PERFORMANCE ANALYSIS OF POLARIZATION EFFECTS AND PRE-COMPENSATION TECHNIQUE IN WDM SYSTEM

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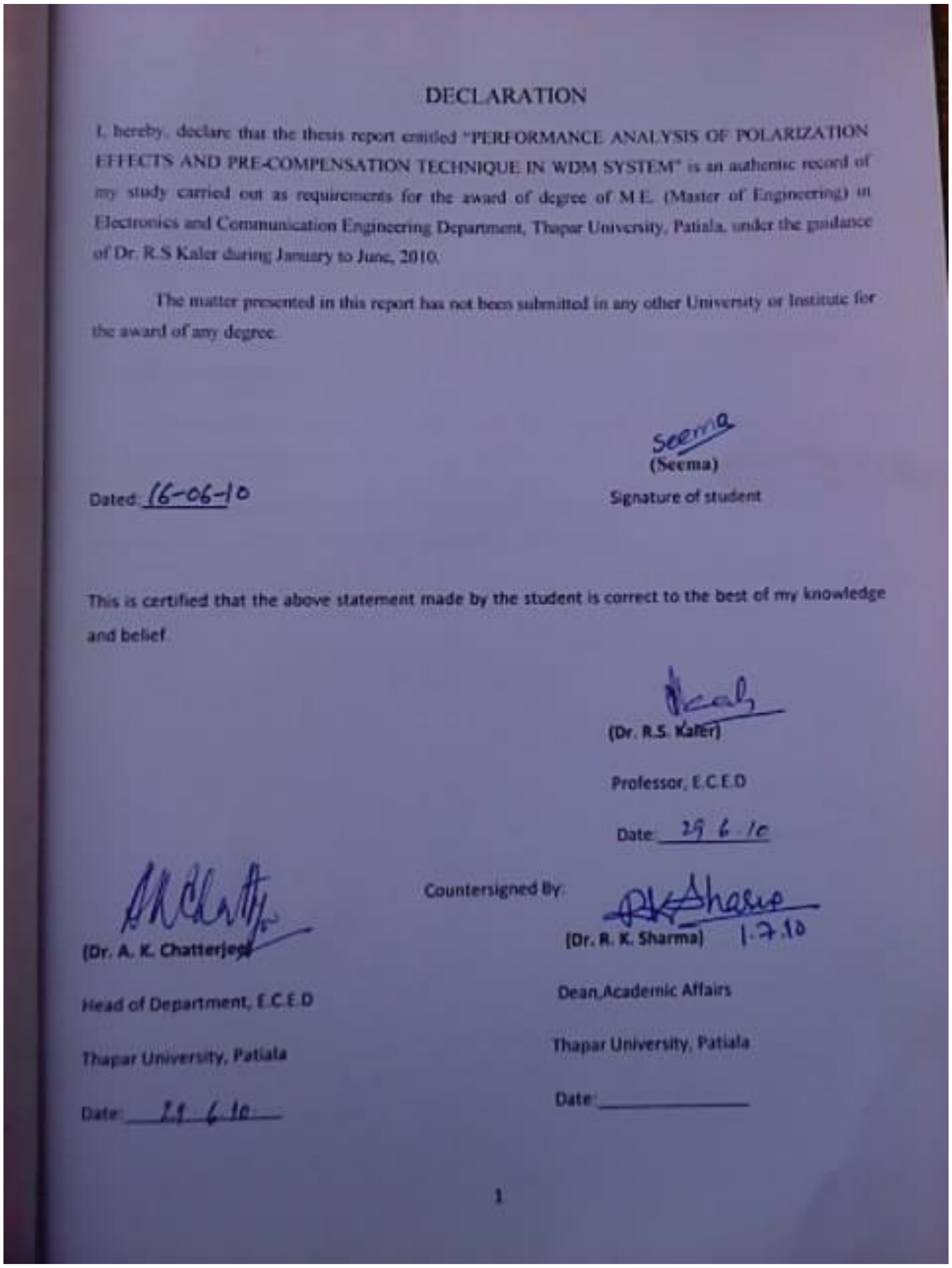

DECLARATION

I, hereby, declare that the thesis report entitled "PERFORMANCE ANALYSIS OF POLARIZATION EFFECTS AND PRE-COMPENSATION TECHNIQUE IN WDM SYSTEM" is an authentic record of my study carried out as requirements for the award of degree of M.E. (Master of Engineering) in Electronics and Communication Engineering Department, Thapar University, Patiala, under the guidance of Dr. R.S Kaler during January to June, 2010.

The matter presented in this report has not been submitted in any other University or Institute for the award of any degree.

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ABSTRACT

In WDM system, each laser must emit light at a different wavelength, with all the lasers' light multiplexed together onto a single optical fiber. After being transmitted through a high-bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. The field of optical wave division Multiplexing has experienced explosive growth over the past few years. As the WDM have many advantages over the all multiplexing techniques. The objectives of this thesis is performance analysis of polarization effects and pre-compensating techniques in WDM system.

Firstly the design, implementation and performance analysis of polarization effect in WDM system for different values of fiber length and polarization angle is presented. The comparison of polarization effect at various values of fiber length and polarization revealed that as we increase the length of the filter, the bit error rate will increase and eye opening will also decrease and the Q-Factor will be reduced. In both even and odd channels, the Q-factor is minimal for polarization angles equal to 0 or 180 degrees, i.e. when all channels have parallel polarization states; and Q has maximum at 90 degrees, i.e. when adjacent channels polarization state is orthogonal to each other. The BER has minimum value at 90 degree, i.e. when adjacent channels polarization state is orthogonal to each other. It is also observed the spectrums of even and odd channels.

