Design of Pulse Generator in 180nm Technology for GPR Applications

A Thesis submitted in partial fulfillment of the Requirements for the degree of

Master of Technology
In
Electronics and Communication Engineering
Specialization: VLSI Design & Embedded System

By

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May 2014

Dedicated to…

My Parents, Brother and

My Dear Friends

DEPT. OF ELECTRONICS AND COMMUNICATION ENGINEERING
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Certificate

This is to certify that the work in the thesis entitled **Design of Pulse Generator in 180nm Technology for GPR Applications** by **Jitendra Kumar Mahanty** is a record of an original research work carried out by him during the year 2013 - 2014 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (VLSI Design & Embedded System), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge and belief, has been submitted for any degree or diploma elsewhere.

Place: ` **Prof. S. Maiti**
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ABSTRACT

In this work, we present a low-complexity and low cost pulse generator in 180nm technology for ground penetrating ultra-wideband (UWB) radar system applications. Here I have implemented an UWB pulse generator circuit. A UWB pulse generator is a method introduced in communication system to simplify the data transmission and remove disadvantages that occurs in other systems. This generator generates a Gaussian pulse for a small period of time of the order of some nanoseconds. As UWB pulses are generated for a short time, hence no carrier signal is required to send a base band or message signal. So power loss due to carrier signal doesn't exist at all. These pulses are very high in frequency; hence it has very less chance to be got affected by noise.

This pulse generator uses a delay generator along with a Gilbert XOR cell for generating a Gaussian pulse which can be shaped by using a FIR filter, and finally a Gaussian mono cycle pulse is observed at the output which has a pulse width of 97ps thereby give rise to a bandwidth of 10.3 GHz which meet the FCC requirements.

The pulse generator comprises of three cascaded delay blocks, a XOR block, and a FIR filter. The interpolation delay blocks uses voltage for adjusting the delay time by the control of the gains of each path. By adjusting the delay time, pulse generator can achieve the required frequency. The XOR gate is implemented using a Gilbert cell. When the two signals given as input have opposite voltage levels at a given time, the XOR gate creates a pulse. After the XOR gate, a Gaussian pulse is generated and then it goes through the FIR filter to shape it to a Gaussian mono cycle pulse. The design and simulation of the pulse generator was performed using the Cadence UMC tool in 180nm CMOS process.

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1

INTRODUCTION

Recently, UWB technology is better option to replace the narrowband wireless technologies. UWB transmitters operate with lower power ultra short pulses. UWB defines transmission systems having spectral bandwidth over 500 MHz or having a fractional bandwidth of more than 20% to 25%. This huge bandwidth provides a better opportunity for number of lower power applications in UWB communication systems, wireless networking and also in imaging of radar. These types of system depend on ultra-short pulses and can be free of carriers. One of the technologies of UWB is the Pulse Generator. Pulse Generator, modulating data in the time domain and improves data throughput with lowest power consumption. A sinusoidal carrier signal is not required in a pulse generator to move the generated signal to a frequency higher than the frequency of carrier signal, but it can communicate with the message signal composed of ultra short pulses.

A series of pulses is used in UWB system by the method of PAM or PPM. It transmits ultra-short pulses to make the frequency spectrum of the generated signal to several GHz wider which leads to lower multipath fading because of the short duration pulse with a wide fractional bandwidth. UWB system provides an excellent immunity to interference from other narrowband systems even in propagation environments. Implementing Pulse generator UWB transceivers with mostly digital circuits using no intermediate frequency (IF) processing makes it easier and cheaper compared with the typical spread spectrum transceivers – as used in Bluetooth and Wi-Fi.

1.1 Motivation

In UWB systems, a pulse generator is one of the key components which enable the UWB communications. The PSD of the Gaussian pulses generated by the simple Pulse Generator is not meeting the requirements of FCC.

For UWB communication systems, the FCC allocated power level is in the band between 3.1 to 10.6 GHz which is very small, i.e. about -41.3 dBm. For meeting FCC regulations, we can pass the Gaussian pulse generated by the pulse generator through a FIR filter which shapes the Gaussian pulse to a Gaussian mono cycle pulse. Thus, we will focus on designing a pulse generator which fits the power spectrum density (PSD) of the FCC regulations in this paper.

1.2 Literature Review

• David J Daniels, in 1988, published a tutorial paper by giving a good technological analysis of the GPR technology. He himself published his book on “Surface Penetrating Radar” on the year 1996 which presents all the key elements of this technique for the non-specialist users and engineers.

• Bart Scheers of Royal Military Academy from the Department of Electrical Engineering and Telecommunication, Brussels, in March 2001 published a thesis on comparision of different types of GPR systems and found GPR as one of the challenging technologies for detection of buried objects of various types. He showed that the range resolution is directly related to the bandwidth of the system which led to development of UWB GPR.

• Shin-Chih Chang of University of Texas at Arlington in December 2005 published a thesis on UWB Pulse Generator producing higher derivative Gaussian Pulse for GPR applications. He claimed that the higher the derivative of the Gaussian pulse, higher is the chance to meet the FCC requirements of bandwidth between 3.1 to 10.6 GHz.

• Kevin M. Marsden of Virginia Polytechnic Institute and State University in December 2003 published a thesis which describes the Low Power CMOS Pulse Generator as a better option for Ultra Wideband Radios. In his thesis he designed a rectified cosine generator by modifying the pulse generator for lower power consumption.

• Prabhat Kumar Barik of National Institute of Technology, Rourkela in June 2011 published a thesis entitled “FIR Filter IC Design Using Redundant Binary Number Systems”. In his thesis he designed a FIR filter using RNS algorithm, which comprising of different blocks like SBD adder, PPM adder, MMP adder, D-FF etc.

1.3 Overview of Thesis

The UWB transmitter generates and transmits very short duration pulses as signals without a carrier. The proposed pulse generator consists of a pulse generator along with an FIR filter. Implementing the FIR filter on the Gaussian pulse from the pulse generator can form the Gaussian mono cycle pulse which meets the requirement of the PSD for UWB systems by maximizing bandwidth. In chapter 2, we briefly discuss about the Ground Penetrating radar (GPR). The principle and applications of the UWB communication system is discussed in chapter 3. The structure and function of the pulse generator is introduced in chapter 4. In chapter 5, we focus on the pulse shaper FIR filter. The simulation result of the proposed pulse generator is discussed in chapter 6. Finally, in chapter 7, the conclusion and future work are introduced.

2

GROUND PENETRATING RADAR

This chapter gives an overview of Ground Penetrating Radar (GPR). In this chapter we focus on the GPR history, applications, principle, and classification. In Section 2.5 we discuss about the different types of GPR and did a comparative study on both time-domain and freq-domain GPR. Finally, we ended up with a result that the time-domain GPR is better than a freq-domain GPR as it doesn’t require a carrier to transmit a message signal. Hence in the next Section 2.6 we describe the main components of a time-domain GPR; like transmitter, receiver and timing circuit. In this thesis, we implemented a Pulse Generator circuit for generating a Gaussian pulse and pass it through a FIR filter for shaping the pulse to a mono cycle pulse which is the key component of the transmitter block of a time-domain GPR.

2.1 Introduction

Ground Penetrating Radar belongs to the family of radar systems that image the subsurface.GPR is also called as Surface Penetrating Radar (SPR). Nowadays, GPR is a fast growing technology and the number of its applications is still growing. Locating pipes and cables, civil engineering (bridge inspection, finding voids), security, archeology investigation, geophysical surveys are few examples of its application. The operating principle of the GPR is based on Maxwell’s equation of EM wave propagation in the inhomogeneous sub surface medium. It sends EM waves into the ground and samples the backscattered signals which are based on the electrical parameters. The special property of GPR is that it can detect signals due to all three types of electrical parameters, i.e. electric resistivity, magnetic permeability and conductivity. Hence a GPR system has the potential for locating and identifying both metallic and non-metallic buried targets based on the signal characteristics.

2.2 History

English scientist J. C. Maxwell proposed EM theory of light in the year 1865. In 1886, H. R. Hertz proved Maxwell theory to be right, who discovered EM waves.

In 1904, Hulsmeyer first used the EM signal to determine the presence of metal objects by measuring the travelling time of EM waves to a metal object like a ship. This is the first practical radar testing and he also registers his invention in Germany and United Kingdom patents. But six years later descriptions of their use for locating buried objects come into sight in one German patent presented by Leimbic and Lowy. The technique consists of dipole antennas in an array of vertical boreholes and comparing the amplitude of the received signals when one pair of antenna is used to transmit and receive at the same time. In this way, an image could be generated on any region within the array which with its higher conductivity than the surrounding medium absorbs the radiation.

In 1917, the super heterodyne receiver was invented by the French Engineer Lucien Levy and he uses the abbreviation of "Intermediate Frequency". In 1921, the US American physicist Albert Wallace Hull invented the magnetron as an efficient transmitting tube. In 1922, the electrical engineers A. H. Taylor and L. C. Young of the Naval Research Lab, USA located a wooden ship for the first time. In 1926, Hulsenbeck used pulsed techniques for determining the structure of buried targets. He noted that any dielectric variation would also produce reflections and the pulsed technique uses an easier realization of directional sources, which had advantages over seismic methods. In 1929, Stern does the first ever GPR survey for determining the depth of Glacier. For the first time in the year 1930, an aircraft is located by L. A. Hyland of Naval Research Laboratory in USA. Also in the same year Cook, Roe and Eller Bruch investigated the probing of rock and coal.

In 1931, radar is mounted on a ship with some antennas which are used with some parabolic dishes with horn radiators. In 1936, two electrical technicians named G. F. Metcalf and W. C. Hahn developed klystron and uses it as an oscillator tube in radar for amplification.

From 1930 onwards, Pulsed techniques were developed for determining the depths of ice, fresh water, salt deposited in water, sands of desert and rock formations. Probing of rock as well as coal was also investigated by Cook, Roe and Eller Bruch. In 1940, different equipments of radar are developed in USA, France, Russia, Japan and Germany.

A researcher, Gerald Ross from Sperry Rand Corporation, in late1960's introduced UWB technologies and his first patent for UWB technologies was granted in the year 1973 and this UWB technology was used in a GPR system in 1974, and became a KEY success for Geophysical Survey Systems, Inc. (GSSI). In US, the Department of Defense starts using the UWB technology to image through walls and into the ground. A more extended history of GPR and its growth up to the mid-1970s is given by Nilsson.

In 1980, the 1st geotechnical applications are done in Denmark and Sweden and reports showed that GPR was a very promising tool especially in surveys in peat areas. In 1988, a tutorial paper with the title "Introduction to Subsurface Radar" was published by Daniels which gives a good overview of the GPR technology. In the year 1996, a book entitled Surface Penetrating Radar was published by D.J. Daniels. From now then the range of applications is increasing very much day-to-day.

In the year 1998, FCC realized that the UWB technology has got the potential to investigate the possibility of allow it for the commercial use. When FCC allocates a defined spectrum for UWB system, the research and development on this field has taken the pace on February 14, 2002. UWB has several advantages such as higher data rate, low power radiation, best immunity to multipath, and simplicity in hardware compared to NB systems. Many of these advantages are directly related to the huge bandwidth of a UWB device.

2.3 Applications

GPR has been used in the following applications:

- Archaeological investigations
- Borehole inspection
- Analysis of Bridge deck
- Assessment in Building conditioning
- Investigation of Contaminated lands
- Anti-tank mines detection
- Investigation of reinforced concrete
- Investigation on Forensic data
- Investigation of Geophysical data
- Detection of cables and pipes
- Medical imaging
- Planetary investigation
- Tunnel linings
- Thickness (soil) determination, etc.

2.4 Principle

Now-a-days, GPR is one of the most capable technologies for close detection and identification of buried Anti-Personnel (AP) Landmines, due to its ability of detecting non-metallic objects in the sub-surface medium. The operating principle of Ground Penetrating Radar is that it sends the EM signals into the ground and receives the backscattered signals. The EM signal will be back scattered when any one of the electrical parameters change in the ground. The property of the GPR is that it can detect signals from all three types of electrical parameters like conductivity, resistivity and susceptibility.

This property of the GPR system has the potential for locating and identifying both metallic and non-metallic buried targets on the echo characteristics. Fig.1.1 shows a block diagram of a basic GPR system. In GPR the antennas are normally scanned over the surface in close to the ground. An EM wave sent into the ground will backscatter on any electrical parameter discontinuity. The backscattered echoes that reach the receiving antenna are sampled and processed by a receiver. Figure 1.2 shows a typical time representation of a signal, received by the GPR at a given fixed position.

