DSSS DIGITAL TRANSCEIVER DESIGN FOR ULTRA WIDEBAND

Mohammad Shamim Imtiaz
Part-time Lecturer, Department of EEE, A.U.S.T, Dhaka, Bangladesh

ABSTRACT

Despite the fact ultra-wideband technology has been around for over 30 years, there is a newfound excitement about its potential for communications. In this paper we are specifically focused on a software radio transceiver design for impulse-based UWB with the ability to transmit a raw data rate of 100 Mbps yet encompass the adaptability of a reconfigurable digital receiver. Direct sequence spread spectrum has become the modulation method of choice for wireless local area networks, because it's numerous advantages such as jammer suppression, code division multiple access and ease of implementation. We also observe its characteristics and complete the modulation techniques with MATLAB Simulink. The latter includes bit error rate testing for variety of modulation schemes and wireless channels using pilot-based matched filter estimation techniques. Ultimately, the transceiver design demonstrates the advantage and challenge of UWB technology while boasting high data rate communication capability and providing the flexibility of a research test bed.

KEYWORDS: *Ultra-wideband (UWB), direct sequence spread spectrum (DSSS), wireless local area networks (WLAN's), personal communication systems (PCS), code division multiple access (CDMA).*

I. INTRODUCTION

Ultra wideband (also known as UWB or as digital pulse wireless) is a wireless technology for transmitting large amount of digital data over a wide spectrum of frequency bands with very low power for a short distance. Ultra wideband radio can carry a huge amount of data over a distance up to 230 feet at very low power (less than 0.5 mW) and it has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and higher power [5]. The concept of UWB was formulated in the early 1960s through research in time-domain electromagnetic and receiver design, both performed primarily by Gerald F. Ross [1]. Through his work, the first UWB communications patent was awarded for the short-pulse receiver, which he developed while working for Sperry Rand Corporation. Throughout that time, UWB was referred in broad terms as "carrier less" or impulse technology. After that UWB was coined in the late 1980s to describe the development, transmission, and reception of ultra-short pulses of radio frequency (RF) energy. For communication applications, high data rates are possible due to the large number of pulses that can be created in short time duration [3][4]. Due to its low power spectral density, UWB can be used in military applications that require low probability of detection [14]. UWB also has traditional applications in non cooperative radar imaging, target sensor data collection, precision locating and tracking applications [13]. A significant difference between traditional radio transmissions and UWB radio transmissions are that traditional systems transmit information by varying the power level, frequency, and/or phase of a sinusoidal wave. UWB transmissions transmit information by generating radio energy at specific time instants and occupying large bandwidth thus enabling a pulse-position or time-modulation [4].UWB communications transmit in a way that doesn't interfere largely with other more traditional 'narrow band' and continuous carrier wave uses in the same frequency band [5][6]. However first studies show that the rise of noise level by a number of UWB transmitters puts a burden on existing communications services [10]. This may be hard to bear for traditional systems designs and may affect the stability of such existing systems. The design of UWB is very different from that of conventional narrow band. In the conventional narrow band, frequency domain should be considered to design the filter or mixer because the signals are in narrow frequency band. On the other hand, in UWB, time domain should be also considered to design especially for miser because the carrier less signals possess wide frequency-band and using short pulse means discontinuous signal. The Federal Communications Commission has recently approved use of Ultra Wideband technology, allowing deployment primarily in frequency band not only from 3.1 GHz, but also below 960 MHz for imaging applications [2]. Hence, pulse width should be about 2 ns in order to be used below 960 MHz frequency band.

Recently there has been a burst of research about UWB; hence more and more papers are being published. However, many papers have been found on the transceiver circuit description for UWB with different technology but here we propose a system model of UWB Transceiver with Direct Sequence Spread Spectrum technology. In this paper we focused on a software based radio transceiver design for impulse-based UWB with the ability to transmit a raw data rate of 100 Mbps yet encompass the adaptability of a reconfigurable digital receiver. Here we also introduce a transmitter and receiver of pulse based ultra wideband modulation. Direct sequence spread spectrum (DSSS) has become the modulation method of choice for wireless local area networks (WLAN's), and personal communication systems (PCS), because it's numerous advantages, such as jammer suppression, code division multiple access (CDMA), and ease of implementation. As with other spread spectrum technologies, the transmitted signal takes up more bandwidth than the information signal that is being modulated. The name 'spread spectrum' comes from the fact that the carrier signals occur over the full bandwidth (spectrum) of a device's transmitting frequency.

