DESIGN AND ANALYSIS OF LOW POWER MINIATURE TYPE ULTRA WIDE BAND TRANSMITTER FOR MEDICAL APPLICATION

SHANJIDA AKTER

M.Sc. ENGINEERING THESIS

DEPARTMENT OF ELECTRICAL, ELECTRONIC AND COMMUNICATION ENGINEERING

MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY
DHAKA, BANGLADESH

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SHANJIDA AKTER (SN.1017160009)

A Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Master of Science in Electrical, Electronic And Communication Engineering

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By

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Approved as to style and content by the Board of Examination on 10 October 2022:

Dr. Pran Kanai Saha Professor Department of EEE, BUET, Dhaka	Chairman (Supervisor)
Lieutenant Colonel Md. Tawfiq Amin, PhD, EME Instructor Class A Department of EECE, MIST, Dhaka	Member (Co-Supervisor)
Brigadier General A K M Nazrul Islam, PhD Head of the Department Department of EECE, MIST, Dhaka	Member (Ex-Officio)
Maj Md Aminul Islam, PhD Instructor Class B Department of EECE, MIST, Dhaka	Member (Internal)
Dr. A. B. M. Harun-Ur-Rashid Professor Department of EEE, BUET, Dhaka.	Member (External)

Department of Electrical, Electronic and Communication Engineering, MIST, Dhaka

DESIGN AND ANALYSIS OF LOW POWER MINIATURE TYPE ULTRA WIDE BAND TRANSMITTER FOR MEDICAL APPLICATION

DECLARATION

I hereby declare that the study reported in this thesis entitled as above is my own original work and has not been submitted before anywhere for any degree or other purpose. Further I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged and/or cited in the reference section.

____

Shanjida Akter

Department of Electrical, Electronic and Communication Engineering, MIST, Dhaka

DESIGN AND ANALYSIS OF LOW POWER MINIATURE TYPE ULTRA WIDE BAND TRANSMITTER FOR MEDICAL APPLICATION

A Thesis

By

Shanjida Akter

DEDICATION

Dedicated to my family for supporting and

encouraging me to believe in myself

ABSTRACT

Design and Analysis of Low Power Miniature Type Ultra Wide Band Transmitter for Medical Application

Recently, there has been a surge in demand for biomedical devices that can continuously monitor essential life indicators including heart rate variability (HRV) and breathing rate etc. This ideal device would be small, wearable, wireless, networkable and low-power, allowing for vital sign monitoring. The impulse radio-based ultra-wideband (IR-UWB) technology is a promising technology that can meet these requirements. IR-UWB has received a lot of attention after Federal Communications Commission (FCC) approved the 3.1GHz-10.6GHz frequency band in 2002. To represent information, IR-UWB uses incredibly narrow Gaussian monocycle pulses or any other type of short RF pulse. IR-UWB system does not necessarily require carrier signals is one of its most appealing features. In light of these advantages, this research proposes a new ultra-wide band (UWB) transmitter system based on impulses with low power consumption and a simple architecture. The illustrated UWB transmitter consumes low-power and generates a 359.44 mV output pulse swing with a pulse width of 100 ps for the Gaussian monocycle pulse. Due to its increased output voltage and low power consumption when compared to other circuits, the given topology is functional and suitable for use in medical applications and short-range wireless communication.For Ultra-wide band (UWB) communication applications a low cost, miniature size coplanar waveguide (CPW) fed ultra-wide band (UWB) antenna is also proposed which is ideal for UWB applications and has return loss less than -10db from 3GHz to 10.6GHz. To accomplish the UWB bandwidth, design characteristics have been optimized. The proposed antenna is a simple coplanar wave guide (CPW) fed aperture antenna where the concept of modified ground plane is applied to enhance the bandwidth and it is compatible with the designed UWB transmitter.

সারসংক্ষেপ

Design and Analysis of Low Power Miniature Type UWB Transmitter for Medical Application

সম্প্রতি বায়োমেডিকেল যন্ত্রপাতির (Device) চাহিদা বৃদ্ধি পেয়েছে যা হার্ট রেট পরিবর্তনশীলতা (Heart Rate Variability) এবং শ্বাস-প্রশ্বাসের হার ইত্যাদি সহ প্রয়োজনীয় জীবন সূচকগুলিকে ক্রমাগত নিরীক্ষণ করতে পারে। এই আদর্শ যন্ত্রটি হবে ছোট, পরিধানযোগ্য, বেতার, নেটওয়ার্কযোগ্য এবং কম শক্তি ক্ষয়কারী যা গুরুত্বপূর্ণ লক্ষণ সমূহ পর্যবেক্ষণ করতে পারে। ইমপালস রেডিও (Impulse-Radio) ভিত্তিক আল্ট্রা-ওয়াইডব্যান্ড (IR-UWB) প্রযুক্তি একটি প্রতিশ্রুতিশীল প্রযুক্তি যা এই প্রয়োজনীয়তাগুলি পূরণ করতে পারে। ২০০২ সালে ফেডারেল কমিউনিকেশন কমিশন (FCC) 3.1GHz-10.6GHz ফ্রিকোয়েন্সি ব্যান্ড অনুমোদন করার ফলে ইমপালস রেডিও আল্ট্রা ওয়াইড ব্যান্ড (IR-UWB) যথেষ্ট মনোযোগ আকর্ষণ করেছে। তথ্য উপস্থাপন করার জন্য, IR-UWB অবিশ্বাস্যভাবে খুব ছোট গসীয়ান মনোসাইকেল পাল্স (Gaussian Monocycle Pulse) বা অন্য কোনো ধরনের ছোট আরএফ পালস ব্যবহার করে। আইআর-ইউডব্লিউবি (IR-UWB) সিস্টেমের তথ্য প্রেরণের জন্য কোন ক্যারিয়ার সিগন্যালের প্রয়োজন হয় না, যা এর সবচেয়ে আকর্ষণীয় বৈশিষ্ট্যগুলির মধ্যে একটি। এই সুবিধাগুলির আলোকে, এই গবেষণাটি একটি নতুন আল্ট্রা-ওয়াইড ব্যান্ড (UWB) ট্রান্সমিটার সিস্টেমের প্রস্তাব করে যা কম বিদ্যুৎ খরচ করে এবং সাধারণ আর্কিটেকচার সম্বলিত। প্রস্তাবিত UWB ট্রান্সমিটার কম বিদ্যুৎ খরচ করে এবং 100 ps প্রস্থের ও 359.44 mV ভোল্টেজ এর একটি গসীয়ান মনোসাইকেল পাল্স (Gaussian Monocycle Pulse) তৈরী করে। অন্যান্য সার্কিটের তুলনায় এর বর্ধিত আউটপুট ভোল্টেজ এবং কম বিদ্যুৎ খরচের কারণে, প্রদত্ত ডিজাইনটি কার্যকরী এবং চিকিৎসা ক্ষেত্রে ব্যাবহার এবং স্বল্প-দুরত্বের বেতার যোগাযোগে ব্যবহারের জন্য উপযুক্ত। আল্ট্রা-ওয়াইড ব্যান্ড (UWB) কমিউনিকেশন সিস্টেমে ব্যাবহারের জন্য একটি কম খরচে, ক্ষুদ্র আকারের কপ্ল্যানার ওয়েভগাইড (Coplaner Waveguide) যুক্ত আল্ট্রা-ওয়াইড ব্যান্ড (UWB) অ্যান্টেনাও প্রস্তাব করা হয়েছে যা UWB অ্যাপ্লিকেশনের জন্য আদর্শ এবং রিটার্ন লস 3GHz থেকে 10.6GHz পর্যন্ত -10dB এর কম। আল্ট্রা ওয়াইড ব্যান্ডউইথ অর্জন করতে, অ্যান্টেনার বিভিন্ন বৈশিষ্ট্য সমন্বয় করা হয়েছে। প্রস্তাবিত অ্যান্টেনাটি একটি সাধারণ কপ্ল্যানার ওয়েভ গাইড (CPW) যুক্ত অ্যাপারচার (Aperture) অ্যান্টেনা যেখানে ব্যান্ডউইথ বাড়ানোর জন্য পরিবর্তিত গ্রাউন্ড প্লেনের ধারণাটি প্রয়োগ করা হয়েছে এবং এটি প্রস্তাবিত UWB ট্রান্সমিটারের সাথে সামঞ্জস্যপূর্ণ।

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In conclusion, I want to say this thesis is one of the most significant accomplishment in my life. This surely can be counted as one of the most memorable event in my life so far. I think this is not just the end here. In fact, this is the new beginning of me as a researcher in the field of VLSI circuit design.

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LIST OF ABBREVIATIONS

ASIC	Application Specific Integrated Circuit
BW	Bandwidth
BPSK	Bipolar phase shift keying
CMOS	Complementary Metal Oxide Semiconductor
DRC	Design Rule Check
DS-OFDM	Direct sequence orthogonal frequency-division multiplexing
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
HRV	Heart rate variability
IC	Integrated Circuit
IR-UWB	Impulse radio ultra-wide band
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NMOS	n-channel MOS
OOK	On-Off Keying
PAM	Pulse-Amplitude Modulation
PMOS	p-channel MOS
PPM	Pulse-Position Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
TSMC	Taiwan Semiconductor Manufacturing Company Ltd.
UWB	Ultra-wideband

CHAPTER 1
INTRODUCTION

1.1 General

Ultra-wideband (UWB) imaging technology has recently shown to be appealing for short-range wireless communications including high-precision data. UWB technology entered in a new era, particularly in invasive medical applications including early breast cancer diagnosis, heart rate variability (HRV), obstetrics, breath routes, and arteries. In addition, advancements in technology have allowed for the construction of compact, low-power, and sophisticated multifunctional integrated circuits over the past ten years [1]. As a result, a growing number of Application Specific Integrated Circuit (ASIC) chips are being drawn to use in medicine field.

1.2 Background and Motivation

The maximum quantity of information that can be communicated across a wireless communication system is specified by Shannon's Formula as

$$C = W log_2(1 + SNR) \tag{1.1}$$

where W denotes the signal's bandwidth and SNR denotes the communication system's signal-to-noise ratio. The mathematical fact indicates that either increasing signal bandwidth or enhancing signal-to-noise ratio (SNR) can result in faster transmission speeds. The advancement of wireless communication technology over the past few decades has been focused on increasing SNR and modulation efficiency. This is primarily caused by the fact that the wireless signal's bandwidth (or spectrum) is a strictly finite resource. However, wideband signal research and application have not gone unnoticed. Early uses of ultra-wideband signals (UWB) span specialized fields such ground penetrating, positioning/geolocation, and military communication. Wideband UWB signals can be converted into ultra-short pulses in the time domain, which has benefits including immunity to multipath, improved spatial resolution, and low intercept probability. The majority of these older specialized UWB systems are hybrid circuit-based, hence circuit integration was not urgently required. Since the Federal Communications Commission (FCC) approved the

3.1GHz-10.6GHz frequency spectrum for UWB applications in 2002, numerous studies have concentrated on UWB technology and applications [2].UWB is defined as a modulated transmission with a bandwidth of at least 500 MHz and a fractional bandwidth of above 20%. Impulse radio (IR) based UWB uses extremely short Gaussian monocycle pulses as the signal. Other UWB technologies include frequency hopping spread spectrum (FHSS) and direct sequence orthogonal frequency-division multiplexing (DS-OFDM). The absence of carrier signals is what distinguishes IR-UWB from traditional wireless communications [3].In IR-UWB, information is communicated using extremely narrow Gaussian monocycle impulses or some other type of quick RF pulse. Extremely broad bandwidth is made possible by the incredibly brief pulses, which has a number of benefits including wide bandwidth, covertness, jamming resistance, low power consumption, and compliance with current radio services [4].

IR-UWB was made ready for commercial use together with recent improvements in micro processing and rapid switching in semiconductor technology [5]. So, it makes more sense to think of UWB as a new phrase pertaining to the age-old technology. The history of IR-UWB development is shown in Fig. 1.1.

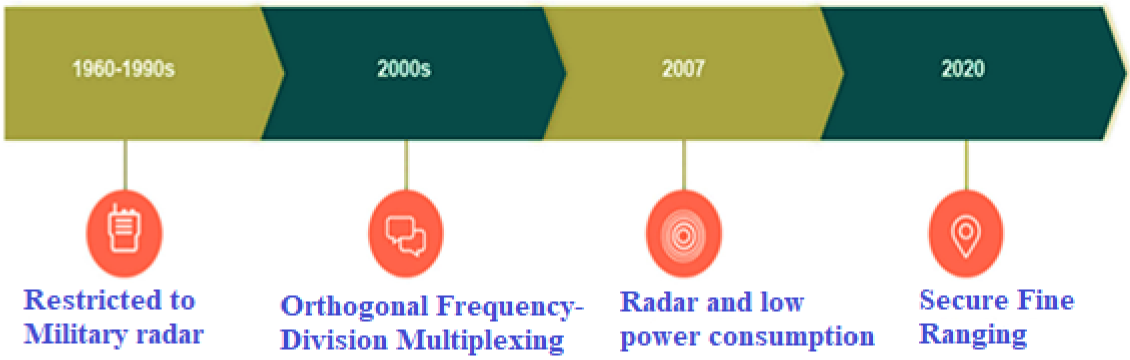


Fig. 1.1: IR-UWB development history [5].

The concept of using radars to track human physiological processes dates back to the 1970s, but further research was constrained due to the cumbersome and costly technology of the time before 1990s, when commercially viable low-power CMOS technology matured [6]. A UWB radar biomedical usage was proposed in 1998, and a number of US patents explaining its biomedical applications were afterwards demanded [7]. One of the publications that has received the most citations was written by Thomas McEwan of the Lawrence Livermore National Laboratory in the United States. McEvan highlighted that "the average emission level utilized (about 1W) is nearly three orders of magnitude lower than most international restrictions for continuous human exposure to microwaves" while outlining the device's potential applications in medical [8]. The most recent developments were made by Wireless2000, whose PAM 3000, their first commercial UWB product that measures heart and breathing rates, was released in the middle of 2007.

Due to the physical characteristics of UWB short pulse, reliable radar sensing and high data rate communication are both possible [9]. The UWB signal may penetrate through human tissue including membranes, fat, and other cells due to its broad frequency range, and the reflection from interior organs makes it possible to monitor vital signs among several other things. Additionally, research has demonstrated that human tissues are not harmed by ultrawide band pulses [10].

Furthermore, due to its simpler transceiver architecture, it causes less electrical strain on the chip's existing circuitry. It has been demonstrated that an antenna integrated onto a chip may be used successfully as a UWB pulse generator, hence avoiding the use of costly and analog parts with high power requirements [11]. Additionally, because it only happens during the pulse data transmission, the power usage of impulse-based UWB devices is exceptionally low. This is advantageous for battery-operated equipment, especially for equipment utilized in wireless medical applications [12].

1.3 Structure of Thesis

To explain the whole research in a convenient way, the thesis work is organized as following:

Chapter 2: Provides a detail literature review of the UWB transmitter with its future prospect. It was shown that the main design constraint is the power consumption and size of device which requires proper selection of circuit components in the architecture.

Chapter 3: Presents the research methodology of this work which explains the approach followed to the research to ensure reliable, valid results that address research aims and objectives.

Chapter 4: Presents the promising application areas of UWB transmitter in the various section of medical field such as body area network, medicine etc which clarifies the motivation behind this line of research.

Chapter 5: Includes a description of the fundamentals of impulse radio ultra-wideband systems, UWB advantages, FCC emission mask, different modulation techniques which can be applied for UWB system.

Chapter 6: Presents the overall block diagram and architecture of the impulse-based UWB transmitter followed by circuit design of each individual functional blocks. It also includes the operating principle of each circuit of the designed transmitter. It also represents a compatible UWB antenna design and integrating the antenna with proposed transmitter.

Chapter 7: Addresses the simulation results and analysis for the designed UWB transmitter and the Post Layout Simulation Result to verify the feasibility of the proposed design for fabrication which are simulated using Cadence tools. Process corner analysis is examined for the suggested circuit. Simulation results of the proposed UWB antenna obtained by using ADS (Advanced Design System) software is also illustrated here.

Chapter 8: Presenting a summary of the overall research, thesis contribution and provides a few suggestions for future work in this field.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The UWB communication system has been proposed with numerous designs for UWB transmitters. All of these models are suited for communication, thus there are no restrictions on power usage or device size. The UWB approach limits the power consumption of transceiver modules by requiring sensors to consume less than 100W in order to construct a wireless body area network. If these devices are to be used for medical imaging, the duty cycle of the UWB pulses must be reduced, resulting in lower baseline power usage. As a result, many kinds of medical applications benefit greatly from UWB transmitters based on Gaussian monocycles.

2.2 Previous Research on UWB Transmitter

A. Djugova *et al.* proposed a low power and low complexity impulse radio ultra-wideband (IR-UWB) transmitter with low power and low complexity [12]. The 0.18 µm UMC CMOS technology was implemented to simulate and design that pulse generator. The circuit diagram of that transmitter is shown in Fig. 2.1. The output pulse width was 0.6 ns, and the peak-to-peak amplitude was 403 mV according to the simulation results.

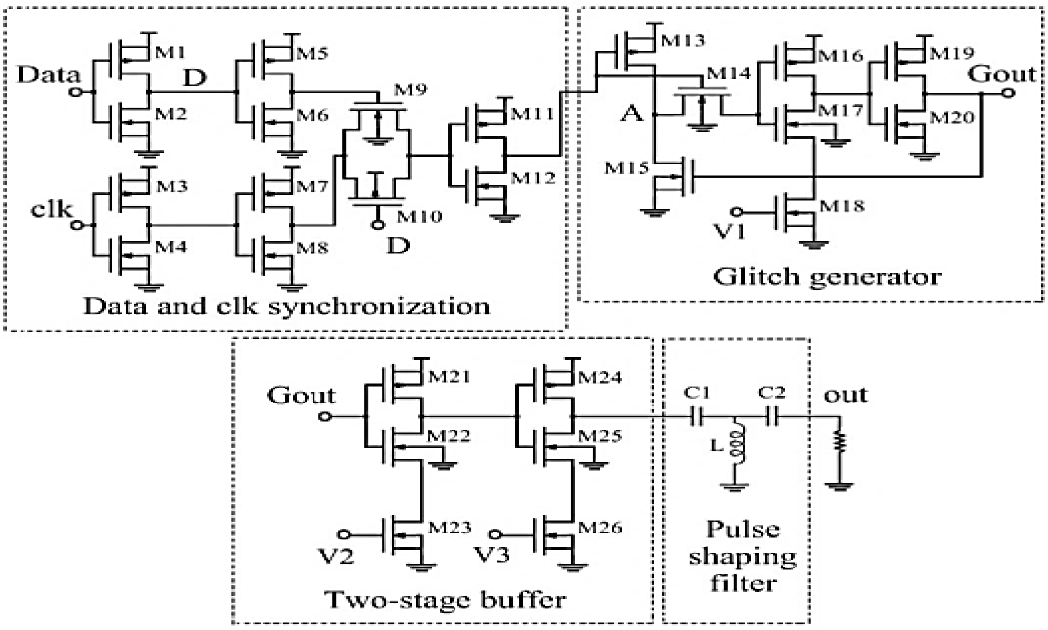


Fig. 2.1: Architecture of designed transmitter [12].

Y. Lin *et al.* designed a 65-nm CMOS all-digital impulse radio ultrawideband pulse generator for a wireless body area network [13]. With pulse-positioned modulation, this system's highest data rate was 100 Mb/s, and with on-off keying, it was 200 Mb/s. At 1.2-V supply voltage without the need for a static bias current, the overall power usage of that pulse generator was 30 pJ/pulse.

For low-power communication and radar sensor applications, an impulse-radio ultra-wideband (IR-UWB) transmitter was introduced by I. Mahbub, S. K. Islam, and A. Fathy in [14]. The transistor stacking technique was used in the construction of the electronically controlled oscillator (ECO) and mask generator, which is depicted in Fig. 2.2, to reduce leakage power for the IR-UWB transmitter. Inductor is utilized in the buffer circuit, which increases size and power consumption. The transmission energy per pulse was 3.6 pJ, and the greatest efficiency was 8.6%.

