ULTRA WIDE BAND (UWB) MODULATION FOR SIGNAL ACQUISITION FROM BIOMEDICAL IMPLANTS

BY

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A dissertation submitted in fulfillment of the requirement for the degree of Master of Science (Communication Engineering)

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ABSTRACT

A circuit for Ultra-Wide-Band (UWB) pulse generation, shaping and modulation is proposed. The circuit is optimized, in terms of component values, to facilitate fabrication in 0.13μm CMOS technology. The circuit is designed to satisfy the main application limitations and constraints. These constraints are in the form of low voltage, low bit error rate, and adherence to FCC spectral emissions mask. The technique used is simple, and capable of producing UWB pulses complying with the Federal Communication Committee (FCC) power spectral mask regulations. The performance of conventional modulation techniques is compared to the Pulse Interval Modulation (PIM) used in this work for its preferential performance parameters, which is meant to be of high utility for extracting data signals from bio-medical implants.

خلا صة البحث

هذه الأطروحة تقدم دراسة عن جدوى استخدام تكنولوجيا Ultra Wide Band (UWB) (الاشارات ذات التذبذب واسع النطاق) لاستخراج إشارة من الطبية الحيوية المزروعة داخل الجسم. وتغطي الدراسة جوانب تشكيل الاشارات وتقنيات الترميز من أجل تطبيقها في الأجهزة المزروعة مع الأخذ في نظر الاعتبار القيود والمعوقات الرئيسية التي تفرضها طبيعة التطبيق مثل استهلاك الطاقة، ومعدل الخطأ، والآثار على شكل الطيف التذبذبي للاشارات. استنادا إلى المصادر الموجوده، وتغطية تلك القيود، تم ,و بعون الله, تصميم دائرة كهربائية جديدة قادرة على تشكيل و ترميز الاشارات. وكانت الدائرة, و على حد علم الكُتاب, الاولى من نوعها التي تؤدي عملية الترميز للاشارات ذات التذبذب واسع النطاق بأستخدام تقنية ترميز الفترة الفاصله بين اشارتين Pulse Interval Modulation (PIM), هذا و قد تم تحسين قيم عناصر الدائرة لتكون ملائمة للتصنيع بأستخدام تقنية (CMOS 0.13 um).

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Communication Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, expect where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Mokhaled M. Mohammed

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To my beloved family

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Praise be to Allah (S.W.T.), the Almighty for bestowing His Grace and Mercy, Solawat and Salam to our beloved prophet (P.B.U.M).

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LIST OF ABBREVIATIONS

UWB	Ultra Wide Band
DC	Direct Current
FCC	Federal Communications Commission
RADAR	RAdio Detection And Ranging
IEEE	Institute of Electrical and Electronics Engineers
PAN	Personal Area Networks
BAN	Body Area Network
SRD	Step Recovery Diode
pH	potential Hydrogen
EM	Electro Magnetic
ICD	Implantable Cardiac Defibrillator
ADC	Analog-to-Digital Converter
VCO	Voltage Controlled Oscillator
OOK	On-Off Keying
PPM	Pulse Position Modulation
PAM	Pulse Amplitude Modulation
BPSK	Bi-Phase Shift Keying
PPAM	Pulse Position Amplitude Modulation
PIM	Pulse Interval Modulation
IR-UWB	Impulse Radio Ultra Wide Band
MC-UWB	Multiple Carrier Ultra Wide Band
MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor
CMOS	Complementary Metal-Oxide-Semiconductor
PSD	Power Spectral Density

LIST OF SYMBOLS

C	channel Capacity
B	Bandwidth
S	Signal power
N	Noise power
f_s	sampling frequency
σ	standard deviation
μ	mean
τ	time constant
V_{sat}	saturation voltage
V_t	threshold voltage

