Ultra-Wideband Research and Implementation

Senior Project Proposal

by:

Jarrod Cook

Nathan Gove

Project Advisors:

Dr. Brian Huggins

Dr. In Soo Ahn

Dr. Prasad Shastry

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1. **Project Summary**

Ultra-wideband (UWB) technology is a wireless transmission standard approved for unlicensed use in 2002 under the FCC Part 15 [1]. This technology is ideal for portable multimedia devices because of its inherent low power consumption, short range, and high bit rates shown in Figure 1 [4]. This project will focus on researching this technology and implementing it on a smaller scale. A model will be created in Simulink to understand the various components required for transmitting and receiving. Then using various tools and hardware, this model will be implemented. This will include DSP platforms for the baseband processing and radio frequency boards for transmitting and receiving.

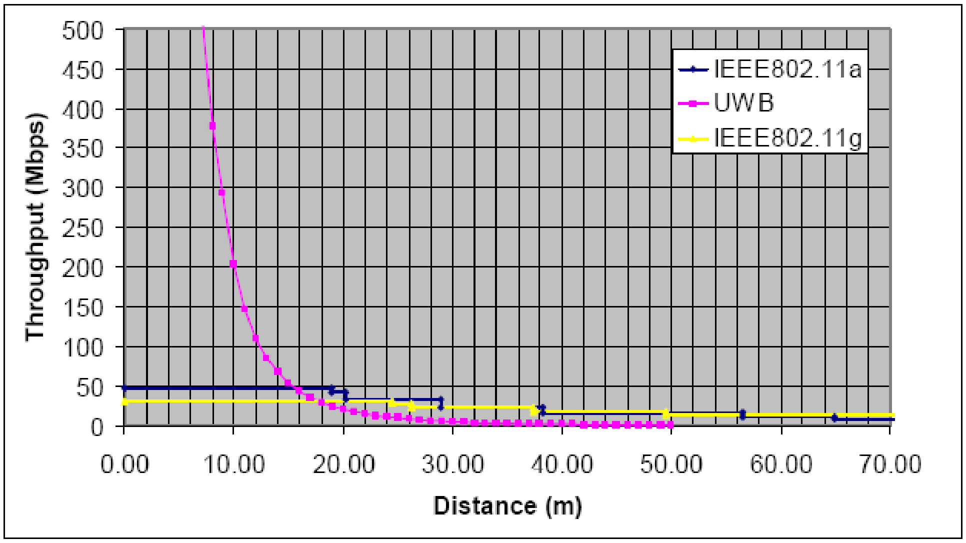


Figure 1 – Transmission Rate versus Distance

2. Functional Description

Overall

The overall system shown in Figure 2 will replicate a scaled-down version of the UWB wireless standard. The baseband processing will be done by a TI C6000 series DSP platform. This platform will be programmed using Code Composer Studio, which takes a Mathworks Simulink model and converts it to C-code. The output of the DSP will be two orthogonal frequency division multiplexed (OFDM) signals – an in-phase (I) signal and a quadrature-phase (Q) signal. These signals will then go to the radio frequency (RF) transmitter circuitry, which up-converts them to the transmitting frequency. This up-converted signal will be amplified and radiated by an antenna.

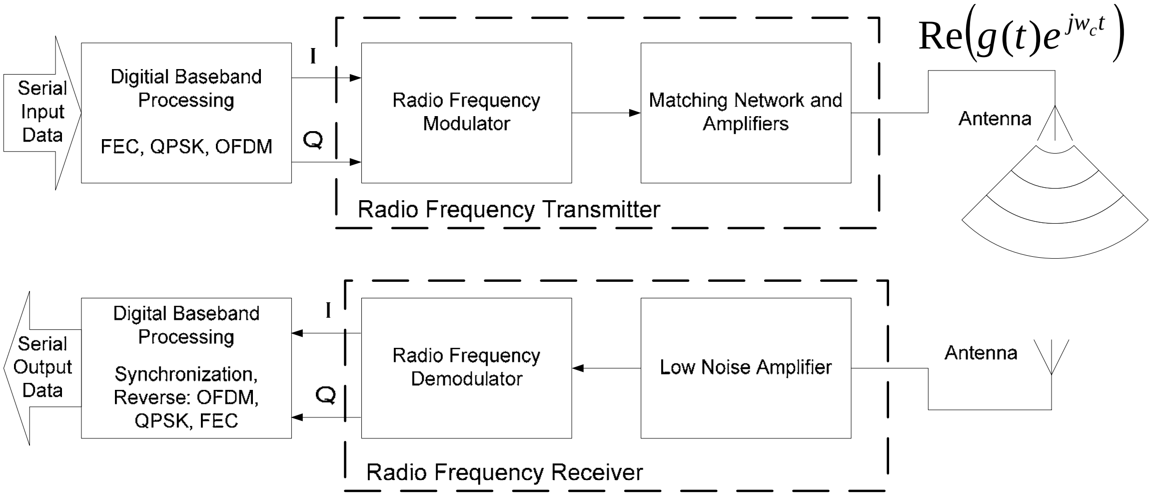


Figure 2 - Overall System Block Diagram

The second portion of this system is the UWB receiver. It consists of an antenna and an RF front end to receive the signal. The Low Noise Amplifier (LNA) delivers an amplified version of the transmitted signal to the RF demodulator. The demodulator converts the signal to baseband frequencies, and delivers the I & Q components to the digital baseband processor. The baseband processing for the receiver will involve a coherent detection which will synchronize the signal. This synchronization will be accomplished with pilot signals added to the transmitted spectrum. After the synchronization is done, all of the processes done in the transmit baseband processing will be reversed. This will include demodulating the OFDM signals and then demodulating the resulting QPSK signals, as well as removing any forward error correcting parity bits. This will return the signal to its original serial binary bit stream.

Transmitter Baseband Processing

Within the overall system shown in Figure 2, there is baseband processing block that will modulate the information. As mentioned above, this baseband processing will be performed with one of TI’s high performance C6000 series DSP platforms. The input to the system at first will consist of randomly generated serial binary bit streams. In the future, the input will be an external input to the DSP from a computer in the form of a picture or possibly video. Next the DSP will perform the baseband processing. Simulink will be used to model the baseband processing. When this model is complete it will be converted to C-code using Code Composer Studio. The C-code that is generated will run on the DSP board and perform the physical baseband processing.

The baseband processing model is shown in Figure 3. This model will take the serial input and buffer it. This buffering will transform the serial stream of data into frame based, or parallel data, so that a group of bits can be processed at a single time. This is required for OFDM because an inverse fast Fourier transform (IFFT) is performed after QPSK modulation to generate the basic OFDM signal. This is explained in the subsection titled OFDM Theory.

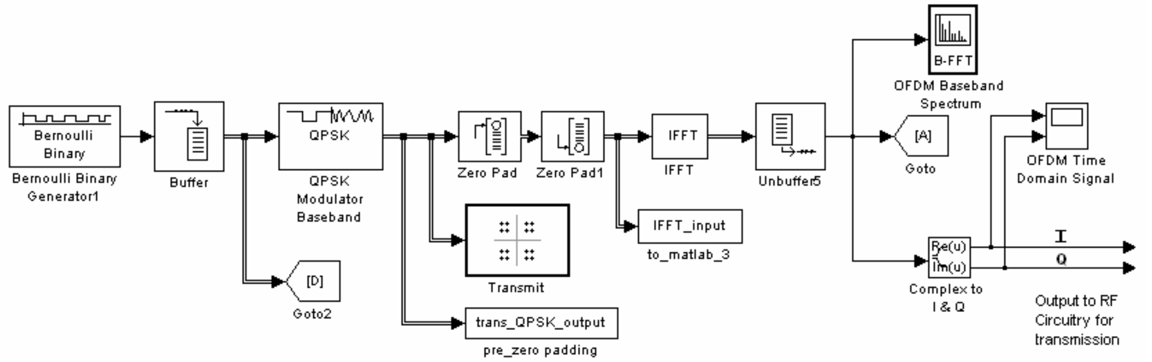


Figure 3 - Initial Simulink Baseband Processing Model

After buffering, the signal is modulated into a quadrature phase shift key (QPSK) mapping, also known as a quadrature amplitude modulation (QAM) scheme. This mapping is one of the two modulation methods required by the UWB specification, and is a way to increase data rates without increasing transmitted bandwidth [5]. Each symbol that the QPSK modulator produces represents numerous bits. These symbols are mapped onto a constellation plane which contains an in-phase or real component, and a quadrature phase or imaginary component as shown in Figure 4. For UWB when the data rate is equal to or below 106.7 Mb/s, four symbols are used, where each symbol represents 2 bits [2].