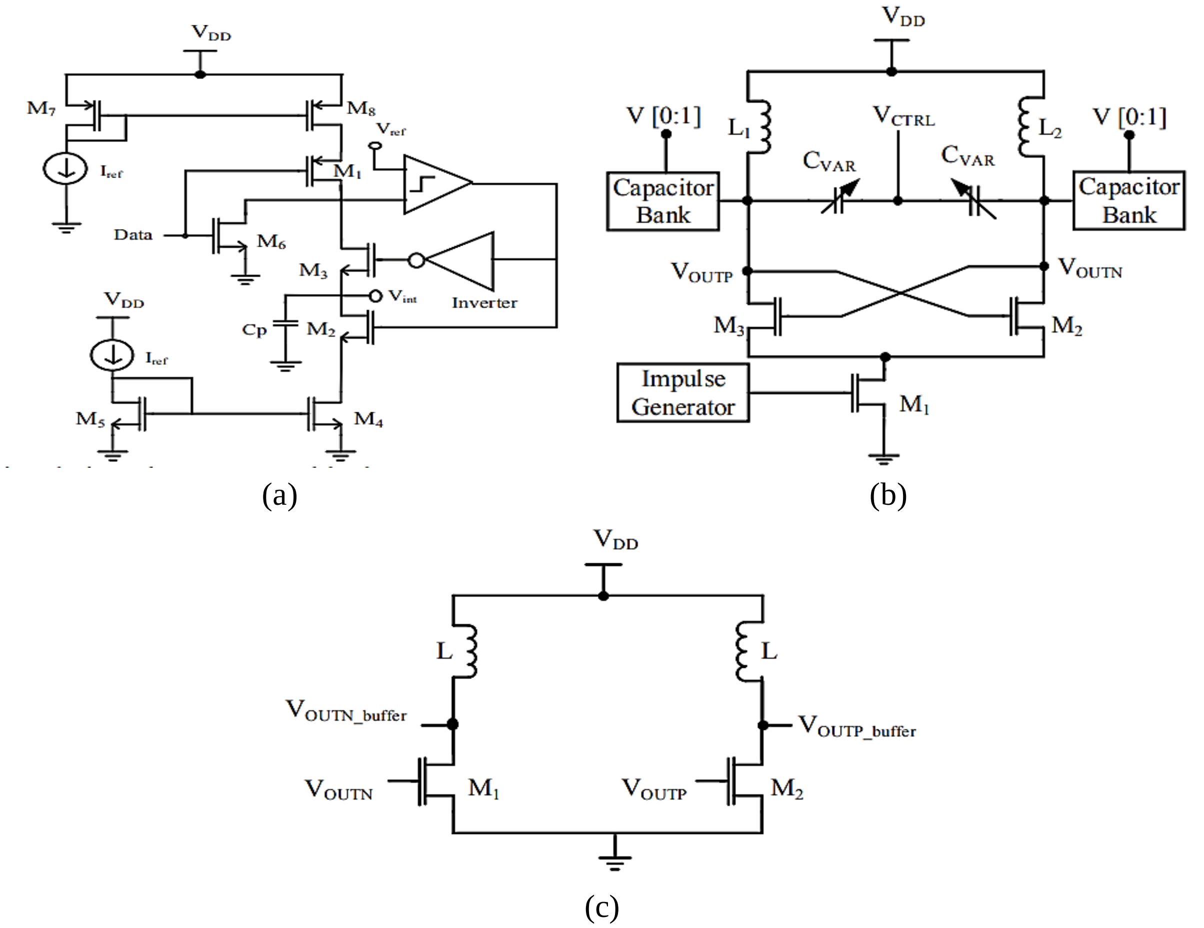


Fig. 2.2: (a) Triangular impulse generator; (b) Tuneable 3-5 GHz band cross coupled differential LC oscillator circuit; (c) Buffer [14].

M. Crepaldi *et al.* introduced a transmission reference pulse cluster (TRPC) modulation scheme-based ultra-wide band (UWB) transmitter [15]. With a configurable transmission rate of 10 to 300 Mbps, this transmitter achieved a respectable energy consumption of 38.4 pJ/pulse and a rated current usage of 24.5 mA out of a 1.2-V power source.

With a spectrum of 2.6 GHz to 5.6 GHz and a top data throughput of 800 Mbps, a narrow ultra-wide band (UWB) transmitter had been developed by P. Rodr [16] which surpassed current low-power UWB transmitters for similar applications. The designed circuit is illustrated in Fig. 2.3.

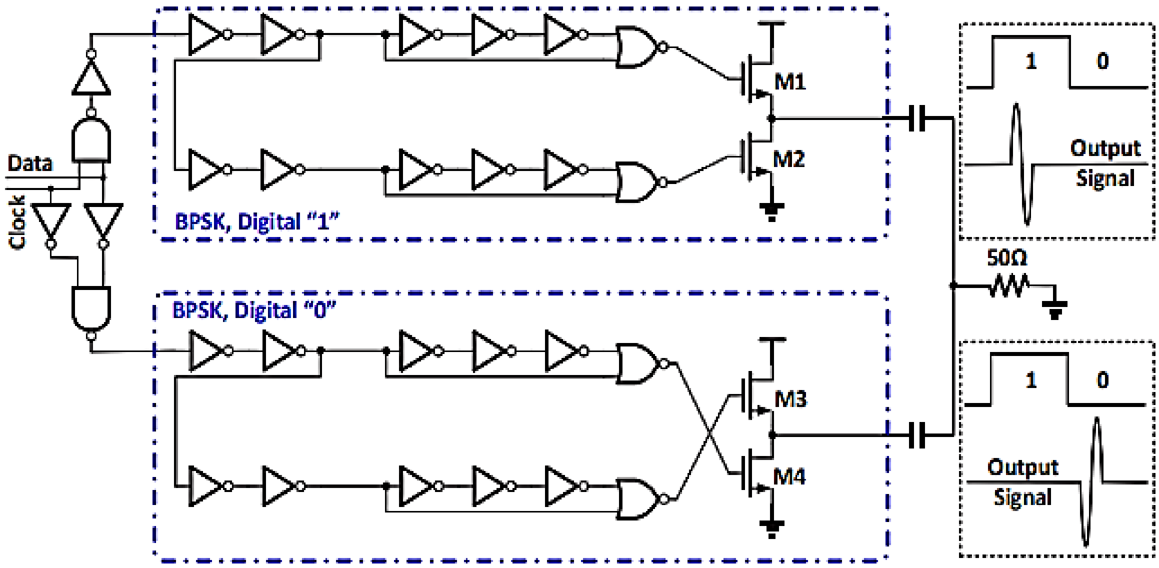


Fig. 2.3: The designed short impulse response transmitter circuit using BPSK modulation technique [16].

L. Xia *et al.* introduced a time-gating technique for the design of on-off keying (OOK) and binary phase-shift keying (BPSK) ultra-wideband impulse transmitters [38]. A leakage-cancelling circuit was embedded with the output buffer of the OOK modulator transmitter and the BPSK transmitter's modulator, respectively, in order to employ a leakage-cancelling technique and suppress leakage digital signal from the oscillator.

Impulse radio ultra-wideband (IR-UWB) transmitter (TX) was created by J. Radic *et al.* in [17]. The low-cost 180 nm UMC CMOS technology is used to build the IR-UWB TX, which has an on-off keying coding capability and takes up 0.63 mm^2 of total device area. The circuit diagram is illustrated in Fig. 2.4. The experimental findings showed a pulse duration of 0.6 ns and a transmitter output swing of 320 mVpp (peak-to-peak amplitude). At a data rate of 200 MHz, the overall DC power usage amounted to 1 mW, or 5 pJ/pulse.

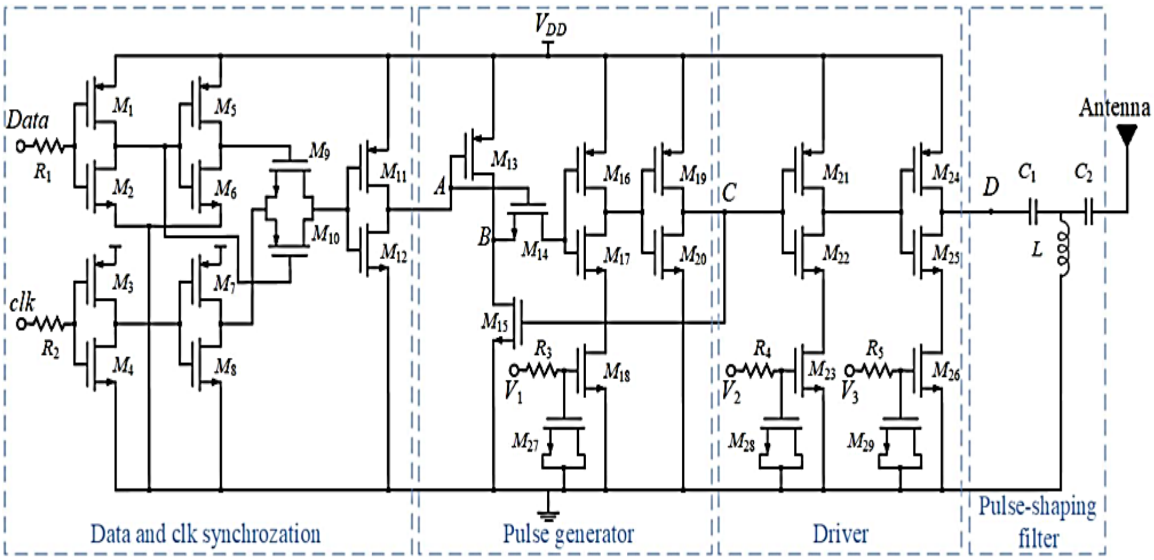


Fig. 2.4: Schematic diagram of the suggested IR-UWB TX [17].

Two transmitter topologies (TX1 and TX2) using various modulation techniques had been designed and compared by H. Bahram *et al.* to transmit data in high-density brain recording devices [18]. The TX and RX antennas in this device are meant to be external and implanted, respectively. Both transmitters have been fully incorporated into TSMC's standard 0.18 µm CMOS technology. TX1 supports both binary phase shift keying (BPSK) and on-off keying (OOK), whereas TX2 only supports OOK modulation. In Fig. 2.5, the suggested circuit is depicted.

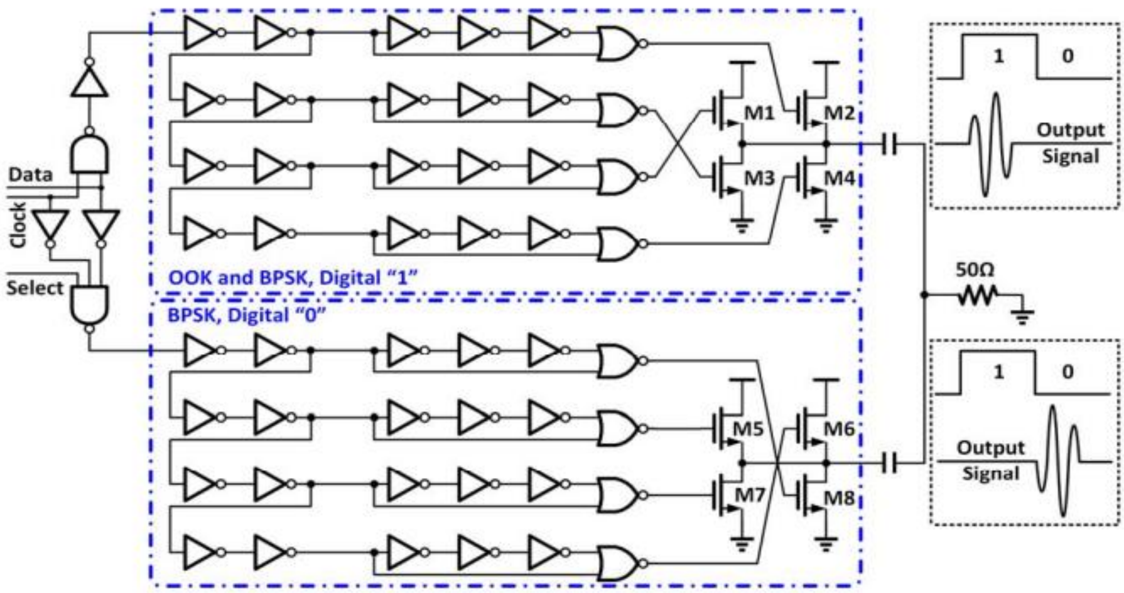


Fig. 2.5: Circuit schematics of the proposed UWB impulse generators a) circuit for generating OOK and BPSK modulated UWB signals [18].

W. I. Notch *et al.* introduced a completely integrated analog impulse-radio UWB TX that generated a distinctive UWB pulse with a notch that could be adjusted at the bandwidth of the IEEE 802.11a system [19]. With a 1.2 V power supply, the TX's peak pulse rate was 400 Mpulse/s and its highest pulse energy was 65 pJ/pulse. The pulse's bandwidth is 5.5 GHz (BW). The pulse's bandwidth is 5.5 GHz (BW). According to the measurements, the pulse exhibits a 30-dB notch and the TX power was less than 78 dBm/MHz. The TX contains biphase modulation and was produced utilizing a 90-nm CMOS manufacturing method.

J. He *et al.* developed antennas and circuits for Ultra-Wideband (UWB) applications [20]. The circuits indicated contain complete UWB transmitters, including UWB antenna and circuitry for creating UWB signals. The study concentrated mostly on UWB systems that used information-carrying, ultra-brief, low-power pulses. Depending on 4th, 5th, and 7th derivative Gaussian pulse forms implemented in 180 nm CMOS technology and modelled with Advanced Design System (ADS) software, an ultra-low power UWB transmitter was created. The output of the simulation for the 5th derivative Gaussian pulse was 20 mV peak to peak pulse magnitude and the duty cycle was 410 ps; for the 4th derivative Gaussian pulse, it was 12.3 mV pulse amplitude and 370 ps; and for the 7th derivative Gaussian pulse, it was 27 mV pulse amplitude and 520 ps.

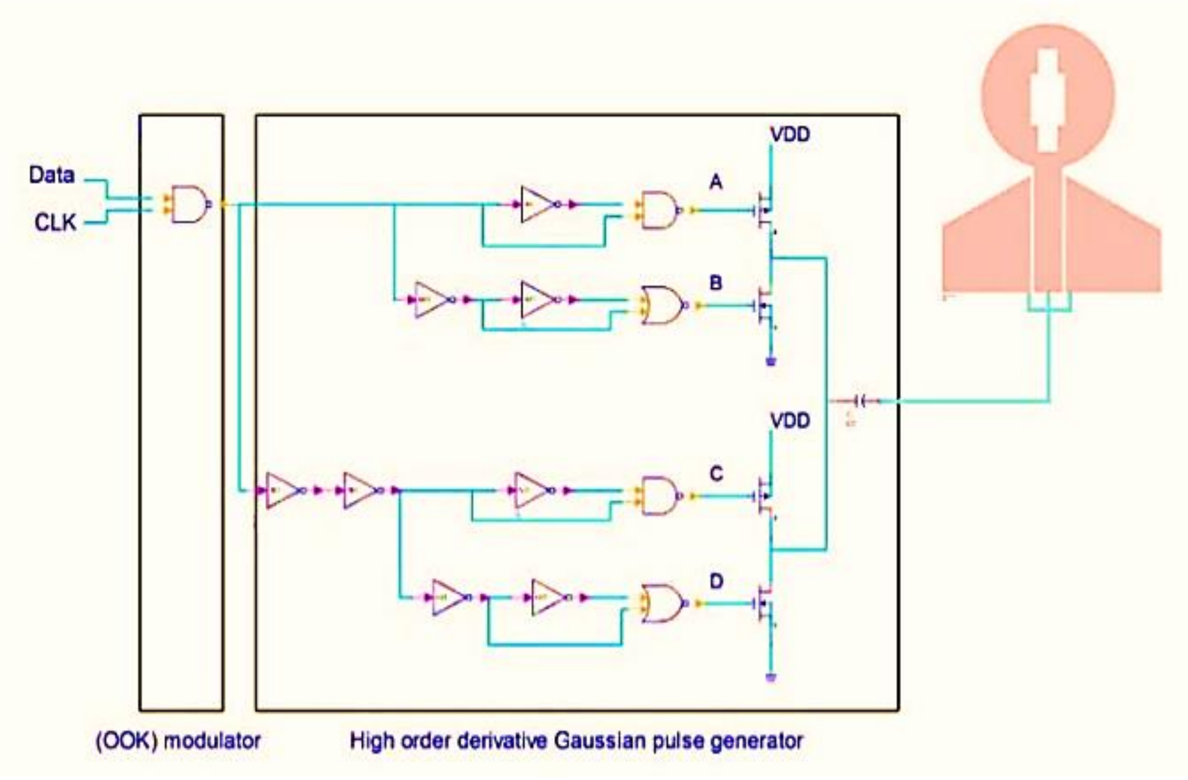


Fig. 2.6: Block diagram schematic for IR-UWB transmitter [20].

S. Bourdel *et al.* designed the architecture of a completely integrated ultra-wideband (UWB) pulse generator for the FCC 3.1-10.6 GHz band [21]. Only medium rate applications made use of this generator, which generated pulses for OOK, PPM, or PIM modulations. This UWB transmitter was based on the impulse response filter technique, which excites an integrated bandpass filter using an edge combiner. The suggested circuit has been implemented using ST Microelectronics' 0.13-micron CMOS technology, which has a 1.2V supply voltage and a 0.54 mm^2 die size. The peak to peak magnitude of the pulse generator was 1.42V, and each pulse uses 9pJ of power. The generator operated at a rate of up to 38 Mbs^{-1} using an OOK modulation, and the pulse complied with FCC regulations.

2.3 Problem Statement

UWB technology are seen as the most promising technology in wireless communication system and specially in medical sectors due to their ability to reduce the size and power consumption. There are still some challenges and scopes to improve the performance. In the above researches it is seen that different modulation techniques with various functional blocks were used and different orders of Gaussian pulse were generated. The mentioned works has reduced the power consumption but there is huge scope and requirement of reducing the power more as power consumption is one important parameter for wireless medical devices. Moreover, there is also area of improvement in pulse duration and pulse amplitude since this parameter will improve the transmitter performance in terms of precision ranging, data rate and proper diagnosis [9]. Most of the previous researches used ideal clock signal instead of designing voltage-controlled oscillator (VCO) circuit. So a VCO circuit which consumes less power in transmitter is very important part to design [22]. And performance of a transmitter with VCO rather than ideal clock pulse gives the actual outputs of the transmitter. With this improvement, circuit complexity needs to be reduced so that it will be more feasible for fabrication. From the previous researches it is also noticeable that there are few works which added UWB antenna along with UWB transmitter.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

Taking all these research gaps into considerations from previous chapter, objectives with aim are set to design a new UWB transmitter. Motivated by these researches and identifying the area of improvement, this research aims to design a low power and miniature size UWB transmitter which is ideal for medical applications.

3.2 Methodology

The methodology which was followed in the presented research is explained bellow:

Stage 1: The first and most important part of any research is literature review. To get idea of the recent researches on a field, literature review is compulsory. At the very initial stage of the presented research, most of the recent research papers were reviewed and other previous relevant literatures were analysed. At the same time, mastering on CADENCE virtuoso software to simulate the designed circuit was done.

Stage 2: After analysing the existing models of previous researches at first a new and better model is designed with five basic blocks. To minimize the energy consumption, circuit of each block is designed with components which requires less power to operate and which helps to keep the circuit size minimum and simple. Such as to generate clock pulse a current starved inverter voltage-controlled ring oscillator (VCO) is chosen as it limits the current through the circuit and hence requires less power. Different types of modulation scheme like PPM, OOK, BPSK etc can be applied and among them OOK is the simplest type and it applied in the design. Moreover, differential amplifier is used which makes the interfacing of the transmitter circuit suitable for UWB antenna. The suggested technique significantly reduces system complexity, overall power consumption, and device size because IR-based UWB transmitter systems operate on a carrier-less transmission topology [23]. An IR-based UWB transmitter that can produce ultra-short Gaussian mono-cycle pulses (GMP) by combining logic gates in various functional blocks is designed. Simple logic functions are used to perform modulation. The suggested transmitter circuit is capable of producing GMP when a data pulse changes from 0 to 1 or 1 to 0. This method relies entirely on the transition of input data pulses, allowing the pulse rate to be adjusted from a few Mbps to Gbps within the FCC-specified spectrum (3.1-10.6GHz). For medical application, the efficient voltage-controlled oscillator (VCO) is needed to be applied for maintaining the low power consumption. Use of inductor is also avoided to reduce the device size [24].

Stage 3: The designed transmitter circuit is the simulated using CADENCE. The outputs of the suggested transmitter analysed and compared with the previous data.

Stage 4: To verify the fabrication possibility layout of each block was generated and outputs for schematics and layouts were compared.

Stage 5: To analyse the feasibility of the designed transmitter with antenna, an UWB antenna is modified and simulated with the designed transmitter. With the aid of Advanced Design System (ADS) software, the antenna is built and simulated.

3.3 Objectives with Aims

This research work has the following four objectives:

- To design a transmitter architecture which consumes less power and have less complex circuit.
- To fit the power spectral density into allotted UWB frequency range (3.1 GHz to 10.6 GHz).
- To reduce pulse duration as small as possible to obtain a higher data rate.
- To validate the designed transmitter performance with existing works.

CHAPTER 4
ULTRA-WIDEBAND IN MEDICAL APPLICATION

4.1 Introduction

Over the past few decades, UWB technology has been used in the radar, sensing, and communications systems industries. Since the FCC approved the use of UWB for data communications as well as the medical sector in February 2002, a significant amount of research has been conducted. Since then, high data rate wireless communication applications utilizing UWB technology have advanced quickly [25]. Medical imaging system using UWB technology is ideal since it enables a doctor to examine a patient's interior health without requiring surgery. Whereas X-ray and ultrasound sensors require direct touch, UWB sensors can operate at a distance.

4.2 UWB Characteristics for Medical Application

The UWB pulse can be produced in a very short duration of time (sub-nano second). As a result, the spectrum is below the acceptable noise level. Using 10GHz spectrum and this functionality, Gbps speed is achievable[20]. UWB can therefore be utilized for high-speed over close distances.

4.2.1 Obstacles Penetration Feature

We may compare UWB with ultrasonography for discussing this capacity. Despite the fact that they are essentially extremely similar and a number of the signal processing methods used in ultrasonic systems may be used to UWB systems, UWB varies from ultrasound, which has a variety of applications in the current world [26]. The key difference is that ultrasound has a very short range and is largely a line-of-sight technology (It is used for medical imaging but it typically works only over a few inches). However, UWB is unique in that it does not use high-frequency sound waves that are impervious to obstructions [27]. The fact that UWB employs RF pulses and has high gain allows it to achieve gains that are far higher than those of other widely used conventional spread spectrum technologies. That explains how UWB can pass through walls as well. The capability makes it simple to photograph human bodily organs for medicinal purposes [28].

