PERFORMANCE ANALYSIS OF HYBRID TDM/DWDM OPTICAL COMMUNICATION SYSTEM IN THE PRESENCE OF FWM & ASE NOISE

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER

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ABSTRACT

The goal of fiber-optic communication system is to transmit maximum number of bits per second over the maximum possible distance with the fewest errors. One such technology is hybrid Dense Wavelength Division Multiplexing (DWDM) and Time Division Multiplexing (TDM). This is to accommodate the consumer demand for ever increasing amount of bandwidth with excellent reliability. These architectures would be of great importance in the application of systems requiring very large number of sensors with limited telemetry cabling.

In the hybrid architecture Erbium Doped Fiber Amplifier (EDFA) is used to compensate for the distribution loss. When number of EDFAs deployed increases ASE noise gets accumulated. This degrades the hybrid system performance. ASE noise can be suppressed using Semiconductor Optical Amplifier (SOA) based Mach-Zehnder Interferometer (MZI) at the receiver end.

The nonlinear effects are severe when the power of optical system is very high and is important in TDM/DWDM systems. Four-Wave Mixing (FWM) is an unwanted parameter which occurs due to the interference of nearby wavelengths. Sum and difference of adjacent wavelengths lead to FWM and it limits the transmission distance and bandwidth of optical communication systems. Various factors which influence FWM are spacing between channels, channel input power, refractive index of fiber and the operating frequency. FWM suppression is necessary to provide good performance to the users and is achieved by providing unequal channel spacing.

The ASE noise is analyzed for different wavelengths and fiber lengths. The hybrid architecture for different modulation formats like RZ, NRZ and Manchester is tested for ASE noise performance measures.

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LIST OF ABBREVIATIONS

WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FWM	Four Wave Mixing
ASE	Amplified Spontaneous Emission
NRZ	Non Return to Zero
RZ	Return to Zero
PRBS	Pseudo Random Bit Sequence
CW LASER	Continuous Wave LASER
BER	Bit Error Rate
LPF	Low Pass Filter
TDM	Time Division Multiplexing
SRS	Stimulated Raman Scattering
FWM	Four Wave Mixing
XPM	Cross Phase Modulation
MZI	Mach-Zehnder Interferometer
SOA	Semiconductor Optical Amplifier
MUX	Multiplexer
DEMUX	Demultiplexer

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF OPTICAL FIBER

Fiber-optic communication is a method of transmitting information from communication equipment at one place to corresponding communication equipment at another place using pulses of light. The light forms an electromagnetic carrier wave that is modulated based in input signal to carry information. Because of its advantages over electrical transmission, optical fibers have largely replaced copper wire communications in core networks. The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal by the use of optical transmitter, transmitting the signal along the fiber, ensuring that the signal does not become too distorted or lost, receiving the optical signal, and converting it into an electrical signal based on intensity.

The important features are,

- Immunity to electromagnetic interference, since the signal is well confined with the core.
- High electrical resistance, making it safe to use near high-voltage equipment or between areas with different earth potentials.
- Lighter weight—optical fibers are much lighter than copper cables, since is manufactured using glass or plastic.
- Much smaller cable size— This feature is important where pathway is limited, such as to provide network in an existing building, where smaller channels can be drilled and space can be saved in existing cable trays.

The fiber-optic communication will face the following major challenges in future.

- Increased traffic flow driven by internet applications
- Merging of data and telecommunication networks
- Maintenance in terms of business feasibility for service providers

1.2 WDM

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths of laser light. This technique enables bidirectional communications over one fiber, as well as it provides multiplication of capacity [11].

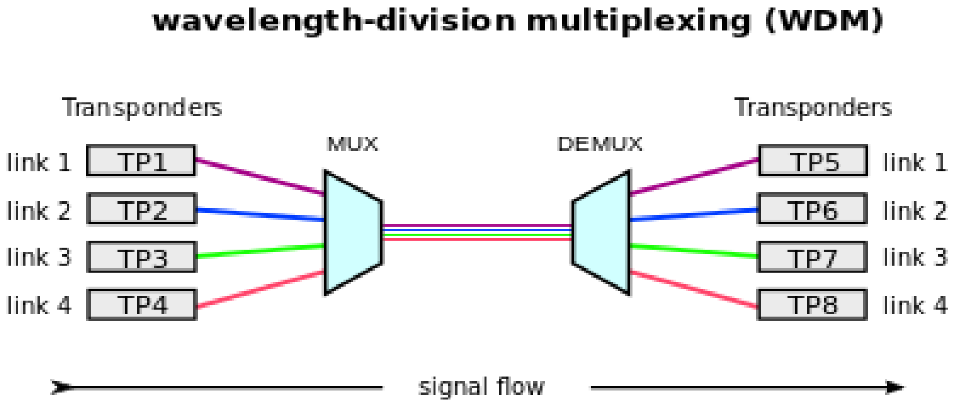

Fig 1.1 Principle of WDM

A WDM system uses a multiplexer at the transmitter to combine the signals together from different sources operating at different wavelengths and a demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer. Although WDM-PONs can provide much higher bandwidth than TDM-PONs, it is still years away from mass deployment. The main challenges of WDM-PON are 1: high cost; and 2: complex maintenance [4].

1.3 DWDM SYSTEMS

At this stage, a basic DWDM system contains several main components:

1. A DWDM **terminal multiplexer:** The terminal multiplexer contains a wavelength-converting transponder, an optical multiplexer and an optical amplifier. Each wavelength-converting transponder receives an optical data signal from the user, such as from Synchronous optical networking [SONET /SDH]. It converts this optical signal into the electrical signal and re-transmits the signal at a specific wavelength using a 1,550 nm band laser. These data signals are then combined together into a multi-wavelength optical signal using an optical multiplexer, for transmission over a single fiber. The terminal multiplexer may or may not also include a local transmit EDFA for power amplification of the multi-wavelength optical signal.
2. An **intermediate line repeater:** It is placed for every 80–100 km to compensate for the loss of optical signal power as it travels along the fiber. The 'multi-wavelength optical signal' is amplified by an EDFA, which usually consists of several amplifier stages.

3. An **intermediate optical terminal** or **optical add-drop multiplexer:** This is a remote amplification site. It amplifies the multi-wavelength signal that may have traversed up to 140 km or more before reaching the remote site. Any particular wavelength can be inserted, to allow for localization of any fiber breaks or signal impairments. In more sophisticated systems which are no longer point-to-point, several signals out of the multi-wavelength optical signal may be removed and dropped locally.
4. A DWDM **terminal demultiplexer:** The terminal de-multiplexer consisting of an optical de-multiplexer and one or more wavelength-converting transponders separates the multi-wavelength optical signal back into individual data signals and outputs them on separate fibers. Originally, this de-multiplexing was performed entirely passively, as most SONET systems can receive 1,550 nm signals. Generally, the functionality of output transponder has been integrated into that of input transponder, so that most commercial systems have transponders that support bi-directional interfaces on both their internal side, and external side.
5. **Optical Supervisory Channel (OSC):** This is data channel which uses an additional wavelength usually outside the EDFA amplification band (at 1,510 nm, 1,620 nm, 1,310 nm or another proprietary wavelength). The OSC carries information about the multi-wavelength optical signal as well as remote conditions at the optical terminal or EDFA site. It is also normally used for user Network Management information and remote software upgrades. Unlike the 1550 nm multi-wavelength signal containing client data, the OSC is always terminated at intermediate amplifier sites, where it receives local information before re-transmission.

1.4 PROPERTIES OF DWDM

- Protocol & Bit Rate independence
- Transparency
    - Physical layer architecture → supports both TDM and data formats such as ATM, Gigabit Ethernet, etc.
- Scalability
    - Utilize abundance of dark fibers in metropolitan areas and enterprise networks.

1.5 TDM

Time-division multiplexing (TDM) is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time in an alternating pattern. Statistical time division multiplexing (STDM) is an advanced version of TDM in which both the address of the terminal and the data itself are transmitted together for better routing. Using STDM allows bandwidth to be split over one line. Many college and corporate campuses use this type of TDM to distribute bandwidth. There are several standards for TDM-PON: (1) IEEE 802.3-EPON; (2) ITU G.983 –APON; and (3) ITU-G.984 GPON. EPON system is dominate in Japan and Europe and GPON system is dominate in US. Basically, TDM-PON can provide steady data rate from 1Gbps (EPON) to 10Gbps (10G-EPON), and its coverage range is 10-20km. The performance is much better than DSL and HFC networks.

1.6 HYBRID TDM/DWDM

There are many multiplexing schemes available based on time, frequency, wavelength and code. The service providers mostly concentrate on Dense Wavelength Division Multiplexing (DWDM) systems to provide large amount of bandwidth for consumers. By using DWDM, the service providers can offer services such as e-mail, image, audio, video and multimedia over Asynchronous Transfer Mode (ATM).

The service providers often face some of the following challenges of fiber-optic communication like increased service needs, fiber breakage, and bandwidth management. So they need to provide an economical solution. One choice is to increase the bit rate using Time Division Multiplexing (TDM). TDM is a technology that increases the transmission capacity of fiber by transmitting independent signals slicing the time into smaller intervals over a shared path. Therefore more bits can be transmitted per second. Another choice for service providers is DWDM, which increases the information carrying capacity of optical fiber. This multiplexes incoming optical signals to specific frequencies within the given frequency band and sends out on a single fiber. The fiber interface can be format and wavelength independent; hence this allows service providers to make use of DWDM technology easily with existing equipment in the network.

A better solution has been developed by combining TDM and DWDM. This is significantly more efficient both in terms of number of channels per fiber and number of channels per laser. Combining DWDM with TDM is a possible way to increase the bandwidth.

The innovations in this field are: 40G, WDM Passive Optical Networks (PON), Opportunistic and Dynamic Spectrum Management PON (ODSM-PON), Orthogonal Frequency Division Multiplexing PON (OFDM-PON), Code Division Multiple Access PON (CDMA-PON), etc [3]. This hybrid architecture increases total number of sensors that can be supported in a single fiber, at the same time it behaves well when compared with the individual architectures of TDM and DWDM.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter presents the literature surveyed in the area of DWDM. The merits and demerits of these methods are discussed in terms of complexity, performance, and speed of computation. The purpose of this is to choose the appropriate encoding and decoding diversity techniques for multiuser communication systems and also calculating different parameter such as BER of the system.

[1] Performance Analysis of WDM Optical Communication System in the Presence of Four Wave Mixing (FWM) Under the Impact of Channel Spacing with Variable Dispersion

Neha Pandey, explained that FWM process is reduced by providing un equal channel spacing and dispersion management. The various methods for suppressing FWM have been reported in the literature. Moreover from the previous literature it is concluded that the FWM is increased at low dispersion (zero dispersion), small and equal channel Spacing as compared to unequal channel spacing. In this paper, new methods have been proposed for the suppression of FWM and compared the results with existing methods like: equal channel spacing and unequal-channel spacing at various dispersion values from 0 to 16 ps-nm-1km-1. BER and Q-factor of 8 channel WDM system, each operating at 10 Gbps have been evaluated over an optical span of 360 km in the presence of FWM under the impact of equal channel spacing of 100 GHz in conjunction with the fiber-dispersion control by means of dispersion compensation fiber.

[2] Highly scalable amplified hybrid TDM/DWDM array architecture for interferometric fiber-optic sensor systems

Yi Liao, says hybrid dense wavelength division multiplexing (DWDM) and time division multiplexing (TDM) array architecture for large scale interferometric fiber-optic sensor array systems. This architecture employs a distributed Erbium doped fiber amplifier (EDFA) scheme to decrease the distribution loss among multiplexed wavelengths, and employs TDM at each wavelength to increase the total number of sensors that can be supported. The first experimental demonstration of this system is reported including results which show the potential for multiplexing and interrogating up to 4096 sensors using a single telemetry fiber pair with good system performance. The number of interrogation sensors could be further increased by increasing the number of wavelength channels.

[3] Performance Evaluation of DWDM Communication Systems with Fiber Optical Parametric Amplifiers

Mahmoud Jazayerifar analyzed the impairments of both transmission fibers and FOPAs are taken into account. The analytical model is verified with simulations. The performance of FOPA is compared with EDFA and it is shown that a broad band long-haul DWDM transmission system based on FOPAs as in-line amplifiers could be feasible.

[4] A Band-Separated, Bidirectional Amplifier Based on Erbium-Doped Bismuth Fiber for Long-Reach Hybrid DWDM–TDM Passive Optical Networks

MinwanJung, says WDM–TDM-PONs is experimentally investigated by performing a series of signal transmission experiments with an exemplary PON configuration having a total reach of 75 km and 8 split users. Error-free bidirectional signal transmission at a line rate of 10 Gbit/s is successfully demonstrated.

[5] An Overview of DWDM Technology & Network

ReenaAntil, says in this article covers functions and applications of DWDM system components. The operation of each component is discussed individually. DWDM terminology like Attenuation, dispersion, and optical signal to noise ratio (OSNR) are measures of optical signal quality and are the key factors involved in DWDM system design and operation.