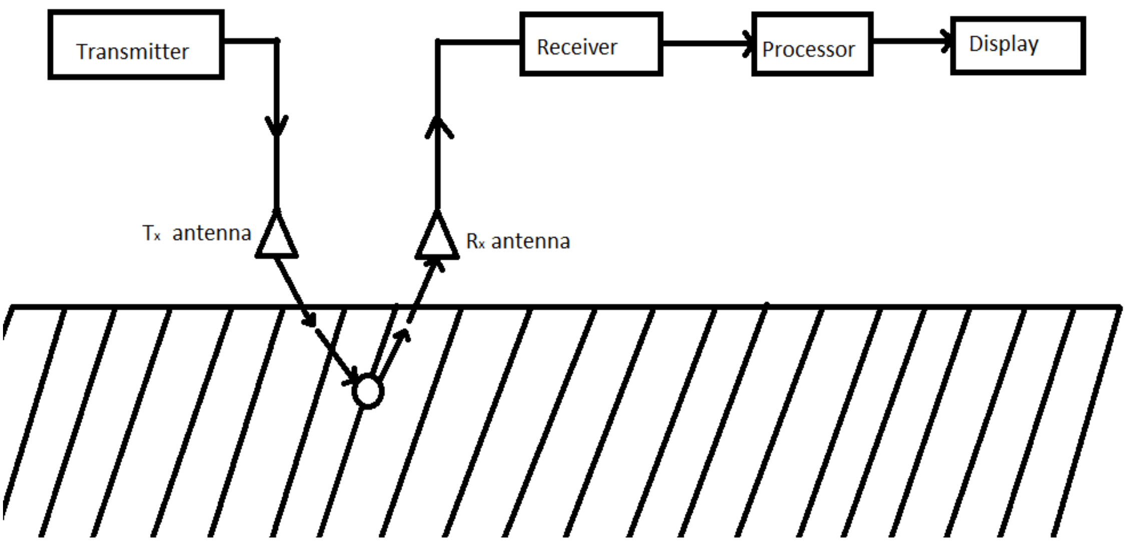

Figure 2.1: GPR block diagram.

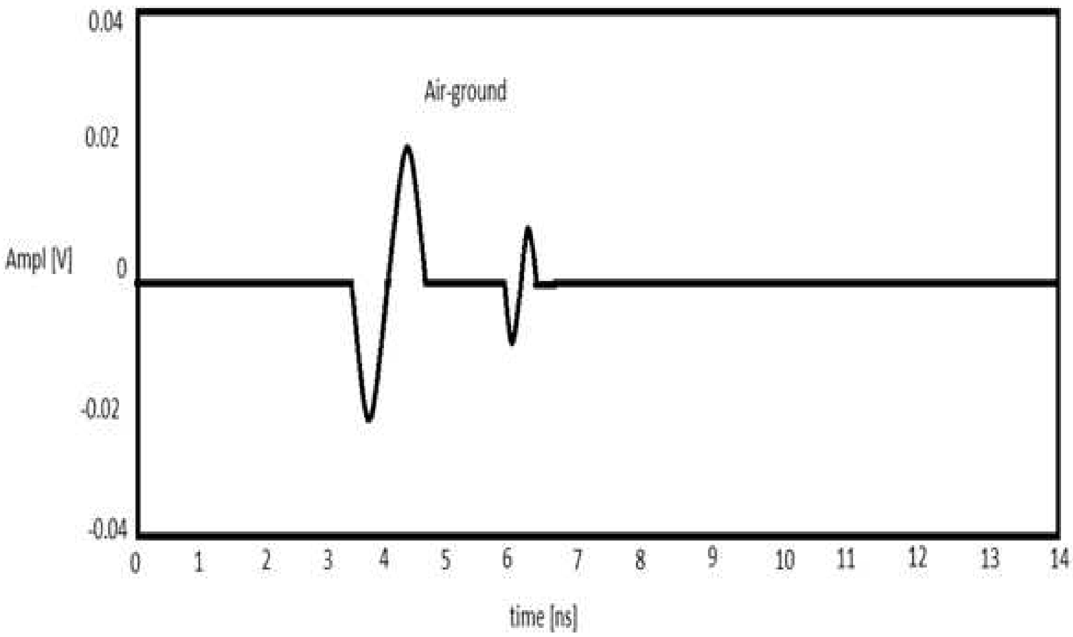

Figure 2.2: Typical signal received by GPR

Normally the first and the largest echo are due to the air-ground interface and other echoes, appearing later in time are reflections on target or clutter present in the subsurface. The GPR can produce two or three-dimensional images by moving the antennas on a line or a two dimensional grid. The main difference between the GPR and metal detector is, the GPR has the potential to detecting non-metallic targets also in the application of AP land mine detection.

2.5 Classification

Ground Penetrating Radar can be classified as below:

• Time Domain GPR

1. amplitude modulated GPR
2. carrier free GPR

• Frequency Domain GPR

1. Linear Sweep GPR
2. Stepped Frequency GPR

The working principle of time domain GPR is that, a Gaussian pulse is sent through the transmitter at a given PRF into the ground and the backscattered signals is received by the receiver. A pulse is sent by the amplitude modulated GPR with a carrier frequency which can be modulated by a square envelope. If the duration of the pulse is very short of the order of some picoseconds, then the depth of resolution is good. So a mono cycle pulse is used and central frequency of the mono cycle is equal to its 3dB BW. The needs for huge bandwidth led to the development of carrier free GPR. In carrier free GPR a pulse is sent without a carrier and the pulse width of the carrier signal is of the order of some picoseconds. In this GPR we can use any type of pulse but generally a standard Gaussian pulse is used. The carrier free GPR is also known as Ultra Wide Band GPR.

The principle of freq-domain GPR is that the freq. of the continuous signal is either modulated with the help of a linear sweep or changes in fixed steps. In the linear sweep or FMCW GPR system, the system continuously transmits a carrier frequency which is changing by means of a Voltage Controlled Oscillator over a wide frequency range. The frequency sweep is carried out due to a saw-tooth or a triangular signal within a certain dwell time. The receiver receives the backscattered signal when the carrier signal emitted by the transmitter strikes a buried object. The depth of the target determines the frequency difference between the transmitted and received signal. The poor dynamic range of FMCW radar is a major disadvantage for this type of systems. The FMCW radar simultaneously receives the signals and transmits the signals. A frequency synthesizer is used in stepped frequency GPR to step through a range of frequencies equally spaced by a given time interval. Here a carrier signal is radiated and mixed with the received signal at each frequency with a higher stability by using a quadrature mixer. In this thesis, we focus on the design of Pulse Generator block of the time-domain GPR.

2.6. Description of a Time-Domain GPR

In this section, we briefly describes the various blocks of a Time-Domain GPR; like,

- ✓ Transmitter
- ✓ Receiver
- ✓ Timing Circuit

2.6.1 Transmitter

The transmitter consists of a pulse generator which produces short Gaussian pulses with certain periodicity which is known as PRF. In this GPR the pulse generated is typically a mono cycle or a standard Gaussian pulse, but Gaussian doublet can also be used. Due to the fast discharge of energy stored in the capacitor, the pulse generation takes place.

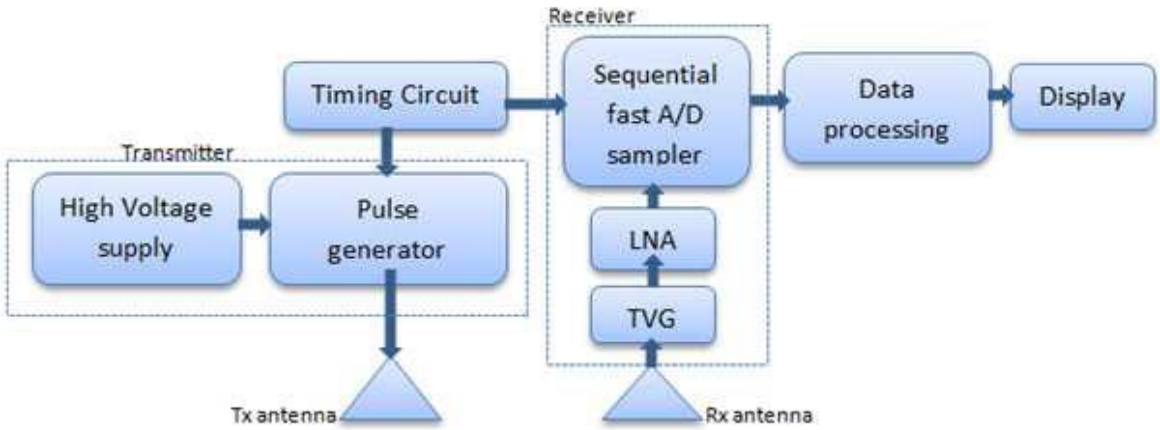

Figure 2.3: Block diagram of a time domain GPR.

2.6.2 Receiver

To design the receiver circuit in the hardware is the biggest challenge. The performance of the receiver circuit can change the over-all performance of the system. The receiver should possess a large fractional bandwidth with a large dynamic range and a better noise performance with high sensitivity.

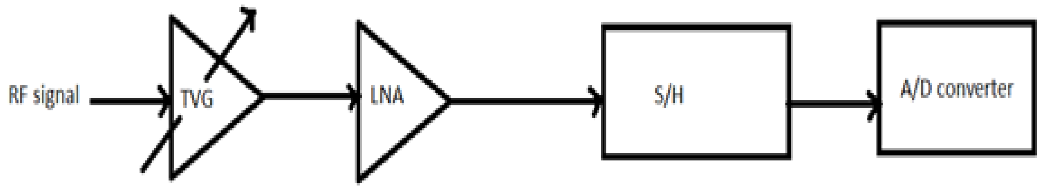

Figure 1.4: Block diagram of receiver.

2.6.2.1 A/D converter

The signal received by the GPR systems is in the frequency range of 3.1 to 10.6 GHz. Hence the use of a standard ADC is impossible to sample the received signals in real time, which should satisfy the Shannon's theorem. The sequential sampling technique should be used to avoid this complexity.

2.6.2.2 Sample and hold circuit

The input to the ADC has to be very stable for a specific time for a correct A/D conversion. This circuit changes the signal variation to maximum extent which must be smaller than the quantization step of the ADC during the conversion time. To provide a constant value to the ADC we must use this circuit. When the capacitor C_s is charged to a voltage which is directly proportional to the input signal, the sample and hold circuit works. Hence the samples correspond to a specific portion of the input signal.

2.6.2.3 The low noise amplifier (LNA)

The signal conditioning is carried out by using a LNA before the RF signal enters through the S/H circuit for the maximum use of the dynamic range of the ADC. Here the Low Noise Amplifier with a very less noise figure is the part of the signal conditioning element. The LNA is not put as first element, but it can be used after the TVG.

2.6.2.4 Time varying gain (TVG)

In GPR systems, the signals transmitted by the antenna and the backscattered signals from the object are both subjected to spreading loss. In lossy medium, the objects are buried. The higher the object is buried into the ground, the higher is the losses that will be introduced by the ground. The TVG is an attenuator whose attenuation changes when we change the time, but sometimes we wrongly consider it as an amplifier. The PIN diodes are used in TVG as the time varying attenuator which is having a variable resistance dependent to voltage and they also have lower junction capacitance.

2.6.3 Timing Circuit

The receiver used in a time domain GPR is based on a non-coherent reception of the backscattered signals from the object. A timing circuit is used to control the reception of the signals which synchronizes the work between the various parts of the GPR system. The timing circuit is used for three operations. First, it has to trigger the pulse generator. Secondly, it has to generate the timing signals which are needed for the sequential sampler, i.e. a trigger for the ADC at the intersection of the slower as well as faster ramps. Lastly, it has to control the timing for the TVG.

2.7 Conclusion

GPR is one of the most challenging technologies for detection of buried objects of various types. The range resolution of a GPR is directly related to the BW of the system. The need for higher BW is the reason for the development of UWB GPR. Generating and receiving UWB pulse is one of the most challenging areas to be addressed by GPR research community to realize cost effective reliable UWB GPR system.

3

UWB COMMUNICATION SYSTEMS

Ultra-wideband (UWB) is a challenging technology having caliber to make a revolution in wireless communications. It operates using lower power ultra-short pulses. In this section, we will introduce the UWB system including its definition, advantages, applications and the FCC regulation.

3.1 Definition of UWB

The most frequently use of the term "Ultra-wide bandwidth (UWB)" comes from the UWB radar family and refers to electromagnetic waveforms. According to the FCC definition, Ultra-Wideband transmission systems must have either an absolute bandwidth equal to or greater than 500 MHz or the fractional bandwidth equal to or greater than 20%. The fractional bandwidth is defined as B / f_C , where $B = f_H - f_L$ denotes –10dB bandwidth and center frequency $f_C = (f_H + f_L) / 2$.

