

Thesis Report
on
**Performance and Analysis of optical fiber communication system
using MZI switching**

Submitted in the partial fulfillment of the
requirement for the award of the Degree of

Master of Engineering
in
Electronics and Communication

Submitted by
Pradeep Kumar Teotia

Roll No.: 80761019

Under the esteemed guidance

Dr. R. S. Kaler
Professor



Department of Electronics and Communication Engineering
Thapar University

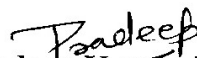
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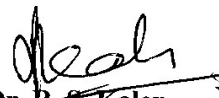
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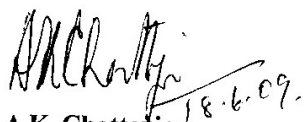
I hereby declare that the thesis report entitled “**Performance and analysis of optical fiber communication system using MZI switching**” is an authentic record of my study carried out as requirements for the award of degree of ME (Electronics and Communication) at Thapar University, Patiala, under the guidance of **Dr. R.S. Kaler** during final year, 2008-09.

Date: 12-06-09


Pradeep Kumar Teotia

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.


Dr. R. S. Kaler
Professor, ECED
Thapar University,
Patiala - 147004


Dr. A.K. Chatterjee
Prof. & Head, (ECED)
Thapar University,
Patiala - 147004


Dr. R. K. Sharma
Dean of Academic Affairs
Thapar University,
Patiala - 147004

DEDICATED TO MY GRANDFATHER & SISTER

SHRI RAJENDRA SINGH

&

SHELLY TEOTIA

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Words are often too less to reveal one's deep regards. An understanding of the work like this is never the outcome of the efforts of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this thesis.

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At the end, I would like to thank all the faculty members of the department and my all friends who directly or indirectly helped me in completion of my thesis

Pradeep Kumar Teotia

(Registration No. 80761019)

ABSTRACT

First a simple all-optical logic device, called Mach Zehnder Interferometer is composed by using a Semiconductor Optical Amplifier (SOA) and an optical coupler. This device is used for generating the logical functions (AND, XOR) and a multiplexer and an Encoder is obtained using this device in Optical Tree Architecture. The simulation of Encoder and Multiplexer is done at a rate of 10 Gbit/s and both are simulated for different input logical combinations. Simulations indicate that the device is suitable to operate at much higher bit rate and also for different logical entities.

A fiber communication system is employed using Giga Ethernet Passive Optical Network (GE-PON) architecture. In this architecture an optical fiber is employed directly from a central office to the home. A 1:8 splitter is used as a PON element which establishes communication between a central office to different users. In this chapter GE-PON architecture has investigated for different lengths from a central office to the PON in the terms of BER. For 10 Gbit/s system the plots between the BER and transmission distance is plotted and it is seen that as the distance increases beyond the 15 Km the BER is increased very sharply. Results in the form of Voice and Data spectrum for different users of FTTH with GE-PON architecture are shown.

Many lower-speed data streams can be multiplexed into one high-speed stream by means of Optical time division multiplexing (OTDM), such that each input channel transmits its data in an assigned time slot. The assignment is performed by a fast multiplexer switch (mux). The routing of different data streams at the end of the TDM link is performed by a demultiplexer switch (demux) and this demultiplexer is employed using MZI switch as it consists a semiconductor optical amplifier (SOA) and a optical coupler. In this chapter four channel OTDM is simulated at 40 Gbit/s and further it is investigated the impact of the signal power, pulse width and control signal power on BER.

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Chapter 1

INTRODUCTION

1.1 Introduction

In the information age, technologies seeing a relentless demand for networks of higher capacities at lower costs. Optical communication technology has developed rapidly to achieve larger transmission capacity and longer transmission distance. For that such data rates can be achieved if the data remain in the optical domain eliminating the need to convert the optical signals.[1] Therefore, to successfully be able to achieve higher data rates, advanced optical networks will require all optical ultra fast signal processing such as wavelength conversion, optical logic and arithmetic processing, add-drop function, etc. Various architectures, algorithms, logical and arithmetic operations have been proposed in the field of optical/optoelectronic computing and parallel processing in the last three decades. Nonlinear optical loop mirror (NOLM) provides a major support to optical switching based all optical logic and algebraic processing where the switching mechanism is based on fiber Kerr nonlinearities. [2] More efficient and compact solutions can be realized by all optical switching in semiconductor optical amplifiers (SOAs) where the non linear coefficient is much higher. Various SOA based switching configurations have been demonstrated earlier such as Tetrahertz optical asymmetric demultiplexers (TOADs), ultra-fast nonlinear interferometers (UNIs) and Mach-Zehnder interferometers (MZIs).[3] Among different topologies, monolithically integrated MZI switches represent the most promising solution due to their compact size, thermal stability and low power. In optical computing, optical interconnecting systems are the primitives that constitute various optical algorithms and architectures. Optical tree architecture (OTA) also takes an important role in this regard. So in this era of rapidly changing technology we represent a new alternative scheme which exploits advantages of both SOA-MZI and OTA, for implementation of all optical parallel logic and arithmetic operations of binary data. [4]

1.2 Mach Zehnder Interferometer

The Mach-Zehnder Interferometer is a device used to determine the phase shift caused by a small sample which is placed in the path of one of two collimated beams from a coherent

light source. A Mach-Zehnder Interferometer is created from two couplers connected by arms of unequal optical length. The Mach-Zehnder Interferometer has two input ports and two output ports. The light is split in the two arms of the input coupler of the interferometer, and they are later recombined in the output coupler of the interferometer. The optical length of the two arms is unequal, making the phase corresponding to delay in Fig.1.1 to be a function of wavelength. The relative phase of the light in the two input ports of the output coupler is therefore a function of wavelength. As the phase of the delay (d) is increased, the MZI cycles between the cross state, where most of the light appears in the waveguide on the same side as the input, and the bar state, where most the light moves to the waveguide on the other side.

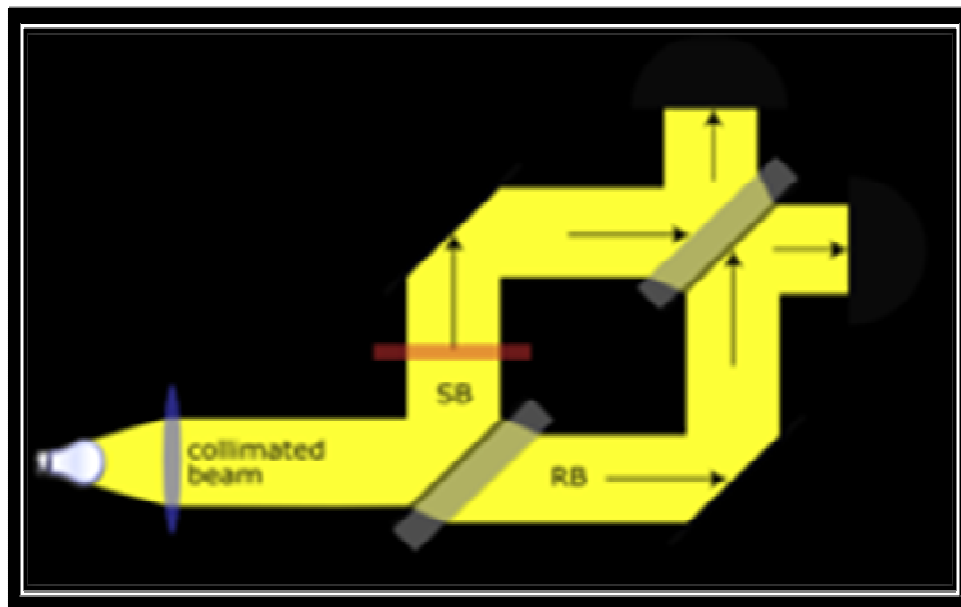


Fig 1.1 Diagram of MZ Inferometer

Extensive research has been carried out over the years in developing practical optical time division multiplexing (OTDM) systems considering its vast potential in future high-speed photonic networks [5]. They have used periodically poled lithium niobate (PPLN) hybrid integrated with planer light wave circuit (PLC) for multiplexing of different channels and studied an all channel multiplexer (MUX) and de-multiplexer (DEMUX) systems. Important characteristics of optical switches include extinction ratio, insertion loss, crosstalk, and switching time. The performance of optical switches is compared on basis of these parameters. Important characteristics of optical switches include extinction ratio, insertion loss, crosstalk, and switching time. The performance of optical switches is compared on basis of these parameters. Investigations revealed that among all the switches symmetric Mach–

Zehnder (SMZ) were found to be most suitable because of compact size, thermal stability, and low power operation analysis [6]. It was also outlined that SMZ has symmetric switching window and hence it is less vulnerable to jitter. The main advantage of SMZ structure over other interferometric switches like terahertz optical asymmetric de-multiplexer (TOAD) is that SMZ can be easily integrated on to a single photonic chip. [7] It is important to mention that OTDM is a time synchronized system and proper signal recovery cannot be achieved without synchronization between the transmitter and the receiver. Inclusion of optical fiber would involve a time delay incurred due to propagation of the signal over the fiber. So we proposed a idea of OTDM system using SMZ switching as this system involves an all channel independent MUX propagation on a fiber of given length and all channel DEMUX.[8]

1.3 SWITCHING

A network is a set of connected devices. Whenever multiple devices require the problem to connect them to make one-to-one communication possible, then switching is used. The number and length of the links require too much infrastructure to be cost efficient, and the majority of these links would be most of the time. Other topologies employing multipoint connections, such as bus, are ruled out because the distances between devices and the total number of the devices increase beyond the capacities of the media and equipment. A better solution is switching. A switched network consists of a series of interlinked nodes, called switches. Switches are capable of creating temporary connections between two or more devices linked to the switch.

It is of three types

1. **Circuit Switching:** In the circuit switching the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase. Circuit Switching takes place at the physical layer. Data transferred between the two stations are not packetized. The data are a continuous flow sent by the source station and received by the destination station, although there may be periods of silence. There is no addressing involved during data transfer. The switches route the data on their occupied band (FDM) or time slot (TDM)

2. Packet Switching: In Packet switching, there is no resource allocation for a packet. This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet. Resources are allocated on demand. This allocation is done on a first come, first serve basis. It is of two types [9]

a. **Datagram Switching:** In datagram switching, each packet is treated independently of all others. Even if a packet is a part of a multi packet transmission, the network treats it as though it existed alone. Packets in this approach are referred to as datagrams. [10]

b. **Virtual Circuit Switching:** This type of switching consists of both type of advantage of circuit switching and datagram switching. In virtual-circuit switching, all the packets belonging to the same source and destination travel the same path; but the packets may arrive at the destination with different delays if resource allocation is on demand. [10]

3. Cell Switching: This type of switching consists of transferring of data in form of small packets as the disadvantage of the Packet switching is that the size of the packet is large it consists of around 65000 bytes so it is too large to sending the packet and packet switching is connectionless service so it is not so economical to send this large amount of data because loss of the data in form of packet can be possible, so to overcome of this problem the new technique is used named as cell switching, in this packets are send in small size of 53 bytes as ATM technique uses this technique, the main advantage of cell switching is that it is also connectionless service but provides a better speed of 155.52 Mbps but also increased in multiple of $N \times 4$. [9]

1.4 SEMICONDUCTOR OPTICAL AMPLIFIER

Semiconductor optical amplifiers are amplifiers which use a semiconductor to provide the gain medium. Recent designs include anti-reflective coatings and tilted waveguide and window regions which can reduce end face reflection to less than 0.001%. Since this creates a loss of power from the cavity which is greater than the gain it prevents the amplifier from acting as a laser. Such amplifiers are often used in telecommunication systems in the form of fibre-pigtailed components, operating at signal wavelengths between 0.85 μm and 1.6 μm and generating gains of up to 30 dB [11]. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc. However, the performance is still not

comparable with the EDFA. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time. This originates from the short nanosecond or less upper state lifetime, so that the gain reacts rapidly to changes of pump or signal power and the changes of gain also because phase changes which can distort the signals. This nonlinearity presents the most severe problem for optical communication applications. However it provides the possibility for gain in different wavelength regions from the EDFA. [11]

1.5 CATEGORIES OF SWITCH

1.5.1 MZI Switch

The Mach-Zehnder interferometer (MZI) based switch consists of a 3 dB splitter and a 3 dB combiner, connected by two interferometer arms. By changing the effective refractive index of one of the arms, the phase difference at the beginning of the combiner can be changed, such that the light switches from one output port to the other. This switch has the advantage that the phase shifting part and the mode coupling part are separated, such that both can be optimized separately. A small effective refractive index change in the interferometer is sufficient for the switching. The disadvantages are its length and the accurate refractive index change that is required for switching. When multimode interference couplers are employed as



Fig 1.2 Mach-Zehnder interferometer based switch

3 dB splitter and combiner, a fabrication tolerant and polarization insensitive wave guiding structure is obtained. A low power data signal is focused into the central input waveguide such that it splits into two equal parts at the Y-junction power splitter. These two beams then propagate through the two arms of the Mach- Zehnder and recombine constructively at the

output Y-junction power combiner and propagate along the output waveguide. A high power control signal is also focused into one of the outer wave guides to produce a nonlinear refractive index change in the waveguide via the nonlinear optical Kerr effect. This produces a phase difference between the two data signals at the output Y junction causing them to interfere destructively when the phase difference between them is π radians. Under this condition, the data signal is coupled into radiation modes and the output falls to zero. Subsequently the device may be used as a modulator. [11, 12, 13, 14]

1.5.2 DC Switch

In a directional coupler switch two adjacent waveguides are designed such, that the light can be transferred from one waveguide to the other by coupling. The switching is obtained by properly adjusting the effective refractive index of one of the waveguides. For switching only a small refractive index change is needed. For a good transfer of the light, an accurate coupling length is required. Since this length is usually polarization and wavelength dependent and strongly influenced by fabrication deviations (etch depth, waveguide spacing), a good switch performance is hard to obtain. [11, 12, 13, 14]

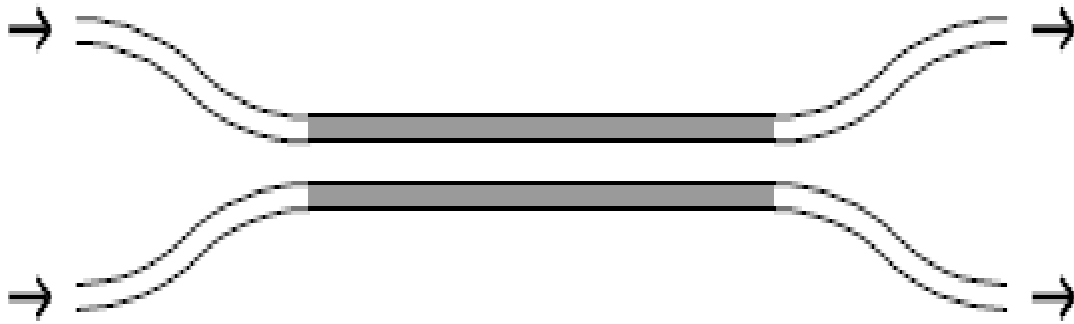


Fig 1.3 Directional Coupler Switch

1.5.3 SOA based MZI Switch

A semiconductor optical amplifier can both be used for amplification and attenuation of an optical signal, by turning the gain on and off. This property can be employed for a simple but effective way of switching by splitting an optical signal with a 3 dB splitter, after which this signal is attenuated in one arm and amplified in the other arm (Fig. 1.4). Since the splitter losses and additional losses (e.g. fibre-chip coupling loss) can be compensated by the SOA,

this type of switch can have low loss or even gain and, in addition, excellent on-off ratios leading to low crosstalk levels. The most important disadvantage of a SOA switch is its high additional noise level in the “on” state caused by spontaneous emission generated in the SOA.[11, 12, 13, 14]

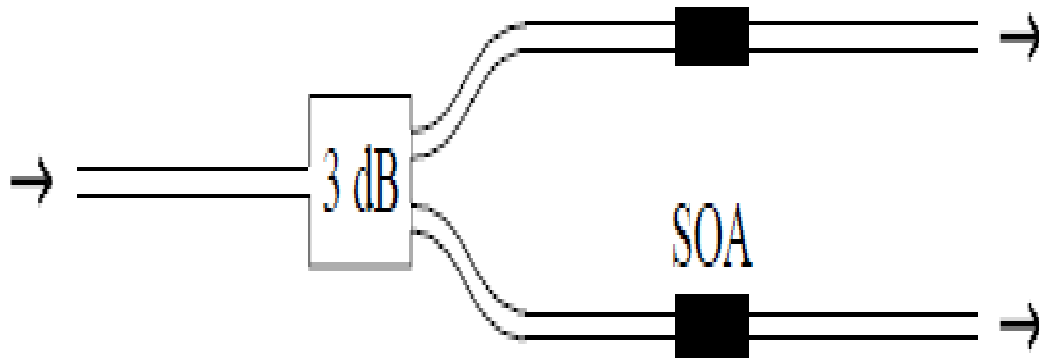


Fig 1.4 SOA based MZI Switch

1.6 FTTH with GE-PON:

Optical fibers, clearly the chosen technology for transmission media, are beginning to find their place in the subscriber’s loop. Currently fiber costs are high as compared to copper but there is a trend towards decreasing costs of optical fiber cables and photonics employed. In addition the tremendous advantage in terms of information capacity of fiber, its small weight and size over copper cable are making it a very attractive technology to replace copper in subs loop when advanced broadband services need to be offered to the customer. To carry the same information as one fiber cable we would need hundreds of reels of twisted wire of Cu cables. In crowded city networks they can easily be accommodated in existing ducted systems.

FITL (Fiber In The Local Loop) can be developed in several configurations

1. Fiber to the Curb (FTTC)

Fiber to the Curb in which the terminal equipment is located on the curb from where it would be convenient to serve a suitable service area. Since the distribution would still be copper, suitable location for the terminal would be one which optimizes the cost, reduces back feeding, reduces distribution cost and takes safety factors into consideration. Space and power availability need to be confirmed before finalizing the location

2. Fiber to the Building (FTTB)

Fiber to the Building in which the terminal equipment is located inside a multi storied building. This brings the higher bandwidth closer to the subscriber. The distribution part is still copper. For new buildings, the planners may negotiate for suitable location well in time. [57]

3. Fiber to the Home (FTTH)

Fiber to the Home in which the fiber goes upto the subscriber premises.

4. Fiber to the Office (FTTO)

Fiber to the Home in which the fiber goes upto the office/subscriber premises.

A PON consists of an Optical Line Terminal (OLT) at the service provider's central office and a number of Optical Network Units (ONUs) near end users. A PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures.

a. OLT: The OLT resides in the Central Office (CO). The OLT system provides aggregation and switching functionality between the core network (various network interfaces) and PON interfaces. The network interface of the OLT is typically connected to the IP network and backbone of the network operator. Multiple services are provided to the access network through this interface

b. ONU/ONT: This provides access to the users i.e. External Plant/Customer Premises equipment providing user interface for many/single customer. The access node installed within user premises for network termination is termed as ONT. Whereas access node installed at other locations i.e. curb/cabinet/building, are known as ONU. The ONU/ONT provide, user interfaces (UNI) towards the customers and uplink interfaces to uplink local traffic towards OLT.

c. Splitter: Distributed or single staged passive optical splitters/combiners provide connectivity between the OLT & multiple ONU/ONTs through one or two optical fibers. Optical splitters are capable of providing up to 1:64 optical split, on end to end basis. These are available in various options like 1:4, 1:8, 1:16, 1:32 and 1:64.

d. NMS: Management of the complete PON system from OLT

- One OLT serves multiple ONU/ONTs through PON
- TDM/TDMA protocol between OLT & ONT

- Single Fiber/ Dual Fiber to be used for upstream & downstream
- Provision to support protection for taking care of fiber cuts, card failure etc.
- Maximum split ratio of 1:64
- Typical distance between OLT & ONU can be greater than 15 Km
- Downstream transmission i.e. from OLT to ONU/ONT is usually TDMA
- PON system may be symmetrical or asymmetrical
- PON and fiber infrastructure can also be used for supporting any one way distributing services e.g. video at a different wavelength

PON is configured in full duplex mode in a single fiber point to multipoint (P2MP) topology. Subscribers see traffic only from head end and not from each other. The OLT (head end) allows only one subscriber at a time to transmit using Time Division Multiplex Access (TDMA) protocol. PON systems use optical fiber splitter architecture, multiplexing signals with different wavelengths for downstream and upstream. [28, 55, 57]

Different Types of PON

1. **APON (ATM Passive Optical Network):** This was the first Passive optical network standard. It was used primarily for business applications, and was based on ATM
2. **BPON (Broadband PON):** It is a standard based on APON. It adds support for WDM, dynamic and higher upstream bandwidth allocation, and survivability. It also created a standard management interface, called OMCI, between the OLT and ONU/ONT, enabling mixed-vendor networks.
3. **EPON or GEPON (Ethernet PON):** It is an IEEE/EFM standard for using Ethernet for packet data. 802.3ah is now part of the IEEE 802.3 standard. There are currently over 15 million installed EPON ports
4. **GPON (Gigabit PON):** It is an evolution of the BPON standard. It supports higher rates, enhanced security, and choice of Layer 2 protocol (ATM, GEM, and Ethernet).
5. **10G-EPON (10 Gigabit Ethernet PON):** It is an IEEE Task Force for 10Gbit/s, backward compatible with 802.3ah EPON. 10GigEPON will use separate wavelengths for 10G and 1G downstream. 802.3av will continue to use a single wavelength for both 10G and 1G upstream with TDMA separation. Compatibility with WDM-PON is out of the scope of 802.3av 10G-EPON. It is also out of the scope to use multiple wavelengths in each direction.

EPON & GEAPON Applications:

- High speed Internet
- Transparent LAN Service
- Broadcast Service
- Multi-Play (Voice, Video, Data etc.)
- TDM Telephony
- Video on Demand
- Online gaming
- IPTV
- Wireless Services
- Wireless Backhaul over PON

1.6 OPTSIM

Optsim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications. It can be used to design optical communication systems and simulate them to determine their performance considering various component parameters. Optsim is designed to combine the greatest accuracy and modeling power with ease of use on both Windows and UNIX platforms. Optsim represents an optical communication system as an interconnected set of blocks, with each block representing a component or subsystem in the communication system. As physical signals are passed between components in a real world communication system, “signal” data is passed between component models in the Optsim simulation.

1.6.1 Simulation

Optsim provides multiple simulation engines that provide complementary simulation techniques. This enables the greatest flexibility in modeling and simulating systems ranging from short-distance data communication links, to ultra long-haul DWDM telecom systems, to

large metro networks with feedback paths and EDFA transients due to adding and dropping of channels.

1.6.2 Analysis

Data Post-Processing and Display OptSim's data post-processing and display facilities provide an intuitive and flexible measurement graphical interface that acts as a lab-like set of virtual instruments. Interactive and post-processing functionality (e.g. graph superimposition, correlation graphs, interactive cursor read-out data, peak search, eye-diagram measurements, BER/Q evaluation) allow one to simulate the project once and perform further analysis of results later (saving time during the design process).