[6] Live Native IP Data Carried End-to-End by 100 GE Router Interfaces and Single Carrier 100 G Transport System Over 1520-km Field Deployed Fiber

Tiejun J,says IP data are carried end-to-end by 100 GE router interfaces and a 100 G optical transport system over 1520-km field deployed fiber. This is accomplished with multisuppliers' 112-Gb/s single carrier real time coherent DP-QPSK DWDM transponder, 100 GE router cards, and 100 G CFP interfaces.

[7] Performance analysis of modulation formats in Dispersive optical communication system

Sunnerud, Karlsson and Andrekson numerically analysed a comparison between NRZ and RZ data formats with respect to PMD-induced system degradation and showed that that RZ performs better than NRZ and the trade-off degradation and showed that that RZ performs better than NRZ and the trade-off between power margin and acceptable PMD is studied.

[8] All-optical format conversion from NRZ to CSRZ and between RZ and CSRZ using SOA-based fiber loop mirror

Kermanshah-Iran investigates the effect of ASE on the gain modulation, referred to also as overmodulation. The gain modulation is the low-frequency (kHz) amplitude modulation of the EDFA pump and the communication signal used for propagating line monitoring information. We develop the model of Novak and Moesle (2002), by including amplified spontaneous emission (ASE), that they neglected it. The derivation of an analytical model for EDFA over modulation response has been presented. This model provides analytical expressions for the pump and input signal over modulation responses, respectively. These expressions describe the output signal modulation index amplitude and phase, assuming small sinusoidal steady-state oscillations of the mean pump or input signal power. In this paper we show that ASE have some effect on predictions in the high gain/low saturation regime.

[9] Quality of light path with ASE noise accumulation in nonlinear optical propagation using global performance metrics

Ajay K.Sharma, S.K.Wadhwa, T.S.Kamal. In this paper, they have targeted their investigations to the inclusion in performance evaluation of light path on the effect of amplified spontaneous emission (ASE) noise accumulated in nonlinear optical propagation. Quality of light- path transmission feasibility has been reported by using a global performance metrics, called Q-factor, optical signal- to-noise ratio (OSNR), BER, extinction ratio and nonlinear frequency shift, which takes into account the interaction between the parameters afore mentioned and returns a unique value corresponding to the performance metrics.

[10] Field-Trial of Optical Regenerator/Multicaster in a 60 Gbit/s, 48 Channel DWDM Transmission Experiment

Radan Slavík, says the performance of future ultra-long haul communication systems exploiting phase-encoded signals is likely to be compromised by noise generated during signal transmission. One potential way to mitigate such noise is to use Phase Sensitive Amplifiers (PSAs) which have been demonstrated to help remove phase as well as amplitude noise from phase-encoded signals.

[11] Passband Narrowing and Crosstalk Impairments in ROADM-Enabled 100G DWDM Networks

Yu-Ting Hsueh,says the solution needed to meet increasing bandwidth and routing flexibility requirements for transport networks. The conventional crosstalk metric is insufficient. The nonlinear parametric interaction between the primary signal and crosstalk. We show that this penalty is more limiting than the nonlinear interactions between signal and amplified spontaneous emission noise.

[12] Performance Analysis Of Dispersed Manage RZ Pulse

Mob, First, Geiger and Flscher analyzed theoretically and experimentally the advantages of nonlinear RZ over NRZ on 10 GB/s single-span links. Griffin, Walker, and Johnstone el at. demonstrated a four-stage integrated module for 10 Gb/s chirped return-to-zero modulation using GaAs/AIGaAs electro-optic guided- wave technology and its performance is verified by dispersion-managed test bed transmission over 3000 km. Hodzic, Konrad, and Petermann et al had proposed alter native modulation formats in N 40 Gb/s WDM standard fiber RZ-transmission systems.

CHAPTER 3

EXISTING SYSTEM

3.1 INTRODUCTION

This technology rectifies the problem of increasing communication channels without installing new cables or when the number of fibers in the cable is limited; this solution makes it very attractive for telecommunication products, and also for the design of real-time data acquisition systems when the required bandwidth is in the order of many gigabits per second. Since introduction to the market of small form factor optical transceivers, which are also interoperable between different manufacturers, the DWDM technique is receiving great attention.

Research based on Interferometric fiber optic sensors have been executed nearly four decades for a range of practical applications, including military sonar and seismic surveying which have been the main drivers behind the development of optical fiber sensor-based hydrophone arrays. Interferometric fiber optic sensor arrays are generally based on measuring the phase modulation of light travelling in an optical fiber due to the strains developed on the fiber [2]. Even with the ultrahigh sensitivities now achieved, single channel applications are only appropriate in a few instances, like cost reasons. Fortunately, fiber-optic sensors used in multiplexing allow the cost of the lasers and other expensive components to be divided between many channels.

Many multiplexing schemes have been proposed and investigated based on techniques including time, frequency, coherence, and wavelength multiplexing, and combinations of the above techniques. In each instance splitting/recombination loss considerably limits the scalability of the approach. The number of fibers needed for telemetry a further critical factor that significantly impacts the overall system cost and practicality. Erbium-doped fiber amplifiers (EDFAs) are widely used in interferometric fiber sensing systems, frequently to compensate for splitting loss and inherent fiber transmission loss. The often used single amplifiers are Pre-amplifiers, post-amplifiers and in-line amplifiers.

DWDM allows many TDM signals at different wavelengths to be combined on a single fiber simultaneously, such that the multiplexing factor is now given by the product of the number of wavelengths and the number of TDM nodes. This architecture has demonstrated high performance from nodes in an optically efficient arrangement with low component numbers. Theoretically it can be extended to interrogate at least 192 sensors through two fibers while achieving a low-phase resolution limited by the optical amplifier noise. However, the optical power levels received for signals significantly decreases with increasing array size.

In the hybrid architecture Erbium Doped Fiber Amplifier (EDFA) is used to compensate for the distribution loss. The signal which is to be amplified and the pump signal are multiplexed into EDFA so that the pump energy is fully converted to signal energy. Along with the signal to be amplified, the noise also gets amplified in EDFA. This process gives rise to Amplified Spontaneous Emission (ASE) noise. When number of EDFAs deployed increases ASE noise gets accumulated. This degrades the hybrid system performance [2].

The nonlinear effects are severe when the power of optical system is very high and is important in TDM/DWDM systems. Four-Wave Mixing (FWM) is an unwanted parameter which occurs due to the interference of nearby wavelengths. Sum and difference of adjacent wavelengths lead to FWM and it limits the transmission distance and bandwidth of optical communication systems. Various factors which influence FWM are spacing between channels, channel input power, refractive index of fiber and the operating frequency [1]. The two types of FWM are degenerate four-wave mixing and non-degenerate four-wave mixing. When different frequency components are involved in the process of interaction it is called as non-degenerate four-wave mixing. When some of the interfering frequency components coincide, it is called as degenerate four-wave mixing.

FWM suppression is necessary to provide good performance to the users and is achieved by providing equal/unequal channel spacing. Possible other methods to suppress FWM are providing equal channel spacing with different source power. This reduces the impact of FWM on Dense Wavelength Division Multiplexing (DWDM) optical communication system. The hybrid TDM/DWDM allows many input signals at different wavelengths to be transmitted on a single fiber simultaneously. Hence the multiplexing factor is the product of the number of TDM nodes and the number of wavelengths.

3.2 HYBRID TDM/DWDM ARCHITECTURE

The principle of the array topology proposed here is based on loss compensation of the distribution bus in hybrid TDM/DWDM architecture.

The array is addressed via an interlink fiber pair, as illustrated in Fig. 3.1. The optical pulses from the wavelength multiplexed sources are coupled into the distribution bus. At the first optical drop multiplexer (ODM), the signal at wavelength is coupled into the first TDM group, again passes through the constituent sub-array of TDM sensors. It is then coupled onto the return bus through the optical add multiplexer (OAM), which delivers it to the detector. The remaining wavelengths of the input signal passes through the distribution bus to the subsequent ODMs, before multiplexed onto the return bus it is successively given to each TDM group. This architecture performs the ‘add’ and ‘drop’ functions by separate devices. Thus it provides the advantage that if the telemetry fiber is severed within the array, then only the signals from the TDM groups corresponding to ODM/OAMs positioned after the break are lost. To balance the powers among different channels, EDFA segments are distributed along the return bus to compensate the insertion loss of the OAM/ODMs. Thus the optical signals from all the TDM sensor groups now experience approximately the same net optical gain.

Amplifiers are applied only on the return bus, because the travelling optical power on the distribution bus where the gain is independent of the input signal power. Another secondary reason is that no additional pumps and multiplexers are required on the distribution bus, which simplifies the system and lowers the cost. The wavelengths out of the add channel bandwidth (0.7 nm) are passed through the express channel of the OAMs on the return bus, there exists a measured stop band attenuation of 20 dB at the OAM express port [2]. This architecture also provides a partial rejection effect on the accumulated in-band amplified spontaneous emission (ASE).

The gain of each amplifying section is set to compensate the subsequent losses for each sensor group. The amplifiers are all co-pumped remotely through the existing return bus fiber by 1480-nm pump lasers located at the front and/or back ends of the array. Since each amplifier must compensate for only a small insertion loss, they provide a low gain and require just a small pump power. The input pump power is selected to be much larger than the first amplifier’s saturation pump power. The couplers are optical drop/add multiplexers so that the pump never couples out of the buses. Therefore this amplifier absorbs only a small fraction of the pump power, so that the large remaining power is transmitted to the downstream amplifiers. The 1480-nm pump wavelength is chosen due to the low transmission loss. Thus it is possible to pump tens of widely distributed low-gain amplifiers with a modest pump power. Since each amplifier is highly inverted and provides low gain, the noise is low. This array architecture provides dramatic advantages for large scale arrays.

The topology uses TDM within an amplified DWDM architecture. The number of multiplexed sensors is now given by the product of the number of TDM sensors and wavelengths, which results in increased repetition rate by several times compared to the number multiplexed in amplified TDM arrays. The repetition rate determines the bandwidth available for the phase-modulated signal to occupy, and it is dependent on the number of sensors and the length of fiber per sensor. This hybrid TDM/DWDM utilizes only one single telemetry fiber pair, which significantly decreases the array complexity, cost and weight.

The insertion loss of the array is compensated by the distributed amplification, which leaves a higher power budget for the remote transmission of the signal along the cable. It limits the chance of nonlinear effects within the fiber bus. These benefits are of prime importance in many applications.

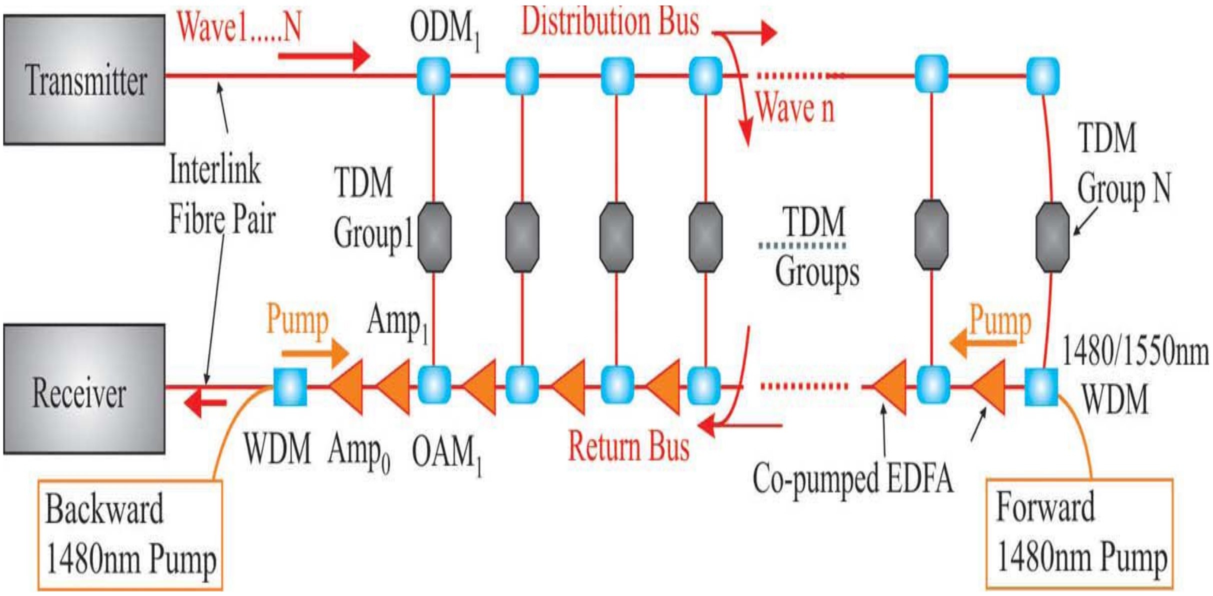

Fig 3.1 : Amplified TDM/DWDM array topology

CHAPTER 4

PROPOSED SYSTEM

4.1 INTRODUCTION

In fiber-optic communication ASE noise from in line amplifiers is considered as a dominant noise source. To filter out ASE noise Semiconductor Optical Amplifier (SOA) based Mach-Zehnder Interferometer (MZI) is used at receiver end.