This paper is structured as follows: Section 2 briefly introduces system blocks that have used to design the DSSS Digital Transceiver. Section 3 and 4 present the design of DPSK Transmitter and DPSK Receiver respectively. Section 5 exhibits the results taken by oscilloscopes and demonstrates the discussion of finding such results. Section 6 suggests the future work and modification of this paper. Section 7 concludes the paper.

II. SYSTEM MODEL

The designed model for the transceiver is shown in Fig-1, consists of a hierarchical system where blocks represent subsystems and oscilloscopes are placed along the path for display purposes.

The main components or blocks of this design are PN sequence generator, XOR, Unite delay, Switch, Pulse generator, Derivative, Integer delay, Digital Filter, Product, Gain and oscilloscope. The PN Sequence Generator block generates a sequence of pseudorandom binary numbers. A pseudo noise sequence generator which uses a shift register to generate sequences, can be used in a pseudorandom scrambler, descrambler and in a direct-sequence spread-spectrum system [12]. The PN Sequence Generator block uses a shift register to generate sequences. Here, PN sequence generator uses for generating both incoming message and high speed pseudo random sequence number for spreading purpose. XOR block work as a mixer, it mixes two different inputs with each other as digital XOR does and gives the output. The Unit Delay block holds and delays its input by the sample period you specify. This block is equivalent to the z^{-1} discrete-time operator. The block accepts one input and generates one output. Each signal can be scalar or vector. If the input is a vector, the block holds and delays all elements of the vector by the same sample period. Pulse generator capable of generating a variety of pulses with an assortment of options.

Switch uses for switching the two different input and direct it to the output as per requirement. Derivative block basically differentiate the input data. The pulse generator and sequentially two derivatives are used for performing Bi-phase modulation as per requirement. Integer delay use to delay the 63 chip incoming data. Digital filter has its special use. It uses for creating digital filter for recovering purpose. Gain blocks use for amplifying process. Oscilloscopes are placed along the path for display purpose.

Direct-sequence spread spectrum (DSSS) is a modulation technique. The DPSK DSSS modulation and dispread techniques are mainly use for designing the whole transceiver with the exception of receiving the signal using Bi-phase modulation. The design for pulse based UWB is divided into three parts as DSSS DPSK transmitter where transmitter part is separately designed, DPSK DSSS transceiver where received signal has dispread with some propagation delay, DPSK DSSS transceiver with Bi-phase modulator and matched filter where original signal has recovered.

