ULTRA WIDEBAND IMPULSE RADIO TRANSCIEVER

PROJECT NO: PRJ085

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INTRODUCTION

The concept of UWB was formulated through research in time-domain electromagnetic and receiver design in the early 1960. by Gerald F. Ross.

In February 2002 the US-FCC ruled that UWB could be used for data communications as well as radar and safety applications.

The band the FCC allocated to UWB communications is 7.5GHz between 3.1 and 10.6GHz.
PROBLEM DEFINITION

• Study Ultra Wideband impulse radio transmission systems for use in wireless sensor networks as a means of providing low power data transmission over short distances.
• Design and demonstration of the working of an Ultra wideband impulse radio transceiver.
PROBLEM JUSTIFICATION

The theoretical motivation why UWB-IR technology is so attractive can be better explained using the Shannon theorem.

\[ C = B \log_2(1 + P/(BN_O)) \]

Where:
- \( C \) is the channel capacity (bps)
- \( B \) is the channel bandwidth (Hz)
- \( P \) is the signal power (W)
- \( N_O \) is the noise power spectral density (W/Hz)

The capacity of a communication system increases faster as a function of the channel bandwidth than as a function of the power.
PROJECT OBJECTIVES

To study the Ultra Wideband impulse radio transmission system for as use in wireless sensor networks as a means for providing low power data transmission over short distances and then design and demonstrate the working of a UWB impulse transceiver.

The design objectives for the impulse radio UWB wireless communication system are as follows:

1. High data rate
2. Pulse waveform: Gaussian Monocycle
3. Modulation Schemes: Bi-phase shift key (BPSK) Modulation
4. Receiver topologies: Correlator receiver
IMPULSE RADIO SYSTEM

Å UWB-IR communication systems are carrier free baseband transmission.
Å Utilize very short, low duty cycle pulses with high bandwidth in transmission.
Å The UWB-IR signal is noise-like making interception and detection quite difficult
Å The UWB signals cause very little interference to existing narrowband radio systems; due to low power spectral density [1]
Characteristics of Impulse Radio UWB signals

Å Have potentially low complexity;
Å Have potentially low cost;
Å Have a noise-like signal spectrum;
Å Have multipath immunity;
Å Have very good time-domain resolution allowing for precise location and tracking applications
Å Have high data rates
A signal can be classified as an UWB signal if:

- fractional bandwidth $B_f$ is greater than 0.20.

$$B_f = \frac{2(f_H - f_L)}{(f_H + f_L)}$$

- Where $f_L$ and $f_H$ are the lower and the higher $-3$dB point in the spectrum, respectively.

- The minimum bandwidth measured at points 10dB below the peak emission level is 500 MHz

- The permissible emission levels for UWB signals in the UWB band are set at -41.3 dBm/MHz.

- The center frequency is given by $f_C = (f_H f_L)^{1/2}$, denoting $-10$dB cut-off frequency of the power spectrum.
Figure 1: UWB Signal Design Points
APPLICATION OF UWB-IR SYSTEMS

1. Communications and sensors
   - The ability to trade data rate for link distance by simply using more or less concatenated pulses to define a bit.
   - The high data rate personal area networks (PANs) can be applied in transmission of digital TV signals via a wireless link.
2. Position location and tracking

Å The narrow time domain pulse means that UWB-IR technology offers the possibility for very high positioning accuracy.

Å The power limitation effectively relegates UWB-IR systems to indoor, short-range communications for high data rates, or very low data rates for longer link distances.
3. Radar.

Together with good material penetration properties, UWB-IR signals offer opportunities for short-range radar applications such as rescue and anti-crime operations, as well as in surveying, and in the mining industry.
UWB-IR SIGNAL PROCESSING

This is a baseband signal approach based on discontinuous transmission of very short pulses.

One transmitted symbol is spread over N monocycles to achieve a processing gain that may be used to combat noise and interference.

The processing gain is given by $PG_1 = 10 \log_{10}(N)$

The UWB pulse does not necessarily occupy the entire chip period, meaning that the duty cycle can be extremely low.