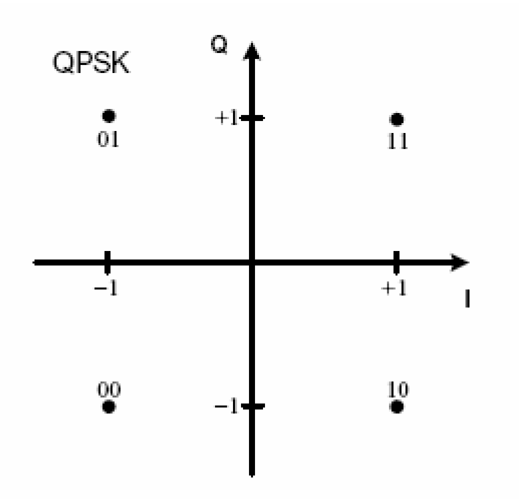


Figure 4 – QPSK Constellation Map

After the information has been QPSK modulated, the vector of the modulated information is defined as w_n in equation 1. Each component within the vector is treated as a frequency sub-carrier, which is defined by the symbols mapped in Figure 4. The sub-carriers in OFDM are orthogonal due to the nature of the IFFT. The proof of this phenomenon is shown in the OFDM Theory subsection of the experimental results.

As defined in the UWB standard, a full UWB spectrum includes 128 sub-carriers. This spectrum includes 100 data, 12 pilot, and 10 guard sub-carriers, as shown in Figure 5 [2]. The pilot sub-carriers are previously determined quantities which allow the receiver to compensate for any channel disturbances or slight frequency drifting, and still acquire all of the transmitted information. The guard sub-carriers are used to shape the spectrum and make sure that nearby frequencies are properly spaced. There is no sub-carrier at DC to avoid difficulties with digital to analog and analog to digital converter offsets [2].

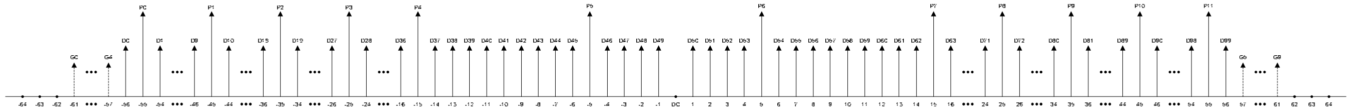


Figure 5 - Full UWB OFDM Spectrum

For this project, there will initially be 24 data and 2 pilot sub-carriers, as shown in Figure 6. The remaining 6 frequency spaces are filled with zeros. All of the sub-carriers are fed through a 32-point IFFT to convert each sub-carrier into their respective frequency.

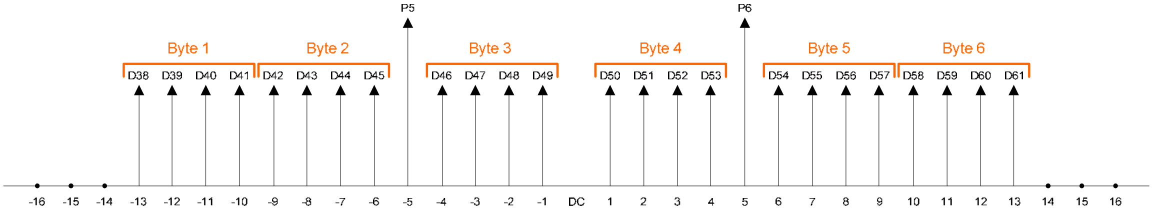


Figure 6 – Initial Scaled-Down OFDM Spectrum

After the IFFT, these frequencies together form the time domain signals shown in Figure 7.

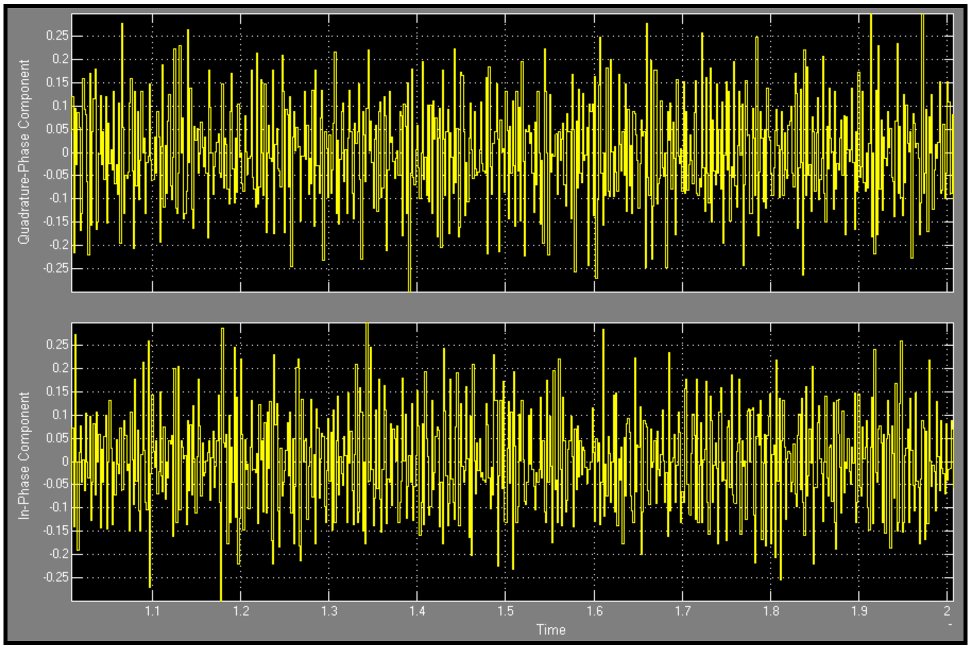


Figure 7 - OFDM I&Q Time Domain Signals

The fast Fourier transform (FFT), shown in Figure 8, gives the frequency domain representation of these time domain signals. The final step before the digital time-domain signals in Figure 7 are sent to the RF transmitter board is to transform them into analog signals. This is done using a digital to analog converter (DAC) which will be a part of the DSP platforms. Finally, these analog signals are sent out to the RF transmitter board.

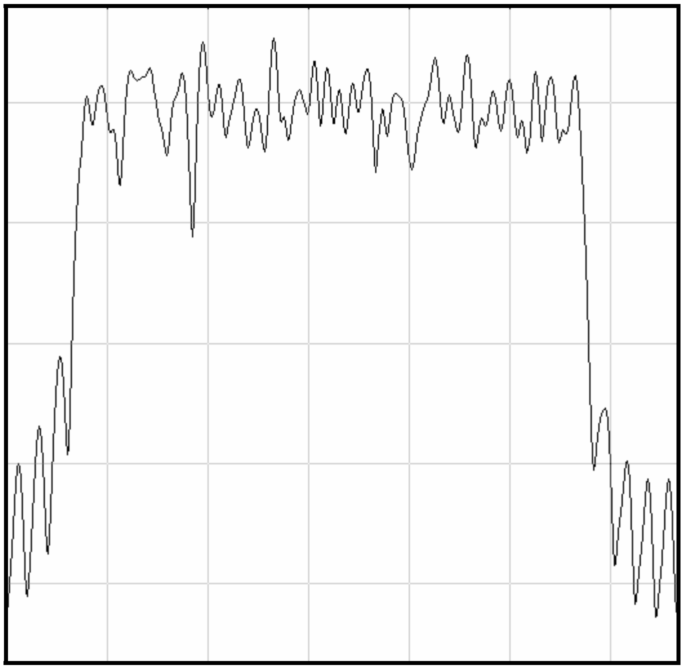


Figure 8 – OFDM FFT Spectrum

Radio Frequency Transmitter Board

The RF block of the transmitter will take the I & Q signals described above and up-convert them to a higher frequency. This frequency is determined by the UWB specification. UWB uses a multi-band OFDM (MB-OFDM) scheme in the full standard. The MB-OFDM provides the following characteristics for the system [1].