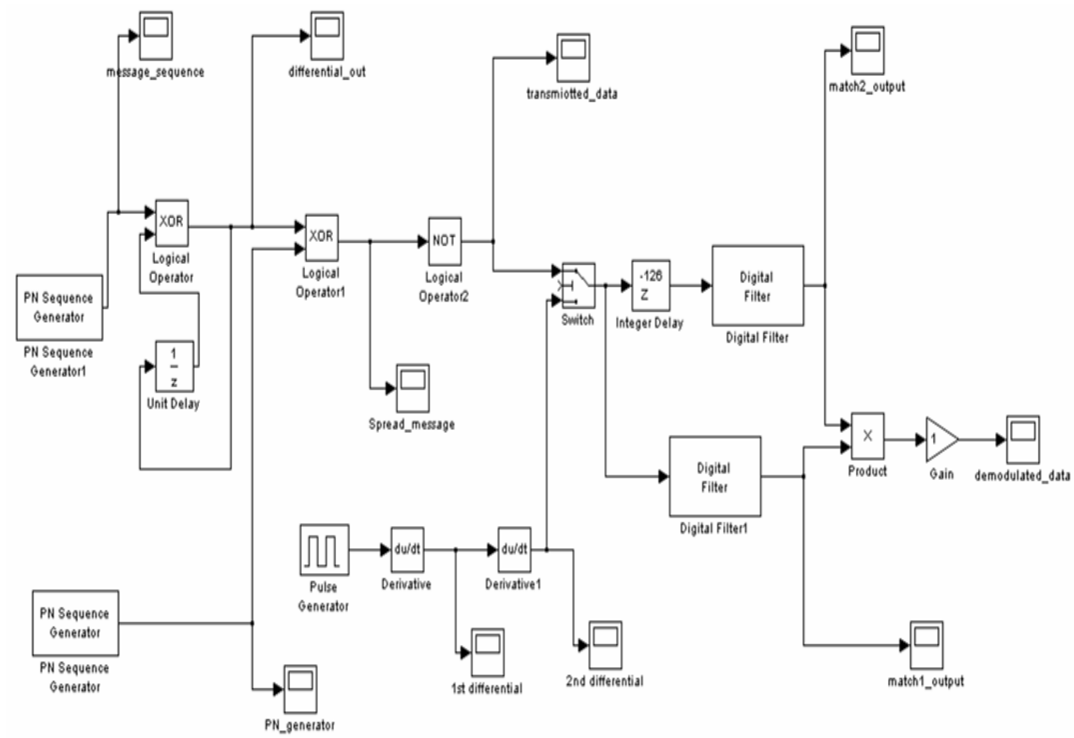

Figure 1: Simulink model of DPSK DSSS Transceiver

The data signal, rather than being transmitted on a narrow band as is done in microwave communications, is spread onto a much larger range of frequencies (RF bandwidth) using a specific encoding scheme. This encoding scheme is known as a Pseudo-noise sequence, or PN sequence. Direct sequence spread spectrum has become the modulation method of choice for wireless local area networks, and personal communication systems. Direct-sequence spread-spectrum transmissions multiply the data being transmitted by a "noise" signal. This noise signal is a pseudorandom sequence of 1 and −1 values, at a frequency much higher than that of the original signal, thereby spreading the energy of the original signal into a much wider band. The resulting signal resembles white noise, like an audio recording of "static". However, this noise-like signal can be used to exactly reconstruct the original data at the receiving end, by multiplying it by the same pseudorandom sequence [12] This process, known as "de-spreading", mathematically constitutes a correlation of the transmitted PN sequence with the PN sequence that the receiver believes the transmitter is using. For de-spreading to work correctly, transmit and receive sequences must be synchronized. This requires the receiver to synchronize its sequence with the transmitter's sequence via some sort of timing search process. However, this apparent drawback can be a significant benefit: if the sequences of multiple transmitters are synchronized with each other, the relative synchronizations the receiver must make between them can be used to determine relative timing, which, in turn, can be used to calculate the receiver's position if the transmitters' positions are known [12]. This is the basis for many satellite navigation systems.
The resulting effect of enhancing signal to noise ratio on the channel is called process gain. This effect can be made larger by employing a longer PN sequence and more chips per bit, but physical devices used to generate the PN sequence impose practical limits on attainable processing gain [12].

III. DPSK TRANSMITTER

DPSK DSSS transmitter consists of PN Sequence generator which generates a sequence of pseudo random binary numbers using a linear-feedback shift register, XOR used for mixing data, Unite delay used for delayed data and oscilloscopes are placed along the path for display purposes. Here, PN

Sequence generator is used as both generating message and a sequence of pseudo random binary numbers for spreading process. Figure 2 is the Simulink model of DPSK DSSS Transmitter.
When differentially encoding an incoming message, each input data bit must be delayed until the next one arrives. The delayed data bit is then mixed with the next incoming data bit. The output of the mixer gives the difference of the incoming data bit and the delayed data bit. The differentially encoded data is then spread by a high-speed pseudo noise sequence (PN).This spreading process assigns each data bit its own unique code, allowing only a receiver with the same spreading to dispread the encoded data.
The 63-bit pseudo noise sequences (PN) used in this papers are generated by a 6th order maximal length sequence shown in equation one,