The optical non-linearities causes distortion, interference and attenuation can lead to system degradation. In specific, stimulated brillouin scattering, stimulated raman scattering and four wave mixing are the major source of degradation. Stimulated raman scattering is the frequency conversion of light caused by the interaction between light and vibrations of silica molecules. Stimulated brillouin scattering is the frequency conversion and reversal of the propagation direction of light caused by the interaction between the light and sound waves of the fiber. Four-Wave Mixing (FWM) is an unwanted parameter which occurs when the nearby wavelengths interfere with each other and produces an extra wavelength that may be the sum and difference of interfering wavelengths. It limits the transmission distance and bandwidth of optical communication systems [1]. All these non-linearities causing frequency conversion can be minimized by providing unequal channel spacing.

The ASE noise is analyzed for different wavelengths and fiber lengths. The hybrid architecture for different modulation formats like RZ, NRZ and Manchester is tested for ASE noise performance measures.

Module :

- The hybrid TDM/DWDM is generated
- The basic transmission of TDM/DWDM over the channels are simulated
- The performance of hybrid architecture is analyzed.

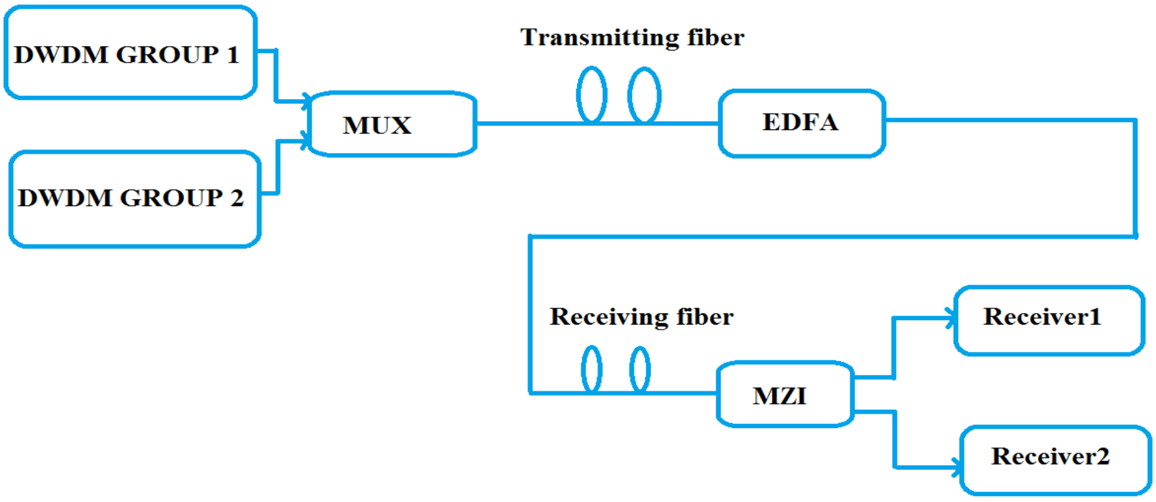

Fig 3.2 : Block diagram of TDM/DWDM

Fig.3.2 shows the simplified architecture of TDM/DWDM Passive Optical Network. DWDM group1 has several wavelengths which are again used in DWDM group2. These wavelengths are multiplexed and passed along the transmitting fiber at different times. EDFA is used to amplify the multiplexed signal. The amplified signal is passed through the fiber of some length. MZI has two ports namely switching port and reflective port. Receiver1 receives the output of switching port and receiver2 receives the output of reflective port.

4.2 ADVANTAGES OF EDFA

- Commercially available in C-band (4-8GHz) & L-band (1-2GHz)
- Insensitivity to light polarization state
- High gain
- No distortion at high bit rates
- Simultaneous amplification of wavelength division multiplexed signals
- Immunity to cross talk among wavelength multiplexed channels

4.3 ADVANTAGES OF DWDM

- Robust and simple design
- Works entirely in the Optical domain
- Multiplies the capacity of the network many fold
- Cheap Components
- Handles the present BW demand cost effectively
- Best suited for long-haul networks

COMPARISION TABLE BETWEEN WDM AND DWDM

WDM	DWDM
Defined by wavelengths	Defined by frequency
Short range communication	Long-haul transmissions
Use wide range of frequencies	Narrow frequencies
Wavelengths spread far apart	Tightly packed wavelengths
Light signal is not amplified	Signal amplification may be used

Table 4.1 Comparison table between WDM and DWDM

4.4 INTRODUCTION TO OPTSIM TOOL AND SIMULATION MODELS

4.4.1 INTRODUCTION TO OPTSIM TOOL

OptSim, RSoft's award-winning software tool for the design and simulation of optical communication systems at the signal propagation level empowers the users with models and simulation techniques that are specifically designed for PM-QPSK and other advanced modulation formats including OFDM, D(Q)PSK and duo binary. It is basically an advanced optical communication optical communication system designed for professional engineers. It can be used to design optical communication systems and simulate them to determine their performance given various component parameters. With user friendly simulation techniques and easy-to-use graphical user interface, OptSim provides unmatched flexibility and usability.

4.4.2 FEATURES

1. Performance analysis (e.g. Q value, BER, Power spectra and OSNR, eye diagram).
2. Wide and complete choice of measurement (e.g. jitter, eye opening/closure, electrical/optical spectra, chirp, optical instantaneous phase/frequency and power)
3. Link optimization: power budget, dispersion map, tailoring of pulse shape and chirp, transmitter pre-emphasis, amplifier positioning.
4. Transmission impairment analysis and assessment of countermeasures (e.g. All-order PMD, SPM, XPM, FWM, Stimulated Raman Scattering effect)
5. Edge design and validation System sensitivity evaluation
6. Extensive library of predefined manufacturer components makes it easy to model commercially available devices

OptSim works on the theory of "blocks". An optical communication system is represented as an interconnection of various blocks. Each block in this set represents a component or sub-system in the communication system. Each block model is presented graphically as an icon, has own set of parameters which can be modified by user. As physical signals are passed between components in a real world communication system, "signal" data is passed between component models in the OptSim simulation. Each block is simulated independently using the parameters specified by the user for that block and the signal information passed into it from other blocks. This is known as a block-oriented simulation methodology. These blocks are graphically represented as icons in OptSim. Internally, they are represented as data structures and sophisticated numerical algorithms.

The twin simulation engines support two complementary simulation approaches.

1. **Block mode simulation engine**: signal data is represented as one block of data and is passed between block to block. Nonlinear fiber is simulated using the Split Step Fourier technique in this mode.

2. **Sample mode simulation engine**: signal data is represented as single sample that is passed between block to block. Features Time Domain Split Step Fiber model.

4.4.3 RESULT ANALYSIS AND POST PROCESSING

Stage 1: General Model (Modeling preliminaries)

Stage 2: Select optimum parameters (Performance Evaluation)

Stage 3: See results after simulation (OptsimValidation)

Simulation results that are produced by OptSim include signal waveform plots and eye diagrams at any point within the optical communication system, and bit error rate (BER) plots vs. various parameters within the system such as the received optical power. Other simulation results can also be obtained which includes signal spectra, frequency chirp, power and dispersion maps, and more. Simulation results may also be plotted against one another and correlated with scanned parameter values. OptSim analysis the effects of noise, crosstalk, jitter, skew, and variations in component parameters using Monte Carlo and quasi analytical methodologies. These tools make it easy to interactively work with the simulation results to present them in the manner desired and analyze them further.

CHAPTER 5

SIMULATION RESULTS

5.1 TIME DIVISION MULTIPLEXING

The design model for the Time Division Multiplexing in OPTSIM tool is shown below.

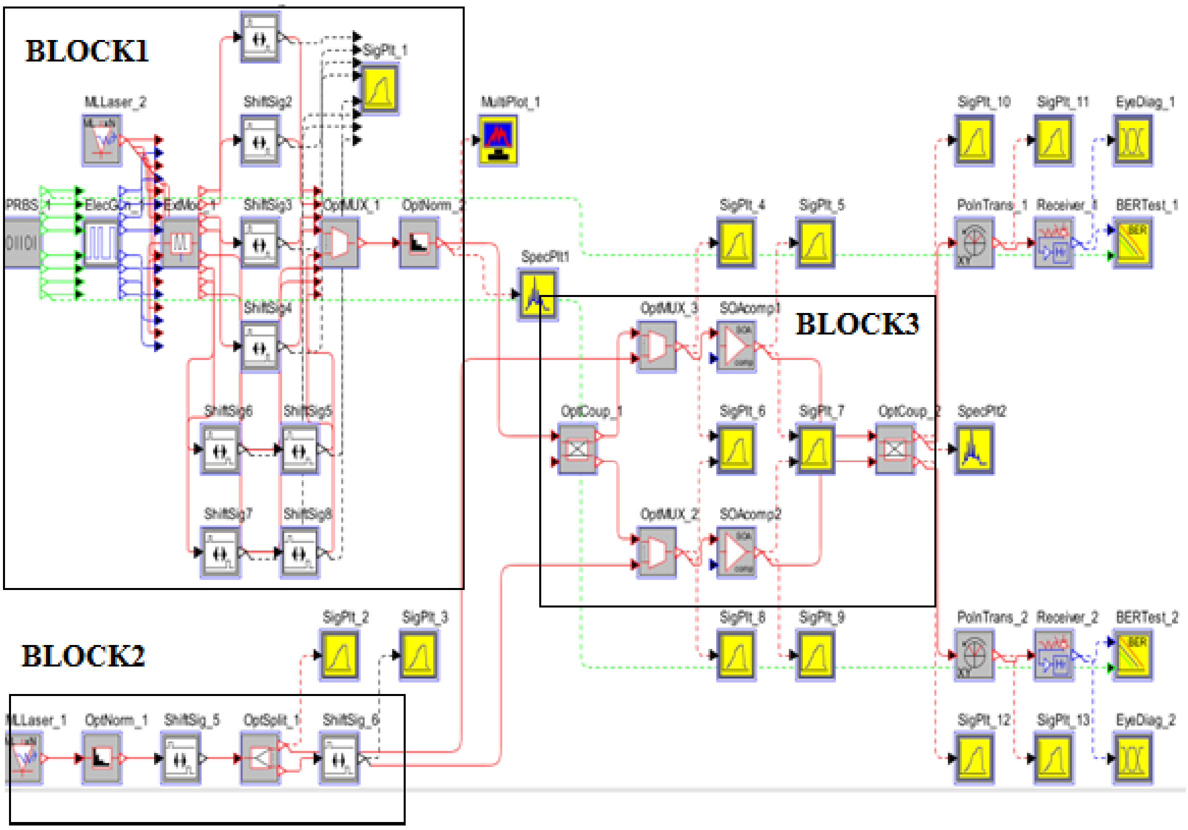

Figure 5.1 Design of Time Division Multiplexing

The design model contains transmitter, receiver and fiber channel blocks.

Block 1 in Fig.5.1 shows setup of 8x10 Gbps TDM transmitter. Eight channels at wavelength 1550nm are RZ-modulated with different PRBS pattern and RZ-format, have a 3-dB pulsewidth of 5 ps and the same power. Before being multiplexed together each consequent channel is delayed by 25 ps. Total power of all channels is set to -12 dBm. Next, the control signal (block 2 in Fig.5.1) consists of pulse train generator with 10 GHz repetition rate, pulse splitter, and two time delay blocks.

The first time delay block will set the control signal to multiplex the channel of interest (e.g. time delay is zero if channel 1 is to be multiplexed, time delay is 25 ps if channel 2 is to be multiplexed, and so on). Control signal is split into two parts before being coupled with data signal in two arms of SMZI. The second time delay block is delayed by data pulse duration of 5ps. Pulsewidth of control signal is set to 5 ps, power per each control signal is set to 9dB higher than data signal, and the state of polarization is set to be orthogonal to data signal. Symmetrical Mach-Zehnder Interferometer (represented by Block 3 in Fig.5.1) consists of two 50/50 couplers, two multiplexers, and two SOAs. Signal data are injected to SMZI through the upper input. Two outputs of SMZI correspond to "switching" and "reflective" ports. Output signals from both the ports then go through the linear polarizer block to separate control pulses from data. Inputs to the receiver blocks will have only data signals.

The output of multiplexer block is shown in Fig.5.2. The eight different colors correspond to eight TDM channels with the same wavelength of 1550nm.