Processing gain due to the low duty cycle is given by $PG_2 = 10 \log_{10}(T_p/p)$

Where $T_p =$ chip period and $p =$ impulse width

The total processing gain $PG$ is given by $PG = PG_1 + PG_2$
UWB-IR communication is resistant to severe multipath propagation; Since the transmitted signal is not continuous.

If the time between pulses is greater than the channel delay spread, there is no inter-symbol interference (ISI) between pulses and so no ISI between bits.

Pulse Generation, modulation, and multiple accesses are time domain dependent functions. Thus the behavior of most wireless systems is well defined in the time domain.

The output of a system in the time domain is defined with the convolution formula: \[ y(t) = (u)x(t-u)du \]

Where

- \( x(t) \) is the input of the system and
- \( y(t) \) is its output.
- \( h(t) \) which is defined as the impulse response of the system.
ULTRA WIDEBAND PULSES

Â The baseband pulses used by UWB-IR signals have very short time duration in the range of a few hundred picoseconds.

Â The shape of the signal is not restricted, but its characteristics are restricted by the FCC mask.

Â A good candidate shape for the UWB signal is the Rayleigh monocycle which is the first derivative of a Gaussian pulse, which has the time-domain representation, $P_{R(t)}$, given by; [1]

$$P_{R(t)} = A_R((t - \mu)/\sigma^2)exp(-1/2)((t - \mu)/\sigma)$$

2.6

Â Where;

Â $\sigma$ is the pulse width and

Â $\mu$ is the centre of the pulse.

Â $A_R$ is a scaling factor

Â Thus by adjusting $\sigma$, the bandwidth can be controlled.
Å Rayleigh monocycles do not have a DC component enabling them to be used in impulse radio systems since they facilitate the design of components such as antennas, amplifiers and sampling down converters.

Å The second derivative of the Gaussian pulse is Gaussian monocycle and it is also used in UWB-IR communication since it does not contain DC term.

The effective time duration of the Gaussian monocycle is $T_p=7$ with center frequency of $\varepsilon=3.5\mu$.

Å Gaussian monocycle has a single zero crossing whereas higher order derivatives have additional zero crossing yielding lower relative bandwidth and higher centre frequencies.
PULSE MODULATION

Modulation schemes used include:
- The pulse position modulation, PPM
- Bi-phase shift key (BPSK) modulation
- Pulse amplitude modulation, PAM
- On-off keying, OOK

PPM and BPSK have a better bit energy performance
Pulse Position Modulation
Å Involves changing the delay between the transmitted pulse according to the binary data; transmitting impulses at high rates
Å The pulses are not necessarily evenly spaced in time. They are spaced at random or pseudo noise (PN) time intervals

Advantages of PPM
Å Orthogonality in signal present in its data. The pulses in time are independent of one another.
Å Better error performance than PAM
Å permits non-coherent reception. [5]

Disadvantage of PPM
Å BER performance. This lack of signal energy causes binary PPM to have a probability bit error of 3 dB worse than BPSK modulation.
Å susceptibility to inter-symbol interference, which limit data rate when using it in impulse-radio UWB applications. [5]
BPSK MODULATION

Involves changing the polarity of the transmitted pulses according to the incoming data.

Advantages of BPSK modulation

Â Improved BER performance, as the $E_b/N_0$ is 3 dB less than PPM for the same probability of bit error.

Â Ability to eliminate spectral lines due to the change in pulse polarity. This minimizes the amount of interference with conventional radio systems. [4]

Disadvantage of bi-phase modulation

Â Its physical implementation is more complex, as two pulse generators, with the opposite polarity, are necessary instead of one. [5]
MULTIPLE ACCESS METHODS

A randomizing technique is applied to the transmitted signal in order to minimize the potential interference from UWB transmission on other communication systems by making the spectrum of the UWB transmission more noise-like.

The pulse train in impulse radio systems is randomized by time-hopping (TH) and direct-sequence (DS) techniques.[5]
DS-UWB

Use pseudo-noise codes to separate different users. [1] The spreading codes in DS-UWB systems is for accommodating multiple users as UWB systems are spread spectrum systems.