$$g(x) = x^6 + x^5 + 1 \qquad (1)$$

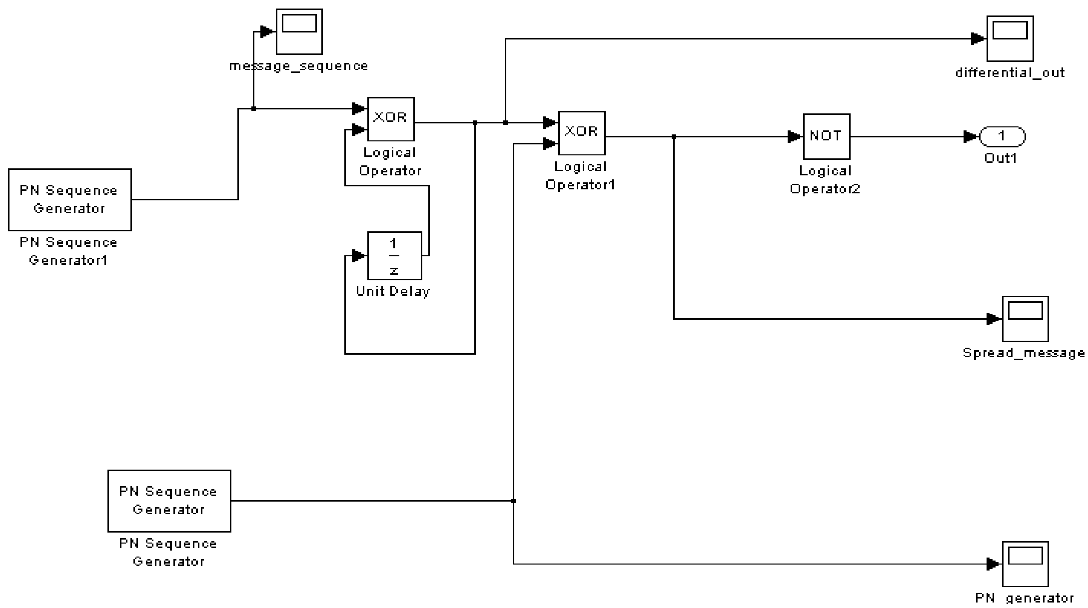

Figure 2: Simulink model of DPSK DSSS Transmitter

The maximal length spreading sequence uses a much wider bandwidth than the encoded data bit stream, which causes the spread sequence to have a much lower power spectral density [11]. The transmitted signal is then given by,

$$x(t) = m(t)\, c(t) \qquad (2)$$

Where $m(t)$ is the differentially encoded data, and $c(t)$ is the 63 chip PN spreading code. For recovering of message sequence, we XOR the modulated signal with same type of 63-bit pseudo noise sequences (PN). Here we also use a unite delay to find the original signal. The signal recovering process is successfully done with some propagation delay which was obvious because of some noise & losses.

IV. DPSK RECEIVER

Before dispreading, the receiving signal is modulated by Bi-phase modulation technique then signal is split into two parallel paths and fed into two identical matched filters with the input to one having a delay of 63 chips. Figure 3 is the Simulink model of DPSK DSSS Receiver.
The BPSK modulation technique is mathematically described as:

$$w(t) = \sum_{j=-\propto}^{\propto} b_j s\left(t - jT_f\right) \qquad (3)$$

Where, b_j is $\varepsilon\{-1,1\}$ a data bits

Certain advantage of Bi-phase modulation is its improvement over OOK and PPM in BER performance, as the Eb/No is 3 dB less than OOK for the same probability of bit error.

The probability of bit error for Bi-phase modulation assuming matched filter reception is:

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad (4)$$

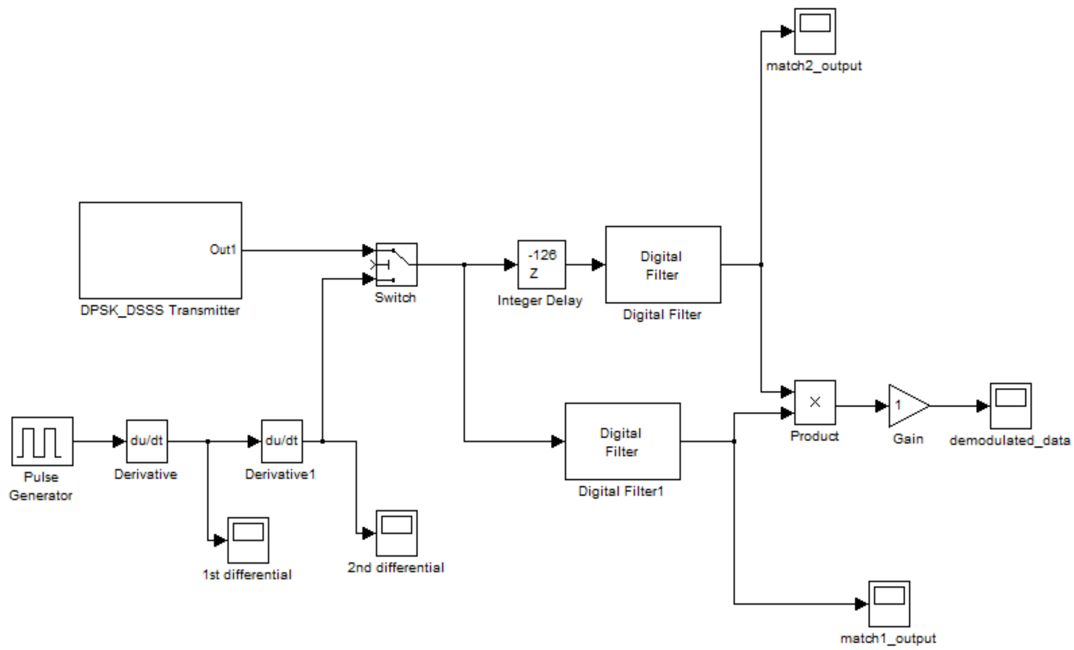

Figure 3: Simulink model of DPSK Receiver

Another benefit of Bi-phase modulation is its ability to eliminate spectral lines due to the change in pulse polarity. This aspect minimizes the amount of interference with conventional radio systems [16]. A decrease in the overall transmitted power could also be attained, making Bi-phase modulation a popular technique in UWB systems when energy efficiency is a priority.