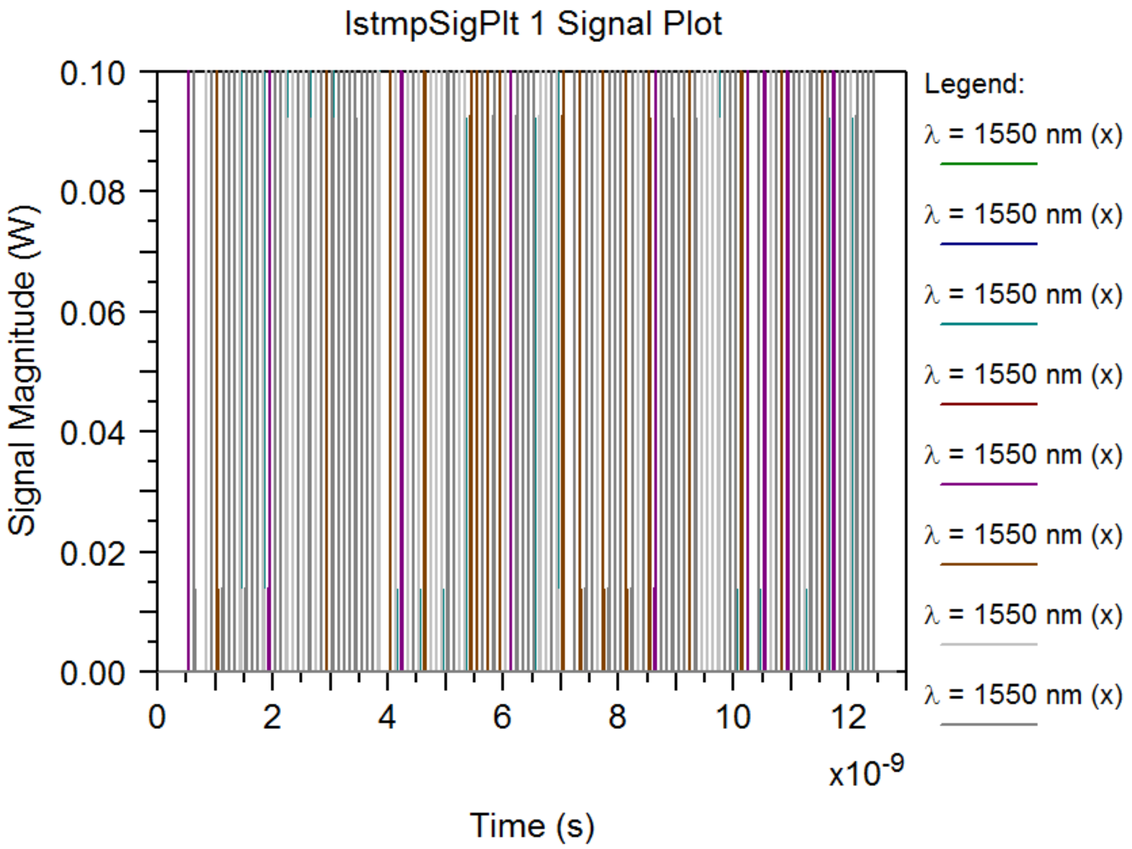

Figure 5.2 Sample of output signal of TDM transmitter from Multiplexer.
Eight different colors correspond to eight TDM channels

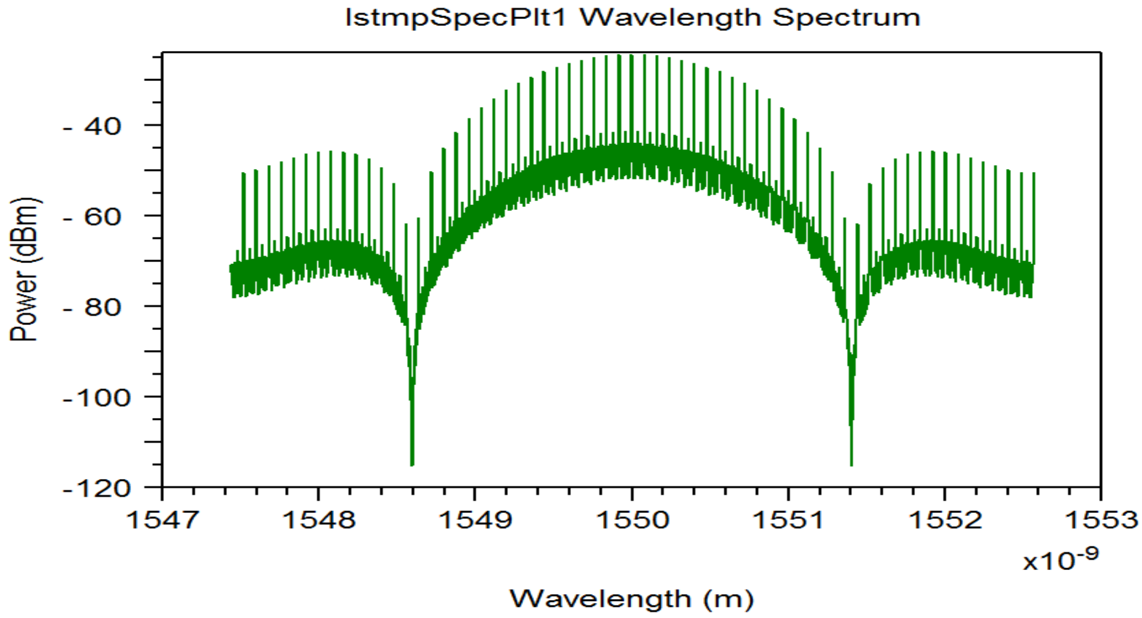

Figure 5.3. Output spectrum from Multiplexer.

Fig.5.4 and Fig.5.5 shows the eye diagram from switching and reflective ports of symmetrical MZI. The interference from other signals is negligible because these are transmitted in different times. It is observed in the eye diagram from switching port that the lower part of eye is nicely suppressed.

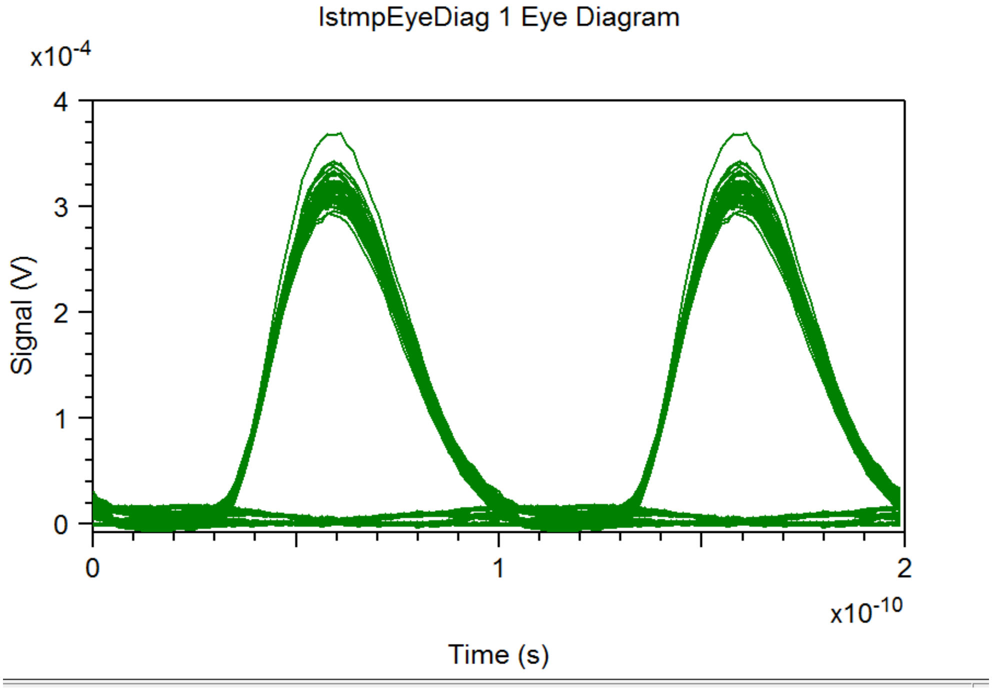

Figure 5.4. Eye diagram from switching port.

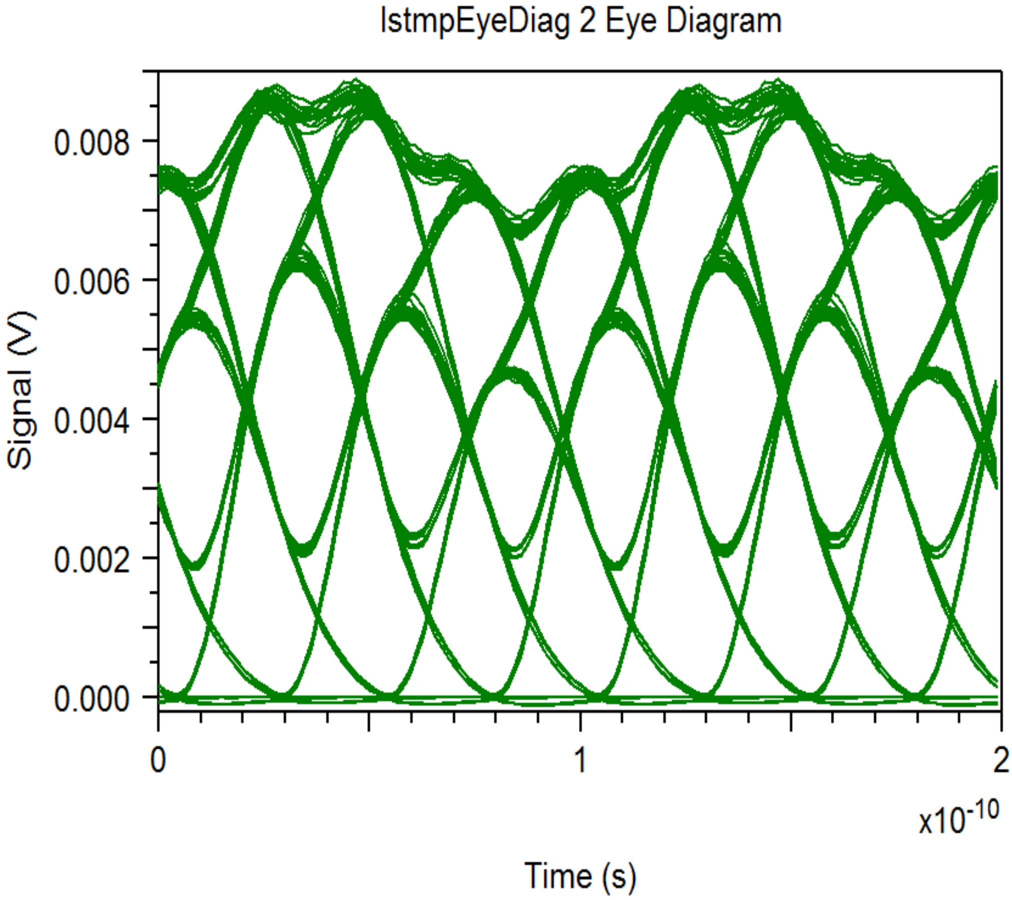

Figure 5.5. Eye diagram from reflective port

5.2 DENSE WAVELENGTH DIVISION MULTIPLEXING

Fig.5.6 represents an eight channel WDM link with equal channel spacing. The eight channels are specified at the wavelengths between 1543-1550 nm. This wavelength region is chosen because the attenuation is minimum at 1550nm, where the dispersion is higher. This dispersion can be compensated by using Dispersion shifted fiber and Dispersion flattened fiber. The PRBS blocks are set to generate sequences which are offset from one another so that each of the signals are not propagating the same bit value at all time points. The component parameter offset determines the number of bits which the sequence should be rotated relative to the default before it is output. After the signals are generated in the direct modulated laser models, they are multiplexed into a single optical signal by the MUX model block.

No filtering or losses are included in the ideal mode. At the output of the MUX, the optical signal passes through a length of fiber. The demultiplexing operation is accounted for by the eight optical filters which receive the input from the fiber. Each of these eight filters is modeled as a Fabry-Perot filter, with the center wavelength set for the desired channel. Fabry-Perot filter analyzes the optical signal based on noise level and bandwidth.

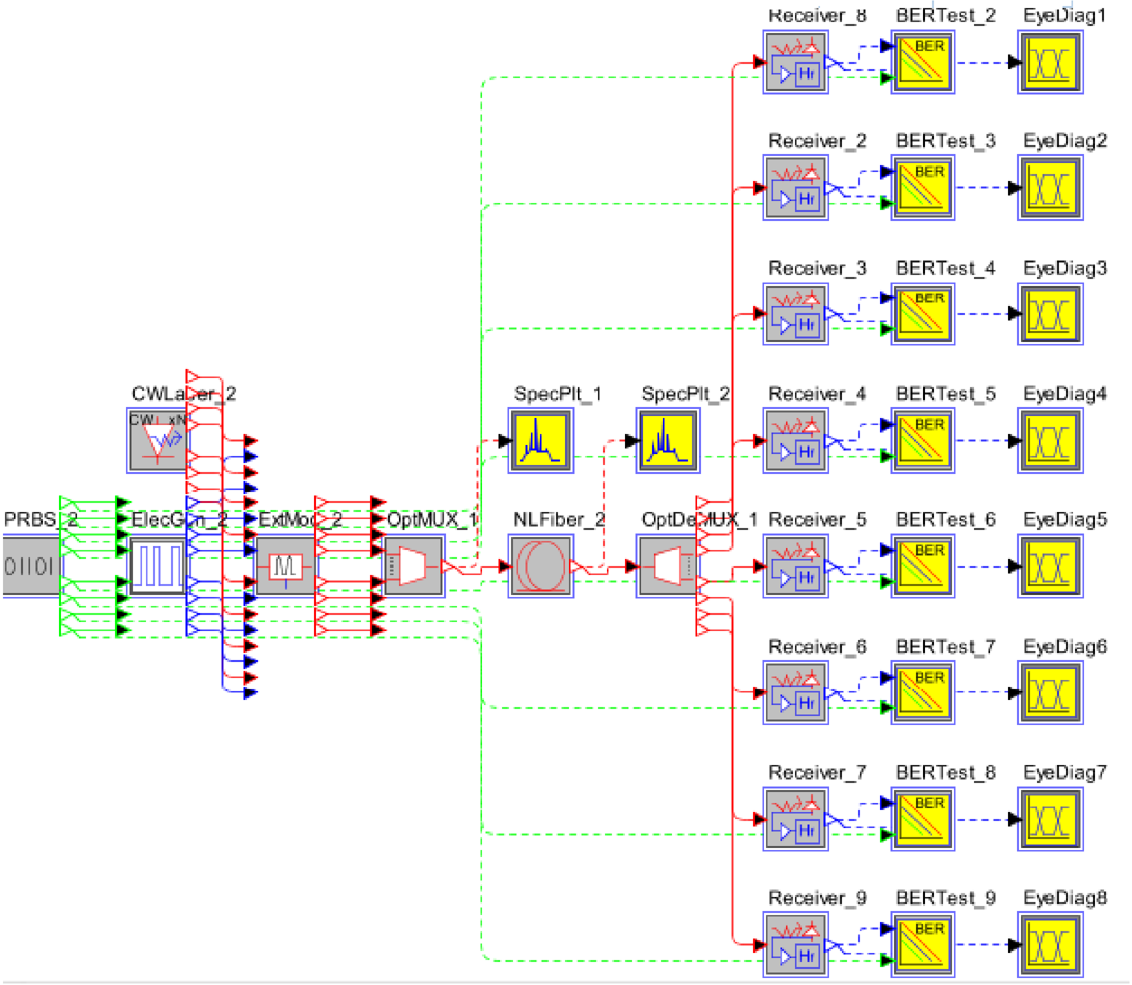

Figure 5.6 Design of Dense Wavelength Division Multiplexing

The filtered optical signals are then passed into power normalizers to allow the generation of BER vs. received optical power graphs. Then each of the filtered signals goes into a receiver model, followed by a BER tester block, and signal plot & eye diagram plot blocks. The eye diagram plots here include the receiver noise, but the signal plots are set to not include the receiver noise. In this design of DWDM, the multichannel optical signal representation is used. This option is controlled by the MUX model block. The MUX output is shown in Fig.5.7. This representation treats each logical optical signal as a separate sampled frequency band. In this Multi channel representation, four wave mixing between the channels in the fiber is not accounted.