4.2.2 High-Precision Centimetre-level Ranging

Another aspect of UWB is its high precision centimetre-level ranging, which is based on the ultra-short pulse feature we covered in the preceding section of the study. Strong multi-path resolving capabilities also translates to high range precision [29]. Continuous waves were employed in the traditional wireless technology, and the standing time was substantially longer than the multi-path transmission time. The UWB pulse has a significantly stronger ability to resolve time and space due to its shorter duration.

4.2.3 Low Electromagnetic Radiation

The low electromagnetic radiation caused by the low radio power pulse of less than -41.3dB in an interior setting is the third feature of UWB [30]. Applications in hospitals can benefit from the low radiation because it has no impact on the surrounding area. Additionally, the human body is safe from the low radiation.

4.2.4 Low Energy Consumption

Due to UWB's use of extremely short radio transmission pulses and architecture design, the transmitter may be built simply and with extremely low energy consumption, allowing for the use of long-lasting battery-operated devices [31]. These characteristics are much similar to those of the nodes in Wireless Sensor Networks (WSN), which must operate in harsh conditions and demand extremely stringent power control mechanisms and high-power effectiveness [32]. Since detection of UWB signals are tough and have excellent jamming resistance, medical sensor implementation is certainly possible due to their intrinsic noise-like characteristics. This makes it possible to use Wireless Body Area Networks (WBANs) for body surveillance.

4.3 UWB in Medical Surveillance

UWB is ideal for the use of medical monitoring because of the characteristics we covered in the preceding section. Patient movement monitoring, wireless vital sign monitoring of the human body, and medication storage monitoring are a few examples of these monitoring applications [33].

4.3.1 Monitoring of Patient Movement

UWB radar can be utilized in the medical area for remote monitoring and measuring the patients' mobility over short distances due to the incredibly intense pulses used in UWB technology [34]. Intensive care units, emergency rooms, home health care, paediatric clinics (to warn for Sudden Infant Death Syndrome, SIDS), and rescue operations could all use this monitoring capability (to look for some heart beating under ruins, or soil, or snow). As illustrated in Fig. 4.1, the use of UWB for patient monitoring in the intensive care unit could prevent the use of excessive amounts of wires close to the patient [35].

Fig. 4.1: Intensive care unit monitoring using UWB [35].

In Fig. 4.1, signals from UWB radars mounted on the ceiling may reflect when they come into contact with a person's body. The reflected signals will vary as the patient moves. The fluctuation of signals indicating item movement is transmitted to the surveillance system's control centre[2]. The doctors or nurses could receive immediate feedback on the material. Additionally, it might be saved and examined later to determine the patient's health status. Fig. 2.2 displays an example of the application's results [36]. The pulse amplitude variation indicates that the patient is moving around the room. The closer a human gets near the UWB radar, the bigger the pulse amplitude is. The tool might be used to keep an eye on patients to see if they were moving during prohibited times. The patient's position and speed in the room might be determined using UWB radar [37].

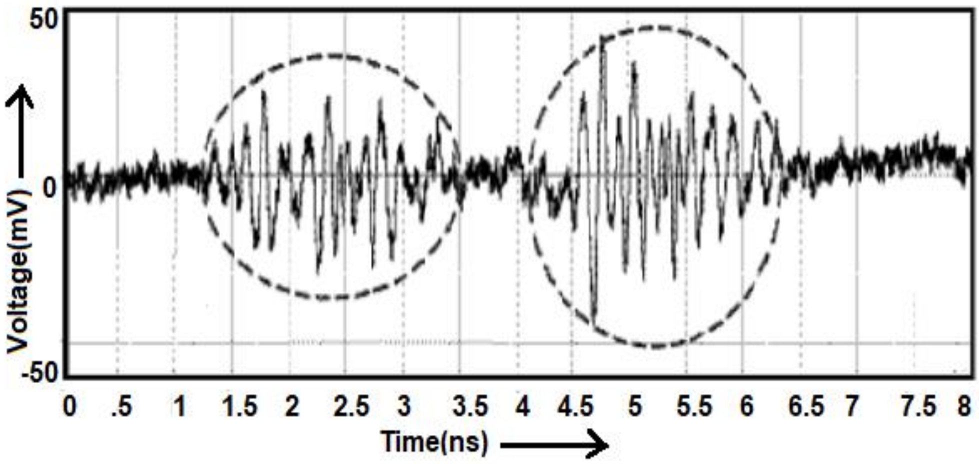


Fig. 4.2: Patient movement detection signal [38].

More UWB detectors will be needed if we want to monitor a huge area because UWB has a small limit of detection of less than 10 meters. Due to UWB's ability to communicate over short distances and at high data rates, these sensors can be driven to capture and transmit a sizable amount of sensory data [39]. UWB devices have a low and acceptable energy need for long-term sensing. Since Zigbee and Bluetooth devices require more energy and have slower data transmission speeds, they are less suitable for medical applications [40].

4.3.2 Monitoring of Vital Signs of Human Body

In reality, the UWB sensors were able to pick up both these macro movements and the tiny movements occurring inside the human body. For instance, the capacity to non-invasively sense crucial factors like the human body's respiratory system is important and beneficial in medical engineering [41]. In particular for large-scale hospitals, the UWB surveillance of respiratory motion in emergency rooms or intensive care units will be appealing and save considerable money. Other common UWB applications for vital sign monitoring include the cardiology, pneumology, neurology, and other systems.

4.3.3 Medicine Storage Monitoring

The medicine storage area can also be watched over using UWB radar. Any moving objects near the secured perimeter line are detected by the defence sphere formed by the UWB electromagnetic waves. When they are close enough, any unauthorized individuals trying to access the monitored object will be alerted [24]. The alert could be set off by a change in radar readings that corresponds to objects attempting to cross a secured line. The fluctuation graph will resemble Fig. 4.2 in appearance.

4.4 UWB in Medical Imaging

Medical imaging is another important UWB application in medicine. Cardiology Imaging, Pneumology Imaging, Obstetrics Imaging, and Ear, Nose, and Throat Imaging are the four key areas in which we go over it.

4.4.1 Cardiology Imaging

Since research on the heart has a significant impact on the general public, heart monitoring was really one of the first uses for UWB radar technology. The first patent for a "radar stethoscope" was created by a scientist by the name of Thomas McEwan at Lawrence Livermore National Laboratory (LLNL) [42].

4.4.2 Pneumology Imaging

The same rule applies to reflection at the chest/lung interface, the air/chest interface, and at vessel borders, much like in cardiology imaging. By varying the emission pulse power, it was possible to picture each one of them. We could monitor breathing patterns, baby apnoea, obstructive sleep apnoea, polysomnography (research connected to sleep), dynamic chest diameter measurement, allergy and asthma crisis monitoring, and chest imaging with the UWB medical imaging system [13]. The organic motion-related signal is obtained from a UWB radar instrument pointed at the human body using the UWB dielectric characteristics. The UWB radar could monitor cardiac movements, arterial wall motion, and breathing movements specifically for the heart as a cardiovascular monitor. The use of UWB radar in cardiovascular motion evaluation can be a significant addition to the ECG because the UWB electromagnetic signal is unaffected by clothing or blankets and has an effective range of only a few meters [43].

4.4.3 Obstetrics Imaging

Obstetrics imaging is illustrated in Fig. 4.3 as an important use of UWB radar in medical imaging. However, despite the fact that everyone believes ultrasounds are typically safe, there is sadly a lot of concern about the RF safety in UWB for the infant. This concern is "fear producing" because of the device's "emissions." It is clear that additional time is required before everyone can adopt the UWB radar [44]. A UWB radar device for obstetrics will likely be manufactured and sold on a significant basis in the future. UWB radar emission is safe, and the system is ideal for equipment that is permanently positioned to monitor the final trimester of pregnancy or to help assess the development of labor.

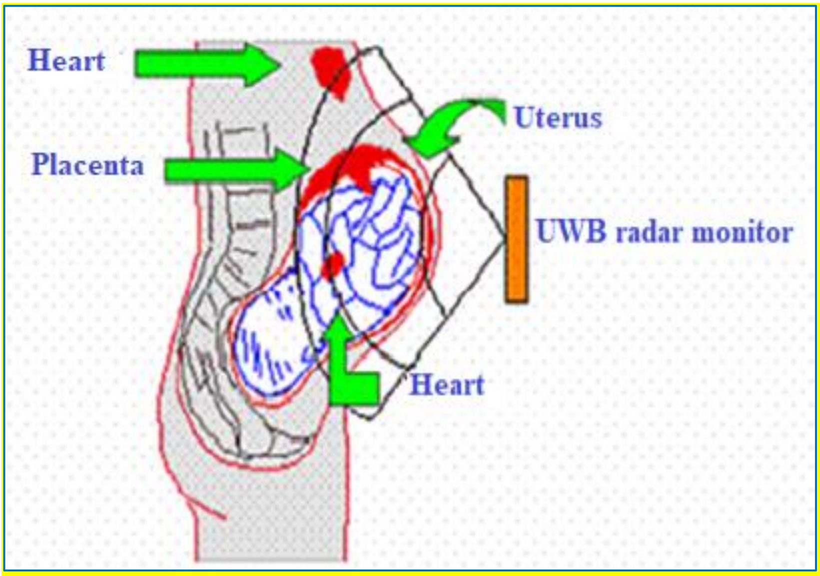


Fig. 4.3: Obstetrics imaging using UWB radar [30].

In comparison to the present fatal monitoring technology that uses ultrasound, UWB radar offers numerous advantages in this application area. The lack of direct patient contact, unfettered mother-and-child care, remote operation, little cleaning, and convenience of use are some of these new advantages.

4.4.4 Capsule Endoscopy

Colonoscopies enable visualization of the bottom portion of the digestive tract, whereas conventional methods such as the insertion of flexible tubes holding cameras can only examine the top portion of the digestive tract (colon). The small intestine can only be visually investigated along about 6 meters of it using these conventional methods. The use of capsule endoscopes closes this gap while minimizing patient pain [44]. The patient fastens a recorder belt around his or her waist after swallowing a modern capsule endoscope with water. After a predetermined period of time, often eight hours, medical professionals review a video created from the still images wirelessly delivered from the capsule endoscope to the recording belt to look for anomalies. By adding the ability to transmit and analyse film in real time, the current technology might become more adaptable and advantageous. The complexity of the circuitry and, thus, the power consumption of the capsule endoscope may grow as a result of this extra capabilities [14]. A capsule endoscope's physical dimension must be no larger than 300 cubic millimetres and its power consumption must be as low as feasible. Real time video transmission calls for a high data rate communication link, using narrowband (NB) devices that operate in the medical implant communication systems (MICS) frequency band of 402-405MHz, all these requirements are challenging to meet. UWB technology, however, has the ability to meet all of them [45].

4.5 Conclusion

The usefulness of UWB technology for medical applications is briefly discussed in this chapter. The key characteristics of UWB that make it appropriate for use in the medical field are listed and addressed. The analysis and discussion of two significant UWB applications-medical monitoring and medical imaging are discussed. In order to support the claim that this UWB transmitter is one of the most promising novel devices in the research field, we also discussed UWB applications in various medical fields, such as patient motion monitoring, monitoring of vital signs of the human body, medicine storage monitoring, UWB in medical imaging, cardiology imaging, pneumology imaging, obstetrics imaging, and capsule endoscopy.

CHAPTER 5
FUNDAMENTALS OF IMPULSE RADIO ULTRA-WIDEBAND SYSTEM

5.1 Introduction

In conventional communication systems, a predetermined carrier frequency is used by the transmitter to deliver data. The signal carrier is a continuous wave, frequently a sinusoidal wave, with a narrow, easily observable energy range. The bits of information are shown as very short pulses with a very low duty cycle in the IR-UWB situation.

5.2 Impulse Radio UWB Signals

Impulse radio has historically been used in UWB systems because it transmits data at exceptionally high data rates by broadcasting energy pulses rather than a narrowband frequency carrier. A few nanoseconds (billionths of a second) or less is a common length for the pulses, creating an ultrawideband frequency spectrum. In the early 1900s, when spark gap transmitters were producing pulsed signals with incredibly broad bandwidths, Marconi developed impulse radio [46]. The wideband energy released by a spark gap transmitter at the time could not be recovered, and there was no practical means to separate many wideband signals in a receiver. Between 1942 and 1945, a number of patents on impulse radio systems were submitted in an effort to lessen interference and boost dependability [47]. However, a lot of them were placed on hold for a long time because of worries about potential military applications by the US government. In the 1960s, the first impulse radio technology was created for radar and military applications. In the middle of the 1980s, the FCC designated the Industrial Scientific and Medical (ISM) frequencies for use in unlicensed wideband communication. This innovative spectrum allocation has led to an explosion in the use of WLAN and Wireless Fidelity (Wi-Fi). Additionally, it motivates the communication sector to investigate the advantages and drawbacks of higher bandwidth connectivity [33]. In order to allow for the use of UWB devices, the FCC amended the Part 15 regulations covering unlicensed radio equipment in February 2002. The FCC has approved UWB applications for a 7.5GHz bandwidth, with frequencies ranging from 3.1GHz to 10.6GHz [10], which is by far the largest spectrum allocation for unlicensed use the FCC has ever approved.

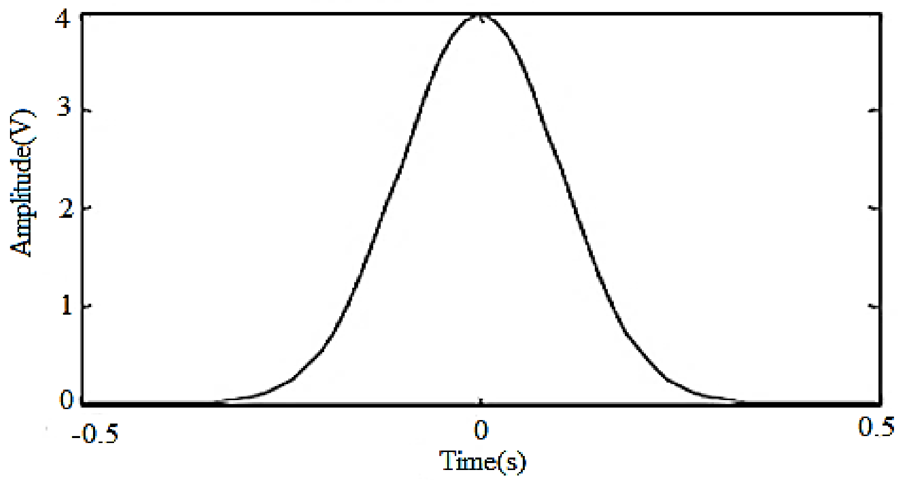


Fig. 5.1: Example of a gaussian pulse [40].

Any signal that occupies at least 500MHz spectrum can be used in UWB systems, according to the FCC's decision. That suggests that UWB is no longer restricted to impulse radio and now includes any technology that operates in the 500MHz band and complies with all other UWB specifications [48]. Before an ultra-short pulse can be generated, the system's intended wave form must be determined. The Gaussian pulse is the best used pulse shape for UWB transceiver systems due to its mathematical simplicity and ease of generation.

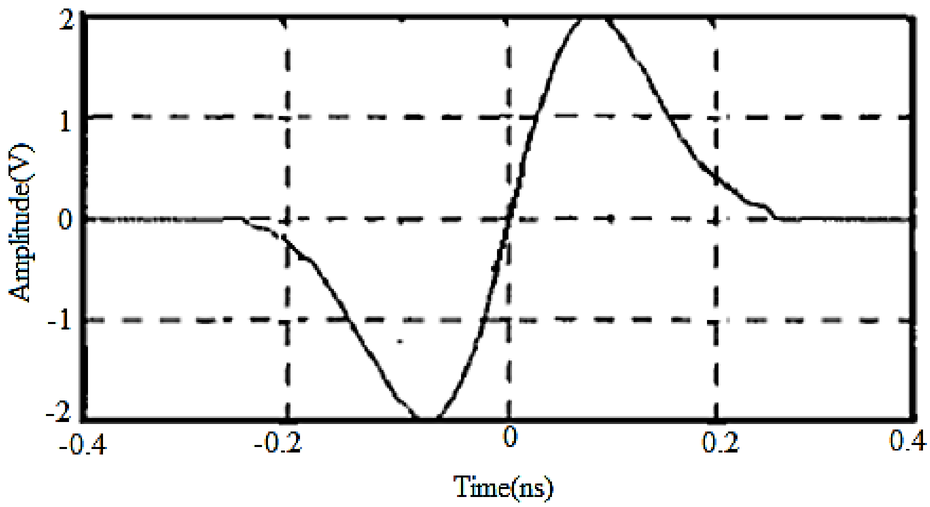


Fig. 5.2: Example of Gaussian Mono Pulse (GMP) [40].

Gaussian Monocycle Pulse (GMP) is depicted in Fig. 5.2. According to Fig. 5.3, where k_c is the central frequency (Hz), the energy of a typical Gaussian pulse has a pulse width of no more than one millisecond and is scattered over a wide frequency range.

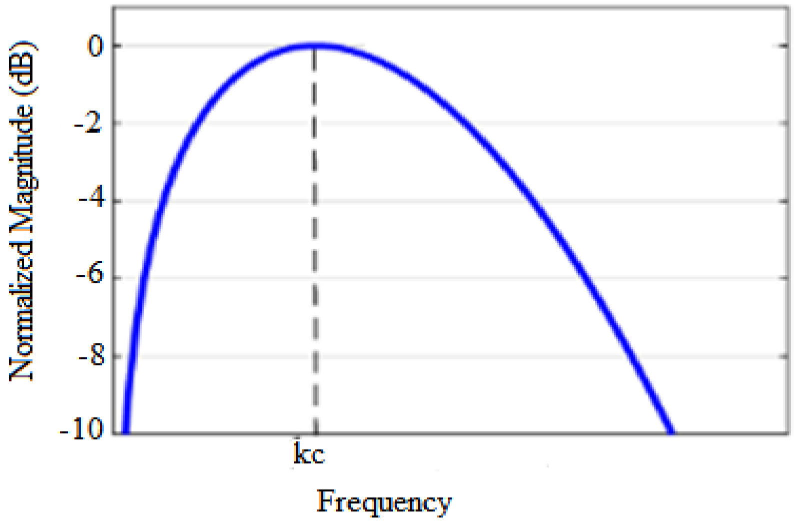


Fig. 5.3: UWB Gaussian pulse spectrum example [40].

With only a small amount of transmit power, the resulting power spectrum density is extremely low. This characteristic lessens the amount of in-band interference that narrowband devices encounter and lowers the possibility of detection [48]. As UWB interference somewhat raises the noise floor of the victim receiver, it mostly affects noise tolerance. Thus, UWB signals and existing communication signals can coexist even in the same frequency band.

5.3 Advantages of Impulse-Radio UWB System

Compared to continuous wave (CW) based systems, UWB impulse systems have many advantages as following:

5.3.1 Fine Resolution and Long Range

Because impulse-type signals are incredibly wideband, UWB impulse systems frequently have instantaneous bandwidths that are noticeably wider than CW-based systems. In applications requiring long range and/or fine range-resolution, impulse systems are ideally suited due to the existence of both low- and high-frequency components in these signals [19]. Given that the relationship between range resolution and bandwidth is inverse, an ultra-wide bandwidth leads directly to fine range-resolution. An ultra-wide frequency range including both low and high frequencies delivers longer range than a CW frequency range by virtue of low attenuation at low frequencies and the large propagation distance of low-frequency signals [34]. It should be noted that while CW-based systems operating at the same bandwidth and frequencies can also achieve similar range-resolution and range, it is exceedingly challenging (if not impossible) to actualize an extremely wide-band CW system [49].

5.4 FCC Emission Mask

The Federal Communication Commission (FCC) allocated a frequency spectrum mask for UWB systems in the frequency range of 3.1GHz to 10.6GHz in order to protect traditional communication networks from interference. There are different sets of masks for vehicle radar systems, through-wall UWB imaging applications, indoor and outdoor UWB applications, and indoor and outdoor UWB applications [50]. The first type of emission is considered in the design because this work is for indoor UWB applications. The FCC's emission mask for indoor UWB applications is shown in Fig. 5.4. The average output power spectrum density for indoor applications is limited to -53 dBm/MHz between 1.99GHz and 3.1GHz and to -41.3 dBm/MHz between 3.1GHz and 10.6GHz. The FCC has long-standing general emission rules for controlled radio interference, and this restriction coexists with those regulations [51]. This work contains brief pulses with frequencies ranging from 3.1GHz to 10.6GHz. As a result, the transmitting power spectrum density level in this 7.5GHz frequency band is restricted to -41.3dBm/MHz. It's important to remember that industrial standardization has not yet been finished, notwithstanding the FCC's oversight of the UWB spectrum. For other countries, like Canada, to implement limits, the FCC masks serve as a model [52].