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND

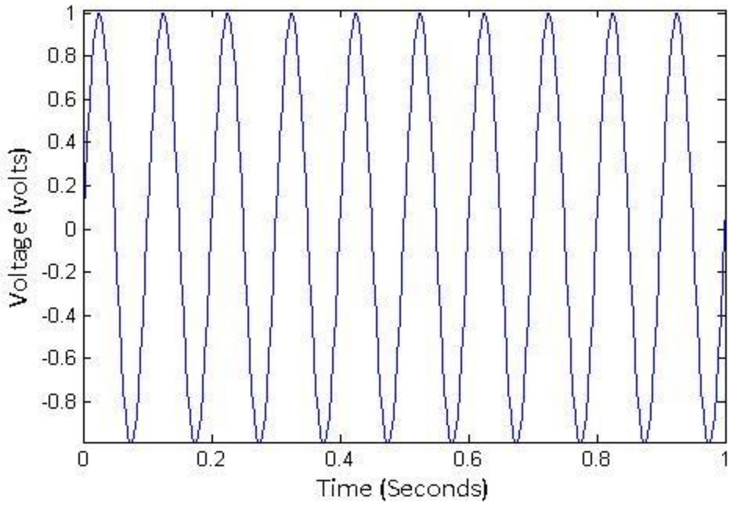
Ultra-Wide Band (UWB) communications is the process of transferring data (communicating) in the form of a stream of very short pulses ranging over an ultra-wide bandwidth. Ultra-wideband technology provides the solution to the spectrum problems by performing the communication task through a concept different from that of the conventional communications systems. UWB communications rely on sending sub-nanosecond time domain pulses extending over an ultra-wide band in the frequency domain. The modulating signal varies some features of the pulses being sent, unlike analog communication systems which make use of sinusoidal signals to perform the modulation task through amplitude, phase, and frequency.

To illustrate the concept of UWB in comparison to that of narrow band technologies the scaling property of the Fourier transform is examined. The scaling property is given by (Benedetto., Kaiser, Molish, Oppermann., Politano, and Porcino, 2006):

$$x(at) \leftrightarrow \frac{1}{|a|} X\left(\frac{f}{a}\right) \tag{1.1}$$

where 'a' is the scaling factor, x(t) is the function in time domain, and X(f) is the corresponding function in frequency domain.

The scaling equation means that if the signal is narrower in the time domain, the corresponding signal in the frequency domain would be wider, and vice versa. To further illustrate the concept the following graphs have been generated using MATLAB.