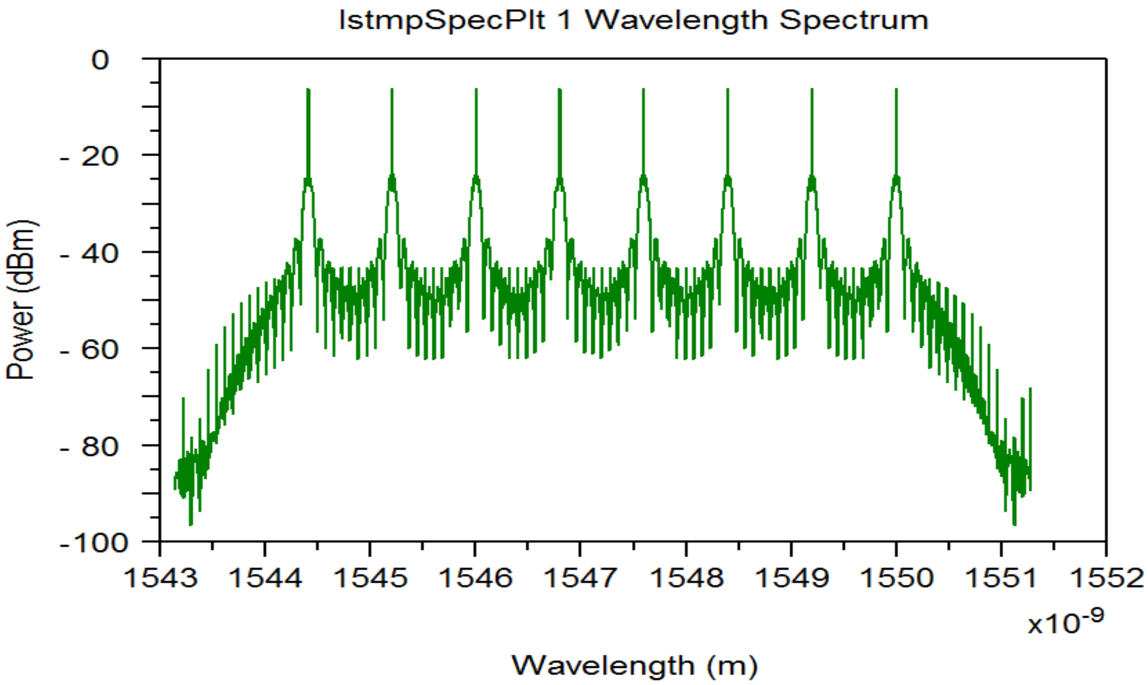

Figure 5.7 Multiplexer Output

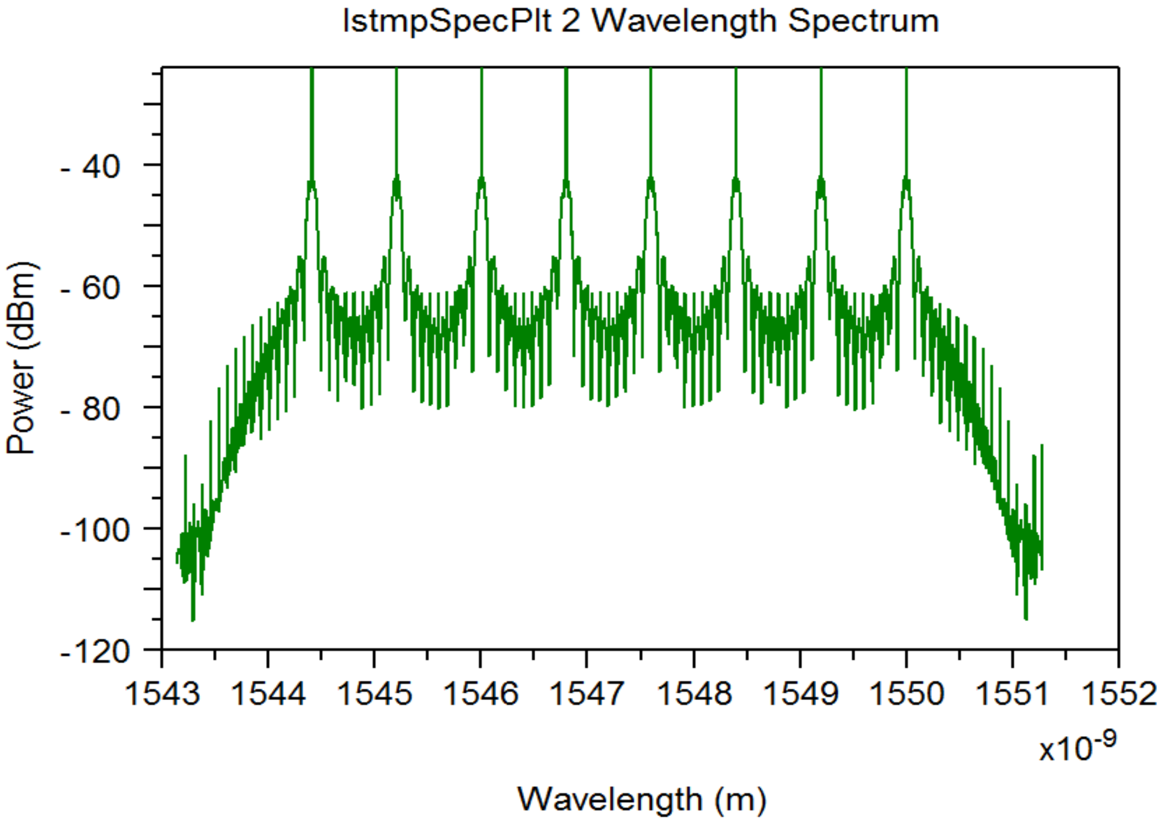

Figure 5.8 Fiber output

The eye diagram of the received signals at the receivers 1 and 8 are shown in Fig.5.9 and Fig.5.10 and is observed that lower part of eye is suppressed and eye opening is also wider with lesser interference.

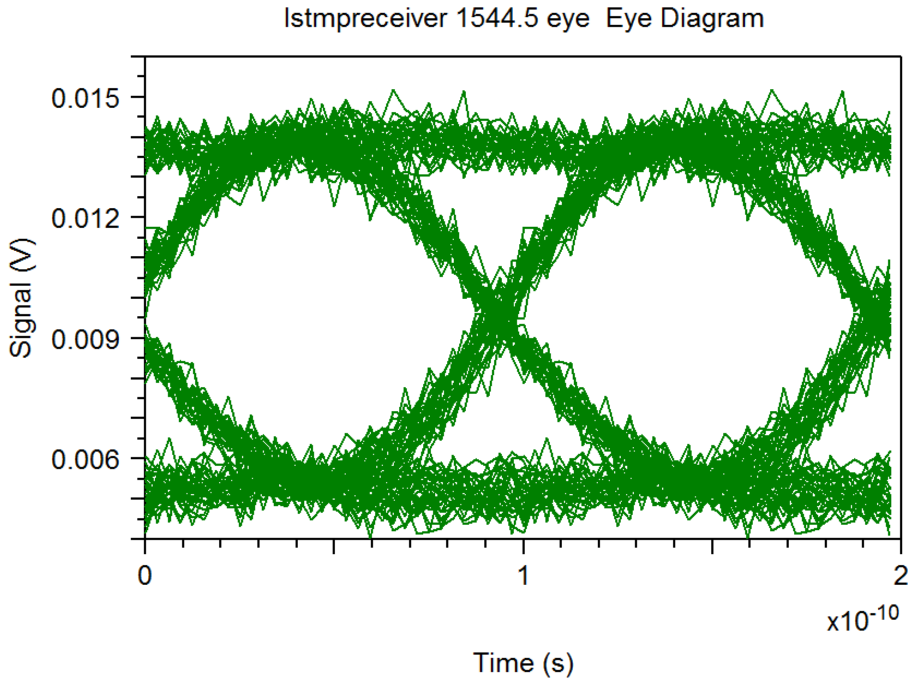

Figure 5.9 Eye diagram of receiver1

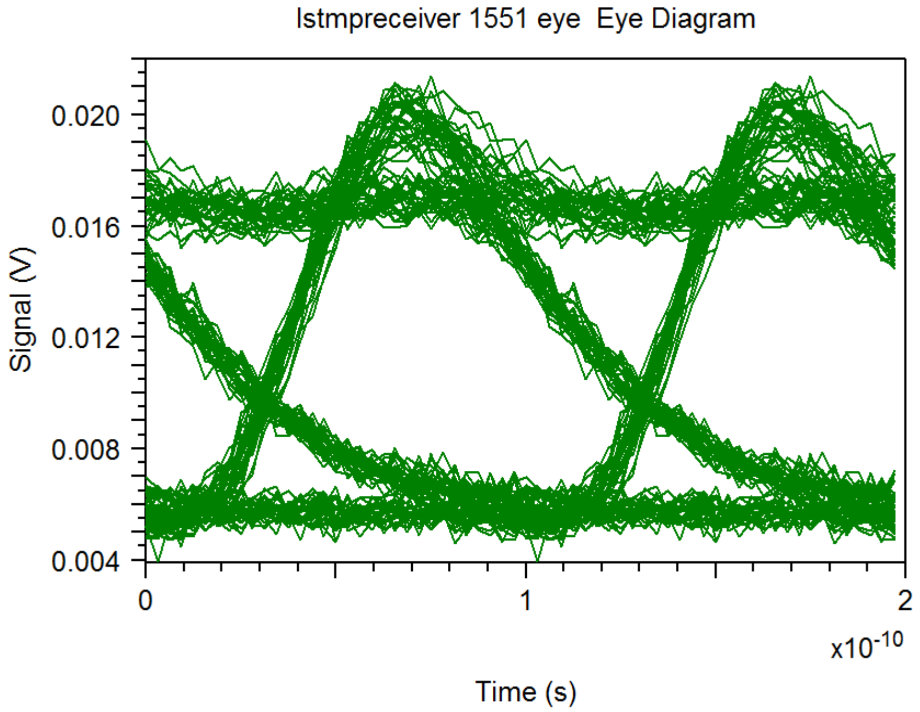

Figure 5.10 Eye diagram of receiver8

5.3 HYBRID TDM/DWDM

The model for the design of TDM/DWDM in OPTSIM 5.0 (Optical Simulator) tool is shown in Fig.5.11. PRBS block is used to generate the binary sequences of several different types. Single block is enough to produce multiple output patterns. Here eight wavelengths are used in DWDM group1 which are from 1544-1550nm. The same sets of wavelengths are used in DWDM group2.

Electrical generator block converts the binary signal from PRBS block to output electrical signal. The output signal can be set as either voltage or current. CW laser is used in conjunction with external modulator to encode the binary signal and gives optical signal. Optical multiplexer is used to combine those eight wavelengths and it is delayed by some time using shiftsgl to induce the concept of Time Division Multiplexing. This shows the setup of DWDM group1. The same blocks are used in DWDM group2 and the multiplexed signal is transmitted in different time.