A user in the system is assigned a pseudorandom sequence which controls pseudorandom inversions of the UWB pulse train. A data bit is then used to modulate this sequence of UWB pulses. In the case of UWB systems, the pulse waveform takes the role of the chip in a spread spectrum system.
TH-UWB

The TH technique randomizes the position of the transmitted UWB pulses in time. Use pseudo-noise codes to separate different users. [1] In TH pulsed UWB systems, the pulse duty cycle is very small. Thus, the transmitter is gated off for the bulk of a symbol period. Multiple access can be implemented by employing appropriately chosen hopping sequences for different users to minimize the probability of collisions due to multiple accessing. Each receiver can detect a signal during its own unique hopping pattern, mitigating interference.
MULTIPLE ACCESS CAPABILITY

- Performance of UWB-IR system deteriorates with increase in number of users sharing the channel. To meet the performance specification of bit error rate (BER), the signal to noise ratio in the receiver must be controlled and the number of users that can share a channel is limited.
- For TH-UW the number of users is a function of the fractional increase in the power required to maintain a fixed BER, and is expressed as: [4]
  \[ N(\Delta P) = M^{-1} SNR^{-1}(1 - 10^{-\frac{\Delta P}{10}}) + 1 \]
- Where;
  - \( N \) is the number of users,
  - \( M \) is the modulation coefficient,
  - \( SNR \) is the signal to noise ratio of the specifications,
  - \( \Delta P \) is the increase in required power to maintain a constant BER
- The maximum number of users in a TH-UWB system is given by:
  \[ N_{\text{max}} = \lim_{\Delta P \to \infty} N(\Delta P) = M^{-1} SNR^{-1} + 1 \]
UWB TRANSMITTER

Â In TH-PPM UWB, the blocks of modulation and code generation control the programmable time delay, which determine the time at which the pulse generator is triggered. This block causes the time-hopping of the signal that permits the multiple access and it is also used as data modulator in this scheme. [4]

Â In Bi-Phase modulation, the block of modulation controls the pulse generator. In DS-UWB with Bi-phase modulation, the programmable time delay is omitted, and the block of modulation and code generation directly control the pulse generator.

Â The antennas behave like filters, and therefore their effect was considered. [4]
The TH-PPM UWB Transmitter
UWB RECEIVERS

- UWB receivers currently used are the correlation and the RAKE receiver. This is because detection of extremely short pulses requires highly specialized receivers. In impulse radios, up/down conversion is not required.

- The received UWB signal experiences as many as 30 multipath components and an rms delay spread of about 5-15 ns as a result of the characteristics of the channel. [4] The RAKE receiver combines the energy of the different multipath components of a received pulse in order to improve the performance. Each correlator is synchronized to a multipath component and the results of all correlators are added. The Decision device finally decides which symbol was transmitted after analyzing the output of the adders. This technique maximizes the amount of energy received per symbol, however it is complex in that the several N components have to be synchronized and their gains adjusted.

- The coherent detection of the main component of the signal is the basis on which the correlation receiver is designed. A local signal called template or reference must be generated in the receiver and correlated with the received signal.

- The template signal presents the expected signal. The correlator is formed by a mixer and an integrator.

- The output of the integrator is fed to a decision device which decides whether a one or zero was transmitted, for example a comparator.
The RAKE Receiver with N Fingers
The Correlation Receiver
THE TRANSCEIVER DESIGN

Å BPSK modulation and Direct Sequence multiple access. The synchronization in DS-UWB is easier to achieve than in TH-UWB.
Å The BER vs. Eb/No curves show that BPSK modulation has a better performance than PPM.
TRANSMITTER ANALYSIS

Â The Gaussian monocycle (second derivative of the Gaussian pulse) was used to implement the ultra wideband impulse radio transmitter system.

Â Adjustment factors were used to correct for inaccuracies in the second derivative equations. For the second derivative Gaussian pulse, the adjustment factor is approximately between 1 and 3, and for this design it was selected at 1.24.

Â The corrected pulse width is given by

\[ P_W = \frac{P_{W1}}{C_F} \]

Where

- \( P_W \) is the corrected pulse width, \( P_{W1} \) is the pulse width and, \( C_F \) is the adjustment factor,
The actual pulse width was considered from tail to tail on the time waveform of the Gaussian monocycle.