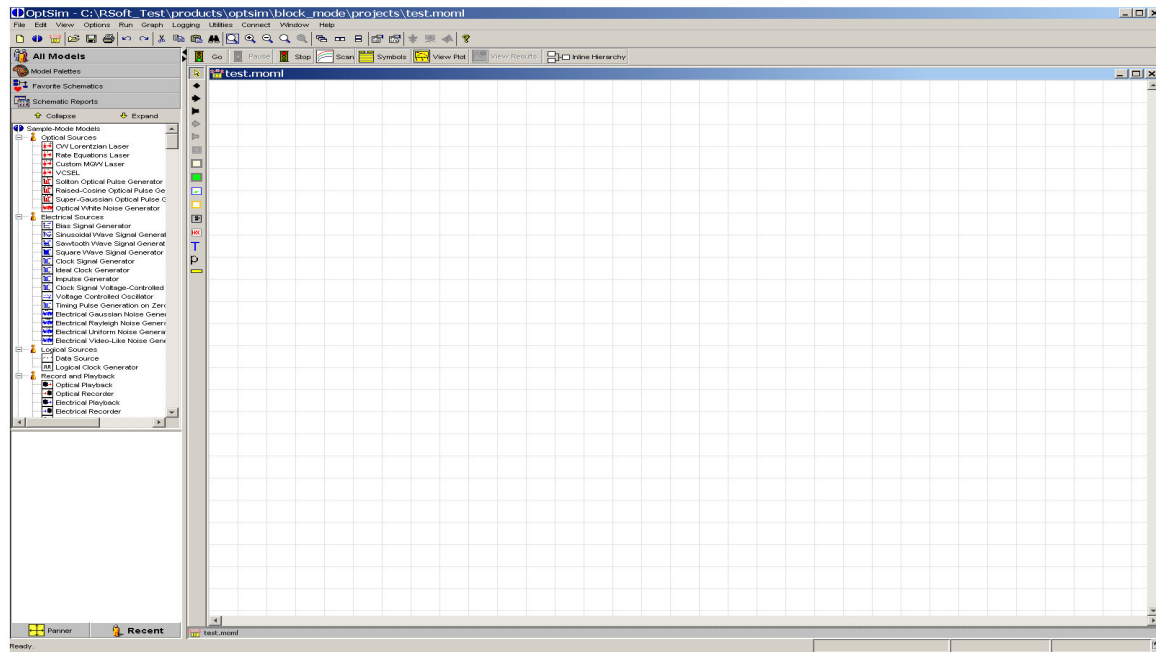


Figure 1.5 The Optsim graphical editor

CHAPTER 2

LITERATURE SURVEY

2.1 All-Optical Logic by MZI switch

Koji Igarashi et al. described optical signal processing based on optical phase modulation and subsequent optical filtering, which is applicable to 160-Gb/s optical time-division multiplexed (OTDM) subsystems. Ultrafast phase modulation of an optical signal is done by self-phase modulation (SPM) and cross-phase modulation (XPM) when an optical pulse passes through a nonlinear optical fiber. Such phase modulation induces the spectral shift of the optical signal. [3]

Jian Wang et. al. presented ultrafast logic AND gate for carrier-suppressed return-to-zero (CSRZ) signals by exploiting two kinds of cascaded second-order nonlinearities in a periodically poled lithium niobate (PPLN) waveguide. The analytical solutions are derived under the nondepletion approximation clearly describing the principle of operation. First, based on cascaded second-harmonic generation and difference-frequency generation (CSHG/DFG) in a PPLN, an all-optical 40 Gbit/s CSRZ logic AND gate is successfully implemented in the experiment and verified by numerical simulations. It is found that the converted idler, taking the AND result, keeps the CSRZ modulation format unchanged. Second, by using cascaded sum- and difference-frequency generation (CSFG/DFG) in a PPLN. [18]

By modifying the design of an existing two-input nano photonic AND gate, whose operation is based on optical near-field (ONF) interactions among three neighboring quantum dots (QDs), they improved the gate ON/OFF ratio by up to about 9 dB. To do this, Arash Karimkhani et al. have eliminated the possibility of direct ONF interaction between the input and output dots. Then, by adding another QD, as the second control dot to both existing and the modified two-input architectures, they proposed two new three-input nanophotonic AND gate schemes—one with direct ONF interaction between its input and output dots, and the other without such interaction. Although, the former gate turns on relatively faster, one of its three possible ON/OFF ratios are shown to be about 7.3 dB lower than the latter. The differences in two other possible ON/OFF ratios of the two new gates were insignificant. [19]

Haijiang Zhang et. al. represented for the first time to our knowledge, the operation of a cascadable, low-optical-switching-power ($\sim 10 \mu\text{W}$) small-area ($\sim 100 \mu\text{m}^2$) high-speed (80 ps fall time) all-optical inverter. This inverter employs cross-gain modulation, polarization gain anisotropy, and highly nonlinear gain characteristics of an electrically pumped vertical-cavity semiconductor optical amplifier (VCSOA). The measured transfer characteristics of such an optical inverter resemble those of standard electronic metal-oxide semiconductor field-effect transistor-based inverters exhibiting high noise margin and high extinction ratio ($\sim 9.3 \text{ dB}$), making VCSOAs an ideal building block for all-optical logic and memory. [20]

Woon-Kyung Choi highlighted the latching optical switches and optical logic gates with AND and OR functionality, they demonstrated for the first time by the monolithic integration of a vertical cavity lasers with depleted optical thyristor structure. The thyristors have a low threshold current of 0.65 mA and a high on/off contrast ratio of more than 50 dB. By simply changing a reference switching voltage, this single device operated as two logic functions, optical logic AND and OR. The thyristor laser fabricated by using the oxidation process and has achieved high optical output power efficiency and a high sensitivity to the optical input light. [21]

Deqiang Song et al reported the operation of an all-optical set-reset (SR) flip-flop based on vertical cavity semiconductor optical amplifiers (VCSOAs). This flip-flop is cascadable, has low optical switching power ($\sim 10 \mu\text{W}$), and had the potential to be integrated on a small footprint ($\sim 100 \mu\text{m}^2$). The flip-flop was composed of two cross-coupled electrically pumped VCSOA inverters and used the principles of cross-gain modulation, polarization gain anisotropy, and highly nonlinear gain characteristics to achieve flip-flop functionality. They highlighted that, when integrated on chip, this type of all-optical flip-flop opens new prospects for implementing all-optical fast memories and timing regeneration circuits. [22]

Jingsheng Yang et al. presented a function-lock strategy for all-optical logic gate (AOLG) utilizing the cross-polarization modulation (CPM) effect in a semiconductor optical amplifier (SOA). By monitoring the power of logic light, the strategy realized controllable methods to capture OR and NOR functions and switch between them. The strategy had been successfully applied in experiment with 10-Gb/s not-return-to-zero (NRZ) signals, which had a high success-rate above 95% and ensures the high extinction ratio of result light above 11.4 dB.

Every step in the strategy had definite numeric evaluation, which provides the potential of automatic implementation. [23]

2. FTTH with GE-PON

The early vision of FTTH, which promised abundant, ubiquitous, and future-proof bandwidth to consumers, has remained largely unrealized nearly 20 years after its birth. N. Frigo et al. presented the historical, competitive, economic, and service reasons for this and prospects for the future. [24]

Large scale projects replacing copper network with optical fiber such as Photonic- access-To-The-Hiome (PATH) in Korea signify the age of fiber based network, making protection to fiber based network a crucial need. It is found that FTTH technology and Ethernet Passive Optical Networks (EPONs), which represent the convergence of low-cost fiber infrastructure and low-cost Ethernet equipment, appear to be the most deployed access network. Most FTTH access networks are protected from failure by having redundant network equipments. These are not economical approaches, as the redundant systems are not efficiently utilized by the network. W. T. P'ng presented a protection method where redundant equipments are not required and protection is provided to end user through sharing of bandwidth during the failure time. A protection control unit and an optical switch is employed connecting 4 Optical Line Terminations (OLT) with each one serving only 32 Optical Network Units (ONU). Protection control unit collects information of ONUs served by each OLT and when an OLT fails, it will instruct an active OLT to serve its original ONUs together with the ONUs served by the failed OLT. [25]

It will be revealed that a myth of deploying low bit-rate uplink fiber-to-the-home (FTTH) services while providing a high bit-rate downlink is wrong. Therefore, for the future broadband FTTH services, the focus should be on the capability to provide gigabit-or even multigigabits-per-second both in up-and downlinks, namely gigabit symmetric systems. Optical code-division multiple access (OCDMA) now deserves a revisit as a powerful alternative to time-division multiple access and wavelength-division multiple (WDM) access in FTTH systems. Ken-ichi Kitayama et al. highlighted the OCDMA systems. The system architecture and its operation principle, code design, optical en/decoding, using a long superstructured fiber Bragg grating (SSFBG) en/decoder, and its system performance was

described. Next, an OCDMA over WDM passive optical network (PON) as a solution km SMF with optimized dispersion tolerance. [26]

H. A. Hmida et. al. highlighted a new FTTH design and deployment guidelines suitable for industrial and residential deployment in green field areas. It also included civil work guidelines: manhole and hand-hole sizes their location, duct and sub-duct structure and section and route selection, cable vault entrance. Cable distribution and numbering guidelines: fiber feeder (primary) design, fiber distribution (secondary) design, fiber drops, fiber distribution terminals (FDT) cabinet sizing and numbering, fiber access terminal (FAT) DP Sizing, Splitters output, distribution types design (centralized, cascaded, and hybrid). [26] It will be revealed that a myth of deploying low bit-rate uplink fiber-to-the-home (FTTH) services while providing a high bit-rate downlink is wrong. Therefore, for the future broadband FTTH services, the focus should be on the capability to provide gigabit-or even multigigabits-per-second both in up-and downlinks, namely gigabit symmetric systems. Optical code-division multiple access (OCDMA) now deserves a revisit as a powerful alternative to time-division multiple access and wavelength-division multiple (WDM) access in FTTH systems. Ken-ichi Kitayama et al. highlighted the OCDMA systems. The system architecture and its operation principle, code design, optical en/decoding, using a long superstructured fiber Bragg grating (SSFBG) en/decoder, and its system performance was described. Next, an OCDMA over WDM passive optical network (PON) as a solution for the gigabit-symmetric FTTH systems proposed. [27]

Dense WDM access network of co-existing analog radio over fiber and digital FTTH systems was presented K. Kitayama et. al., by focusing on enabling techniques including optical frequency interleaving, supercontinuum light source and optical channel allocation for wireless services. [28]

R. Llorente et al. presented the proposal, experimental demonstration and performance comparison of impulse-radio UWB and OFDM UWB distribution in FTTH networks for high-definition audio/video broadcasting is presented. OFDM-UWB exhibits better performance compared with its impulse-radio counterpart with better spectral efficiency. [29]

Recent progress on low-bending-loss single-mode optical fibers for fiber-to-the-home (FTTH) was reviewed. Kuniharu Himeno et. al. presented the designing and manufacturing for three types of fibers-a step-index-profile fiber, a trench-index-profile fiber, and a holey

fiber-are discussed. The trench-index-profile fibers and the holey fibers are confirmed to be candidates for indoor wiring because of their low bending losses, as well as splice losses. [30]

A dual-channel integrated multiplexer, based on holographic Bragg reflector (HBR) devices and exhibiting flat-top, 4-nm-wide channels was presented by D. Iazikov et. al. Theory calibrated by the achieved performance indicates that HBR waveguide grating devices can be implemented to provide fully integrated and high-performance multiplexer solutions for CWDM and FTTH applications.[31]

Increasing fiber applications such as DWDM, Ultra Long Haul and FTTH are rapidly taxing manually managed fiber infrastructure. New fiber management technologies and architectures were evaluated M. F. Lane et al.to meet the growth of emerging networks and applications. [32]

3. OTDM BY MZI SWITCHING

D. Petrantonakis, P. Zakyntinos et. al demonstrated an all-optical four-wavelength 3R burst mode regenerator, operating error-free with 10-Gb/s variable length data packets that exhibit 6-dB packet-to-packet power variation. The circuit was implemented using a sequence of three integrated quadruple semiconductor optical amplifier-based Mach–Zehnder interferometric arrays. [35]

T. Ohara, H. Takara et. al provides the first report of 160-Gb/s optical time-division-multiplexed transmission with all-channel independent modulation and all-channel simultaneous demultiplexing. By using a multiplexer and a demultiplexer based on periodically poled lithium niobate and semiconductor optical amplifier hybrid integrated planar lightwave circuits, 160-km transmission was successfully demonstrated. [36]

Colja Schubert et al. investigated three interferometric all-optical switches based on cross-phase modulation (XPM) in semiconductor optical amplifiers (SOAs), the semiconductor laser amplifier in a loop mirror (SLALOM) switch, the Mach–Zehnder interferometer (MZI) switch, and the ultrafast nonlinear interferometer (UNI) switch. Switching windows with different widths are measured under similar conditions for all three switching configurations. [37]

E. J. M. Verdurmen highlighted all-optical time domain add-drop multiplexing for a phase modulated OTDM signal for the first time, to our knowledge. The add-drop multiplexer is

constructed of a Kerr shutter consisting of a 375 m long highly nonlinear fiber (HNLF), $\gamma=20 \text{ W}^{-1}\text{km}^{-1}$. Successful time domain add-drop multiplexing is shown for 80 Gb/s RZ-DPSK OTDM signals with a 10 Gb/s base rate. [38]

J. Bell, et al. reported the observation of ultrafast all-optical switching in an integrated symmetric Mach-Zehnder interferometer using the non resonant nonlinearity of Al & Ga, 8 2Å~be low half the bandgap. A relative switching fraction of ~50% has been achieved using picosecond pulses at a wavelength of 1.55 μm in a synchronously pumped mode locked colour-centre laser. [39]

The impact of varying the phase relationship between adjacent OTDM channels was investigated in 80 Gbit/s transmissions experimentally and numerically. A fiber-based coherent multiplexer is proposed for OTDM experiments - a phase shifter in the multiplexer and an external phase control circuit are used to set and maintain the phase difference. Sergejs Makovejs et. al. presented that the optimum modulation format for maximum transmission distance strongly depends on pulse width, e.g. 120°-RZ provides the best performance for pulse width of 8 ps; however, 90°-RZ is advantageous when pulse width is reduced to 2 ps. Power in 'zero' bit slots and amplitude jitter are calculated to demonstrate that the performance variation is due to intra-channel four-wave mixing (IFWM) and different receiver sensitivity at back-to-back. We also show that phase modulation formats are sensitive to optical filtering. [41]

XIN Ming, et. al stated an alternative to label swapping, an all-optical label stripping scheme based on SOA-MZI. The stripping process is self-controlled without any synchronization process. Simulation results show that a high quality stripping can be achieved, with no more than 0.09dB of power fluctuation and 0.05dB of phase fluctuation in both stripped and remained label. A power contrast ratio of 28dB between the remained and residual stripped label, and 30dB signal-to-noise ratio (SNR) can be reached respectively. [42]

S. Spälter et. al. stated transmission properties and high-speed switching technologies are presented for 160-Gb/s OTDM systems, which need to prove cost-effective in point-to-point link transmission and should offer time-domain routing capabilities in order to become a commercial reality. Parameters tolerance analysis shows that the stripping performance deteriorates little when considering the devices' imperfection in practice. The multi-hop simulation results also show that our scheme is applicable to large scale OPS networks. [43]

Conventional all-optical feedback-based clock recovery techniques for optical time-domain multiplexing (OTDM) networks place restrictions on the allowed data patterns that can be transmitted. Konstantin Kravtsov et al. presented a data-independent clock distribution solution based on amplitude discrimination and experimentally demonstrate it in an 80 Gbits/s self-locked OTDM transmission. According to the method a single OTDM subchannel is used for exchanging clock information. All processing is performed all optically in low latency nonlinear-optical-loop-mirror-based switches with short (~ 10 m) nonlinear elements.[44]

An 8*10 Gb/s optical time-division-multiplexing (OTDM) system was presented Li Huo, Yanfu et al. with an electroabsorption modulator (EAM) based short pulse generator followed by a two-stage nonlinear compression scheme which generated stable 10-GHz, 2-ps full-width at half-maximum (FWHM) pulse train, an opto-electronic oscillator (OEO) that extracted 10-GHz clock with a timing jitter of 300 fs from 80-Gb/s OTDM signal and a self cascaded EAM which produced a switching window of about 10 ps. A back-to-back error free demultiplexing experiment with a power penalty of 3.25 dB was carried out to verify the system performance.[45]

Hans-Georg Weber et al. presented ultrahigh-speed data transmission in optical fibers based on optical time division multiplexing (OTDM) transmission technology. Optical signal processing in the transmitter and receiver as well as the requirements on ultrahigh-speed data transmission over a fiber link were discussed. Finally, results of several OTDM-transmission experiments, including 160-Gb/s transmission over 4320 km, 1.28-Tb/s transmission over 240 km, and 2.56-Tb/s transmission over 160-km fiber link, were described. [46]

2.4 Objectives

In this thesis, the research is carried out keeping in view of the following objectives.

1. To investigate the bit error rate and power control of a 4 X 40 Gbit/s optical time domain multiplexed system using Mach-Zehnder switching.
2. To investigate the optical logical operations of multiplexer and encoder using Mach-Zehnder Interferometer.
3. To investigate the bit error rate of FTTH at 40 Gbit/s by Mach-Zehnder Switching.

2.5 Thesis Outlines

After studying the basic introduction, literature survey, we define the objectives in chapter 2. In chapter 3, we investigate the optical logical operations of multiplexer and encoder by Mach-Zhender Inferometer at 10 Gbit/s. In chapter 4, we investigate the bit error rate of FTTH at 40 Gbit/s by Mach-Zhender switching for 8 different users. We finally discuss conclusions in chapter 6 and also the future work. In chapter 5, we practically investigate and validate bit rate and power control of the power normalizer of the Mach-Zehnder switching at different four channels at different time shifts at same bit rate of 40 Gbit/s.

CHAPTER 3

IMPLEMENTATION OF OPTICAL ENCODER AND

MULTIPLEXER USING MACH-ZEHNDER INTERFEROMETER

In this chapter a simple all-optical logic device, called Mach Zehnder Interferometer is composed by using a Semiconductor Optical Amplifier (SOA) and an optical coupler. This device is used for generating the logical functions (AND, XOR) and a multiplexer and an Encoder is obtained using this device in Optical Tree Architecture. The simulation of Encoder and Multiplexer is done at a rate of 10 Gbit/s and both are simulated for different input logical combinations. Simulations indicate that the device is suitable to operate at much higher bit rate and also for different logical entities.

3.1 INTRODUCTION

As we know in recent days the research in optical computing increasing day by day and many scientists working upon them, but in electronics computing the logical operations plays a very important role because they require less power, as they are digital circuits and as compared to the analog circuits, they are very flexible. But they have certain disadvantage also that they work up to limited frequency, but if we used that logic using optical instruments then it gives better stability, better speed and switching. In digital optical computing, optical interconnecting systems are the primitives that constitute various optical algorithms and architectures. High speed all-optical logic gates are key elements in next-generation optical networks and computing systems to perform optical signal processing functions[1], such as all-optical label swapping, header recognition, parity checking, binary addition and data encryption. In the last few years, several approaches have been proposed to realize various logic gates using either high nonlinear fibers or semiconductor optical amplifiers (SOA) [2, 3]. The SOA-based devices have the potential of monolithically integration, which offer the advantages of compactness, increased reliability and cost reduction. Up to now, most SOA based logic gates have been performed by employing cross-gain modulation (XGM) [2] and cross-phase modulation (XPM) [3], which inevitably limit the operating speed of such devices due to the intrinsic slow carrier recovery time of SOA. Although the operating speed can be increased to 40Gb/s or higher with the use of a high-power continuous-wave holding beam [48] or different interferometer structures [49], the

complexity and cost of the devices are increased. The request for high-speed all-optical signal processing has been posed by current and near-future optical networks in an effort to release the network nodes from undesirable latencies and speed limitations imposed by O/E/O conversion stages and to match the processing and transmission speeds. In this respect, a significant increase in research efforts towards the deployment of high-speed all-optical signal processing technology, application concepts and demonstrations has been witnessed during the past few years [50, 51, 52, 53]. Semiconductor optical amplifier (SOA)-based, interferometric optical gates have appeared as the main-stream photonic signal processing units [51, 52, 53, 54], exploiting their fast response for high-speed operation and taking advantage of the remarkable advance of hybrid and monolithic integration techniques for offering compact switching elements. To this end, single element, high-speed all-optical gates have been demonstrated as integrated devices in a number of laboratories across the world and have been developed as commercial products primarily for wavelength conversion and regeneration purposes. [54, 55]

Yanming Feng et al. presented and experimentally demonstrated all-optical logic gates using a single SOA and delay interference filtering that enable simultaneous logic functions of or and nor at 40 Gbits/s. The proposed scheme, which utilizes the combinative filtering profile of a delay interferometer and an optical bandpass filter, has great merits for use in generating logic outputs with high quality in terms of pulse shape, extinction ratio, and eye diagram.[20] Interferometric devices have drawn a great interest in all-optical signal processing for their high-speed photonic activity. The nonlinear optical loop mirror provides a major support to optical switching based all-optical logic and algebraic operations. The gate based on the terahertz optical asymmetric demultiplexer (TOAD) has added new momentum in this field. Optical tree architecture (OTA) plays a significant role in the optical interconnecting network. Jitendra Nath Roy et al. highlighted to exploit the advantages of both OTA- and TOAD-based switches. [21] Zhihong Li et al. presented reconfigurable all optical logic gates based on FWM in single SOA using polarization encoded signals. Six different logic functions can be realized by simply adjusting two polarization controllers in the setup. [23] In this chapter we extend the advantage of SOA based MZI switch by including Optical Tree Architecture for the implementation of the Multiplexer and the Encoder at a higher data bit rate.

3.2 MULTIPLEXER

A multiplexer or mux is a device that performs multiplexing; it selects one of many analog or digital input signals and outputs that into a single line. A multiplexer of $2n$ inputs has n select bits, which are used to select which input line to send to the output.

Input A	Input B	Output
0	0	Output 1
0	1	Output 2
1	0	Output 3
1	1	Output 4

Table 2.1 Truth table of 2:1 Multiplexer

2.3 ENCODER

An encoder is a device, circuit, transducer, software program and algorithm that convert information from one format, or code to another, for the purposes of standardization, speed, secrecy, security, or saving space by shrinking size. An encoder can be a device used to change a signal (such as a bit stream) or data into a code. The code serves any of a number of purposes such as compressing information for transmission or storage, encrypting or adding redundancies to the input code, or translating from one code to another. This is usually done by means of a programmed algorithm, especially if any part is digital, while most analog encoding is done with analog circuitry. [9, 10]

2.4 THEORY

The above multiplexer and encoder is implemented using SOA based MZI switch, so on the reference of that this chapter firstly describe the SOA based MZI switch. An MZI switch is a very powerful technique to realize ultra fast switching. In this switch a SOA is inserted in each arm of an MZI. The pulsed signal at the wavelength λ_1 is split at the first coupler such that more power passes through one arm. At the same time, the CW signal at the wavelength λ_2 is split equally by this coupler and propagates simultaneously in the two arms. In the

absence of the λ_1 beam, the CW beam exits from the cross port (lower port in the figure). However, when both means are present simultaneously, all one bits are directed towards the bar port (upper port in the figure) because of the refractive-index change induced by λ_1 beam. The physical mechanism behind the behavior is cross-phase modulation (XPM). Gain saturation induced by λ_1 beam reduces carrier density inside one SOA, which in turn increases the refractive index only in the arm through which the λ_1 passes. As a result, an additional π phase shift can be introduced on the CW beam because of the XPM, and the CW wave is directed towards the bar port during each one bit. Optical filters are placed in front of the output ports for blocking the original signal λ_1 . The MZ scheme is preferable over cross gain saturation as it does not reverse the bit pattern and results in a higher on-off contrast simply because nothing exits from the bar port during 0 bit.

Now it is clear that in the absence of control signal λ_1 , the incoming signal (CW signal) exits through the cross port (lower channel) of MZI. In this case no light is present in the bar port as shown in the below figure. But in the presence of the control signal, the incoming signal exits through the bar port of the MZI as shown in the figure. In this case no light is present in the cross port. In the absence of the incoming signal, the bar port and cross port receive no light as the filter blocks the control signal. [2, 48, 49]

2.5 WORKING OF MULTIPLEXER

As we already discussed the MZI switch for all-optical logic so here the working of the optical tree using MZI based optical switches.

There is a constant source of CW beam of λ_1 which may be a laser source. The light signal that comes from CWLS can be taken as the incoming signal. The incoming light signal is incident on switch s_1 first. Now we can obtain the light in different desired branches or sub-branches by proper placing of control signals. Control signals are also light signals.