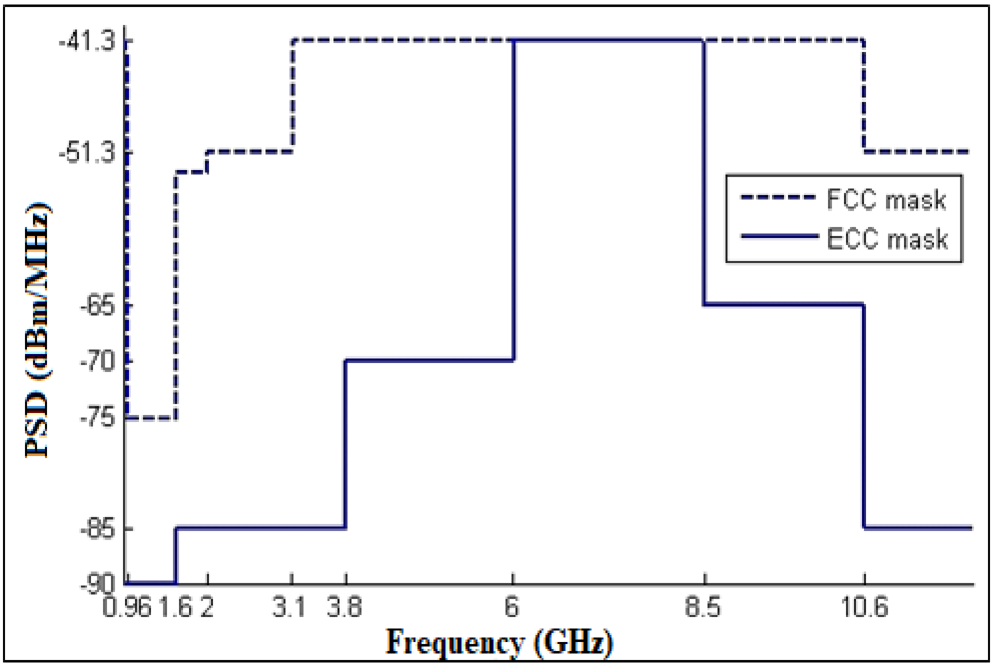


Fig. 5.4: FCC indoor UWB applications emission mask [53].

5.5 Different Types of Modulation Scheme

Modulation is a technique for changing a carrier signal's property by a message signal in order to transmit the information contained in the message signal. Analog modulation, digital modulation, and pulse modulation are the three different types of carrier modulation. The three types of analog modulation are amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM)[54]. In ultrawideband (UWB) communication, techniques for pulse and digital modulation are used. The most popular techniques include on-off keying (OOK), bipolar phase shift keying (BPSK), quadrature phase shift keying (QPSK), pulse amplitude modulation (PAM), pulse position modulation (PPM), and others. Here is a brief overview of these methods:

5.5.1 PAM Modulation

The basic idea behind the traditional PAM system is to encode data depending on the amplitude of the pulses, as seen in Fig. 5.5.

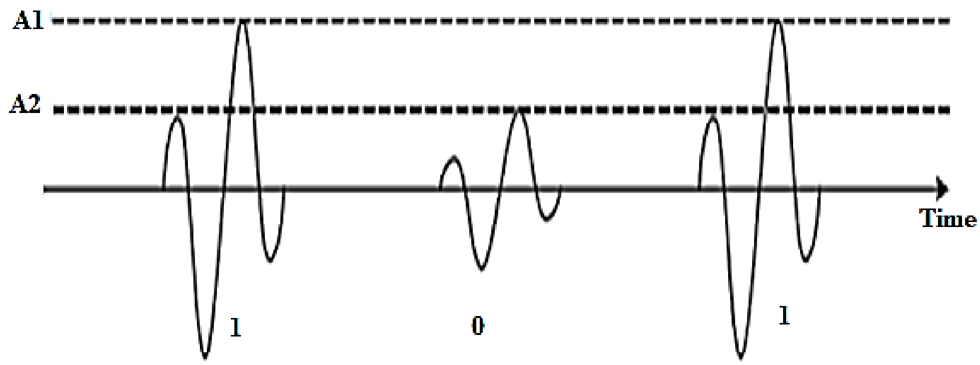


Fig. 5.5: PAM modulation [5].

The transmitted pulse amplitude modulated information signal x(t) can be represented by equation 5.1 [5]:

$$x(t) = d_i . w_{tr}(t) \tag{5.1}$$

where wtr(t) denotes the UWB pulse waveform, i is the bit transmitted (i.e. ‘1’ or ‘0’), where,

$d_i = A_1$ when i=1 and

$d_i = A_2$ when i=0.

Fig. 5.5 illustrates a two-level (A1 and A2) PAM scheme where one bit is encoded in one pulse. More amplitude levels can be used to encode more bits per symbol [55].

5.5.2 PPM Modulation

The position of the UWB pulse in PPM is determined by the bit to be conveyed. The bit '0' is represented by a pulse that is broadcast at nominal position, as illustrated in Fig. 5.6, while the bit '1' is delayed by a time from nominal position.

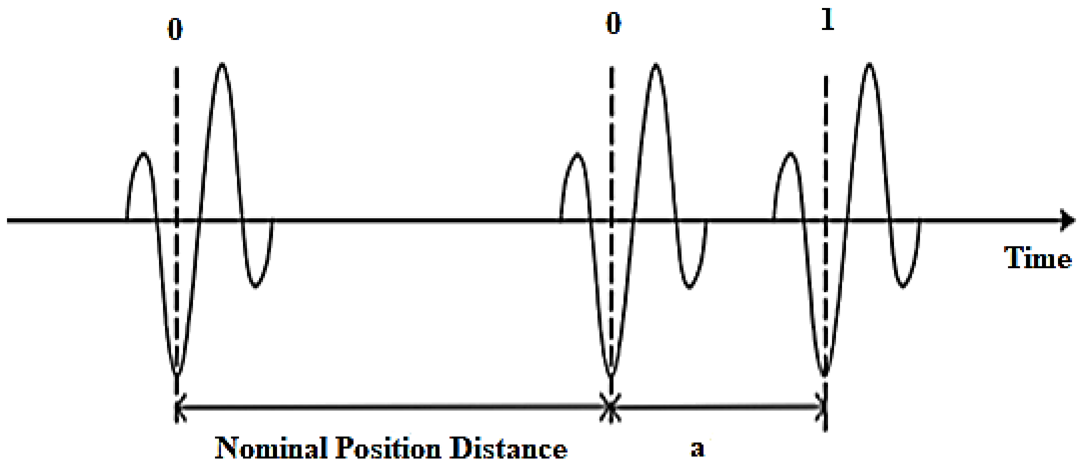


Fig. 5.6: PPM modulation [5] .

The pulse position modulated signal x(t) can be represented by equation 5.2 [5] as:

$$x(t) = wtr(t - a \cdot d_i) \quad (5.2)$$

where,

di = 1 when i=1 and

di = 0 when i=0.

Fig. 5.6 illustrates a two-position (0 and a) PPM scheme and additional positions can be used to achieve more bits per symbol.

5.5.3 OOK Modulation

Fig. 5.7 represents the existence of carrier signal when data is 1 and 0 represents the absence of carrier signal in on-off keying modulation. When i=0, it can be considered a special case of PAM modulation, with di = A_2 =0.

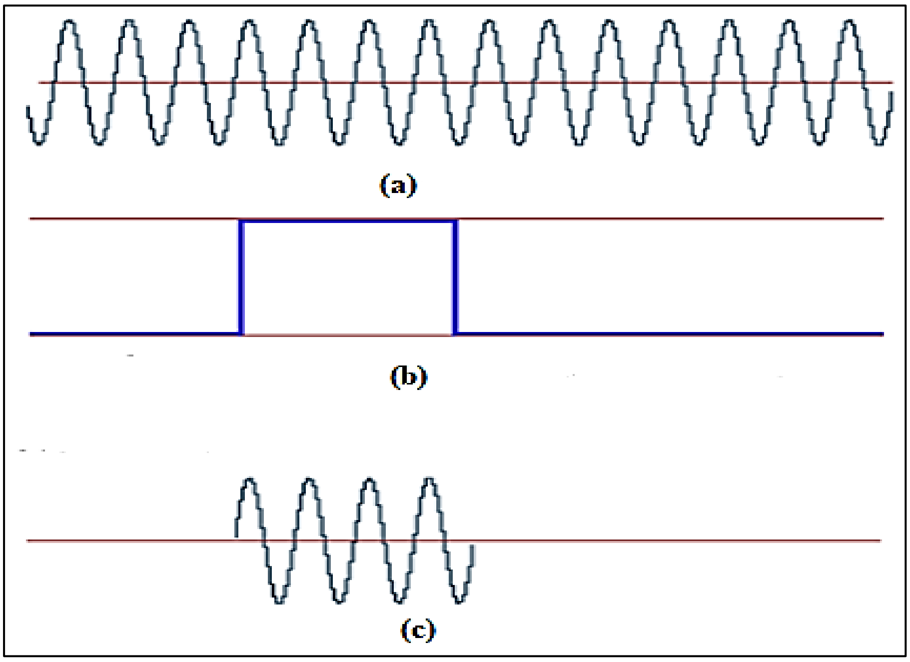


Fig. 5.7: OOK modulation (a) Carrier (b) Modulating digital wave (c) Modulated Signal [56].

In this thesis, we have applied the OOK modulation technique. The most widely used method for transmitting code across radio frequencies is on-off keying, though any digital encoding method can be used (this is known as CW (continuous wave) operation). OOK, for instance, has been used to transfer data between computers using ISM bands.

5.5.4 BPSK Modulation

The phase of the UWB pulse in BPSK modulation depends on the bit that needs to be conveyed. Fig. 5.8 shows that when a pulse is in phase, it represents the bit "0," and when it is out of phase, it represents the bit "1." In this case, just one bit is encoded per pulse because there are only two phases available. More bits per symbol can be obtained by adding more phases.

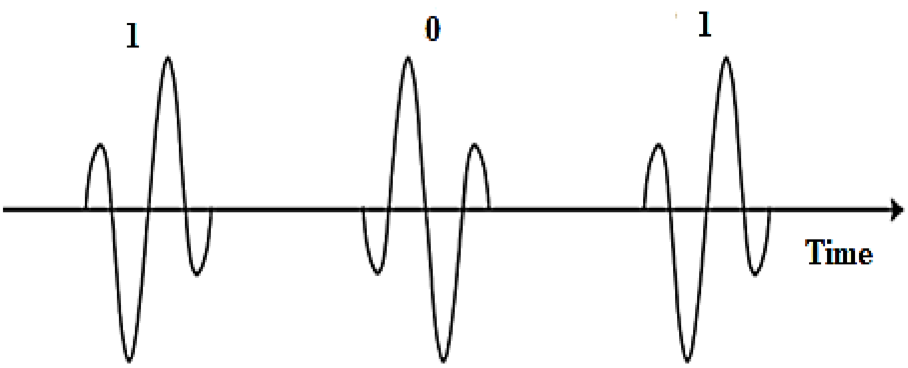


Fig. 5.8: BPSK modulation [5].

The BPSK modulated signal x(t) can be represented by equation 5.3 as:

$$x(t)=wtr\,(t).\; e\wedge(-i\,(di.\,\pi)) \tag{5.3}$$

Where,

di = 1 when i=1 and

di = 0 when i=0.

5.5.5 QPSK Modulation

Quadrature phase shift keying (QPSK), a different modulation method, is particularly noteworthy because it sends two bits each symbol. A QPSK symbol, then, represents 00, 01, 10, or 11 rather than 0 or 1. There are four different possible phase shifts for the carrier in QPSK, as opposed to variations in frequency [53]. Because we have 360 degrees of phase to work with and four phase states, the spacing should be 360°/4 = 90 degrees. As illustrated in Fig. 5.9, our four QPSK phase shifts are 45°, 135°, 225°, and 315°.

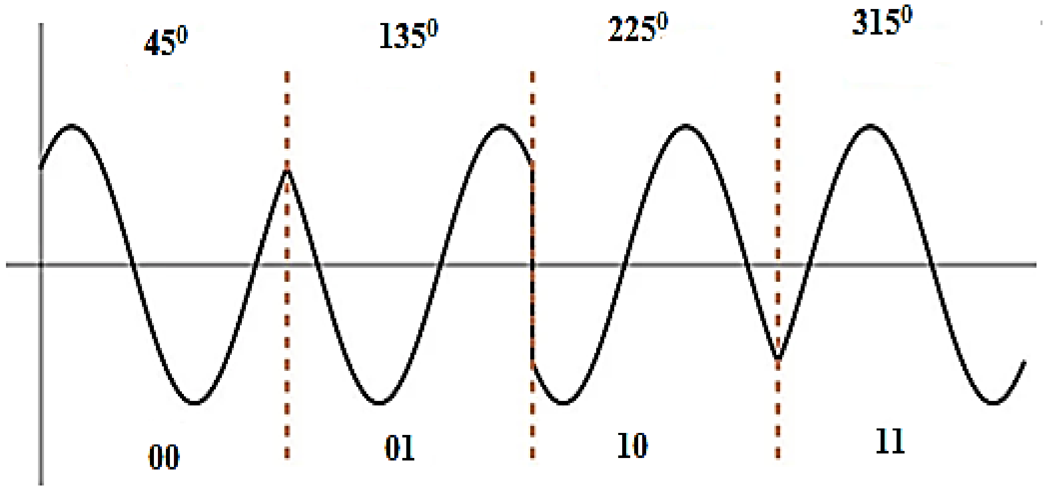


Fig. 5.9: QPSK modulation [57].

QPSK outperforms one-bit-per-symbol modulation methods in terms of bandwidth efficiency. For instance, an analog baseband signal in a BPSK (binary phase shift keying) system can only transmit one bit per symbol since there are only two potential phase shifts, as opposed to four in other systems. The same frequency baseband signal can be used by a QPSK system while transmitting two bits per symbol period.

5.6 Conclusion

In this chapter, because it sends data at extremely high data speeds by broadcasting energy pulses rather than a narrowband frequency carrier, why impulse radio has historically been employed in UWB systems is explained in terms of data transmission. Advantage of impulse radio over continuous wave is also described. FCC Emission Mask for UWB transmission system is also important which is also discussed. In addition, different modulation techniques which are applicable for UWB transmitter are also explained.

CHAPTER 6
UWB TRANSMITTER DESIGN

6.1 Introduction

It is a difficult and challenging task to design an ultra-wideband (UWB) transmitter system with a huge voltage swing, high speed data transmission, and low power consumption. This chapter outlines the step-by-step process for creating a low overhead CMOS UWB pulse using the on-off-keying (OOK) modulation technique.

6.2 Block Diagram for the Transmitter

For clarity, the provided structure was created by cascading five functional blocks, each of which is discussed in its own section. The five main blocks are:

- Current Starved Voltage Controlled Oscillator (CSVCO)
- Data Modulator
- Gaussian Pulse Generator
- Differentiator
- Differential Amplifier

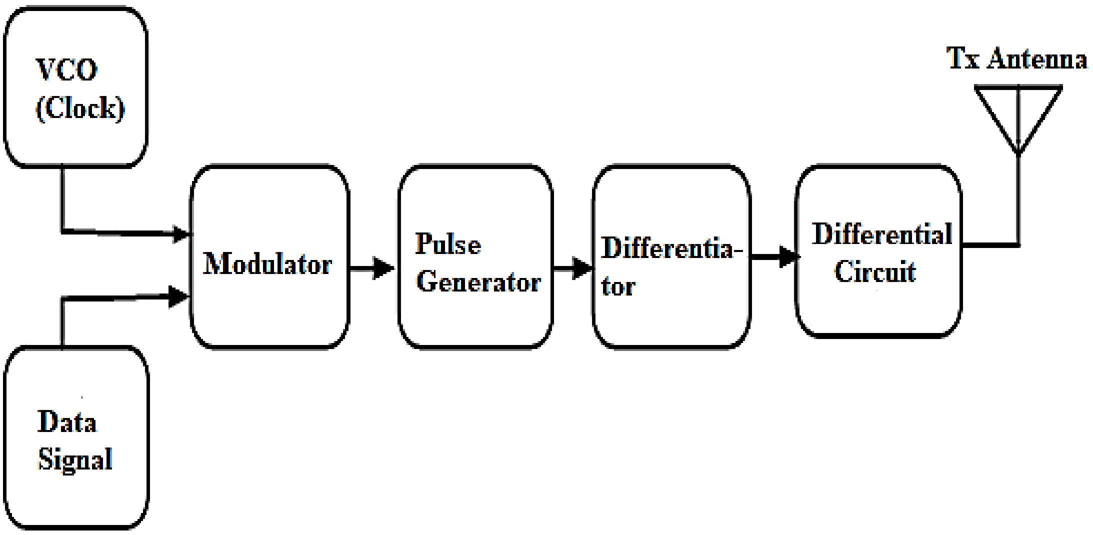


Fig. 6.1: Block diagram of the designed transmitter with antenna.

6.3 Architecture and Operation

The design of UWB transmitters for wireless biomedical field has been the subject of numerous researches, and in each of these architectures, power consumption and size were considered because they are two important design considerations for medical applications [17]. This work suggests a new design for an impulse-based ultra-wideband (UWB) transmitter system that satisfies all these requirements. The use the Gaussian monocycle pulse (GMP) generation technique is applied in the proposed UWB transmitter to simplify the circuitry and reduce the circuit. The transmitter is low-power and sized appropriately for use in medical applications, and the output does not require frequency recovery [17]. The suggested transmitter includes the following components: Current Starved Voltage Controlled Oscillator (CSVCO), Data Modulator, Gaussian Pulse generator, Differentiator and Differential amplifier.

6.3.1 Current Starved Voltage Controlled Oscillator (CSVCO)

The regulating voltage at the input controls the frequency of an oscillating signal generated by a current-starved voltage-controlled oscillator (CSVCO) [58]. Depending on the regulating voltage, the generated output frequency of clock signal can be changed over a large range (a few Hertz to Giga Hertz). A few factors, including as time, phase noise, layout area, technology, and others, are generally used to evaluate any VCO's performance [59]. The current starved oscillator is perfect for a number of applications since it offers a higher tuning range with relatively low power consumption. The amplitude is constant, which is another important advantage of CSVCO. These advantages lead to the suggested transmitter architecture using a Current Starved VCO, which uses less power, has a wide range of oscillation frequencies, and is easy to make [60]. The current-starved VCO used in this investigation contains three stages, as shown in Fig. 6.2. In each delay stage, an inverter is created by two MOSFETs (one NMOS and one PMOS), with the other two acting as current sources to limit the amount of current the inverter can use. The current from the first stage of the inverter is mirrored in later stages. For controlling voltage ranges of 300 mV to 1.5 V, the oscillation frequency ranges from 1 GHz to 7.35 GHz. The linearity of the circuit is influenced by temperature [61].

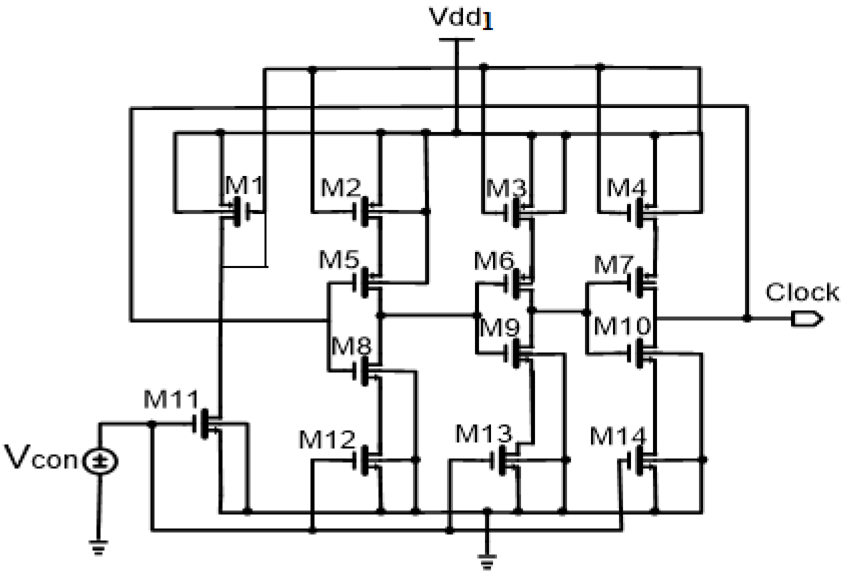


Fig. 6.2: Current Starved Voltage Controlled Oscillator (CSVCO).

6.3.2 Modulator

One of the most fundamental modulation methods for representing binary data is on-off keying (OOK), which delivers no carrier for low digital values. OOK modulation is particularly beneficial in case of bandwidth efficiency when utilizing a regenerative receiver, but noise sensitivity is high [60]. A BPSK (Binary Phase Shift Keying) modulation's signal bandwidth and an OOK modulation's signal bandwidth are equivalent for a particular data rate. OOK modulation is appropriate for RF carrier waves and optical communication systems. Furthermore, the digital logic circuit of the modulator section consumes very little power [62]. Considering all these features of OOK modulation is applied in the proposed design. The CSVCO-produced clock signal is one of the OOK modulator's two inputs, and a binary data signal is the other input [53]. The modulator is one of the main elements of the given transmitter block (schematic is shown in Fig. 6.3). A basic NAND gate and two inverter stages constitute the overall OOK modulator. If the information bit is 1, this modulation mechanism sends pulses; if it is 0, no pulses are sent. Large numbers of pulses are used to represent a single bit, reducing noise and attenuation while facilitating easy energy identification at the receiving end. The clock input controls the pulse's frequency, while the binary data signal controls how many pulses are sent in all [63].