- Reduces precision of digital logic (i.e. IFFT, FFT, ADC, DAC)
- Relaxes phase-noise requirements and improves robustness
- Helps combat multi-path fading and allows for max transfer of power

MB-OFDM involves time interleaving, or changing the center frequency of the modulation with time in a specified sequence. This is a very interesting topic; however, this project will focus on implementing UWB in only one sub-band without changing the modulation frequency. Table 1 and Figure 9 shown below list all of the possible frequency sub-bands allocated in the UWB specification [2]. The single frequency this project will use is sub-band one of band group one. Therefore, a center frequency of 3.432 GHz will be used.

Table 1 – UWB Band Allocation Frequencies

Band Group	BAND_ID (n_b)	Lower Frequency (MHz)	Center Frequency (MHz)	Upper Frequency (MHz)
1	1	3 168	3 432	3 696
	2	3 696	3 960	4 224
	3	4 224	4 488	4 752
2	4	4 752	5 016	5 280
	5	5 280	5 544	5 808
	6	5 808	6 072	6 336
3	7	6 336	6 600	6 864
	8	6 864	7 128	7 392
	9	7 392	7 656	7 920
4	10	7 920	8 184	8 448
	11	8 448	8 712	8 976
	12	8 976	9 240	9 504
5	13	9 504	9 768	10 032
	14	10 032	10 296	10 560

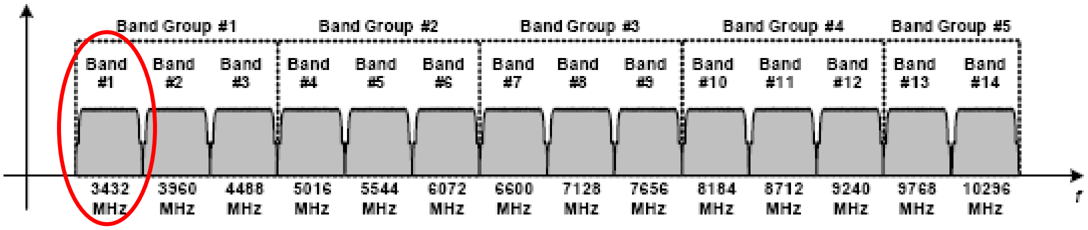


Figure 9 - UWB Graphical Spectrum Allocation

The overall system block diagram for the RF transmitter is show below in Figure 10. The in-phase and quadrature components from the baseband processor are input to a device called a direct quadrature modulator, which mixes the in-phase and quadrature components to a specific microwave frequency. The modulated signals are then summed, filtered and amplified before being transmitted through an antenna.

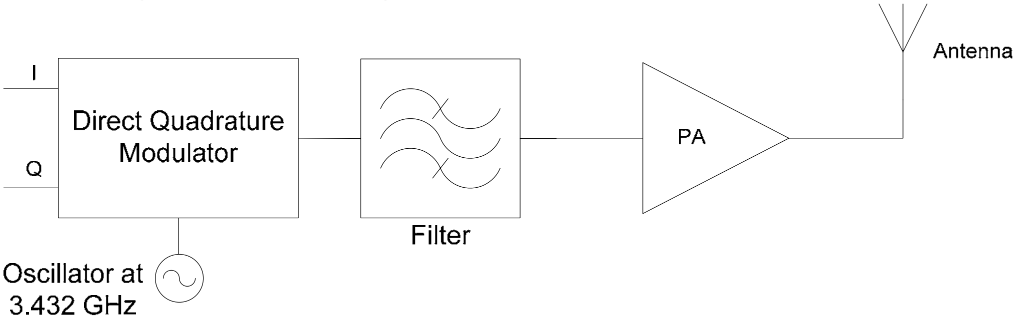


Figure 10 – Basic RF Transmitter Block Diagram

To easily modulate the in-phase and quadrature baseband components to microwave frequencies, a direct-quadrature modulator chip will be purchased from a vendor. Figure 11 shows the basic block diagram for the direct-quadrature modulator. The in-phase component is mixed with the local oscillator frequency, while the quadrature component is mixed with the local oscillator frequency that has been shifted 90^{o} out of phase by a phase-shifter. These two mixed signals are then added to produce the RF output, given by:

$$\mathrm{Re}\left(g(t)e^{j(\omega_{LO}t)}\right) = x(t)\cos(\omega_{LO}t) - y(t)\sin(\omega_{LO}t)$$ [7],

where (ω_{LO})is the local oscillator frequency, x(t) is the I component signal, and y(t) is the Q component signal.

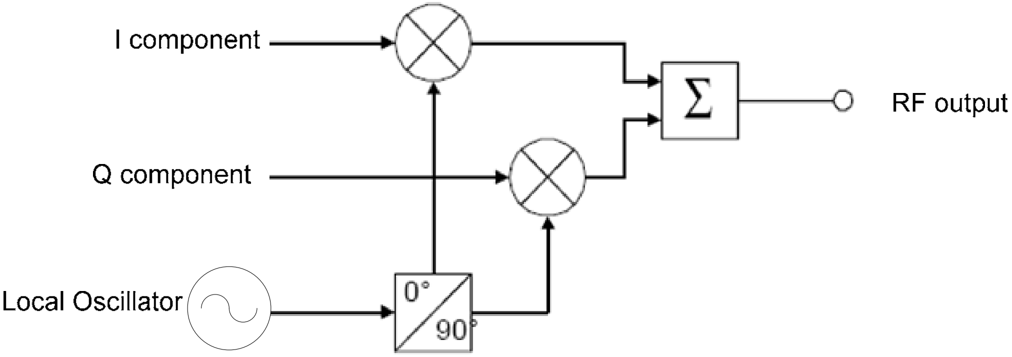


Figure 11 – Direct Quadrature Modulator Block Diagram

The next stage in the RF subsection takes the RF output from Figure 11, and filters out any spurious frequencies caused by the mixing process, and then a power amplifier boosts the signal. Finally, this signal gets transmitted through a UWB antenna.

Radio Frequency Receiver Board

The basic architecture for the UWB receiver is shown in Figure 12. The signal is received by another UWB antenna, and is then filtered to remove signals and noise outside the frequency band. Next, an LNA is used to boost the signal strength. Subsequently, the signal is demodulated by mixing the RF signal with an oscillator frequency that is relatively the same frequency as the transmitting oscillator. The synchronization of this signal will be done in the baseband processor so the local oscillator does not need to be exact. However the frequencies of the two oscillators will need to be close. After mixing, the filters will pass only the frequency components that are needed for the baseband processing. Finally, these signals will be converted to digital form by the baseband DSP processor.

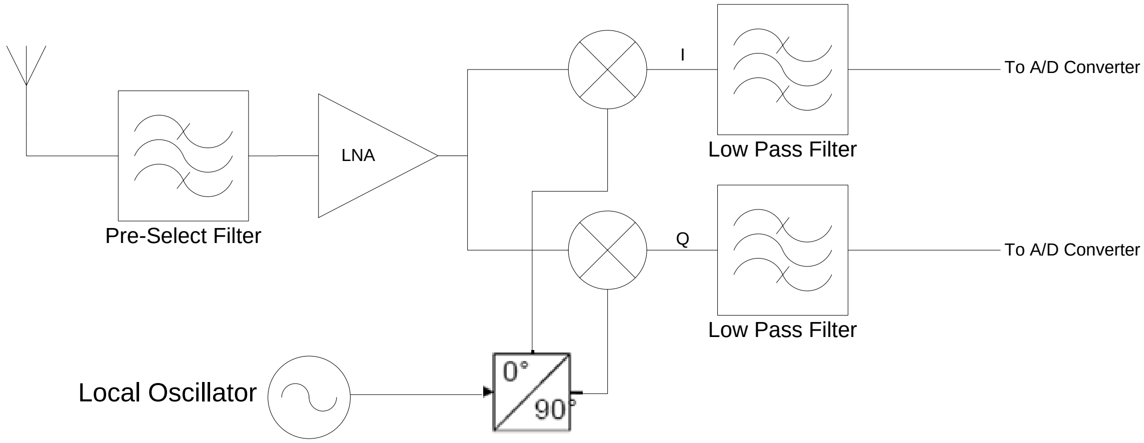


Figure 12 – Basic Receiver Block Diagram

Baseband Receiver

The baseband receiver will take the received signals and return them to their original structure. A simplified receiver is shown in Figure 13. This receiver is simplified because it does not include down-conversion or synchronization. The first step in this receiver is to take digital samples of the incoming analog data with an analog to digital converter (ADC), and then buffer it. The buffering, as explained earlier, will allow a frame of data to be processed at a single time. After that, the pilot signals embedded within the spectrum will be used to correct for any phase shift or frequency drift the signal has encountered from the channel. This process is not shown in Figure 13, but will be researched and implemented in the receiver model.

