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Design of Orthogonal Frequency Division Multiplexing Based Single Band Ultra Wideband System with Analysis of Impact of Channel Delay

Santosh Parajuli
Teaching Assistant, Department of Electrical and Electronics Engineering, Kathmandu University, Nepal

Brajesh Mishra
Assistant Professor, Department of Electrical and Electronics Engineering, Kathmandu University, Nepal

Abstract

OFDM based Ultra Wideband (UWB) system combines OFDM modulation technique which divides the spectrum into several sub-bands, whose bandwidth is approximately 500MHz. Single band OFDM UWB system, has been designed. QPSK is chosen as modulation technique within OFDM.
The important blocks in the transmitter side are QPSK modulator, IFFT and DAC. We model channel as a simple delay element. A basic receiver just follows the inverse of the transmission process so important blocks in the receiver side are down converter, ADC and FFT.

OFDM based system is very sensitive to timing and frequency offsets, the received constellation is slightly different from transmitted constellation due to processing delay and additional delay introduced from the channel. This paper provides the impact of delay on OFDM based UWB system.

1. Introduction

Ultra Wide Band (UWB) offers a high data rate, low cost solution to Wireless Personal Area Networks (WPANs). Shannon Hartley theorem shows that higher data rate can be achieved at a faster rate by increasing the bandwidth rather than the received SNR according to equation-1.

$$C = B\log_2(1 + SNR) \qquad (1)$$

FCC allows UWB radio to use 7500 MHz of spectrum in unlicensed band especially for communication applications in the 3.1–10.6 GHz frequency band [1]. FCC requires UWB to use at least 500 MHz bandwidth in the above mentioned band by limiting the transmission within the interference mask as shown in fig. 1.

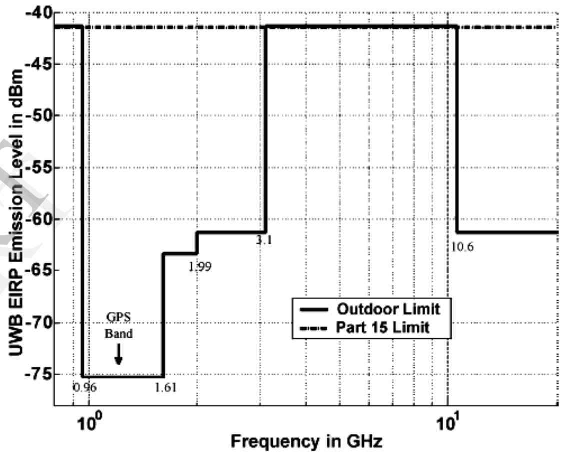

Fig 1: UWB spectral mask for outdoor communication systems. Emission level is measured in 1-MHz bandwidth [2]

UWB always operate below -41.3dBm/MHz. UWB is power limited communication system. Due to the power limitation and since received SNR is a function of distance due to path loss, there is fundamental trade-off between data rate and distance also in UWB [3].

Single-band and multi-band UWB technologies are widely used. Single-band UWB is the traditional way of generating UWB pulse also known by the name of Impulse Radio (IR). OFDM based multi-band UWB is the most popular in the present day scenario. In this paper we design an OFDM based single-band UWB system. So, our paper shows that IR principle is not only a choice for UWB signal generation which demands a difficult pulse shaping method to meet UWB standard [4]. We also analyze the performance of our system in terms of recovered constellation.

This paper is organized as follows. Section 1 gives the introduction to UWB and the objectives of this paper. Section 2 describes OFDM its advantages along with its use in UWB. In section 3 we give the system model and simulation parameters used in the study. Section 4 gives the simulation results. Finally section 5 concludes the paper.

2. Orthogonal Frequency Division Multiplex

OFDM is a type of multi channel modulation technique that divides a given channel into many parallel sub-channels so that multiple symbols are sent in parallel so that each sub-carrier experience a flat channel. An OFDM signal consists of N orthogonal sub-carriers modulated by N parallel data streams. Each base-band sub-carrier is of the form given by equation-2.

$$\phi_k(t) = e^{j2\pi f_k t} \quad (2)$$

where, f_k is the frequency of k_{th} sub-carrier. $\phi_k(t)$ forms an ortho-normal basis function. One baseband OFDM symbol multiplexes N modulated subcarriers as given by equation-3.