Case 1: When A= '0' and B= '0'

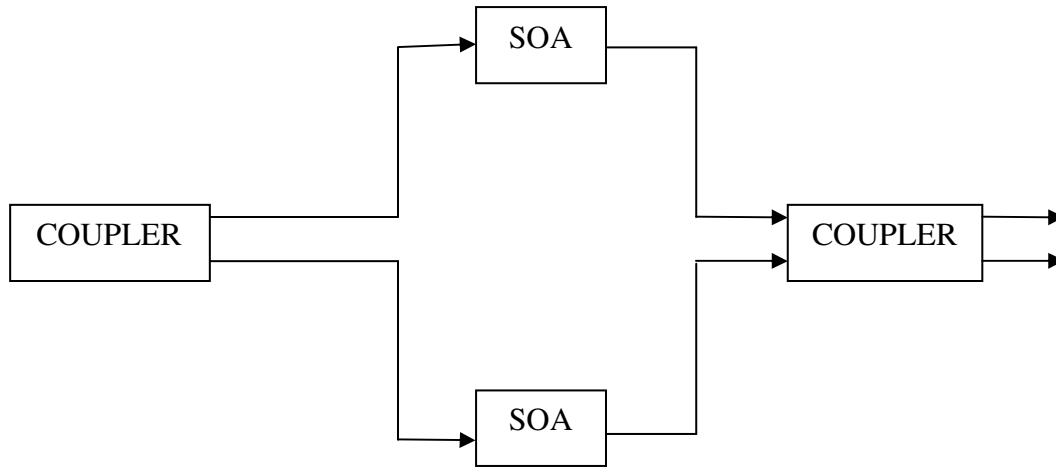


Fig 2.1 Block Diagram of Optical logic using MZ Interferometer Switch

The CW light beam that comes from constant CWLS is incident on switch s_1 first. As here $A = '0'$, the control signal A is absent, that means only incoming light signal is present at s_1 . As per the switching principle discussed above, the light emerges through the lower channel and falls on switch s_3 at C. Here the control signal B is absent. As signal B is absent so light finally comes out through lower channel of s_3 and reaches output 1. In this case, no light is present at other outputs ports, so output port 1 is one state and others are in zero state.

Case 2: When $A = '0'$ and $B = '1'$

Light from the CW light source is incident on s_1 . As $A = '0'$, the light beam emerges through the lower channel and falls on s_3 . At s_3 the control signal B is present. In the presence of the control signal emerges through the upper channel of s_3 and finally reaches to the output port 2. In this case light is only present in output port 2. Hence output port shows one state while others shows zero state.

Case 3: When $A = '1'$ and $B = '0'$

The light from CWLS is incident on switch s_1 first. As here $A = '1'$, the control signal A is present. Because of that, the light emerges through the upper channel of s_1 and falls on s_2 at O. As $B = '0'$, no control signal is present at B, that means the light comes out from the lower channel of s_2 to reach output port 3. So output port 3 is in one state and others are in zero state.

Case 4: When $A = '1'$ and $B = '1'$

The light from CWLS is incident on switch s_1 first. As here $A = '1'$, the input control signal A is present. Because of that, the light emerges through the upper channel of s_1 and falls on s_2 at O . As $B = '1'$, the control signal is present at B . Hence the light follows the upper channel of s_2 to reach output 4. So output port 4 is in one state and the others is in zero state. [2, 49, 50, 53]

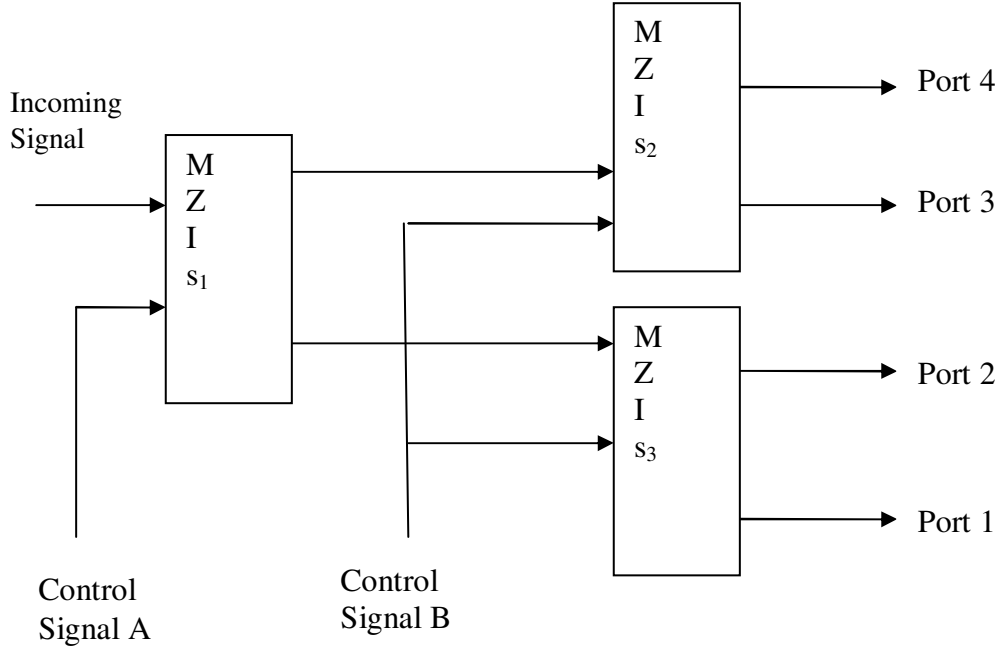


Fig 2.2 Block Diagram of Multiplexer

2.6 SIMULATION RESULTS AND DISCUSSIONS

This section of the thesis tells about the results of multiplexer and encoder using Mach-Zehnder Interferometer for all-optical logic. This project simulated in OPT Sim 4.7.1 specified in Block mode which carries different components to generate the required circuit which gives the finally result.

2.6.1 SYSTEM DESCRIPTION OF MULTIPLEXER

This given below figure represents the schematic diagram of all-optical logic multiplexer by mzi switch. As it contains two sine wave generator having a frequency of 10 GHz which acts as signal generator followed by Direct Modulated Laser, as laser converts electrical signal into light signal and the output of both the lasers fed to optical coupler which contains two port named as bar port and cross port, now from each arm of the coupler fed to the

semiconductor optical amplifier and finally goes to the optical coupler as optical coupler followed by semiconductor optical amplifier is called Mach Zehnder Switch and different outputs of optical coupler fed to the Spectrum Analyzer.

Signal Generator generates 10 GHz signal in sinusoidal form which is fed to the DM laser.

Direct Mode Laser block shows simplified continuous wave (CW) laser. Its phase noise is taken into account by generating a signal generator whose FWHM (Full Width Half Maximum) is specified by Laser parameters. In model considered has 193.42 THz center emission frequency, 1550 nm wavelength, 1650 nm wavelength, 0 dBm CW Power, 1 mW CW Power, ideal laser noise bandwidth, 10 FWHM line width and laser random phase.

Optical couplers, also referred to as optocouplers, are well known devices used to direct light from one light source to a light receiving member. An optical coupler is a passive device for branching or coupling an optical signal. Generally, a coupler is centralized by joining the two fibers together so that the light can pass from the sender unit to the two receivers, or else it can be made by juxtaposing the two "receiver" fibers which will then be aligned and positioned so as to be facing the "sender" fiber.

Semiconductor optical amplifiers are amplifiers which use a semiconductor to provide the gain medium. The semiconductor optical amplifier is of small size and electrically pumped. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time. This originates from the short nanosecond or less upper state lifetime, so that the gain reacts rapidly to changes of pump or signal power and the changes of gain also cause phase changes which can distort the signals.

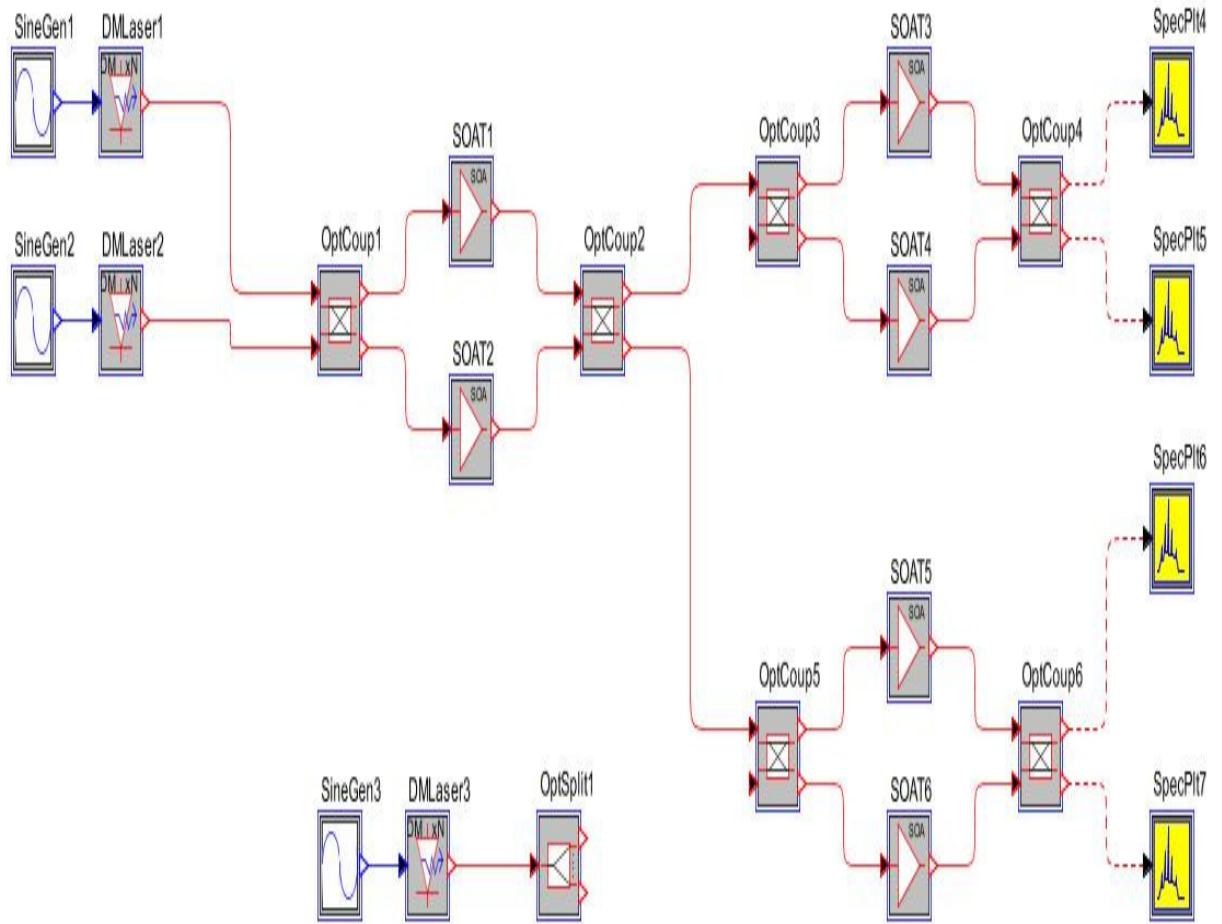


Fig 2.3 Schematic Diagram of Multiplexer (A = '1', B = '0')

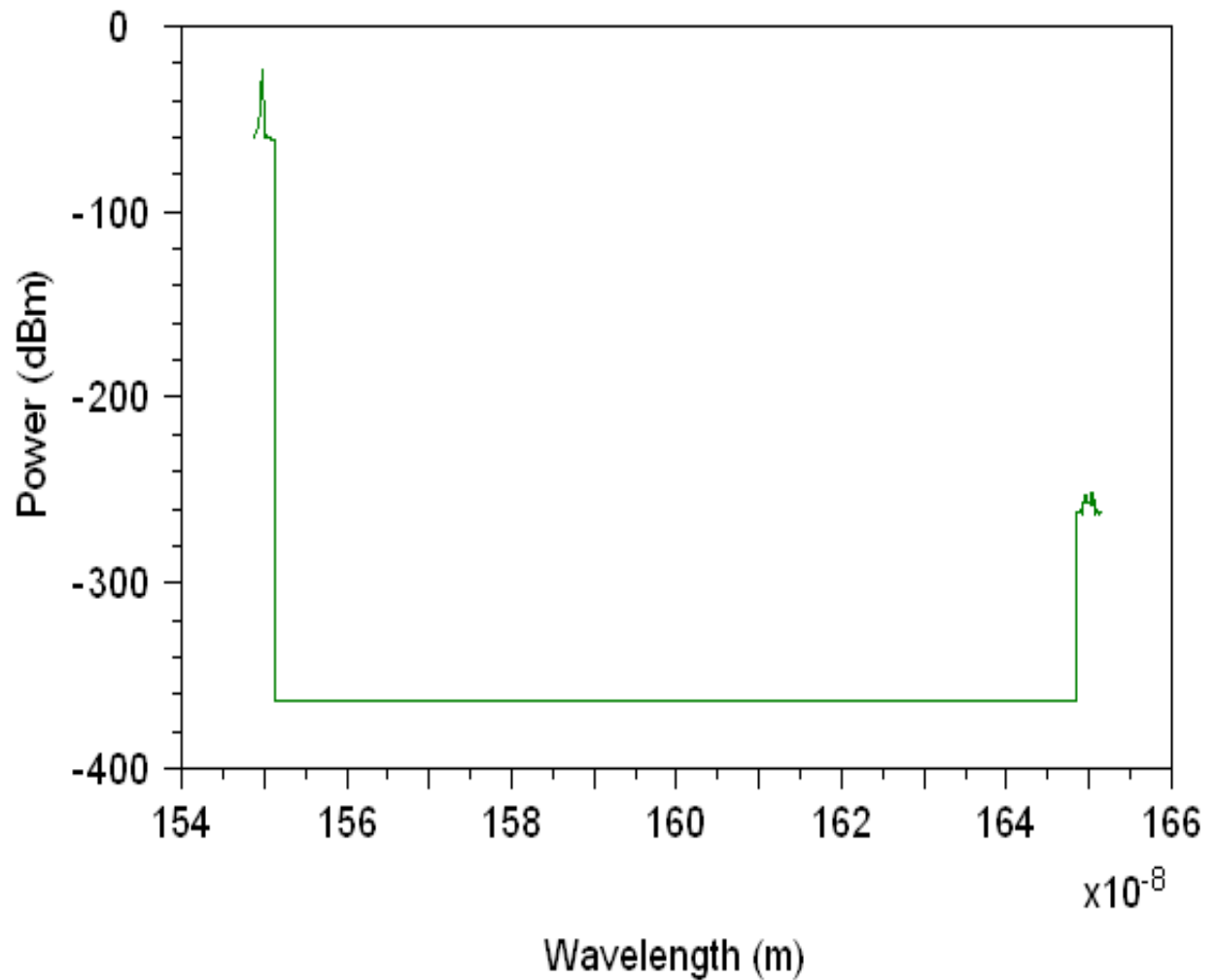


Fig 2.4 Wavelength spectrum of A = '1' & B = '0'

The above diagram shows the wavelength spectrum of the required logic at output port 1. As the spectrum that both the input signal and the control signal has the different wavelength so we have using for control signal is 1550 μm while the incoming signal consists the wavelength of 1650 μm so the it has maximum amplitude at wavelength of the control signal. For below diagram the components is already described earlier in the above portion.

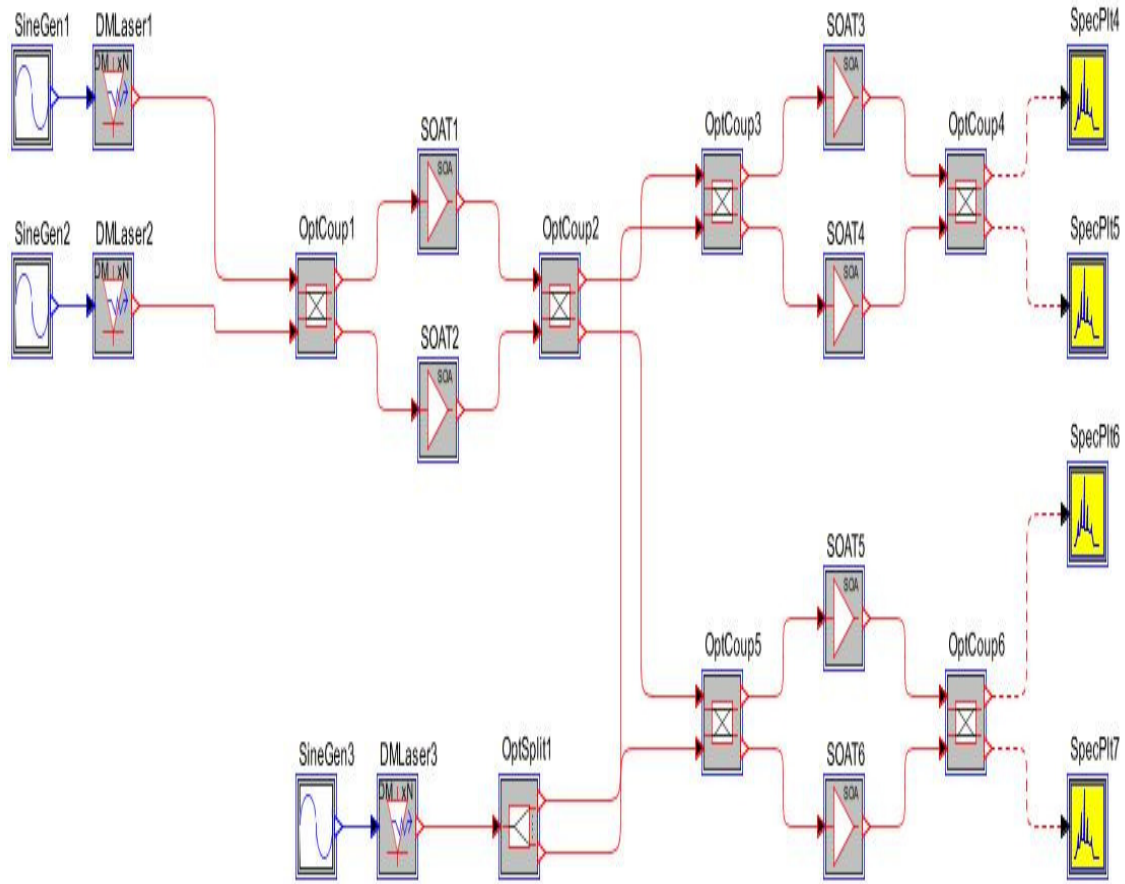


Fig 2.5 Schematic Diagram of Multiplexer (A = '1', B = '1')

The above diagram shows the wavelength spectrum of the required logic at output port 1. As the spectrum that both the input signal and the control signal has the different wavelength so we have using for control signal is 1550 μm while the incoming signal consists the wavelength of 1650 μm so the it has maximum amplitude at wavelength of the control signal.

2.6.2 SYSTEM DESCRIPTION OF ENCODER

A decoder for all optical logic is designed by OPTSim 4.7.1 as it contains many libraries then using that component we design a schematic of the encoder while in that digital logic is implemented by giving a pulse of light at a particular wavelength. In this we using a enable as selector through which we selecting a output port at which we want our signal in the form of light. So schematic diagram of encoder using optical components is given below.

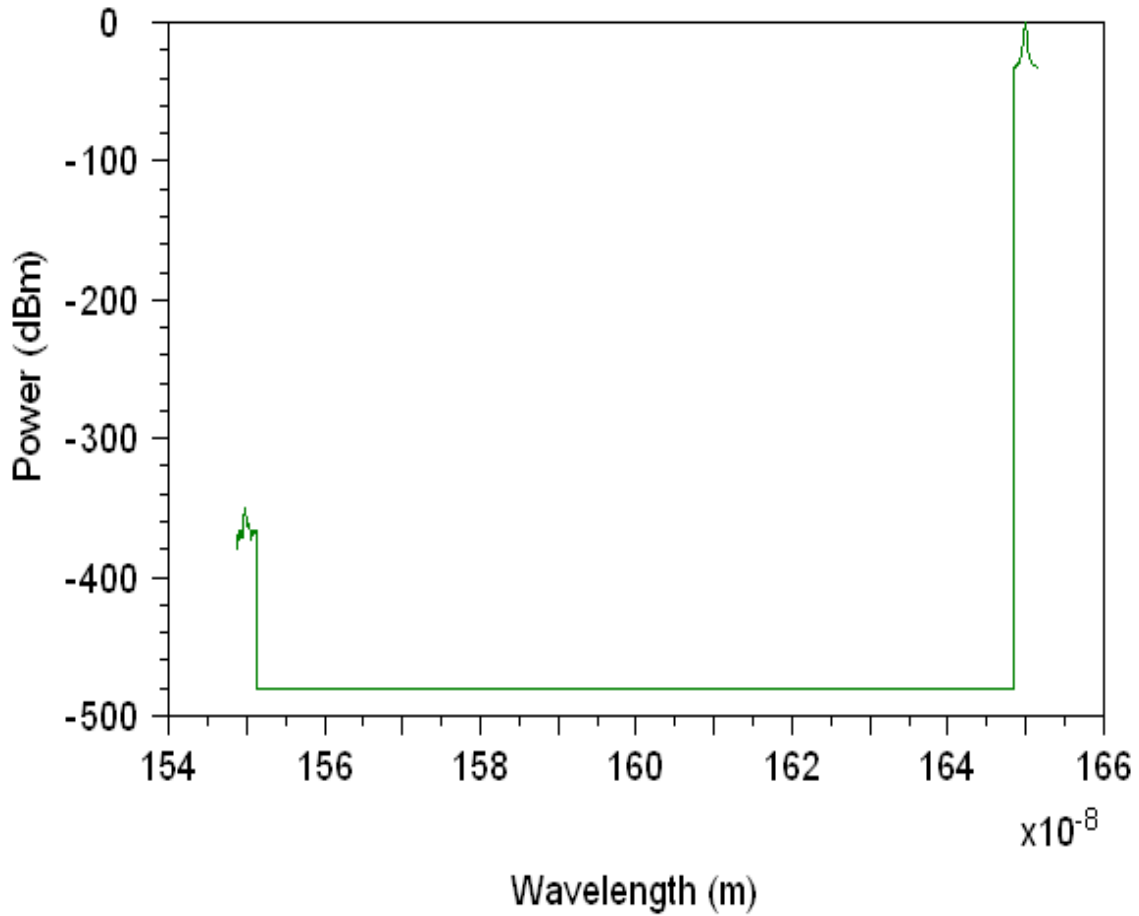


Fig 2.6 Wavelength spectrum of A = '1' & B = '1'

Case 1: When A = '1', B = '0', & EN = '1'

In this schematic diagram of the encoder three sine wave generators used to generate a sinusoidal pulse which directly fed to the direct modulated laser which is working at different wavelength for particular input signal, as this encoder having three input signal and an enable signal at different wavelength from the input signal and this enable signal is fed directly to the input arm of the coupler of mzi switch by beam splitter and providing the required logic.

