A

DISSERTATION REPORT

ON

DESIGN OF OPTICAL LOGIC GATES AND HALF ADDER USING SOA

is submitted as a partial fulfillment of the degree of

MASTER OF TECHNOLOGY

in

WIRELESS AND OPTICAL COMMUNICATON

to the

DEPARTMENT OF ELECTRONICS AND

COMMUNICATION ENGINEERING

by

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(2017PWC5386)

Under the guidance of

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JULY 2019

Certificate

This is to certify that the dissertation report entitled **Design of Optical logic gates and Half Adder using SOA** submitted by **Rahul Kumar (2017PWC5386)**, in the partial fulfilment of the Degree Master of Technology in **Wireless and Optical Communication** of Malaviya National Institute of Technology, is the work completed by her under our supervision, and approved for submission during academic session 2018-2019.

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Declaration

I, Rahul Kumar, declare that this Dissertation titled as "**Design of Optical logic gates and Half Adder using SOA**" and the work presented in it is my own and that, to the best of my knowledge and belief.

I confirm that the major portion of the report except the refereed works, contains no material previously published nor present a material which to be substantial extent has been accepted or the award of any other degree by university or other institute of higher learning. Wherever I used data (Theories, results) from other sources, credit has been made to that source by citing them (to the best of my knowledge). Due care has been taken in writing this thesis, errors and omissions are regretted.

Date : **Rahul Kumar**

Place : ID : 2017PWC5386

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I would like to thank all peoples who have helped me in this project, directly or indirectly.

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Rahul Kumar

Abstract

In today's era the fibre optic communication has become a very interesting and fast growing area with providing reliability and high speed data transfer. The transmission need in case of broadband internet and the telecommunication field has increased at an exponential rate and is being met with the help of fibre optic communication. The era demands the ultra high speed transmission which forced every aspect to convert into optical. The best example is of the submarine communication cable under sea by the Google.

Switching is the most important factor governing the cost factor of the various equipments or subsystems for information processing. The most successful design includes all optical network elements for data processing as they don't require optical to electrical to optical conversion.

This thesis reviews the realisation of all optical half adder using SOA. There are two techniques based on the use of semiconductor and other on non semiconductor, to design the logic gates for developing the half adder which has been discussed in the thesis. We have used the semiconductor based technique to create non linearity because it offers an advantage to integrate and develope different subsystems from them leading to cost effectiveness.

In our thesis work we have designed basic optical gates, which in turn helped us in development of XOR gate and finally the SOA based half adder with better accuracy and using less number of SOAs.

List of Abbreviation

ALU	-	Arithmetic logic unit
XOR	-	Exclusive OR gate
SOA	-	Semiconductor optical amplifier
SPM	-	Self phase modulation
XGM	-	Cross gain modulation
FWM	-	Four wave mixing
EO	-	Electro Optic
HNLF	-	High non linear fibre
NRZ	-	Non return to zero
CW	-	Continuous wave
MZI	-	Mach Zehnder Interferometer
OEO	-	Optical Electrical Optical Conversion
RI	-	Refractive Index
BPF	-	Band Pass filter
TM	-	Transverse magnetic
TE	-	Transverse Electrical
VOA	-	Variable optical amplifier
O/P	-	Output
I/P	-	Input
FP	-	Fabry Perot
SI	-	Sagnac Interferometer
A/D	-	Analog to digital
UNI	-	Ultra high non linear interferometer
MI	-	Michelson Interferometer
DI	-	Delay Interferometer

List of Symbols

µm - Micrometer

eV - Electron Volt

dB - Decibel

D_H - Lateral Diffusion Length

D_V - Diffusion Length Depth

E - Electric Field

G - Gram

K - Kelvin

L - Length of Electrode Region

Mm - Millimeter

Mw - Milliwatt

N - Refractive Index

Nm - Nanometer

P_{in} - Power at output

P_{off} - Power at output for output low or 0

P_{on} - Power at output for output high or 1

P_{out} - Power at output

R - Electro-optic coefficient

V - Voltage

V_π - Voltage at $\Delta\varphi = \pi$

Δn - Effective Refractive Index

$\Delta\varphi$ - Phase change

Λ - Wavelength

P_{out1} - Power at out port 1

P_{out2} - Power at out port 2

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The increasing demand of transmission speed trends to optical signal processing. This helps in better speed, increase in capacity volume and reliability of the data avoiding expenses and time consumption. Now a day's arithmetic based devices are great area of interest to enhance the data communication. The half adderiis basic buildingiblock for any of the arithmeticilogic unit (ALU). Various technologies are being used to design half adder by creating non linearity based on the usage of semiconductor and non semiconductor. The most prominent way to design these basic building blocks is SOA based technique.

For optical signal processing the building blocks are logic gates. The basic gates will be integrated to form the subsystems such as XOR gate, adders, flip flops etc. SOAs are compact, pumped electrically and have large volume of bandwidth to accommodate more data. The basic gates are demonstrated using non linearity function of the cross gain modulation of SOAs. This gain non linearity factor is used to design all basic gates.

The various steps required to develop a half adders are developing basic gates such as AND, OR, NOT. From these gates we will develop a XOR gate which will be combined with AND gate to develop a HALF adder.

Due to increased bandwidth demand, the scale of electronic devices to higher transmission rates is particularly challenging owing to their dissipation of power and use of energy. Changing the optical packet is a pleasant replacement for boosting the forwarding speed of the router. An important segment of any router is a memory unit needed to store a packet's header intelligence shortly.

For high-speed telecommunication systems, optical logic gates require significant elements as they have to achieve various functionalities in optical signal processing like switching, regeneration, addressing, multiplexing/demultiplexing, decision making, computation, coding/decoding and so on.

Due to its unique characteristics of large bandwidth, low distortion of signal distribution, spatial coherence and high spectral, robustness of cosmic radiation's robustness, and RF interference which is free, signal processing of optical digital has drawn extensive study interest in past years. Although different writers have shown their keen interest in designing the digital logic gates using different optical processing methods in the past, while designing of universal gates is the main problem in the processing of optical signals. NAND and NOR gates are called universal because with the support of these universal logic gates, all other logic operations can be performed.

SOAs are very small non-linear amplifiers that will provide the benefits to be incorporated into the optical communication system to produce the necessary post-system. This integration property of SOAs makes them cheap, compact and more reliable. SOAs shows very low consumption in power and the single waveguide structures makes them the especially suitable for use as the single mode fiber. In the present scenario SOA is mostly used and makes great development in the direction in the optical processing of the signal. The SOA has non-linear effect and its builds is very promising in the building blocks of basic logic gates. The 3 Non-linear effects of Cross Non Modulation, XPM and FWM makes it possible for the realization of gates. Theses gates will help us in developing the combinational circuits such as Half adder, full adder, flip flops etc. In this dissertation we have designed and verifies all basic logic gates and half adder.

1.2 Objectives

The primary goal of developing the methods of optical digital computing is to significantly improve fundamental and complicated digital equipment. Optical digital computing methods offer the best choice for high-speed processing of data. It can allow huge numbers of functions for signal processing like switching, addressing, encoding, and complicated digital computations .Many scholars have demonstrated the various processes for implementing the various combinational and sequential logic circuits. Using multiple optical signal processing methods, the fundamental combination logic gates such as AND Gate, OR Gate, and NOT logic gates are applied. SOAs are very small non-linear amplifiers that will provide the benefits to be incorporated into the optical communication system to produce the necessary post-system. This integration property of SOAs makes them cheap, compact and more reliable. SOAs shows very low consumption in power and the single waveguide structures makes them the especially suitable for use as the single mode fiber. In the present scenario SOA is mostly used and makes great development in the direction in the optical processing of the signal. The SOA has non-linear effect and its builds is very promising in the building blocks of basic logic gates. The 3 Non-linear effects of Cross Non Modulation, XPM and FWM makes it possible for the realization of gates. By using this phenomenon all logic gates in optical domain and combinational circuits are implemented using SOA method and results of these designs are verified through Opti-system simulation.

1.3 Thesis Organization

This thesis is organized in 7 chapters containing this introduction chapter. Following is the thesis organization

Chapter 2 describe the literature survey of proposed work on optical logic gates and half adder using SOA.

In chapter 3, we have described the software used and its components to implement and derive the results. How we can design a device through it and how any device is simulated in this simulator all steps are explained in this chapter.

In chapter 4, we have described the basic idea of various techniques which can be used to develop the gates and other combination circuits and analyze their behaviour in detail.

In chapter 5, we have discuss about the block diagram of all logic gates like AND, OR, NOT, NOR,XOR, and half adder and their results are verified.

In chapter 6, In this chapter we have described various parameters which affects the results in the optisystem software while we implement various basic logic gates.

Finally in chapter 7, conclusion of whole project and future work which can be done after this work is explained.

CHAPTER 2: LITERATURE SURVEY

Dagens, B., Labrousse et Al.[1] In this research paper the author has emphasized on the advantages of various semiconductor optical amplifier techniques such as cross gain modulation, four wave mixing and cross phase modulation and non semiconductor optical amplifier techniques such as HNLF, UNI etc.

R.Manohari et al.[2] In this paper the author has explained the design and realization of various logic gates along with flip flop using SOA. He has further explained about various other methods which can be used to design the gates such as using MZM and MZM.

Verma, D., Ramachandran et Al.[3] Here the author has used basic logic gates to develop a half adder using SOA-MZI and has explained its Q factor and BER rates. The number of SOA they have used are comparatively more than what we have used in our project.

CHAPTER 3: OPTISYSTEM SOFTWARE

3.1 Introduction

Optical communication systems design and analysis, which usually include nonlinear equipment and non-Gaussian sources of noise, are very time-consuming and highly complicated so we use new software which is more effective.

OptiSystem is an advanced simulation package for optical communication scheme, designed, tested or optimized the physical layer which has wide variety of optical systems by nearly any optical link type. It's a simulator based on fiber-optic communication systems realistically modeling. According to the user parts, its capabilities is expanded readily and effortlessly interfaced with a large range of component [4]. A Graphical User Interface (GUI) controls the optical component design and netlist, display graphics and component models. The comprehensive library of active and passive components includes wavelength-dependent parameters and realistic elements.

3.2 Main features:-

3.2.1 Component Library

Based on the chosen precision and effectiveness, component modules should be replicating the actual performance of the actual system and definite effects.

3.2.2 Mixed signal representation

OptiSystem combined signal arrangements in Component Library for both electrical signals and optical signals.

3.2.3 Measured components

You can enter factors which are measured from actual components using the OptiSystem Component Library. This is integrated into testing and measuring facilities from distinct providers.

3.2.4 Integration with Optiwave Software Tools

The OptiSystem enables the use of certain Optiwave component instruments, including OptiAmplifier, OptiGrating, OptiBPM, OptiFiber and WDM Phaser for embedded fiber and optic applications.[4]

3.2.5 Advanced visualization tools

OSA's spectrum, visual charts, constellation charts, polarisation state, signal chirp, and many other advanced visualization tools are available.

3.2.6 Data monitors

After the simulation ends, you can select component ports for data storage or attach the monitor. At a time many visualizers can be connected at the same port to monitor signals.

3.2.7 Multiple layouts

Using the same project file, you can generate many designs that allow you to easily and effectively generate and change your designs. A different design version can be contained with every project file.

3.2.8 Report page

With a fully customizable report page, you can show any set of parameters and outcomes in the design. The reports produced are organized in 2D and 3D graphs and resizable and moveable spreadsheet.

3.2.9 Parameter sweeps and optimizations

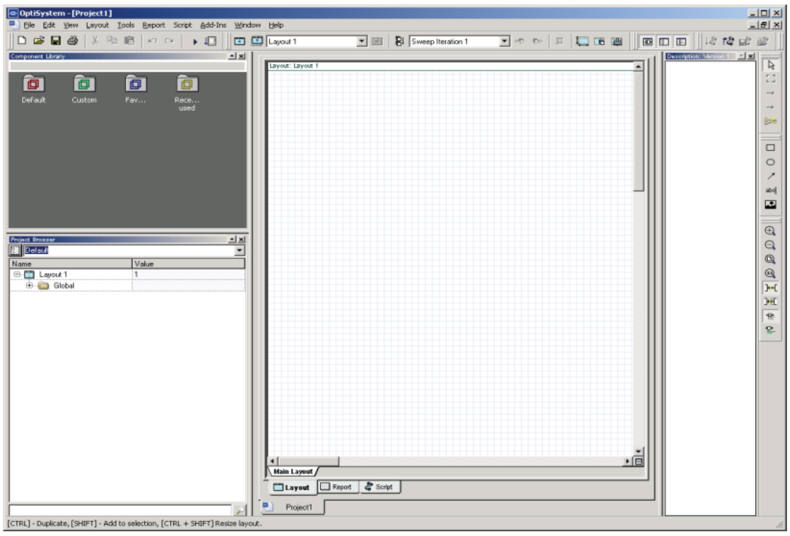
If parameters changes in same layout so for changing this parameter Sweep iteration is used. To achieve accurate results, parameters can be maximize or minimize through optimization in the Optisystem simulation. Combinations of different parametric sweeps along with different optimization.

3.2.10 Bill of materials

OptiSystem offers system design, system, layout or component cost assessment table for the system being built, organized.

3.3 Quick Start :-

Now we'll learn how to load a model, simulate, customize local parameters and global parameters, and get outcomes.



[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

Figure 3.1: Graphical user interface (GUI) in OptiSystem[4]

3.4 Main Feature of the GUI (1 of 3)

3.4.1 Project layout

This window shows the work area where element is inserted and edit their parameters of the component.

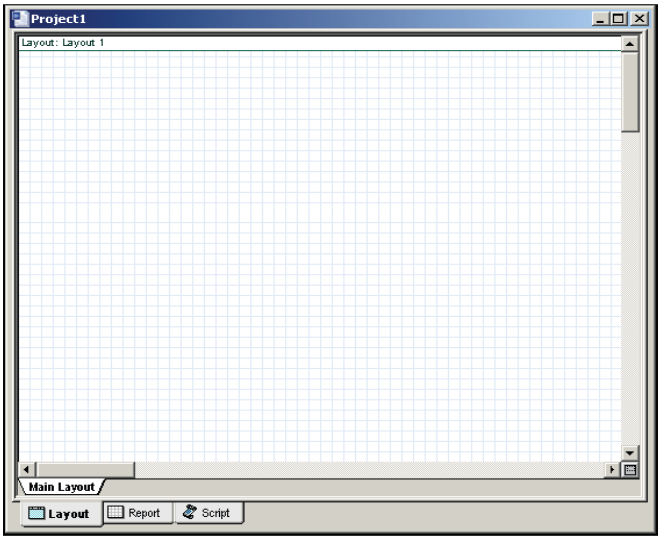


Figure 3.2 : Project layout[4]

3.4.2 Dockers :-

To show the active (present) project data. Component Library, Access elements for designing the system. Project Browser is formatting the project to obtain outcomes further effectively. Displaying the detailed project details of that layout.