Secondly, the design, implementation and performance analysis of pre-compensation technique in WDM system on changing the different transmitter components in the circuit is presented. Components involve different modulator drivers like NRZ and RZ raised cosine, NRZ and RZ rectangular, Manchester and rectangular, Manchester and raised cosine. The investigations on pre-compensation technique has been carried out for 8 channels having bit rate of 10 Gbps and the performance has been evaluated in terms of eye diagrams, dispersion map and optical power map for different values of DCF and SMF length. The simulation results revealed that eye opening is maximum when NRZ rectangular modulator driver is used and is minimum when RZ

Manchester modulation driver is used. Also, it has been observed that pre-compensated fiber gives better results than the uncompensated fiber. Moreover, the DCF of length 20km and SMF of length 80 km give the best results amongst all other fibers.

Lastly, the design, implementation and performance analysis of DWDM system for different values of fiber length and channel spacing is presented. The comparison of DWDM at various values of channel spacing revealed that 100 GHz spacing has the lowest BER and better system performance. Hence, the higher spacing values between the input channels are recommended for long distance transmission without dispersion. It can be seen from the graphs of BER, Q-factor and eye opening that higher channel spacing gives the best performance as compared to lower channel spacing. The comparison of DWDM at various values of fiber length revealed that as we increase the length of the filter, the bit error rate will increase and the Q-Factor will be reduced.

Thus, the thesis presents the performance analysis of WDM system on the basis of various factors.

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ABBREVIATIONS

BER	Bit Error Rate
CS-RZ	Carrier-Suppressed Return-to-Zero
CWDM	Course Wavelength Division Multiplexing
DCF	Dispersion compensating fiber
DPSK	Differential Phase-Shift Keying
DWDM	Dense Wavelength Division Multiplexing
FDM	Frequency Division Multiplexing
ITU-T	International Telecommunication Union-Telecommunication
MB	Multiple bi-stability
NRZ	Non Return-to-Zero
PMD	Polarization Mode Dispersion
Q-factor	Quality Factor
RZ	Return-to-Zero
SBS	Stimulated Brillion Scattering
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SPM	Self Phase Modulation
SRS	Stimulated Raman Scattering
TDM	Time Division Multiplexing
WB	Wavelength bi-stability

WDM	Wavelength Division Multiplexing
XPM	Cross Phase Modulation

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO OPTICAL COMMUNICATION

Ever since the mid 90’s optical fibers have been used for point to point communication at a very high speed. Often the optical fiber offers much higher speed than the speed of electronic signal processing at both ends of the fiber. Optical communication systems in the optical fiber play a main part of the digital communications in backbone networks, high speed LAN, MAN and FTTH [1]. The main advantage of the optical fiber communications are the high speed, large capacity and high reliability by the use of the broadband of the optical fiber. So to be able to take the full advantage of the speed in optical fibers one of the basics concepts in fiber optic communication is the idea of allowing several users to transmit data simultaneously over the communication channel.

1.2 MULTIPLEXING:

Since the first wires were laid for telegraphs in the 1800’s, the drive has been to increase the amount of information that can be sent in a given interval. In the early years of telegraphs, telephones, and other telecommunications, the simple and obvious solution was to add more lines of communication. The increased cost of wire-laying and maintenance quickly built up, however, and a new answer to the problem had to be invented. The answer was multiplexing, in which more than one signal is sent over the same line [2].

1.3 Types of multiplexing techniques

1.3.1 TIME DIVISION MULTIPLEXING: In TDM, the transmission capacity of a communications channel is logically divided into time frames of equal duration. Each time frame is further divided into a set of n time slots. A sub channel with a capacity equal to 1/n of the channel capacity is obtained by using the same slot in successive frames. Since very few individual applications today utilize this high bandwidth. These lower-speed channels are multiplexed together in time to form a higher-speed channel. This time-division multiplexing (TDM) can be accomplished in the electrical or optical domain, with each lower-speed channel transmitting a bit (or allocation of bits known as a packet) in a given time slot and the waiting its turn to transmit another bit (or packet) after all the other channels have had their opportunity to transmit (Figure 1.1). TDM is quite popular with today's electrical networks, and is fairly straightforward to implement in an optical network at < 100-Gbps speeds. This scheme by itself cannot hope to utilize the available bandwidth because it is limited by the speed of the time-multiplexing and demultiplexing components.

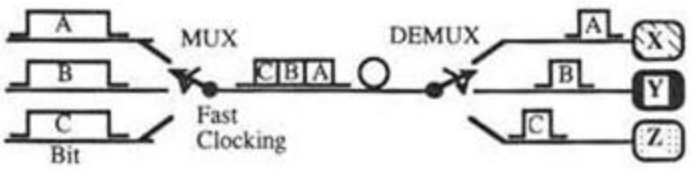


FIG 1.1: several TDM channels with bit interleaved multiplexing

1.3.2 WAVELENGTH DIVISION MULTIPLEXING:

A WDM system uses a multiplexer at the transmitter to join the signals together 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. The concept was first published in 1970, and by 1978, WDM systems were being realized in the laboratory. The first WDM systems only combined two signals. Modern systems can handle up to 160 signals and can thus expand a basic 10 Gbps fiber system to a theoretical total capacity of over 1.6 Tbps over a single fiber pair. WDM systems are popular with telecommunications companies because they allow them to expand the capacity of the network without laying more fiber. By using WDM and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure without having to overhaul the backbone network. Capacity of a given link can be expanded by simply upgrading the multiplexers and demultiplexer at each end. This is often done by using optical-to-electrical-to-optical (O/E/O) translation at the very edge of the transport network, thus permitting interoperation with existing equipment with optical interfaces. Most WDM systems operate on single mode fiber optical cables, which have a core diameter of 9 µm. Certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 µm. Early WDM systems were expensive and complicated to run. However, recent standardization and better understanding of the dynamics of WDM systems have made WDM less expensive to deploy.

WDM systems are divided in different wavelength patterns, conventional or coarse and dense WDM. Conventional WDM systems provide up to 16 channels in the 3rd transmission window (C-band) of silica fibers around 1550 nm. DWDM uses the same transmission window but with denser channel spacing. Channel plans vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 25 GHz spacing (sometimes called ultra dense WDM). New amplification options (Raman amplification) enable the extension of the usable wavelengths to the L-band, more or less doubling these numbers.