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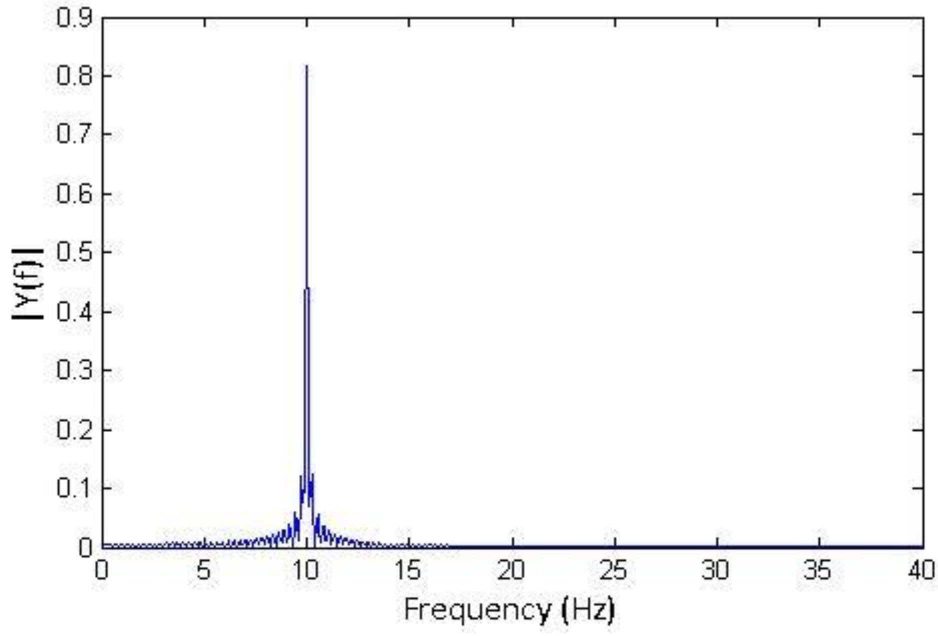
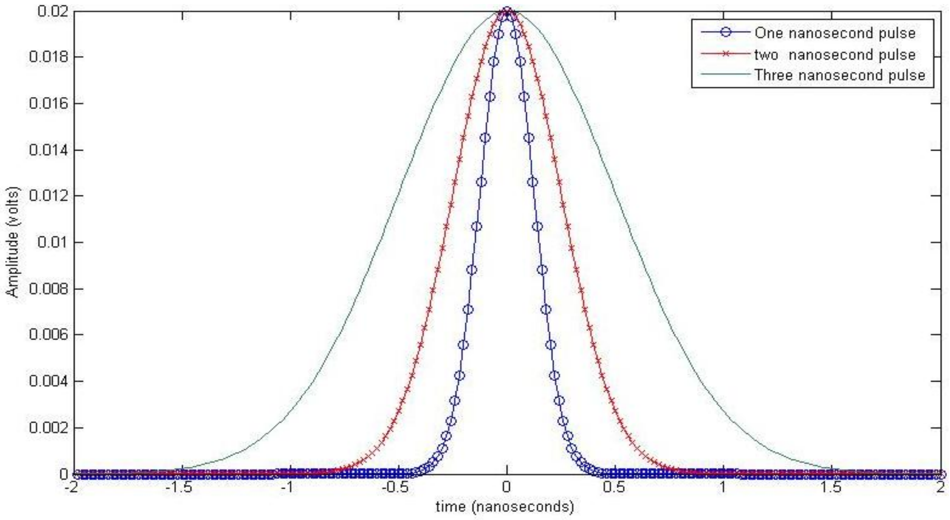
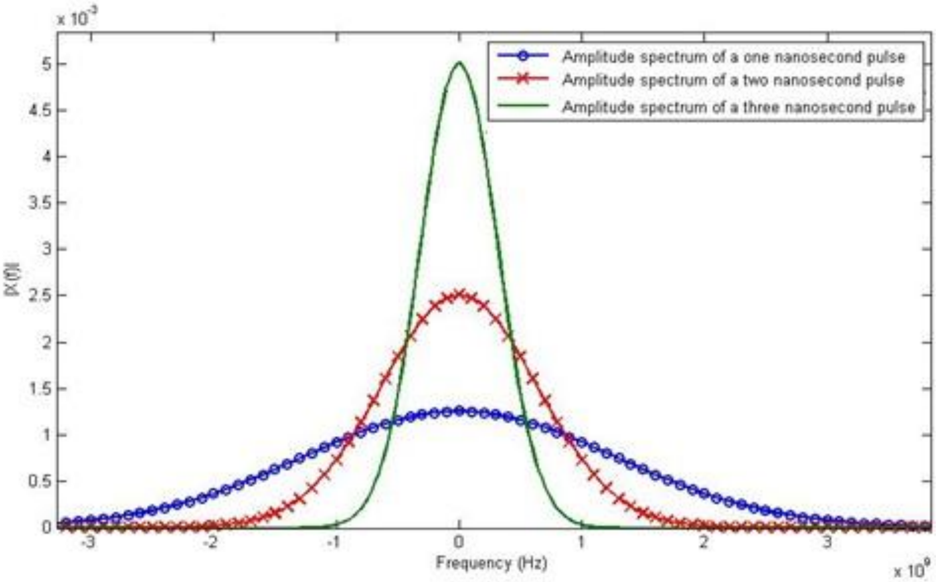


(b)

Figure 1.1: (a) Single frequency sinusoid and (b) its single sided amplitude spectrum



(a)



(b)

Figure 1.2: (a) Three Gaussian pulses and (b) their double sided amplitude spectrum

In Figure 1.1, a sinusoidal signal has been shown in the time domain with its corresponding frequency domain representation. A sinusoid is a continuous signal and hence 'a' in Eq. (1.1) one is very large (theoretically approaching infinity) and therefore the signal in the frequency domain is very narrow (the width is approaching zero and hence it's represented by a spike). As for Figure 1.2, the concept is illustrated through showing three narrow pulses with different durations. It can be observed that the narrower the signal is, in the time domain (shorter duration), the wider the frequency domain representation of the signal becomes. The width of a pulse in time domain and the spread of its band in frequency domain are inversely related to each other. A pulse spreading over the entire length in time domain is actually regarded DC, and hence its frequency spectrum is an impulse. When the DC starts shrinking towards becoming shorter and shorter pulse, its frequency equivalent are spreading out and out to become wider, leading to ultimately to situation where an impulse in time domain becomes like DC stretches over the entire frequency range; hence giving rise to the name of ultra-wide band.

UWB communication systems have developed vastly during recent years, particularly in short range communication applications. Though it is being looked at from new applications' perspective; UWB technology has been around for some time and most commonly used in earth penetrating radars and military radars. (Nikookar, and Prasad, 2009). The recent developments of miniature sizes in electronic devices, systems and components with reduced power requirement have generated a renewed research interest in UWB communication from applications view point never imagined before. A major turning point in the development of UWB communications was the release of the first set of regulations for the utilization of UWB communications for commercial purposes by the Federal Communications Commission (FCC) in 2002. (Nekoogar, 2006). This step has stirred a lot of attention and interest from different researchers all over the world to utilize and develop the UWB technology further to the fields of wireless communications and indoor monitoring applications.