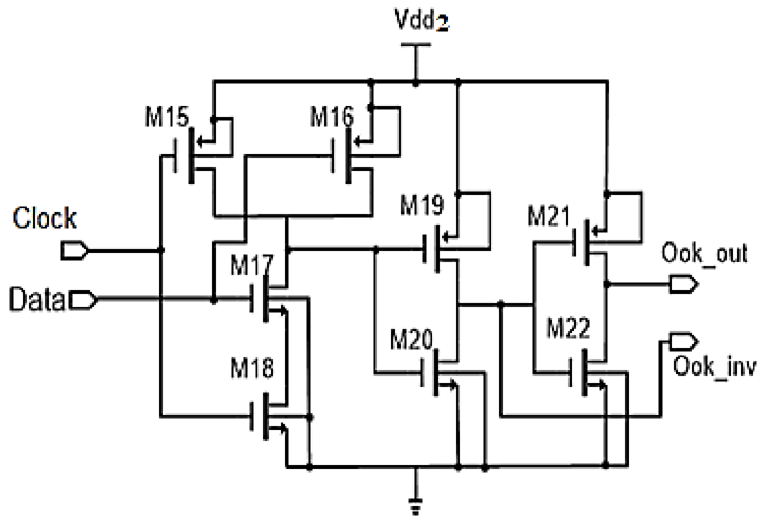


Fig. 6.3: On-off keying modulator.

6.3.3 Pulse generator, Differentiator and Differential Circuit

Because they are easy to make and affordable, Gaussian pulses are used in short and medium-range communication systems. Although the generating method is straightforward, getting pulse widths of 100 picoseconds is rather challenging [64]. For generating gaussian pulse train either sinusoidal or square wave can be used. A few of the topologies that can produce sub-nanosecond Gaussian pulses are step recovery diodes (SRDs), avalanche transistors, and nonlinear transmission lines (NLTLs). Large amplitude pulses benefit from the usage of avalanche transistors. SRDs are widely used in pulse-generating and pulse-shaping networks.

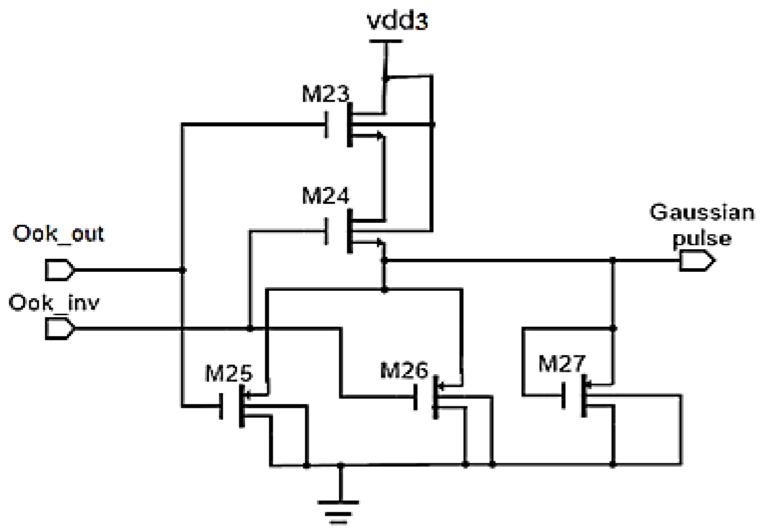


Fig. 6.4: Gaussian pulse generator.

A NOR gate is used to produce a rudimentary Gaussian pulse generator in this experiment. OOK modulated clock signal is applied as one input of NOR gate, and the other is the inverted and delayed version of the modulated clock output signal (shown in Fig. 6.4). Two NOR inputs are both low as a result of the inverted clock signal being low on the falling edge of the modulated clock signal, producing a positively-peaked Gaussian pulse [65]. Due to the short length of the logic zero input, the NOR gate output produces a narrow logic high pulse. The delay time period of the inverter affects the pulse width. An inverter is used to convert a positive gaussian pulse into negative gaussian pulse. The positive Gaussian pulse is then passed through an inverter to create a negative Gaussian pulse [66].

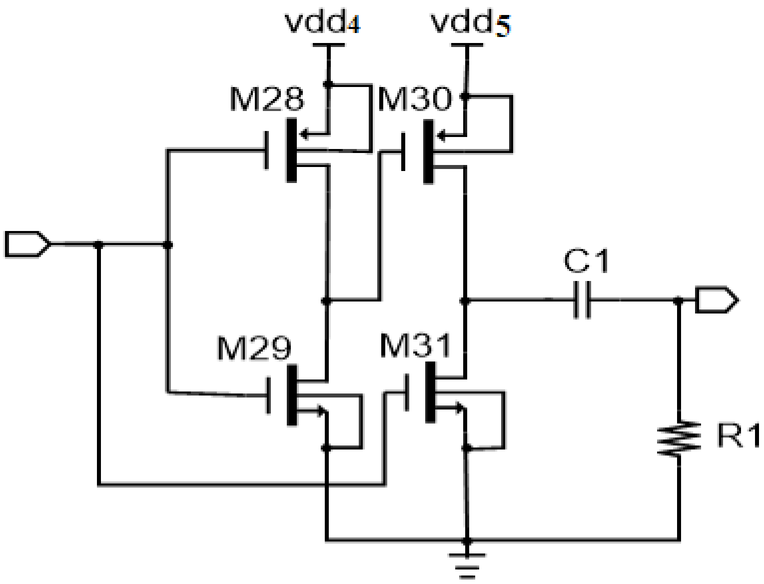


Fig. 6.5: Differentiator.

The positive and negative Gaussian pulses are then separated using a differentiator circuit (as shown in Fig.6.5). One input of a dual input balanced output differential amplifier receives the output of the differentiator circuit while the other input is grounded (as shown in Fig. 6.6).

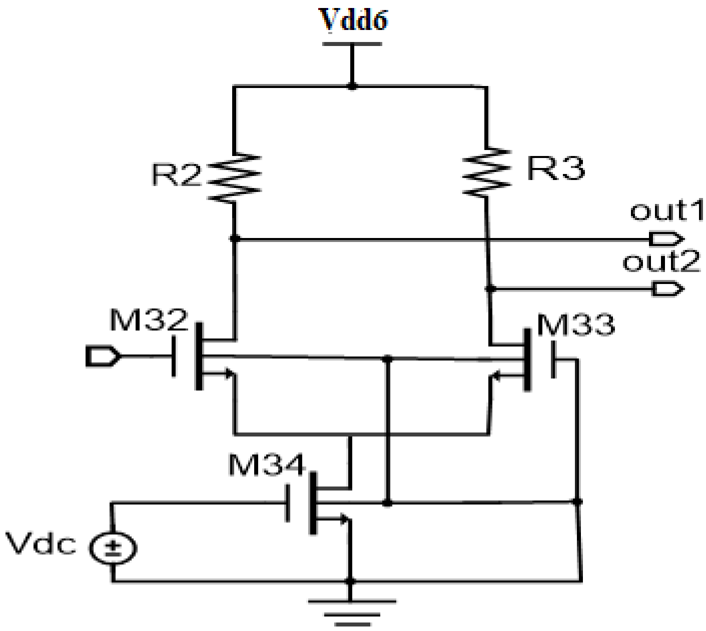


Fig. 6.6: Differential amplifier.

The rising and falling times of the rectangular input of this block determine the GMP centre frequency (fc), and the centre frequency is the reciprocal of the sum of the rising and falling times of the rectangular pulse [67]. Because of the differential output, it can be used to connect the transmitter circuit to UWB antennas. The complete architecture of the proposed transmitter is shown in Fig 6.7. Output signal flow through various circuit stages is also shown here with the complete circuit of the proposed transmitter.

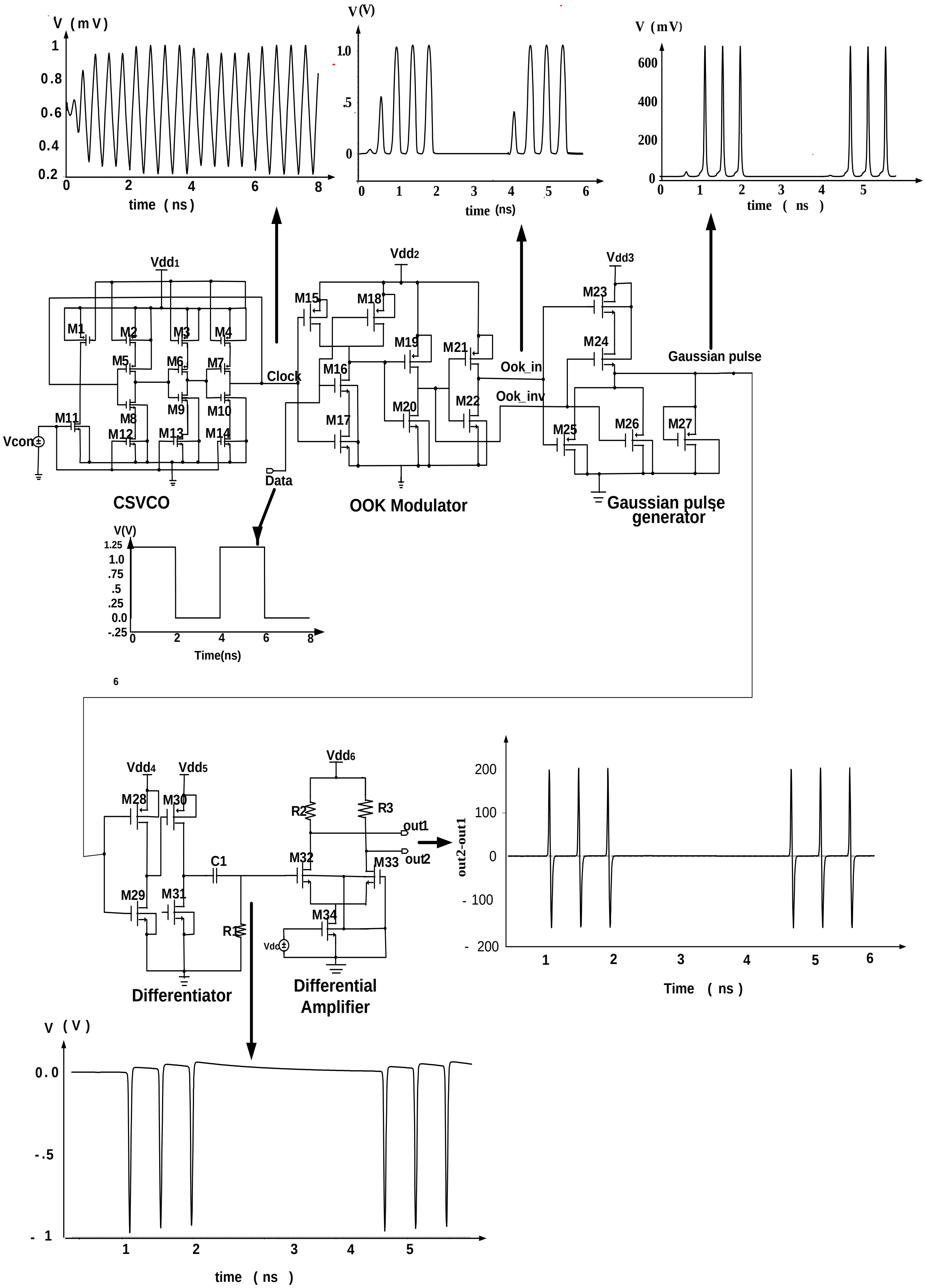


Fig. 6.7: Schematic diagram of proposed transmitter circuit.

Table 6.1: Transmitter Circuit Component Parameters

Component	**Parameters**		**Components**	**Parameters**	
MOSFET	Width (μm)	Length (nm)	MOSFET	Width	Length
M1	1	100	M25	15	100
M2	1	100	M26	15	100
M3	1	100	M27	5	100
M4	1	100	M28	2	100
M5	1	100	M29	1	100
M6	1	100	M30	2	100
M7	1	100	M31	1	100
M8	0.5	100	M32	5	100
M9	0.5	100	M33	5	100
M10	0.5	100	M34	5	100
M11	0.5	100	Resistors	Resistance (KΩ)	
M12	0.5	100	R1	2	
M13	0.5	100	R2	2	
M14	0.5	100	R3	2	
M15	3	100	Capacitors	Capacitance (fF)	
M17	3	100	C1	500	
M18	3	100	Voltage Source	Magnitude(V)	
M19	20	100	V_{dd1}	1.2	
M20	10	100	V_{dd2}	1.2	
M21	4	100	V_{dd3}	1.5	
M22	2	100	V_{dd4}	1.2	
M23	30	100	V_{dd5}	1.8	
M24	30	100	V_{dd6}	1	

6.4 UWB Antenna Design

The design of UWB antennas is getting a lot of attention, which can be attributed to the growing development of UWB systems. A few specifications for the UWB include ultra-wide impedance bandwidth, omnidirectional radiation pattern, constant gain, good radiation efficiency, uniform group delay, compact size, and ease of fabrication [77]. Planar monopole antennas, slot antennas, and dipoles were among the antenna configurations that were employed. One of the best options for wide-band applications is the planar monopole antenna because of its large impedance bandwidth, compact design, and ease of construction [78]. Due to its low profile, large bandwidth and easy manufacture, the coplanar waveguide fed slot antenna has attracted a lot of attention recently. Two important characteristics that determine the antenna impedance bandwidth in a planar slot antenna are size of slot and ground plane structure. The suggested transmitter circuit is coupled with a simple coplanar wave guide (CPW) fed aperture antenna with UWB properties [79].

To achieve a wider impedance bandwidth and an omnidirectional radiation pattern, the idea of a modified ground plane with a slot in the radiating patch is applied in this research. These techniques are utilized to cut down on copper usage and antenna size without sacrificing antenna characteristics [80]. The antenna's impedance bandwidth and other outputs are influenced by the ground plane edges, feed size, and slot. Therefore, in order to get a larger bandwidth, proper investigations into such qualities are needed.

N. Taher *et al.* have proposed, a Coplanar Waveguide (CPW)-fed patch antenna for Ultra-Wide Band (UWB) application [81]. This work introduces an umbrella-shaped antenna with a modified ground plane and slotted radiation patch which is a modified form of antenna proposed by N. Taher *et al*. [80]. After modification, the antenna's overall size is lowered, and the radiation pattern and gain are both enhanced. The proposed UWB antenna configuration is shown in Fig. 6.8. The dimension of the antenna including ground plane corners is 32mm x 28.5mm x1.5mm. A rectangular aperture cut out of the ground plane of a PCB and a CPW-fed umbrella-shaped radiation patch forms the antenna [82]. The antenna is structured on a moderate FR4 substrate with a dielectric constant of 4.3 and a thickness of 1.5 mm. The optimal dimensions of the various parts of the antenna is presented in Table 6.2. The end of the feed line of the CPW is attached with the semicircle endpoint of radius r1. The extrusion depth is 2mm of the umbrella-shaped patch and a semicircle slot is introduced onto the radiation patch to improve the bandwidth and gain of the proposed antenna. A 50 Ω CPW transmission line powers the tiny rectangular aperture antenna [83].

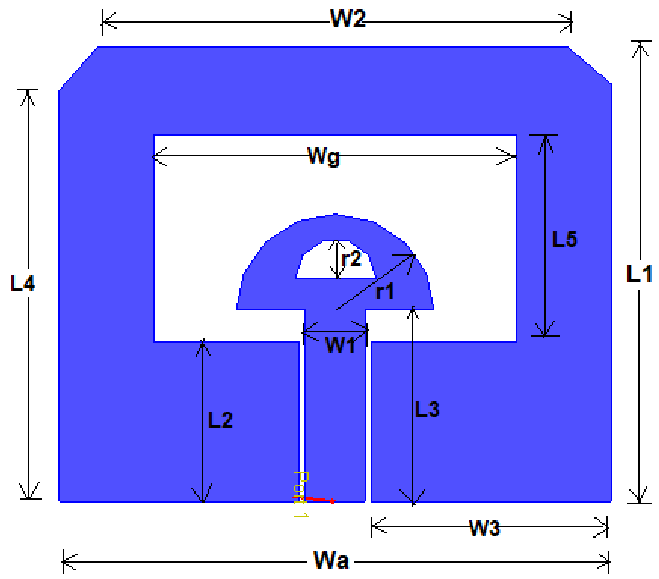


Fig. 6.8 : Geometry of proposed antenna.

Table 6.2 : Antenna Dimensions, mm

L1	**L2**	**L3**	**L4**	**L5**	**W1**
28.5	10	12	26	13	3.6
W2	**W3**	**Wa**	**Wg**	**r 1**	**r 2**
28	14	32	22	6	2.3

The constructed antenna makes use of the patch's umbrella shape to improve the bond between the feed line and the slot, allowing for ultra-wideband performance. The top two corners of the ground plane have been rounded off (angularly), which also improves antenna performance and reduces size [84]. The antenna return loss bandwidth, radiation patterns, gain, group delay, and transmitted pulse waveform distortion were analysed using the Advanced Design System (ADS) software [80]. The suggested antenna creates a 50Ω input impedance using a technique made available by CPW.

6.5 Designed Transmitter Circuit with Suggested Antenna

The schematic and layout of the various circuit blocks of transmitter was initially designed using the same Cadence virtuoso software. The Advanced Design System (ADS) software is then utilized to couple the transmitter circuitry with the UWB antenna and to perform EM/circuit co-simulation of the transmitter and UWB antenna [85]. The last two blocks with the antenna are illustrated in Fig. 6.9. The entire transmitter circuit, which includes a CSVCO, OOK modulator, Gaussian pulse generator, differentiator, and differential amplifier, was co-simulated with a UWB antenna using ADS software.

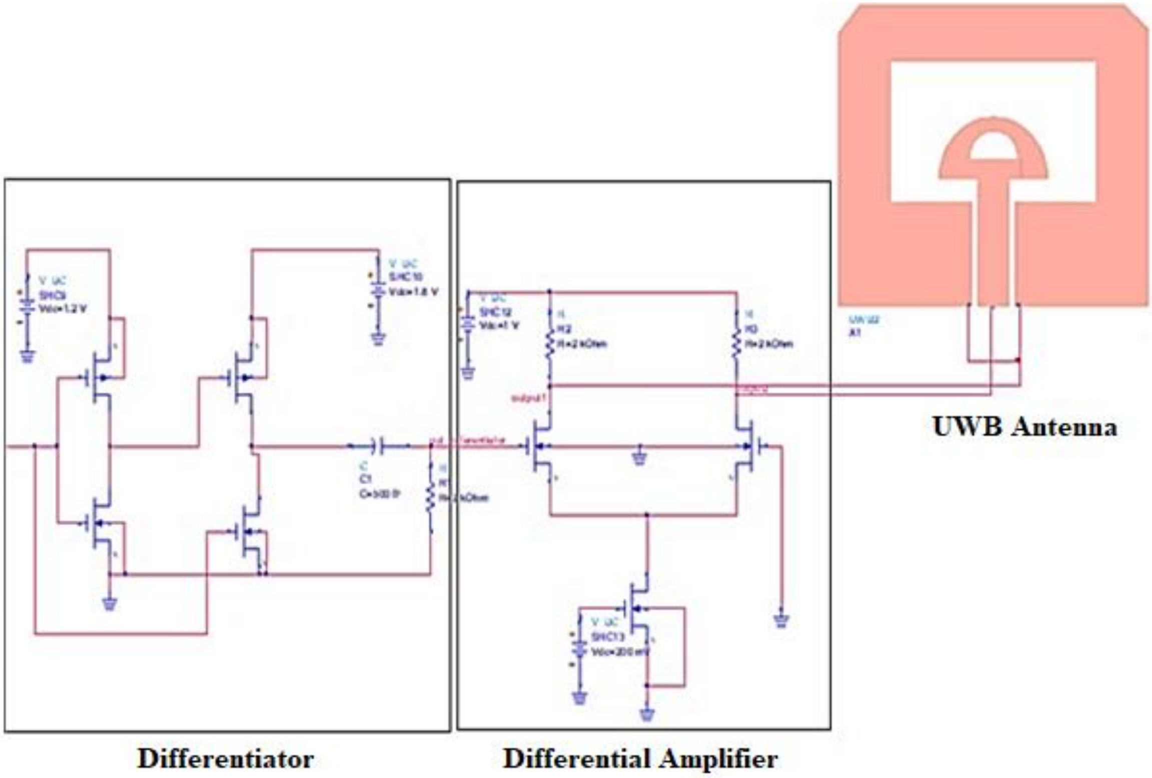


Fig. 6.9: Schematic diagram representing coupling of transmitter circuit with Antenna (Last 2 blocks of transmitter circuit are shown with antenna).

6.6 Conclusion

In this chapter, the different functional blocks which are designed to formulate the total UWB transmitter are explained and also block diagram of the overall transmitter architecture is presented. Here, what are the techniques that followed to enhance the performance of the device are also discussed for each block. After explaining each block separately with designed circuit, the total transmitter circuitry is presented, and value of the transmitter circuit parameters are also specified in tabular form. To check the compatibility of the designed transmitter with UWB antenna, a rectangular aperture CPW fed antenna is modified and it is also proved that the proposed transmitter operates properly even after connecting it with the modified antenna.

CHAPTER 7
RESULTS AND DISCUSSIONS

7.1 Introduction

The designed UWB transmitter in this thesis work is appropriate for UWB networks used for medical applications. The transmitter can be used for many other wireless communication systems with only simple circuit modifications. Cadence software and 90nm CMOS technology was used to design and simulate the UWB transmitter.

7.2 Simulation Results of the Presented UWB Transmitter

The proposed transmitter output pulses at various stages of the circuitry and FFT of single GMP are shown in Fig. 7.1 to Fig. 7.7. The OOK modulation technique is utilized, which reduces the circuit's power consumption because no pulse is generated and broadcast for low input data values [16]. The voltage that is supplied has a significant impact on how well this type of UWB transmitter circuit performs. The configuration of the generated Gaussian pulse, which is significantly affected by the propagation delay between the input signals of the logic NAND and NOR gates, depends on the applied voltage [68]. Getting the right propagation delay for the inputs of the logic gate is the most important design factor for this type of transmitter.