The effective time duration (the time duration of the waveform that contains 99.99% of total monocycle power.) For the Gaussian monocycle, its given by;

\[ T_{\text{eff}} = 7P_{W1} \]

and centered at

\[ P_{C} = 3.5P_{W1} \]

Where

\[ T_{\text{eff}} \] is the effective time duration

\[ P_{C} \] is the center of the pulse
The generated signal to be transmitted, had the following parameters:

- Pulse width, \( P_{w1} = 0.2 \) ns
- Corrected pulse width, \( P_w = P_{w1}/1.24 = 0.1613 \) ns
- Sampling frequency, \( F_s = 100 \) GHz
- Nyquist frequency, \( F_n = F_s/2 = 50 \) GHz

The AWGN noise added by the transmitter antenna has SNR of 7DB.

The pulse repetition frequency (PRF) was set at 156MHz, thus waveform repeated every 6.41nsec.

A modulated bit stream of 5 pulses, (10101) with bit rate of 156Mb/s was used.
RECEIVER ANALYSIS

The Correlator Receiver

- The correlation receiver was assumed to be perfect synch.
- The received signal is first added with additive white Gaussian noise (AWGN).
- The signal is then amplified and mixed with a template (reference) signal.
- The signal is integrated over a period of time, and then sampled.
- A comparator to zero then takes the output and produces a digital output that is fed to the baseband processing.
The Correlator
The output of the filter can be defined as
\[ Y(f) = X(f)H(f) \] in frequency domain and
\[ y(t) = x(t) * h(t) = \int_{-\infty}^{t} x(\tau) h(t - \tau) d\tau \] in time domain
where
* Is the convolution operation
h(t) is the impulse response of the filter
The correlation function is defined as;
\[ R(\tau) = \int_{-\infty}^{+\infty} x(t) h(t - \tau) dt \]
Where
is the delay between the two signals that are correlated.
When the signal h(t) is the same as the input signal of the mixer, this signal produces the maximum SNR and when used in the correlation, the detector is called maximum likelihood, optimum correlator or matched filter.
The output of the correlation function becomes autocorrelation as the signals are the same. Peak of this function occurs when \( \tau = 0 \) and is equivalent to the energy of the signal.
Additive White Gaussian Noise added to Transmitted Signal
The generated Second Derivative Gaussian Pulse in Time Domain
The Generated Second Derivative Gaussian Pulse Frequency Spectrum
The Received Filtered Correlator Output Signal in Frequency Domain
The received Filtered Correlator Output Signal Frequency Spectrum
DISCUSSION

The number of pulses used were only 5 per symbol. This number could be expanded to modulate for a longer series, but this would lower the bit rate.

The system simulation was designed for only one user, thus the pseudo noise code generation was not included.

The shape of the second derivative Gaussian pulse at the receiver is a little bit changed from the expected signal; this is due to the differentiation effects of the transmission and reception antennas.

In order to keep power consumption minimum, a high sampling rate was used. The information rate of the system was determined by the pulse repetition frequency.
RECOMMENDATION AND FUTURE WORK

Â Future design modification of the wireless communication system can be made based on future simulation and implementation results desired.

Â The matlab code of the receiver can be improved in order to execute other system level simulations such as: investigating Other pulse waveforms that may be as template in the receiver, including multi-user interface so as to confirm the theoretical multi user capability and implementing of a phase detector to find the time that the receiver needs to achieve pulse synchronization.

Â In the future a schematic and PCB layout of the system should be created and fabrication of the same be done. The ultra wide band impulse radio transceiver should then be tested and hence physically implemented.
CONCLUSION

• The design and simulation of the UWB-IR transceiver demonstrated the working of the system.
• The designed system achieved a high data rate of about 156Mhz and low power consumption.
• The UWB-IR system design was simplified, eliminating some of the components required in baseband signal processing with carrier, thus low power consumption. In order to keep power consumption minimum, a high sampling rate was also used.
• This project report presents a Ultra Wideband impulse radio transmission system that can be used in wireless sensor networks as a means of providing low power data transmission over short distances.