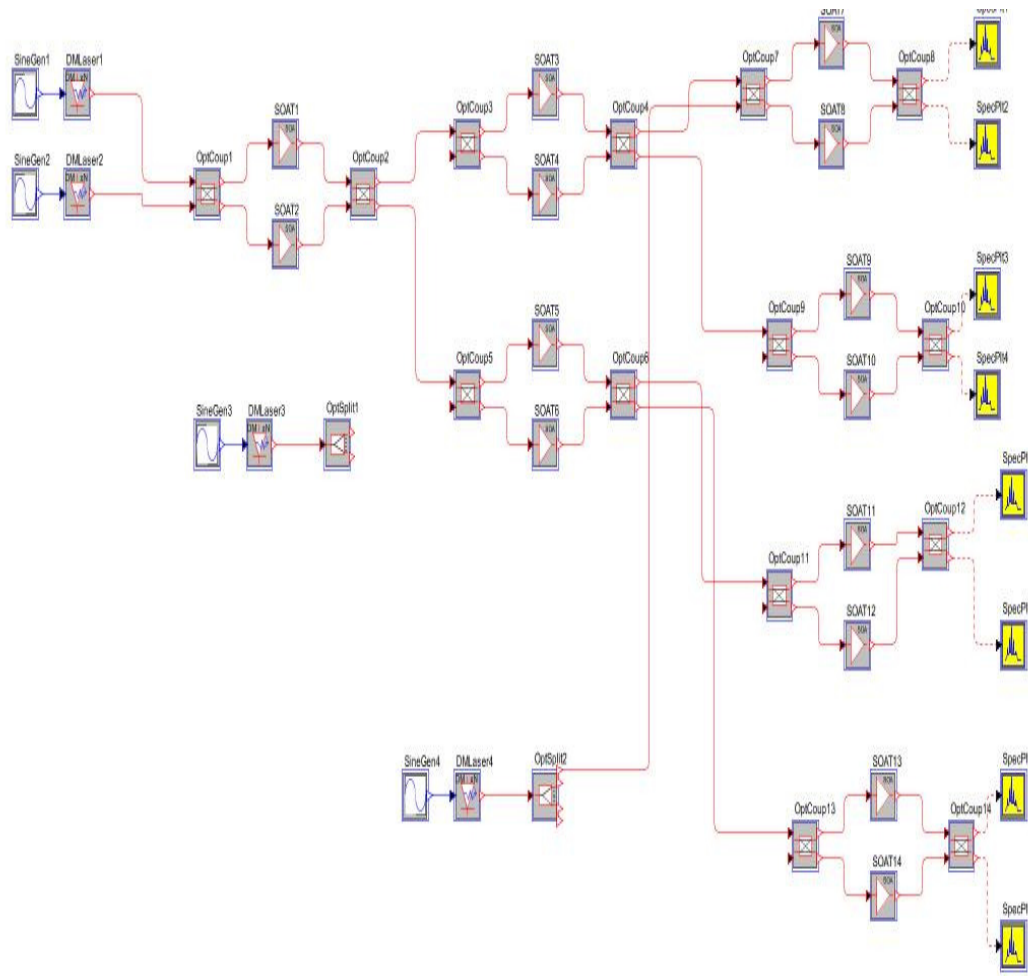


Fig 2.7 Schematic diagram of encoder (A = '1', B = '0', EN = '1')

Case 2: When A = '1', B = '1' & EN = '1'

In this schematic as the last diagram represents two sinusoidal generator 10 GHz is followed by the Direct Mode laser which converts the electrical signal into optical signal or light signal and the output of the laser is directly fed into the input arms of the coupler which passes the signal on bar port as depend upon the control signal. Here control signal is inserted into the circuit at the third level of the MZI switch as it consists of the two semiconductor optical amplifier at the both port of the optical coupler at the input and the same thing is followed at the output of the switch.

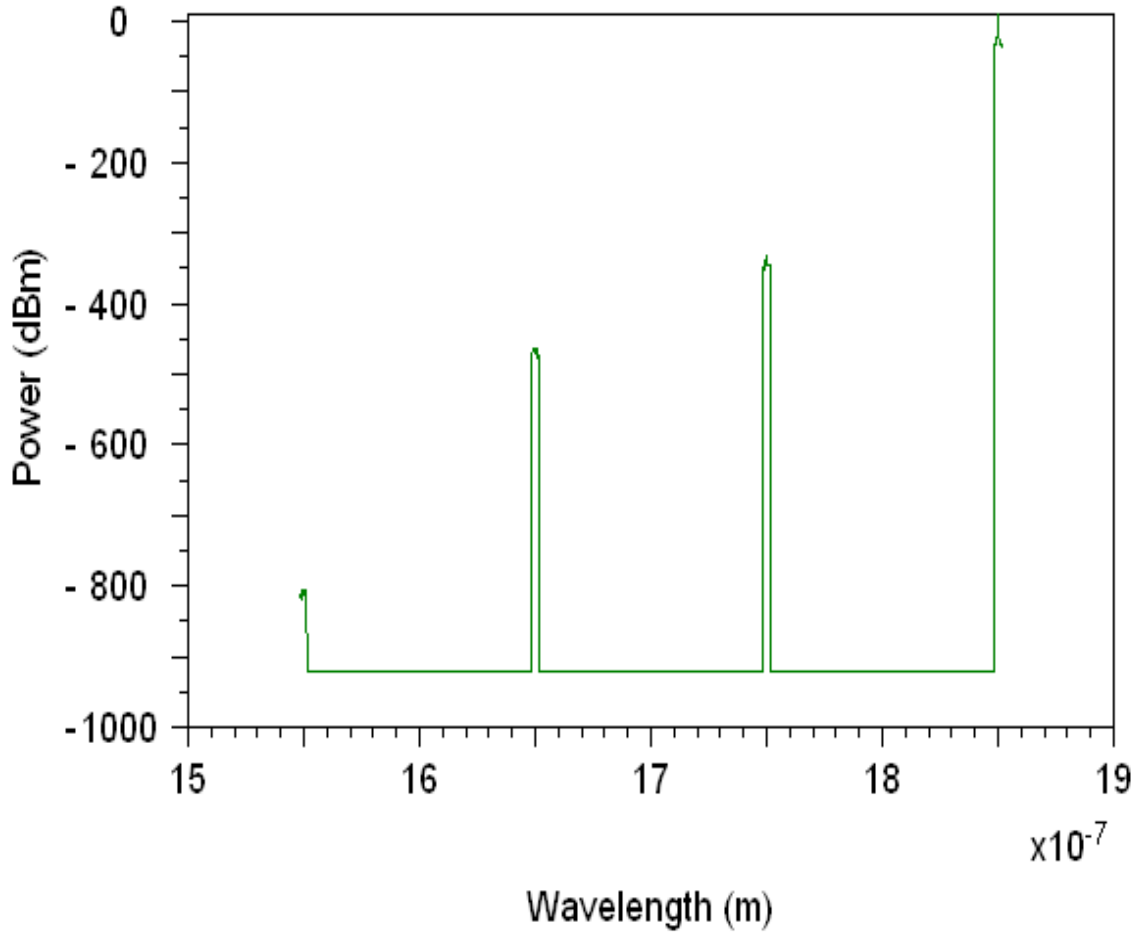


Fig 2.8 Wavelength spectrum of A = '1' & B = '0', EN = '1'

So here in this circuit control signal is applied to the all the inputs of the encoder but according to the principle of the MZI switch the input is received at the bar port of the coupler when control signal is present so as we applied two continuous signal at input of the both the laser so at first stage output is received at the bar port of the optical coupler 2 according to the Fig 2.9 so output of the optical coupler is fed to the input of the optical coupler 3 and at the same time third input also feeds to the input of the optical coupler 3 now again the same phenomena exists as control signal becomes the output of the optical coupler 2 and continuous wave signal treated as input so similarly same output of the optical coupler is fed to the input of optical coupler 5 and also same continuous signal is fed to the optical coupler 4 and now the output of the optical coupler 3 & 5 is processed properly.

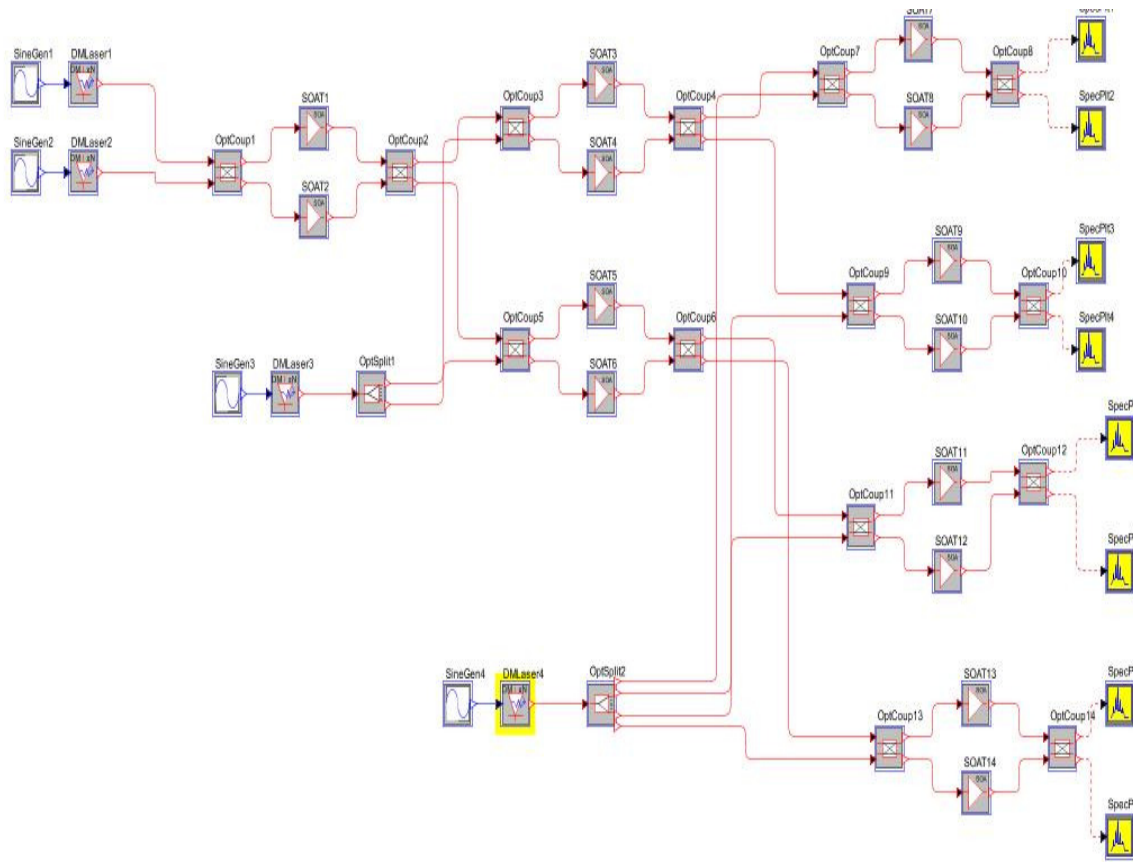


Fig 2.9 Schematic diagram of encoder (A = '1', B = '1', EN = '1')

Now the output of the optical coupler 4 & 6 is fed to the one input arm of the optical fiber 7, 9, 11, 13 and then the output from these required optical coupler are goes to the optical coupler 8, 10, 12, 14 through passing with the Semiconductor optical amplifier (SOA). At the both the port of the optical coupler spectrum analyzer is connected to measure the spectrum of the wavelength passing through the proper channel as we see earlier if we applied input at both the end of the coupler one of continuous and other is of control signal having a wavelength different from the continuous wave signal then output is received on only one port of the coupler so in that manner MZI switch works as a logical inverter so here EN is same as working as inverter so different spectrum received at the output of the optical coupler but the correct manner of output received at the spectrum analyzer 10 and it is shown at fig 2.10 which shows the wavelength spectrum of the received signal of all optical logic encoder in the form of '1'.

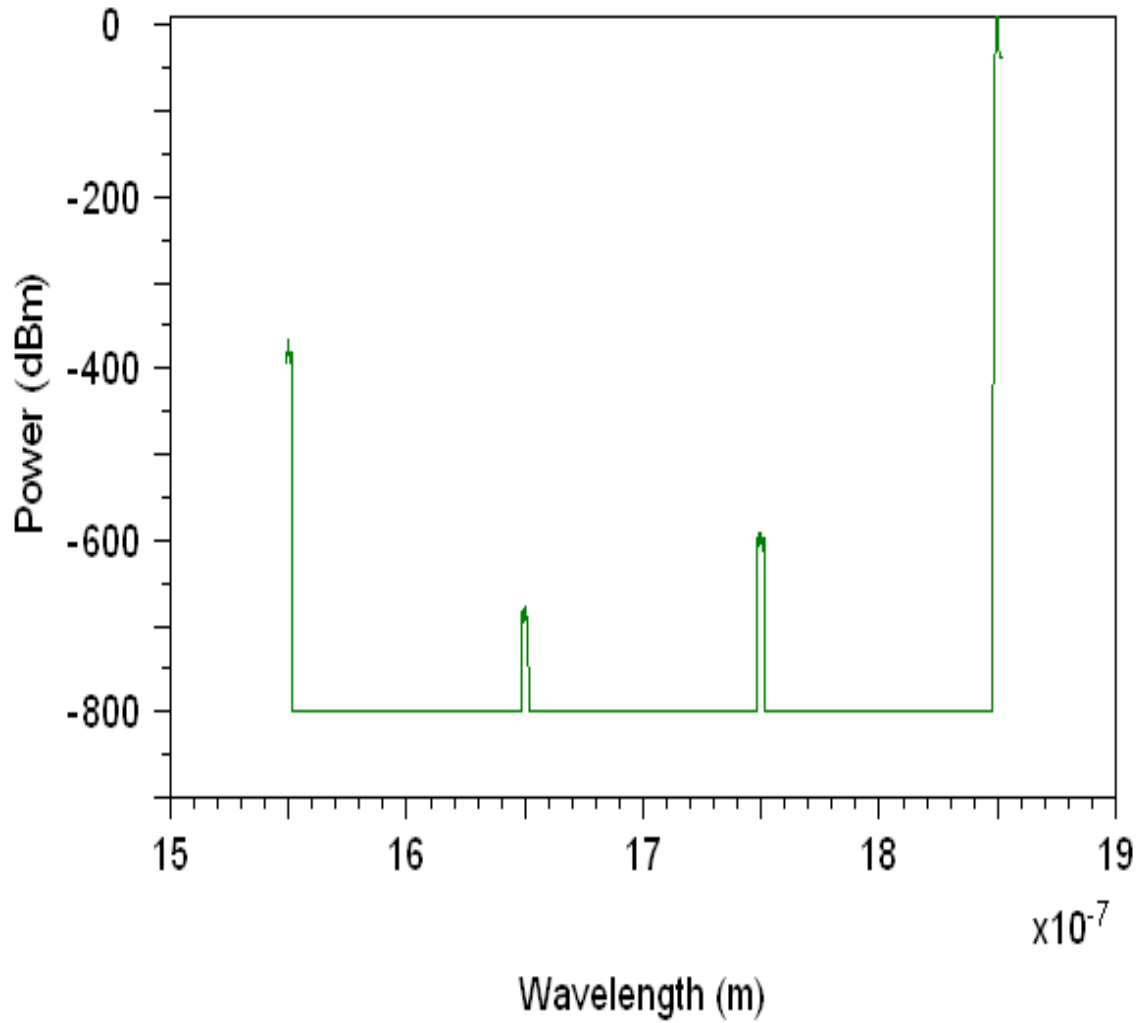


Fig 2.10 Wavelength spectrum of A = '1' & B = '1', EN = '1'

2.7 CONCLUSIONS

We have simulated an all-optical logic based Multiplexer and Encoder using MZ Interferometer. As different logic functions can be realized by simply adjusting two components i.e multiplexer and the encoder. The simulated method has the potential to operate at above 40Gb/s

CHAPTER 4

SIMULATION OF FTTH AT 10 GBIT/S FOR 8 OTU BY GE-PON ARCHITECTURE

In this chapter a fiber communication system is employed using Giga Ethernet Passive Optical Network (GE-PON) architecture. In this architecture an optical fiber is employed directly from a central office to the home. A 1:8 splitter is used as a PON element which establishes communication between a central office to different users. In this chapter GE-PON architecture has investigated for different lengths from a central office to the PON in the terms of BER. For 10 Gbit/s system the plots between the BER and transmission distance is plotted and it is seen that as the distance increases beyond the 15 Km the BER is increased very sharply. Results in the form of Voice and Data spectrum for different users of FTTH with GE-PON architecture are shown.

4.1 INTRODUCTION

Leading this investment wave is the deployment of single-mode optical fiber deeper into these access networks to curb the high bandwidth requirements of their customers. Increasingly, carriers are finding that deploying the fiber all the way to the customer enables network future-proofing, maximizes the symmetrical bandwidth throughput of a carrier's access network, provides for network reliability, reaps significantly reduced operating expenses and affords enhanced revenue opportunities. The industry refers to this technology as FTTH. As the FTTH service expands, improved throughput is indispensable to remain competitive. FTTH is simply the 100 percent deployment of optical fiber in the access network. This thesis considers the migration of the access network from a copper based digital subscriber line (DSL) network towards fiber to the home (FTTH), which is a foreseen trend. A first driver for this migration which is often cited is the resulting increased bandwidth. As the real killer application demanding immediate bandwidth upgrade remains to be found, a more likely scenario is the following. All offered bandwidth gets used; however, the customer demand for it is not strong enough in order to really accelerate the FTTH migration process. Second, a fiber based access network is expected to be cheaper to operate. Out phasing the old copper network, which requires a lot of maintenance and repair

actions and replacing it by an optical network which is far less vulnerable to outside conditions could lead to important operational savings for the operator in the long run. [56, 57] H. Iwamura et al. represented the first demonstration of asymmetric PON system using OTDM and OCDM technologies is presented. We accomplished a transmission over 20 km SMF with optimized dispersion tolerance. [26] K. E. Rookstool et al. presented the results of a study examining the economics of Central Office versus Remote Terminal Broadband Distribution Terminals for deploying Fiber to the Home. The effects of integrating DSL for copper distribution areas with FTTH were also examined. [33] In this chapter we simulated the FTTH with GE-PON architecture for a bit rate of 10Gbit/s for different wavelength used for voice and the data as user are separated by splitter and BER is investigated against different distances.

4.2 THEORY

Fiber to the Home refers to fiber optic cable that replaces the standard copper wire of the local Telecom. FTTH is desirable because it can carry high-speed broadband services integrating voice, data and video, and runs directly to the junction box at the home or building. Fiber to the Home network architectures can be divided into two main categories

1. Home Run architecture: In this a dedicated fiber connects each home to the Central Office)
2. Star architectures: In this many homes share one feeder fiber through a remote node that performs switching, multiplexing or splitting - combining functions and is located between the homes served and the CO.
3. Passive Star (more commonly known as the Passive Optical Network or PON)
4. Wavelength Division Multiplexed (WDM) PON

The star architectures can be active or passive depending on whether the remote node is powered or not. Further, the passive star can be a single wavelength system (all homes served by a common wavelength) or a Wavelength Division Multiplexed (WDM) system (where each home is served by a different wavelength).

Regardless of architecture, each feeder fiber is terminated at the Central Office (CO) on an Optical Line Termination (OLT) unit. The CO equipment can be designed to support various data-link layer interface types and densities: 100FX Fast Ethernet, SONET, ATM, and Gigabit Ethernet among others. The Customer Premises Equipment (CPE), also known as the

Optical Network Unit (ONU) has POTS (Plain Old Telephone Service) and 10/100 Base-T Ethernet interfaces and, in the case of PONs and Home Run architectures, the ONU can also have an RF video interface. All FTTH models discussed here use single mode fiber. [57, 59]

1. Home Run Fiber

The Home Run architecture (also known as a Point-to-Point architecture or Single Star architecture) has a dedicated fiber that is deployed all the way from the CO to each subscriber premises. This architecture requires considerably more fiber and OLTs (one OLT port per home) compared to the other, shared, infrastructures.

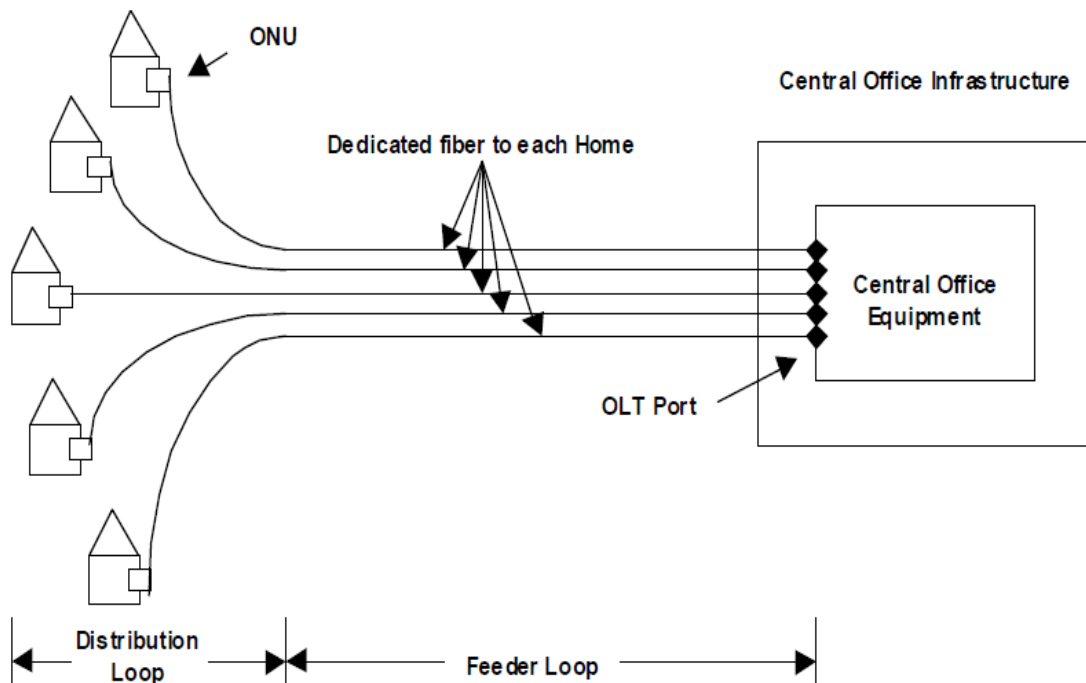


Fig 4.1 Home Run Fiber Architecture

2. Active Star

A Star architecture (also known as a Double Star) is an attempt to reduce the total amount of fiber deployed and hence lower costs by introducing feeder fiber sharing. In a star architecture, a remote node is deployed between the CO and the subscriber's premises. Each OLT port and the feeder fiber between the CO and the remote node is shared by anywhere from four to a thousand homes (the split ratio) via dedicated distribution links from the remote node. When the remote node contains active devices such as a multiplexer (or switch), the architecture is referred to as an Active Star as the remote node needs to be

powered. The Remote Node in the Active Star network has a multiplexer / demultiplexer. The remote node switches the signal in the electrical domain (to the intended recipient) and hence OEO conversions are necessary at the remote node. Since the feeder bandwidth is shared among multiple end points, the maximum sustained capacity available to each home – both upstream and downstream – is less with an active star architecture than with Home Run fiber. Typically each remote node in an active star architecture supports anywhere from sixteen to a thousand (or more) homes. [57, 58]

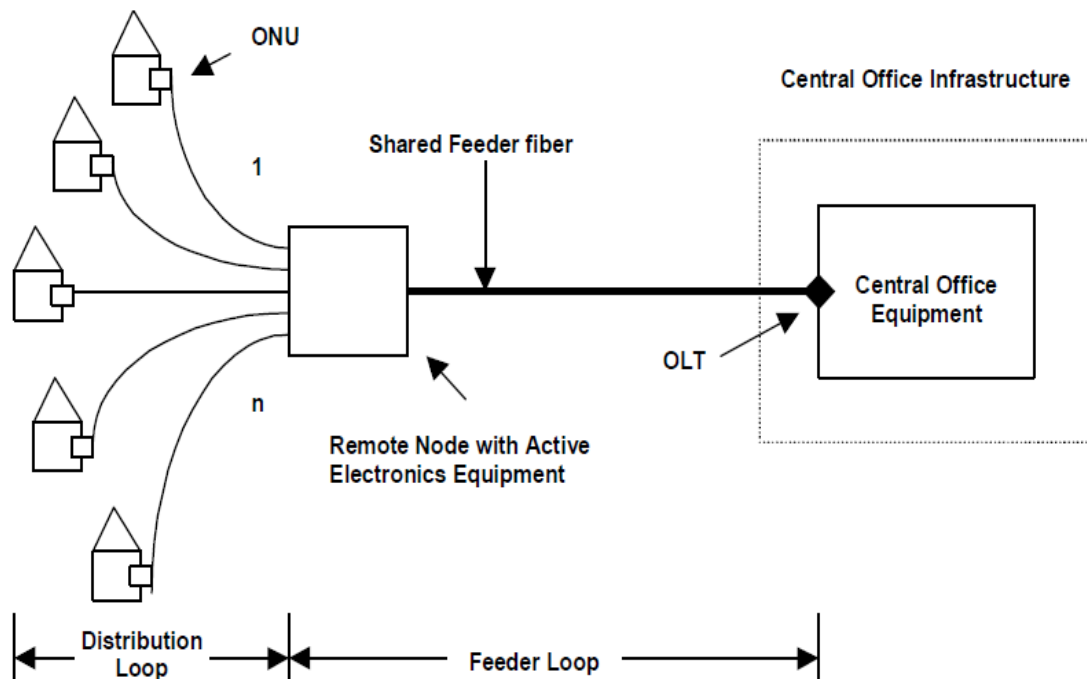


Fig 4.2 Active Star Architecture

In this one fiber is shared (via a power splitter) among a set number of users, typically between sixteen and thirty-two. This is called a passive optical network (PON). Better upstream speeds will also be critical for providing two-way high-speed services, likely to be used for video communication or other similar services in the near future. The Giga-Bit PON satisfied these requirements. Two types of Giga-Bit PON systems have been standardized: G-PON by ITU-T and GE-PON by IEEE. PONs are characterized by the "splitting" of the optical fiber one or more times in the field, resulting in the sharing of the optical fiber among multiple users. The fiber in a PON is typically shared by sixteen to thirty-two users. Hence the bandwidth of the fiber originating at the CO/HE is shared among a group of users. The

splitting of the network is accomplished by an optical splitter. These splitters can split the fiber one to thirty-two times and, by their nature, introduce inherently high losses in the network. Therefore, their use is limited because of the power budget considerations of the network. A PON will have less optical reach than a PTP network, which does not use splitters. [25, 32, 55]