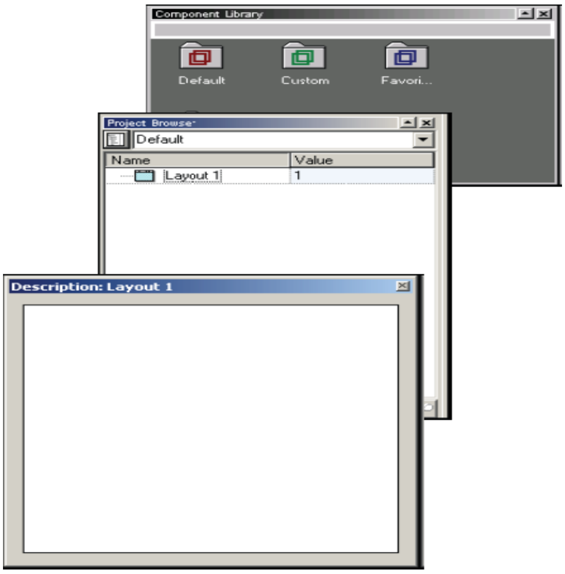


Figure 3.3: Layout description[4]

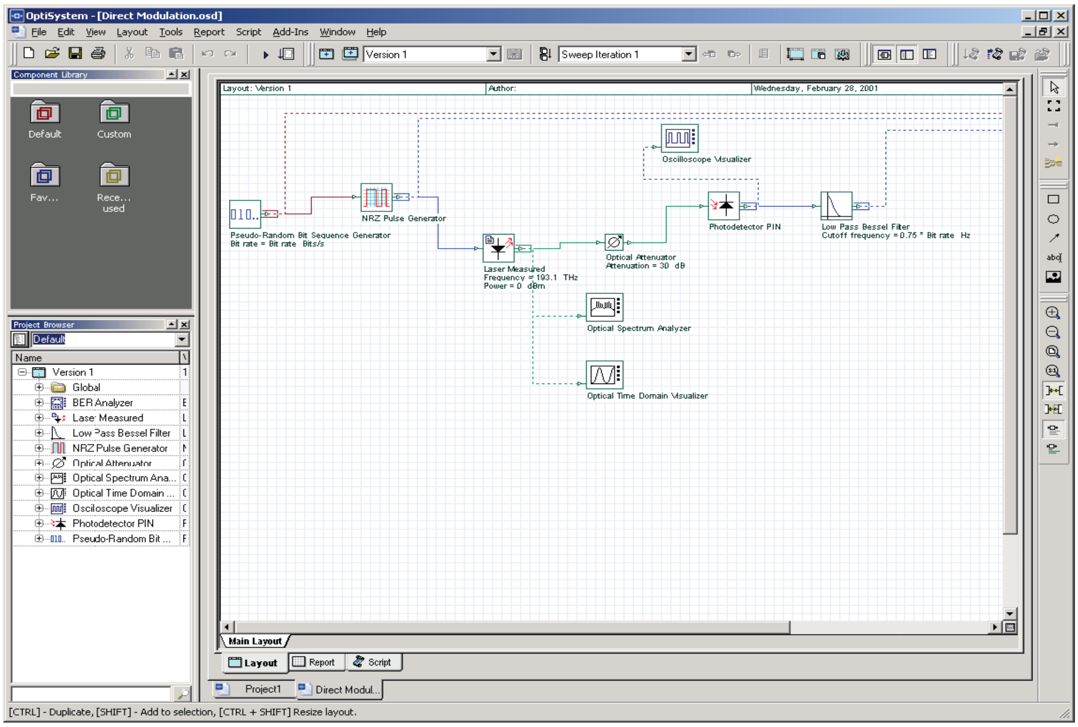
3.4.3 Status Bar :-

Display the project advance calculation data for using OptiSystem and other assists. This window shows in the layout's bottom.

[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

Figure 3.4: Status Bar

3.5 Loading a sample file:-



[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

Figure 3.5: Sample file loading[4]

3.5.1 Direct Modulation sample file:-

The transmitter section is creating by a laser modulation scheme, and it consists the following components:

i. Pseudo-Random Bit Sequence Generator (PRBSG):- it generates the bit sequence and transmits to the NRZ Pulse Generator.

ii. MZM is used for modulate the signal and it modulate the optical signal according to the electrical signal.

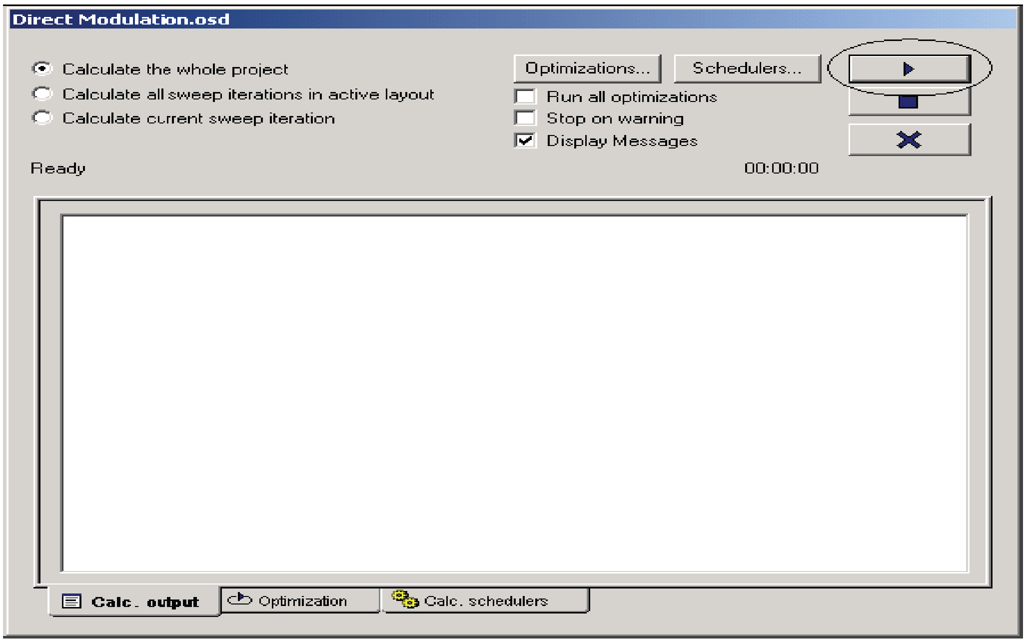
iii. Signal can be received by the PIN photodetector and it convert the optical signal into electrical signal.

iv. LPF filter is used to reconstruct the message signal.

v. Optical Time Domain Visualizer is display a response of optical signal in time domain.

vi. Oscilloscope Visualizer is display a response of optical signal in frequency domain.

vii. BER Analyzer shows the response of the signal and compare before and after propagation response.



Direct Modulation.osd

● Calculate the whole project
○ Calculate all sweep iterations in active layout
○ Calculate current sweep iteration

☐ Run all optimizations
☐ Stop on warning
☑ Display Messages

Ready 00:00:00

Figure 3 6: Calculation dialog box[4]

3.5.2 Displaying results from a visualizer

To view the graphs and outcomes generated by the simulation, double-click the visualizer in the project design.

CHAPTER 4: SOA AND NON SOA TECHNIQUES

4.1 Non SOAs Gates

The various non semiconductor and semiconductor techniques are used to create non linearity for the design of optical gates. The non semiconductor techniques use various factors to create non linearity such as the length of fibres, refractive index alteration, waveguides, circulators and filters[5].The non linearity is created by the alteration in the refractive index of the silica fibre. This non linear refractive index gives rise to intensity dependent phase modulations of three types which includes SPM, XPM and FWM.

4.1.1 Self phase modulation

SPM will undertake intensity modulation signal will travel through the fibre. The peak is always slow while travelling and the side lobes are the faster ones while signal travels in the fibre. This causes the wavelength of the pulse to broaden at peak and compress while it steeps downwards. This causes trailing edge is blue and leading edge red shift. This broadens the pulse and modulates the signal.

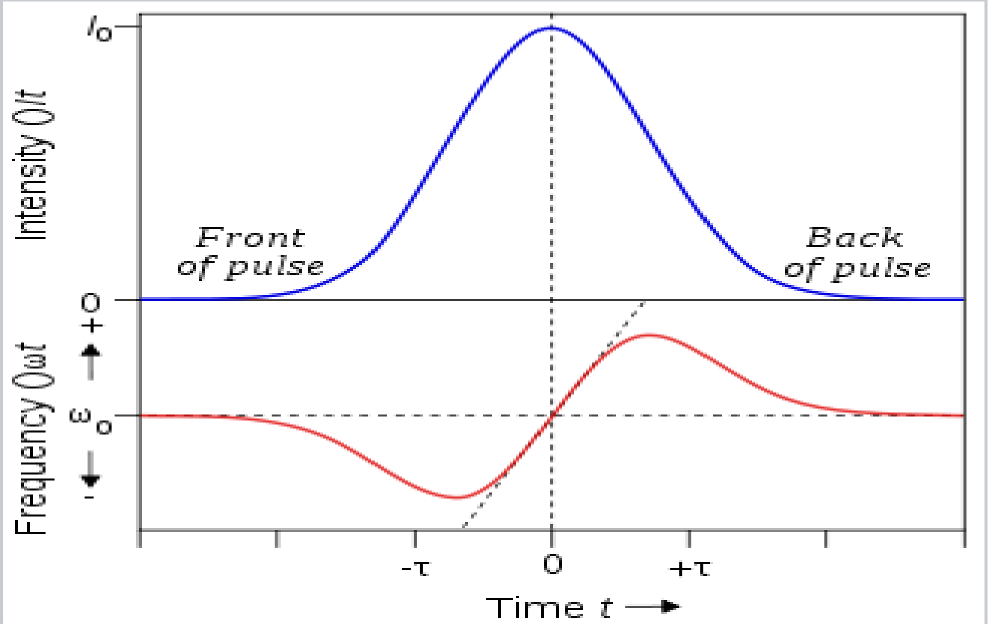


Figure 4.1: A pulse goes through self frequency change by SPM[5]

4.1.2 Cross gain modulation

Here the intensity varies with the phase of the signal. Chromatic dispersion will react for signals gain modulation. Hence, the change in the signal power will vary the signal phase.

4.1.3 Four wave mixing

Here the non linearity is caused due to distortion of the signal. Modulate the two channels and generate a third signal triggered by the necessary wave length and nonlinearity. Signal power is greater than the strength of the side band.

4.1.4 HNLF

Due to the fiber length, HNLF induces nonlinearity. Fiber length is divided into three parts, dispersed fiber , highly non-linear shifted fiber dispersion and highly non-linear fiber. Due to the impact of self-phase modulation, it contributes a change in the output in DSF. The data transmission creates a cross phase modulation that varies the level of the energy and generates [1] . The two signals uses the same wavelength.

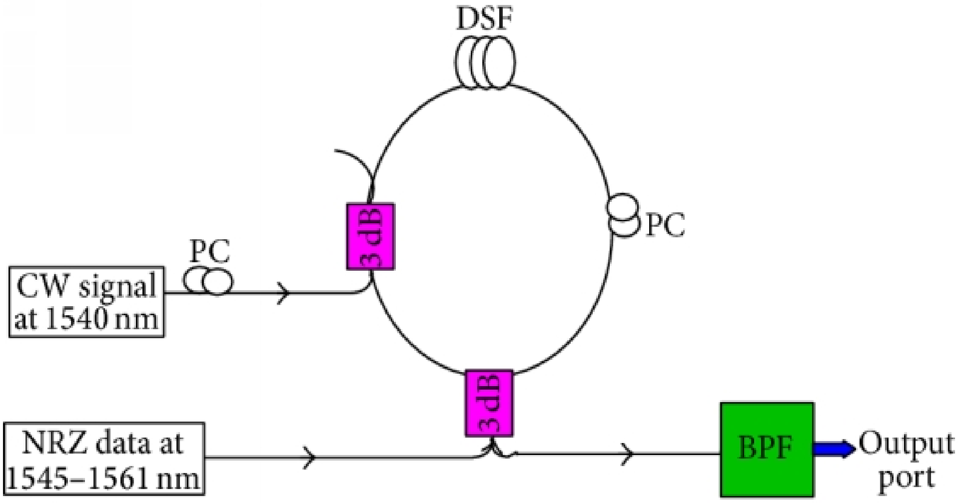


Figure 4.2: DSFas reported in [1]

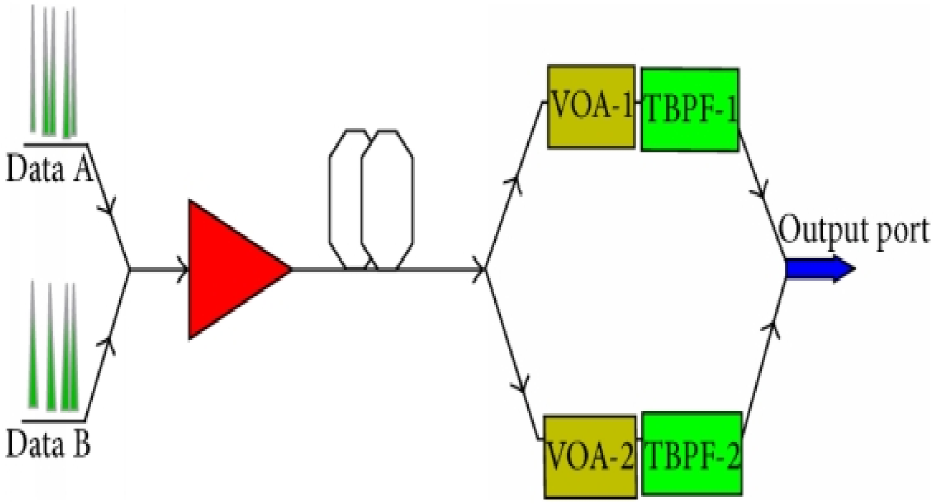


Figure 4.3: HNLF-DSF [1]

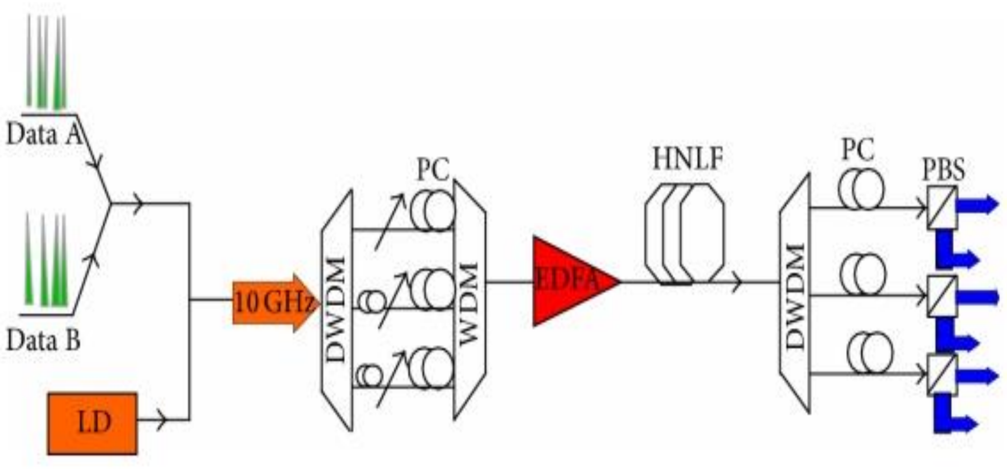


Figure 4.4: HNLF[1]

In HNLF-DSF, cross-gain modulation triggered by the energy sent to the fresh FWM element reduces the information. If one signal is present and is sent to the High non linear-DSF, it will come as an O/P, but in case if both the signals are given as the input then there will be no signal power at the output owing to the impact of polarization in the information. Depending on the intensity of the cross-gain modulation impact, one can obtain the required outcomes when coupling the specified two output signals. In HNLF design, the nonlinear polarization rotation produces all-optical logic gates. Light polarization will always rely on the signal's strength and relative polarization.

When pump and probe signals are transmitted through the HNLF, owing to the single phase modulation impact and crossgain modulation, it will produce a nonlinear phase shift. Because of these impacts, the probe signal'spolarization will change and various gates will be generated. This process of designing or realisation of gates through the length of the fibre to produce the phase shift has disadvantages of giving big designs.

4.1.5 Waveguide Configuration

Two separate data of various wavelengths is being created by the microwavearonic and mechanical system laser in design. These two produced data packets are mixed in the Fabry Pirot Chip (FP-Chip) through the mirror [6] . Multimode Wavelength output will be in the FP-chip. When this data packet is passed through given cavity, then the produced signal will be non-linearity. FP-chip will lock alternatively due to non-purity of the signals. The filter will select the signal from them and the gate will realize the gates.