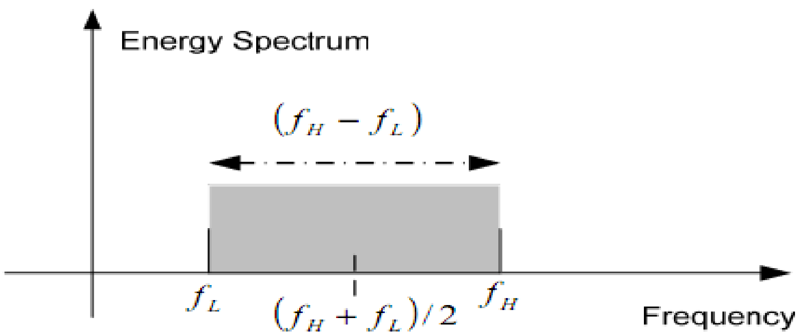

Figure 3.1 Frequency Spectrum Analysis on Bandwidth and Center frequency

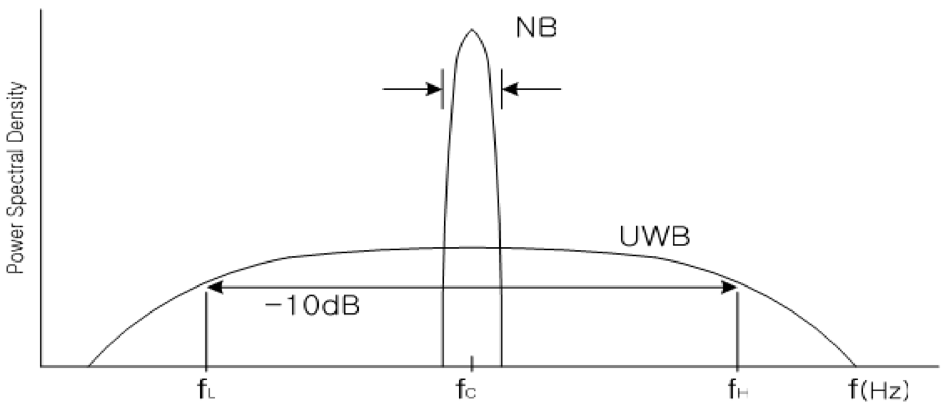

Figure 3.2 Comparision on Bandwidth between UWB and NB systems

3.2 FCC Regulation

In 1998, FCC starts the process of UWB technology regulatory analysis. In February 2002, FCC announces the rules which permit UWB for operating under certain indoor and outdoor PSD specifications. In this thesis, the indoor power spectral mask will be discussed. The Figure below shows the operating and FCC acceptable frequency range of some high frequency services. Most high frequency cases are regulated by FCC Part 15. Of course, UWB systems including wireless communications are defined in this. According to the Figure, UWB wireless communication systems must operate at above 3.1 GHz and with less than -40dBm of EIRP, which stands for Equivalent Isotropically Radiated Power, which means the signal power supplied to the UWB antenna.

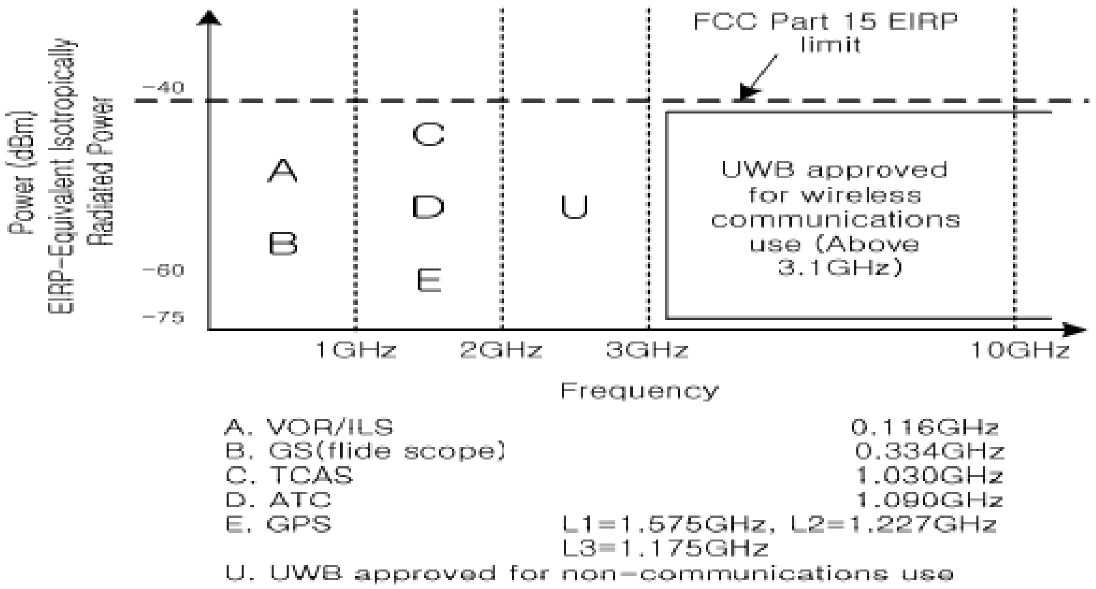

Figure 3.3 FCC Part 15 for high frequency devices

As shown in Figure 3.4, for indoor applications, the emission power of UWB devices should be less than -41.3 dBm between 0 to 0.96 GHz, less than -75.1 dBm between 0.96 to 1.61 GHz, less than -53 dBm between 1.61 to 1.99 GHz, less than -51.3 dBm between 1.99 to 3.1 GHz, less than -41.3 dBm between 3.1 to 10.6 GHz, and less than -51.3 dBm from 10.6 GHz above. Same type of analysis can be carried out for outdoor applications presented in Figure 3.5.

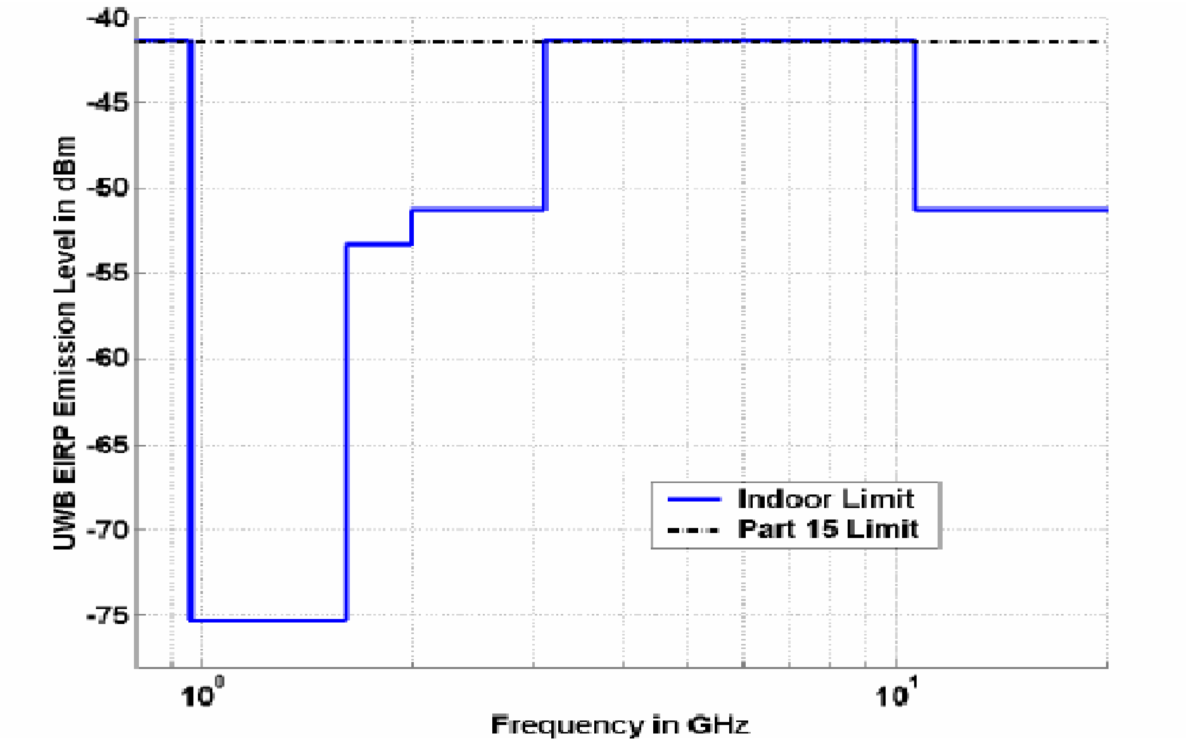

Figure 3.4 FCC spectral Mask for UWB systems for indoor applications

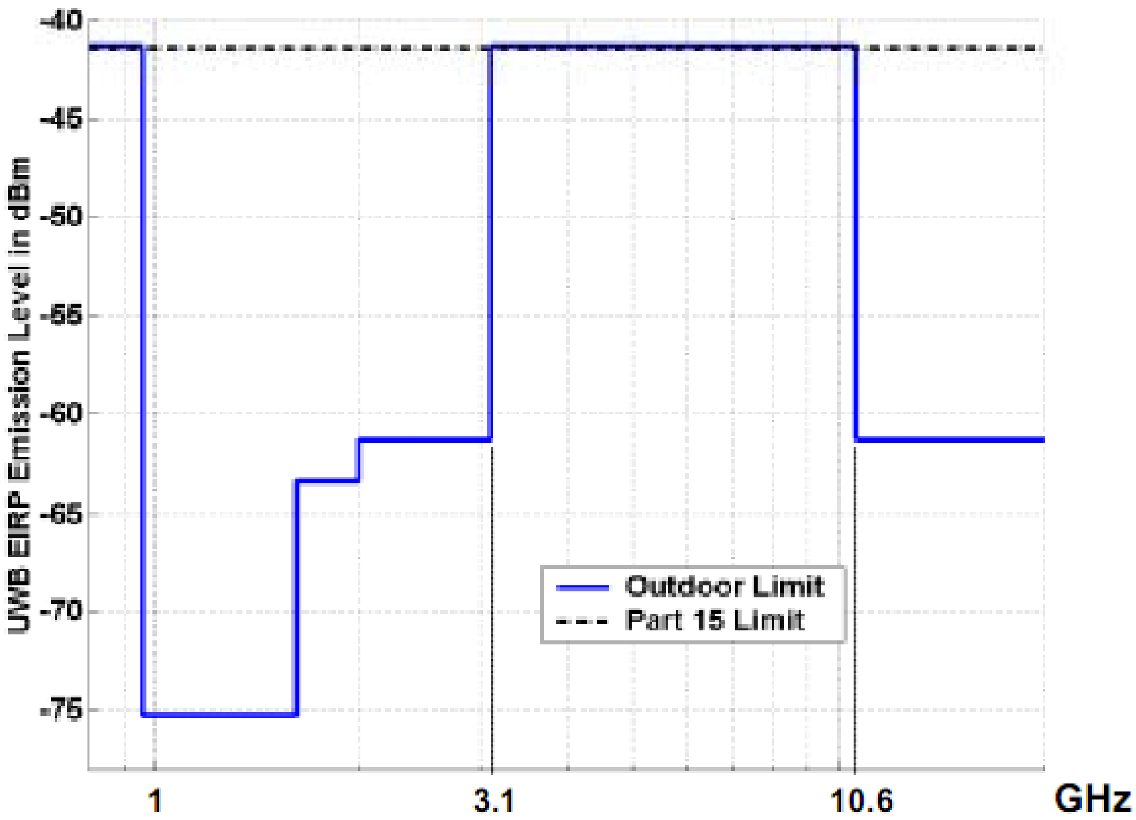

Figure 3.5 FCC spectral Mask for UWB systems for outdoor applications

3.3 Advantages

Since UWB technology is based on the transmission of pulses with a small amount of power, UWB communication system have certain advantages over narrow band communication systems. According to Shannon's communication theory,

$C_C = B \log_2 (1+SNR)$

Cc: channel capacity

B: bandwidth

SNR: ratio between the signal power to the noise power.

Since Ultra wideband has wide bandwidth, it is suitable for higher data rate communication which is defined by IEEE 802.15.3a standards and can get a speed limited to 480Mbps. This data rate is far beyond the existing speed of 1 Mbps of Bluetooth, 11 Mbps of 802.11b, and 54 Mbps of 802.11a/g. In multipath environment, the huge transmission BW allow us for fine time resolution for multipath arrivals, which got the potential to reduce the fading compared with the narrow bandwidth. Since the transmitter and receiver work in high resolution time domain, each multi path signal can be detected as an individual signal, i.e. without fading. UWB technology can be applied for locating wireless networks because of its high range of resolution. In addition, very lower power and higher processing gain will enable overlay and ensure minimum mutual interference between UWB and other applications. Another advantage of UWB is low cost. Since impulse radio does not require a carrier, and it only has a message signal for processing, hence no intermediate frequency processing is needed for the IR UWB systems. That is, resulting in simpler circuitry. As UWB devices do not require Local Oscillators and up- or down- converters, hence they are cheap.