Aside from the communications purposes UWB technology can be used in tracking and monitoring purposes. This is due to the high resolution of the pulses. UWB can be used for through wall RADAR imaging for monitoring and tracking, and earth penetrating RADARs (Nekoogar, 2006).

The low power emission imposed by regulatory bodies enables the usage of UWB technology in Radio Frequency sensitive zones like hospitals for short range communications. The high data rates achievable with UWB communications systems enable indoor communications with high speeds which makes applications like connecting to wireless monitors and interconnecting streaming devices very viable. UWB technologies has been recommended in IEEE 802.15.3a draft PAN standards to wirelessly connect devices in personal area networks enabling the high speed transfer of files between handheld devices such as phones, camcorders, and other portable devices (Nekoogar, 2006). It can be used for printing high quality digital photos without the necessity to connect to a computer or other devices.

One of the major applications for UWB communications is the utilization of this technology in the development of sensor networks requiring high bit rates, low power consumption, and simple and compact circuit and component designs both at transmitting and receiving ends. In this work, we focus on the use of UWB technology for the purpose of signal extraction from implantable devices in locations and spots inaccessible to wiring. Implantable devices can be in the form of sensors or actuators or both, implanted inside a human's or animal's body, or building/bridge structure in order to monitor a parameter at a time for drawing attention of the concerned personnel when that attention is highly required. Such implants, such as Implantable Cardiac Defibrillators and Artificial pacemakers, are already in use in patients with arrhythmia to regulate the heart beats and avoid sudden cardiac arrests. Another emerging technology in implantable devices is Body Area Networks (BAN). (Karulf, 2008) The vision for this technology goes back to the 1970s however the available technology was not powerful enough then to develop such systems. However, due to recent developments, the vision of Body Area Networks looks more achievable in the near future. UWB technology equipped with relevant features certainly proves to be a favorable candidate for this particular application due to their low power consumption and the ability to achieve high bit rates. The BAN concept is shown in Figure 1.3 (Karulf, 2008).

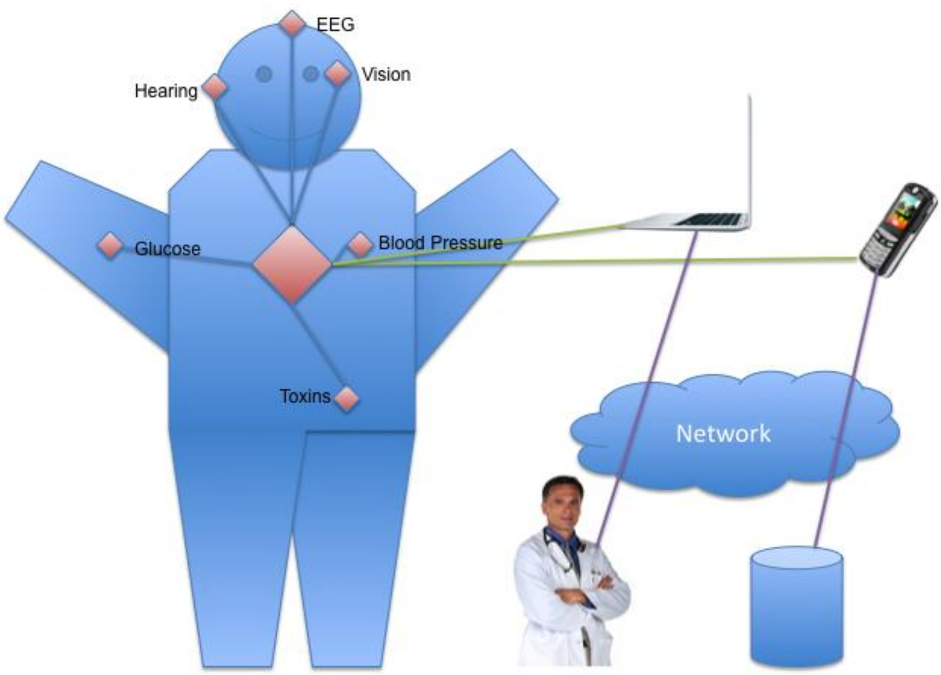


Figure 1.3: Body Area Networks (Karulf, 2008)

The typical structure of a bio-sensing element is shown in figure 1.4. The powering element can take several forms such as inductive power or battery powering. However, given the nature of the application there would a limitation on the input voltage and over all power consumption. There is also a constraint on the size of the different components.