WDM, DWDM and CWDM are based on the same concept of using multiple wavelengths of light on a single fiber, but differ in the spacing of the wavelengths, number of channels, and the ability to amplify the multiplexed signals in the optical space. EDFA provide efficient wideband amplification for the C-band, Raman amplification adds a mechanism for amplification in the L-band. For CWDM wideband optical amplification is not available, limiting the optical spans to several tens of kilometers [3].

WDM enables the utilization of a significant portion of the available fiber bandwidth by allowing many independent signals to be transmitted simultaneously on one fiber, with each signal located at a different wavelength. Routing and detection of these signals can be accomplished independently, with the wavelength determining the communication path by acting as the signature address of the origin, destination or routing. Components are therefore required that are wavelength selective, allowing for the transmission, recovery, or routing of specific wavelengths.

In a simple WDM system (Figure 1.2), each laser must emit light at a different wavelength, with all the lasers' light multiplexed together onto a single optical fiber. After being transmitted through a high-bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. Each laser is modulated at a given speed, and the total aggregate capacity being transmitted along the high-bandwidth fiber is the sum total of the bit rates of the individual lasers. An example of the system capacity enhancement is the situation in which ten 2.5-Gbps signals can be transmitted on one fiber, producing a system capacity of 25 Gbps. This wavelength-parallelism circumvents the problem of typical optoelectronic devices, which do not have bandwidths exceeding a few gigahertzes unless they are exotic and expensive. The speed requirements for the individual optoelectronic components are, therefore, relaxed, even though a significant amount of total fiber bandwidth is still being utilized.

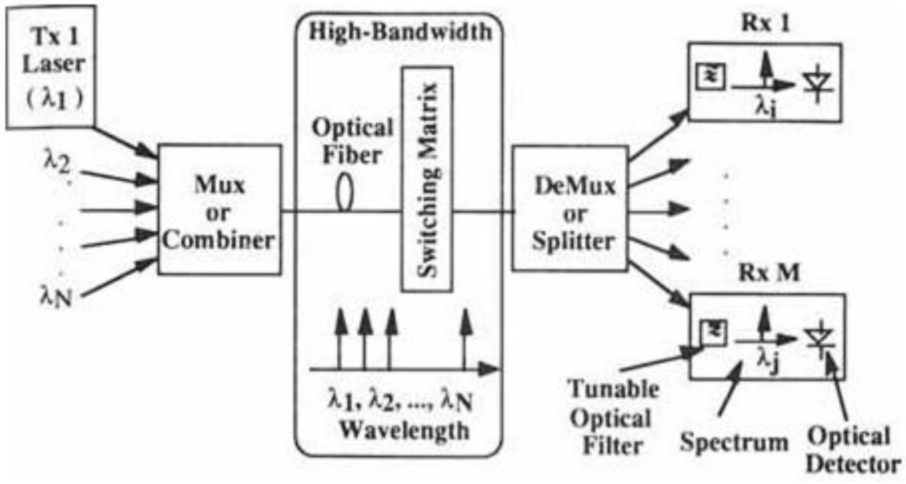


Fig 1.2: simple WDM system [3]

The concept of wavelength demultiplexing using an optical filter is illustrated in 1.3. In the figure, four channels are input to an optical filter that has a no ideal transmission filtering function. The filter transmission peak is centred over the desired channel, in this case, l3, thereby transmitting that channel and blocking all other channels. Because of the non-ideal filter transmission function, some optical energy of the neighbouring channels leaks through the filter, causing inter-channel, inter-wavelength cross-talk. This cross-talk has the effect of reducing the selected signal's contrast ratio and can be minimized by increasing the spectral separation between channels. Although there is no set definition, a non-standardized convention exists for defining optical WDM as encompassing a system for which the channel spacing is approximately 10 nm [4].

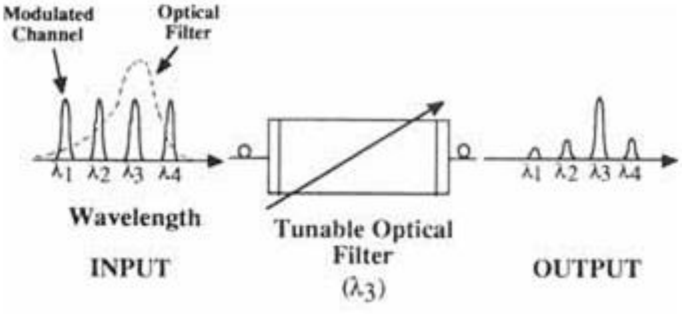


Fig 1.3: optical WDM channels being demultiplexed by an optical amplifier [5]

1.4 CLASSIFICATION OF WDM

1.4.1 DWDM

Early WDM began in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm regions, sometimes called wideband WDM. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were now spaced at an interval of about 400 GHz in the 1550-nm window. By the mid-1990s, Dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz [6]. By the late 1990s DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even 25 GHz intervals. Along with increased density of wavelengths, systems also advanced in their flexibility of configuration, through add-drop functions, and management capabilities. Thus dense wavelength-division multiplexing (DWDM) revolutionized data transmission technology by increasing the capacity signal of embedded fiber [6, 7]. This increase means that the incoming optical signals are assigned to specific (wavelengths) within a designated frequency band, and then multiplexed onto one fiber. This process allows for multiple video, audio, and data channels to be transmitted over one fiber while maintaining system performance and enhancing transport systems. This technology responds to the growing need for efficient and capable data transmission by working with different formats, such as, SONET/SDH while increasing bandwidth. Dense Wavelength Division Multiplexing (DWDM) is a fiber-optic transmission technique. DWDM is a technology that allows multiple information streams to be transmitted simultaneously over a single fiber. It involves the process of multiplexing many different wavelength signals onto a single fiber. Optical networks use Dense Wavelength Multiplexing as the underlying carrier. The most important components for a DWDM system are transmitters, receivers, fiber amplifiers, DWDM multiplexer, and DWDM demultiplexer [7]. These components allow a DWDM system to interface with other equipment and to implement optical solutions throughout the network.