Once this data is synchronized, it will then be sent through an FFT. This will demodulate the OFDM signals into their frequency sub-carrier equivalents shown in Figure 6. Then once the extra padded zeros are removed, these signals are passed through a QPSK demodulator. Finally, the signal will be processed for error correction (e.g. forward error correction), if implemented in the transmitter, and returned to its original serial bit stream.

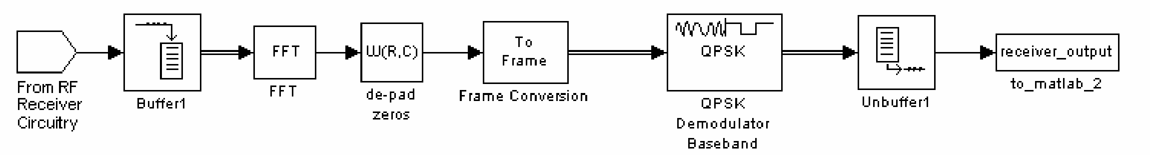


Figure 13 - Baseband Receiver Processing

3. Functional Requirements

Baseband Processing Requirements

- In order to ensure reliable transmission (i.e. combating multi-path fading), the transmitter baseband processor shall utilize OFDM modulation.
- The baseband signal shall occupy a bandwidth between 250 and 528 MHz.
- The baseband processor shall be capable of handling serial data rates less than or equal to 480 Mb/s.
- The baseband modulation shall follow parameter specifications detailed in Table 2.
- The baseband receiver shall be capable of compensating for frequency drifts from the channel.

Table 2 - Baseband UWB Parameters

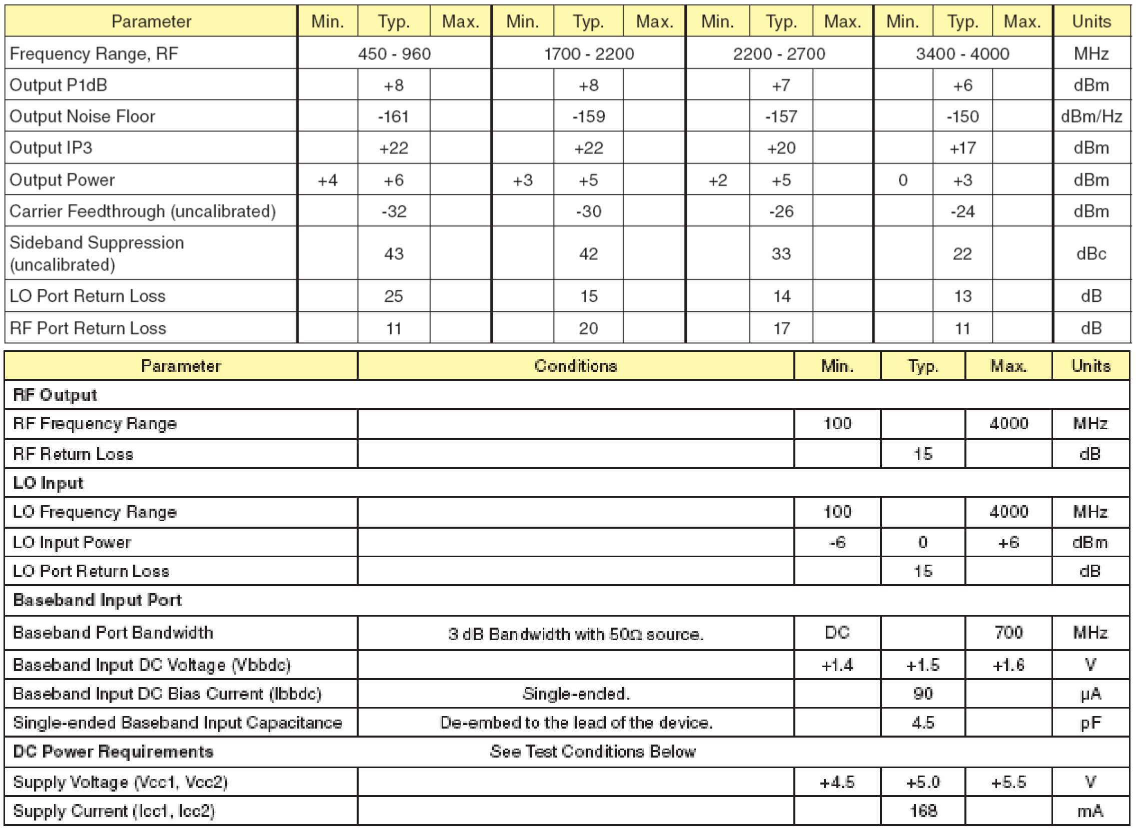
Parameter	Description	Value
f_S	Sampling Frequency [initial]	528 MHz
f_C	Center Frequency	3.432 GHz
N_{FFT}	Total number of subcarriers (FFT size)	32
N_D	Number of data subcarriers	24
N_P	Number of pilot subcarriers	2
N_G	Number of guard subcarriers	0
N_T	Total number of subcarriers ($N_D + N_P + N_G$)	26
D_F	Subcarrier frequency spacing (f_S/N_{FFT}) [initial]	16.5 MHz
T_{FFT}	FFT & IFFT period	TBD
N_{ZP}	Number of Zeros-padded	8

RF System Requirements

- The maximum power spectral density of the transmission shall not exceed -41.3 dBm/MHz per the UWB standard.
- The transmitted bandwidth shall lie in the region of 3.168 and 3.696 GHz.
- The transmitted signal shall not interfere with any other wireless devices.
- The transmitter antenna shall be omni-directional.
- The transmitter shall have a filter to attenuate spurious frequencies caused by the mixing process.
- Other non-UWB signals shall be rejected by the receiver.
- The receiver shall be capable of amplifying the incoming signal enough to make the baseband processing detect the signal.

RF Component Requirements

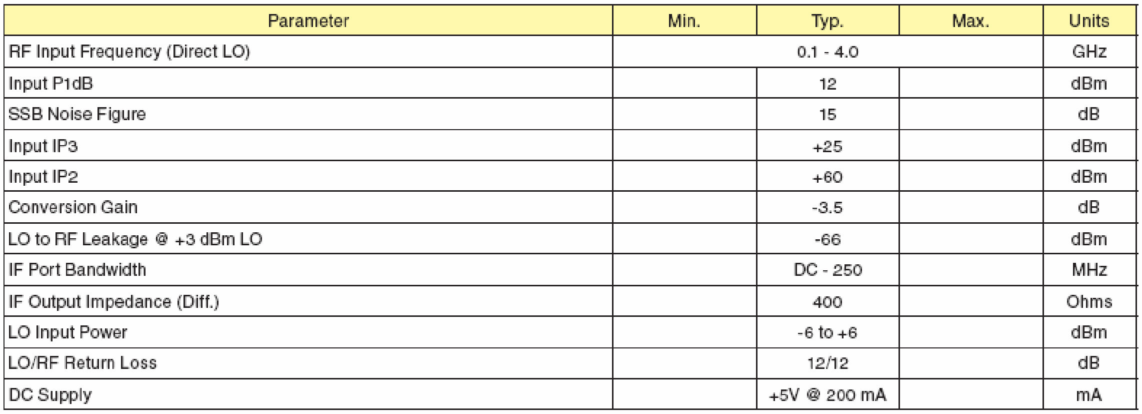
To facilitate the fastest development of the transceiver, RF components will be purchased from vendors. These components will have connectors that allow connections to other devices without implementing RF microstrip boards. The exact specifications of the transmitter and receiver hardware components are still to be determined, as these will depend on the data rates and bandwidth of the baseband processors. To modulate the baseband signals to RF, a direct quadrature modulator will be used. The quadrature modulator and demodulator will require a local oscillator with a frequency of 3.432 GHz. The stability and power output of the oscillator will be determined. Furthermore, any amplification that may be needed will be determined once the exact specifications of the local oscillators and quadrature modulators are determined. Several vendors offer quadrature modulators and demodulators. One company, Hittite Microwave Corporation, offers one that has specifications shown in Figure 14 [6]. Figure 14 (a) shows the modulator specifications, and Figure 14 (b) shows the demodulator specifications.



