximal width (blue line) in time domain a) and frequency domain b)

No matter how the shaping frequency is recognizable in the shaped frequency domain signal (Figure 3), it is necessary to mention that we assume no other radio users at this significant frequency. Otherwise the power of the harmonic frequency could decrease or another shifting frequency will be chosen. In Figure 3 it is possible to see the 5 GHz harmonic function modulated on the pulse.

5. Conclusion

A UWB system using pulse shaping to create a pulse with specific properties was presented in this paper. The system is based on the multiplication of the Gaussian pulse with the harmonic function (single frequency spectrum). Several types of frequency spectrums of the shaped pulse were presented and these were predetermined to pass several spectral limitations. In every particular way, it is possible to fill any type of spectral mask (FCC, EC) with different pulse shapes or power and frequency limitations. This fact is important when setting up UWB technology into the modern cognitive system. The sub-band limitation (up to zero power in the sub-band) allows the modified UWB pulse with the primary users in the shared spectrum to be used. The sub-bands are limited according to the frequency sensing data which is the practical implementation of the awareness aspect of the cognitive radio. The shaping technique could also be used for optimal spectral filling. The power limitations of the wireless systems represent the biggest potential problem for error-free radio communication.

Future work will be focused on further experimental validations. A new experiment to prove even more complex system models based on multiple shifting frequencies and several types of pulses is under preparation

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