The fiber-to-the-home service is mainly based on passive optical network in which upstream and downstream signals are transmitted through a single optical fiber with the aid of so-called diplexers. Transmission standards utilized in FTTH networks are based on ATM and Ethernet technologies. Carriers are extremely familiar with both technologies, which support a variety of services. PTP networks are simply an extension of legacy Ethernet used in metropolitan and enterprise spaces and extended into the access network. The A/BPON protocol is characterized by having two downstream wavelengths and one upstream wavelength. The 1550 nanometer (nm) and 1490 nm wavelengths are used for downstream traffic, with the 1490nm channel typically an IP channel for voice and data service. The 1550nm channel will be used for a radio frequency (RF) or IP video overlay. Broadband PON has evolved into Gigabit PON (GPON) to address bandwidth and protocol limitations. Capable of up to 2.5 Gbps shared bandwidth among 32 users; GPON utilizes the same wavelength plan of BPON. It is governed under ITU standard G.984 and provides for protocol flexibility across ATM, Ethernet, and TDM platforms. The earliest FTTH networks borrowed from the designs of metro and long-haul networks and became simple extensions of these networks. All FTTH networks inherently are designed to deliver an optical fiber to the subscriber. At their core, FTTH networks contain an optical line terminal (OLT), optical cable, and optical network terminal (ONT). The OLT is typically at the CO/HE but can also be in a remote terminal in the field. The OLT houses the laser transmitters dedicated to each user in a PTP network or shared across several users in a PON. The OLT is also the aggregation point of voice from the public switch telephone network (PSTN), data from a router, and video via its multiple forms. The ONT receives the signal from the OLT and converts it into usable electronic signals that a user's telephone, computer, TV, or any other number of devices can receive. The ONT also serves to communicate IP traffic back to the OLT such that voice conversations can occur. [55, 57]

3. PON ARCHITECTURE

A passive optical network (PON) is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 32-128. The key interface points of PON are in the central office equipment, called the OLT for optical line terminal, and the CPE, called ONU for optical network unit (for EPON) and ONT for optical network terminal (for

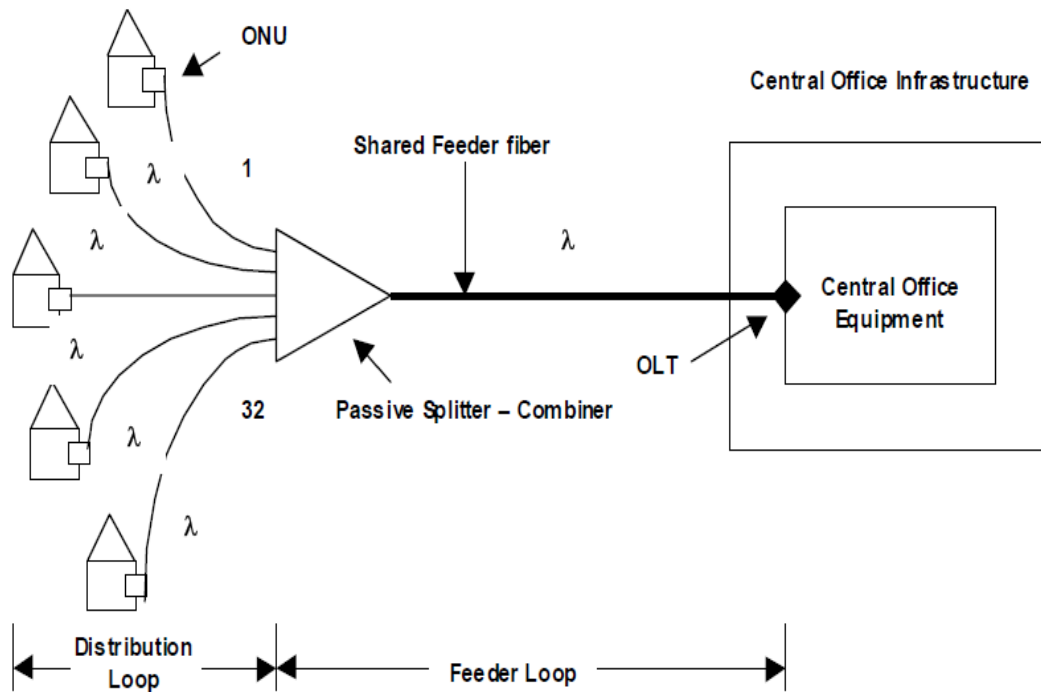


Fig 4.3 PON Architecture

GPON). Regardless of nomenclature, the important difference between OLT and ONT devices is their purpose. OLT devices support management functions and manage maximum up to 128 downstream links. In practice, it is common for only 8 to 32 ports to be linked to a single OLT in the central office. Consequently, the ONT/ONU devices are much less expensive while the OLTs tend to be more capable and therefore more expensive.

4. WDM PON ARCHITECTURE

PONs can have multiple wavelengths as well. Though it will be sometime before there are affordable WDM PONs (if ever), some vendors are introducing products that can introduce more wavelengths on to a PON. Wavelength Division Multiplexing (WDM) is Coarse (CWDM) or Dense (DWDM) depending on the number of wavelengths multiplexed on to the

same fiber. Vendors are of the opinion that a CWDM PON can support 3 – 5 wavelengths, while supporting more than 5 wavelengths requires a DWDM overlay¹³. For DWDM, the ONUs (and the OLTs) require expensive frequency stable, temperature controlled lasers⁶. The OLT puts all the wavelengths onto the shared feeder fiber and the splitters replicate the wavelengths to each home.

4.3 SIMULATION SETUP FOR FTTH USING GEAPON ARCHITECTURE

The particular system setup of FTTH using GEAPON architecture is shown in figure (4.4). The component used in figure (4.4) are chosen from the Optsim Ver.4.7.0 component library palette and placed as per requirement in the design area of the Optsim editor. Then various simulation parameters are set. The schematic diagram consists of a PRBS generator which is producing the 10 Gbits/s and is directly fed to the RZ electrical driver as RZ driver has an advantage of better clock recovery, now the output of the electrical driver is goes to the laser and finally get amplified it just for voice but if we considered about the data then we also combine data with voice for voice we have two sine wave generator having different frequencies of about the TERA Hz and have phase shift of 90 degree and goes to the input of the summer, then summer mixes both the frequencies and finally goes to modulator which is type of Mach Zehnder and here both the voice and data combines transfer on optical fiber over a length of 5 to 20 Km. Now the output of the optical fiber which is a single mode fiber is then fed to the input of the optical splitter which splits the input into the 1:8 output, now the 8 outputs of the filter is fed to the receiver side of users. Here we consider about the 1:8 splitter, it is further expanded upto the 1:16, 1:32 depending upon the capacity of the users. At the transmitter side we combine both the voice as well as data and this is in the form of the electrical signal which is converted to the light signal with the help of the laser and this form of light is also received at the receiver side now this combined form of voice and data is again splitted into two forms as discussed earlier and here the voice and data becomes separated. To convert the data and voice in again in the original form we use a High sensitivity receiver or detector which performs both the function the first one is to detect whether data or voice is and again converted in the form of the electrical signal. The same phenomena is repeated or done simultaneously for different users at the same time. To

measure the spectrum of the voice and data at the user's end we use spectrum analyzer. But

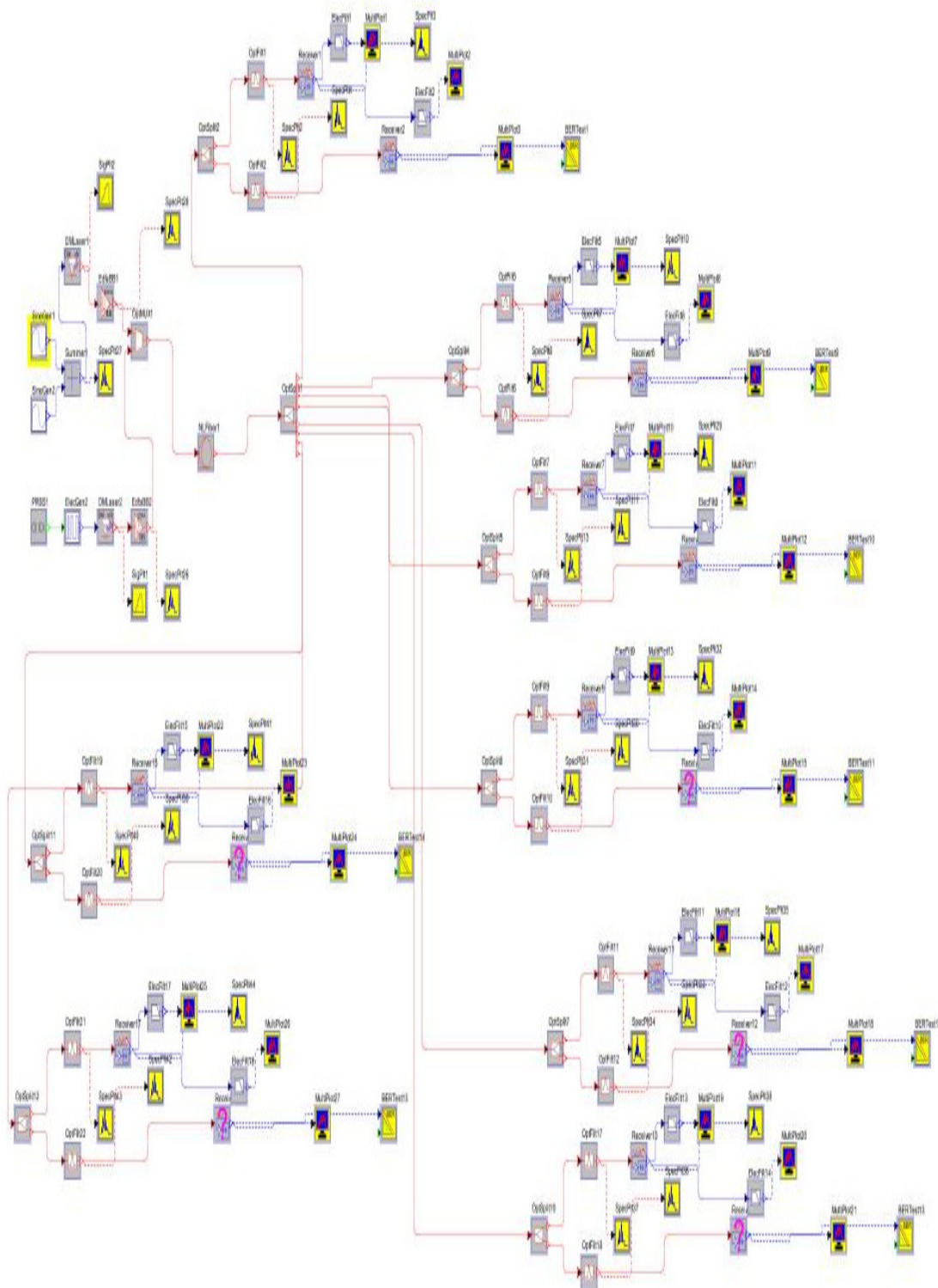


Fig 4.4 Schematic Diagram of FTTH using GEPON Architecture

as we know that data is transmitted in the digital domain or also in the light pulses so in transmission on the fiber such type of noise also produced e.g. Inter symbol Interference, Noise so in the effect of such things error should be occurred. So to measure the error we applied a instrument called BER Tester, as we know some standard also made to accept that type of error by ITU-T standard.

Now at end of the receiver side every ONT has a particular receiver for both the reception of the Voice and the data. Before the reception a splitter is used to differentiate the particular user.

Optical splitter component simulates an "Ideal" optical splitter. It works as a balanced splitter with the same attenuation on each output. Attenuation is set to a default value of 0dB, so this component implements an ideal splitter without any insertion loss, i.e. a component that perfectly splits the input signals.

Photodiode considered as a PIN photodiode. The output current generated by the photodetection process depends on the input optical power and on the dark current. Its parameters are 193.42THz/1550nm reference freq./wavelength, 0.80 quantum efficiency, 0.99 A/W responsivity and zero dark current.

4.4 RESULT AND DISCUSSION

The above diagram shows the description of the FTTH using GEPON architecture. From the above discussion we know the advantage of the GE-PON architecture in respect of the other architectures such as G-PON, B-PON. First of all this is the standard of the IEEE where as other are of ITU standard. As both works for transmission technology of the optical fiber. In the above section it is described that optical fiber generates from the Central Office which is terminated to the user premises for providing a higher bandwidth. This chapter involves the transmission of data and voice through optical fiber at 10 Gbit/s as GE (Giga Ethernet specifies according to IEEE standard is 1000 MB/s for a particular transmission). While from the Central office the line through terminates at the optical splitter and also followed by transceiver as we know that we use optical splitter as a passive device which has some limitations. So on the basis of these factors some experimental results have been obtained. As we already discussed FTTH has separate channels for the voice and the data so it has two spectrums one for the voice and one for the data. In this data is transmitted at the wavelength of 1550 nm and the voice is transmitted at the wavelength of 1650 nm. Both the wavelengths

are selected because these wavelengths window has certain advantage i.e. it is low attenuation window. So Each user has separate or slightly different wavelength spectrum for voice and the data but FTTH is passed through the broadband channel of the media so that the third and last diagram shows the broadband spectrum of the both voice and the data. Upon the distance some errors has also occurred so how much distance disturb the data and the voice so BER is calculated a graph is showing the effect the distance on the BER.

1. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 1

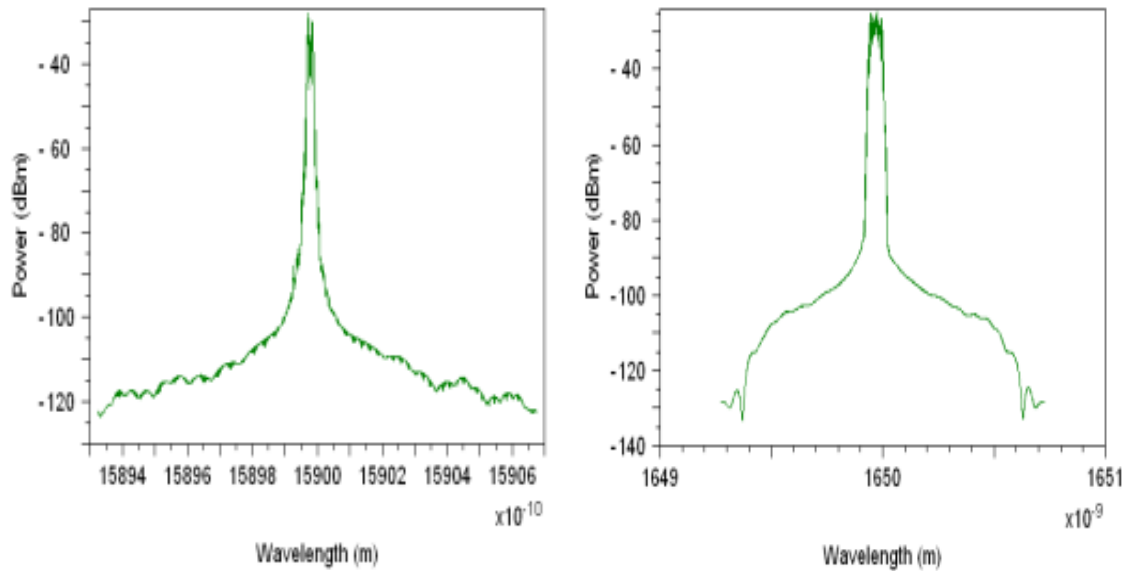


Fig 4.5 Wavelength Spectrum of Voice and Data

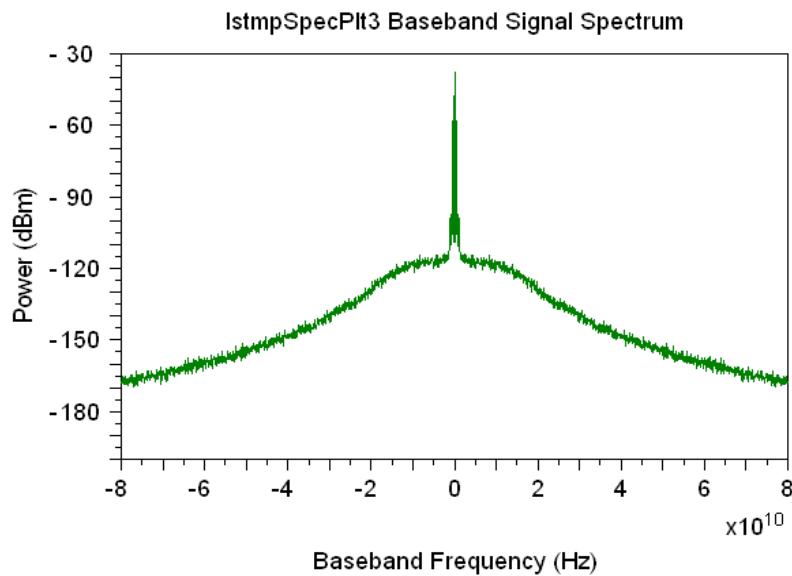


Fig 4.6 Frequency Spectrum of both Voice and Data

The above diagram represents the wavelength spectrum of user 1. These spectrum are observed at the receiver side as data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise. This diagram stated the voice should be transmitted at the 1650 nm while the data is transmitted at the 1590 nm. In the above architecture different users are separated by the optical splitter.

2. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 2

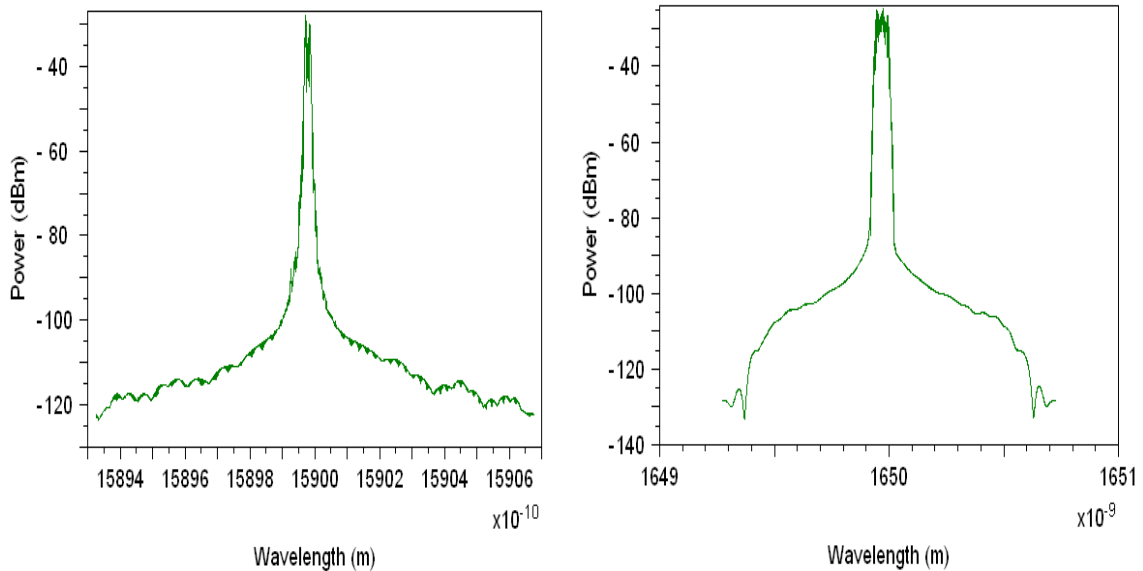


Fig 4.7 Wavelength Spectrum of Voice and Data

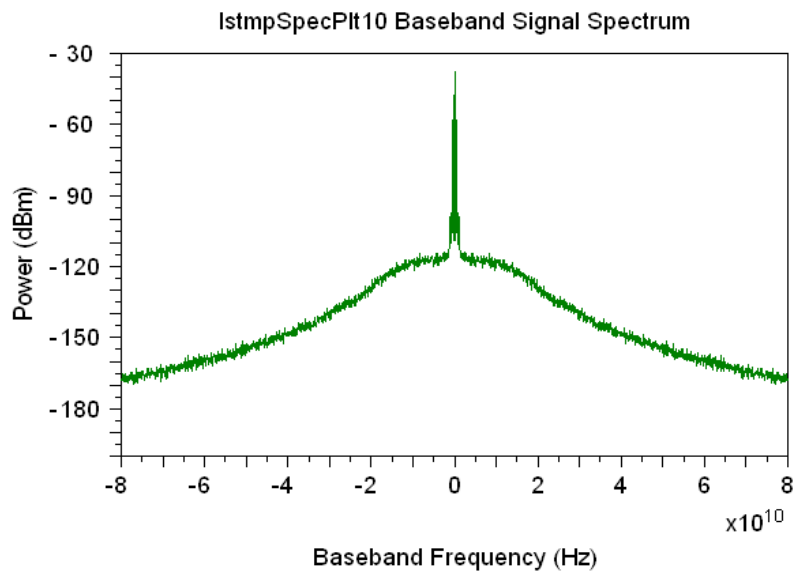


Fig 4.8 Frequency Spectrum of Voice and Data

The wavelength spectrum of user 2 is shown in fig. 4.8. The data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise at the receiver side. From the above diagram, it is clear that for the voice transmission 1650 nm is most suitable while for the data transmission 1590 nm is most suitable. In the above architecture different users are separated by the optical splitter.

3. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 3

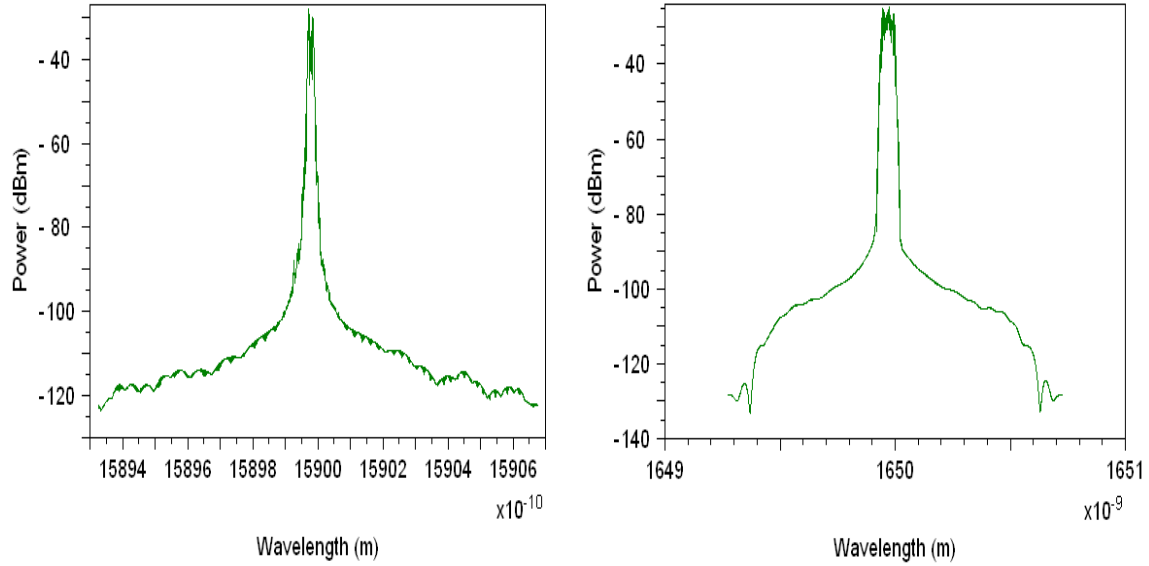


Fig 4.9 Wavelength Spectrum of Voice and Data

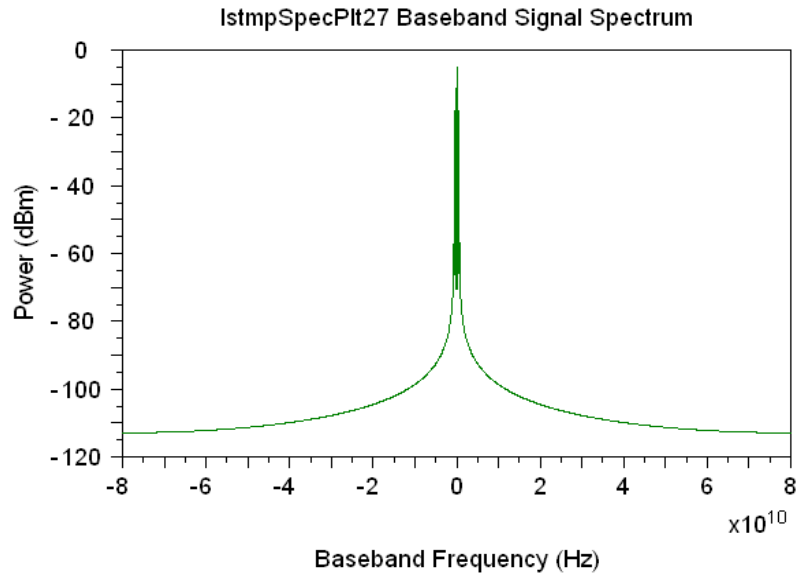


Fig 4.10 Frequency Spectrum of Voice and Data

The above diagram represents the wavelength spectrum of user 3. These spectrum are observed at the receiver side as data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise. This diagram stated the voice should be transmitted at the 1650 nm while the data is transmitted at the 1590 nm.

4. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 4

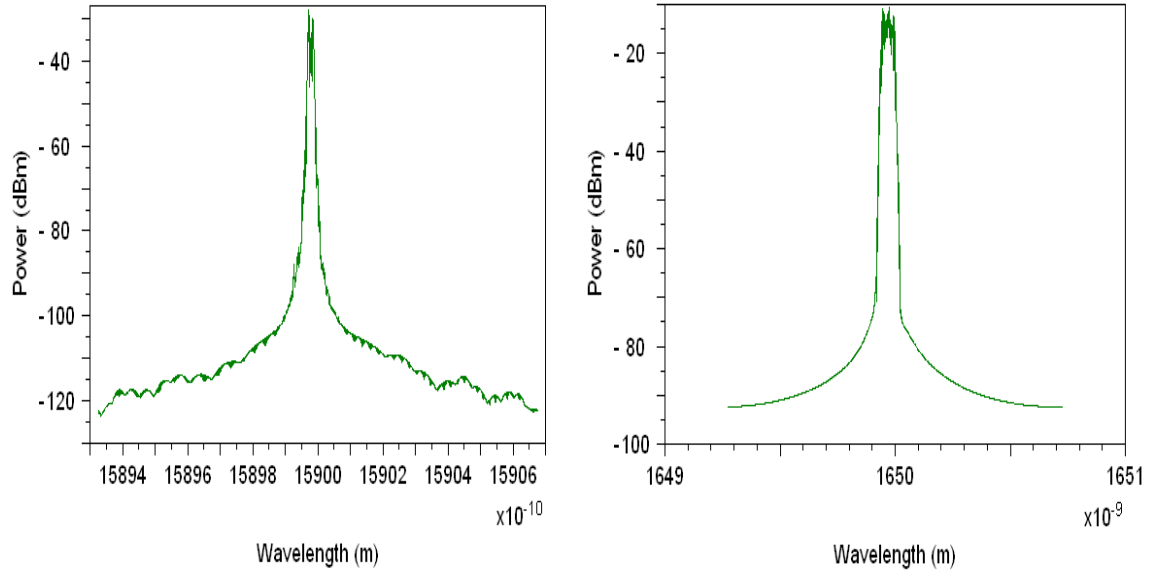


Fig 4.11 Wavelength Spectrum of Voice and Data

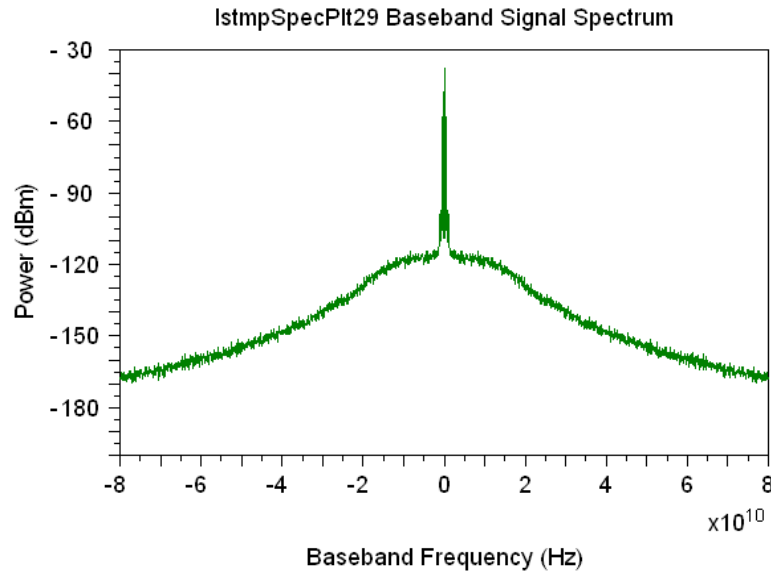


Fig 4.12 Frequency Spectrum of Voice and Data

The wavelength spectrum of user 4 is shown in fig. 4.12. The data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise at the receiver side. From the above diagram, it is clear that for the voice transmission 1650 nm is most suitable while for the data transmission 1590 nm is most suitable. In the above architecture different users are separated by the optical splitter.

5. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 5

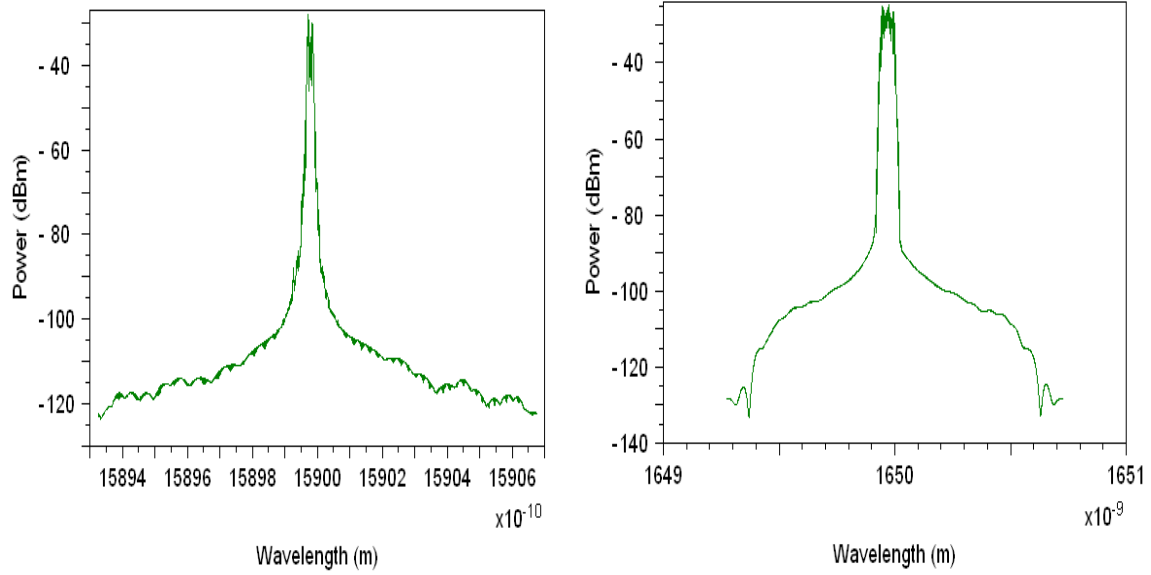


Fig 4.13 Wavelength Spectrum of Voice and Data

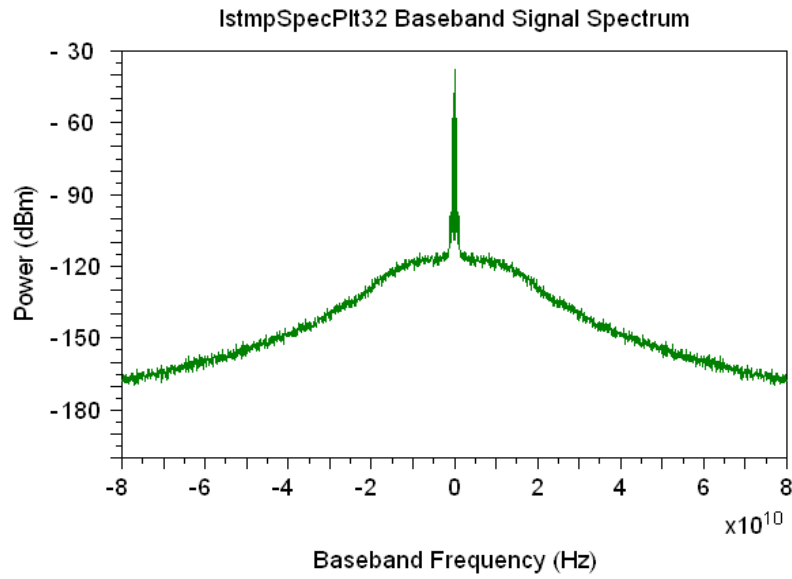


Fig 4.14 Frequency Spectrum of Voice and Data

The above diagram represents the wavelength spectrum of user 5. These spectrum are observed at the receiver side as data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise. This diagram stated the voice should be transmitted at the 1650 nm while the data is transmitted at the 1590 nm. In the above architecture different users are separated by the optical splitter.

6. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 6

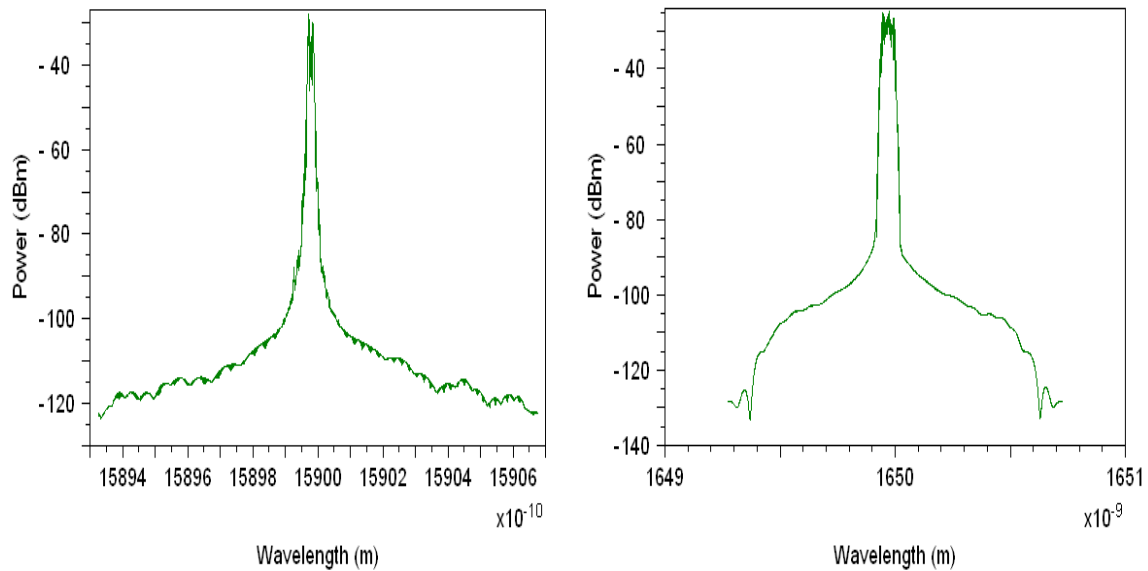


Fig 4.15 Wavelength Spectrum of Voice and Data

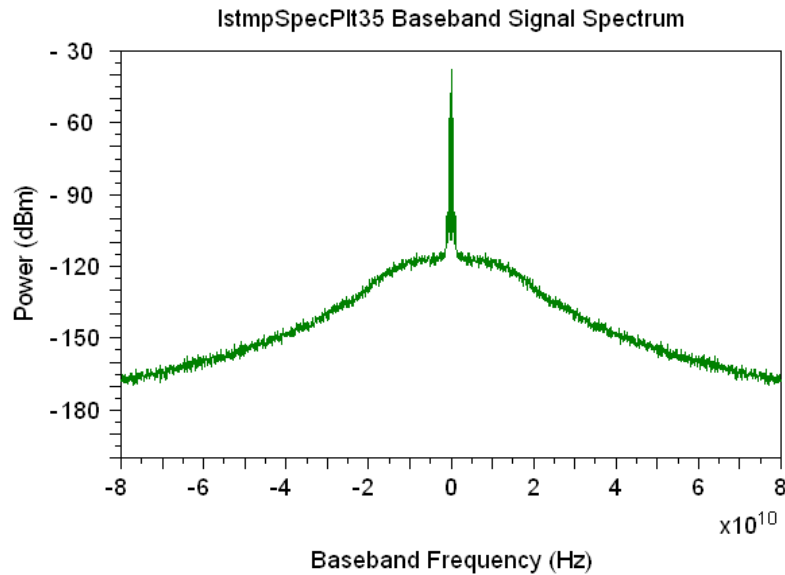


Fig 4.16 Frequency Spectrum of Voice and Data

The wavelength spectrum of user 6 is shown in fig. 4.16. The data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise at the receiver side. From the above diagram, it is clear that for the voice transmission 1650 nm is most suitable while for the data transmission 1590 nm is most suitable. In the above architecture different users are separated by the optical splitter.

7. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 7

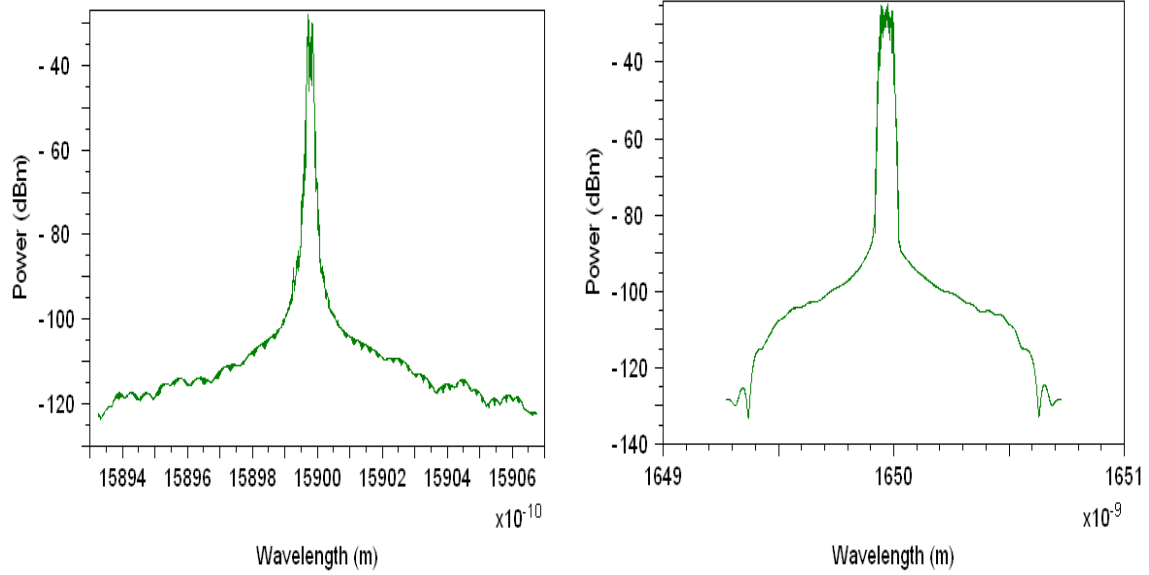


Fig 4.17 Wavelength Spectrum of Voice and Data

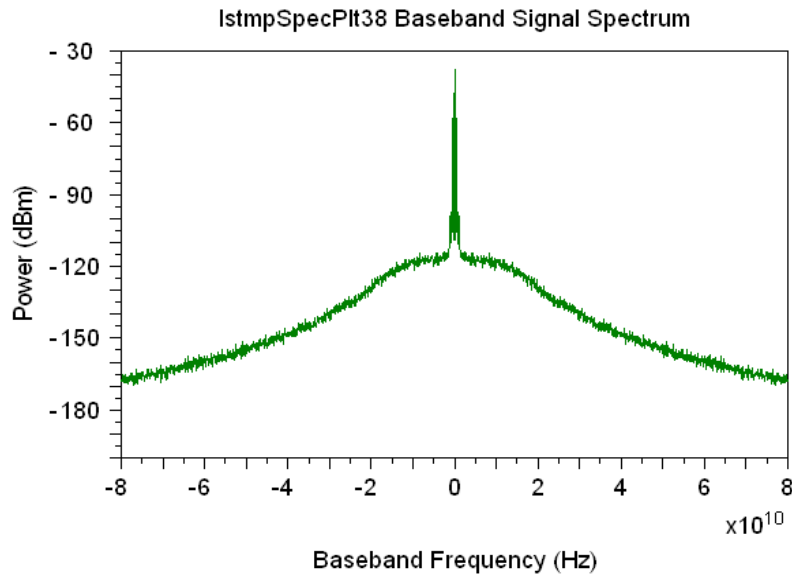


Fig 4.18 Frequency Spectrum of Voice and Data

The above diagram represents the wavelength spectrum of user 7. These spectrum are observed at the receiver side as data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise. This diagram stated the voice should be transmitted at the 1650 nm while the data is transmitted at the 1590 nm. In the above architecture different users are separated by the optical splitter.

8. Wavelength Spectrum of data and voice and Baseband Spectrum at USER 8

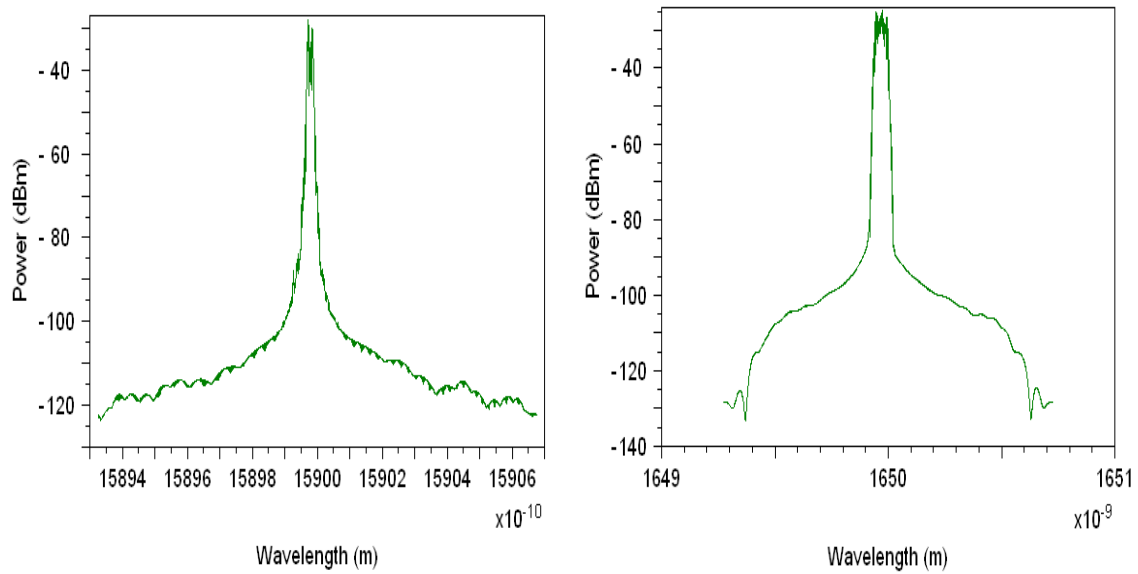


Fig 4.19 Wavelength Spectrum of Voice and Data

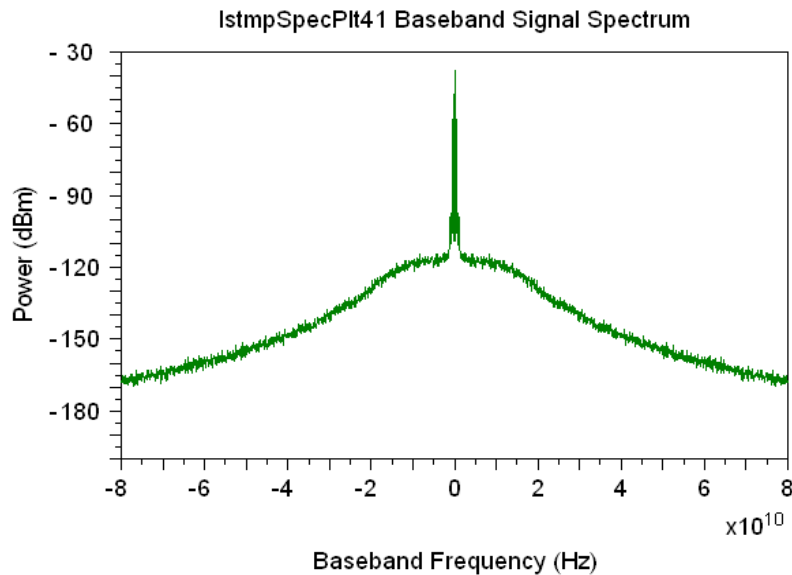


Fig 4.20 Frequency Spectrum of Voice and Data

The wavelength spectrum of user 8 is shown in fig. 4.20. The data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise at the receiver side. From the above diagram, it is clear that for the voice transmission 1650 nm is most suitable while for the data transmission 1590 nm is most suitable. In the above architecture different users are separated by the optical splitter.

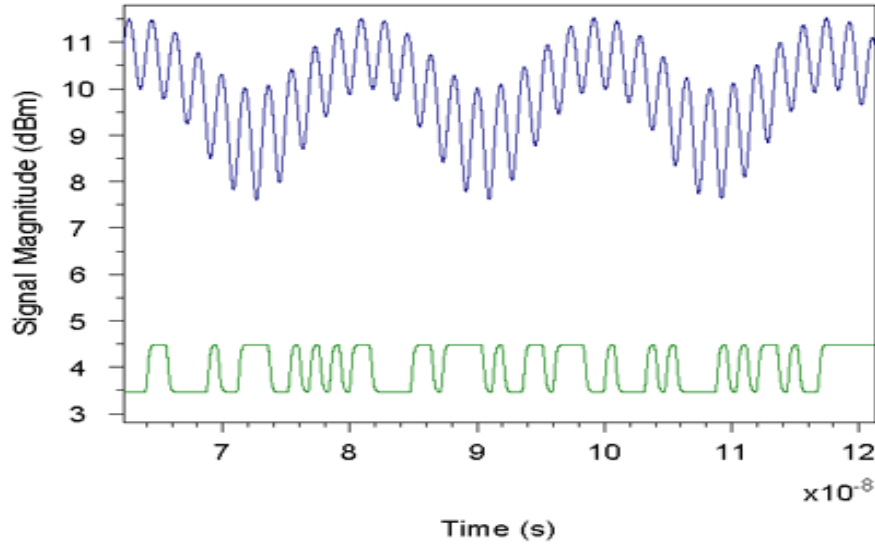


Fig. 4.21 OLT output optical waveforms for data and video signal

The Fig. 4.21 shows the OLT output optical waveforms for data and video signal. The data and voice are modulated by MZ modulator and then transmitted over the optical fiber so optical medium also inserted some error in the form of noise at the receiver side. From the above diagram, it is clear that for the voice transmission 1650 nm is most suitable while for the data transmission 1590 nm is most suitable. In the above architecture different users are separated by the optical splitter.