3.4 Applications

Based on the above advantages, the potential of UWB systems is vast. The four major applications of UWB are:

- ☑ Wireless personal area networks
- ☑ Sensor networks
- ☑ Vehicular radars
- ☑ Imaging systems

3.5 Conclusion

Hence an UWB communication system is preferably used to simplify the data transmission and remove disadvantages that occur in other narrowband systems. As UWB pulses are generated for a shorter duration, hence no carrier signal is required to send a base band or message signal. The pulses generated by UWB systems are very high in frequency; hence it has very less chance to be got affected by noise.

4

PULSE GENERATOR

An UWB pulse generator is a method introduced in communication system to simplify the data transmission and remove disadvantages that occurs in other systems. This generator generates a Gaussian pulse for a small period of time of the order of some nanoseconds. As UWB pulses are generated for a short time, hence no carrier signal is required to send a base band or message signal. So power loss due to carrier signal doesn't exist at all. These pulses are very high in frequency; hence it has very less chance to be got affected by noise. Initially we discuss about the different types of pulses and pulse modulations in this chapter. After that in section 4.3 we discuss the principle of pulse generation and next to it the comparision between MCML and CMOS logic is carried out; and we conclude that on designing a delay generator block MCML is a better choice. In section 4.5 the operation of Gilbert XOR cell is discussed because it is used to generate a Gaussian pulse.

4.1 Gaussian Pulse Types

The most popular UWB system is IR-UWB system because it does not require a sinusoidal carrier signal to shift the signal frequency to a higher level. A standard Gaussian pulse is one of the signals generated in UWB IR systems given by:

$$y(t) = \frac{A}{\sqrt{2\pi\sigma^2}} \exp(-\frac{t^2}{2\sigma^2})$$

If the transmitter produces a Gaussian pulse, the output of the transmitter antenna will be the first derivative Gaussian pulse, given by:

$$y(t) = -\frac{At}{\sqrt{2\pi}\,\sigma^3} \exp(-\frac{t^2}{2\sigma^2})$$

If the transmitter produces a first derivative Gaussian pulse, the output from the antenna will be a Gaussian doublet pulse, given by

$$y(t) = -\frac{At}{\sqrt{2\pi}\,\sigma^3} (1-\frac{t^2}{\sigma^2})\exp(-\frac{t^2}{2\sigma^2})$$

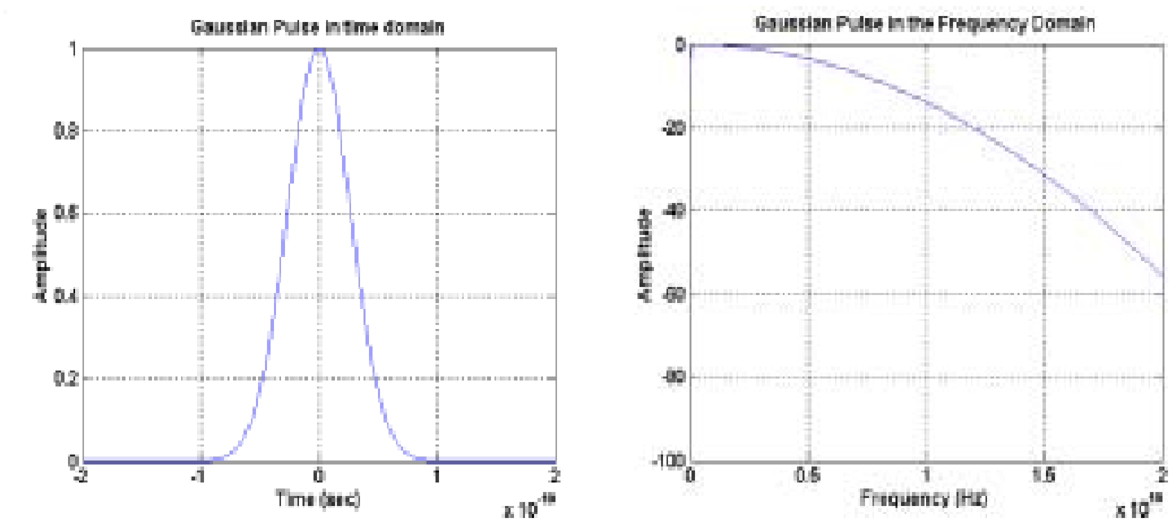

Figure 4.1 Standard Gaussian Pulse type and its PSD

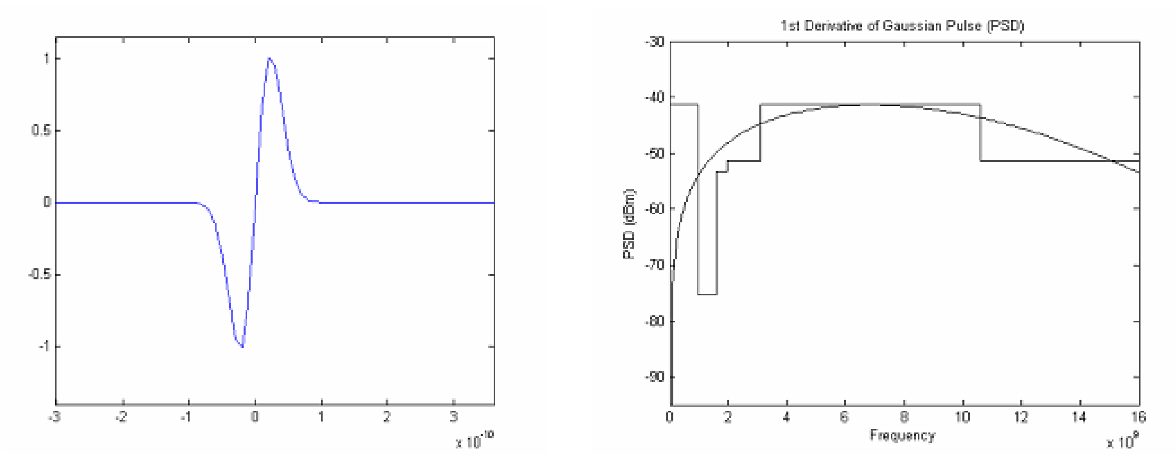

Figure 4.2 Gaussian Mono cycle Pulse type and its PSD

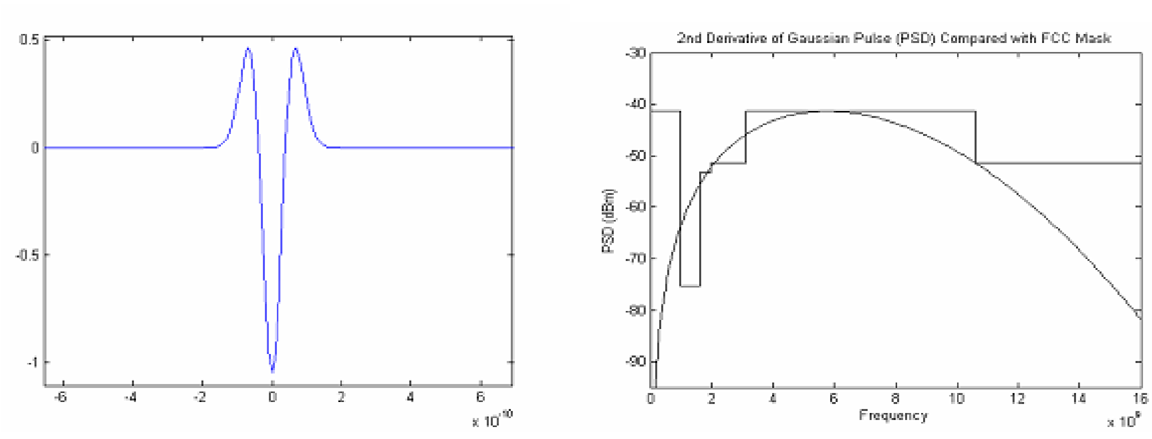

Figure 4.3 Gaussian Doublet Pulse type and its PSD

4.2 Pulse Modulation

In UWB system there is variety of modulation types used. In some modulations, the information bits are directly modulated to very short pulses. Since there is no IF, the base band processing of the signal is done. Well-known modulations types include TH-PPM, TH-PAM, and DS- PAM. On the other hand, some UWB systems use carriers.

4.2.1 IR Vs OFDM

Table 4-1 Comparision between OFDM and IR

Parameters	OFDM	IR
Band	Multi	Single
Bandwidth	Sub bands of approx. 500 MHz each.	Uses all available bandwidth
Speed	480Mbps	1Gbps
Carrier Based	Yes	No
Power Consumption	More	Less
Complexity	More	Less
Up-Down Converter	Yes	No
DAC	Yes	No
PAR	High	Low

4.3 Pulse Generation

In the UWB communication systems, the pulse transmitting block has to generate short duration pulses before modulating the message signal. For this kind of function, this block can be composed of a digital pulse generator and a pulse shaping circuitry. In this thesis, the digital transmitter consists of a delay generator and a XOR cell, and the impulse shaping circuitry uses a band pass FIR filter. The final output shape must be a Gaussian Monocycle pulse.

To design the pulse generator, delay circuits and XOR circuits have been used. Firstly a reference clock signal is sent into the delay circuit, and the delayed signal at the output is applied to the XOR gate with the reference input clock signal. In the delay circuit, the delay time is controlled by the voltage. Using the control voltage to adjust the delay time in the delay circuit; the pulse generator can change the pulse width (1/f) to achieve a required frequency. The Gilbert XOR Cell is used as an XOR gate to create short transient pulses. When the two different input signals have opposite voltage levels at the same time into the XOR, short pulses will be generated out from XOR gate. Those short pulses are Gaussian pulses, and then become the input signals to the pulse shaping FIR filter. The proposed FIR filter performs a convolution of the impulse response with a sequence of input sampled values and produces the output values with an equally numbered sequence.

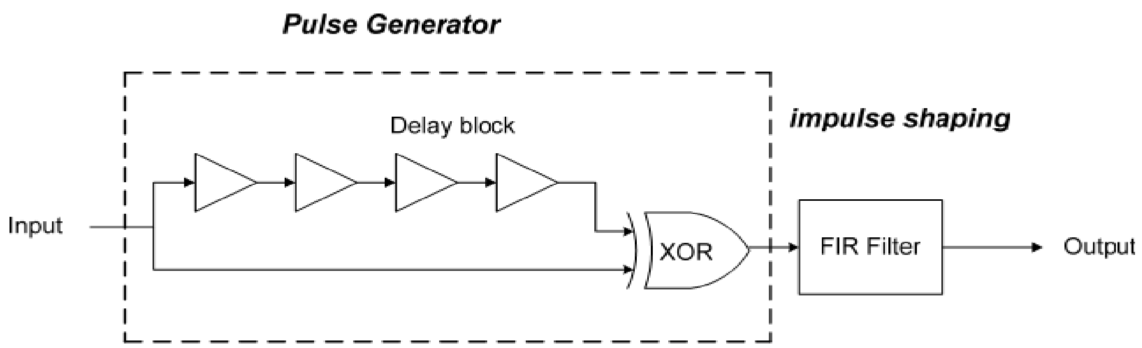

Figure 4.4 Pulse Generator Block Diagram

4.4 MOS Current Mode Logic (MCML)

MOS Current Mode Logic (MCML) is studied for low power, high speed and mixed signal environment. Since it has lower output swing than CMOS, MCML has lower power consumption and high speed. Since the MCML is a differential logic style, the PDN is fully differential. The basic CML structure contains three mail blocks: differential pull down network (PDN), pull up resistor, and a constant current source.

The total propagation delay is given by:

$$Delay = N * R * C = \frac{N * C * \Delta V}{I}$$

Therefore, the voltage swings ΔV along with the bias current I control the delay. These two parameters can be adjusted to obtain the necessary delay in my design. The static power consumption of the MCML circuit can be calculated as follows:

$$Power = N * I * Vdd$$

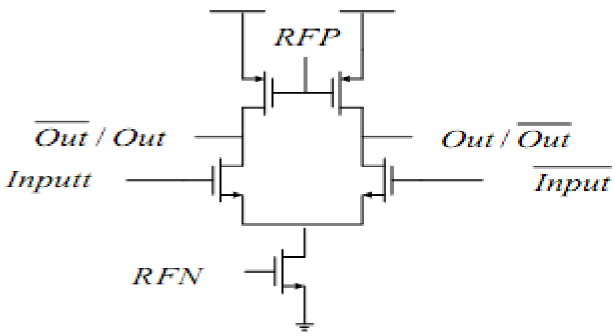

Figure 4.5 Basic MCML inverter/buffer circuit

Table 4-2 Comparision between CMOS and MCML

Parameter	CMOS	MCML
Power Supply Voltage	High	Low
Power Dissipation	Dynamic (High)	Static (Low)
Noise Margin	High	Low
Voltage Swing / SwitchingCurrent	High	Low
Threshold Voltage	High	Low
Speed	Low	High
Input Capacitance	High	Low
Rate of Charge and Discharge	Different	Same
Transistors	May be ON/OFF	Always ON
Transistor Size	Varying	Identical
Area	More	Less

4.5 Gilbert XOR Cell

This Gilbert cell is very famous circuitry in RF, and it is being used as a standardized structure. So in this thesis, the Gilbert cell has been applied for XOR directly. Also, on this Gilbert cell, all passive components have been replaced by all active components. When the two input signals have opposite voltage levels at the same time into the XOR, short pulses will be generated out from XOR gate. Each input voltage values can be decided by DC common mode simulation. In this thesis, in place of the pull-up resistors RFP is used where as RFN is used in place of current source.