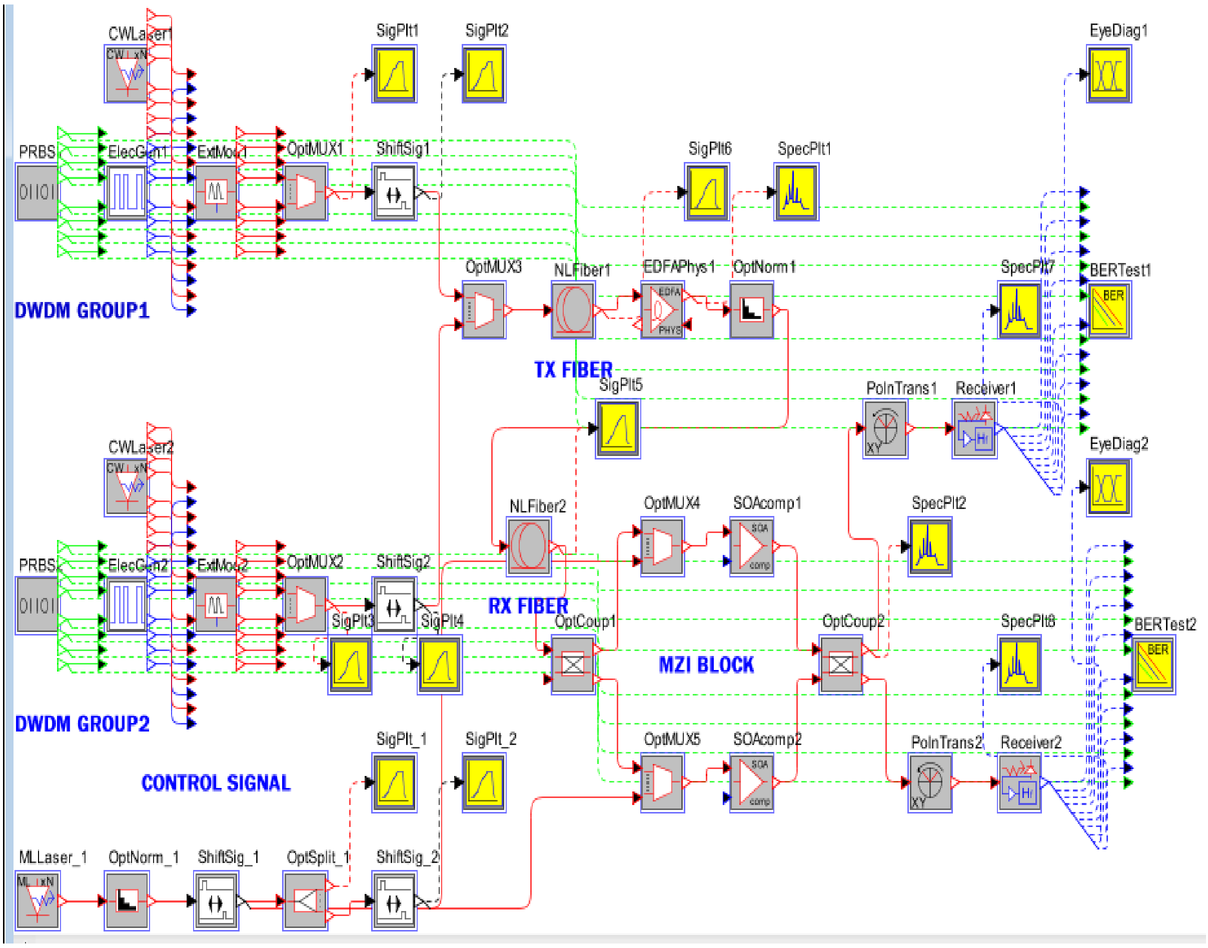

Figure 5.11 Design of TDM/DWDM

PRBS Pattern Generator:

This model generates maximal length pseudo random binary sequences of several different types. A single model is enough to provide multiple pattern outputs, optionally offset from each other, to drive different channels of a WDM or parallel optical bus simulation. Or, each channel may have its own model instance configured to provide a different pattern than the other model instances. The bit rate of the binary sequence is set to 10Gbps in this block.

Electrical Signal Generator:

This model converts an input binary signal into an output electrical signal. The output signal may be specified as either voltage or current. The user parameters are used to configure the electrical signal output. Different modulation formats available are RZ, NRZ and Manchester. The ASE noise is analyzed for these three modulation formats.

CW Laser:

This model produces the optical signal output of one or more CW lasers. It is most commonly used in conjunction with the external modulator model to encode a binary signal. The peak power of the signal is 10^{-3} watts and the wavelengths are between 1544-1550nm.

Modulator:

This models an electro-optic modulator. Several types of modulators may be modeled with this block, including the Mach-Zehnder type. Mach-Zehnder modulator is used so that the modulated signal will have the same polarity as the original binary sequence.

Shift Signal:

This model may be used to do one of two primary functions: delay the output signal relative to the input signal, or shift the signal data around in the data structure’s array without modifying the signal timing. Here it is used for delaying the signal. The ‘timeDelay’ mode delays the output signal relative to the input signal by adjusting the start time of the signal.

Nonlinear Fiber:

This model provides a detailed implementation of propagation of one or more optical channels in a Single Mode Fiber(SMF). SMF takes single path through the core. It has no intramodal dispersion and the information capacity is large. It takes into account attenuation, dispersion, polarization mode dispersion (PMD) and nonlinearities including Raman effects.

When the Single Channel mode of the MUX is used prior to the fiber model, it also takes into account four wave mixing. The transmitting fiber length is set to 10km and receiving fiber length is set to 360km.

Optical Multiplexer (Nx1 MUX):

This model represents an optical WDM multiplexer. It accepts multiple optical signals at its input ports and produces a WDM optical signal at its output port which contains all the input WDM optical signals. The multiple-band mode will put each optical signal band in its own signal representation, thus decreasing the overall memory load of the simulation. Because it will not include the unused frequency bands between the band and the approximation can only be made when the bands do not overlap significantly. The single-band mode must be used if there is significant overlap, or it is desired to include the effects of four wave mixing in the fiber simulation.

Physical EDFA:

This block models the operation of an erbium-doped fiber amplifier (EDFA) via a set of well-established physical equations. The model supports component specifications at different levels of complexity, as well as a variety of pump and signal configurations. Forward-propagating optical signals are launched into the EDFA via the first input node, while backward-propagating signals enter via the second input node. OptSim’s multiplexer components can be used to combine signals and pumps at either input. The EDFA output is available at the output node contains amplified signal, pumps, and amplified spontaneous emission (ASE) that are exiting the amplifier. The EDFA may also be used to simulate bidirectional signal propagation.

Semiconductor Optical Amplifier (SOA):

This module simulates a Semiconductor Optical Amplifier (SOA). The SOA is a highly nonlinear device. It can be used not only for signal amplification but also for other optical signal processing applications, such as switching, wavelength converting and optical time domain demultiplexing.

Optical Coupler (2x2):

This model represents an optical coupler. It takes an optical input signal on each port, and uses one of two ways to couple the optical signals together.

Optical Splitter (1xN):

This model represents an ideal optical splitter. It takes a single input signal, and divides it equally among N output ports with 1/N splitting loss, plus excess loss determined by the transmission model parameter.

Optical Multiplexer (Nx1 MUX):

This model represents an optical WDM multiplexer. It accepts multiple optical signals at its input ports and produces a WDM optical signal at its output port which includes all the input WDM optical signals.

Optical DeMultiplexer (1xN DEMUX):

This model represents an optical WDM demultiplexer. It accepts a WDM optical signal at its input port and produces N single channel optical signals at its output ports, one channel per port. This is accomplished by applying the specified filter to the input signal for each of the output ports.

Optical Power Normalizer:

This model normalizes the optical signal power by attenuating the input optical signal to the specified average output power level. The power level is specified in CW laser block. This model is most often used to control the input optical power at the receiver when preparing a BER vs. received optical power curve plot. The model may be used to attenuate all input optical signals to the same average output power regardless of their different average input powers, or it may be used to attenuate all input optical signals by the same amount such that the signal with the largest average input power has the specified average output power.

Compound Optical Receiver:

This models an optical receiver and all its standard parts. The OptSim photoreceiver model is composed of several individual building blocks: the photodetector, the preamplifier, and the postamplifier/filter. Each block is a separate entity complete with its own input parameters and options. The photodetector model converts an optical input signal to an electrical current. This photocurrent is then passed to the preamplifier model which converts it to a voltage. Finally, the postamplifier model contains a set of baseband filters that shape the output waveforms. The model also computes the photoreceiver noise components. In fact the receiver model is implemented directly in terms of the three stand-alone models PIN/APD Photodetector, Electrical Amplifier and Electrical Filter model.

Polarization Transformer:

This model transforms the polarization of the input optical signal according to the specified parameters. This model may be used anywhere in the topology where a specified polarization transformation is desired.

Signal Analyzer:

The Signal Analyzer block is used to display the signal waveform of a signal at the node connected to its input port. The timing offset of the start of the plot, title of the plot, filename and whether to display the electrical signal noise or optical ASE noise on the plotted signal value or not can be decided at the time of simulation.

Signal Spectrum Analyzer:

The Signal Spectrum block is used to display the spectrum of a signal at the node connected to its input port. In addition to plotting the magnitude of the spectrum the phase and group delays may also be plotted. A parameter may be set to only plot the phase and group delays over regions where the power exceeds the specified power threshold. It has options to plot the baseband signal spectrum, or in the case of an optical signal, the optical spectrum in either wavelength domain or frequency domain.

Eye Diagram Analyzer:

The Eye Diagram block is used to display the eye diagram of a signal at the node connected to its input port. It displays the magnitude of optical signals and the real value of electrical signals.

Bit Error Rate Tester:

This model computes the Bit Error Rate (BER) for the input electrical signal as well as a number of useful parameters such as the Q factor and electrical eye properties such as the height, width, area and extinction ratio.

The signals from DWDM group1 and DWDM group2 are multiplexed and passed along the transmitted fiber of length 10km and it is amplified using EDFA block. The ASE noise generated from EDFA block is analyzed using spectrum analyzer block. OptNorm block is used to normalize the power for the generation of BER vs received signal power graphs. The normalized signal is passed through the receiving fiber of length 360km. The receiving fiber length is much greater than the transmitting fiber length, so the analysis of ASE noise can be done at the receiving end. This received signal is given as input to the MZI block. Symmetrical MZI consists of two 50/50 couplers, two multiplexers, and two SOAs. The output of MZI can be used for ASE noise analysis. Control signal block consists of pulse train generator, pulse splitter, and time delay blocks. The linear polarizer block is used to separate the control pulses from data signal. Finally receiver block receives the data signals which are used for analysis.

The output of multiplexer block is shown in Fig.5.12. The eight different colors correspond to eight TDM channels with the same wavelength of 1550nm.

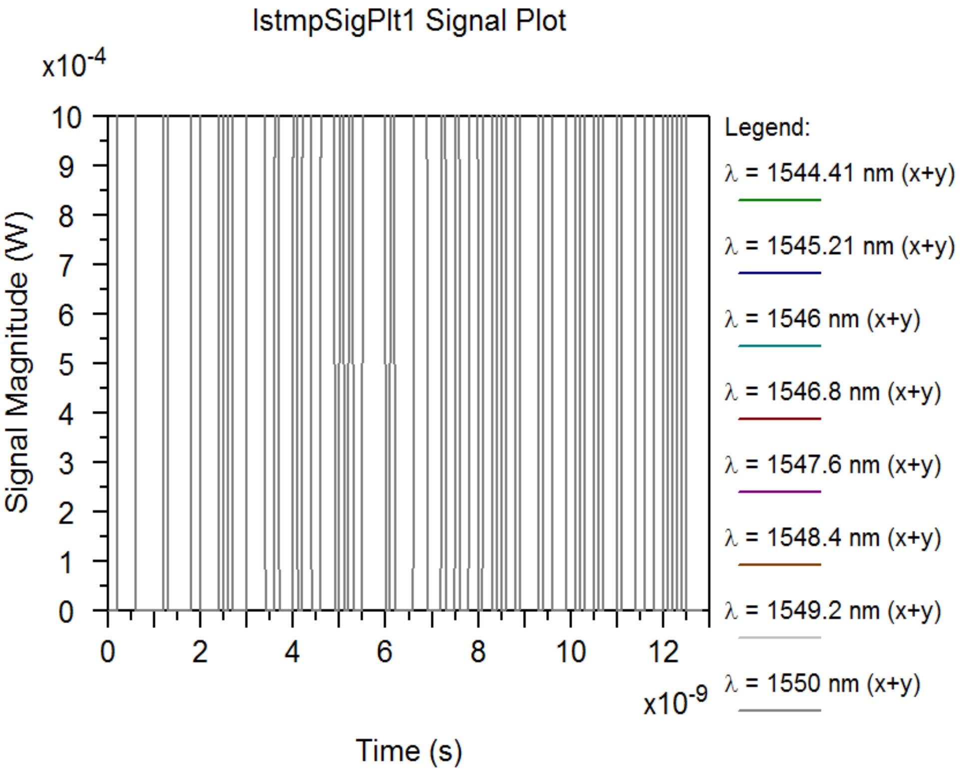

Figure 5.12 Output signal from Multiplexer

Fig.5.13 and Fig.5.14 shows signal from transmitting fiber and receiving fiber. From the received signal it is observed that the signal is affected by non-linearities.