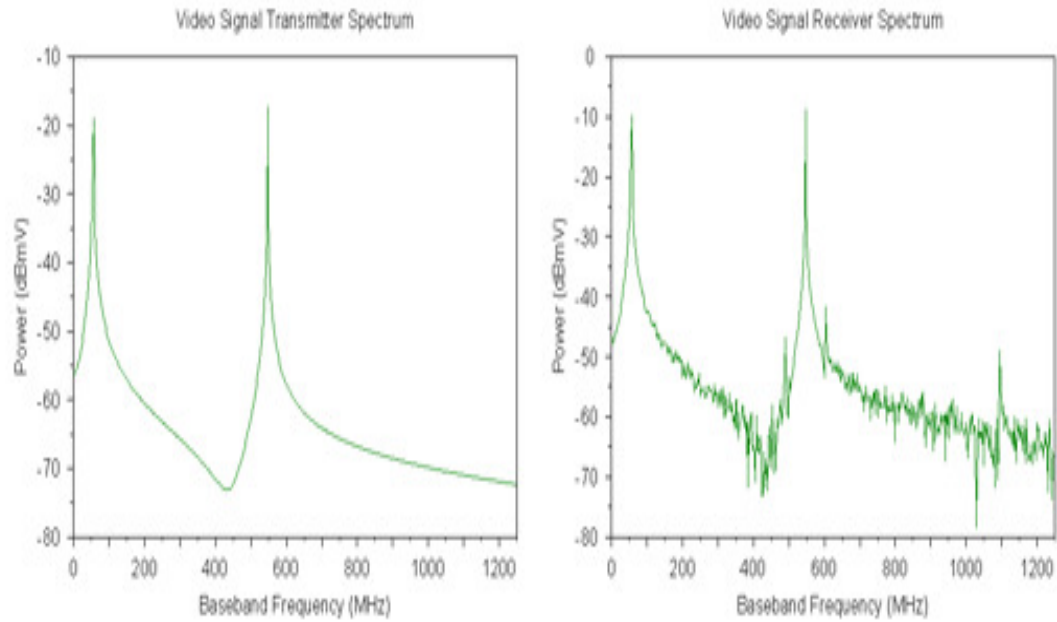


Fig. 4.22 Received RF spectrum of video signal with two tones (channels)

The figure 4.22 shows the received RF spectrum of video signal with two tones (channels) recovered, and for comparison the RF video spectrum at the transmitter. This layout can be further modified to study links with more specific details and provided components specifications. For example, a fiber trunk can consist of few fiber spans and splices, the drop-off cables from splitter to users ONTs can be added. The upstream configuration can be studied as well.

Bit Error Rate (BER): The BER is the measure of error bits with respect to the total number of bits transmitted in given time.

USER NO.	BER		
Distance	5 Km	10 Km	20 Km
1	2.1394e-024	1.4281e-022	8.0149e-021
2	2.9481e-024	1.3942e-022	8.3188e-021
3	2.7122e-024	1.5946e-022	8.0009e-021

4	2.2139e-024	1.5009e-022	8.7433e-021
5	1.2292e-025	8.0744e-024	4.5087e-022
6	8.6259e-026	8.3475e-024	7.0850e-022
7	6.8504e-027	8.4789e-025	9.0398e-023
8	6.4948e-027	7.8976e-025	9.7640e-023

Table 4.1 BER versus Distance

The above table represents BER observed at the distance from the PON to the NTU/ONT. Basically we extend or increase the number of users by using a passive device named as optical splitter. But optical splitter has also some limitations that by an OLT we have using only four optical splitters up to certain distance. So this chapter describes the distance between the OLT and Optical splitter, so if we increase the distance between the OLT and optical splitter then our data and voice becomes distorted and become error full so the PON is used upto the particular and specified length. The diagram represents the BER versus the distance, BER is measured along three different distances and BER is calculated for 8 different users and shown on the graph. Graph show as we increases the distance the BER continuously increases.

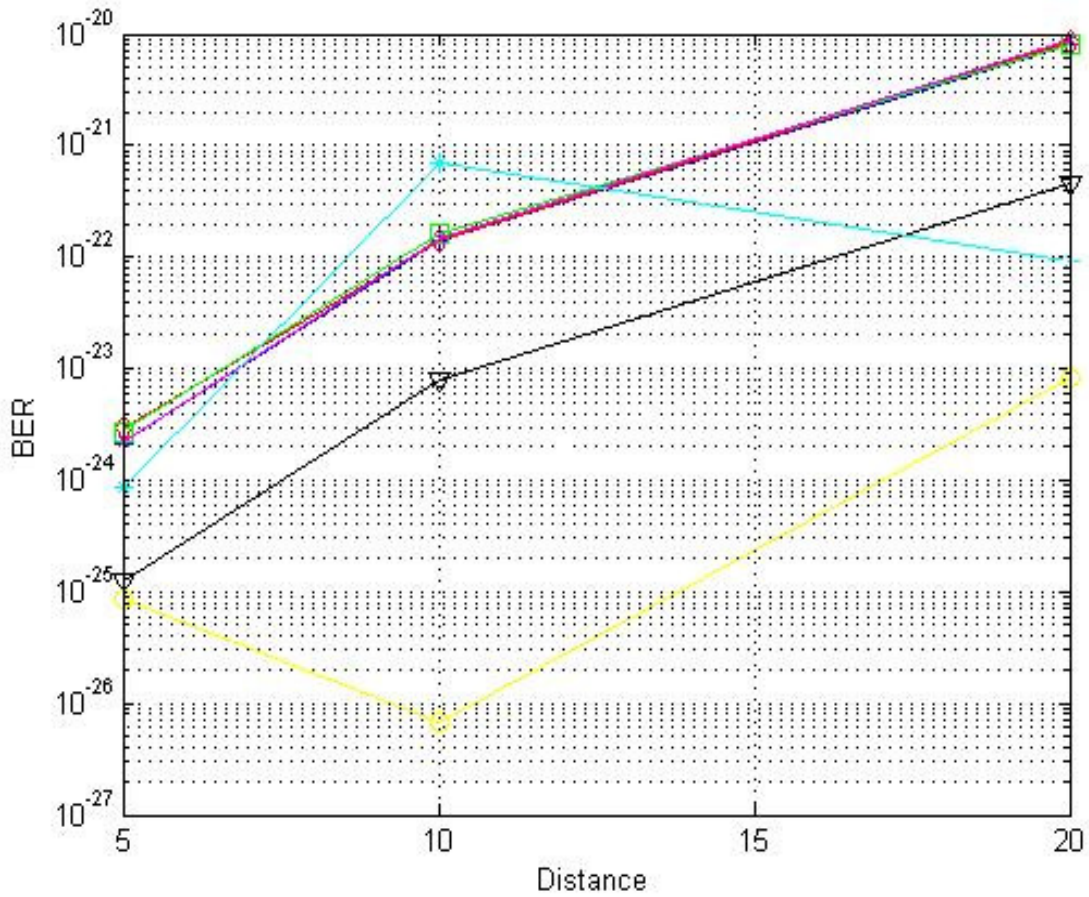


Fig 4.23 BER versus Distance

4.6 CONCLUSIONS

This chapter simulated an optimized GE-PON based FTTH access network to provide residential subscribers with full services. In this chapter, we describe the requirements of GE-PON access network with considerations of services and PON specific layered functions. To satisfy those requirements, we simulated an optimized architecture and describe the detailed functions of major elements. Finally, we consider the major technical issues i.e. BER to realize the GE-PON based FTTH access network. Considering the future prospect of FTTH access network, the FTTH will be motivated by the following factors. There is no need for outdoor cabinet sites, resulting in simpler network configuration and operation. No change of intermediate ONU is required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services. Maintenance is easy, because it requires

maintenance only for fiber systems, and fiber systems are regarded more reliable than hybrid fiber-metal ones. FTTH is a driver for the development of advanced optoelectronics technologies, and the great volume in production of optical modules will also accelerate the reduction in cost.

CHAPTER 5

OPTICAL TIME DIVISION MULTIPLEXING USING MZI

SWITCHING

Many lower-speed data streams can be multiplexed into one high-speed stream by means of Optical time division multiplexing (OTDM), such that each input channel transmits its data in an assigned time slot. The assignment is performed by a fast multiplexer switch (mux). The routing of different data streams at the end of the TDM link is performed by a demultiplexer switch (demux) and this demultiplexer is employed using MZI switch as it consists a semiconductor optical amplifier (SOA) and a optical coupler. In this chapter four channel OTDM is simulated at 40 Gbit/s and further it is investigated the impact of the signal power, pulse width and control signal power on BER.

5.1 INTRODUCTION

The transmission capacity of an optical network could be extended in a simple way by installing additional fibres (space division multiplexing or SDM). Since this is very expensive, methods have been developed for a more efficient use of the available bandwidth in the existing fibre network. A first solution is to increase the bit rate in the network, which requires higher-speed electronics at the nodes of the network. The interleaving can be carried out on a bit-by-bit basis, like, or on a packet-by-packet basis. As data speeds become higher and higher, it becomes more difficult for the electronic parts (switches) in the system to handle the data properly. [37, 39] A. Cheng et al. Presented 40 Gb/s OTDM demultiplexing using an all-optical tunable delay line and an electro-absorption modulator. The continuous fiber-optic delay for channel selection is realized using four-wave-mixing and wavelength-dependent group delay. [34] Ken Morito et al. presented uniform output powers and high extinction ratios for a Mach-Zehnder interferometer type all optical switches with asymmetrically biased amplifiers and a phase shifter are found in a dynamic analysis for narrow control pulses and optimized switching windows. [40] The performance of optical time division multiplexing (OTDM) system is limited by a complex combination of noise. In this paper we present a theoretical framework for the optical receiver in OTDM system based on the moment generation function. Jianfeng Zhang et. al. presented the proposed receiver

model is showed to be more accurate in predicting the bit error rate (BER) performance than the former ones.[47] This problem can be overcome by routing the data through the optical domain, which is denoted as optical time division multiplexing (OTDM). The speed of the present day experimental OTDM systems is in the order of 10 Gb/s (single channel), and is mostly limited by the speed of the non-linear elements and the influence of physical effects like chromatic dispersion on the optical pulses in the employed fibres. Mach-Zehnder interferometers with integrated SOAs (SOA-MZI) are particularly attractive as high-speed optical gates. They feature low switching energy, high compactness and stability, as well as the potential for further optical integration. In this chapter we simulated four channel OTDM channels at speed of 40 Gbit/s for BER with pulse width, Control Signal Power.

Multiplexing is the sending of a number of separate signals together, over the same cable or bearer, simultaneously and without interference. Whenever the bandwidth of a medium link two devices is greater than the bandwidths needs of the devices, the link can be shared. Multiplexing is set of techniques that allow the simultaneous transmission of multiple signals across a single data link. In a multiplexed system, n lines share the bandwidth of one link. The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many to one). At the receiving end, that stream is fed into demultiplexers (DEMUX), which separates the stream back into its component transmissions (one to many) and directs them into their corresponding lines. In figure link refers to the physical path. The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many channels. [9, 10]

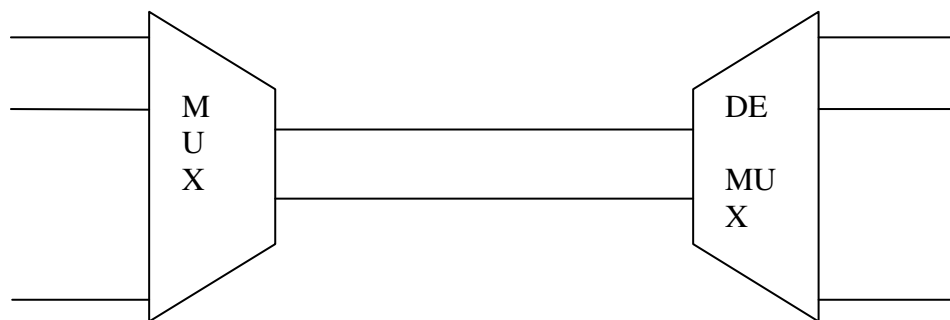


Fig 5.1 Dividing a link into channels

5.2 TIME DIVISION MULTIPLEXING

TDM is digital process that allows several connections to share the high bandwidth of a link. Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link. TDM is a digital multiplexing technique for combining several low rate channels into one high rate one. In TDM, the data rate of the link is n times faster, and unit duration is n times shorter.[9, 10]

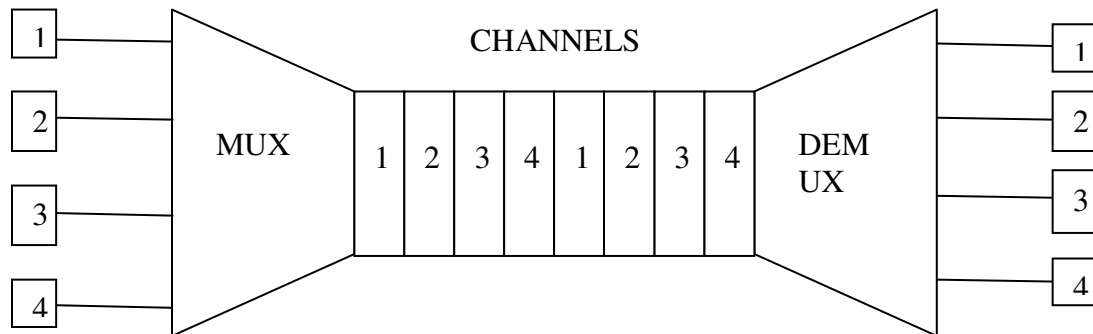


Fig 5.2 Time Division Multiplexing

5.3 OPTICAL TIME DIVISION MULTIPLEXING

Electronic multiplexing at such speeds remains difficult and presents a restriction on the bandwidth utilization of a single-mode fiber link. An alternative strategy for increasing the bit rate of digital optical fiber system beyond the bandwidth capabilities of the drive electronics is known as optical time division multiplexing (OTDM). At the begin of the fiber optic data transmission the electrical digital channel signals have been electrically up-multiplexed to the maximal aggregated data rate following a predefined data hierarchy. This aggregated electrical signal was converted electro-optically into the optical domain only for the transmission. For demultiplexing, the transmitted optical signal is converted into the electrical domain and demultiplexed in the electrical domain. The principle of this technique is to extend time division multiplexing by optically combining a number of lower speed electronic baseband digital channels. Figure shows the optical multiplexing and demultiplexing ratio is 1:4, with a baseband channel rate of required bit rate. Hence the

system can be referred to as a four channel OTDM system. The four transmitters in figure are driven by a common 40 GHz clock using quarter bit period time delays. Mode Locked semiconductor laser sources which produced short optical pulses were utilized at the transmitters to provide low duty cycle pulse streams for subsequent time multiplexing. Data was encoded onto these pulse streams using integrated optical MZ modulator which gave RZ transmitter outputs at 10 Gbit/s. these IO devices are employed to eliminate the laser chirp would result in dispersion of the transmitted pulses as they propagated within the single-mode fiber, thus limiting the achievable transmission distance. [58, 59]

The four 40 Gbit/s data signals are combined in a passive optical power combiner but, in principle, an active switching element could be utilized. Although four optical sources are employed, they all emitted at the same optical wavelength within a tolerance of ± 0.2 nm and hence 40 Gbit/s data streams are bit interleaved to produce the 160 Gbit/s baseband components in a demultiplexer which comprised two levels. Again IO waveguide devices were used to provide a switching function at each level. At the first level the IO switch is driven by a sinusoid at 80 GHz to demultiplex the incoming 160 Gbit/s stream into 80 Gbit/s signals. Hence single wavelength 160 Gbit/s optical transmission is obtained with electronics which only required a maximum bandwidth of about 25 GHz, as return to zero pulses are employed.

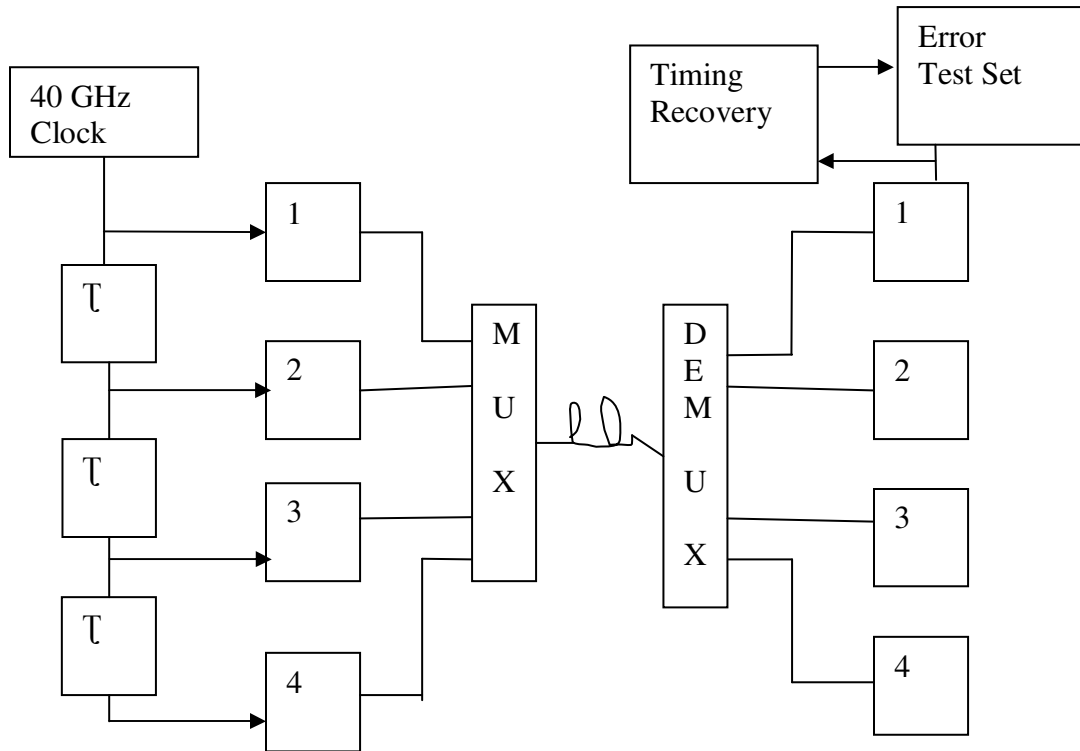


Fig 5.3 Optical Time Division Multiplexing

5.4 DEMUX OPERATION USING MZI-SOA SWITCH

The MZI-SOA all optical switch is shown in Fig 5.4 It consists of two symmetric 2x2 multimode interferometer (MMI) splitters for dividing and combining data pulses, two couplers for introducing control pulses, two SOA's for providing phase shift, and a phase shifter (PS) for adjusting offset phases. The data signals injected from the input port are directed to the cross port or the bar port depending on the phase difference between the two SOA's. By injecting the control pulse 2 with a certain time delay and a proper energy difference against the control pulse 1, the slow phase change associated with the slow gain recoveries in two SOA's are completely eliminated. This gives rise to short switching windows. By adjusting the injection times of the two control pulses, one of the multiplexed data pulse signals can be dropped to the bar port and the other signals can be transmitted to the cross state. Here counter propagating data and control pulses are assumed. [60, 61, 62, 63]

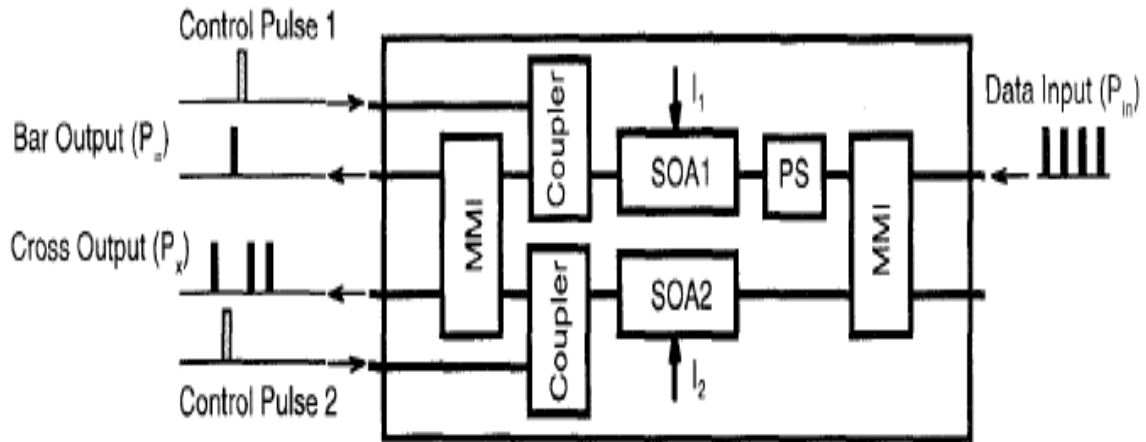


Fig 5.4 DEMUX using MZI switch

5.5 SIMULATION SETUP FOR OTDM

The particular system setup of OTDM is shown in figure (5.5). The component used in figure (5.5) are chosen from the Optsim Ver.4.7.0 component library palette and placed as per requirement in the design area of the Optsim editor. Then various simulation parameters are set. The transmitter comprises of a pseudo-random binary sequence or PRBS generator, mode locked laser diode, an electrical generator, four time shifting blocks, an optical MUX and an optical normalizer. Multiple channels from a MLLD are RZ modulated with a different PRBS patterns. The PRBS block generates multiple pattern outputs, each different from the other and at same bit rate. All the channels from MLLD are at same wave length of 1650nm and of same power. Before being multiplexed together each consequent channel is delayed by 1/4 of time window in succession. Total power of all the channels is controlled by an optical normalizer, which determines the average output power of OTDM signal before propagation over the fiber length. The OTDM signal travels over optical fiber of 100 km length and then it is de-multiplexed at the receiver end. The receiver consists of four identical SMZ switch (but with different time delays), each consists of a pulse train generator (with same repetition rate as the transmitter), optical normalizer block, pulse splitter and two time delay blocks and an SMZ switch with two output ports. The BER meter is connected at both output and reflected port to get the results. All the SMZ switch are connected at the output of the nonlinear fiber.

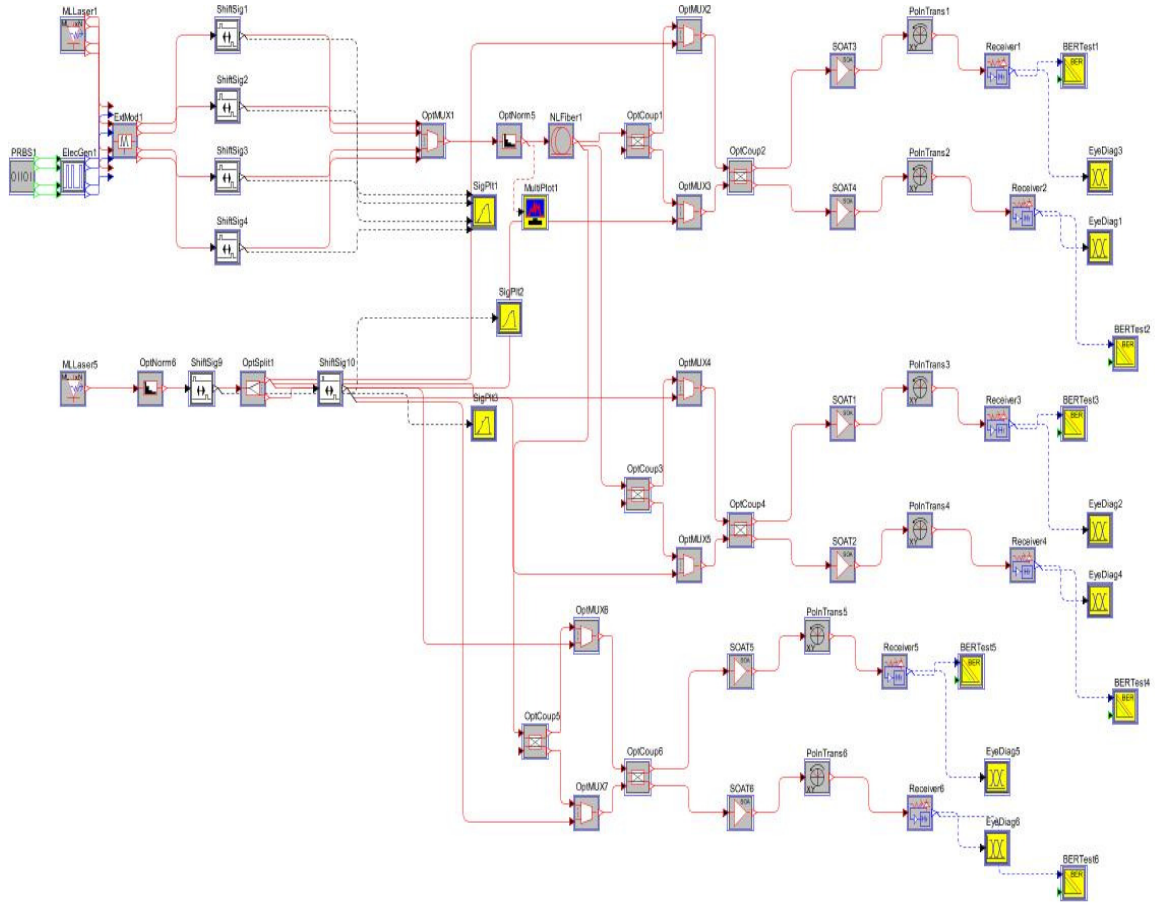


Fig 5.5 Schematic Diagram of OTDM using MZI switching

5.5 RESULTS AND DISCUSSIONS

Synchronization between transmitter and receiver in OTDM is a critical issue for optimum performance of system. In this paper, the transmitter and the receiver has been synchronized by the addition of optical delay in the control signal. The optical delay is varied as an integer multiple of $1/4$ of the pulse width within an expected bound. The pattern that emerges from such variation determines the optimum optical delay required for each channel. The effect of noise and distortion are well known in digital transmission. Noise causes bit errors at the decision gate of the receiver and distortion causes changes to the pulse shapes resulting in inter symbol interferences (ISI), which also produces bit errors. The major parameter in addition to bandwidth, which characterizes a digital optical link, is BER. So the effect of signal power (P_{signal}), control signals power (P_{control}), and pulse width on BER is

investigated. Fig shows variation of BER with change in signal power. As mentioned previously optical normalizer controls the average output power of the multiplexed signal. The BER for channel 1 is in the range of 10^{-21} – 10^{-28} for P_{signal} values 5 and 10 dBm, respectively.