Special type of Digital Matched Filter have used for recovering the transmitted message. This Digital matched filtering is a data processing routine which is optimal in term of signal-to-noise ratio (SNR). Specifically, it can be shown for an additive white Gaussian noise (AWGN) channel with no interference that the matched filter maximizes the SNR for a pulse modulated system. To perform this operation, the received waveform is over sampled to allow for multiple samples per pulse period. Over sampling gives a more accurate representation of the pulse shape, which then produces better results using a digital matched filter [11]. Correlation processing, another form of matched filtering, is often used in the digital domain when dealing with white noise channels. The method for calculating the correlation output is the following:

$$g(\kappa) = \sum_{t=1}^{N-1} r(t)h(t) \quad (5)$$

Where:

$g(k)$ Is the resulting correlation value
κ Is the κ^{th} pulse period
N Is the number of samples in one pulse width
$r(t)$ Is the received sampled waveform
$h(t)$ Is the known pulse waveform

One of the primary drawbacks of the matched filter receiver topology is the lack of knowledge of the pulse shape at the receiver due to distortion in the channel. Imperfect correlations can occur by processing the data with an incorrect pulse shape, causing degradation in correlation energy. There are numerous ways to correct this problem, including an adaptive digital equalizer or matching a template by storing multiple pulse shapes at the receiver. A more accurate approach is to estimate the pulse shape from the pilot pulses, which will experience the same channel distortion as the data pulses [11]. This estimation technique is a promising solution to UWB pulse distortion.

The outputs of the two matched filters are denoted by $x_1(t)$ and $x_2(t)$ are given by

$$x_1(t) = d(t - t_0)\, R_c(t) \quad (6)$$

$$x_2(t) = d(t - t_0 - T_b)\, R_c(t - T_b) \quad (7)$$

Where $T_b$the data is bit period, and $R_c(t)$ is the autocorrelation function of the 63-chip pseudorandom sequence. Since there are exactly 63 chips per data bit the PN sequence is periodic with T_b so

$$R(t) = R_c(t - T_b) \quad (8)$$

The two outputs of the matched filters are then mixed and then low pass filtered and the original message is recovered.

V. RESULTS AND DISCUSSION

Following the analytical approach presented in section 3 and 4, we evaluate the simulation result of UWB technology. The simulations are performed using MATLAB [15], and the proof-of-concept is valid as the BER curves are slightly worse than theoretical values for a perfectly matched receiver due to the imperfections in the template caused by noise and aperture delay variation. Figure 4 shows the original input message sequence that is generated from a PN sequence generator. Then, the incoming message are differentially encoded by using mixer and unite delay where each input data bit has delayed with Unit delay until the next one arrives where the delayed data bit is then mixed with the next incoming data bit. Figure 5 shows such a differential output of the original message signal.
Eventually the mixer will give the difference of the incoming data bit and the delayed data bit. The differentially encoded data is then spread by a high-speed 63-bit pseudo noise (PN) Sequence generator which is generated by a 6th order maximal length sequence. This spreading process assigns each data bit its own unique code which is shown in Figure 6 allowing only a receiver with the same spreading to dispread the encoded data.