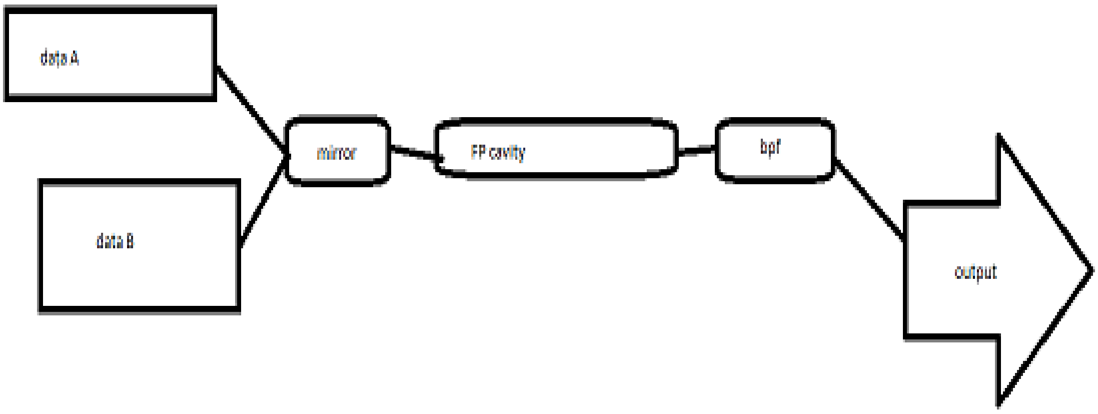


Figure 4.5: Design of gates using FP-cavity[6]

In Design of gates using the SI wire, the two different wavelengths are feed into the SI wire and the band pass filter which will modulate the signal through the cross gain modulation. If we adjust the signal power and the probe light power we can create a signal.

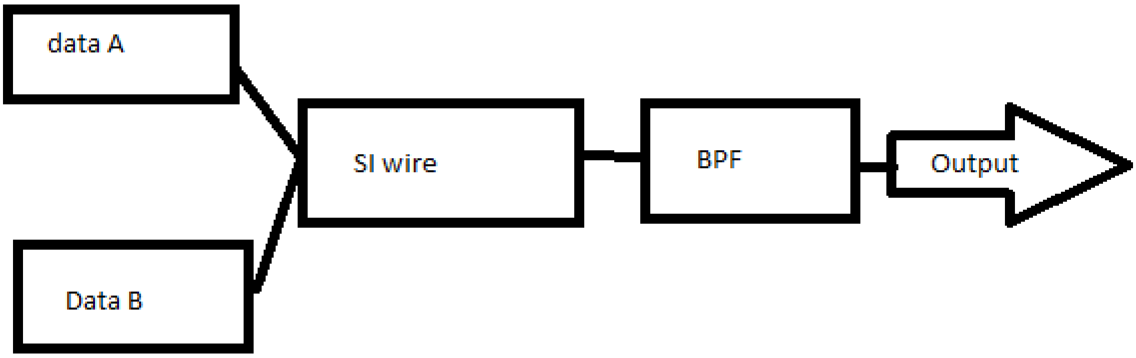


Figure 4.6: Design of gates using SI wire[6]

In ChG waveguide production, two different data with different wavelength are being fed into the chalcogenide As_2S_3 (ChG) waveguide. This ChG waveguide with its fast non-linear response , which is the result of the kerr non-linear index coefficient produces non- linearity in the signal. The generated wavelength is given into a tunable band pass filter (TBPF) to realize different kind of gates.

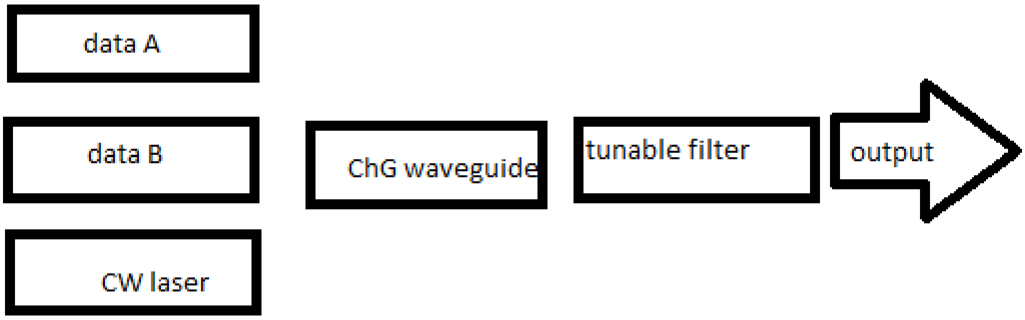


Figure 4.7: Design of gates using ChG waveguide[6]

4.1.6 Circulator

In this the circulator can be used to design a gate by giving two data’s with various wavelength and further passing them through 2 × 2 coupler and second 2 × 2 coupler. After this process both pump light and probe signal is passed through Fabrey Parot LD. The unique property of FP-LD is that if a single mode beam in the longitudinal Fabrey Perot-LD mode, a slightly higher wavelength is given, the light beam experiences the gain benefits while other methods of FP-LD are suppressed and down lined. While we inject the second beam along with a different range than the given last beam, then output beam will be degraded or suppressed, while the 2nd beam will get a gain level higher than previous, as well as the other beam-locked FP-LD Will also be done. It is "gain modulation" where pump power is lower than the probe signal power.

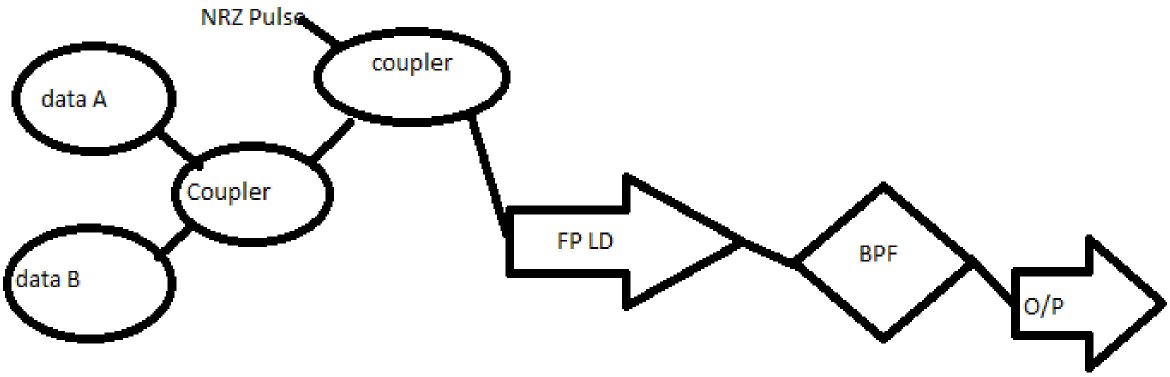


Figure 4.8: Design of gate using circulator.

4.1.7 Optical Channel Dropping (OCD) filter

The architecture using the optical logic dark-shiny solitone conversion is given below. Here Dark (D) and Bright (B) Solitons shows the input logic as "0" and "1", respectively. The input given at Stage-1 OCDF(optical channel dropping filter) will be dark solitone (stage"0") and it will be a light pulse as controlled one. At phase 1 optical channel dropping filter, dark solitone will be converted into dark and bright solitone. The next data A is fed into the Phase-2A / D filter, and then Data B is given into the phase-3 optical channel dropping filter. The steps are divided as per the sequence of the taken input. OCDF is made up of two figures of coupled waveguides that will give output as a phase shift in relation to the input signal.

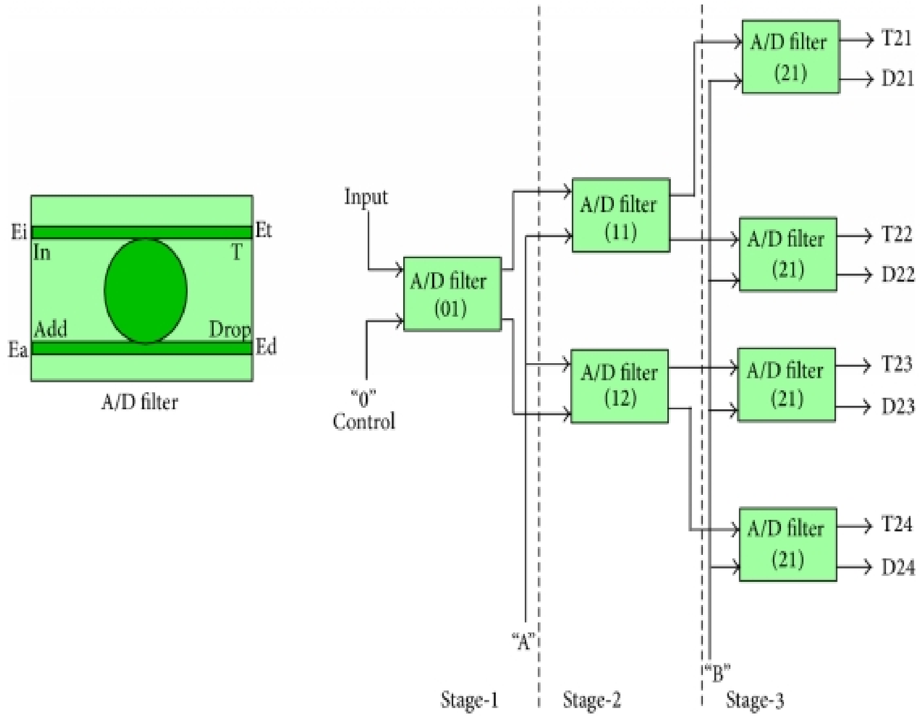


Figure 4. 9: Design of gates using A/D filter[6]

4.1.8 Multilayer Waveguide for gate realisation

Optical non linearity is used to develop many of the all optical devices. A planer waveguide with non-linear guide films in the design are applied below. Waveguide is divided into three sections L1, L2, and L3, which corresponds to 3 branches as output, respectively, Non-linear double rapt waveguide and two input sections as linear in nature. The upper three sides and the lower two arms has different refractive index. The optical gate is being realized by varying the non-purity of O/P branch and giving I/P power as per requirement.

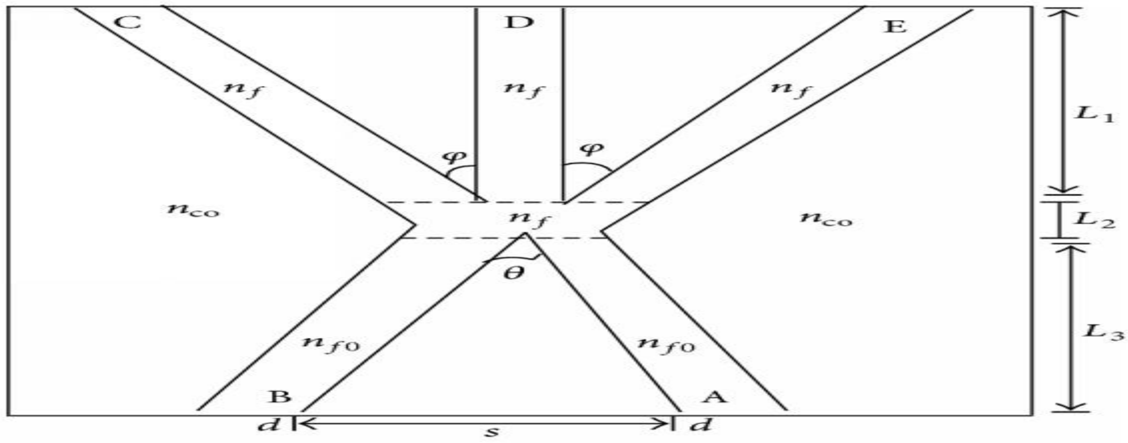


Figure 4.10: Gates realized by using multilayer waveguide[6]

4.1.9 Optical Gates using optical thyristor

In the data given below, we have demonstrated a monolithic incorporated perpendicular cavity laser at a low optical thyristor arrangement, which is configured in several optical logics task by varying the state at the input voltage, using a simple operating technique can be done. As it is a bnable PnpN active field tool in the picture. If the forward bias is being applied to the thyristor, then the current-voltage characteristics of the S-shaped are divided into three different steps, further blocking area,-ive resistance zone and front conduction area. Further the area of conduction is called as ON-STATE. Further stopping area is known by the term OFF-state in optical thyristor. Boolean gates are realized by adding it in the parallel/series and varying the reference voltage.

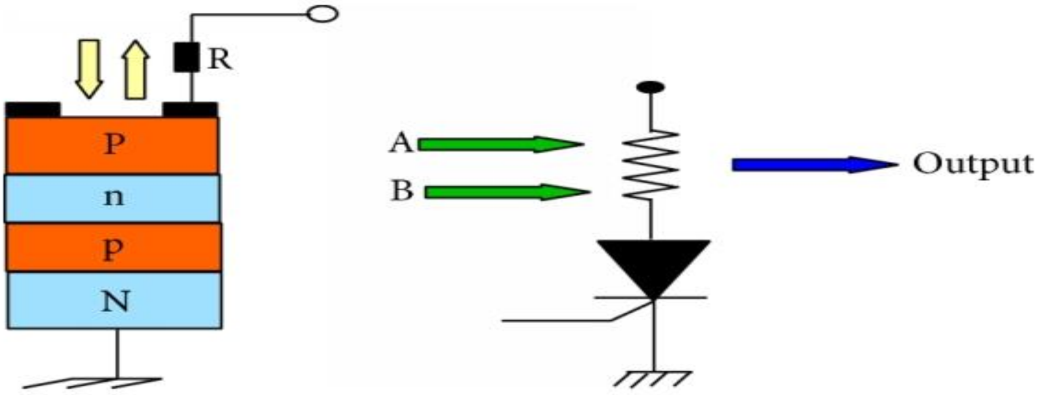


Figure 4.11: Gates realized by optical thyristor

4.1.10 Acoustic-optic tunable filter

Gates are operational on the basis of TM and TE polarization data ATE/BTM as shown in the picture below. Polarized data is then being modified in Pulse Position Modulation (PPM). Then the polarized data will be excited by the SAW Transducer. The porridge passes through the acoustic-optic waveguide and it will transmit the acoustic optic waveguide wavelength. Boolean logic gates are being realized and checked by temporary dislocation of the O/P pulse.

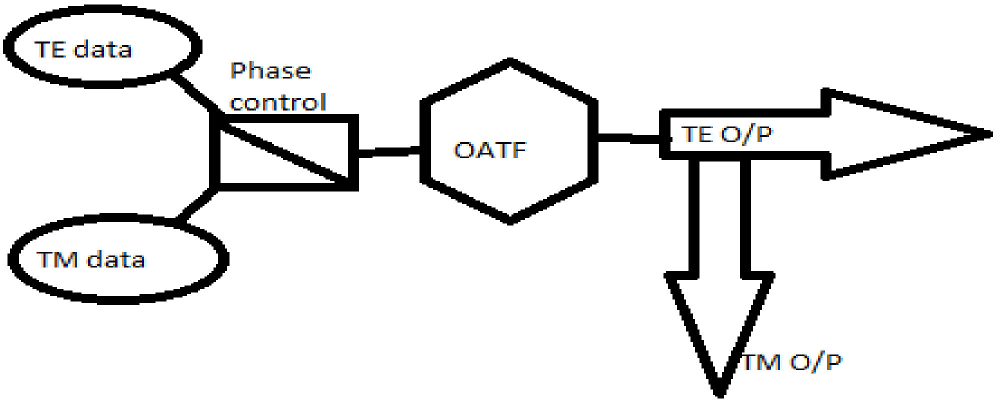


Figure 4.12: Gate design using OATF

4.2 SOA Based Gates

Again the interferometric techniques are used to split the gates such as Signal Interferometer (SI), (UNI) Ultra-High Nonlinear Interferometer, Mach-Zander Interferometer (MZI), Michelson Interferometer (MI), Delay Interferometer (DI). Implementation of impurity In the below given sections, impurity of Semiconductor optical amplifier is used in different ways. Various design architectures and categories of Semiconductor optical amplifier-based all-optical gates are examined in the section. SOAs are very small non-linear amplifiers that will provide the benefits to be incorporated into the optical communication system to produce the necessary post-system [8] . This integration property of SOAs makes them cheap, compact and more reliable. SOAs shows very low consumption in power and the single waveguide structures makes them the especially suitable for use as the single mode fiber. In the present scenario SOA is mostly used and makes great development in the direction in the optical processing of the signal. The SOA has non-linear effect and its builds is very promising in the building blocks of basic logic gates. The 3 Non-linear effects of Cross Non Modulation, XPM and FWM makes it possible for the realization of gates

4.2.1 XGM/XPM/FWM

In a wavelength, XGM will modify the carrier density in the data pulses and at the same time, the resultant indication induction for injecting clock pulse is injected in the Semiconductor optical ampilifier as a result is given in the figures given below. The modulated carrier density, the pump signal will have gain compression which produces the signal of the signal which is converted. SOA is being used under high intensity to reduce the profitability time. Problem related to cross gain mlodulation is associated with long-term wavelength extinction ratios penalties. This method can easily be adjusted at high bit rate. Change of the signal strength will be used as a benefit by adding SOA to an interferometer configuration, which will convert this cross-phase modulation into intensity modulation.