Parameter	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Units
Frequency Range, RF	450 - 960			1700 - 2200			2200 - 2700			3400 - 4000			MHz
Output P1dB		+8			+8			+7			+6		dBm
Output Noise Floor		-161			-159			-157			-150		dBm/Hz
Output IP3		+22			+22			+20			+17		dBm
Output Power	+4	+6		+3	+5		+2	+5		0	+3		dBm
Carrier Feedthrough (uncalibrated)		-32			-30			-26			-24		dBm
Sideband Suppression (uncalibrated)		43			42			33			22		dBc
LO Port Return Loss		25			15			14			13		dB
RF Port Return Loss		11			20			17			11		dB

Parameter	Conditions	Min.	Typ.	Max.	Units
RF Output					
RF Frequency Range		100		4000	MHz
RF Return Loss			15		dB
LO Input					
LO Frequency Range		100		4000	MHz
LO Input Power		-6	0	+6	dBm
LO Port Return Loss			15		dB
Baseband Input Port					
Baseband Port Bandwidth	3 dB Bandwidth with 50Ω source.	DC		700	MHz
Baseband Input DC Voltage (Vbbdc)		+1.4	+1.5	+1.6	V
Baseband Input DC Bias Current (Ibbdc)	Single-ended.		90		µA
Single-ended Baseband Input Capacitance	De-embed to the lead of the device.		4.5		pF
DC Power Requirements	See Test Conditions Below				
Supply Voltage (Vcc1, Vcc2)		+4.5	+5.0	+5.5	V
Supply Current (Icc1, Icc2)			168		mA

Figure 14 (a) - Hittite Quadrature Modulator Datasheet



Parameter	Min.	Typ.	Max.	Units
RF Input Frequency (Direct LO)	0.1 - 4.0			GHz
Input P1dB		12		dBm
SSB Noise Figure		15		dB
Input IP3		+25		dBm
Input IP2		+60		dBm
Conversion Gain		-3.5		dB
LO to RF Leakage @ +3 dBm LO		-66		dBm
IF Port Bandwidth		DC - 250		MHz
IF Output Impedance (Diff.)		400		Ohms
LO Input Power		-6 to +6		dBm
LO/RF Return Loss		12/12		dB
DC Supply		+5V @ 200 mA		mA

Figure 15 (b) - Hittite Quadrature Demodulator Datasheet

4. Patents and Standards

Patents

Number	Description
7139454	Ultra-wideband fully synthesized high-resolution receiver and method
7099422	Synchronization of ultra-wideband communications using a transmitted-reference preamble
7061442	Ultra-wideband antenna
7020224	Ultra-wideband correlating receiver

Patent Applications

Number	Description
20060165155	System and method for ultra-wideband (UWB) communication transceiver
20060062277	Ultra-wideband signal amplifier
20060045134	Ultra-wideband synchronization systems and methods

Standards

ECMA 368 – High Rate Ultra Wideband PHY and MAC Standard
ECMA 369 – MAC-PHY Interface for ECMA-368

5. Experimental Results and Equations

The first several weeks were spent researching UWB development systems that could be purchased and used to investigate a complete system. However, the focus of the project shifted when no useful or practical systems were found. An overview of the development system research can be found in the appendix. The focus of the project then shifted to developing a scaled-down version of a UWB system. So far, the majority of the time has been spent developing Simulink models of the baseband processors, as well as researching RF components.

Simulink Modeling

The initial goal for the modeling portion of the project was to complete a transmitter and receiver pair working in conjunction with a simple channel. It was decided that this project incorporate the signal processing blocks that are available through Mathwork's Communication Block Set. These blocks will decrease the time spent on modeling the baseband processing aspect of the project. The transmitter baseband processing model is shown in Figure 15.

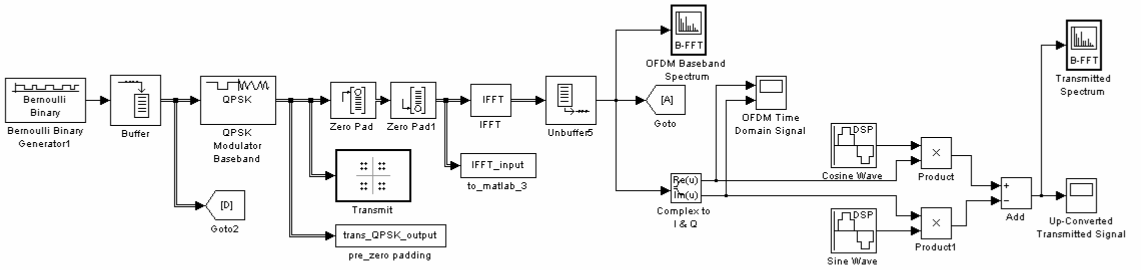


Figure 16 - Transmitter Model

The transmitter functionality is described in the functional description. This scaled down model of a UWB transmitter has the parameter characteristics defined in Table 4. The QPSK block in the transmitter modulates the signal according to the Gray-coded mapping (shown in Figure 4) before it is then modulated again into an OFDM signal. This transmitter model does not include pilot signals which will help the receiver to synchronize the transmitted information.

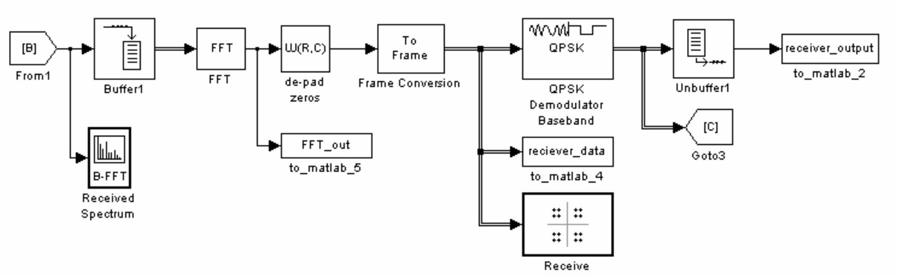


Figure 17 - Receiver Model

The receiver shown in Figure 16 is an ideal receiver, which has no RF front end or down-conversion. The down-conversion will be implemented in the model before hardware is realized. The current receiver model cannot acknowledge signals with any multi-path fading or frequency drifting. The next step for this model will be to implement a coherent synchronous receiver that will be able to handle pilot signals and multi-path fading issues.

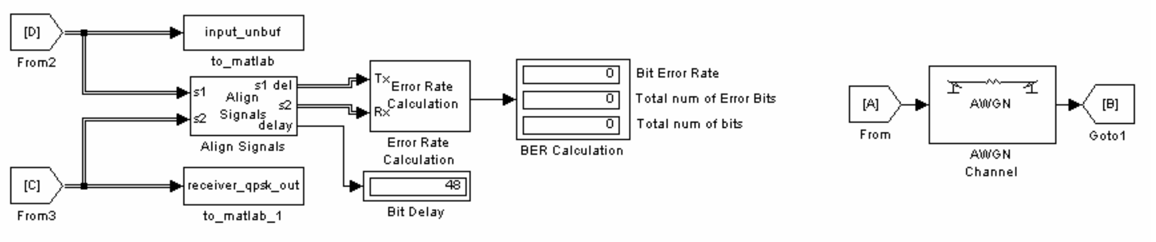


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Figure 18 - Bit Error Rate Calculation & Channel Model

Another important issue in modeling is to confirm that the model is working correctly. A bit error rate (BER) calculator has been implemented in Figure 17 that will calculate how many received bits are errors. A ratio will then be displayed of numbers of error bits by total number of bits. This BER is a standard measurement for any communication system. The results from this calculator were ideal because the components were ideal. The channel implemented was simple additive white Gaussian noise (AWGN) shown in Figure 17. If the signal-to-noise ratio (SNR) is high enough within this block, then all of the bits transmitted will be received, yielding a BER of zero. In a practical system, this will not be the case.

Model Results

Though ideal components were used in the models, the measurements taken were able show that AWGN can still affect the overall performance of any communications system. Furthermore, these measurements can demonstrate the difference between a correctly received signal and an incorrectly received signal.