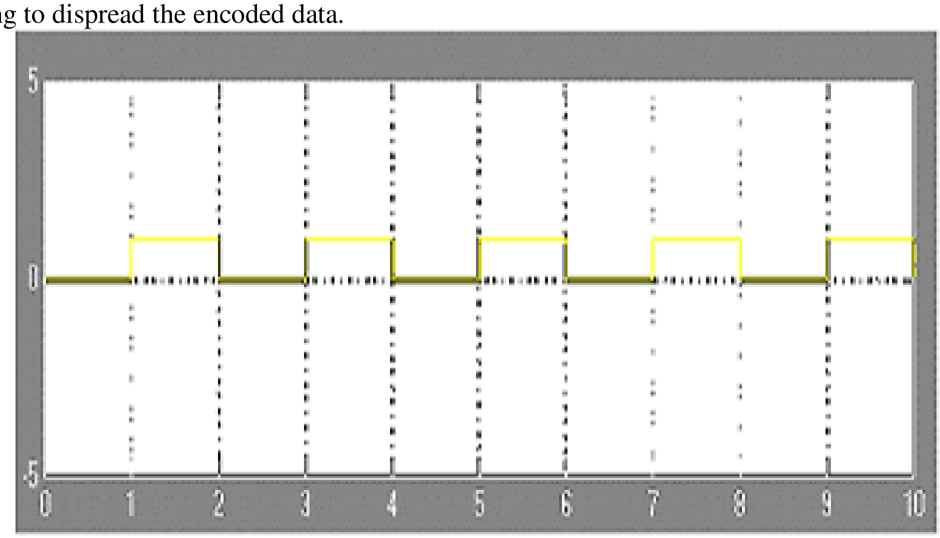

Figure 4: Original Input message signal

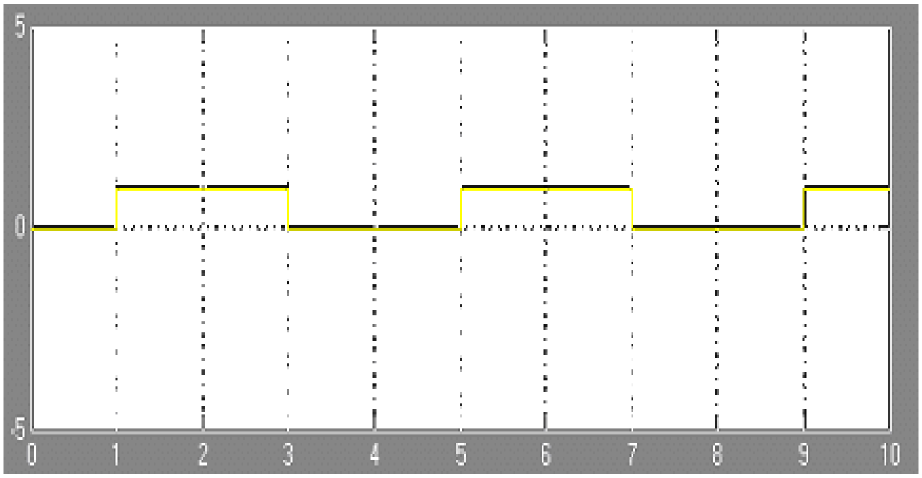

Figure 5: Differential output of message signal

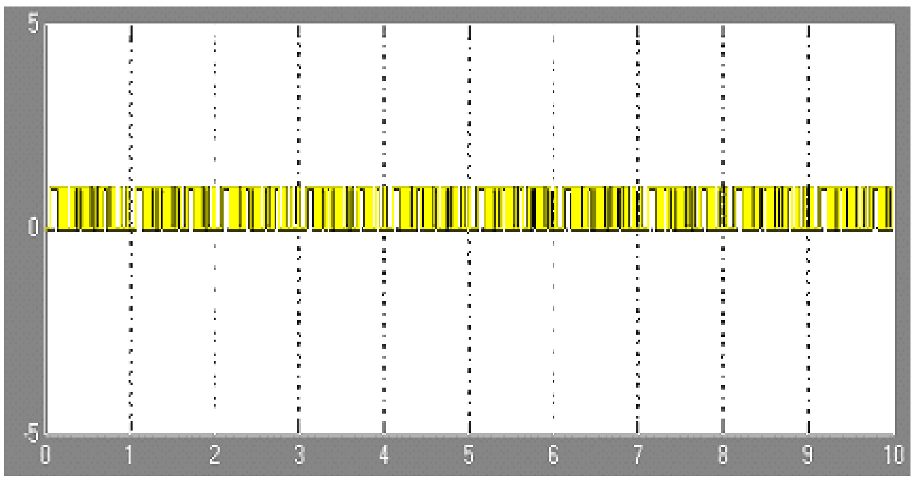

Figure 6: Output waveforms of Simulink DPSK DSSS Transmitter

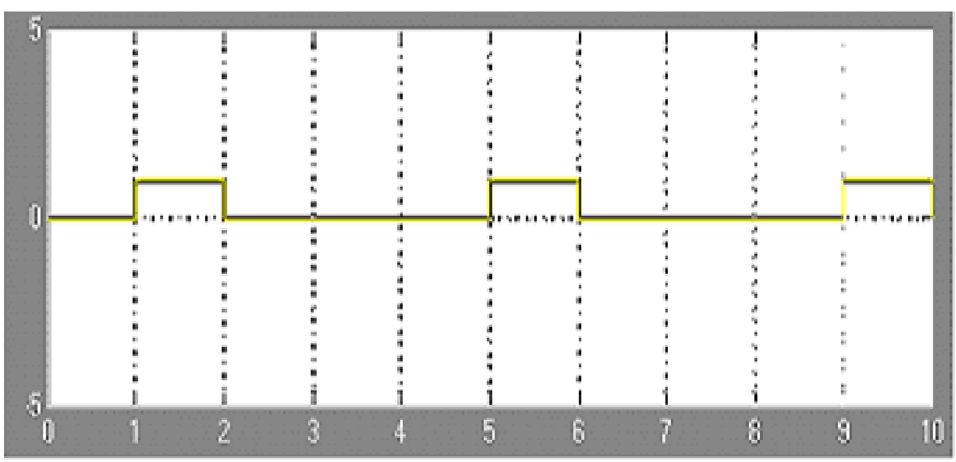

Figure 7: Received Signal into DPSK DSSS Receiver after Dispreading

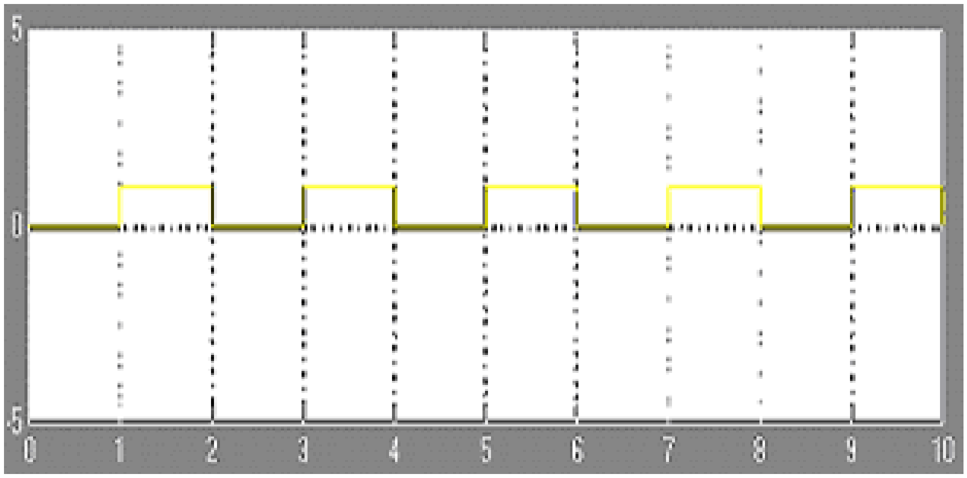

Figure 8: Original recovered output signal

For recovering of message sequence in the receiving part of DPSK DSSS transceiver, the modulated signal has been dispread using same type of 63-bit pseudo noise sequences and also use a unite delay to find the original signal. Before dispreading, the receiving signal is modulated by Bi-phase modulation technique then signal is split into two parallel paths and fed into two identical matched filters with the input to one having a delay of 63 chips. Among two split signal, one is spreading received message and another is Bi-phase modulated signal. The signal recovering process is successfully done with some propagation delay which was obvious because of some noise & losses. Figure 7 represented the received signal into DPSK DSSS receiver after dispreading and Figure 8 denoted original recovered messages.

VI. FUTURE MODIFICATION AND WORK

Designing of Transceiver was difficult and it took time to resolve the obstacles. The transmitter side was easy to build but it was hard to recover it in the receiver side due to spreading process. The recovered massage came with unwanted delays after dispreading it into DPSK DSSS receiver with the same 63-bit PN Sequence generator. To remove the delay a BPSK modulator and two special matched filters were used. This Matched filters are usually FIT filters which are designed in a special way to recover the original signal. Its have used for detecting the 6^{th} order maximal length sequence and recovering the transmitted message. In the first matched filter the input signal was delayed due to correlating purpose. It was obtained by correlating the