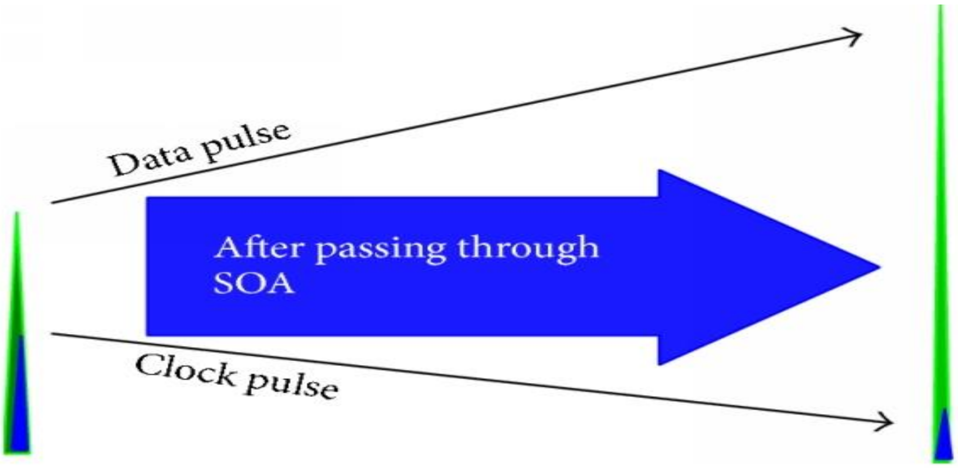


Figure 4.13: XGM[5]

In order to be completely extinct in an interferometer, a phase change is required, which may be derived with profit compression in the SOA. The phase shift in the signal is independent of the wavelength, so there is no problem with XPM from the conversion in the long wavelength. The disadvantage in an interferometer architecture is that if the phase shift will increase further, it will increase the proportion of extinction and this can be controlled by varying the bias position of SO amplifier. Interferometric configurations can be derived in 2 ways and they are co-dissemination and counter-promotion. In the co-distribution, the filter is needed because of the probe with probe and pump will travel in the same direction to filter the signal, but in the counter-promotion, both will travel in the two opposite directions, hence the filter will not be required.

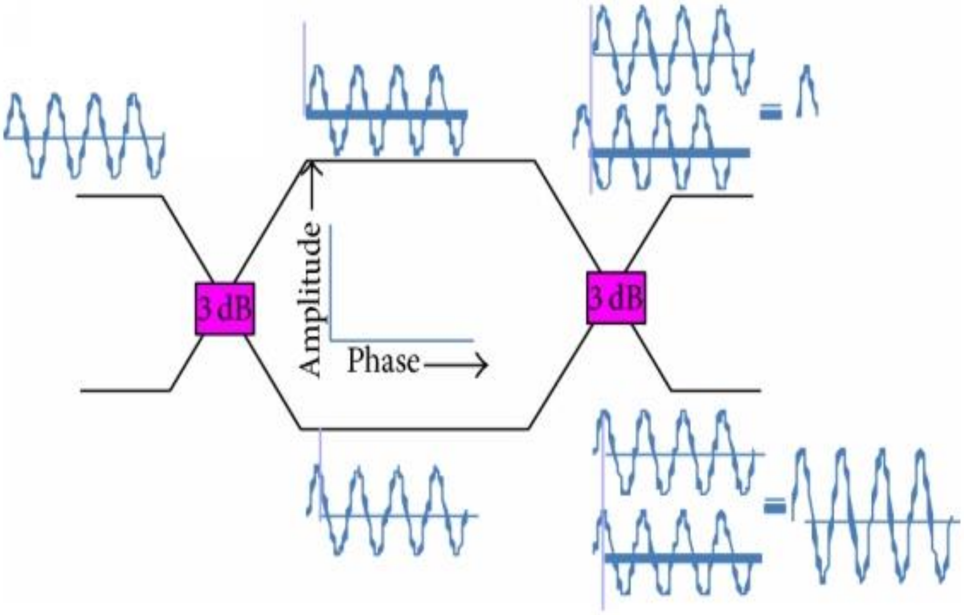


Figure 4.14: XPM[5]

2in number signals of various wavelengths are being given into SOA in FWM while passing through SOA there will be intensity beating occurs due to modulations of the two signals. The carrier density will be changed if frequency gap is smaller. If the frequency gap is larger, then the newly modified carrier signal will establish the moving grating in SOAs active band. The grating will scatter the I/P signal and will produce the sidebands that are situated between the I/P signals at high and low frequency. Compared to signal power, the strength of the side band is usually less. This process depends on the optical signals phase rather than depending on their intensity.

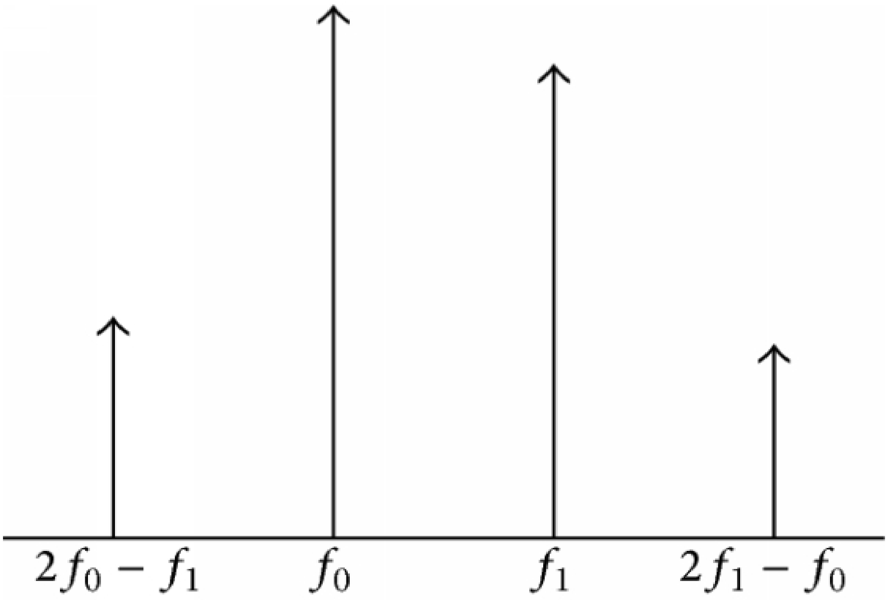


Figure 4.15: FWM[5]

4.2.2 Ultra Non linear Interferometer

In this UNI,the incoming signal will depend on the rotation polarisation of the incoming signals in On state of the switch pulse in SOA. There are two kinds of UNI gates as co propagating and counter propagating.

4.2.2.1 UNI Co-propagating Gates

As per the architecture, the UNI co-transmission door can be distributed into two types. In the first design, the clock and data are straight away interfused in the semiconductor optical amplifier and on the next end the data is modified through the delayed interferometer and then given to the semiconductor optical amplifier [5]. The original operation of UNI Gates will depend upon the inter-phase changes among the 2 polarized parts of the perpendicular signal. Here the clock pulse will be perpendicularly polarized and the delay while passing through the polarization fiber is delayed. The dimension and the phase of the modulated signal data with high strength is co-propagated by the SOA. If both of the data are available or phase shift difference between test signal is absent, it contains destructive interference so the output will be zero.

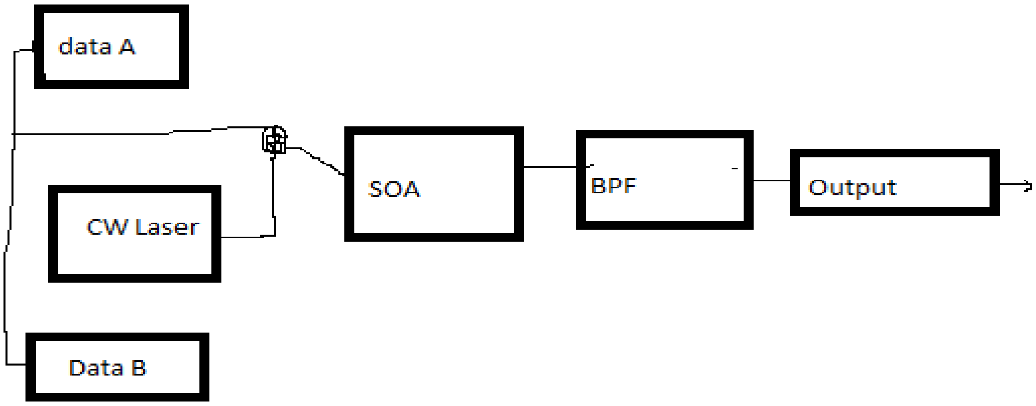


Figure 4.16: UNI with single SOA

4.2.2.2 UNI Counter-propagating Gates.

Counter-propagation in UNI Gates is shown below in figures, where data along with clock signals will be transferred in two opposite directions. So, the pump signal will pass by the Semiconductor optical amplifier and it may lead to a shortage of career in the SOA. Carrier reduction will lead to achieving saturation in the Semiconductor optical amplifier. Due to this, there will be decrease in the intensity of coming probe signal and it does not come in the pulse for output signal. If 2 SOA are being given in parallel, then the first one SOA may be used to produce multifunctional gates.

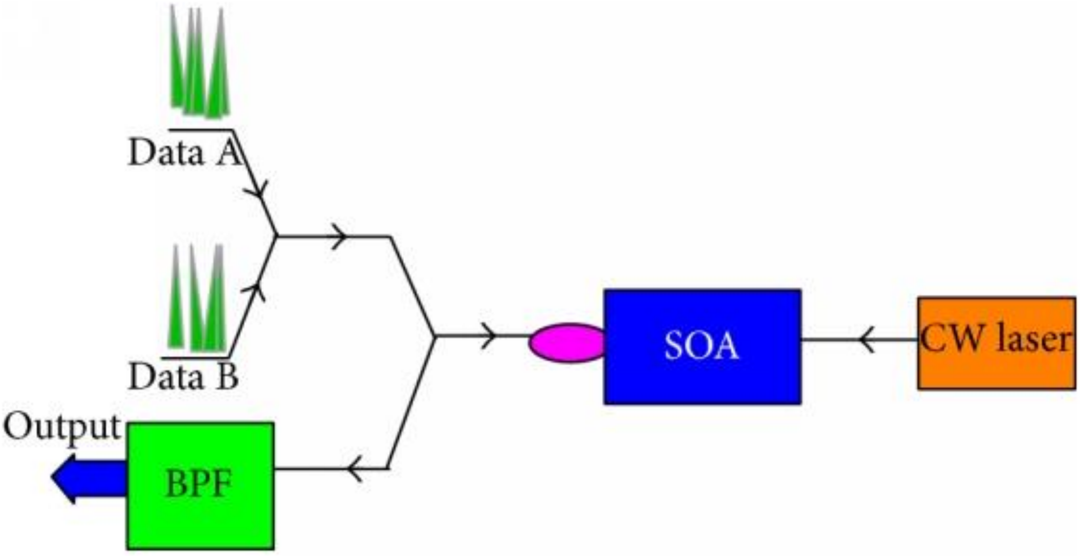


Figure 4.17: Counter-propagating Gates[5]

4.2.3 Sagnac Interferometer Gates

In the picture given below, the design contains an optical fiber loop with SOA that is kept oddly. This gate will use the TOAD principle (terrairts optical asymmetric demuliplexer).In sagnac interferometer gate the data is given along with the CW laser data which is coupled with 2x2 coupler and passed through the SOA to attain the non linearity for realization of the gates. This helps in cross phase modulation of the input signal and the band pass filter passes the signal required. There is coherence between the CW and CCW. The clock signal parts into two signals and one of them travels into clock wise direction and the other is vice versa. Orthogonal polarized data enters the fibre loop through polarisation selective coupler.

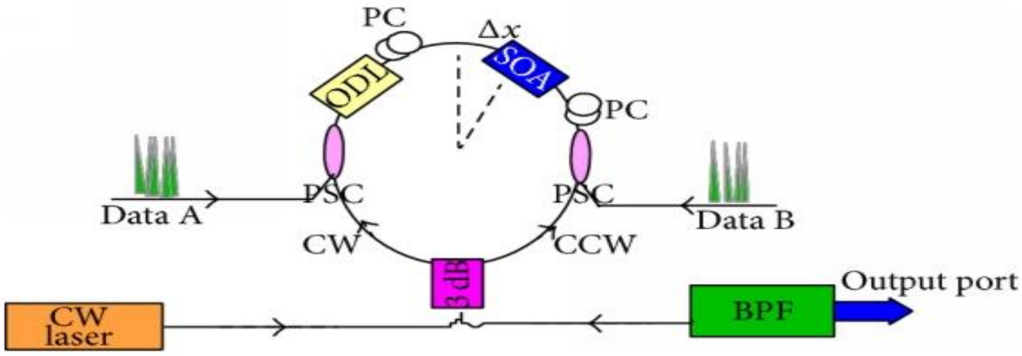


Figure 4.18:Sagnac Interferometer Gates[5]

4.2.4 MZI Configuration

One of the most significant mediums to impose data on or modulate a light wave carrier is the EO effect. Electro-optic devices are created to be used for modulation or switching or so many purposes in optical communications. Example devices include phase and amplitude modulators. The electro-optic effect enables frequency modulation to be much greater than other techniques, such as mechanical shutters, moving mirrors or acousto-optic equipment, owing to quicker response time.The fundamental concept behind electro-optic systems is to alter in a controlled manner the optical properties of a material with an applied electric field. An optical signal's shift in optical properties refers to change in phase, amplitude, frequency, polarization, or position as it propagates through the device. According to change in properties we differentiate the electro-optic effect [9].

4.3 Electro-Optic Effect

Some materials have the property that if a optical signal passes through it, it's properties change according to applied external force. Reasons to change these properties are change in positions, orientations, or shapes of the molecules originating from the material by applying any external forces eg. Voltage, temperature, acoustic waves etc. The shift in the refractive index arising from the implementation of an electrical dc or low frequency field known as the electro-optic effect [8].

4.4 Lithium Niobate- A crystal for optical processing

In linear and non-linear applications different kind of devices can be included like mobile device, optical modulators and sensors based on piezo-elecric effect all these are based Lithium Niobate crystal material. It is a compound material made of niobium, lithium, and oxygen, Lithium Niobate has a trigonal geometry class of R3c and 3m point group framework without anti symmetry and show properties of Ferroelectricity, Pockel’s impact, piezoelectric impact, photo elasticity and nonlinear optical polarizability. It is a hard no soluble in water having negative uniaxial birefringence dependent on the stoichiometry and temperature of the crystal. It can be operate under the range of 350 and 5200 nm wavelength. Single crystal of LN wafers grown using the Czochralski process after then wafer is cut into different cuts eg. Z-cut, X-cut, Y-cut

Lithium Niobate ($LiNbO_3$) is a colorless, insoluble with water and ferroelectric material. In integrated optics developers use its electro-optical, acousto-optical and non-linear optical characteristics and proved to be great material for the manufacture of optical waveguides. Property of intrinsic modulation of high bandwidth makes it an appropriate person for communication technology.