First, the transmitted signal spectrum is shown in Figure 18. This spectrum spans approximately 500 MHz. This meets the minimum requirement for UWB bandwidth.

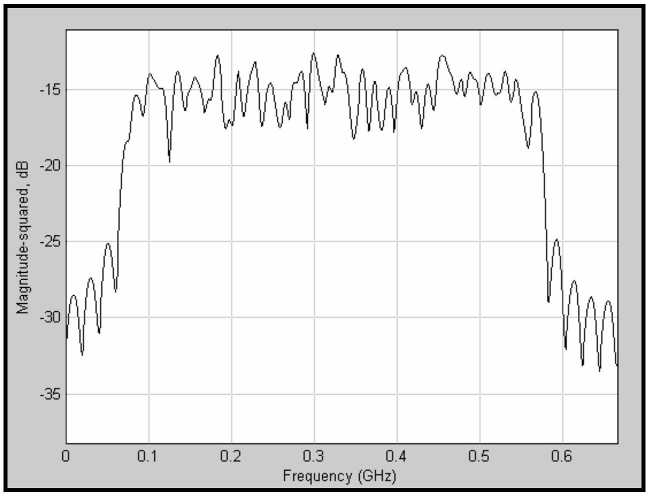

Figure 19 - OFDM Transmitted Spectrum

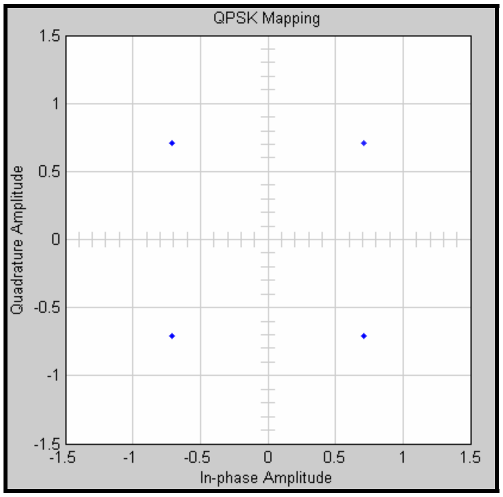

Figure 20 - QPSK Transmitted Constellation

The transmitted QPSK shown in Figure 19 is ideal. All of the information lies exactly on one of the four points within the constellation. With noise included in the channel model, as discussed below, all of the data will not be exactly in the same location.

Furthermore, in Figure 20 and 21 the up converted OFDM spectrums are shown. Figure 20 shows the double sided spectrum where the negative frequencies are just a repeat of the positive ones, which is an attribute of MATLAB. While in Figure 21 the single sided spectrum is shown of the up-converted signal ready to be transmitted. Figure 21 represents what the physical transmitted spectrum will look like. The center frequency of this signal is 3.432 GHz as defined by Table 4 in the functional requirements.

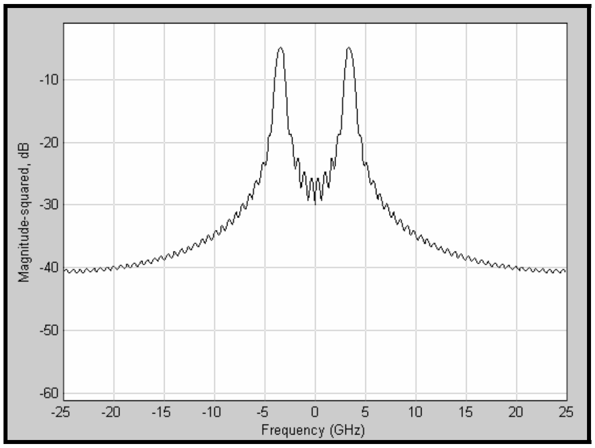

Figure 21 - Up Converted OFDM Signal

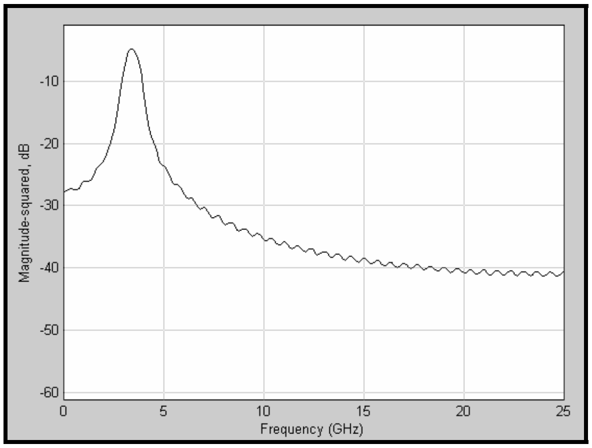

Figure 22 - Up Converted OFDM Spectrum Positive Spectrum

The AWGN model is set up to allow variations in the SNR, which was changed for three different simulations. For this first case, the parameters within the model were set up with the SNR equal to 30, number of bits per symbol equal to 2, input signal power equal to one watt, and symbol period equal to 2 nanoseconds. The results from this simulation are show in Figures 22 and 23. In Figure 22, the side lobes of the received signal are slightly higher than the transmitted signal. This is due to the noise introduced by the channel. The noise is easier to see in the QPSK constellation shown in Figure 23 because the noise clouds can be seen. A noise cloud is a region where a mapped signal may appear on a received constellation. These are due to attenuation or gains caused by the channel in both the in-phase and the quadrature phase of the signal. Because the noise is Gaussian, the noise clouds form circles from the even distribution of noise. These noise clouds are acceptable because there is still a clear definition between the 4 points. Thus, a correct decision can be made for each symbol that is received. This simulation yielded a BER of zero because the noise clouds never drifted beyond their decision lines. For this project, the decision lines are the x and y axis in any of the QPSK mapping figures shown.

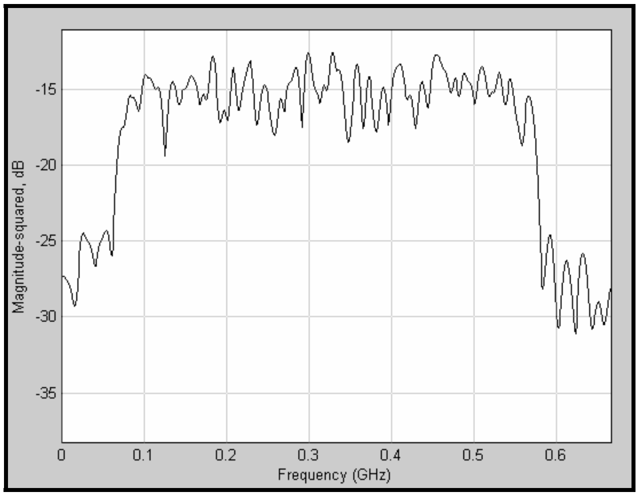

Figure 23 - Received OFDM Signal with SNR 30dB

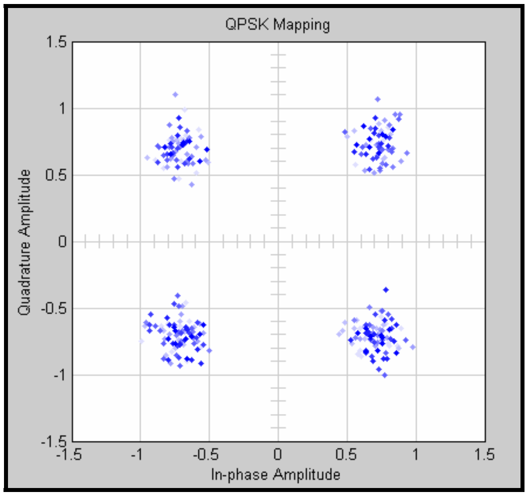

Figure 24 - Received QPSK Constellation with SNR 30 dB

For the next simulation all parameters are the same, except the SNR in the channel. The SNR for Figure 24 and 25 is equal to 20 dB, a degradation of 10 dB from the prior simulation. In Figure 24, the side lobes that define the signal's shape have moved up further. This means that it is harder to tell the difference between noise and the signal spectrum. Reinforcing this idea, Figure 25 shows that the noise clouds are so large that they overlap. This overlap leads to occasional incorrect decisions made by the receiver. For this simulation the BER is approximately equal to 0.013 or 13 errors for every 1000 bits sent.