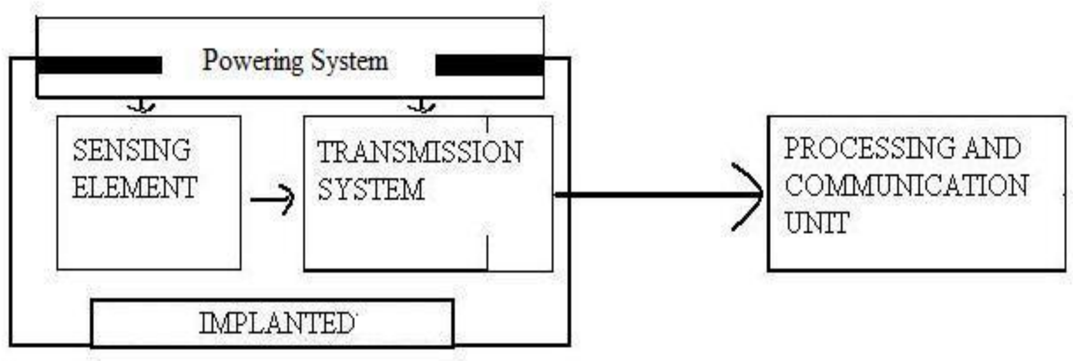


Figure 1.4: Typical Biosensing Implant system

The typical structure of communication system is shown in figure 1.5. This would constitute the main block diagrams of the transmission system indicated in figure 1.4 if UWB is used in an implantable sensing element. This communication system typically involves three major blocks or elements which are modulation, pulse generation, and filtering. The encoder is an optional component used to encode a signal either for cryptography or compression. The modulator would modulate the input signal into a certain feature (amplitude, phase, position, etc.) of the UWB pulses from the pulse generator. The order of pulse generation and modulation is exchangeable. In other words, in most proposed designs the data pulses are modulated first and then the equivalent pulse shapes are generated and shaped. There are various approaches in order to generate and shape the pulses but figure 1.5 represents a general overview of the main blocks that could be approached in different ways.

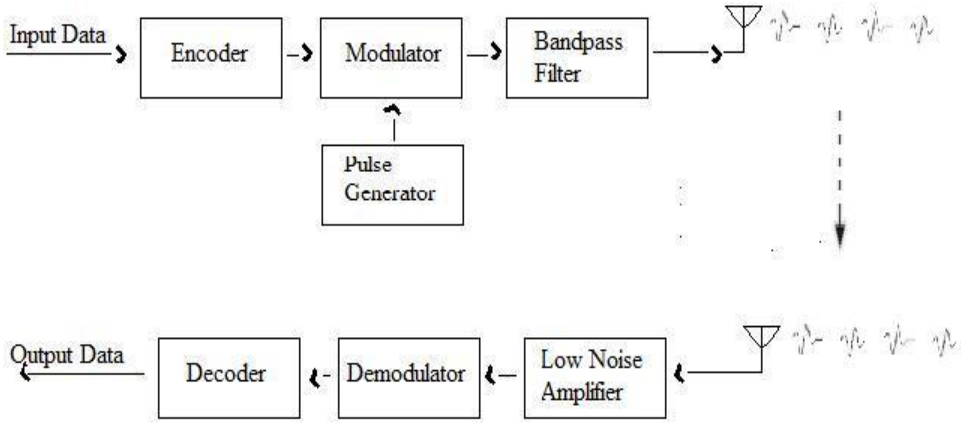


Figure 1.5: Overview of typical UWB Communications Systems (Novak and Charles, 2009)

The prospect of generating those short pulses and modulating them is one of the most challenging aspects of a UWB communications system design. This is mainly due to the short duration of the pulses which requires significantly quick switching capabilities. Researchers have tackled this problem through numerous approaches such as using Step Recovery Diodes (SRDs), logic gates, and various other techniques. However, each of those designs has a drawback, like failing to meet the FCC mask, or inconsistency, etc. This research aims to identify the main drawbacks of each technique and also address the issue of choosing an appropriate modulation technique for the targeted application.

1.2 PROBLEM STATEMENT AND SIGNIFICANCE

Transmission of data signals from implantable devices is of great importance. The current and emerging technologies require high bit rates which are not supported by current technologies (Djemouai, and Sawan, 2004; Gudnason, 2000; Joonsung,