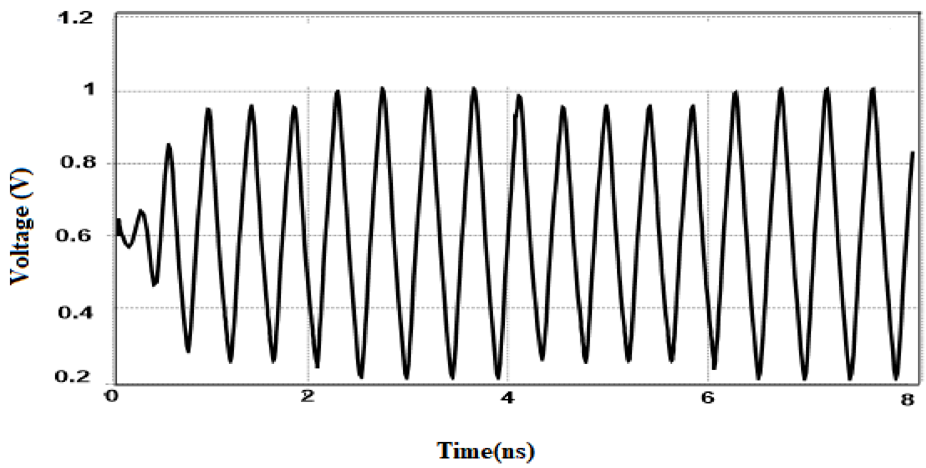


Fig. 7.1: Clock output of current starved VCO.

The output signal waveform of CSVCO is shown in Fig 7.1. The oscillator's voltage can be adjusted to change the frequency of the generated clock signal, and the amplitude is nearly steady. Here, Vcon=460mV is applied, and the produced signal has a frequency of 2.5 GHz. The next operational circuit which is an OOK modulator uses this generated signal as the clock input [69].

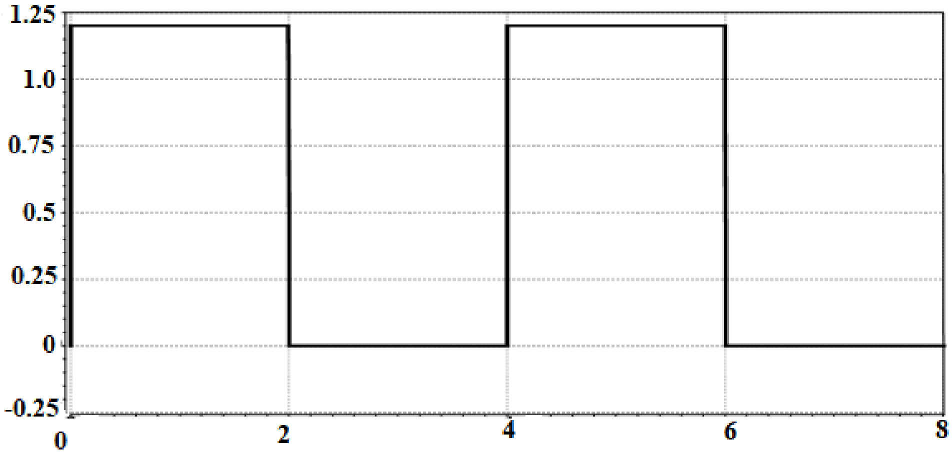


Fig. 7.2: Input Data

Figure 7.2 shows the input data pulse and the frequency of this data input is 250 MHz. This data input is used as another input in the OOK modulator.

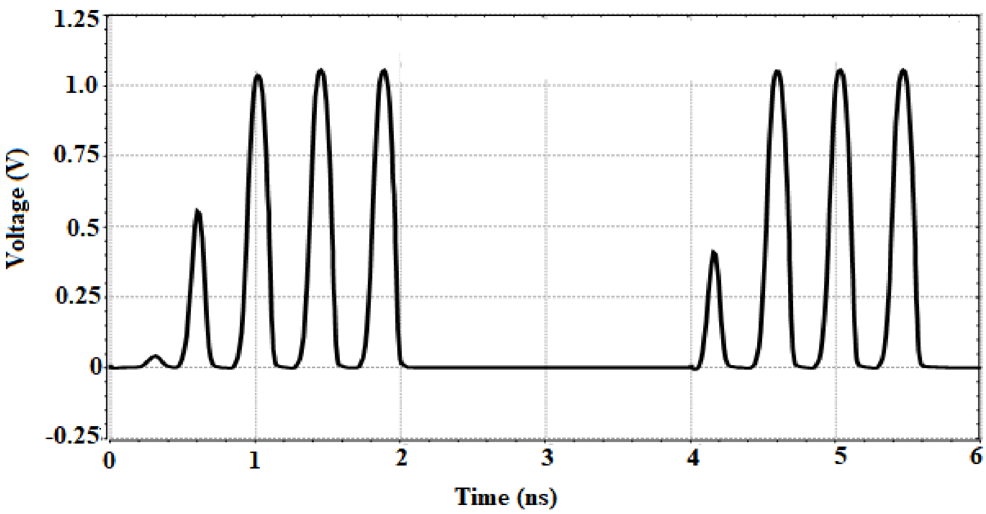


Fig. 7.3: Output of On-off keying modulator.

The OOK modulator's output waveform is depicted in Fig 7.3. Here, we can see that if the data signal is high, modulated clock pulses are delivered, and if the data signal is low, the output is "0." The following block Gaussian pulse generator receives this modulated output as one of its input.

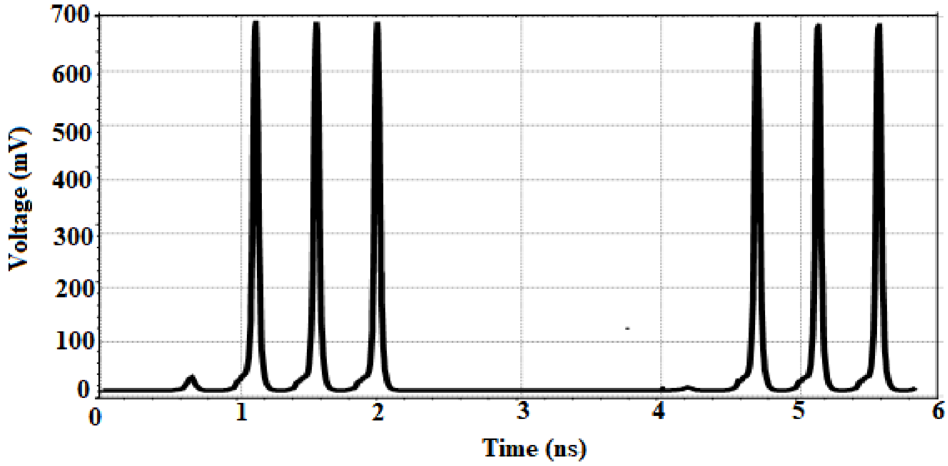


Fig. 7.4: Output of Gaussian pulse generator.

The output of the Gaussian pulse generator is depicted in Fig. 7.4. The MOS transistor's width can be changed to alter the rise and fall timings. This approach will not only decrease the number of MOS transistors in the circuit but also prevent the complexity of producing a Gaussian pulse [70]. The shape of a Gaussian pulse produced from a modulated clock pulse is seen in Fig. 7.4.

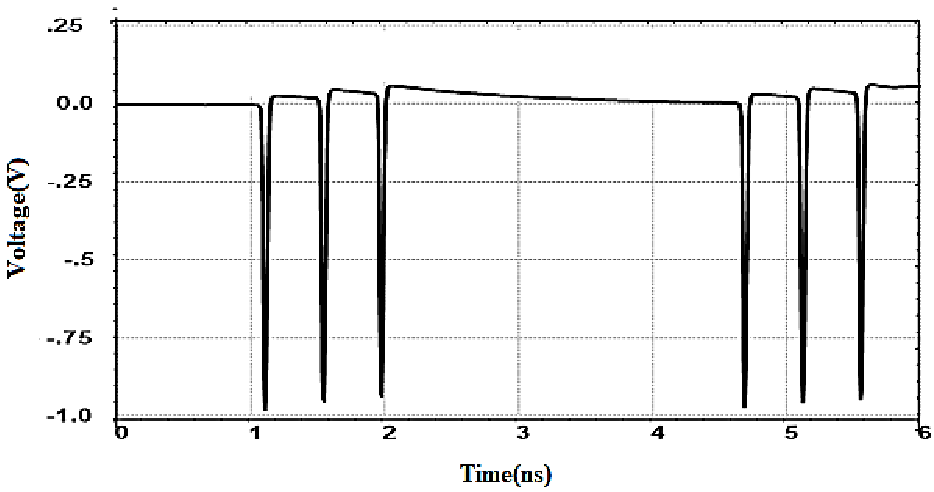


Fig. 7.5: Output of differentiator.

These short pulses are delayed around ~100ps and feed to a charge pump stage consecutively to get a Gaussian mono-pulse at output. This is similar to the distributed wave generation technique [71]. A charge pump stage is composed of one NMOS and PMOS transistor and a network of capacitor and resistor as load. Two Gaussian pulses with opposite polarity delayed by sub-nano second are feed to NMOS and PMOS and output is seen across a load resistance. To filter out any DC component capacitor is introduced. The output of that stage is shown in Fig. 7.5.

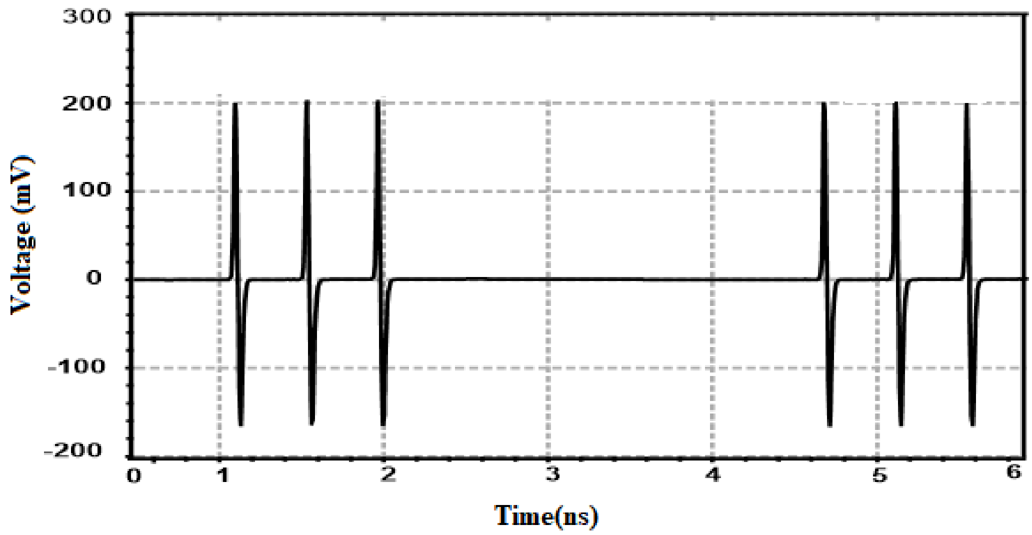


Fig. 7.6: Output of differential Amplifier.

The differential output between the differential amplifier's two output nodes is shown in Fig. 7.6. The distorted Gaussian mono pulse is transformed into an undistorted Gaussian mono pulse by the differential amplifier [72].

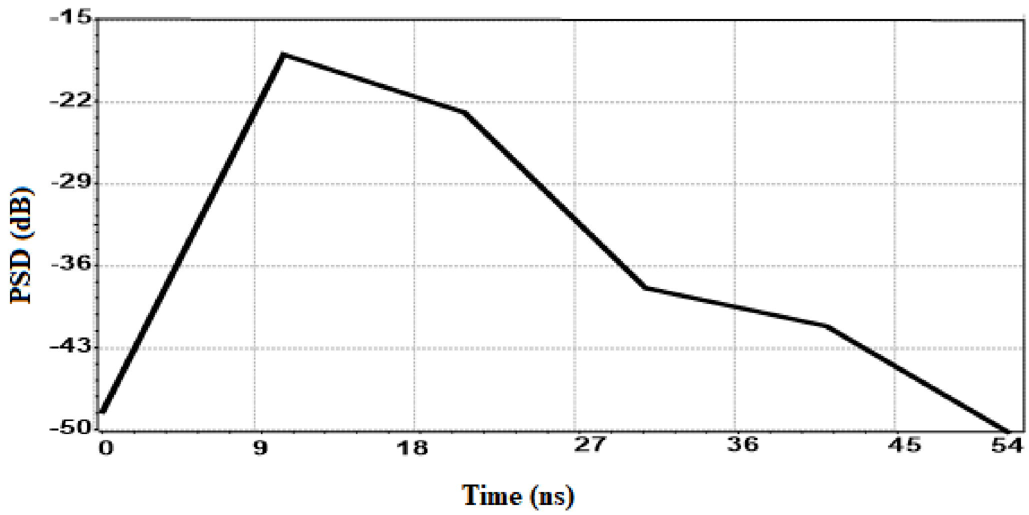


Fig. 7.7: Power spectral density (PSD) of a single Gaussian mono cycle pulse.

By performing FFT on the generated single Gaussian mono pulse, Fig. 7.7 illustrates the power spectral density of the transmitter [73]. From this graph, it can be determined that the transmitter's -3dB bandwidth is 8.5 GHz.

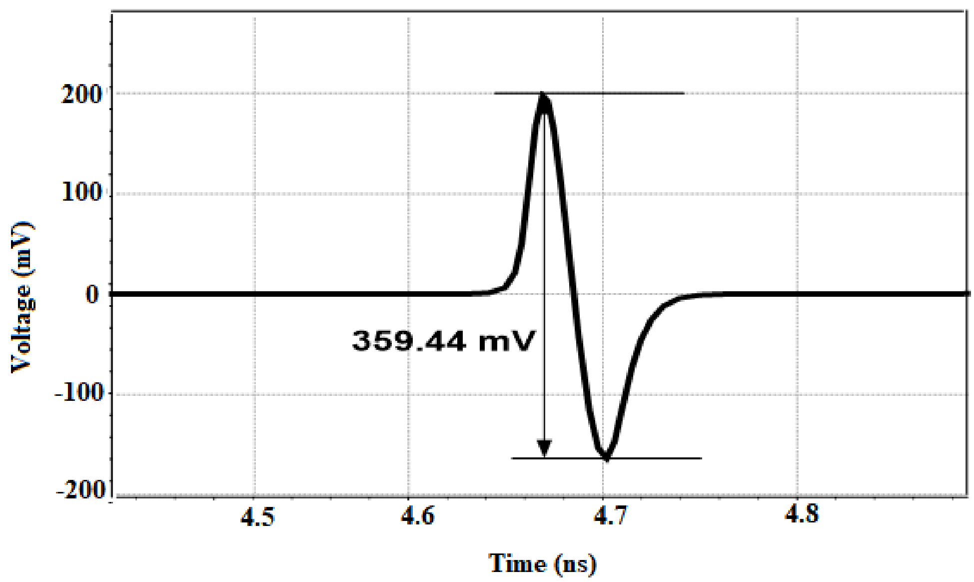


Fig. 7.8: Single Gaussian monocycle pulse.

The single gaussian mono cyclic pulse is depicted in Fig. 7.8. The output waveform shows that the generated GMP has an amplitude of 359.44 mV and a pulse width of 117 ps. The total power consumption is 2.685 mW, which is considerably less than the biomedical equipment power consumption limit.

7.3 Post Layout Simulation Result

The overall layout of the various building blocks of the proposed transmitter employing 90nm CMOS technology is depicted in Fig. 7.9 to Fig. 7.13.

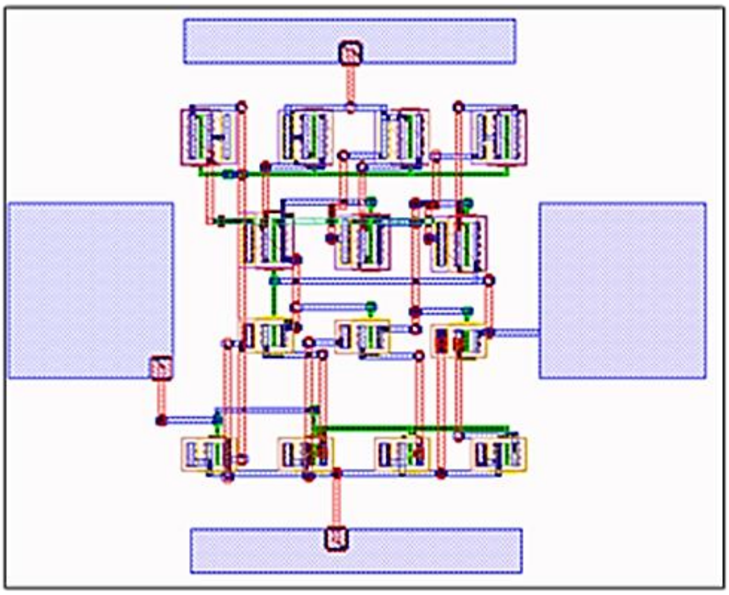


Fig. 7.9: Current starved VCO layout in Cadence.

The parasitic has minimal effects on the overall functioning of the circuit, as demonstrated in the simulated outputs from the layout and schematic in Fig. 7.14 to Fig. 7.18. Both parasitic capacitance and parasitic resistance are extracted from the post-layout schematic view. The Cadence tools are unable to physically extract an inductor. CSVCO's layout is depicted in Fig. 7.9, and its dimensions is 12.64µm × 16.73µm.

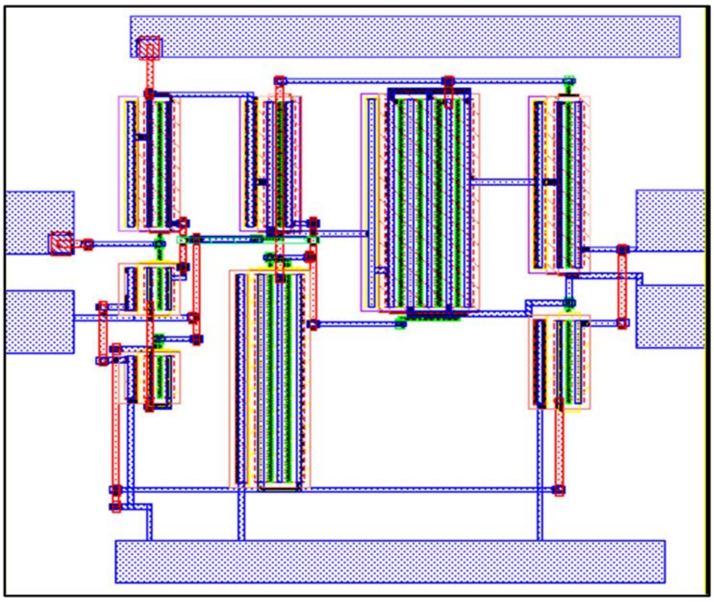


Fig. 7.10: On-off keying modulator layout in Cadence.

Fig. 7.10 shows the OOK modulator layout which is extracted from schematic and the dimension is 15.3µm×13.53µm.

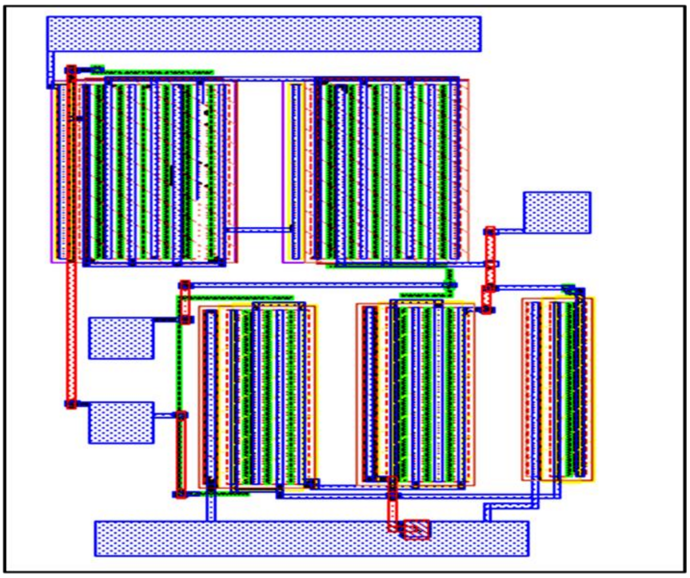


Fig. 7.11: Gaussian pulse generator layout in Cadence.

The extracted layout of the Gaussian pulse generator is depicted in Fig. 7.11, and its dimensions are 10 µm x 15.61 µm. Two circuit units are created to be uniquely identifiable in an analog circuit layout in order to accomplish the same functional performance. Symmetric layout design is required for unit matching [42]. The symmetric design is necessary for sensitive digital blocks and analog circuit blocks that use differential signals, such as the differential amplifier that detects and amplifies the difference between the two signals [1].