1.4.2 CWDM

CWDM is also being used in cable television networks, where different wavelengths are used for the downstream and upstream signals. In these systems, the wavelengths used are often widely separated, for example the downstream signal might be at 1310 nm while the upstream signal is at 1550 nm.WDM system has been segmented into two parts, “dense” and “coarse” WDM. Dense WDM (DWDM) is generally held to be WDM with more than 8 active wavelengths per fiber, with systems with fewer active wavelengths being classed as coarse WDM (CWDM). DWDM systems are significantly more expensive than CWDM because the laser transmitters need to be significantly more stable than those needed for CWDM. CWDM is a lower-cost alternative to DWDM for short-haul (less than 31 miles) optical transport from the enterprise edge to the service provider metropolitan core [7]. Therefore, it is best suited for applications that have lower data- capacity requirements and for fiber spans that are 31 miles or less. As a result, lower-cost CWDM systems provide more economic benefits while providing the same security, reliability and equality as a DWDM system.

1.4.3 CWDM vs. DWDM

CWDM (Coarse Wavelength Division Multiplexing) uses 18 wavelengths from 1270 nm to 1610 nm with a channel bandwidth of 13 nm [8]. CWDM permits cheap components, such as a thermal AWG and uncooled lasers in the network due to the wide channel spacing (20 nm): There is no need to (temperature-) stabilize laser sources or optical filters. On the other hand, DWDM (Dense Wavelength Division Multiplexing) achieves greater spectral efficiency and with commercially available fiber-based optical amplifiers, can provide longer reach, which makes it a better upgrade option in the long-term future [8].

1.4.4 ADVANTAGES OF WDM

- Huge bandwidth
- Enhanced flexibility
- Upgradability
- It directly interfaces with customer premises and thus must accommodate a range of data formats and data rates.
- WDM allows the logical network topology to adapt to changing customer requirements, further enhancing the scalability of the network [9].

An access network must be scalable in terms of both number of customers and demands of any given customer. In a WDM solution, additional customers can be accommodated by dropping more wavelengths (up to a limit). In a dedicated-fiber solution, an increase in customer base can result in all the fibers in a sheath being consumed, thereby requiring more fiber to be laid - a very costly upgrade. Or, a customer may request an additional optical connection, due to large traffic volume or due to the desire to transmit multiple services in their native data format or rate. This latter application, which potentially benefits from the transparent nature of wavelength routing, is growing in importance as customers request that access networks provide virtual-LAN like functionality over a range of protocols. With WDM, the needs of the customer can be met by dropping an additional wavelength. In a dedicated-fiber solution, an additional fiber needs to be run to the customer [9].

Furthermore, WDM more readily provides shared-over-time bandwidth. Using passive WDM technology, a set of wavelengths can be made accessible to multiple customers. A shared wavelength can be dropped at a particular customer only when needed, allowing it to be used by other customers at other times. This capability will be greatly enhanced once the technology for remotely tunable passive wavelengths add/drops is developed. In a dedicated-fiber solution, another fiber needs to be permanently tied up at a customer needing only occasional extra bandwidth.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE SURVEY

Ivan T. Lima, et. al. [10] proposed a technique that uses Monte Carlo simulations with importance sampling and a reduced Stokes model to compute the probability density function of the Q-factor and the outage probability for a channel in a long-haul wavelength-division multiplexed optical-fiber transmission system due to the combination of polarization mode dispersion, polarization dependent loss, and polarization dependent gain. This technique allows to compute outage probabilities as small as 10^{-6} at a fraction of the computational cost required by standard Monte Carlo simulations.

P. J. Winzer et. al.[11] demonstrated that the importance of sampling to efficiently and accurately calculate outage probabilities on the order of due to the combination of the polarization effects of PMD, PDL, and PDG using a reduced Stokes model, provided that the PMD is small enough that it did not distort the pulses within a channel. By using importance sampling, the time required can be reduce to compute small outage probabilities by three orders of magnitude when compared with standard Monte Carlo simulations. This result holds independent of the particular choice of receiver model. For currently improving the receiver model to include realistic filter shapes and to account for noise re-polarization during transmission.

J. P. R. Lacey et. al. [12] described that Multichannel wavelength converters might be important components in the cross connects in future wavelength division multiplexed (WDM) transport networks. Here multichannel, polarization-insensitive, optically transparent wavelength converter, based on four-wave mixing in two semiconductor optical amplifiers in a polarization-diversity arrangement has been demonstrated. The Bit-error-rate (BER) measurements with four input 2.5-Gb/s WDM channels, spaced by 2 nm, showed penalties for wavelength conversion less than 2.6 dB at 10^{-9} BER. The changes in the state of polarization of the input signals cause the output power to change by less than 1.2 dB, and the corresponding power penalties change by less than 0.9 dB.

Wang D et. al [13] derived a Stokes parameter model to calculate the penalties due to the combination of polarization mode dispersion (PMD), polarization dependent loss (PDL), and polarization dependent gain (PDG) in long-haul, dense wavelength divison multiplexed (WDM) systems. In this model, they followed the Stokes parameters for the signal and the noise in each channel instead of following the full time domain behavior of each channel.

Jiping Wen et. al [14] described that in WDM system, the intra-channel nonlinearity induced Q fluctuation is comparable to that due to PDL alone, and the inter-channel nonlinearity dominates Q fluctuations at narrow channel spacings.

Djupsjobaka A. et.al. [15] described that different compensation methods like Optical Phase Conjugation method, Fiber chirped method , Bragg-Grating method , Filter method, Differential time delay method and dispersion equalizers were studied in the last decade and based on these methods efforts were made to increase the transmission distances and bandwidth of optical communication systems.