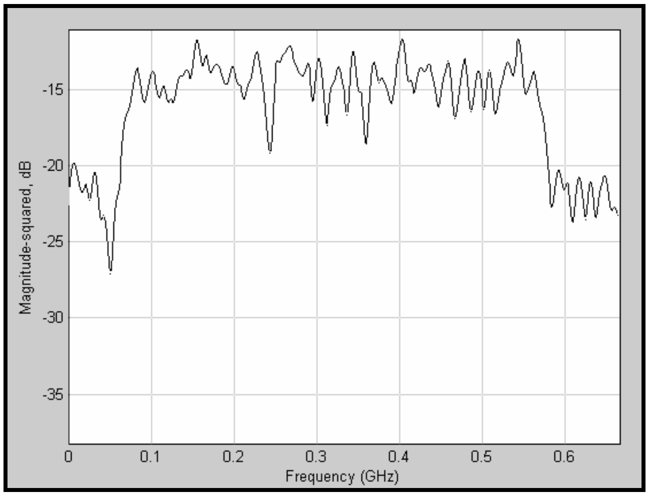

Figure 25 - Received OFDM Signal with SNR 20 dB

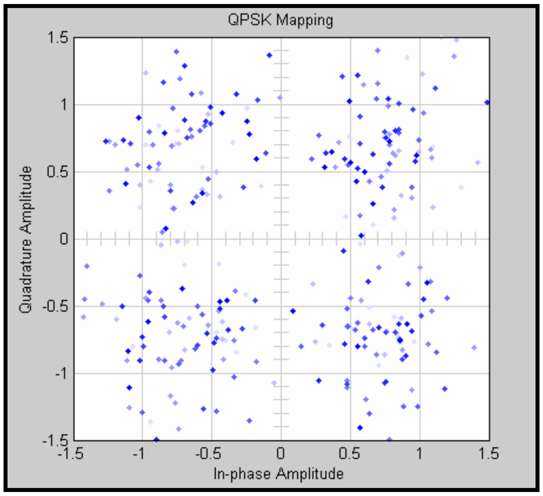

Figure 26 - Received QPSK Constellation with SNR 20 dB

The final simulation shows that if the SNR is low enough it is impossible to receive the transmitted signals. Figure 26 and 27 are the same simulation as above with the SNR equal to 10 dB. Clearly in Figure 26 there is no difference between the surrounding noise and the spectrum that was transmitted. Essentially the transmitted signal is completely immersed in the channel noise. Emphasizing this notion is the randomness shown in the QPSK constellation mapping in Figure 27. There is no way for the receiver to correctly detect any signal because there is no significant grouping of symbols to detect. The BER from this simulation is equal to approximately 0.31 or 310 errors for every 1000 bits sent. A BER rate of this value is not acceptable in any communications system.

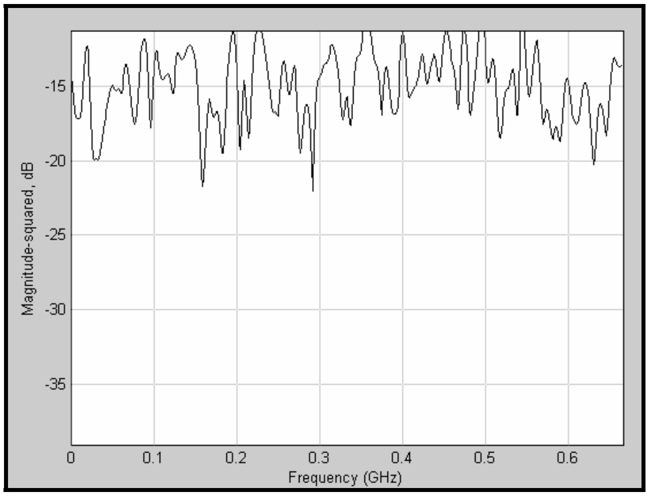

Figure 27 - Received OFDM Spectrum with SNR 10 dB

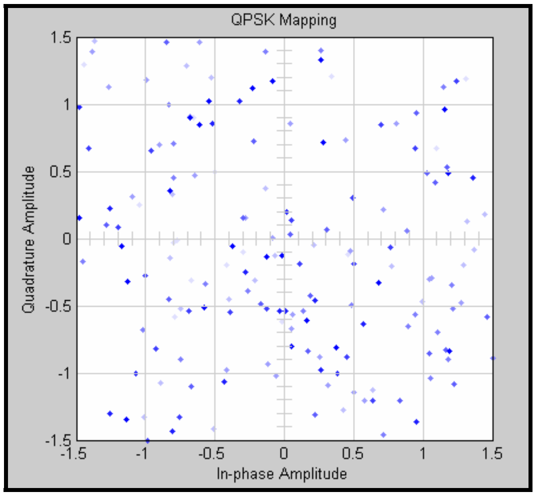

Figure 28 - Received QPSK Constellation with SNR 10 dB

In conclusion, it is important to know the characteristics of the channel. Without knowing the characteristics of the channel there is no way to estimate how well your communication system will operate overall. Continued research will be done to investigate the UWB channel characteristics, taking into account multi-path fading, and AWGN so that an accurate model can be implemented for simulation purposes before building any hardware.

OFDM Theory

The complex envelope signal, or the OFDM signal before up-conversion, is represented by equation 1. In this equation, (N) represents total number of sub-carriers, while (n) represents a single sub-carrier within the spectrum. w_n is a vector of complex numbers obtained from the constellation mapping.

$$g(t) = A_c \sum_{n=0}^{N-1} w_n \, \phi_n(t) \qquad (1)$$

Figure 28 shows each sub-carrier's location defined by frequency (f_n). Note also that (f_n) is given by equation 2.

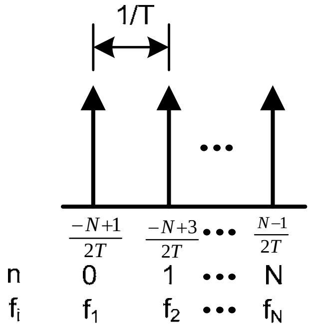

Figure 29 - OFDM Spectral Sub-carriers

$$f_n = \frac{1}{T}\left(n - \frac{N-1}{2}\right) \qquad (2)$$

The locations of the sub-carriers are defined in the complex envelope function as ϕ_n(t). ϕ_n(t) is also given by equation 3.

$$\phi_n(t) = e^{j2\pi f_n t} \qquad (3)$$

Two functions are said to be orthogonal with respect to each other over the interval a<t<b if the following condition is met:

$$\int_a^b \phi_n(t)\phi_m^*(t)dt = 0 \qquad (4)$$

Using any two consecutive signals in the OFDM spectrum (shown in Figure 28), equation 4 becomes equation 5 by substituting ϕ_n(t) for each frequency, in this case n=i & j, where $\left|i-j\right| = 1$.

$$\int_0^T e^{j2\pi f_i t} e^{-j2\pi f_j t} dt \qquad (5)$$

Doing algebraic manipulations on equation 5 and evaluating the integral, equation 6 is obtained.

$$\int_0^T e^{j2\pi(f_i - f_j)t} dt = \frac{e^{j2\pi(f_i - f_j)T} - 1}{j2\pi(f_i - f_j)} = \begin{cases} 1, & when \quad f_i = f_j \\ 0, & when \quad f_i \neq f_j \end{cases} \qquad (6)$$

The result in equation 6 is obtained from Euler's Identity. When equation 6 is equal to zero then the two frequencies are orthogonally spaced. Therefore all frequencies defined within the complex envelope function shown in equation 1 will be orthogonal.

From Figure 28 f_i is approximately equal to $\frac{n}{T}$. Substituting into equation 1, equation 2 is obtained.

$$g(t) = A_c \sum_{n=0}^{N-1} w_n \, e^{j2\pi \frac{n}{T} t} \qquad (7)$$

Substituting $t = \frac{kT}{N}$ into equation 7, equation 8 is obtained.

$$g\left(\frac{kT}{N}\right) = A_c \sum_{n=0}^{N-1} w_n \, e^{j2\pi \frac{n}{T}\frac{kT}{N}} \qquad (8)$$

Finally by reducing equation 8, equation 9 is obtained.

$$g(k) = A_c \sum_{n=0}^{N-1} w_n \, e^{\frac{j2\pi nk}{N}} \qquad (9)$$

Equation 9 is the definition of inverse direct Fourier transform (IDFT). This IDFT can be implemented with an IFFT, which is done in our model to create the OFDM spectrum.