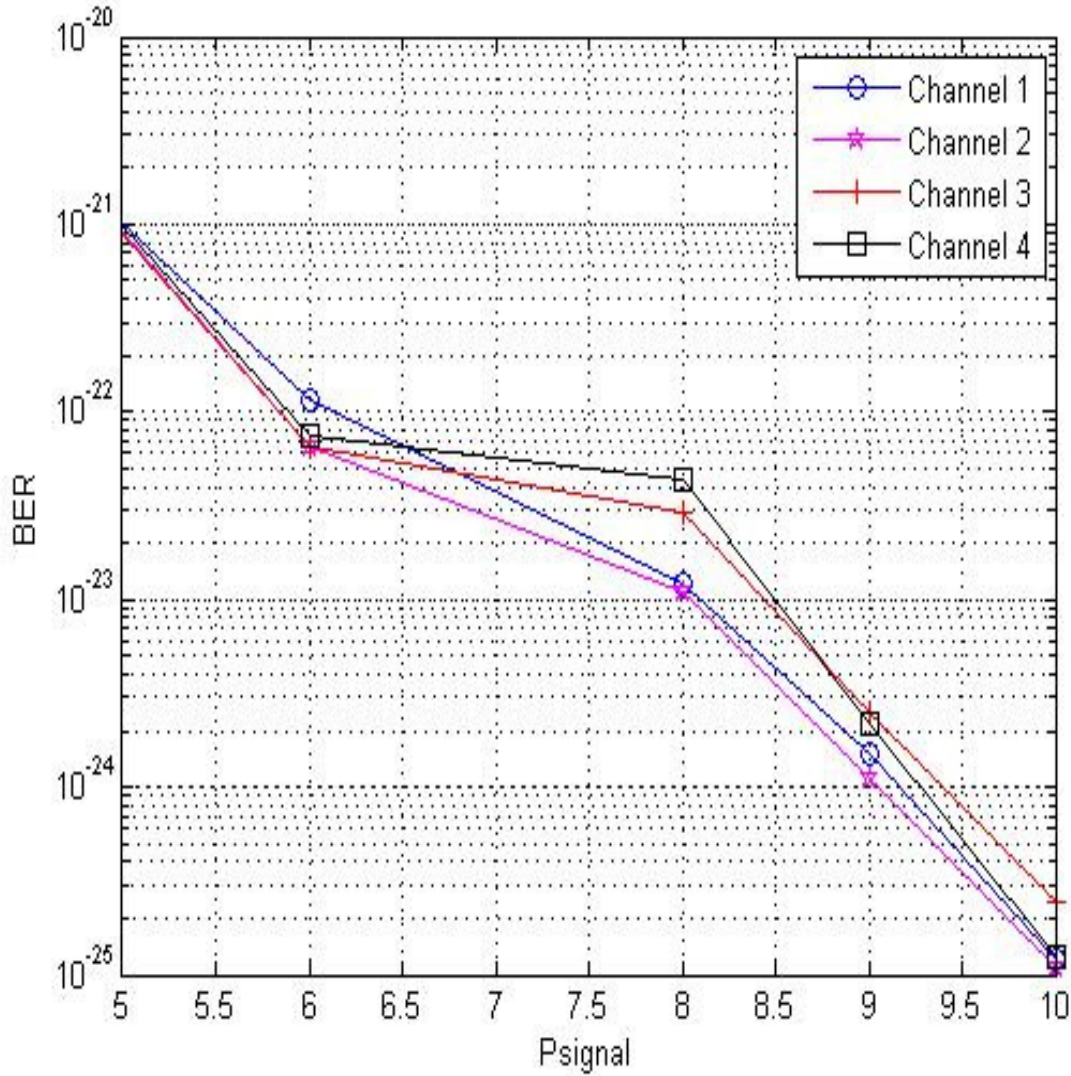


Fig 5.7 BER versus input signal power with dispersion

So it is observed that with the increase in signal power (P_{signal}) the BER is improved. Similarly for channels 2 and 4 this variation is in the range of 10^{-22} – 10^{-25} and 10^{-22} – 10^{-25} for P_{signal} values of 5 and 10 dBm, respectively. It is interesting to note that BER for channels 2 and 3 is same for all the P_{signal} values. BER of an optical receiver is inversely proportional

to SNR, which is in turn dependent on optical power of the signal. Thus BER decreases with increase in signal power.

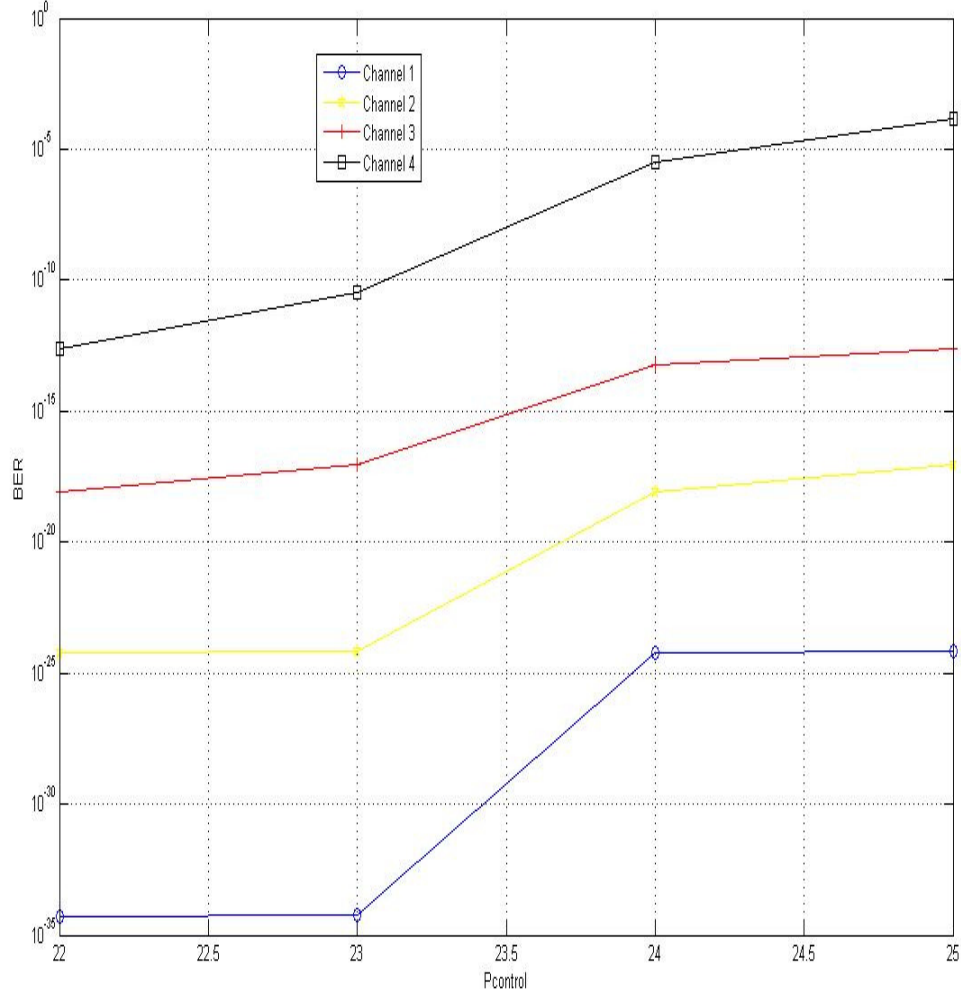


Fig 5.8 BER versus pulse width with dispersion

Further in Fig. 5.8 the effect of change in pulse width on BER is investigated. The pulse width of the input signal was varied within the bounds of $5e^{-12}$ – $12e^{-12}$ m and variation in BER was observed. As seen in the figure for channel 1 BER at $5e^{-12}$ m is 10^{-140} and with increase in pulse width it decreases to 10^{-27} for pulse width $12e^{-12}$ m. Once again there is an overlap in curves for channels 2 and 3 and the variation for BER is from 10^{-140} to 10^{-167} for above-mentioned variation in pulse width. For channel 4 the value of BER varies from 10^{-140} to 10^{-162} for above-mentioned variation in pulse width. The results indicate an improvement in

receiver performance with increase in pulse width. This improvement can be attributed to reduction in pulse width distortion. shows a significant degradation in receiver performance when control signal power is increased gradually beyond 22 dBm. Thus in case of channel 1 BER at 22dBm control signal is 10^{-35} and increases to 10^{-4} at 26 dBm. Channels 2 and 3 once again exhibit identical BER patterns and variation is in the

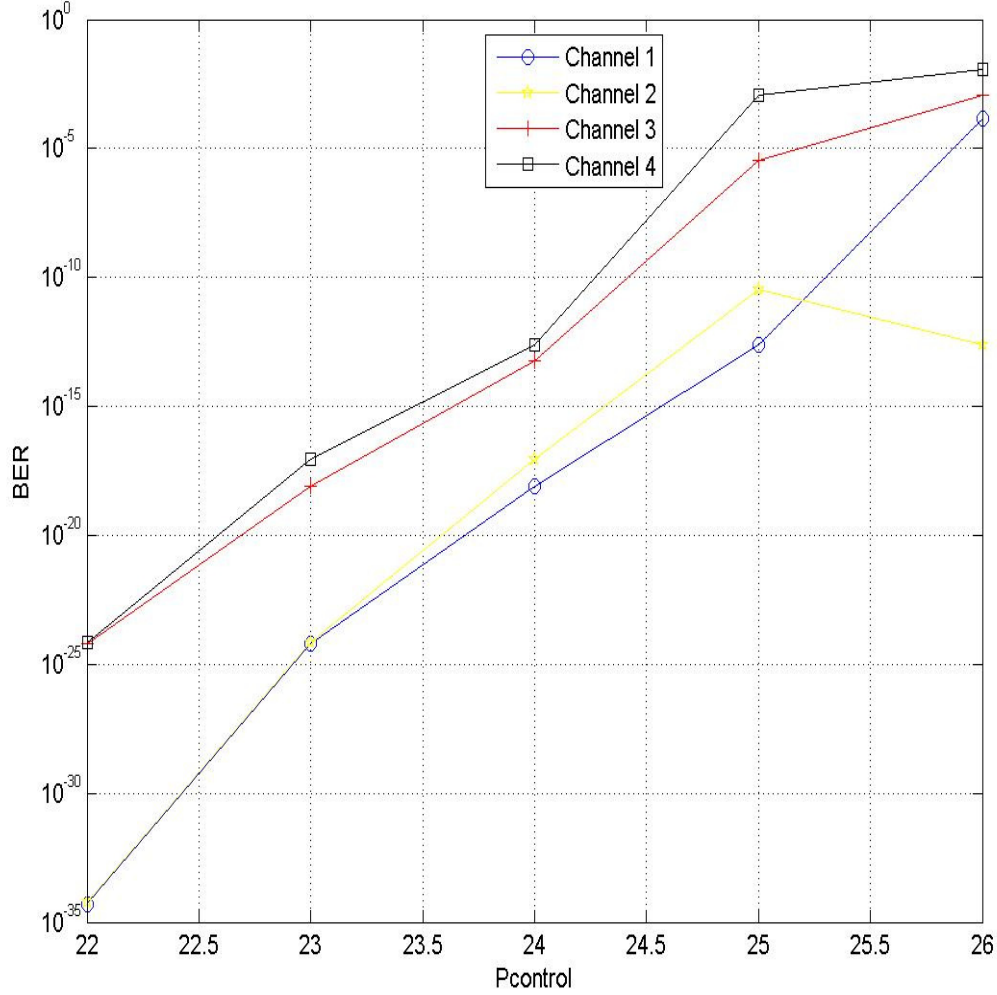


Fig 5.9 BER versus power control signal with dispersion

range of 10^{-35} – 10^{-4} at 22 and 26 dbm, respectively. The variation in BER for channel 4 is in the range of 10^{-35} – 10^{-2} for the above-mentioned variations in control signal power. It is understood that principle of operations of an MZI switch is based on interference between signals passing through the two legs of an MZI. The control signal affects a change in

refractive index of semi-conductor material. The change in refractive index in turn introduces a phase shift in the input signal. It shows the effect of Pcontrol on BER with no dispersion for all the channels. The two signals interference at the output and the resultant output is dependent on their relative phase shifts. Thus, the signals may interfere either constructively or destructively. From the graphs it is evident that an increase in control signal beyond 22 dBm introduces a phase shift, which degrades the receiver performance and BER goes on increasing with increases in control signal power. Fig. 5.12 depicts eye diagrams for channel1, at Pcontrol values of 22 and 26, respectively. There is degradation in decision level offset values from 1.5×10^{-5} to 7×10^{-6} with increase in Pcontrol values from 22 to 26. This observation supports the conclusion drawn from BER verses Pcontrol signal.

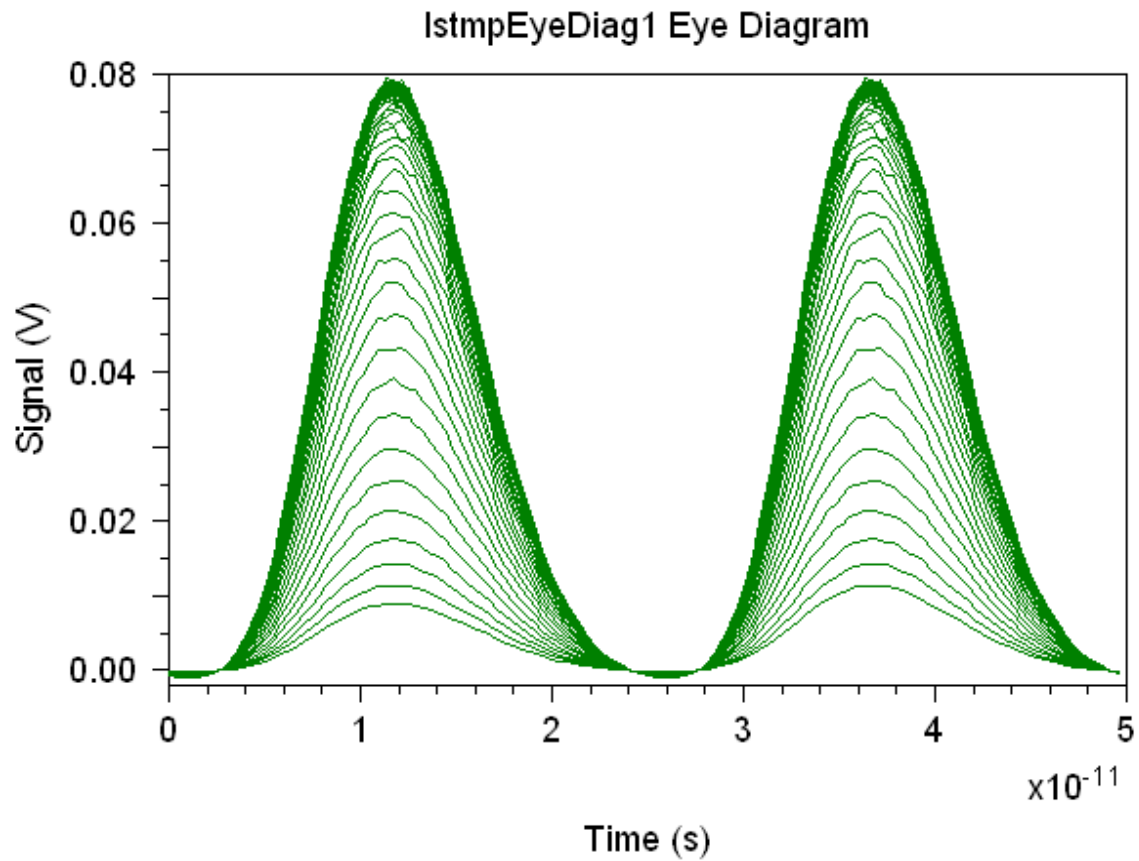


Fig 5.10(a) Eye Diagram

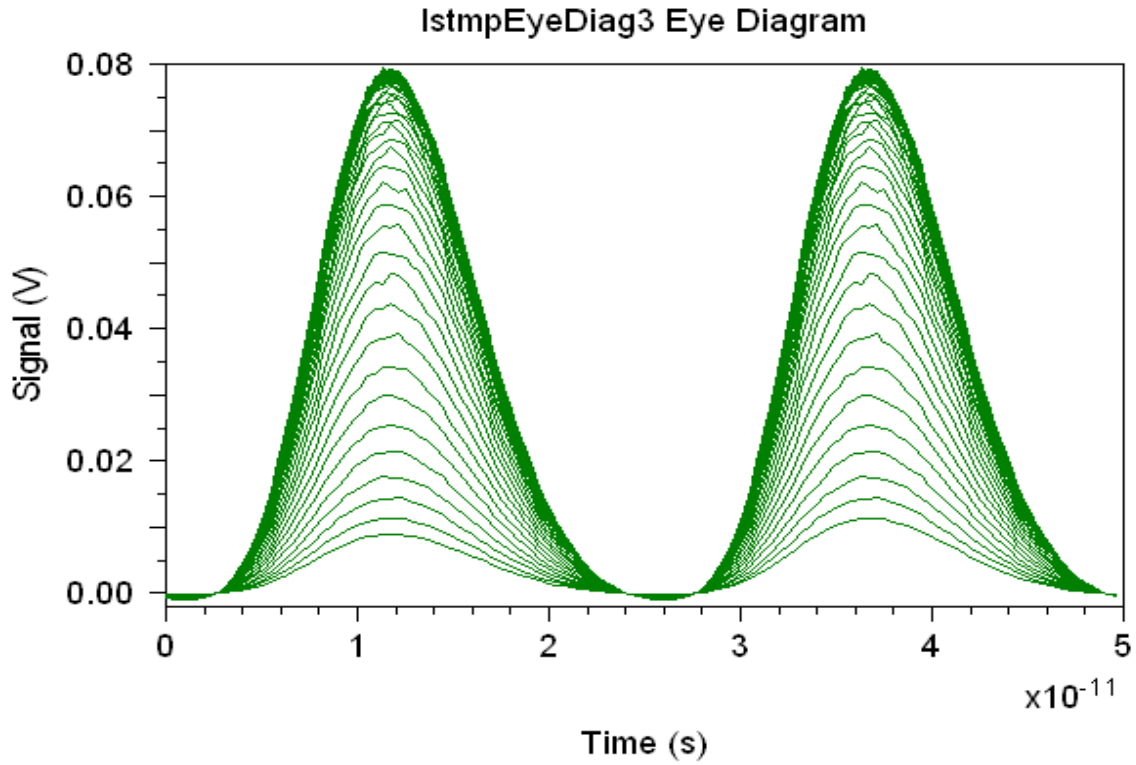


Fig 5.10(b) Eye Diagram

5.6 CONCLUSIONS

A 160-Gb/s OTDM transmission with all-channel modulation and all-channel simultaneous demultiplexing has been successfully simulated for the first time. The MUX and DEMUX using of MZI switch strictly maintain the delay time between adjacent channels and offer high-temperature stability because they are hybrid integrated on MZI switch; they will, therefore, be the keys to future OTDM transmission systems.

CHAPTER 6

CONCLUSION AND FUTURE ASPECTS

6.1 CONCLUSION

In this thesis the scheme generating optical logic is implemented by MZ Interferometer as discussed in chapter 2 can be used for different purposes. This scheme can easily and successfully be extended and implemented for any higher number of input digits by proper incorporation of MZI based optical switches, vertical and horizontal extension of the tree and by suitable branch selection. Again the whole operation is parallel in nature, i.e. the results of different operations between the data are obtained at a time. Here we can implement the multiple instruction multiple data type operation nicely. Arithmetic operations can be conducted here between any two large-shaped data. The proposed one bit digital comparison scheme also successfully exploits non-linear material based tree structures for its operation. It is important to note that the above discussions are based on a simple model. In this simulation some walk parameter has to be considered such that dispersion, polarization properties of the fiber, predetermined values of the intensities/wavelength of laser light for control and incoming signals, introduction of the filter, intensity losses due to the beam splitters/fiber couplers etc. As in this thesis the wavelength of the continuous wave of laser beam is 1550 μm and pulsed signal of wavelength of 1650 μm can be used as incoming and control signals, respectively. Intensity losses due to the couplers and splitters in the interconnecting stage may not create much trouble in producing the desired optical bits at the output as the whole system is a digital one and the output depends on the presence and absence of the light. In interconnecting stages fiber couplers can be used instead of the beam splitters.

FTTH for eight users (ONU) at rate of 10 Gbit/s for different wavelength for the transmission of both the data and voice is verified and the BER is calculated at different distance. As it matched according to the standard so it is quite acceptable and further be demonstrated in future for different technologies. Fiber to the home solves important societal problems, promises to accelerate the recovery of both computer and communication industries worldwide, and constitutes, for a given country, an important national competitive asset. FTTH system has been matured by both technical and economical baptism during the past

several years, so we can believe that FTTH will be deployed as a more cost-effective architecture for providing familiar voice, video, and data services. As FTTH becomes more widespread, it will be exciting to watch the new applications that emerge to make use of the increased bandwidth. And it will keep on being a promising technology as an ultimate solution for local broadband access network.

Four channel 4 X 40 Gbit/s OTDM system (all channel) with a Mach-Zehnder modulator, MZI switching and a fiber length of 100 Km, has been experimentally and successfully verified. Experimental results reveal that BER decreases with increase in signal power and increase in pulse width. As in this thesis BER increases with increase in control signal power with dispersion in single mode fiber. It is also concluded that the performance of OTDM system can be improved using dispersion compensating fiber.

6.2 FUTURE ASPECTS

All-optical logic is recent research in the field of optical computing as this scheme also provides the idea of optical memory if we design a optical flip-flop which stores data as an optical pulse.

As FTTH has many advantage over the all transmission techniques so, Providers could use ATM, SONET, Ethernet or Analog modulated RF carriers as their data link layer technology. Since all users served by the same splitter – combiner on a curbside PON (and by the same Remote Node in an Active Star architecture) have to be served by the same data-link layer technology. FTTH infrastructure that is technologically and competitively neutral; where voice, video and data service providers can choose and deploy the technology of their choice to support the services they plan to offer. FTTH also provides additional services over it just like UWB (Ultra wide band), WCDMA, Radio over fiber, so many other services as network will use FTTH network as the interface for access network.

A focus has been put on the future-proof PON system having gigabit symmetry in bandwidth between the up- and downlinks. It has been shown that OCDMA is capable of providing a gigabit- or even multi gigabit-per-second for each user both in the up- and downlinks, and OCDMA over WDM PON could be one of the most promising system architectures that can break through the last/first mile bottleneck.

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