delayed signal with the received signal to detect the presence of the template in the received signal. This is equivalent to convolving the unknown signal with a conjugated time-reversed version of the template. As it is known that matched filter is the optimal linear filter for maximizing the signal to noise ratio in the presence of additive stochastic noise, use of more matched filter increase the possibilities of recovering the original signal and maximizing the signal to noise ratio depending on signal that is being transmitted. In this whole work we have discussed about UWB basics, modulation technique and transmitter circuits but all of those were limited in the design and system level. Though we have included some present important features and applications of UWB but implementation or circuit level simulation has not been done here. People who are interested in analyzing UWB technology can work on circuit level simulation.

VII. CONCLUSIONS

We have analyzed the performance of UWB technology using Time Hopping (TH) technique. The results from the system simulation were very encouraging for the UWB receiver design presented in this paper. It was also shown by increasing the number of averaged pilot pulses in the pilot-based matched filter template, better performance can be obtained, although the data rate will suffer. Performance for multipath was also examined (albeit for perfect synchronization) and was close to the theoretical values. Finally, use of the template sliding matched filter synchronization routine led to worse BER performance when compared with perfect synchronization results. Although these simulations were specific in terms of data bits and number of multipath, other simulations were successfully run on a smaller-scale varying these two parameters. The results of the system simulation give a solid foundation for the design as a whole, but also will assist in the future with issues such as the implementation of receiver algorithms within the PGA and determining timing limitations when the receiver is being constructed.