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x_k \phi_k(t) \qquad 0 < t < T_S \quad (3)$$

where, x_k is the k_{th} complex data symbol taken usually from a QPSK constellation and T_S is the length of the OFDM symbol, $T_S = NT$ where N is the number of sub-carriers and T is the base band elementary period. The subcarrier frequencies f_k are equally spaced as $f_k = k / T_S$ which makes the subcarriers $\phi_k(t)$ on $0 < t < T_S$ orthogonal.

For continuous time implementation as in equation-3 it needs N oscillators and DACs, which is of very high complexity. So, discrete time implementation of equation-3 is commonly used in practice, which is achieved by T spaced sampling as given by equation-4

$$s(nT) = IDFT(x_k) \quad (4)$$

IDFT is implemented by using IFFT and the frequencies are orthogonal because the basis function of Fourier transform is orthonormal [5].

2.1 Single Band OFDM based UWB

Traditional single band UWB radio is base-band transmission scheme. The OFDM based UWB can be easily converted into pass-band transmission just by using an up-converter. The centre frequency can be shifted to any frequency band. This relaxes the hardware complexity which was a problem for IR radio. 500 MHz bandwidth can be obtained by properly selecting the OFDM symbol duration. For e.g., OFDM symbol duration of 242.4ns consisting of 128 sub-carriers give 528MHz bandwidth which is the minimum requirement to be UWB radio.

3. System Model

The model in fig. 2 can be used to implement OFDM based UWB system by suitably choosing the pass-band carrier frequency. The complete system level block diagram is shown below.

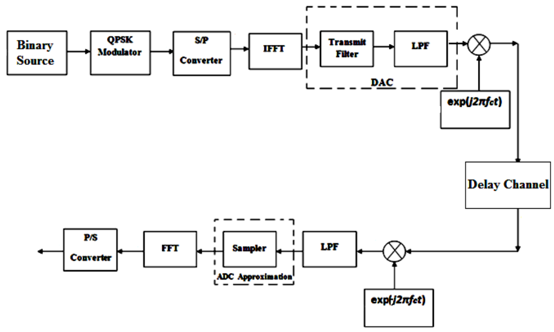

Fig 2: System level block diagram of single-band OFDM UWB

QPSK block is a complex vector generator. This takes input bit streams and maps into QPSK signal constellation lowering the input data rate. Serial to parallel converter block further increases symbol duration which helps to reduce the influence of ISI [6]. IFFT block convert the frequency bins from QPSK constellation to discrete time domain signal. So, we need digital to analog converter after doing IFFT for continuous time analog transmission. Transmit filter and low-pass filter can be used to simulate the DAC. Two methods are considered to design the Transmit Low Pass Filter (TX LPF) [7]

- Fix 528MHz sampling rate of DAC, and design high order TX LPF.
- Increase sampling rate of DAC, and reduce the order of TX LPF.

The continuous time signal after DAC is up-converted at center frequency of 3960MHz. We model channel as a simple delay element. We will show the effect of channel delay on the received constellation. A basic receiver just follows the inverse of the transmission process so important blocks in the receiver side are down converter, ADC and FFT. The simulation parameters used are shown in Table 1.

Table 1: OFDM based UWB system parameters used in the simulation

Simulation Parameter	Value
Center frequency (f_c)	3960MHz
Number of Subcarriers (N)	128
Constellation	QPSK
FFT Size	256
OFDM Symbol Duration (Ts)	$242.4e{-}9S$
Baseband Period (T)	$242.4e^{-9}/128S = 1.89nS$
System Bandwidth	$528MHz$
Transmit Filter Duration	$T/2 = 0.9469nS$
Transmit LPF cut-off frequency	$1/T = 528MHz$
Cyclic Prefix	$60.6nS$
Guard Interval	9.5nS
Transmit spectrum power	Always less then $-41.25dBm/MHz$

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4. Results

The baseband OFDM spectrum, at transmitter side is shown in fig. 3. Note that the sub-carriers are orthogonal in the baseband and not in the pass-band.