6. Schedule and Objectives

Objectives

To research the UWB technology, two approaches will be used. The first approach will be to understand the theory behind UWB transmissions. This will involve researching the UWB specifications, and understanding the mathematical theory behind the modulation schemes used. The second step in researching UWB technology will be to create a model of a UWB system with Simulink. This model mentioned above will allow a greater understanding of the components required to build a UWB system. Within this model, different parameters and performance of a UWB system will be tested.

The next objective of the project is to implement a scaled-down version of a UWB transmitter and receiver. To do this, a DSP development platform will be purchased from Texas Instruments to facilitate all of the baseband signal processing. Once the Simulink model is complete, it will aid in choosing the correct DSP board for the project. This board must be capable of processing the baseband signals at a sufficient speed.

The second stage of implementation will involve designing RF circuitry to transmit and receive the UWB signal wirelessly. The functionality of these boards is described in detail in the functional description above. Depending on how much time is left to work on the project, an antenna may either be designed, or purchased from an antenna manufacturer.

The final stage of the project will be to test the results of the designed system. There will be many measurements taken on the system to verify its functionality and performance. These measurements might include but are not limited to the following:

- Frequency spectrum measurements using a spectrum analyzer to view transmitted signals.
- Measurements on the baseband signal before it is modulated to determine data rates and measure the performance of the digital hardware.
- Transmission range at various frequencies.
- Measurement of the antenna characteristics (for possible improvements).
- Power consumption at different data rates.

These measurements will verify and confirm that the performance of the system meets our design goals and also the majority of the UWB specifications.

Schedule

Based on the objectives, the schedule proposed for this project is shown in Table 3. This table is subject to change as more issues concerning the project arise.

Table 3 - Proposed Schedule

Week	Description of Tasks Nate	Jarrod	Both
11/28/2006	Simulink Model Basics - Transmitter and Receiver	Research RF Hardware for Transmit Board (ie. price, specs, lead times for direct-modulator)	Research new DSP boards (ie. price, specs, lead times)
12/5/2006			Oral Pressentation of Project Proposal
			Finish Website Development
Winter Break	Finalize Transmitter Simulink Model	RF Hardware Research for transmitter board.	Determine spectrum of the baseband signal for the RF board
	Research Downloading the Simulink Model onto the TI DSP platform.	Develop RF transmitter and receiver schematics	
	Research Synchronous Receiver for Simulink Model	Model transmitter and receiver circuitry	
1/30/2007	Download transmit model to DSP platform	Consult with Dr. Shastry about RF Circuitry	
	Determine / Estimate the required speed of a new DSP if required.	Work with frequency synthesizer and oscillator	Work on getting DSP boards working
	Implement Receiver Model		
2/6/2007	Finalize Receiver Model	Work on RF Modulator	Work on getting DSP boards working
2/13/2007	Download receiver onto DSP platform	Test RF Modulator	Work on getting DSP boards working
2/20/2007	Troubleshooting DSP platform	Work on filtering and amplification	Test RF components
2/27/2007	Troubleshooting DSP platform	Work on filtering and amplification	Test RF components
3/6/2007			Obtain antennas
3/13/2007			Test transmitted spectrum
3/20/2007	**Spring Break**		
3/27/2007	LNA implementation	Debug transmitter problems	Test transmitter/receiver circuitry
4/3/2007	LNA implementation	Demodulator implementation	Test transmitter/receiver circuitry
4/10/2007		Demodulator implementation	Prepare for final report
4/17/2007		Filtering	Work on final report
4/24/2007			Prepare for oral presentation
5/1/2007			Work on final report
5/8/2007			Work on final report

7. Equipment List

Table 4 - Equipment List

Part Description	Qty	Manufacturer	Part Number
DSP Platform C6000	2	Texas Instruments	TBD
Quadrature Modulator	1	Hittite (TBD)	**HMC497LP4**
Stable Oscillators	2	TBD	
Quadrature Demodulator	1	Hittite (TBD)	**HMC597LP4**
RF Amplifier	1	TBD	
LNA	1	TBD	
Filters	4	TBD	
Antenna	2	TBD	

*Note: TBD = To be decided

8. Conclusion

Ultra-Wideband technology will most likely revolutionize the consumer electronics market in the near future. The technology allows wireless devices to communicate with each other using high data transmission speeds, as well as consuming very little power. The UWB Research and Implementation design team hopes to design a fully functional, scaled-down version of a UWB system – showing people the advantages of this exciting technology.

9. References

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[5] Couch, Leon W., Digital and Analog Communication Systems. 7th Edition. New Jersey: Pearson Prentice Hall, 2007.

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10. Appendix

The first portion of this project was spent searching for a UWB development kit. This kit was going to be used to evaluate the performance and versatility of the UWB standard. There were five companies that were examined for available UWB platforms. The comparison of these companies and their products are shown in the Table 5. Of these companies, Staccato Communications had one of the more impressive development kits currently on the market. It included many interfaces that could be implemented in a variety of different ways. Wisair also had a board with many features that would have been useful for this project; however, the kits were very expensive and would lead to a “plug and play” evaluation board that would not be suitable for a senior project.

The next two companies were quite deceptive with their documentation and advertising. Focus Enhancements Semiconductor Group in particular had great documentation and features that could have been practical, but their product was still in development. Nevertheless, they are scheduled to release their product early to mid 2007, which is just barely out of our time frame. The same issue was also seen with Alereon. Their projected launch was also forecasted for release in mid 2007.

Finally, the last company left was PulsON Technologies. PulsON had been in production of their UWB evaluation kit for some time. They also had an education program setup specifically for universities level projects. This was promising, but on further investigation it was discovered that their modulation scheme was not what this project was focusing on. PulsON’s P210 modulation scheme was based on direct sequence UWB (DS-UWB).

Table 2 – Development Kit Comparison

Company	Staccato Communications	Focus Enhancement	Wisair	Alereon	PusION Time Domain
Product Name	Ripcord	Talaria	UWB Development Kit	WiMedia PHY Eval Board	e^2 Evaluation Kit
Product Part Number	SC3111D	TT-2101	DV9110	AL4401-EVK	P210
Contact Info	Martin Humphries		Sadir	Jim Meyer	Jon Hedges
Contact Info	(858) 812-1000	(503) 615-7700	(408) 399-7747	(512) 345- 4200	(256) 922-9229
Email	mhumphries@staccatocommunication.com		wisusa@wisair.com		jon.hedges@timedomain.com
Purchasing Issues	Too expensive	Still in development. Launch early ’07.	Too expensive	Still in development. Launch mid ’07.	Not desired modulation scheme
Total Cost	$25,000	N/A	$12,000	N/A	$7,500
Cost Per Board	$12,500	N/A	$6,000	N/A	$3,750
Lead Time	unknown	N/A	1 month	N/A	3 months
Frequency	3.1-4.8 GHz	3.2-7.2 GHz	3.1-4.8 GHz	3.1-5.0 GHz	3.1-6.3 GHz
Modulation Schemes	Multiband OFDM	Multiband OFDM	Multiband OFDM	Unknown	Direct Sequence-UWB
		DS-OFDM			
Interfaces:					
USB 2.0 Host	Yes	Yes	Yes	Unknown	Unknown
USB 2.0 Device	Yes	Yes	Yes	Unknown	Unknown
Direct CPU Interface	No	No	Yes	Unknown	Unknown
SDIO 1.1 Device	Yes	No	No	Unknown	Unknown
GPIO	Yes	No	No	Unknown	Unknown
Ethernet	No	Yes	Yes	Unknown	Unknown
Firewire	No	Yes	No	Unknown	Unknown
SPI to MPEG	No	No	Yes	Unknown	Unknown
Memory	Serial flash	SRAM/DRAM	Unknown	Unknown	Unknown
Internal	Unknown	1 MB SRAM	Unknown	Unknown	Unknown
External	N/A	DRAM Interface	Unknown	Unknown	Unknown
Security	128-bit AES Hardware Encryption	128-bit AES Hardware Encryption	No	Unknown	Unknown
Antenna	Unknown	Unknown	Yes / Omni	Unknown	Unknown
Documents	Yes	Yes	Yes	Unknown	Unknown