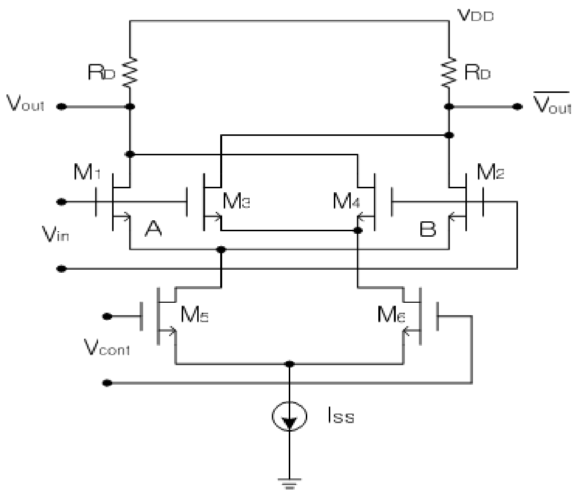

Figure 4.6 Basic Gilbert XOR cell

4.6 Conclusion

In the UWB communication systems, the pulse transmitting block has to generate short duration pulses before modulating the message signal. For this kind of function, this block can be composed of a digital pulse generator with an impulse shaping circuitry. In this chapter, we discuss about the digital transmitter block which consists of a delay generator and a Gilbert XOR cell which is responsible for generating Gaussian pulse can be generated. But to meet the FCC mask, we should shape it to a Gaussian mono cycle pulse with the help of a FIR filter which is discussed in the next chapter.

5

FIR FILTER

A filter is used to modify some characteristics of a signal when passed through it. The multiplication of two spectral sequences in frequency domain is the linear convolution of two sequences given in the time domain stated by Fourier transform. In this chapter, initially we discuss the basic principle of FIR filter along with its architecture.

5.1 Introduction

A FIR filter performs a weighted average of a finite number of samples of the given input sequence. The basic input output structure of the FIR filter is a time-domain computation based on a difference equation. Figure 5.1 shows a signal flow diagram of a standard 4-tap FIR filter. Since the FIR filter coefficients are similar to the values of impulse response, the general format of a standard FIR filter can also be represented as the equation given by:

$$y[n] = \sum_{k=0}^{M} \mathrm{h[k]x[n-k]}$$

The relation of the input and output of the designed FIR filter is expressed in terms of the input and the finite impulse response which is also known as finite convolutions sum. We can find the output by obtaining the convolution of the two given sequences x[n] and h[n]. The characteristics of the filter are controlled by the filter coefficient.

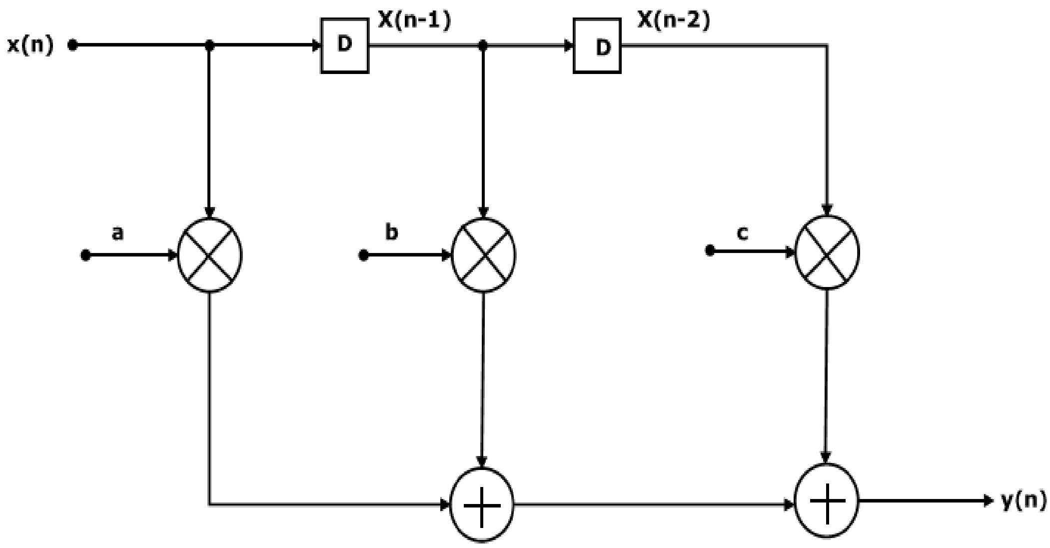

Fig. 5.1 FIR Filter

5.2 Architecture

The speed of the filter is defined as the rate at which input samples can be processed. To increase the speed it is necessary to reduce the critical path between the input and output. The critical path is defined as the path with the highest computation time among all available paths that contain no delays. Pipelining reduces the effective critical path by introducing pipelined latches along the data path. In this arrangement while the left adder initiates the computation of the current iteration, at the same time the right adder is completing the computation of the previous iteration result.

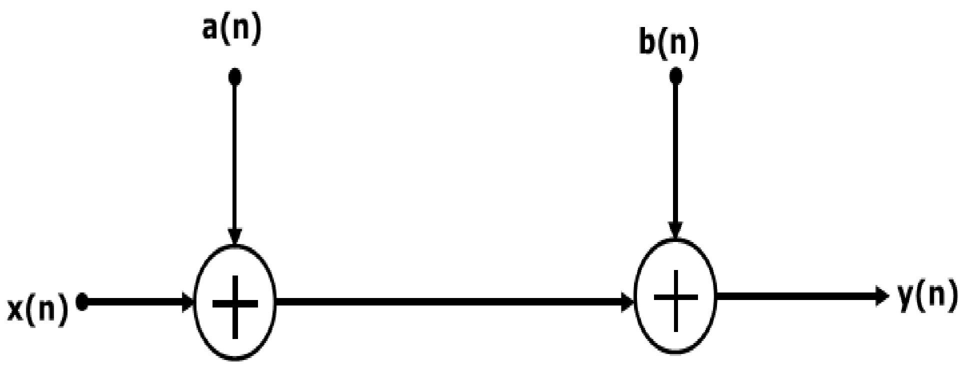

Fig. 5.2 Datapath

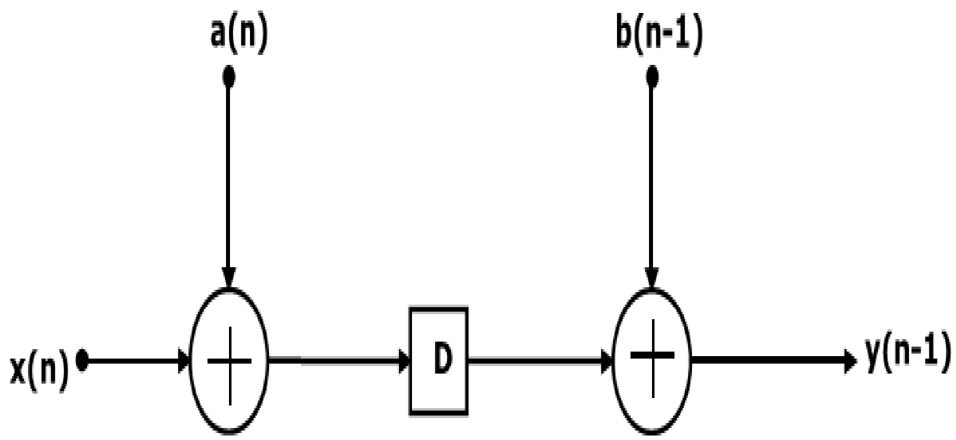

Fig. 5.3 Pipelining

Another FIR filter structure known as the transposed FIR filter does not require any pipelining to reduce the critical path.

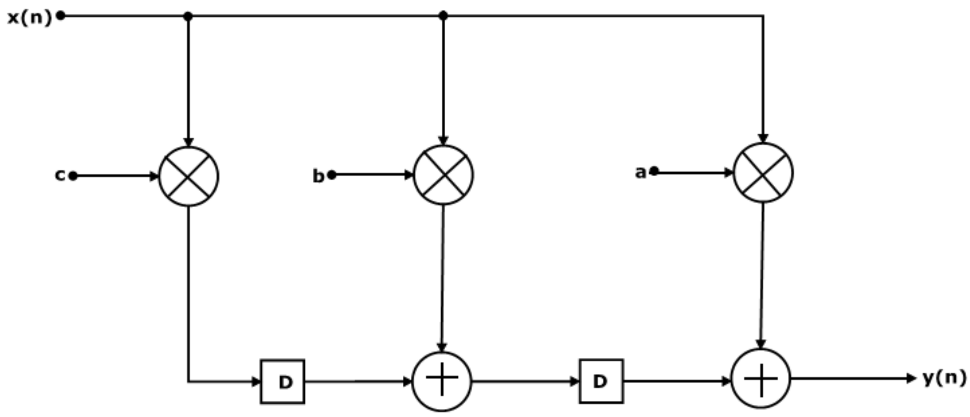

Fig. 5.4 Transposed FIR filter

In this thesis, we implemented a FIR filter by using RNS because the conventional number system is a fixed positive radix number system having different weight for each bit, where as a sign is used as a symbol followed by the number in r's complemented form (where r is the radix or base of the number system) in signed number. Addition of conventional number systems requires carry propagation (serial signal propagation) from LSD to MSD and the addition time depends on word-length, which is the main limitation of the conventional number systems.

But Redundant number systems (RNS) is used to allow addition of two different numbers in which no serial carry propagation is required because the time duration of the operation is independent of the word-length of the operands and the time required for the addition of two digits. This is the advantage of RNS over conventional number systems. For implementation of the FIR filter, the structural blocks are to be designed such as PPM adder, MMP subtractor, D- FF, SBD adder etc.

5.3 Signed Digit Number System

In conventional radix-*r* number system, a digit can take on values {0, 1, 2…, *r*-1} and the digit set is *S* = {-(*r*-1), -(*r*-2) …, -1, 0, 1…, (*r*-1)}. For example, the digit set {-1, 0, 1} is used for radix-*2* (*r =2*) number system. A signed-digit is represented by the digits z_i and has the algebraic value

$$Z = \sum z_i r^i \tag{5.2}$$

In this case, the number 3 can be represented as 0011 or 0101-1. Hence every number allows multiple representations in signed-digit format and these numbers are known as Redundant Number Systems. Signed-digit representation limits the carry propagation to one bit position to left during the operation of addition and subtraction in digital computers.

5.4 Redundant Number Systems (RNS)

The purpose of redundant number representations is to allow both addition and subtraction of two different numbers in which no serial carry propagation is required. The signed-digit representation must have an unique representation of zero algebraic value of a number. The redundant number is represented by *n*+*m*+1 digits z_i (where *i=-n… -1, 0, 1 …m)* has the integer value

$$Z = \sum_{i=-n}^{m} z_i r^i \tag{5.3}$$

5.5 PPM Adder (Carry-Free Radix-2 Addition)

RNS limits the carry propagation to a fewer bit positions, which is not dependent on the word length. Hence faster addition results due to the carry propagation-free feature. Using two unsigned binary numbers; positive and negative both, the radix-2 SBD number is coded as $X = X^+ - X^-$. Hence each signed bit is represented using two bits as $x_i = x_i^+ - x_i^-$ where x_i^+ and x_i^- is either 0 or 1; x_i belongs to 1^-, 0 or 1.

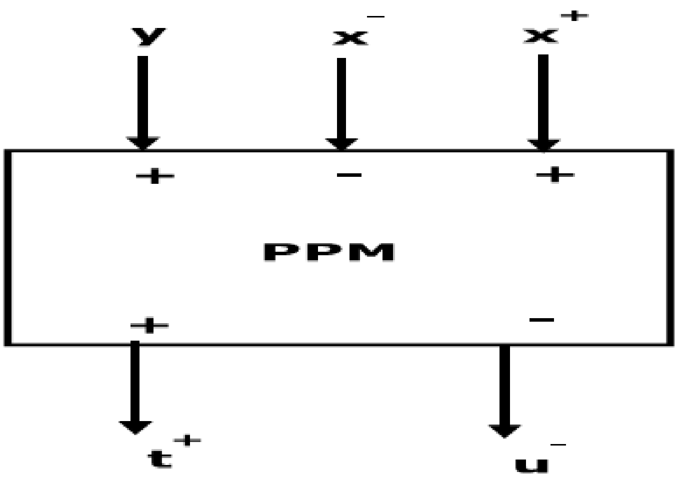

Figure 5.5 PPM Adder

In this adder a signed digit number x_i is to be added to an unsigned digit y_i which can be solved using two steps. To generate intermediate sum p_i in first step, all bits are added simultaneously which lies in the range $\{1^-, 0, 1, 2\}$ and is expressed as:

$p_i = x_i + y_i = 2t_i + u_i$

where t_i denotes the transfer digit having the value of either -1 or 0 and is denoted as t_i^+ and u_i is the interim sum having the value of either 0 or 1^- and is denoted as $-u_i^-$.