Cartaxo et. al. [16] derived that expression for relative intensity noise due to dispersion and nonlinearity including fiber loss and showed its impact with first order dispersion term. The optimization procedure was carried out for short span of single mode fiber using parabolic law.

Sono et. al. [17] described the WDM transmission with SPM/XPM suppression through pre chirping and dispersion management.

Nutys and Park et al. [18] investigated that the theoretically and experimentally the transmission performance of a 10 GB/s repeater transmission system using dispersion compensating fibers (DCFs). The system configuration that they considered is a 360 km standard (1300 nm zero-dispersion) fiber transmission system with an optical repeater including DCFs located every 120 km (or every 2100 ps/nm dispersion). The transmitter was a DFB laser externally modulated by a zero-chirp LiNbO3 modulator with NRZ (non-return to zero), 4×40 PRBS data. The results of this investigation clearly demonstrated that the use of DCFs is an extremely effective method to overcome the chromatic dispersion in high-speed transmission systems.

Weinert et al. [19] investigated the possibilities of 40 and 4× 40 Gb/s time division multiplexing wavelength division multiplexing (TDM/WDM) return-to-zero (RZ) transmission over embedded standard single-mode fibers (SMF) at a transmission wavelength of 1.55μm both experimentally and theoretically. Dispersion of the SMF was compensated by a dispersion compensating fiber (DCF). Transmission over a span of 150 km of SMF in the single channel case and of 100 km SMF in the multichannel case is reported. It was shown numerically that improvement was achieved by employing the newest type DCF which also compensates the dispersion slope of the SMF.

R. I. Killey et al.[20] have given the impact of fibre nonlinearity on the performance of systems employing electronic pre-compensation is assessed for single channel and WDM transmission. Simulation results predicting effective compensation of nonlinearity and dispersion in 10 Gb/s transmission were presented.

Chung and Y. G. Jang el at. [21] demonstrated the transmission of directly modulated 10-Gb/s wavelength-division-multiplexing (WDM) signals over 320 km of negative dispersion fiber [(NDF) dispersion: 2.5 ps/km/nm at 1550 nm] without dispersion compensation. The results indicated that a regional metro WDM network could be implemented cost-effectively by using the NDF and direct modulated lasers.

M. I. Hayee et. al [22] analyzed the 10-Gbps non dispersion managed and dispersion-managed wavelength-division multiplexed (WDM) systems that use pre-compensation, post-compensation, or dual-compensation of each channel to minimize dispersion and nonlinear effects.

G.P Aggarwal [23] provided the background material and the mathematical tools needed for understanding the various nonlinear effects. Starting from the Maxwell's equation, the wave equation in a nonlinear dispersive medium was used to discuss the fiber modes and to obtain the basic propagation equation.

V. Bobrovs et. al. [24] demonstrated the minimal allowed channel spacing in HDWDM systems, and provide recommendations for future WDM solutions. The revealed that, the minimal channel interval for 2.5 Gbit/s HDWDM system should be more than 0.2 nm, and for 10 Gbit/s system not less than 0.3 nm. Future optimization of the existing WDM systems will be necessary, and the minimal allowed channel spacing is only the first step for dense optical network optimization.

Ahmed S. Samra et.al.[25] estimated the upper bound of the spectral efficiency (i.e. the channel capacity) of the DWDM long haul transmission system (100×10Gb/s) considering the presence of fiber nonlinear effects with different modulation/detection regimes and considered the collision induced timing jitter of the soliton based DWDM system with amplification and filtering, also calculated the BER of each channel.

Zhang Dechao et. al.[26] demonstrated experimentally a 43 Gbps DWDM optical transmission system over 900km single mode fiber with 100km spans using NRZ format and Raman amplification without FEC. A commercial LiNbO3 modulator and a self-designed 43 Gbps transmitter based on electro-absorption modulator and compared in the system, and for the first time the electro-absorption modulation was shown to be able to realize up to 1200km transmission with a power penalty less than 2dB.

Kaler et al. [27] presented simulated results for DWDM systems using NRZ format with ultra-high capacity upto 1.28 Tb/s and spectral efficiency approaching 0.4 b/s/Hz. They investigated the impact of signal to noise ratio (SNR) on channel spacing, dispersion, length of the fiber and number of channels.

2.2 MOTIVATION

Up till now, Monte Carlo simulations on the basis of stokes parameters has been done to calculate the power penalties but the comparison on the basis of different fiber length and polarization angle is rarely considered. According to literature survey, polarization effect has been evaluated with 2 channels but no evaluation has been done for 4 channels. The polarization effect has been evaluated for different values of polarization angle and fiber length. Up till now, svarious methods to reduce dispersion effect have been proposed and theoretically compared. The performance of pre-compensation technique with 4 channels and dispersion map, eye diagram and power map have been shown. According to literature survey, pre-compensation technique has been evaluated with 4 channels but no evaluation has been done for 8 channels. In this paper, the pre-compensation technique has been evaluated for different values of fiber length and comparison of modulator drivers. It is also reported the comparison of pre-compensation in wdm with uncompensated fiber in wdm. Up till now, various methods to reduce channel spacing have been proposed and theoretically compared. The performance of DWDM with 16 channels using Mach-zender modulator and eye diagrams has been showns. According to literature survey, DWDM has been evaluated with 64 channels and on the basis of this work; it has been done for 96 channels. In this paper, the DWDM has been evaluated for different values of fiber length and channel spacing. It is also reported the BER and Q-factor by varying fiber length.

2.3 OBJECTIVES OF THESIS:

The objectives of thesis are:

- To investigate the polarization effects at different fiber length and polarization angle for WDM system.
- To design and performance analysis of pre-compensating technique with different driver modulators and eye diagrams at different fiber length for WDM system.
- To investigate the performance of DWDM at different fiber length and channel spacing with the help of eye diagrams.

2.4 THESIS ORGANISATION

This thesis is divided into six chapters.