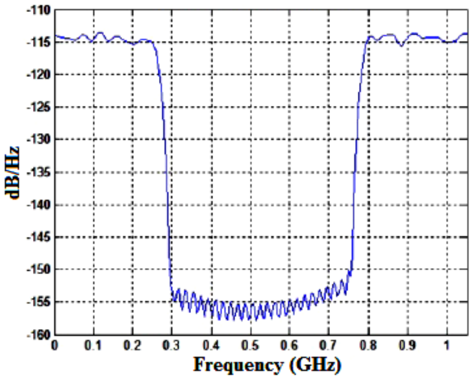

Fig 3: Baseband OFDM UWB spectrum

The transmitted OFDM spectrum is shown in fig. 4. The spectrum is under the FCC UWB mask occupying bandwidth of $\approx 528MHz$.

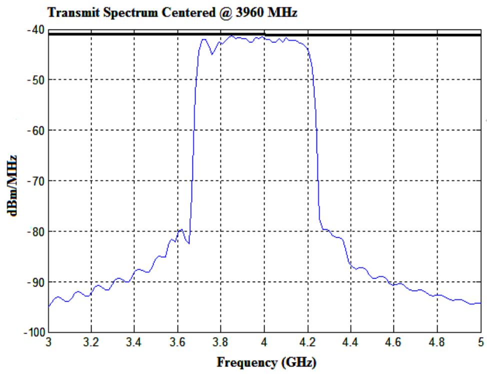

Fig 4: Transmitted OFDM UWB spectrum

The recovered baseband spectrum at the receiver side is shown in fig. 5.

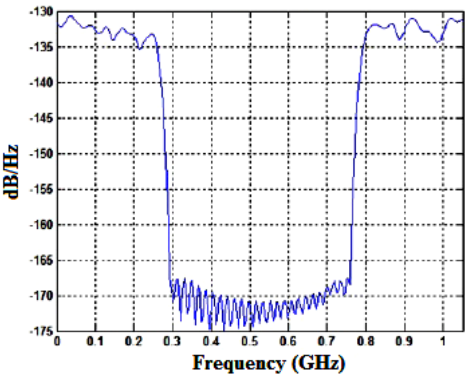

Fig 5: Recovered baseband OFDM UWB spectrum

Recovered QPSK constellation at different channel delay is shown in fig. 6.

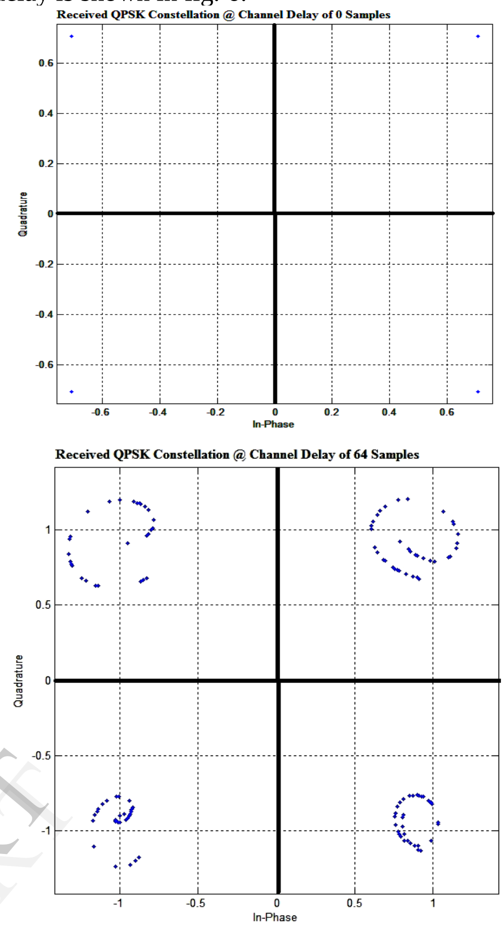

Fig 6: Received QPSK constellation @ channel delay of 0 and 64 samples

5. Conclusion and Further Work

We design a single-band OFDM based UWB system. OFDM is very sensitive to timing and frequency offsets. Even in this ideal simulation environment, we have to consider the delay produced by the filtering operation and channel. This delay is enough to impede the reception, and it is the cause of the slight differences we can see between the transmitted and received signals spectrum and constellation. There is a phase rotation due to the delay. This phase rotation has to be taken into account to fix the decision boundary in the receiver in order to minimize the symbol error.

As a further work we can convert the single-band OFDM based UWB system into multi-band OFDM based UWB system just by switching the center frequencies.

6. References

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