In second step, s_i is generated at the output by addimg t_{i-1}^+ and u_i^- as 1 digit given by:

$s_i = t_{i-1}^+ + u_i^-$

Then the arithmetic operation performed by the PPM adder (otherwise known as Redundant Binary Full Adder- RBFA) is expressed as:

$x_i^+ - x_i^- + y_i^+ = 2t_i^+ - u_i^-$

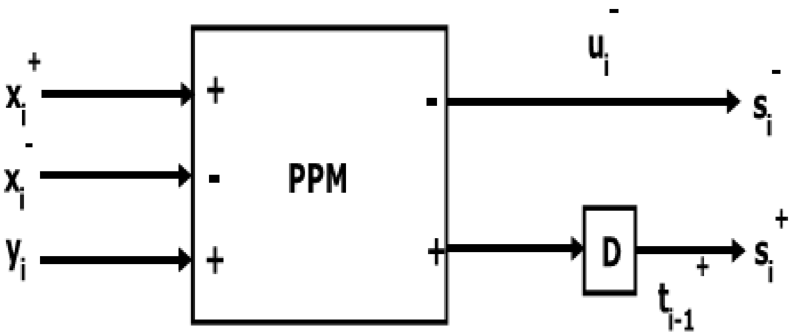

Figure 5.6 LSD PPM Adder

Table 5-1 Digit Sets in Addition of PPM Adder

Digit	Digit Set	Binary Code
x_i	-1,0,1	$x_i^+ - x_i^-$
y_i	0,1	y_i^+
p_i	-1,0,1,2	$2t_i + u_i$
u_i	-1,0	$- u_i^-$
t_i	0,1	t_i^+
s_i	-1,0,1	$s_i^+ - s_i^-$

5.6 MMP Subtractor (Radix-2 Subtraction)

This subtractor can subtract an unsigned digit number from a signed binary numbers. Using two unsigned binary numbers; positive and negative both, the radix-2 SBD number is coded as $X = X^+ - X^-$. Hence each signed bit is represented using two bits as $x_i = x_i^+ - x_i^-$ where x_i^+ and x_i^- is either 0 or 1; x_i belongs to 1^-, 0 or 1.

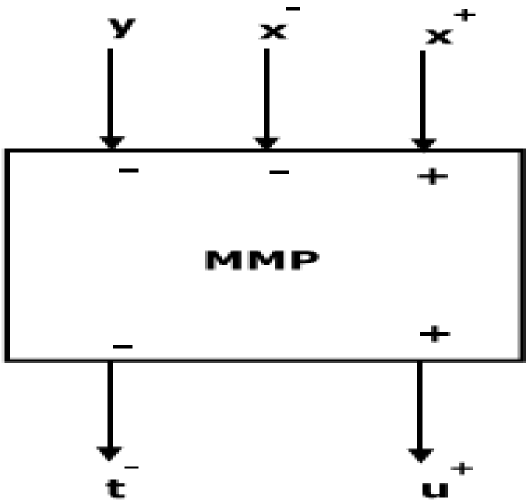

Figure 5.7 MMP Subtractor

In this subtractor a signed digit number x_i is to be subtracted to an unsigned digit y_i which can be carried out in 2 steps.

For all bit positions, the first step is carried out in parallel and an intermediate difference p_i is produced, which lies in the range {2^-, 1^-, 0, 1} and is expressed as:

$p_i = x_i - y_i = 2t_i + u_i$

where t_i denotes the transfer digit having the value of either -1 or 0 and is denoted as $-t_i^-$ and u_i is the interim difference having the value of either 0 or 1 and is denoted as u_i^+.

In second step, s_i is generated at the output by addimg t_{i-1}^- and u_i^+ as 1 digit given by:

$s_i = t_{i-1}^- - u_i^+$

Then the arithmetic operation performed by the MMP subtractor is expressed as:

$x_i^+ - x_i^- - y_i^- = -2t_i^- + u_i^+$

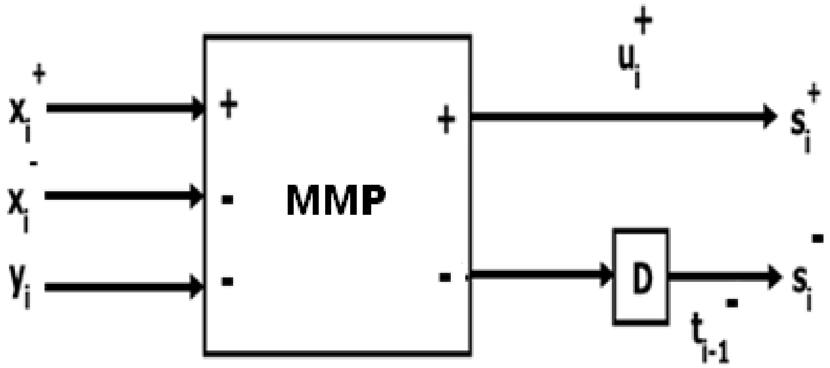

Figure 5.8 LSD MMP Subtractor

Table 5-2 Digit Sets in Addition of MMP Subtractor

Digit	Digit Set	Binary Code
x_i	-1,0,1	$x_i^+ - x_i^-$
y_i	0,1	y_i^-
p_i	-2,-1,0,1	$2t_i - u_i$
u_i	0,1	u_i^+
t_i	-1,0	$-t_i^-$
s_i	-1,0,1	$s_i^+ - s_i^-$

5.7 Digit Serial SBD redundant Adder

In Digit-serial SBD adder, two redundant binary numbers x_i (x_i^+ - x_i^-) and y_i (y_i^+ - y_i^-) can be added simultaneously and gives the result s_i (s_i^+ - s_i^-) as a redundant binary digit sum. This adder consists of PPM adder, MMP subtractor and D-FF (delay). This adder behaves as pipelining architecture, by which critical path will be reduced and hence reduction of the propagation delays.

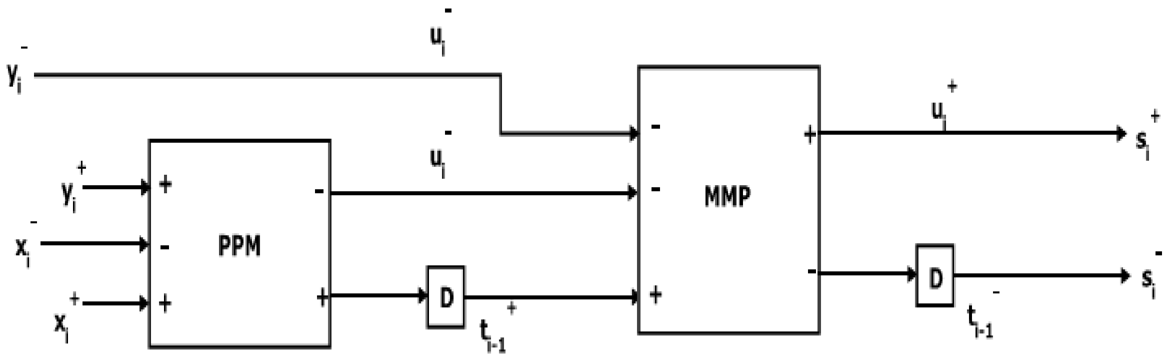

Figure 5.9 SBD Adder

5.8 Conclusion

A FIR filter performs a weighted average of a finite number of samples of the given input sequences. In this thesis, we use the FIR filter as a band pass filter to shape the Gaussian pulse to a Gaussian mono cycle pulse to meet the FCC requirements of bandwidth between 3.1 to 10.6 GHz. This chapter shows the design of a FIR filter with the help of RNS by implementing different SBD adder blocks with D flip-flops. Here each SBD adder is designed with the help of one LSD PPM adder and one LSD MMP subtractor.

6

DESIGN, IMPLEMENTATION AND SIMULATION OF PULSE GENERATOR

As mentioned in chapter 4, this pulse generator consists of interpolation delay blocks and an XOR block for the Gaussian pulse generation, and the FIR filter is used as a pulse shaping circuitry as mentioned in chapter 5. The design and simulations of various circuits were performed with Cadence in conjunction with UMC 180nm technology.

When the input signal is passed into the three delay blocks through an XOR gate and compared with the original input signal through an XOR gate, approximate Gaussian pulses are generated. The purpose is making the pulse in the UWB frequency range; i.e. in between 3.1 to 10.6 GHz. So the generated Gaussian pulse is passed through a FIR filter for generating the Gaussian mono cycle pulse in the time domain to meet the FCC mask.

6.1 Delay Generator

At first, a delay generator is implemented with three MCML delay blocks to generate a delay of approx. 140 picoseconds; i.e. each MCML delay block approx. generates a delay of 47 picoseconds.

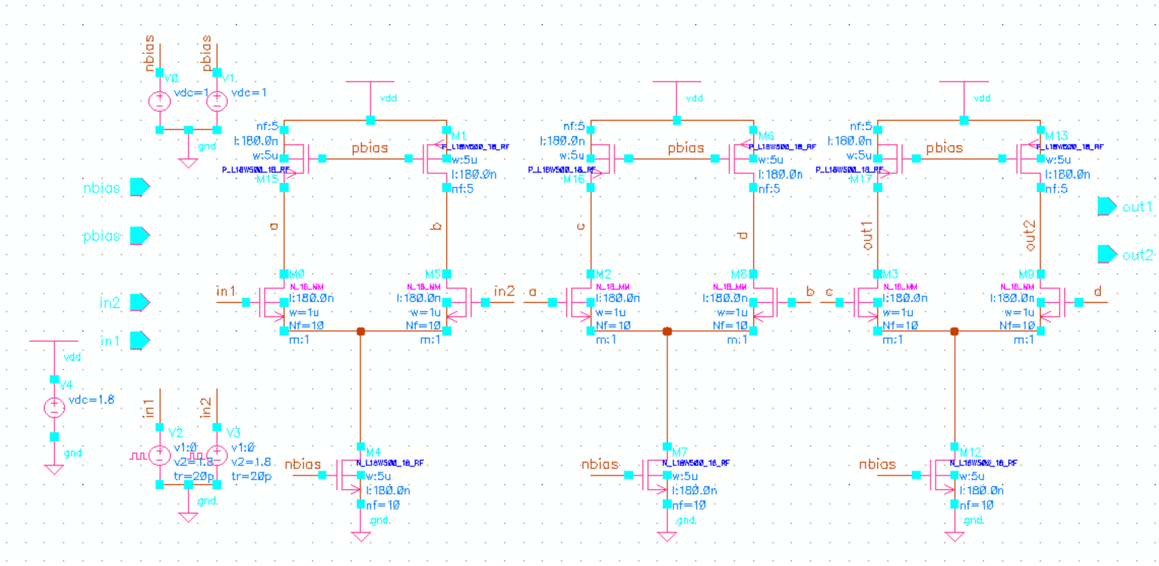

Figure 6.1 Schematic of Delay Generator

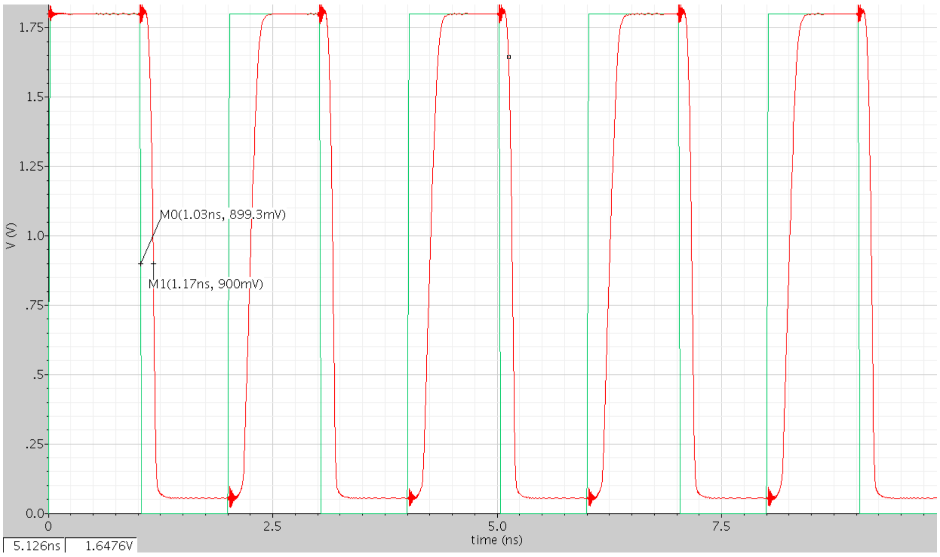

Figure 6.2 Output of Delay Generator

6.2 Gilbert XOR cell

When the original input signal is passed through three delay blocks a delay of 140ps is observed in the output of the delay generator. After that the generated delay signal is passed through the XOR gate as one input and at the same time the original input signal is sent as another input with the help of a Gilbert XOR cell, and at the output of the XOR cell approximate Gaussian pulses are generated when the two given input signals have two opposite voltage levels.