Specification of lithium Niobate are described as that chemical formula of lithium Niobate is $LiNbO_3$, crystal glass is trigonal with 3m, lithium Niobate is non-soluble in water and colorless, molecular weight is 147.9 g/mol, density is 4.644 g/cm^3, transmittance range is 350-5500 nm, melting point is 1530 K, curie temperature is 1415 K, thermal conductivity is 5.6 W/(m K) at 300 K, and bandgap is 4 eV.

For multiple technical innovations, it’s piezoelectric and photo elastic characteristics were used. By virtue of its large electro-optic coefficient, optical damage resistance and minimum losses, lithium niobate was used to manufacture embedded waveguides. For wavelength-tunable polarization converters implementation Strain-optic impacts are used. To design low-loss switches, $LiNbO_3$ material has been used widely, but the main problem is their polarization dependence. For high and low velocity schemes, the selection of Lithium Niobate based switches is proven to be the best. The modulation requirements in digital fiber optic TDM which is time-domain-multiplexed and WDM which is wavelength-division-multiplexed schemes have been effectively resolved by $LiNbO_3$ devices in latest years [9].

4.5 Ti-diffused Lithium Niobate

Waveguides of lithium niobate material can be manufactured using either in-diffusion of titanium or annealed proton exchange procedures to design switches and modulators. The entire $LiNbO_3$ is subjected to the manufacture of planner waveguides while, with these procedures, the photolithography method is used to define masks for chosen areas on it. In some cases, to control optical damage, Mg oxide is doped with LiNbO3. The lithium niobate waveguides exchanged for protons are simple to manufacture and can function at low temperatures. For multiple communication, sensor systems and signal processing, Ti diffused lithium niobate waveguides are helpful. Ti doping in lithium niobate crystal increases refraction indexes, allowing both TE and TM modes to propagate along the wave guides, which fulfills the necessary optical signal processing requirements.

4.6 MZI Switch

Mach–Zehnder interferometer (MZI)-based structures are among the numerous techniques available to transform a modulation of phase into a modulation of intensity. These designs are widely used by electro-optic (EO) or thermo-optic (TO) impacts to create a various applications like optical modulators, splitters, switches, etc. The symmetric MZI structure was proposed to design high speed switches for lower bandwidth operation using the EO effects. Lithium niobate (LN) is an appropriate material for MZI structure based switches because of its large EO-coefficients, but a latest material potassium niobate (KN) has recently been discovered that can substitute lithium niobate. These systems have stable performance parameters, even for inputs with a broad range of concentrations of optical power. Under the influence of an electric field MZI switches produce the refractive index in optical medium, due to this bending of light occur through the medium, this phenomenon is known as phase modulation. By optimized different design parameters like diffusion parameter, dimension of the waveguide, applied field etc., increase the performance of switch. There are two types of MZI switches such as counter propagating and co propagating switches as shown below in the figures

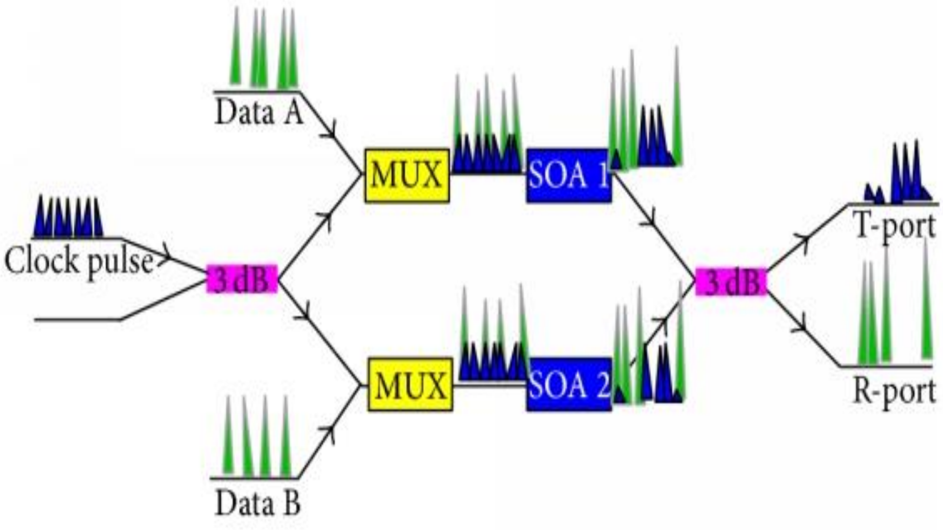


Figure 4.19: MZI Co-propagating Gates

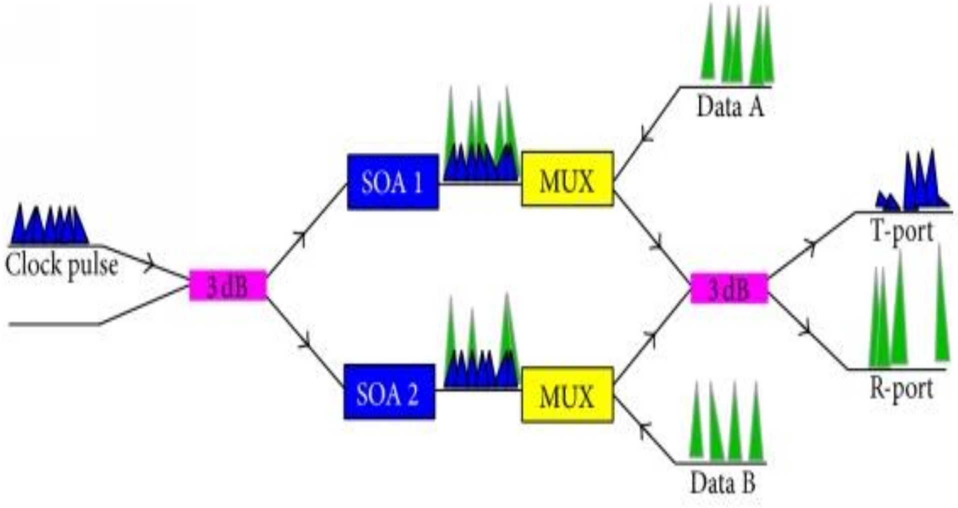
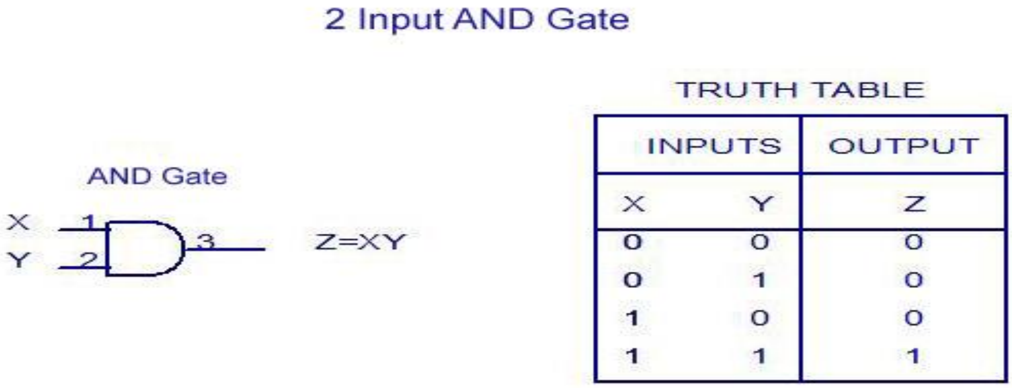


Figure 4.20: MZI Counter-propagating Gates[9]

CHAPTER 5: LOGIC GATES AND INTEGRATED CIRCUITS USING SOA

5.1 Design of AND gate using SOA

AND gate are the gates with the two or motre than two inputs and with the single output produced. AND logicgate logic generates 1 state output when each input is in 1 state and logic generates the output of 0 state, even if it has any input logic at 0 state. If the input is A and B, the output can be expressed as Z = AB. AND logic Gate has been designated as gate or all or nothing. Here we use port-1 and port-3 for input signal and ports 5/6 for output signal in Fig. 5.1The block diagram of two input AND logic gate is shown below and the truth table is also shown below[2].



INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1

Figure 5.1: AND Gate[2]

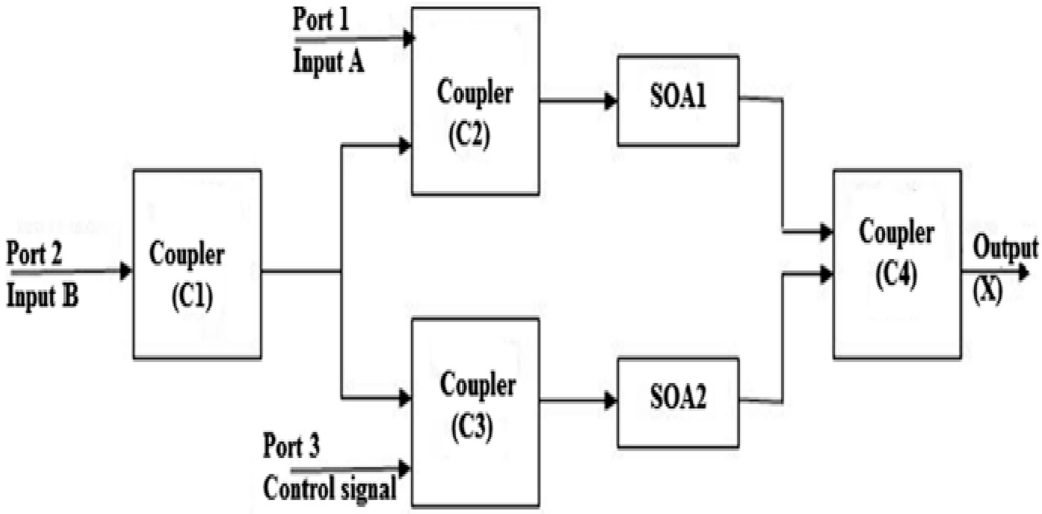


Figure 5.2: Block diagram for AND Gate realization

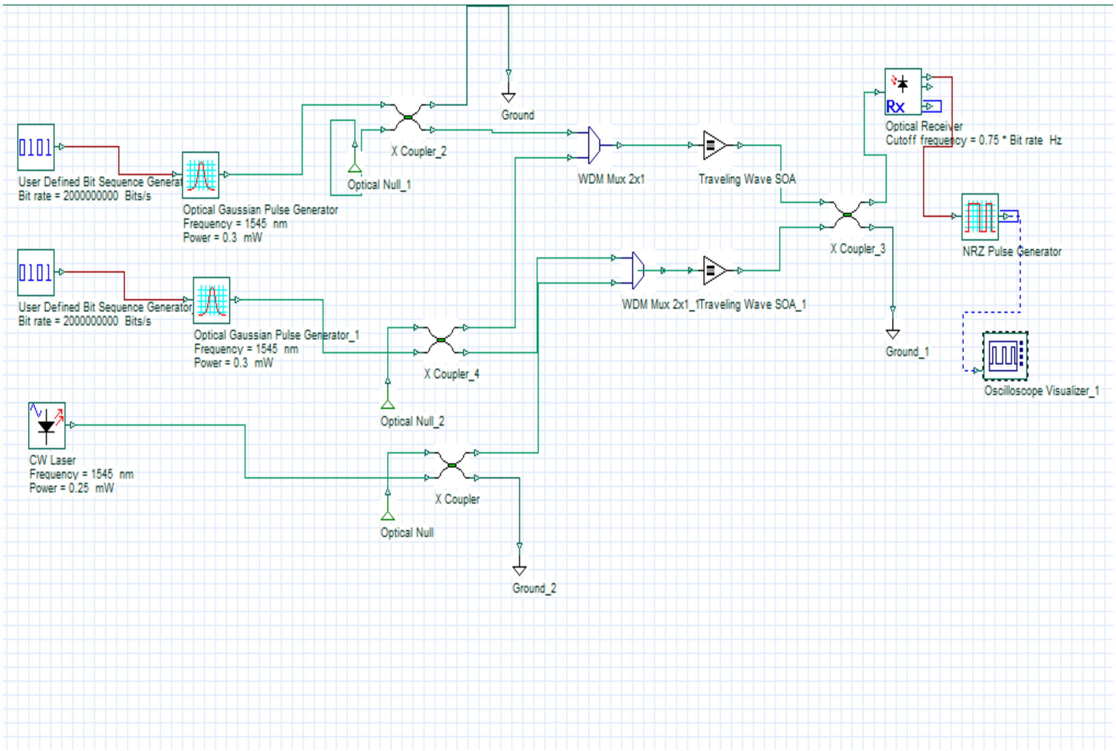


Figure 5.3: Layout for AND Gate realization

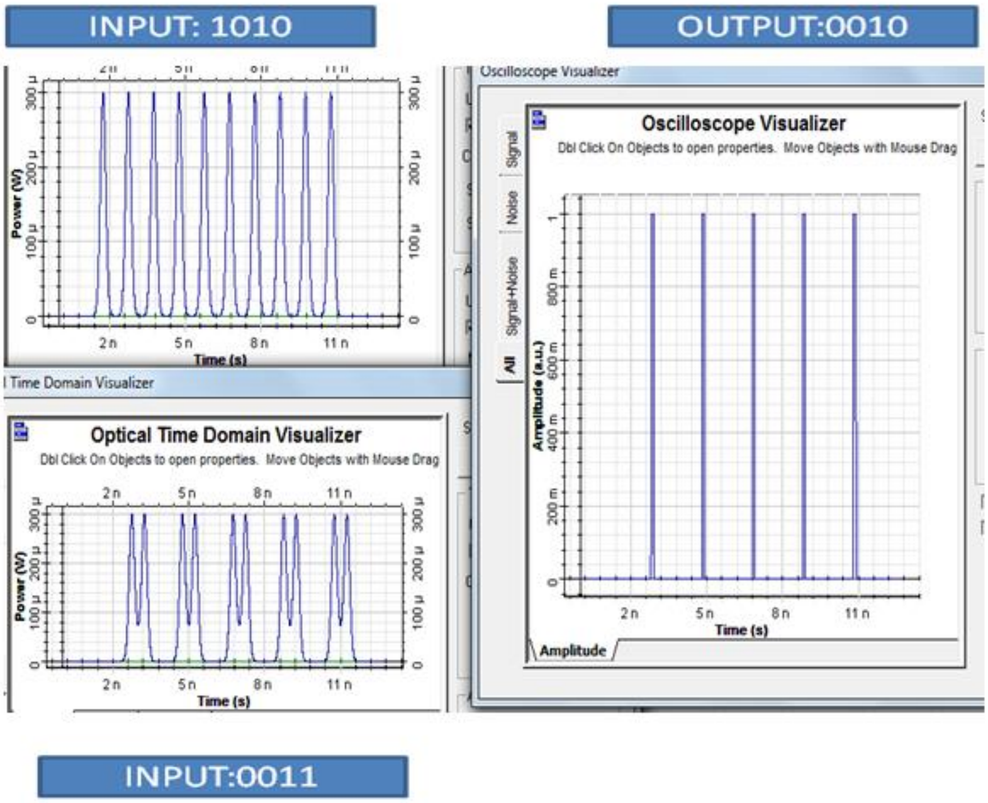
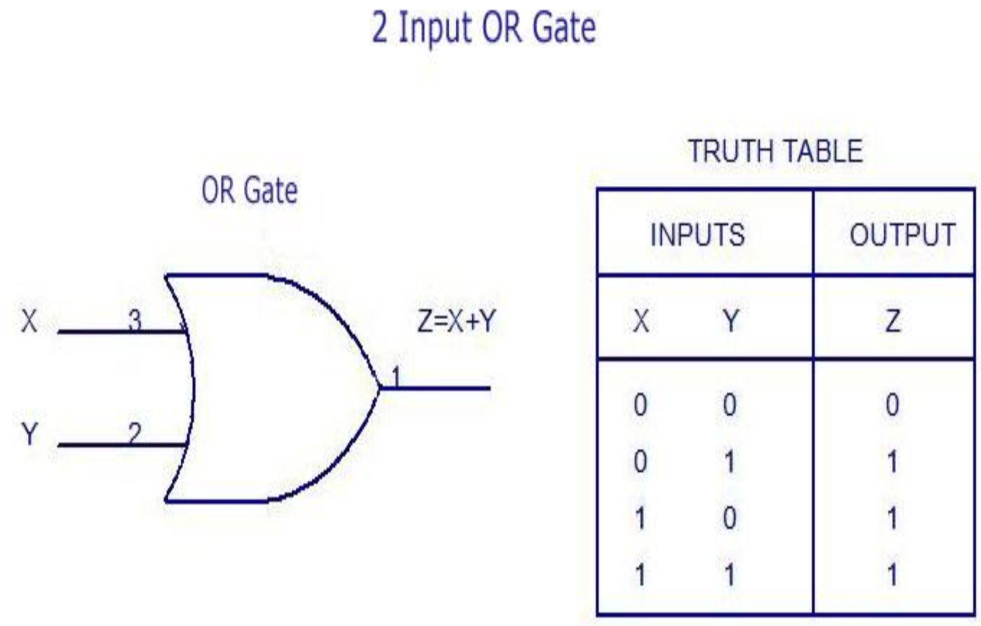


Figure 5.4: Input/Output of AND Gate

5.2 Design of OR gate using SOA

There are two or more inputs in the OR gate, but only one output is produced. OR gate logic generates ‘1’ state output, even if it has any of input logic as ‘1’ state and also produces the output as logic ‘0’ state if it has any input logic in 0 state. If the I/P are A and B, the output may be seen as Z = A+B. The OR logic gate can also be explained as an instrument who has an O/P ‘1’, even if it has an I/P ‘1’. The gate is also called as any or the all of the logic gate.



INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	1
1	0	1
1	1	1

Figure 5.5: OR Gate[2]

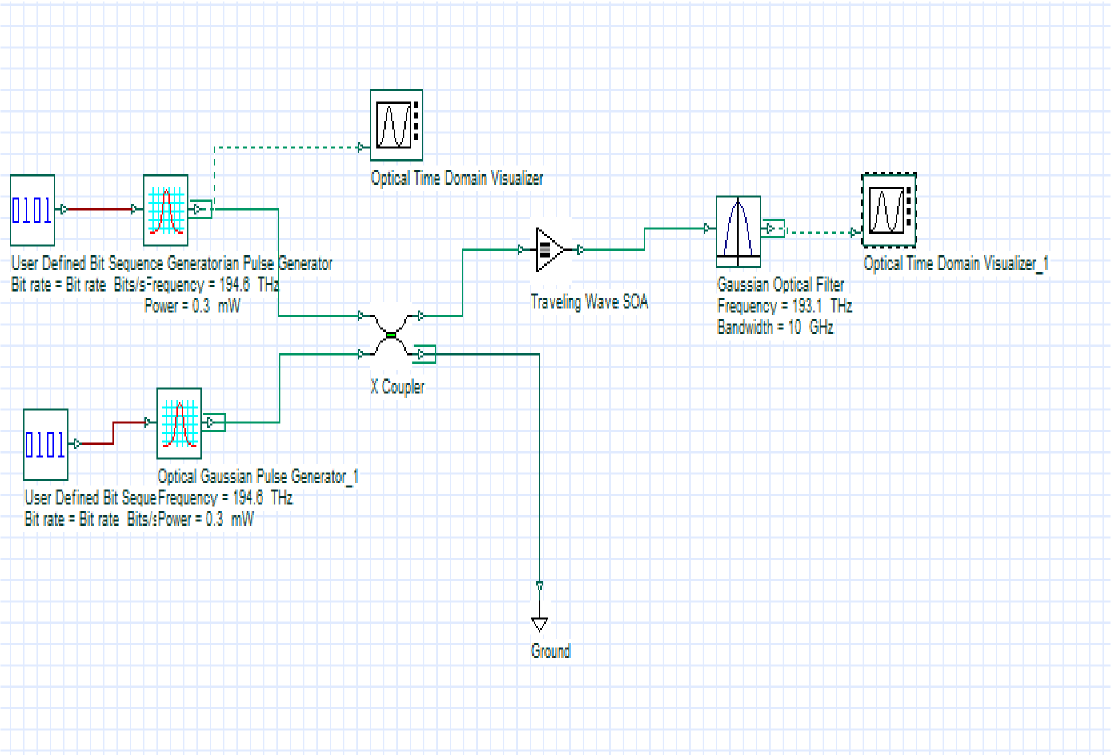
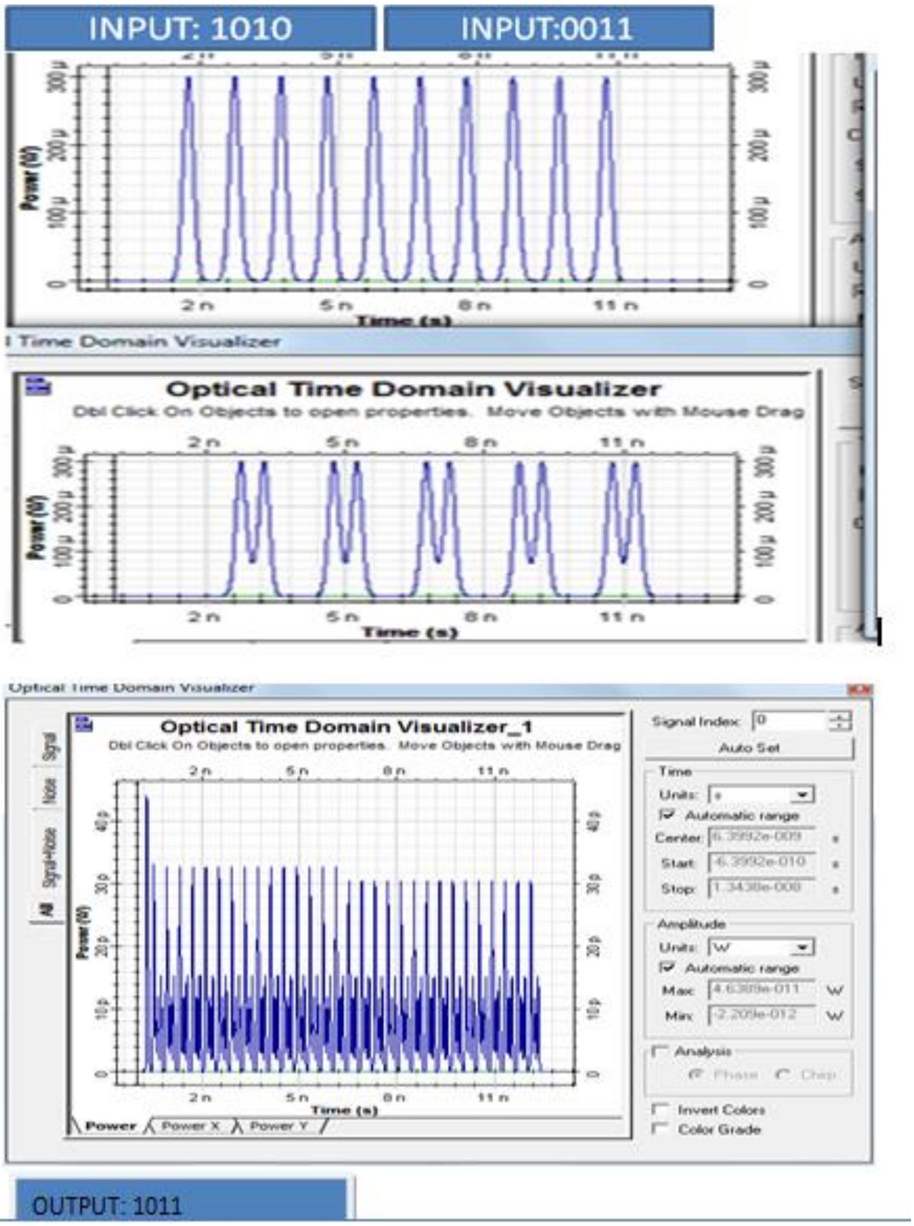


Figure 5.6: Layout for OR Gate realization



Signal Index: 0

Time
Units: s
☑ Automatic range
Center: 6.3992e-009 s
Start: -6.3992e-010 s
Stop: 1.3438e-008 s

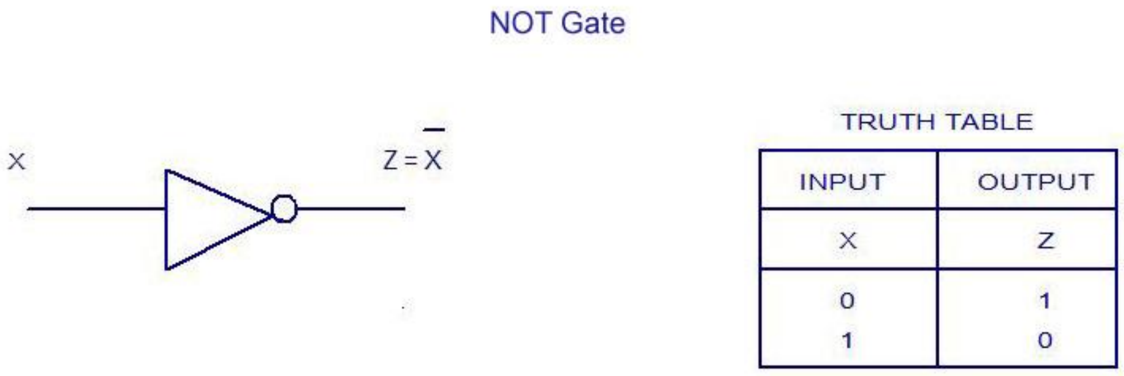
Amplitude
Units: W
☑ Automatic range
Max: 4.6389e-011 W
Min: -2.209e-012 W

☐ Analysis
☐ Invert Colors
☐ Color Grade

Figure 5.7: Input/Output of OR Gate

5.3 NOT GATE USING SOA

This gate may also be known by the name of inverter as it inverts the result. It changes the state to ‘1’ if the input is ‘0’ and vice versa. This inverter has a single output as well as single input. This inverter has O/P which is always appreciated by the input given. This means that the gate logic gives the state of ‘1’ state if the input state is of ‘0’ logic and when the state is of ‘1’ state, then the logic generates the state of 0 state[2]. Here we use port-1 for input signals and in Figure 4 uses port 4 for output signal.



INPUT	OUTPUT
X	Z
0 1	1 0

Figure 5.8: NOT Gate[2]

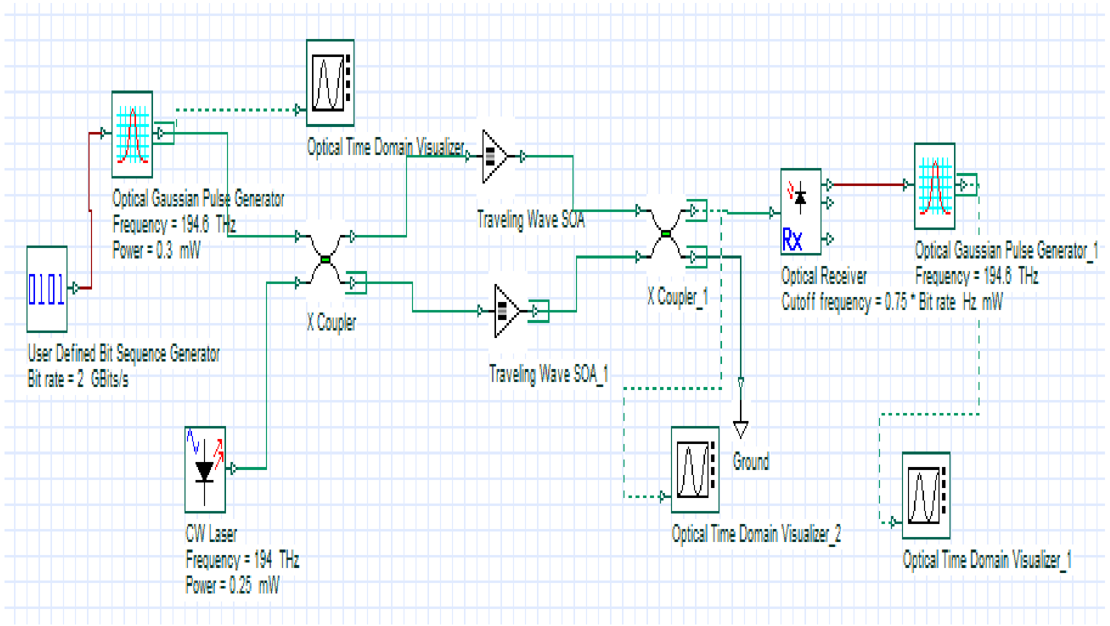


Figure 5.9: Layout for NOT Gate realization

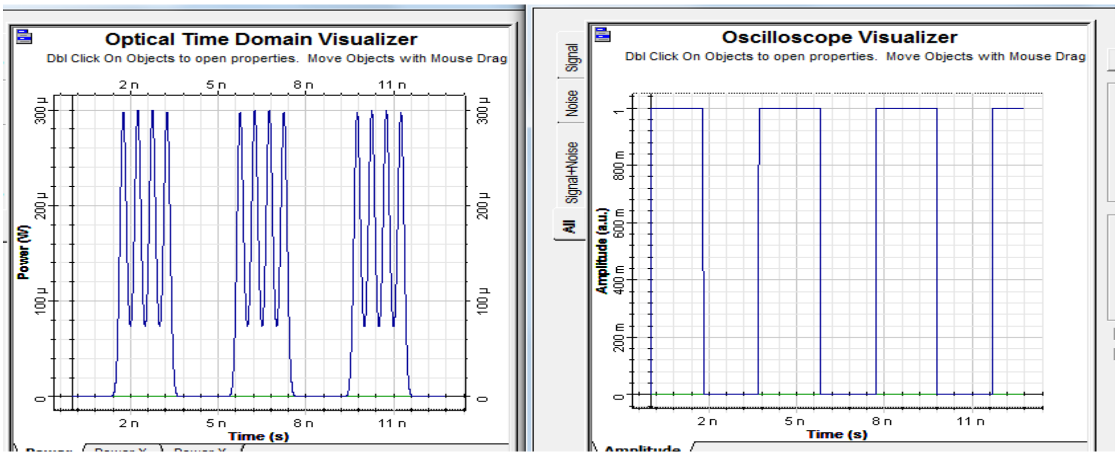
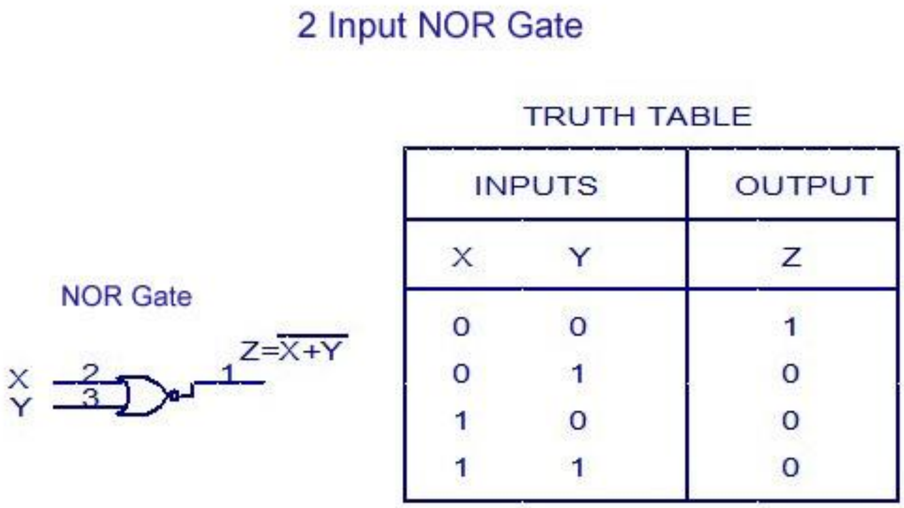


Figure 5.10: Input/Output of NOT Gate

5.4 NOR LOGIC GATE USING SOA

NOR means , the combination of OR gate and NOT gate. Output logic is 1 level, only when its each of the input logic values 0. For any other combination of input, the output is a logic level 0. Here we use port-1 and port-3 for input signals and port 5/6 for output signal in Fig. The truth table of two input NOR gate is given below[7].