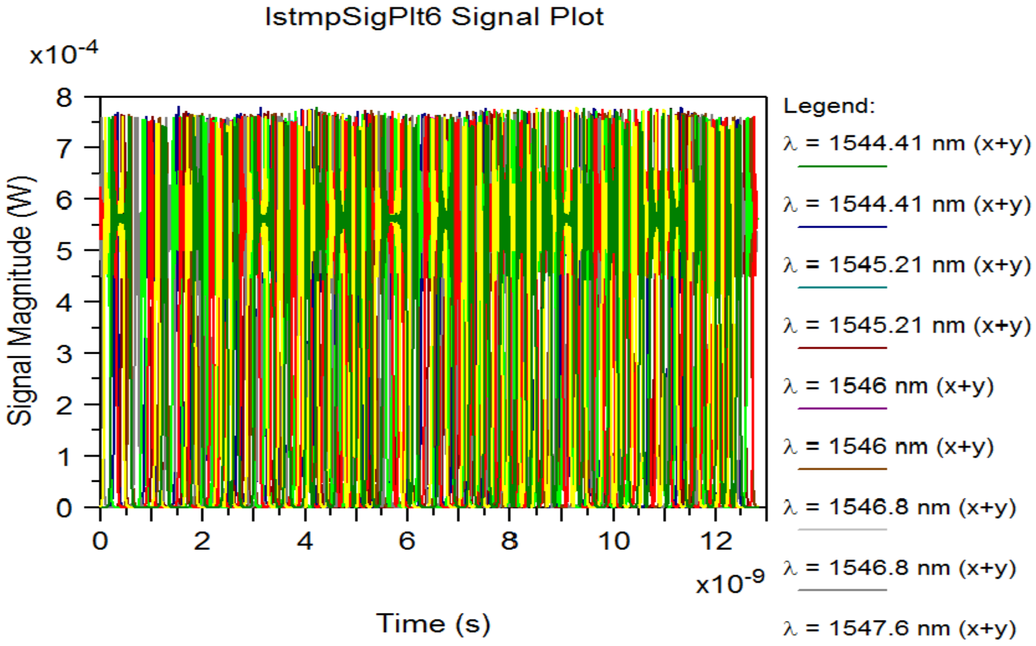

Figure 5.13 Signal at transmitting fiber

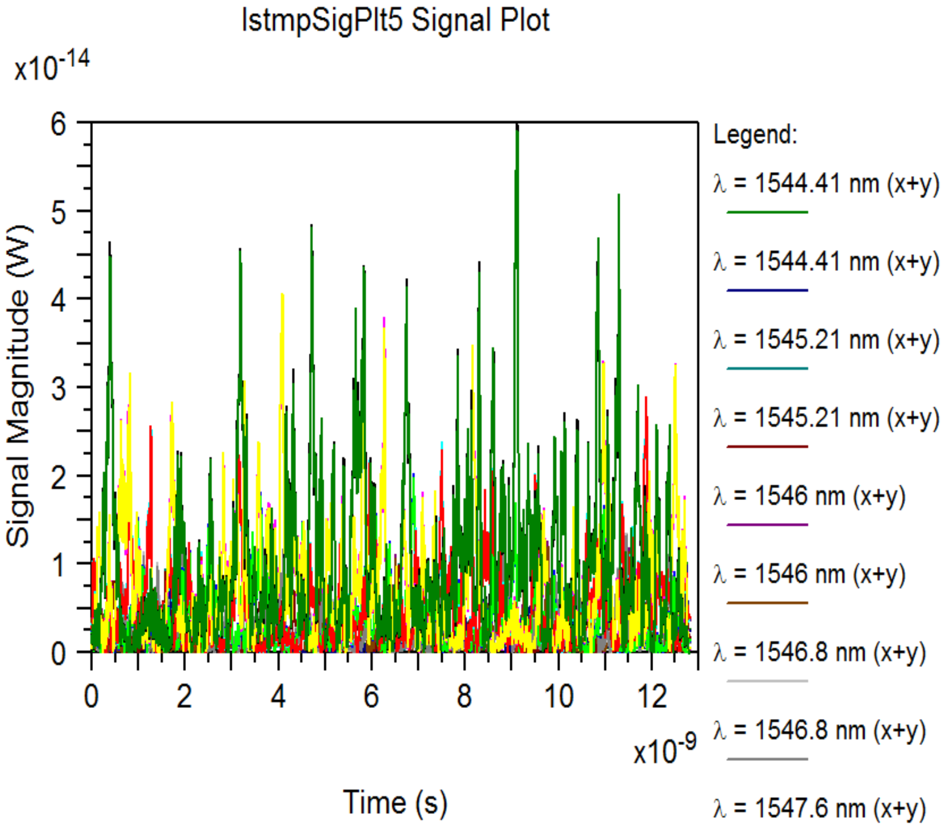

Figure 5.14 Signal at receiving fiber

Fig.5.15 and Fig.5.16 shows the eye diagram from switching and reflective ports of symmetrical MZI. It is observed from switching port that the lower part of eye is nicely suppressed which means there is no interference from other signals, because these are transmitted at different times.

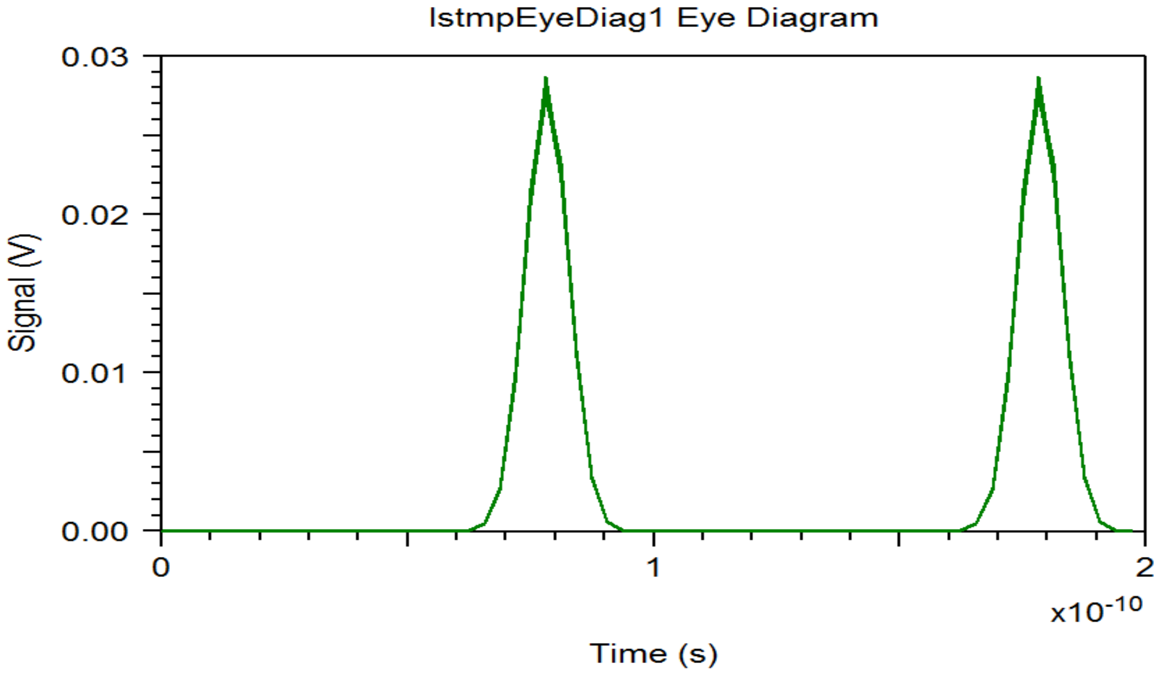

Figure 5.15 Eye diagram of switching port

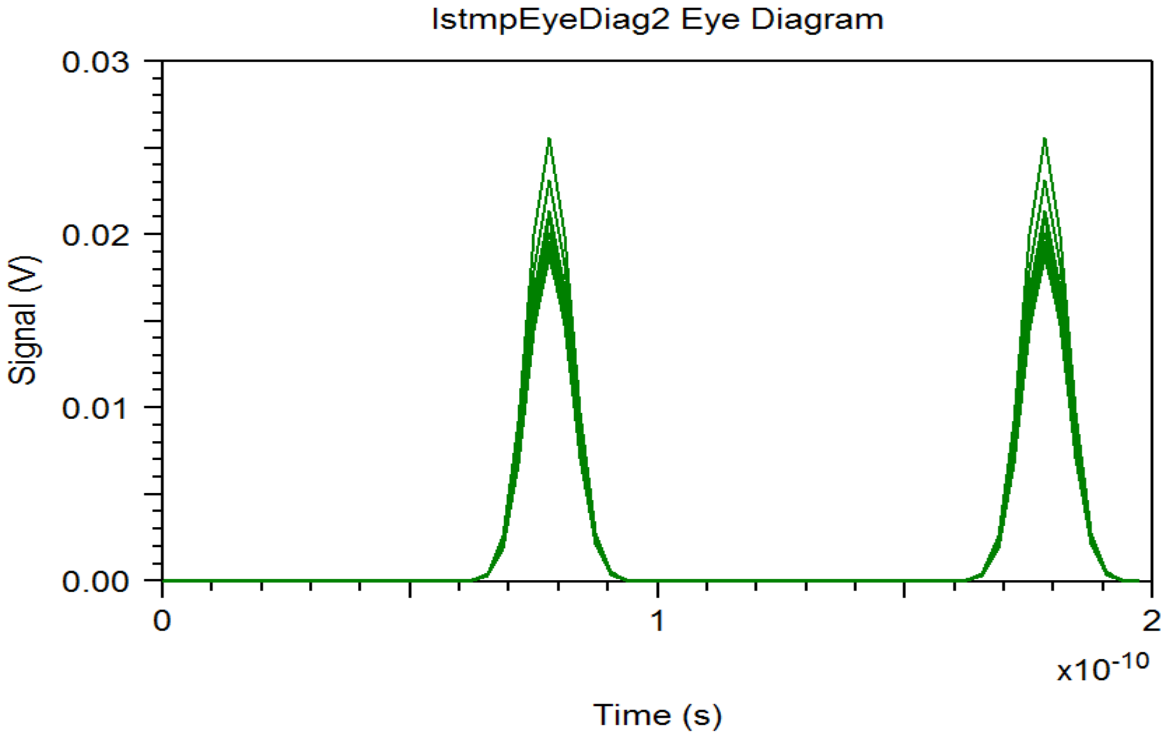

Figure 5.16 Eye diagram of reflective port

5.3.1 HYBRID TDM/DWDM FOR RZ MODULATION FORMAT

Return-to-zero (RZ) is a line code used in communication signals in which the signal drops to zero between each pulse. Symbol 1 is mapped to positive amplitude for the first half of the bit duration followed by zero amplitude for the second half of the bit duration. Symbol 0 is mapped to amplitude close to zero. But it requires twice the bandwidth to achieve the same data-rate as compared to non-return-to-zero format. Fig. 5.17 shows the line coding example for RZ modulation format.

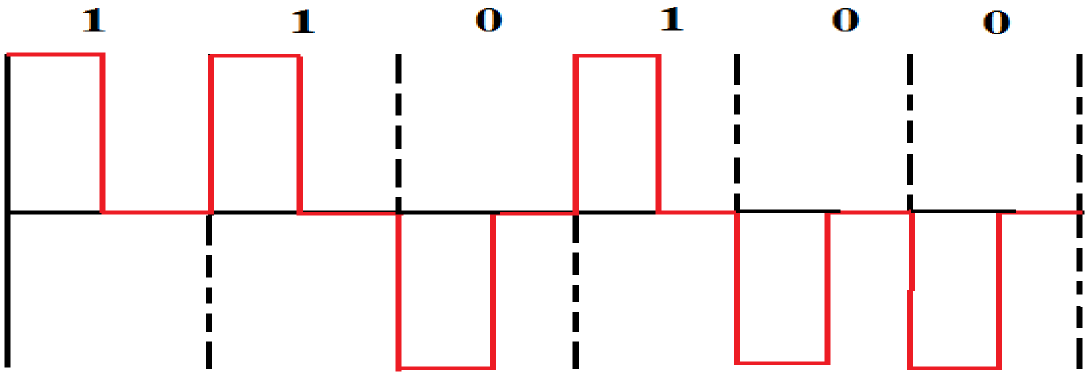

Figure 5.17 Example for RZ modulation format

Fig.5.18 and Fig.5.19 shows the ASE noise spectrum of the multiplexed signal indicating signals from each DWDM group, observed before and after MZI for RZ modulation format.