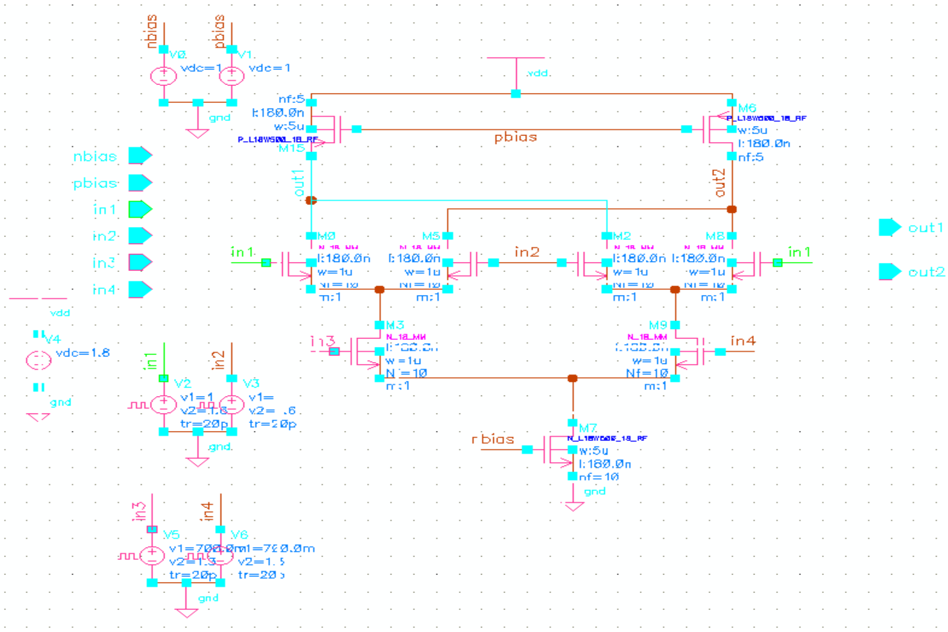

Figure 6.3 Schematic of a Gilbert XOR cell

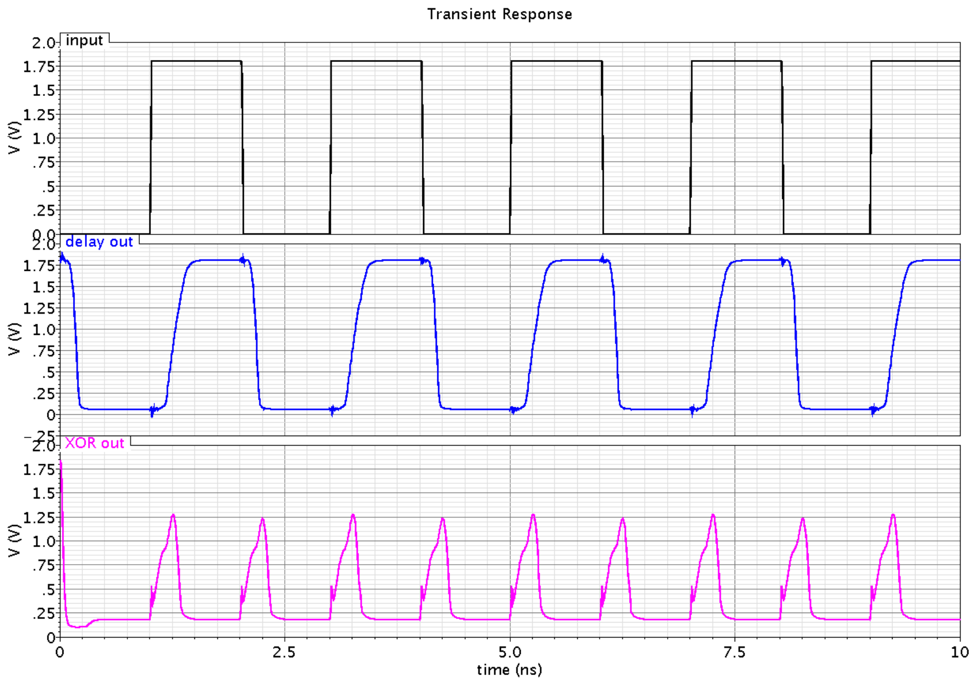

Figure 6.4 Gaussian Pulse output of Gilbert XOR cell

6.3 FIR Filter

In this thesis, we implemented a FIR filter by using RNS because the conventional number systems is a fixed positive radix number systems having different weights for each bit, where as a sign has to be used for every signed number in r's complemented form. Addition of conventional number systems requires carry propagation from LSD to MSD and the addition time depends on word-length. But RNS is used to allow addition of two different numbers in which no serial carry propagation is required because the time needed for the operation is not dependent on the word-length of the operands and the time required for the addition of two digits. For implementation of the FIR filter, the structural blocks are to be designed such as PPM adder, MMP subtractor, D- FF, SBD adder etc.

6.3.1 PPM Adder

Redundant number system limits the propagation of the carry to a fewer bit positions, which is not dependent on the word length. Hence a faster addition results due to the carry propagation-free feature.

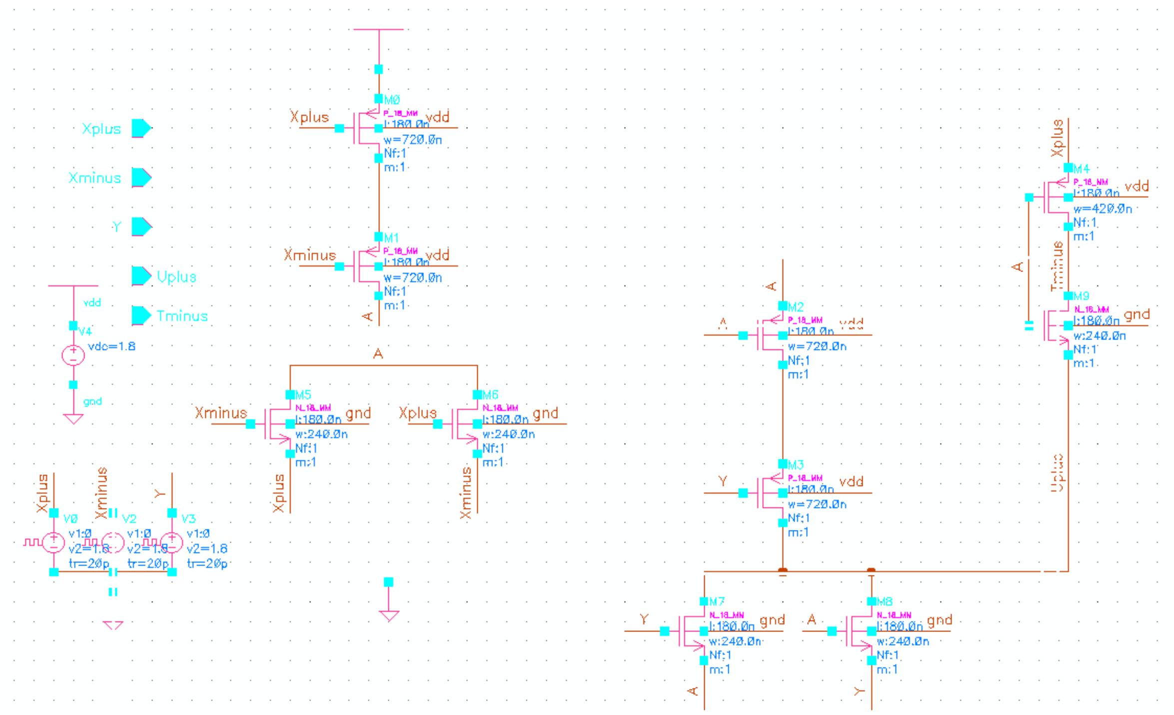

Figure 6.5 Schematic of PPM Adder

6.3.2 MMP Subtractor

This subtractor can subtract an unsigned digit number from a signed binary numbers. In this subtractor, using two unsigned binary numbers; positive and negative both a radix-2 SBD number is to be coded .

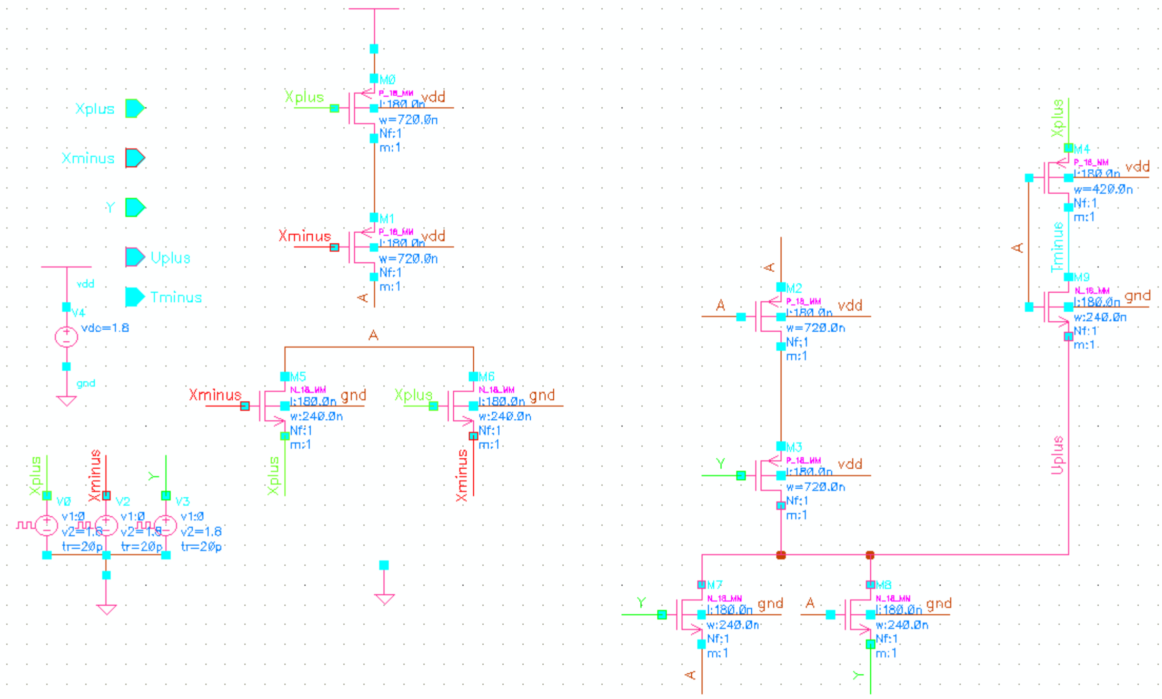

Figure 6.6 Schematic of MMP Subtractor

6.3.3 D Flip-Flop

In this thesis, the D flip-flop is used to generate delays while propagating the carry from LSD to MSD. Hence it is used along with PPM adder and MMP subtractor both for designing a SBD adder. It is also used along with SBD adder for designing a FIR filter which is used as a pulse shaper in this thesis.