2 Input NOR Gate

TRUTH TABLE

INPUTS		OUTPUT
X	Y	Z
0	0	1
0	1	0
1	0	0
1	1	0

Figure 5.11: NOR Gate[7]

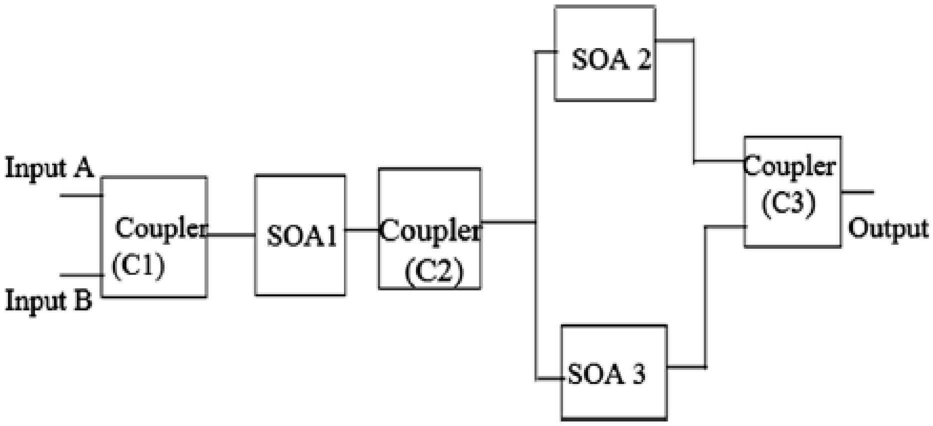


Figure 5.12: Block diagram for realization of NOR Gate

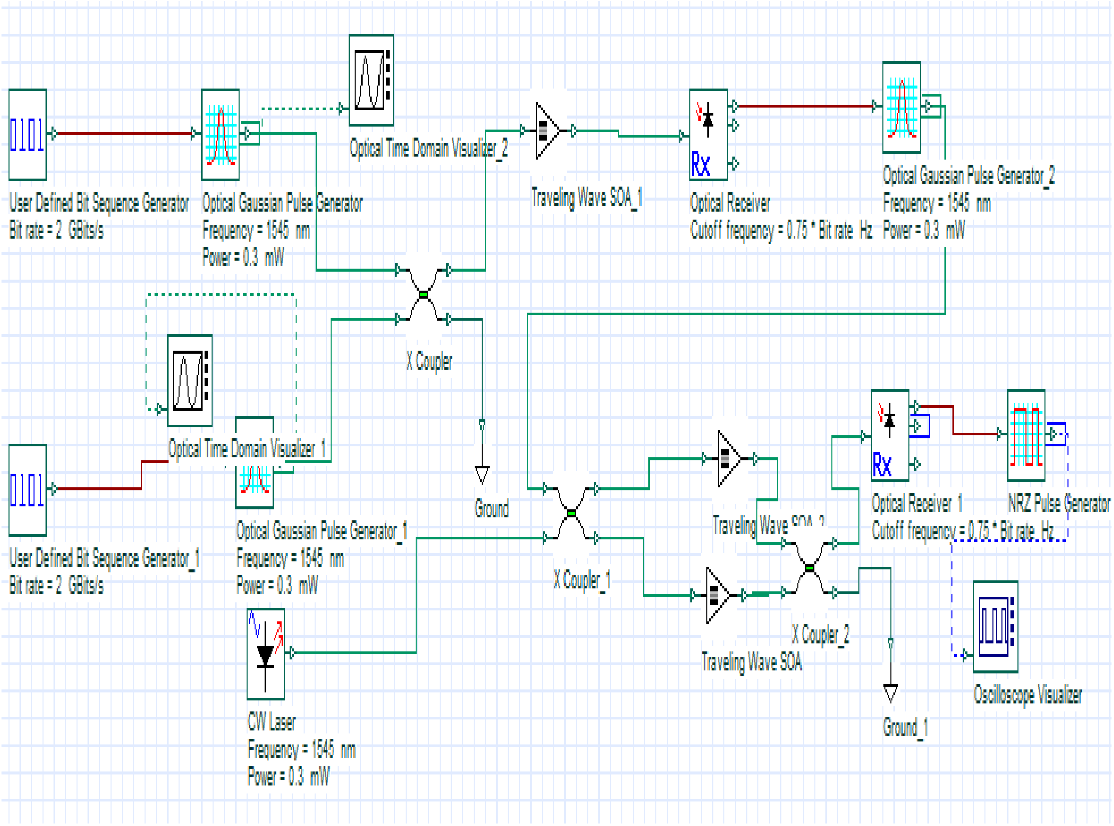


Figure 5.13: Layout for NOR Gate realization

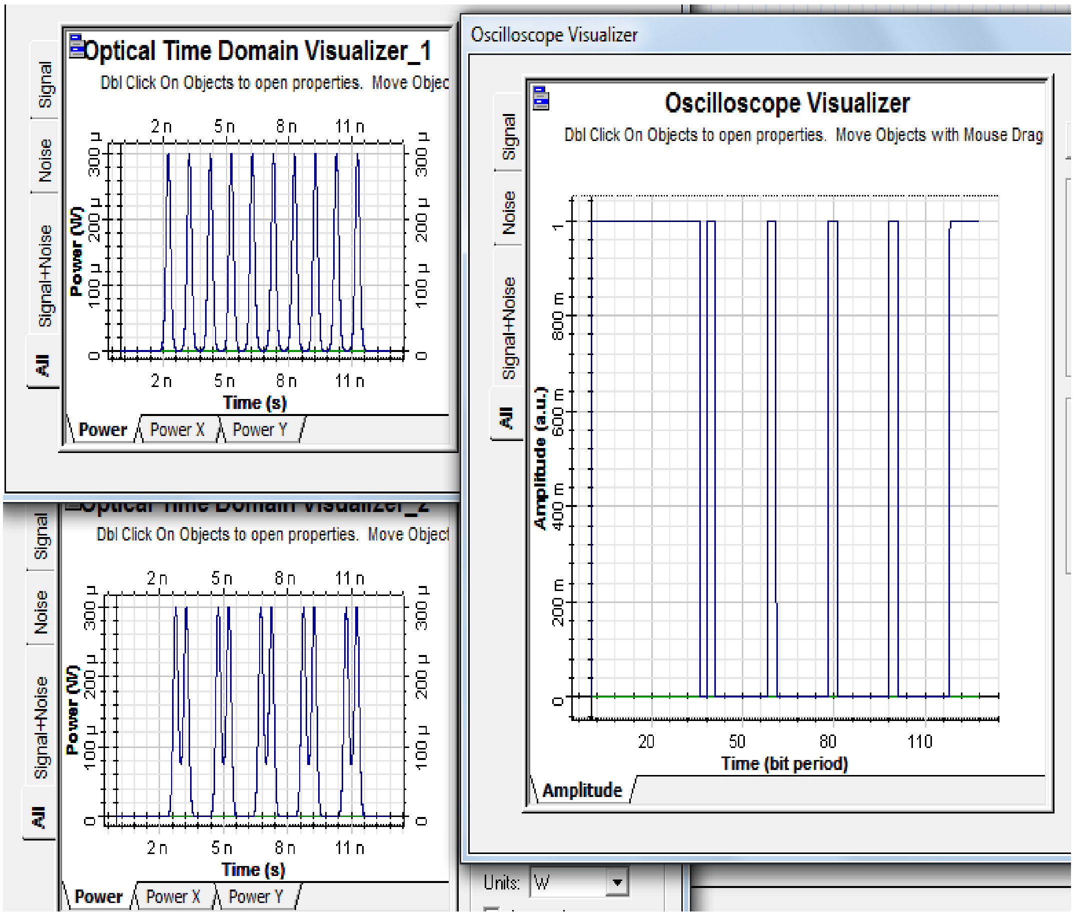
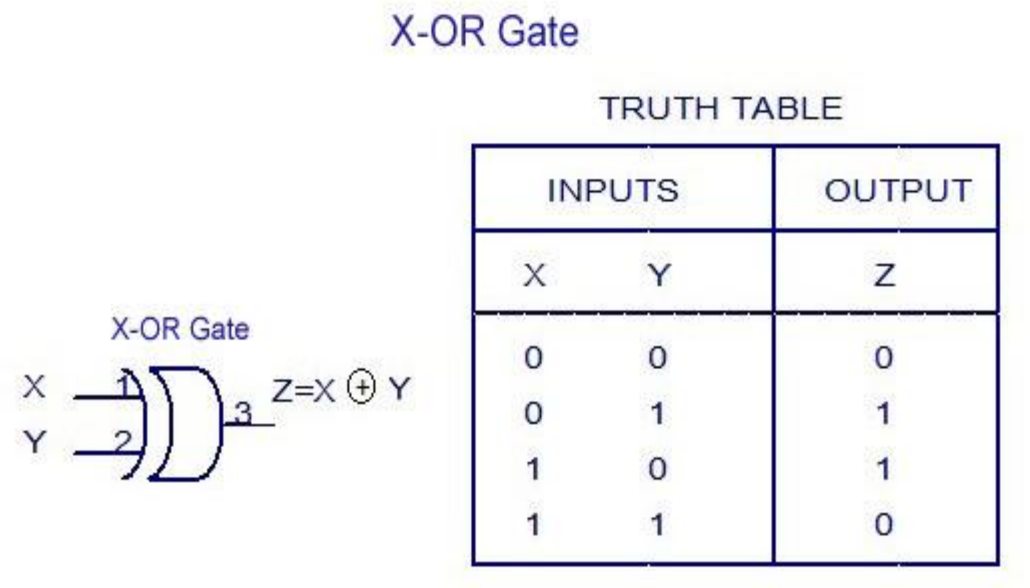


Figure 5.14: Input/Output of NOR Gate

The input given in port A is 0011 and port B is 1010 and the output attained is 1000.

5.5 XOR GATE

An XOR gate has two inputs, an produces an output logic state. In Xor gate if both the states are in state ‘0’ or ‘1’ then it will produce an zero output and if any of the input state is’1’ then it will produce ‘1’ as the output logic state. It is also called as Inequality Detector as well as coincidence logic gate [7]. It can also act as inverter by connecting one of two I/P points to the argument 1 and by giving the sequence on the other terminal. Here we use port-1 and port-3 for input signal and port 5/6 for output signal in Figure5.15 [7].



INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	1
1	0	1
1	1	0

Figure 5.15: XOR Gate[7]

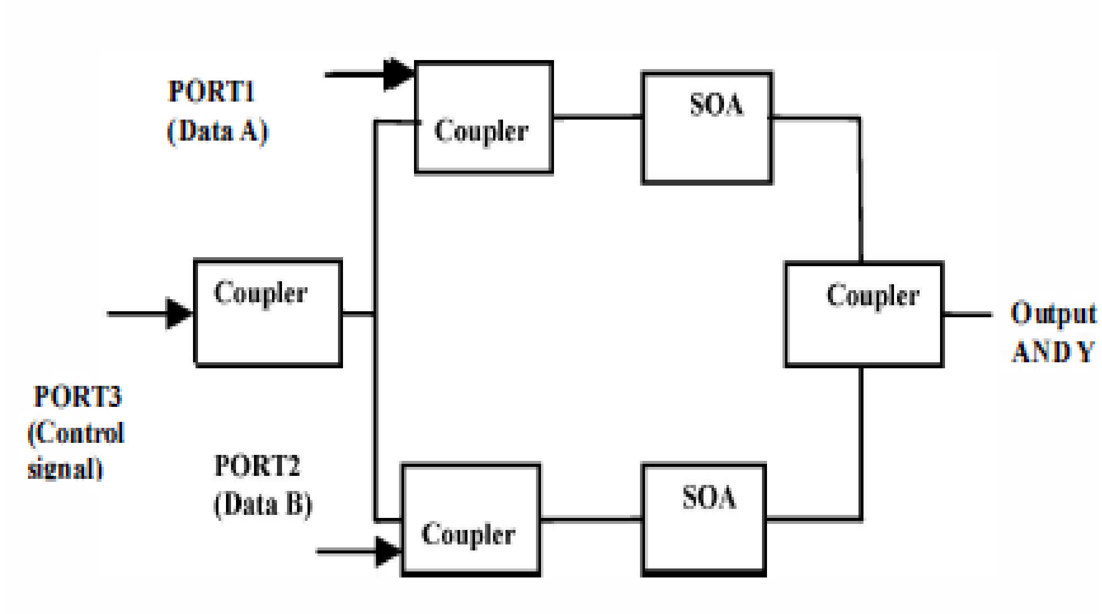


Figure 5.16: Block Diagram for XOR Gate realization

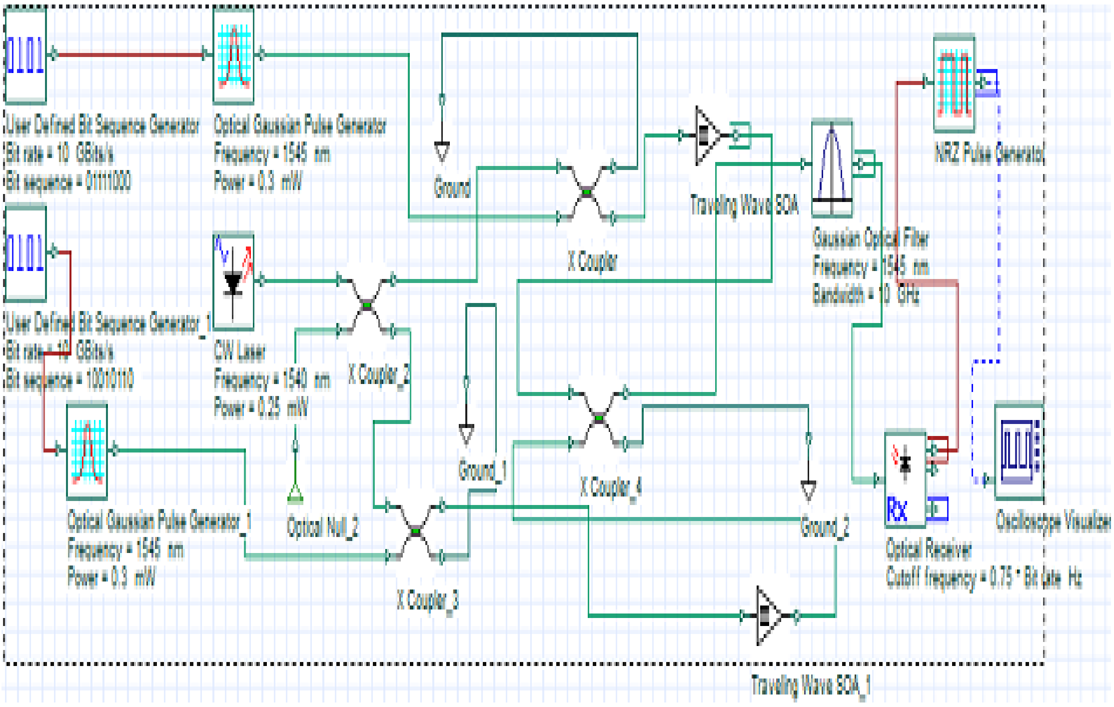
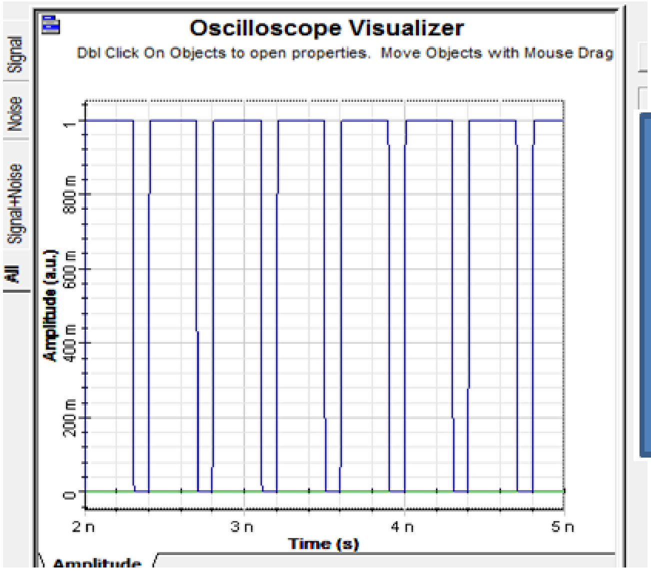