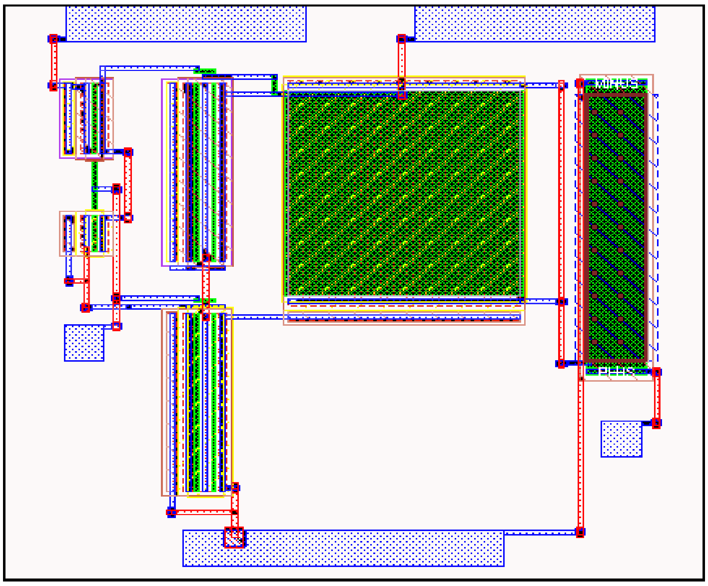


Fig. 7.12: Differentiator circuit layout in Cadence

The extracted layout of the differentiator, with dimensions 15.03 µm x 15.64 µm, is shown in Fig. 7.12. Base resistors, emitter resistors, N-well resistors, high-sheet resistors, and metal resistors are only a few of the several types of resistors. But due to the high resistive density of polysilicon, it is the most often used form of resistor in the 90nm CMOS process [5]. The poly that is used to build MOS gates has a sheet resistance of between 25 to 50Ω /square and is highly doped to increase conductivity.

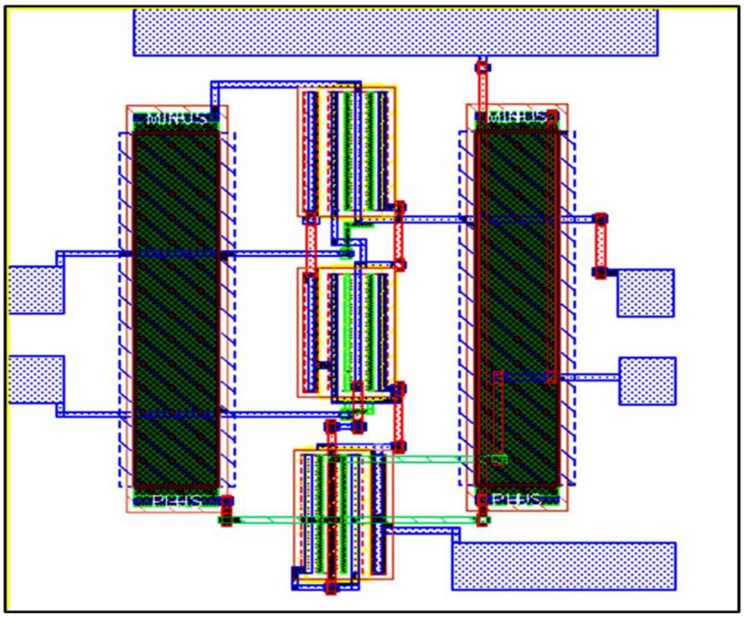


Fig.7.13: Differential amplifier circuit layout in Cadence

Fig. 7.13 represents a symmetric layout for the differential amplifier used in the UWB transmitter circuit whose dimension is 12.22μm×11.63μm. In this pattern, the left half is an exact replica of the right half. The gradient-induced temperature, stress, and oxide thickness mismatches between two sides are minimized by such an arrangement [9]. At its peak performance, it also produces identical electrical properties for the amplifier's two halves. The different offset voltages are kept to a minimum in terms of circuitry. The total assembling of five blocks has an overall dimension of 94.62μm x16.99μm.

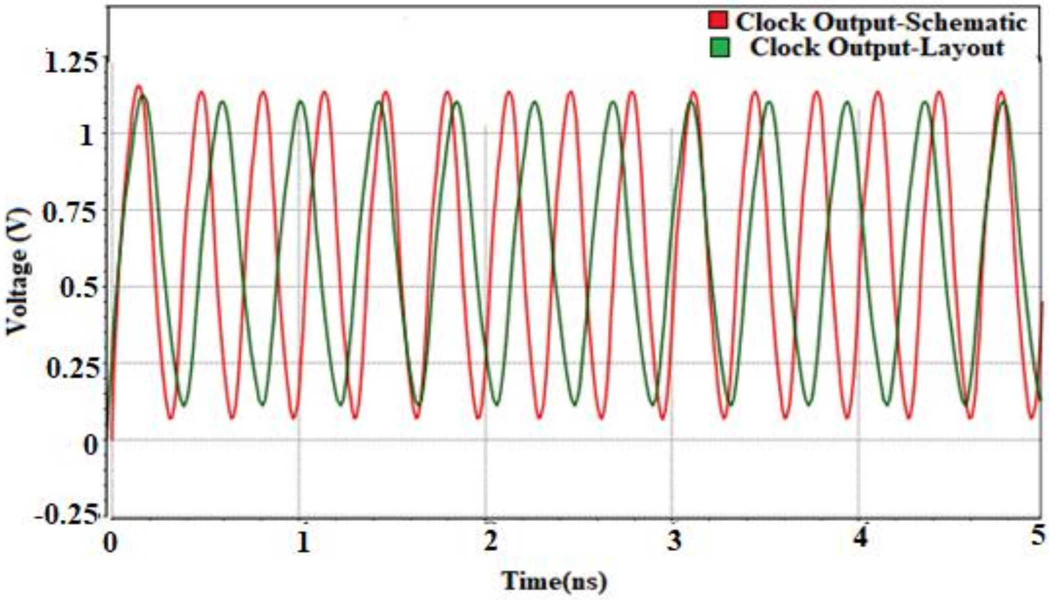


Fig. 7.14: Current starved VCO output for layout and schematic.

The output characteristic parameters at several stages are compared for schematic and layout using an ideal sinusoidal input signal. Fig. 7.14 depicts the schematic's output in red and the layout's output in green, demonstrating how little of an impact the parasitic has on how the circuit functions as a whole [74]. The layout successfully passed the LVS, RC, and 90nm CMOS design rule checks (DRC), ensuring a successful design following fabrication.

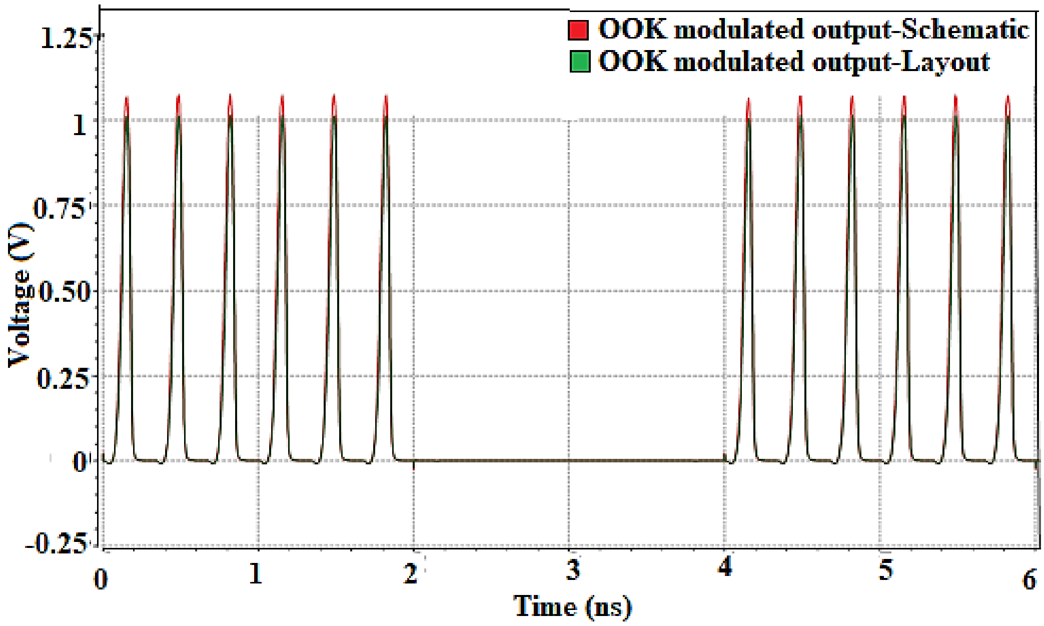


Fig. 7.15: On-off keying modulator output for layout and schematic.

Fig. 7.15 shows the schematic and layout outputs of an OOK modulator where a square pulse was used as one input and a sinusoidal input was used for another input of OOK modulator layout.

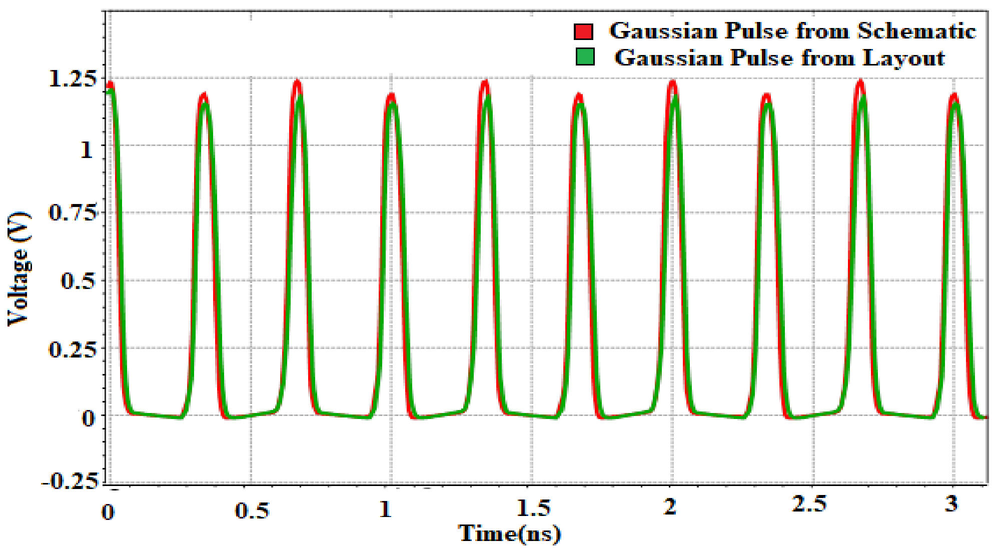


Fig 7.16: Gaussian pulse generator output for layout and schematic.

Fig. 7.16 shows the schematic and layout outputs of a Gaussian pulse generator where a sinusoidal input was used as input of OOK modulator.

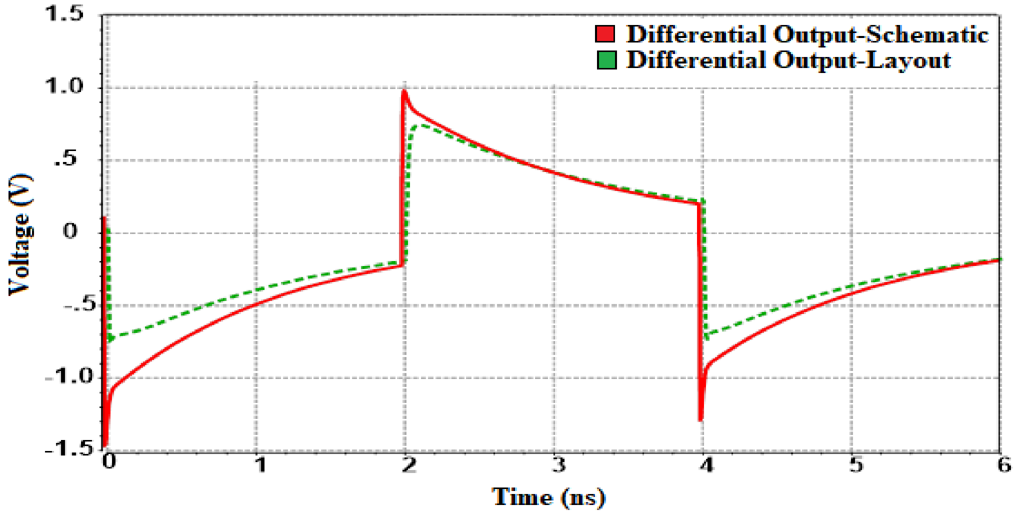


Fig. 7.17: Differentiator circuit output for layout and schematic.

Only for differentiator circuit, square wave was used as input. And the output for both schematic and layout was close to ideal output of a differentiator circuit for square wave. Due to parasitic components, a small deviation is found for the outputs between schematic and layout.

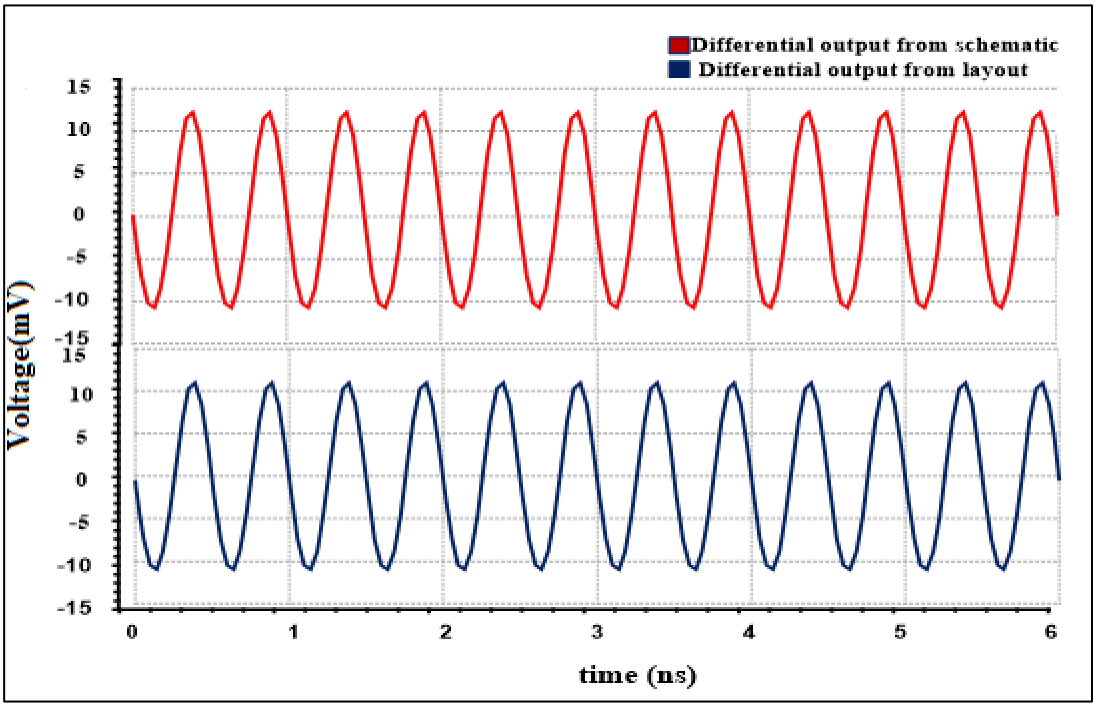


Fig. 7.18: Differential amplifier circuit output for layout and schematic.

Fig. 7.18 shows the schematic and layout outputs of a Differential circuit where a sinusoidal input was used as input. Almost similar outputs for schematic and layout confirms the feasibility of fabrication for the designed transmitter.

7.4 Process Corner Analysis of Designed UWB Transmitter

Any circuit built with components made at some of these process corners can operate at higher or lower temperatures and voltages, as well as at a faster or slower rate than necessary. To guarantee that the planned transmitter operates properly at various process corners and temperatures, an evaluation of the suggested transmitter's process corners is also done [75].

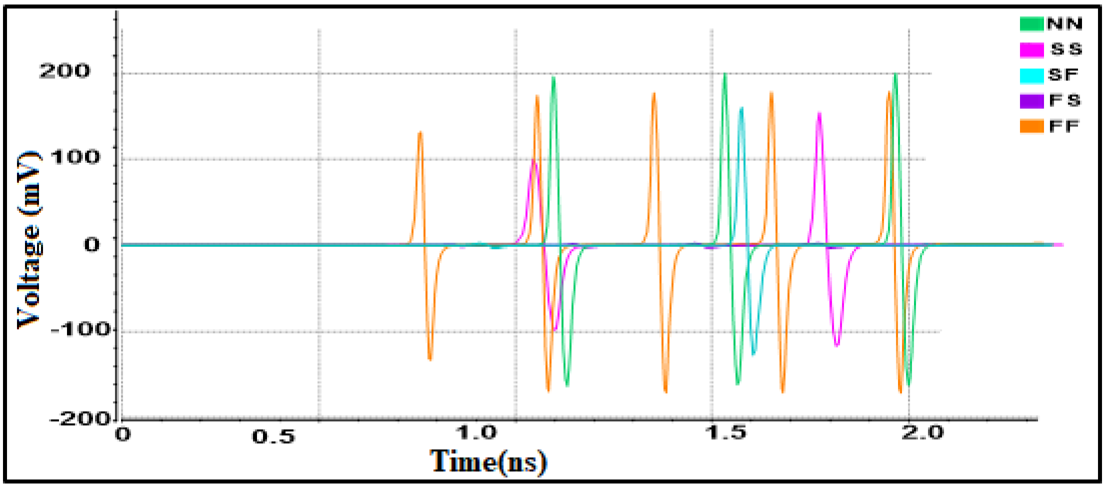


Fig. 7.19: Output Gaussian pulse at different process corners.

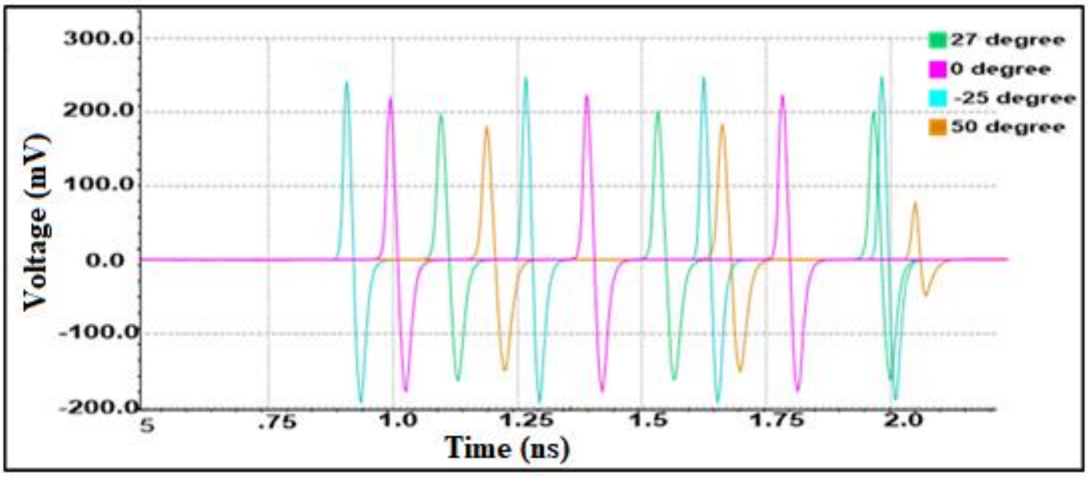


Fig. 7.20: Output Gaussian pulse at different temperatures.

For the NN, SS, SF, FS, and FF conditions, the simulated output varies as illustrated in Fig. 7.19. And output waveform at four different temperature also determined which is illustrated in Fig. 7.20.

Table 7.1: Comparison of Presented Transmitter Parameters with Previous Works

Ref	CMOS Tech.	Si Area (μm^2)	Power Con. (mW)	Energy (pJ/b)	Output Pulse width (ps)	Modulation technique	Measured/ Simulated
[76]	180nm	1370x 1370	11.8	98.3	1000	OOK	Measured
[17]	180nm	500x 500	23	460	820	OOK	Simulated
[18]	180nm	100x 100	5.4	10.8	800	OOK	Simulated
[19]	90nm	1380x1380	26.4	65	2500	BPSK	Measured
This work	90nm	94.62x16.99	2.685	10.74	117	OOK	Simulated

To justify the contribution of the model, a comparison table is also specified in Table 7.1 which shows the improvement of different outputs of this research comparing to previous works in this field. From this comparison table it is shown that the power consumption and energy per bit is lower than the previous reported researches. The short pulse duration of 117 ps is an improvement over most other researches on this topic and it results in a high achievable data rate of 8.5 Gbps which is the highest of all the related literatures reviewed. The device size is another most important parameter which is also reduced significantly.

7.5 Simulated Results of Proposed Antenna

The simulated outputs of proposed UWB transmitter's different stages from ADS simulator software is identical to the waveforms previously created by Cadence software.

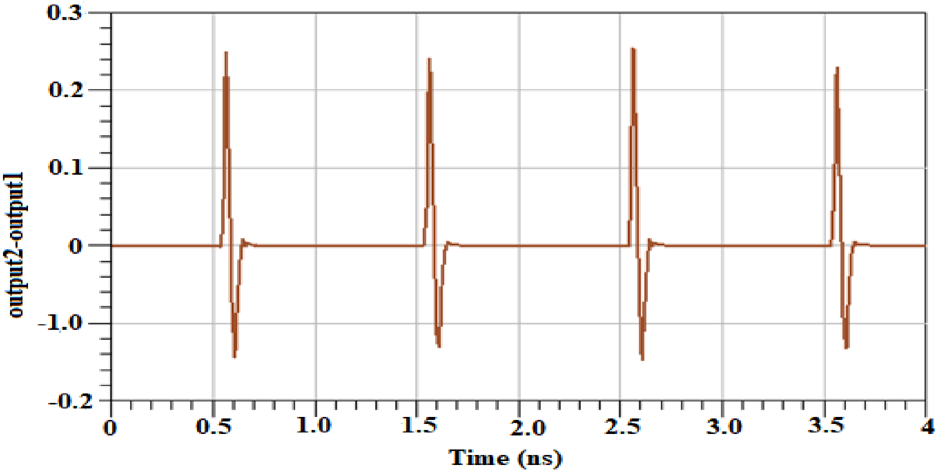


Fig. 7.21: Output GMP of proposed transmitter from ADS simulator.