First chapter presents a brief introduction of WDM system which includes classification of WDM and its advantages.

Second chapter includes the literature survey of polarization effects on WDM and dispersion compensating technique (pre-compensation) for WDM system. The literature survey of DWDM is also done.

Third chapter includes brief introduction of polarization effects on WDM and performance analysis of WDM in terms of eye diagrams, BER, eye diagrams and Q-factor for different values of polarization angle and fiber length.

In Fourth chapter, after brief introduction of pre-compensating technique, implementation and performance analysis of pre-compensation technique in WDM system is done by changing the modulator drivers. The investigations on pre-compensation technique has been carried out for 8 channels having bit rate of 10 Gbps and the performance has been evaluated in terms of eye diagrams, dispersion map and optical power map for different values of DCF and SMF length.

In fifth chapter, a brief introduction of DWDM system is given in starting. The investigation of performance of DWDM is done at different fiber length and channel spacing in terms of BER,Q-factor, eye diagram and graphs.

Finally sixth chapter includes conclusion and future scope of the work done.

CHAPTER 3

INVESTIGATION OF POLARIZATION EFFECTS AT DIFFERENT FIBER LENGTH AND POLARIZATION ANGLE

In this chapter, the investigations on WDM random polarization has been carried out for 4 channels having channel spacing of 50 GHz and the performance has been evaluated in terms of output spectrums, eye diagrams, BER, eye opening and Q-factor for different values of polarization angle and fiber length. The simulation results reveal that Q-factor is minimum for polarization angles of 0 or 180 degrees, i.e. when all channels have parallel polarization states; and Q is maximum at 90 degrees, i.e. when adjacent channels polarization state is orthogonal to each other. Further, it has been observed that on increasing the fiber length, Q-factor decreases and BER will increase.

3.1 INTRODUCTION

Polarization is a property of waves that describes the orientation of their oscillations. This chapter primarily covers the polarization of electromagnetic waves such as light although other types of wave also exhibit polarization. The introduction of wavelength converters into the cross-connects in WDM transport networks may allow improved blocking performance [27] and simpler network management. So-called optically transparent wavelength converters are modulation format independent and can perform multichannel wavelength conversion, in which a single wavelength converter simultaneously shifts the wavelengths of a comb of independently modulated wavelength-division multiplexing (WDM) channels. Large WDM cross connects based on multichannel wavelength converters may use fewer components and be more gracefully scalable than those based on single-channel wavelength converters [28]. An ideal multichannel wavelength converter is polarization insensitive; widely and arbitrarily tunable; and compact, because large arrays of wavelength converters may be required.

High-performance optical transmission systems may be degraded by several types of polarization-dependent effects [29], including polarization-mode-dispersion (PMD) from optical fiber and in-line components, polarization dependent gain (PDG) in optical amplifiers, and polarization-dependent loss (PDL) from many types of inline devices [30].

Most sources of electromagnetic radiation contain a large number of atoms or molecules that emit light. The orientation of the electric fields produced by these emitters may not be statistical correlation, in which case the light is said to be "un-polarized". If there is partial correlation between the emitters, the light is "partially polarized". If the polarization is consistent across the spectrum of the source, partially polarized light can be described as a superposition of a completely un-polarized component, and a completely polarized one. One may then describe the light in terms of the degree of polarization, and the parameters of the polarization ellipse [31].

Both wavelength bi-stability (WB) and multiple bi-stability (MB) were predicted theoretically by Adams' model in resonant optical amplifiers. Their experimental observation in 850nm Vertical-Cavity Semiconductor Optical Amplifiers (VCSOA). Clockwise hysteresis of WB is observed at constant input power while the input wavelength is swept across the gain window. MB is observed at a fixed operation wavelength biased on the long wavelength side of the two separated Polarization-Dependent Gain (PDG) windows of the VCSOA by sweeping the optical input. The polarization of the input is set to a fixed angle with respect to the two intrinsic principal axes of the VCSOA. Two MB levels were experimentally observed at 160μW and 320μW, respectively. These observations are in good agreement with theoretical prediction by Adams' model and may lead to multi-valued optical information manipulation.

Light reflected by shiny transparent materials is partly or fully polarized, except when the light is surface normal/perpendicular to the surface. It was through this effect that polarization was first discovered in 1808 by the mathematician Etienne Louis Malus. A polarizing filter, such as a pair of polarizing sunglasses, can be used to observe this effect by rotating the filter while looking through it at the reflection off of a distant horizontal surface. At certain rotation angles, the reflected light will be reduced or eliminated. Polarizing filters remove light polarized at 90° to the filter's polarization axis. If two polarizers are placed a top one another at 90° angles to one another, there is minimal light transmission [31].

Polarization by scattering is observed as light passes through the earth's atmosphere. The Rayleigh scattered light produces the brightness and colour in clear sky. This partial polarization of scattered light can be used to darken the sky in photographs, increasing the contrast. This effect is easiest to observe at sunset, on the horizon at a 90° angle from the setting sun. Another easily observed effect is the drastic reduction in brightness of images of the sky and clouds reflected from horizontal surfaces which is the main reason polarizing filters are often used in sunglasses. Polarization is of 2 types.

3.1.1 WDM ORTHOGONAL POLARIZATION

The polarization angle is scanned from 0 to 180 degrees with 10 degrees step and Q factor is measured versus polarization angle.

3.1.2 WDM RANDOM POLARIZATION

The polarization angle is a randomly changing number with distribution statistics defined as uniform distribution within a range from –180 to +180 degrees.

Up till now, various methods to reduce polarization effect have been proposed and theoretically compared. Monte Carlo simulations on the basis of stokes parameters has been done to calculate the power penalties but the comparison on the basis of different fiber length and polarization angle is rarely considered. According to literature survey, polarization effect has been evaluated with 2 channels but no evaluation has been done for 4 channels. In this paper, the polarization effect has been evaluated for different values of polarization angle and fiber length.