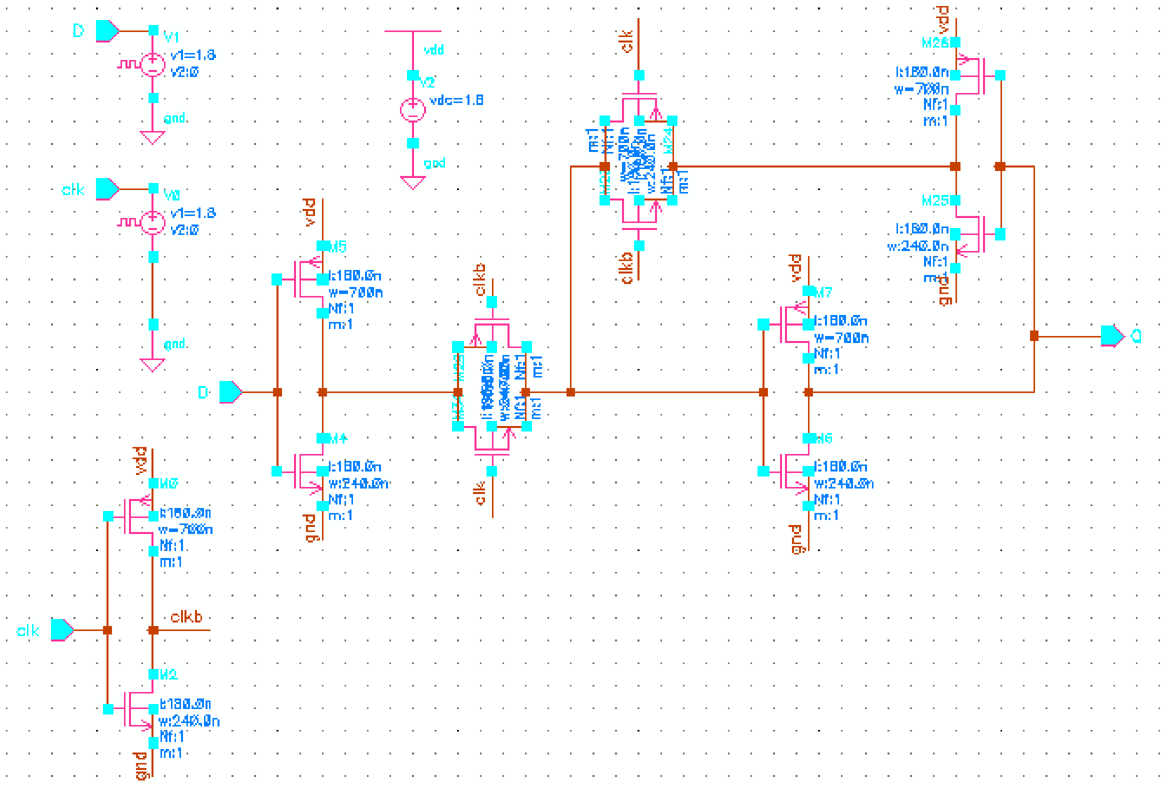

Figure 6.7 Schematic of D Flip-flop

6.3.4 SBD Adder

In Digit-serial SBD adder, two redundant binary numbers x_i and y_i can be added simultaneously and gives the result s_i as a redundant binary digit sum. This adder consists of PPM adder, MMP subtractor and D-FF (delay). This adder behaves as pipelining architecture, by which critical path will be reduced and hence reduction of the propagation delays can be seen. In this thesis, the SBD adder is used as a key component for designing a FIR filter which is used for pulse shaping.

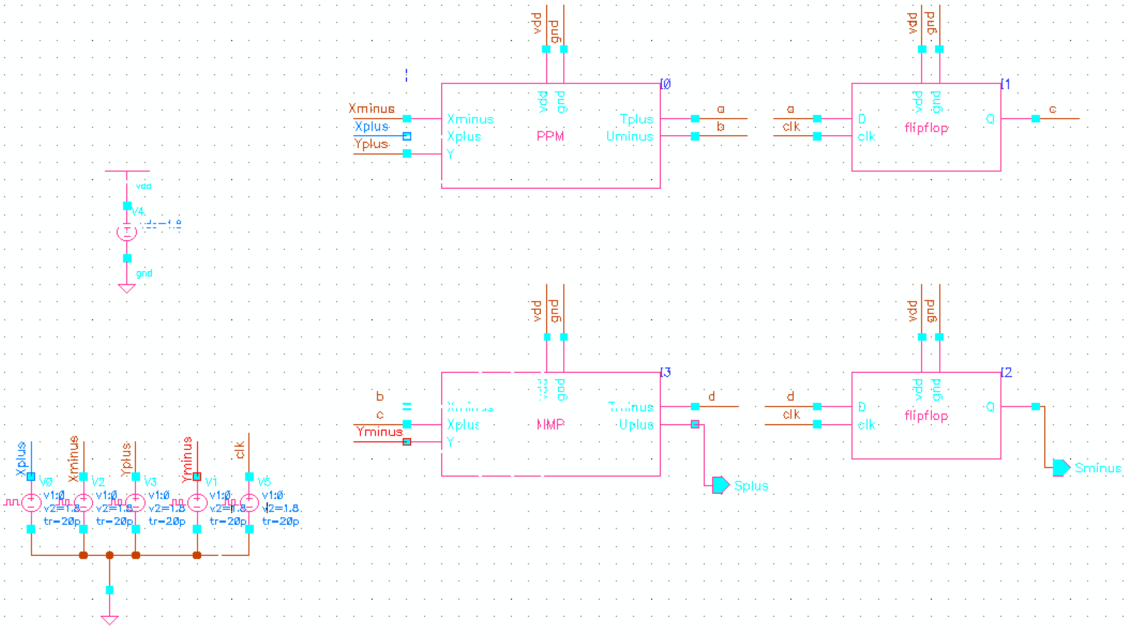

Figure 6.8 Schematic of SBD Adder

6.3.5 Proposed FIR filter

For implementation of the FIR filter, we use the structural blocks of SBD adders along with D flip-flops. After generating a Gaussian pulse at the output of the Gilbert XOR cell, the pulse is passed through this designed FIR filter for pulse shaping; i.e. at the output we can a observe a Gaussian mono cycle pulse which meet the FCC requirements.

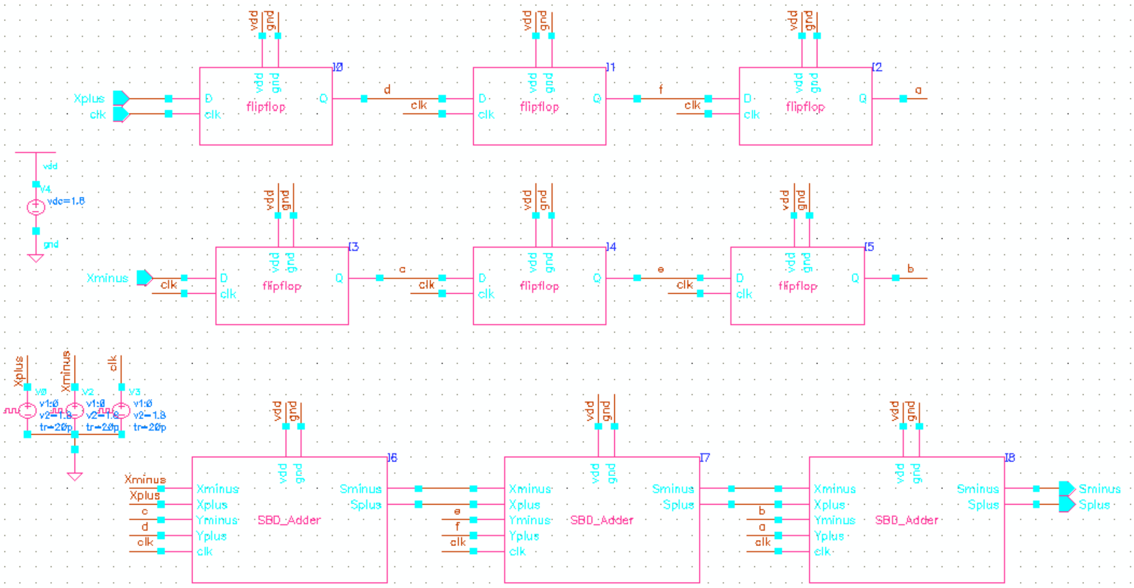

Figure 6.9 Schematic of FIR filter

6.4 Proposed Pulse Generator

In this thesis, a low-complexity and low cost pulse generator is designed in 180nm technology for ground penetrating ultra-wideband (UWB) radar system applications. Here I have implemented an UWB pulse generator circuit which is used in communication system to simplify the data transmission and remove disadvantages that occurs in other systems. This pulse generator uses a delay generator along with a Gilbert XOR cell for generating a Gaussian pulse which can be shaped by using a FIR filter, and finally a Gaussian mono cycle pulse is observed at the output which has a pulse width of 97ps thereby give rise to a bandwidth of 10.3 GHz which meet the FCC requirements.

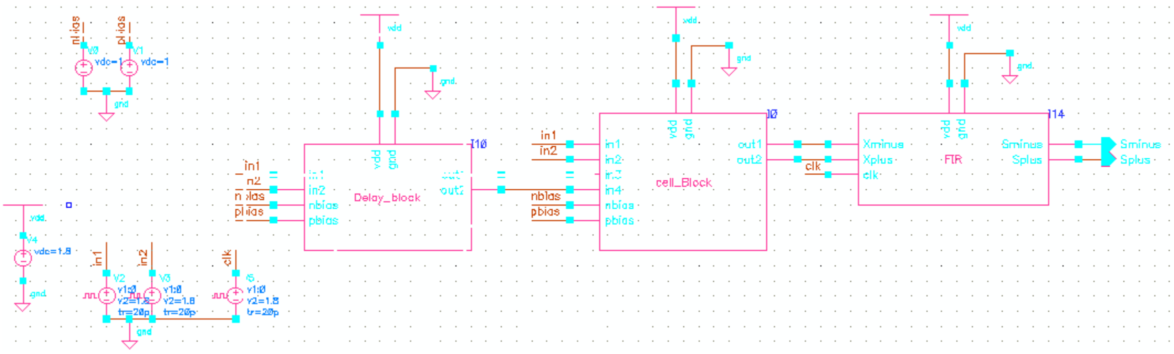

Figure 6.10 Schematic of Proposed Pulse Generator

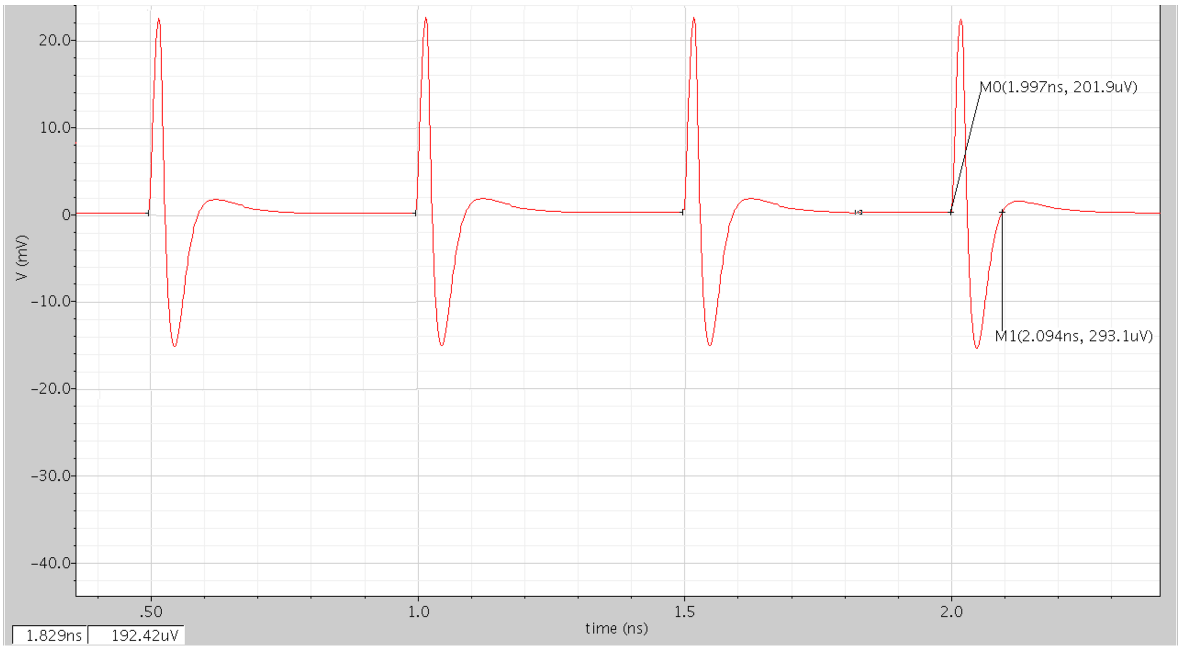

Figure 6.11 Gaussian Mono cycle pulse output of the proposed pulse generator

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CONCLUSION AND FUTURE WORK

For an IR-UWB wireless communication system, a pulse generator with a FIR filter was designed. When the adjustment in the control voltage was done, an ultra short duration Gaussian pulse was generated from the XOR gate which uses the Gilbert cell. The FIR filter is designed as a pulse shaping circuitry to give a shape to the Gaussian pulse to a Gaussian mono cycle pulse using CADENCE UMC tool in 180nm technology. By the convolution of the input signal with the coefficients of the FIR filter, the Gaussian mono cycle pulse has been generated. As an IR UWB signal source, the generated pulse should meet FCC emission requirements. According to the simulation result, the PSD of the standard Gaussian pulse coming from the XOR gate can't meet the FCC mask. However, after shaping the pulse using designed FIR filter, the PSD of the pulse is in between the BW requirements of 3.1 to 10.6 GHz.

If the derivative of the Gaussian pulse is higher, then the center frequency is also moving higher subject to a smaller bandwidth which meets the FCC requirements for GPR applications. Hence generating a higher derivative Gaussian pulse is the future work.

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