Gaussian monocycle pulse output from ADS is shown in Fig. 7.21 which is same as Fig. 7.6. Fig. 7.22 displays the return loss of the CPW fed UWB aperture antenna. The recommended antenna meets the -10 dB return loss from 3.1GHz–10.6 GHz requirement.

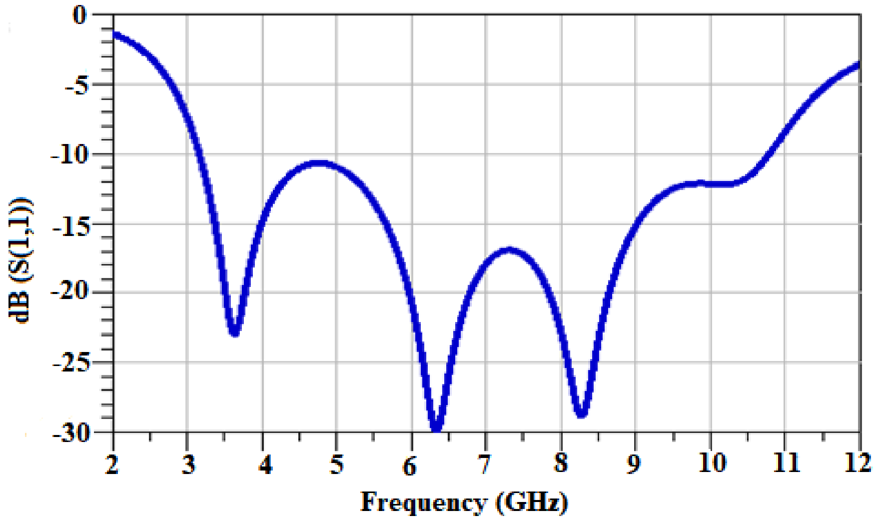


Fig. 7.22: Return loss plot of suggested UWB Antenna.

The simulated output of current distribution on the surface of proposed antenna at specified frequencies of 3.6 GHz and 8.5 GHz is shown in Figure 7.23. Fig. 7.24 shows an ADS 3D representation of the anticipated radiation pattern from the proposed antenna at (3.6 GHz, 8.5 GHz).

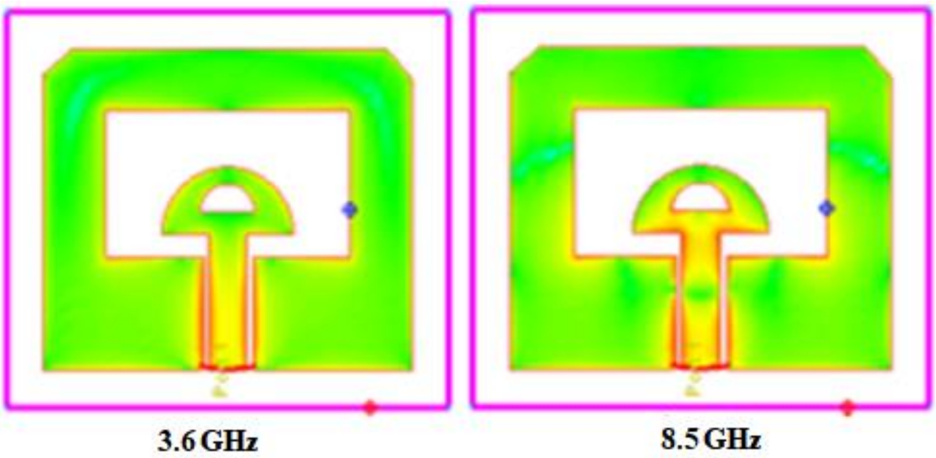
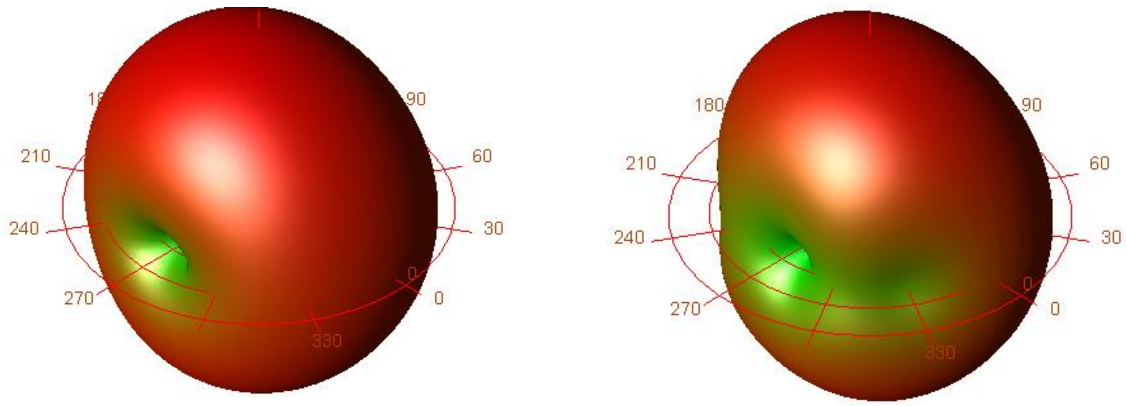


Fig. 7.23: Simulation result of current distributions on the surface of the suggested antenna.

The antenna displays consistent radiation patterns over the UWB, with the direction of highest radiation always being around the z-axis(normal to the aperture plane), according to the simulation result shown in Fig. 7.24.[30].



(a) (b)

Fig 7.24: 3D plot of radiation pattern of proposed antenna (a) Frequency= 3.6 GHz, (b) Frequency=8.5 GHz.

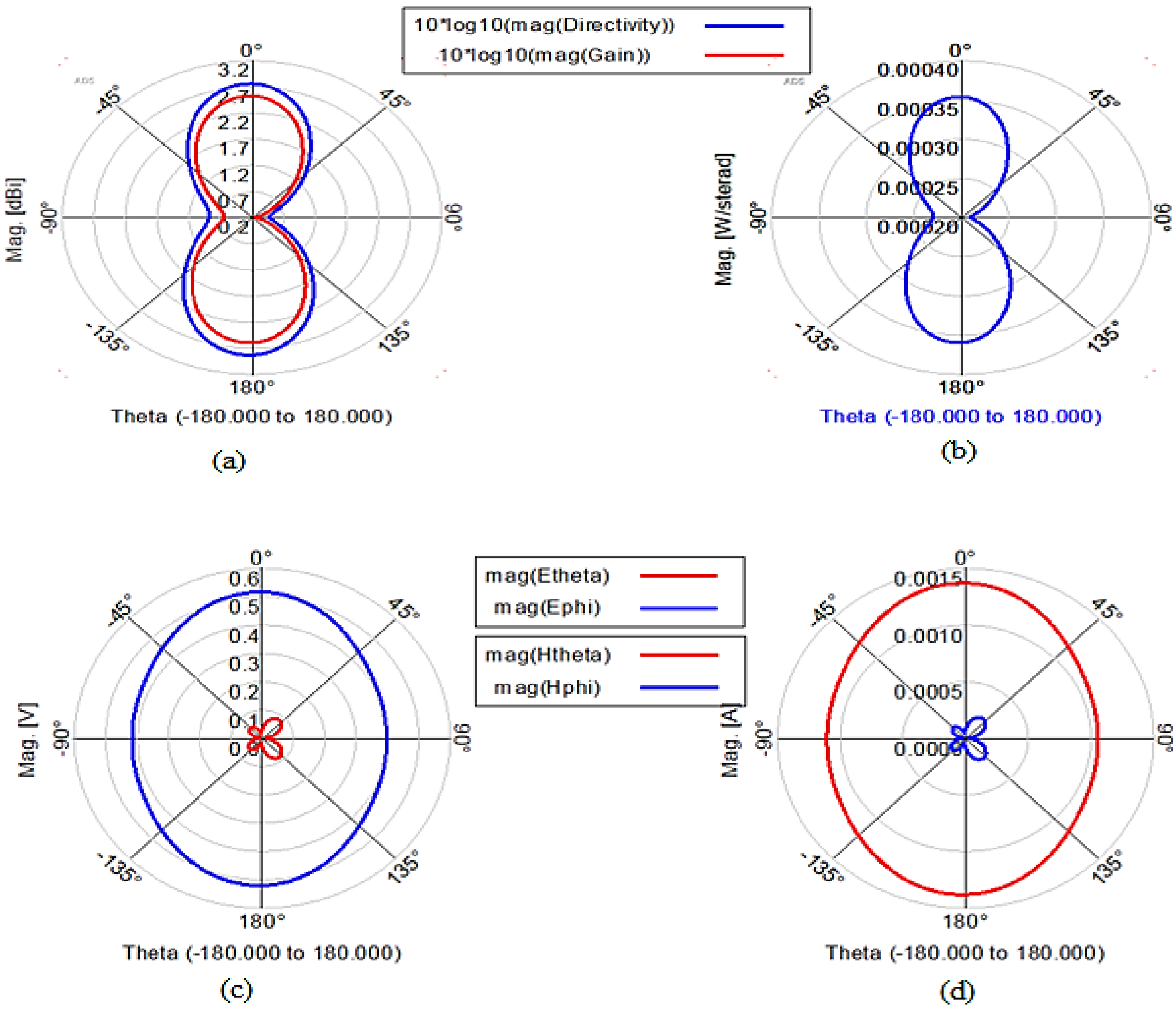


Fig. 7.25: (a) Gain, directivity (b) Radiated power (c) Electric far field (d) Magnetic far field of the proposed antenna at 3.6 GHz.

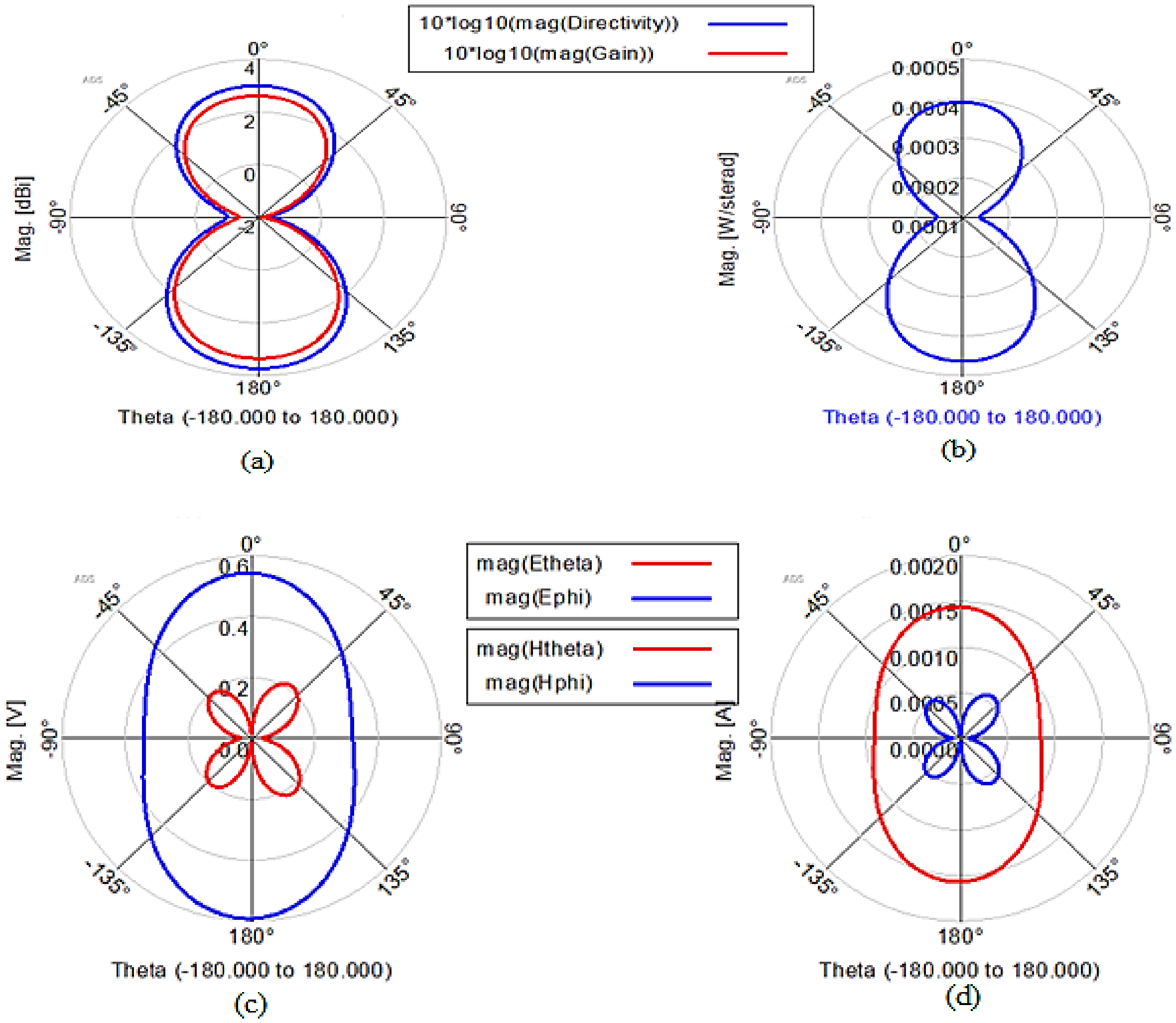


Fig. 7.26: (a) Gain, directivity (b) Radiated power (c) Electric far field (d) Magnetic far field of the proposed antenna at 8.5 GHz.

Fig. 7.25 and Fig. 7.26 illustrate the gain, directivity, radiated power, and absolute fields of the suggested antenna. Simulated data was run at two distinct frequencies (3.6 GHz and 8.5 GHz). Slices of a 3-dimensional radiation pattern in 2-dimensions represent the information. Fig. 7.27 illustrates the antenna return loss after connecting the antenna with transmitter circuit which is obtained from EM/circuit co-simulation using ADS software (from circuit set-up of Fig. 6.9).

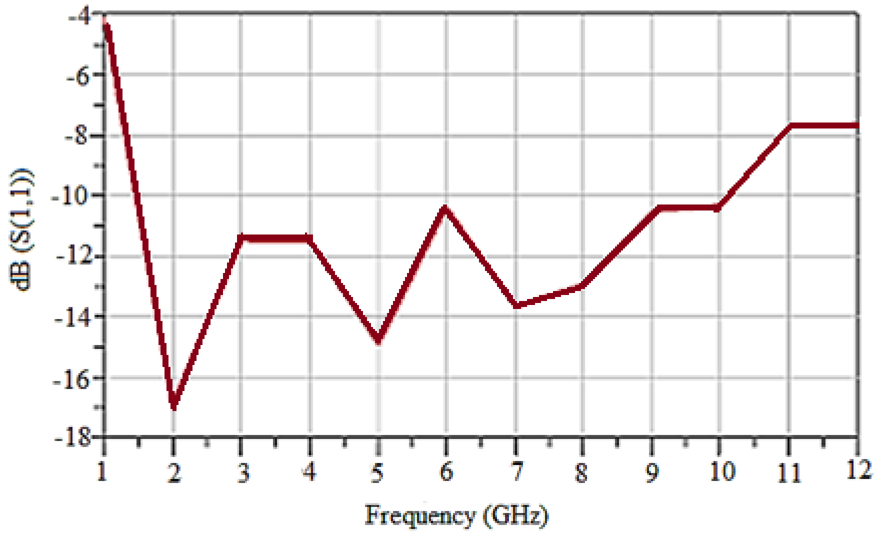


Fig. 7.27: Antenna return loss from EM/circuit co-simulation.

7.6 Conclusion

The performance of the proposed transmitter is evaluated and validated with simulation outputs. The output waveforms at different stages of the transmitter circuitry is presented. Different parameters are examined from the simulated outputs. After examining the outputs from transmitter schematic, layout for each block is generated. The simulated outputs from schematic and layout are compared, and it is proved that the layout passed the DRC and LVS without error. It has been observed that the performance of the proposed architecture varies slightly for different process corners and temperatures. Best performance recorded for NN corner and -25-degree centigrade temperature. Also, UWB aperture antenna with a radiation patch in the pattern of an umbrella is proposed. For the lowest frequency which is 3.1 GHz, the antenna's small aperture area is less than a quarter-wavelength of it. Simple geometry with few parameters whose impacts on impedance match are examined. The designed UWB antenna has a steady radiation pattern and an omnidirectional radiation pattern.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

8.1 Conclusions

To design a low power and small UWB transmitter which is ideal for medical applications, basic electronics are used in the developed architecture, which consumes 0.831 mW power in total. Due to the minimal power dissipation which occurs only during circuit switching, 90nm CMOS process technology is used to design the transmitter. The output waveforms acquired from the simulation demonstrate the transmitter performance and capability. By generating and analysing the post layout simulated output in terms of parasitic extraction for each functional block it is proved that this design can be further extended to fabrication and physical experimentation. Additionally, a UWB antenna that can work with the UWB sensor is also suggested. A simple, low-profile, high-gain, slotted, and optimized ground UWB antenna has been successfully constructed on FR4 substrate for UWB applications. Changes in the essential construction factors' dimensions have an effect on the performance of the designed antenna. For improved performance, all the important parameters are simulated and tuned. The antenna's outputs were also enhanced by changing the ground plane's upper two corners and adding a slot to the radiating patch. Semi-omnidirectional and omnidirectional radiation patterns are observed for different frequencies. The proposed antenna provides a number of other benefits, such as small size, wonderful radiation patterns, and higher gains for a broad range of frequencies [62].

8.2 Major Contribution of the Thesis

This thesis covers several aspects of pulse generation and transmitter implementation for pulsed ultra-wideband medical application. The broad theme of this thesis is to explore trade-offs that can be made in the pulse generation in order to reduce energy consumption. The task can be broken up into the following contributions:

- **Inductor less transmitter circuitry** – In the proposed transmitter circuit, no inductor is used as circuit component to reduce the overall size of the transmitter and to lower the power consumption as inductor consumes a large amount of power.

- **Gaussian pulse approximation**-Spectral efficiency and pulse localization in the time and frequency domains is critical for high data rate pulsed-UWB transmitters. The Gaussian pulse shape offers the best combination of these metrics; however, the Gaussian shape is nontrivial to generate with low power and high bandwidths. A technique for generating pulses that accurately approximates a Gaussian shape is presented that does not compromise spectral efficiency or matching between OOK pulses. This is performed by exploiting the exponential properties of a MOSFETs. The proposed pulse generation technique has been implemented in a 90nm CMOS process.

- **All-digital pulse generation** - The available bandwidth in the UWB band far exceeds what is required for low data rate applications. UWB transmitters may capitalize on this fact by relaxing the specifications on frequency precision in order to reduce the energy/bit of the system. This approach has been applied to develop an all-digital UWB transmitter architecture that supports programmable pulse widths and centre frequencies. This transmitter is designed using only full-swing static CMOS circuits, and no analog biases are required.

- **Compatible UWB antenna**- To make the transmitter circuitry compatible with antenna a differential amplifier is used which makes the connection between transmitter and antenna easier and to check the designed transmitter's compatibility with UWB antenna, an UWB antenna is also modified and added with transmitter and examined.

- **Transmitter's performance improvement**- Pulse duration is reduced vigilantly which improves the data transmission rate. Moreover, energy consumption per bit is reduced and the layout size is also reduced significantly. A simple architecture with basic logic circuit is designed which gives better output than other complex architecture.

From the presented results, it can be concluded that this structure provides wide range of benefits to the UWB transmitter performance. Here, the simulation results have proven as an effective means to investigate the transmitter behaviour. So, this transmitter can be considered as an ideal model by way of it covers all the requirements for low-power medical applications. Moreover, it can be expected that, in future this proposed model can be successfully applied in fabrication scenarios of advanced VLSI design.

8.3 Recommendations for Future Work

UWB transmitter provides a significant amount of scope for further investigation because it is ideal for low power electronic devices and the provided devices are ideal for applying in various fields like medical, consumer electronics and military communication. In fact, there is still a huge scope of work to be done to improve the device features. To enhance performance, the UWB transmitter's architecture can be altered in several different ways. Few of them are specified as follows:

(a) An integrated Si-Substrate antenna utilizing ADS software can be designed so that the output of the constructed transmitter can be integrated in a same chip in the future as an extension of that research, and the output signal of that antenna will be examined.

(b) The system's current architecture is based on OOK modulation. However, the OOK modulation technique may have trouble telling the difference between a received pulse and a burst of noise in a more complex application context. Therefore, alternative modulation technique can be used to transmit the pulses as well.

(c) A higher-order differentiator circuit may also be used. It is possible to create additional Gaussian pulse derivatives; however, this work needs to be done in the future.

LIST OF PUBLICATIONS

[1] **S. Akter,** P. K. Saha, and M. T. Amin, “Design of CMOS IR-UWB Transmitter with UWB Antenna,” 2022 Second International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT) 2022, vol. 1, pp. 4–9. doi: 10.1109/ICAECT54875.2022.9808031.

[2] **S. Akter,** P. K. Saha, and M. T. Amin, “Design and Analysis of Miniature Type Impulse Based UWB Transmitter in 90 nm CMOS for Medical Application,” *2021 5th Int. Conf. Electr. Eng. Inf. Commun. Technol. ICEEICT 2021*, pp. 1–6, 2021, doi: 10.1109/ICEEICT53905.2021.9667814.

[3] **S. Akter,** P. K. Saha, and M. T. Amin, “Design and Analysis of Impulse Radio (IR) Based UWB Transmitter with Antenna," (Accepted in MIST International Journal of Science and Technology).

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