Figure 5.17: Layout for XOR Gate realization



Dbl Click On Objects to open properties. Move Objects with Mouse Drag

Input A= 01111000

Input B= 10010110

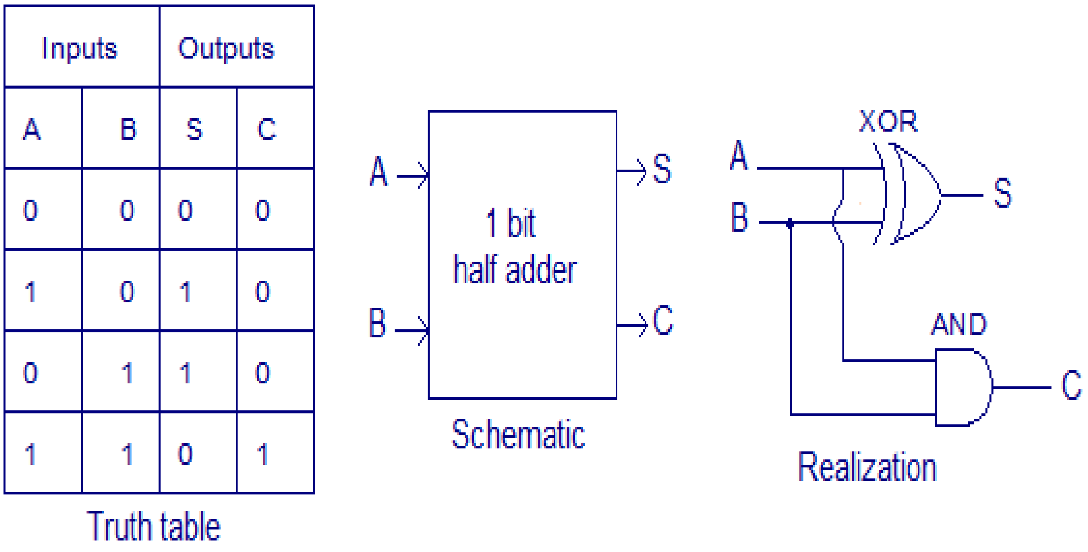
Output= 11101110

Figure 5.18: Input/Output of XOR Gate

5.6 Half adder Using Basic logic gates

To understand what half adders are, you need to know what is a connector first.It is an integral circuit which uses the various basic logic gates to produce the outputs. This integral circuit is used to add two number . It produces a carry as ‘c’ and a single bit as ‘S’. It is usually realized to add additional binary numbers, but they may also be made to add other formats like Binary Coded Decimal and XS-3. Even, lots of digital electronics Connector circuits are used for other applications, address coding and decoding, various table index calculation etc[3].

Half connector is a combination symmetric design that connects two states and gives output as one carry bit (C) and bit bit (S). Half adder is the one among the simplest of all the connecting circuits. Port-1 and Port-3 are used as input ports in here and Port-5 and Port-6 are used as output ports for both Half-Enter. Real table, schematic representation and perception of a half connector are given in the picture shown below.



Inputs		Outputs	
A	B	S	C
0	0	0	0
1	0	1	0
0	1	1	0
1	1	0	1

Figure 5.19: Half Adder[3]

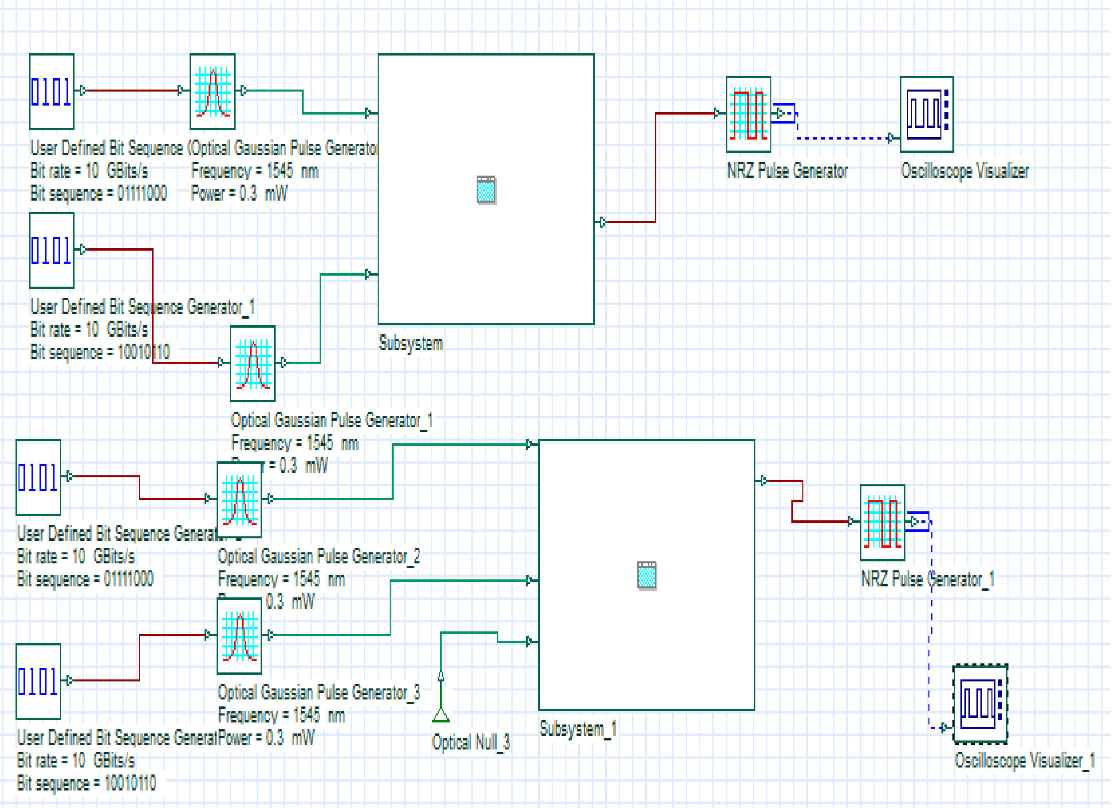
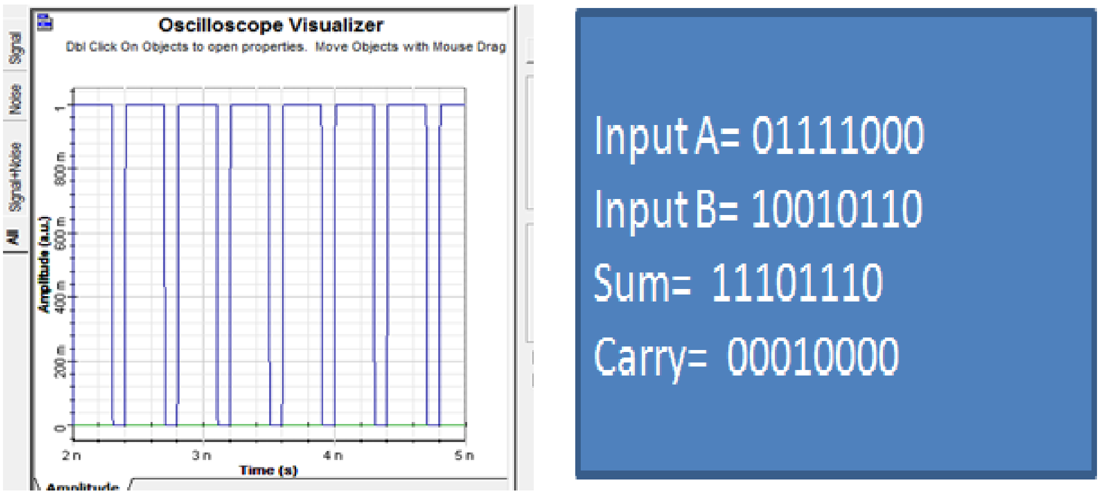


Figure 5.20: Layout for Half Adder realization



Input A= 01111000

Input B= 10010110

Sum= 11101110

Carry= 00010000

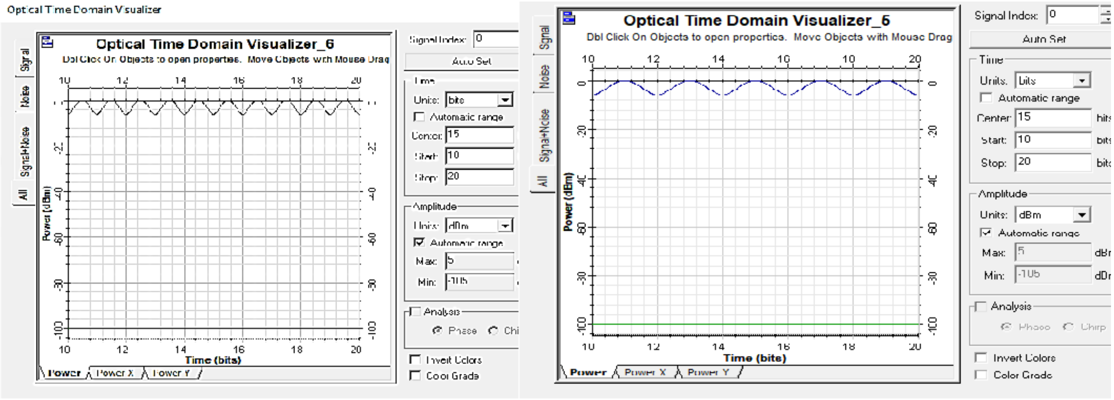
Figure 5.21: Sum Output of Half Adder

CHAPTER 6: PARAMETERS AFFECTING DESIGN RESULTS

6.1 Parameters Affecting Results

The various parameters which will affect the results are mentioned below[12]:

6.1.1 Bit Rate



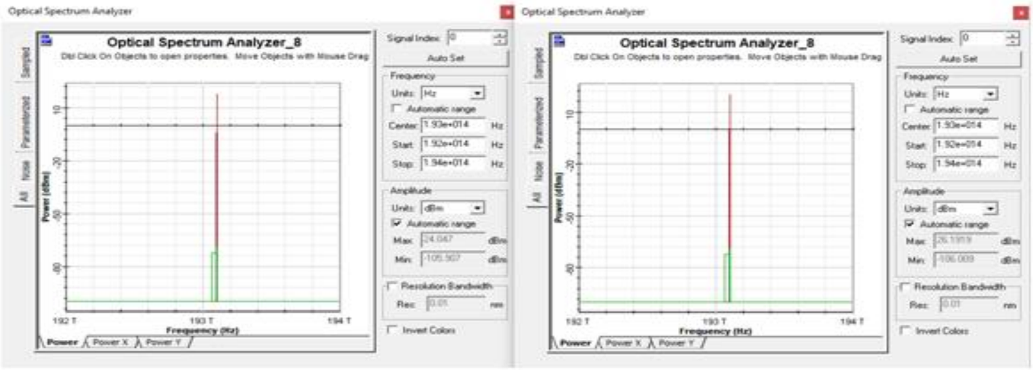
Signal Index: 0
Time
Units: bits
☐ Automatic range
Center: 15 bits
Start: 10 bits
Stop: 20 bits
Amplitude
Units: dBm
☑ Automatic range
Max: 5 dBm
Min: -105 dBm

BIT RATE = BIT RATE

BIT RATE = BIT RATE/2

Figure 6.1: Bit Rate Comparison

6.1.2 Frequency of Pump signal



Signal Index: 0
Frequency
Units: Hz
☐ Automatic range
Center: 1.93e+014 Hz
Start: 1.92e+014 Hz
Stop: 1.94e+014 Hz
Amplitude
Units: dBm
☑ Automatic range
Max: 24.047 dBm
Min: -105.907 dBm
☐ Resolution Bandwidth
Res: 0.01 nm

Max: 26.1959 dBm
Min: -106.009 dBm

Fa=Fb=200 THz

Fa=200 THz, Fb=150 THz

Figure 6.2: Pump frequency comparison

6.1.3 Power of pump signals (for a=1,b=1)

Table 6. 1 Output power w.r.t input pump signals

P_a (dbm)	**P_b (dbm)**	**Output power (dbm)**
20	20	16.920
10	20	16.976
0	20	17.000

6.1.4 Frequency of probe signal (CW laser)

- If there is a change in the frequency of probe signal, then we need to adjust the frequency of the filter used.
- So the frequency of the filter must be equal to the frequency of probe signal.
- If it is not equal, then it is difficult to realize the gate.

6.1.5 Power of probe signal (CW laser) (a=0,b=0)

Table 6. 2 Output power w.r.t probe signal

P_a (dbm)	**Output power (dbm)**
0	17.065
10	18.693
20	22.080

6.1.6 Bandwidth of the filters

- If bandwidth of filter is high, then we would get the side frequencies along with center frequency.
- If bandwidth of filter is low, then we would be some non linearity in the output.
- We have to optimize the bandwidth. Here we take bandwidth =10 Ghz.

6.1.7 EDFA length (a=0,b=0)

Table 6. 3 Output power w.r.t change in EDFA length

EDFA length (m)	Output power (dbm)
5	22.080
100	48.506
160	38.590

6.2 Effect of parameters on NOR Gate output

For implementing NOR Gate the following parameters are used and the output is shown in Table 6.4.

EDFA length = 5m, CW laser (power = 20 dbm, frequency =193.1 THz), for a (Frequency = 200 THz, power = 20 dbm), for b(Freq =150 THz, power =-20 dbm), for SOA (Injection current=0.8 A, active region length =0.0005 m).

Table 6. 4 Outputs power showing the behavior of NOR Gate

I/P (A)	I/P (B)	Output power (dbm)
0	0	27.485
0	1	18.520
1	0	18.607
1	1	18.397

These output powers on respective bits shows that above circuit is behaving as NOR gate.

CHAPTER 7: CONCLUSION AND FUTURE ASPECTS

7.1 Conclusion

In this dissertation work, various basic logic gates have been developed using SOA on Optisystem software and the results have been analysed based on the truth table of the respective gates. As the SOA is used due to its property of integrating large circuits, hence we have further designed and analysed integrated XOR gate and Half Adder.

It is even experimented that if we use an additional input beam of CW laser in XOR gate then the extinction ratio of the XOR gate is enhanced from 11db to 44.7db. Further it was seen that the speed of operation of various gates is 10Gbps which can be increased if we cascade multiple SOAs ion the circuit but this will increase the complexity of the circuit and design.

7.2 Future prospects

Further using these basic logic gates, Full adder and flip flops can be implemented. The present speed of operation is 10GBPS which is using single SOA. This speed is a limitation in this project. This limitation can be removed by using the process of cascading of multiple SOAs. The extinction ration can also be enhanced using an additional beam of CW laser as an input and this can be connected using a 3db coupler.

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