This chapter is divided into different sections. In the first section, the introduction of polarization effect is presented. In the second section, the schematic model is proposed. The third section describes the simulation setup for an optical communication system implementing these requirements. In the fourth section, the comparison of performance of polarization on the basis of different fiber length and polarization angle is done in terms of output spectrums, eye diagrams, BER, Q-factor. The fifth section gives the conclusion of this paper.

3.2 SCHEMATIC MODEL

The schematic model for WDM implementing the polarization effect for various values of fiber length and polarization angle between different users is presented in figure 3.1. N input channels/users are taken in this case for reference. The number of users can vary depending on various constraints like the bandwidth range.

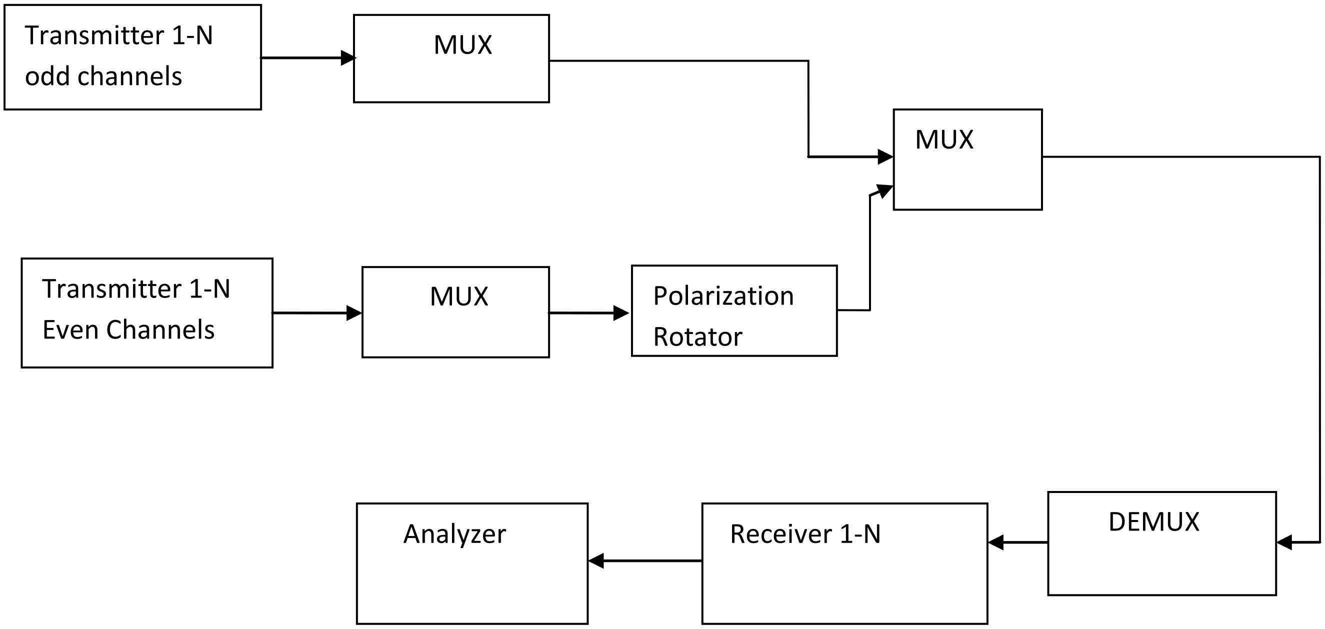


Figure 3.1 Schematic model

The transmitter section consists of a laser, modulator driver, pn-sequence generator i.e. data source and modulator. The wavelength of various channels is set by keeping the difference equal to the spacing required. Then all these transmitted signals are combined/multiplexed together. Then the signal is transmitted over the non linear fiber which adds the non linearities into the signal. At the receiver side, the signal is demultiplexed and analyzed with the help of BER Tester and eye diagram analyzer.

3.3 SIMULATION SETUP FOR POLARIZATION EFFECT ON WDM

The simulation setup for showing the effect of polarization by changing the fiber length and polarization angle on WDM is shown in figure 2. The continuous wave laser is used to create the carrier signal. In this setup, four users are taken in account whose wavelengths have a specific difference i.e. spacing between them. The wavelength of first user is kept at 1537.4GHZ. The wavelengths of next users are set as the spacing of 50 GHZ. The data source is used to generate the random input data bit sequence at the rate of 10 Gbps. The light signal modulates the input data. The modulator is driven by the modulator driver which decides the input data format. The input data format used here is NRZ Rectangular. The modulated data from odd channel users is combined using a multiplexer and the modulated data from even channel users is multiplexed and sent to polarization rotator. After that the output of MUX from odd channels and polarization rotator is combined by multiplexer and is sent over different fiber lengths as 75 km,80 km and 85 km. All the attenuation, dispersion and non linear effects are activated. At the receiver, the signal is demultiplexed and sent to 8 receivers followed by BER Tester to measure channel performance (BER and Q-factor) for given polarization state difference between adjacent channels. Initially all channels have the same polarization state. A BER Tester is attached at the output of receiver to examine the BER and Q-factor of input signal.