REFERENCES

[1]. G. F. Ross, "Transmission and reception system for generating and receiving base-band duration pulse signals without distortion for short base-band pulse communication system," US Patent 3,728,632, April 17, 1973.
[2]. Authorization of Ultra wideband Technology, First Report and Order, Federal Communications Commission, February 14, 2002.
[3]. C. R. Anderson, "Ultra wideband Communication System Design Issues and Tradeoffs," Ph.D. Qualifier Exam, Virginia Polytechnic Institute and State University, May 12, 2003.
[4]. J. R. Foerster, "The performance of a direct-sequence spread ultra-wideband system in the presence of multipath, narrowband interference, and multiuser interference," IEEE Conference on Ultra Wideband Systems and Technologies, May 2002.
[5]. C. R. Anderson, A. M. Orndorff, R. M. Buehrer, and J. H. Reed, "An Introduction and Overview of an Impulse-Radio Ultra wideband Communication System Design," tech. rep., MPRG, Virginia Polytechnic Institute and State University, June 2004
[6]. J. Han and C. Nguyen, "A new ultra-wideband, ultra-short monocycle pulse generator with reduced ringing," IEEE Microwave and Wireless Components Letters, Vol. 12, No. 6, pp. 206-208, June 2002.
[7]. S. Licul, J. A. N. Noronha, W. A. Davis, D. G. Sweeney, C. R. Anderson, T. M. Bielawa, "A parametric study of time-domain characteristics of possible UWB antenna architectures," submitted to IEEE Vehicular Technology Conference, February 2003.
[8]. M. Z. Win and R. A. Scholtz, "Impulse radio: how it works," IEEE Communications Letters, Vol. 2, No. 1, pp. 10-12, January 1998.
[9]. J. Ibrahim "Notes on Ultra Wideband Receiver Design," April 14, 2004.
[10]. Takahide Terada, Shingo Yoshizumi,Yukitoshi and Tadahiro kuroda, "Transceiver Circuits for Pulsed-Based Ultra Wideband" Department of Electrical Engineering, Keio University, Japan, Circuits and Systems, 2004. ISCAS '04.L. W. Couch II, Digital and Analog Communication Systems, 6th Edition, New Jersey: Prentice Hall, 2001.
[11]. S.M. Nabritt, M.Qahwash, M.A. Belkerdid, "Simulink Simulation of a Direct Sequence Spread Spectrum Differential Phase Shift Keying SAW Correlator", Electrical and Comp. Engr. Dept, University of Central Florida, Orlando FL 32816, Wireless Personal Communications, The Kluwer International Series in Engineering and Computer Science, 2000, Volume 536, VI, 239-249
[12]. Alonso Morgado, Rocio del Rio and Jose M. de la Rosa, "A Simulink Block Set for the High-Level Simulation of Multistandard Radio Receivers", Instituto de Microelectronica de Sevilla-IMSE-CNM (CSIC), Edif. CICA-CNM, Avda Reina Mercedes s/n, 41012-Sevilla, Spain
[13]. M. I. Skolnik, Introduction to Radar Systems, 3rd Edition. New York: McGraw- Hill, 2001.
[14]. Military Applications of Ultra-Wideband Communications, James W. McCulloch and Bob Walters
[15]. Matlab, Version 7 Release 13, The Mathworks, Inc., Natick, MA.
[16]. L. W. Couch II, Digital and Analog Communication Systems, 6th Edition, New Jersey: Prentice Hall, 2001.

Author

Mohammad Shamim Imtiaz was born in Dhaka, Bangladesh in 1987. He received his Bachelor degree in Electrical and Electronic Engineering from Ahsanullah University of Science and Technology, Dhaka, Bangladesh in 2009. He is working as a Part-Time Lecturer in the same university from where he has completed his Bachelor degree. Currently he is focusing on getting into MSc Program. His research interests include digital system, digital signal processing, multimedia signal processing, digital communication and signal processing for data transmission and storage. There are other several projects he is working on and they are "Comparison of DSSS Transceiver and FHSS Transceiver on the basis of Bit Error Rate and Signal to Noise Ratio", "Mobile Charging Device using Human Heart Pulse", "Analysis of CMOS Full Adder Circuit of Different Area and Models".