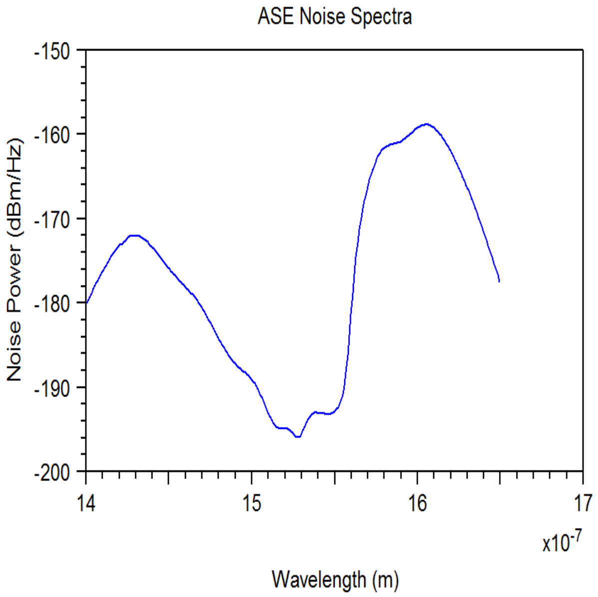

Fig.5.18 ASE noise spectrum before MZI for RZ modulation format

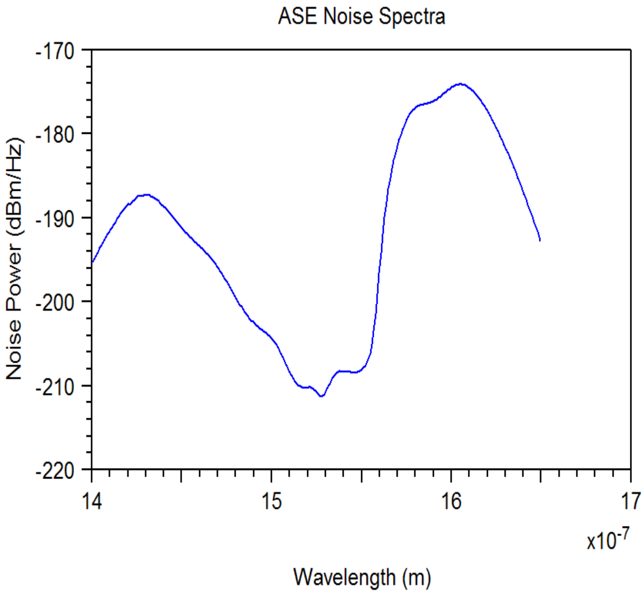

Fig.5.19 ASE noise spectrum after MZI for RZ modulation format

5.3.2 HYBRID TDM/DWDM FOR NRZ MODULATION FORMAT

Symbol 1 is represented by a pulse of constant amplitude for the entire duration, and symbol 0 is represented by no pulse. NRZ systems are more susceptible to interchannel nonlinear effects than RZ systems. Fig.5.20 shows the line coding example for NRZ modulation format.

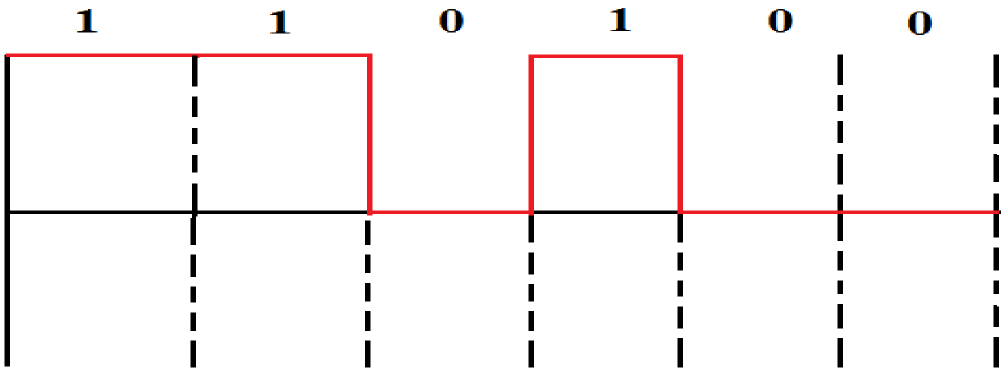

Fig.5.20 Example for NRZ modulation format

Fig.5.21 and Fig.5.22 shows the ASE noise spectrum of the multiplexed signal indicating signals from each DWDM group, observed before and after MZI for NRZ modulation format.

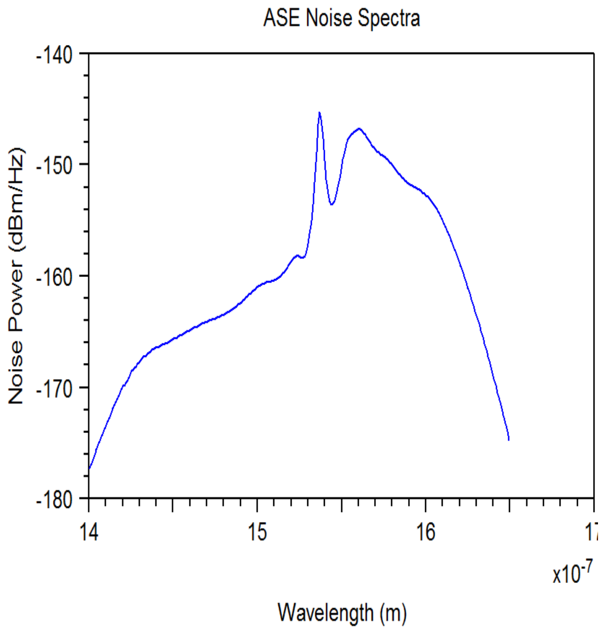

Fig.5.21 ASE noise spectrum before MZI for NRZ modulation format

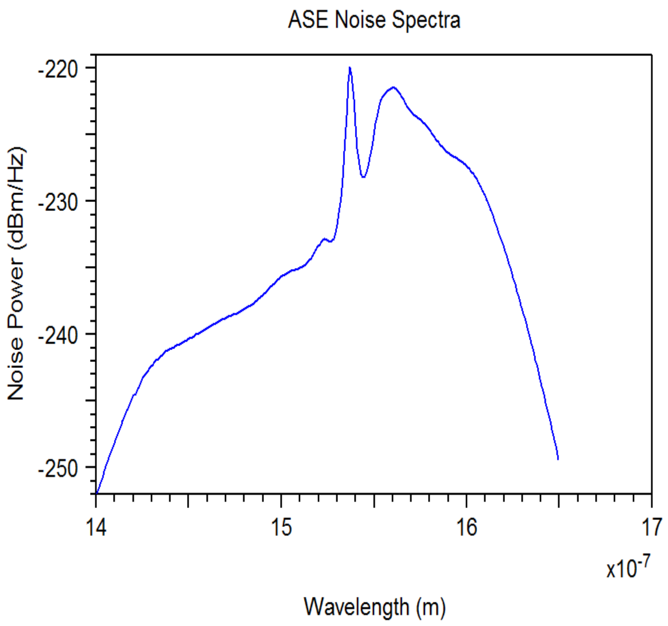

Fig.5.22 ASE noise spectrum after MZI for NRZ modulation format

5.3.3 HYBRID TDM/DWDM FOR MANCHESTER MODULATION FORMAT

Symbol 0 is represented by an equal amplitude positive pulse followed by a negative pulse. Symbol 1 is represented by a negative pulse followed by a positive pulse. Manchester coding has an advantage that it is easy to recover the original data clock. Fig.5.23 shows the line coding example for Manchester modulation format.

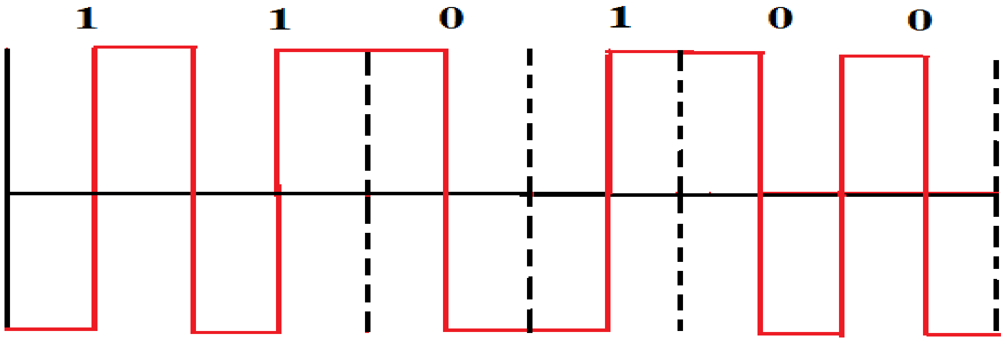

Fig.5.23 Example for manchester modulation format

Fig.5.24 and Fig.5.25 shows the ASE noise spectrum of the multiplexed signal indicating signals from each DWDM group, observed before and after MZI for Manchester modulation format.

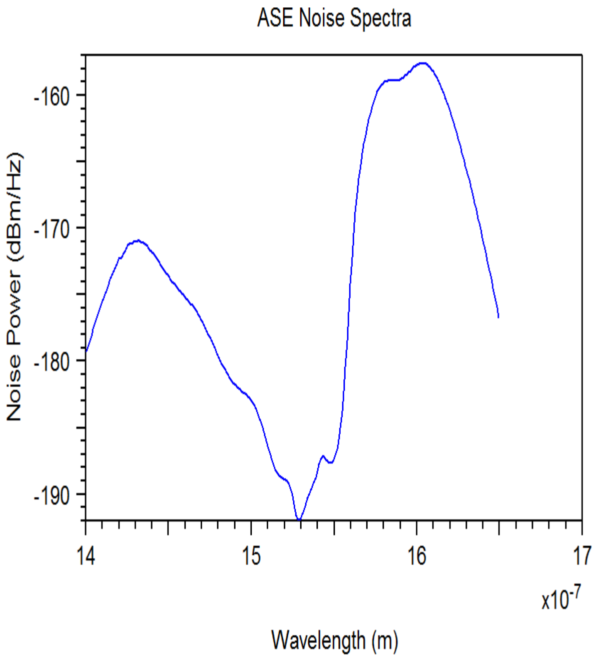

Fig.5.24 ASE noise spectrum before MZI for Manchester modulation format

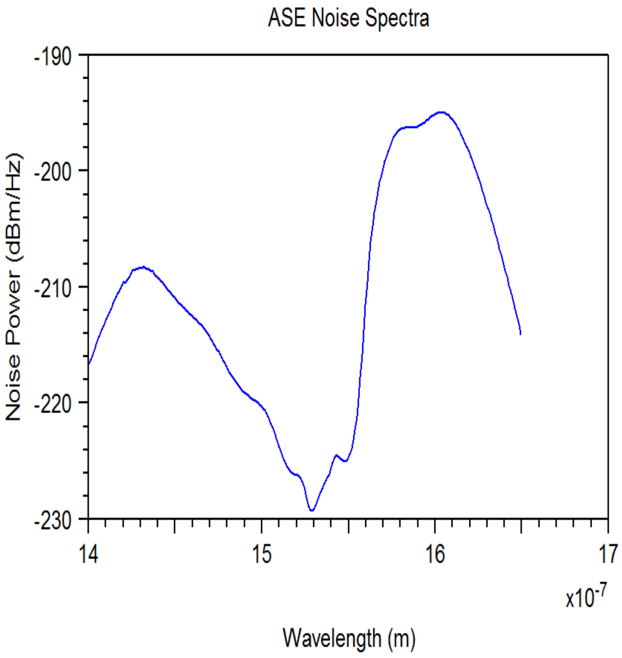

Fig.5.25 ASE noise spectrum after MZI for Manchester modulation format

From Table.5.1 it is observed that NRZ signal format is superior to RZ and Manchester signal formats at the receiving end. Amongst these three modulation formats, ASE effects occur more in NRZ signal format for hybrid TDM/DWDM. Thus, NRZ is more affected by ASE noise of amplifier. NRZ, RZ and Manchester modulation signals are almost equally affected by noise before MZI. After MZI, the performance of hybrid TDM/DWDM with NRZ modulation format has been improved. Due to lack of synchronization and the presence DC component problem, NRZ modulation format is not preferred. Thus comparatively Manchester modulation format is better for hybrid TDM/DWDM. These results have been seen at power=1mW and bit rate of 10-Gb/s. So with increase in bit rate or power, the effects of ASE would increase and will thus limit the transmission distance for long haul systems. The FWM is strongest when pulses at different wavelengths completely overlap with one another in the time domain. This condition can be easily satisfied in the case of the NRZ signal format.

Noise Power(dBm/Hz)						
Modulation format	**RZ**		**NRZ**		**MANCHESTER**	
Wavelengths (nm)	***Before MZI***	***After MZI***	***Before MZI***	***After MZI***	***Before MZI***	***After MZI***
1400	-180	-196	-178	-252	-178	-216
1450	-178	-194	-168	-241	-172	-210
1500	-190	-208	-162	-237	-184	-224
1550	-192	-210	-155	-228	-188	-226
1600	-160	-178	-152	-226	-158	-198
1650	-176	-192	-174	-249	-176	-212

Table 5.1 ASE Noise Analysis for Different Wavelengths

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

Hybrid TDM/DWDM PON architecture was proposed to accommodate the consumer demand for ever increasing amount of bandwidth. The optical communication system with hybrid TDM/DWDM PON was constructed using OptSim 5.0 and the performance has been analyzed in the presence of Four Wave Mixing. The ASE noise is filtered out using a Semiconductor Optical Amplifier based Mach-Zehnder Interferometer at receiver end. The hybrid architecture has been analyzed for different modulation formats and it is observed that Manchester modulation format is suitable for hybrid TDM/DWDM architecture.

6.2 FUTURE WORK

The work can be enhanced by increasing the length of transmitting and receiving fiber. Further, different Four Wave Mixing suppression techniques can be employed. Instead of using EDFA, the hybrid architecture can also be developed using Fiber Optic Parametric Amplifier and its performance may be analyzed and compared with the proposed architecture.

CHAPTER 7

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