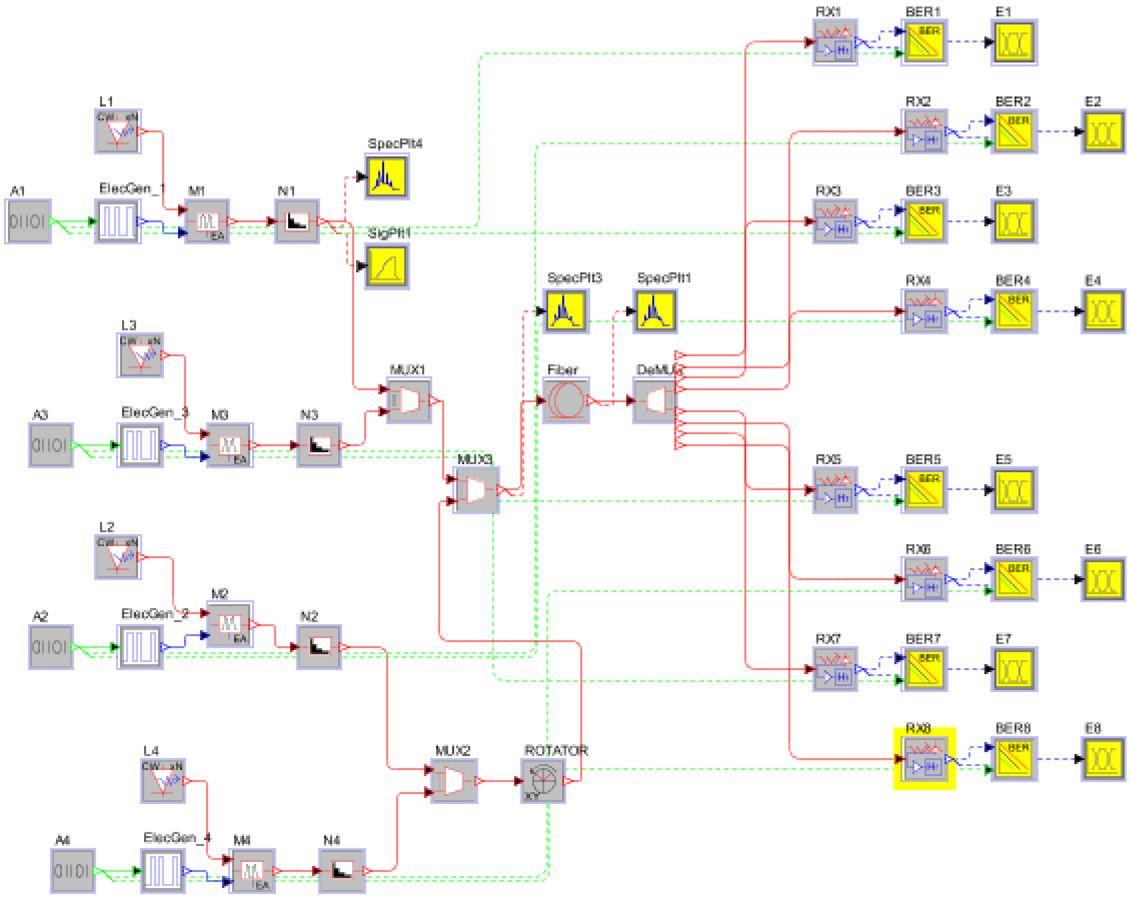


Fig 3.2: Simulation setup for polarization dependence studies

3.4 RESULTS AND DISCUSSIONS

Using simulation setup, the value of BER, Q-factor, eye diagrams, input optical spectrum of odd and even channels are measured. Optical scope measures the input and output wavelength spectrums. BER and Q-factor is measured at the receiver output by using a BER Tester. Eye diagram is seen by using an eye diagram analyzer.

Here following points are discussed for one odd channel and one even channel for different length of fiber and different channel spacing at random polarization.

Figure 3.3 shows the eye diagrams for the even and odd channels. The eye opening in odd channels is better than even channel. In Polarization State for Fiber Length of 75 km, the polarization angle is scanned from 0 to 180 degrees with 5 degrees step and Q-factor is measured versus polarization angle. Figure 4 shows results for one odd (chanel1) and Figure 5 for one even channel (chanel2).As the polarization angle varies from 0-90 degree, BER will increase and Q-factor will be reduced as shown in fig 3.4. At 90 degree, BER is minimum and Q-factor is maximum. If polarization angle is increased further, BER will start increasing and Q-factor will start decreasing as shown in fig 3.4. It is also observed that Q-factor is more in case of odd channel at zero polarization angle.

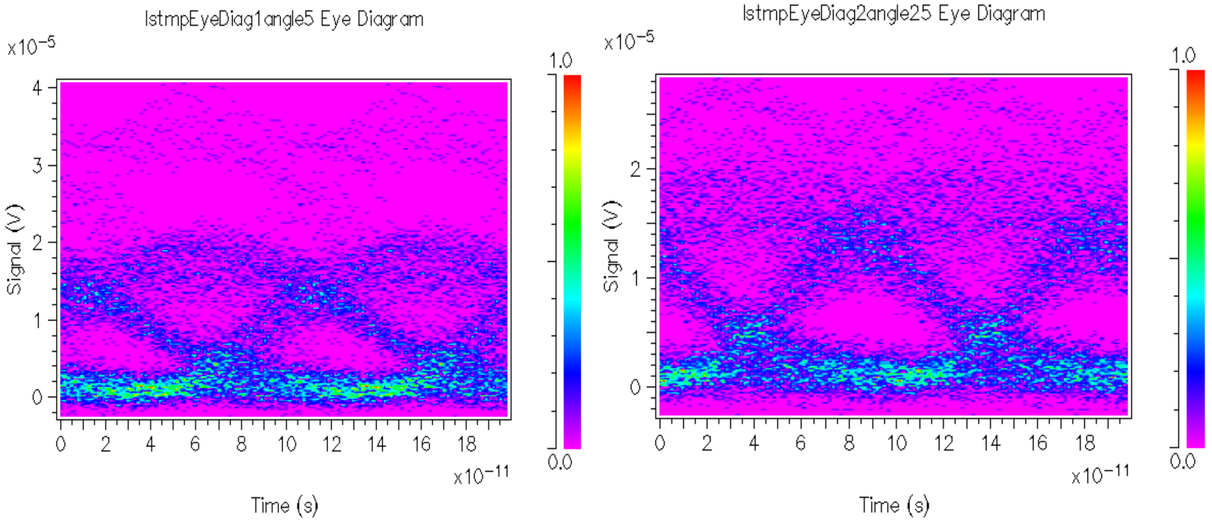


Fig 3.3 : Eye diagrams of odd and even channels

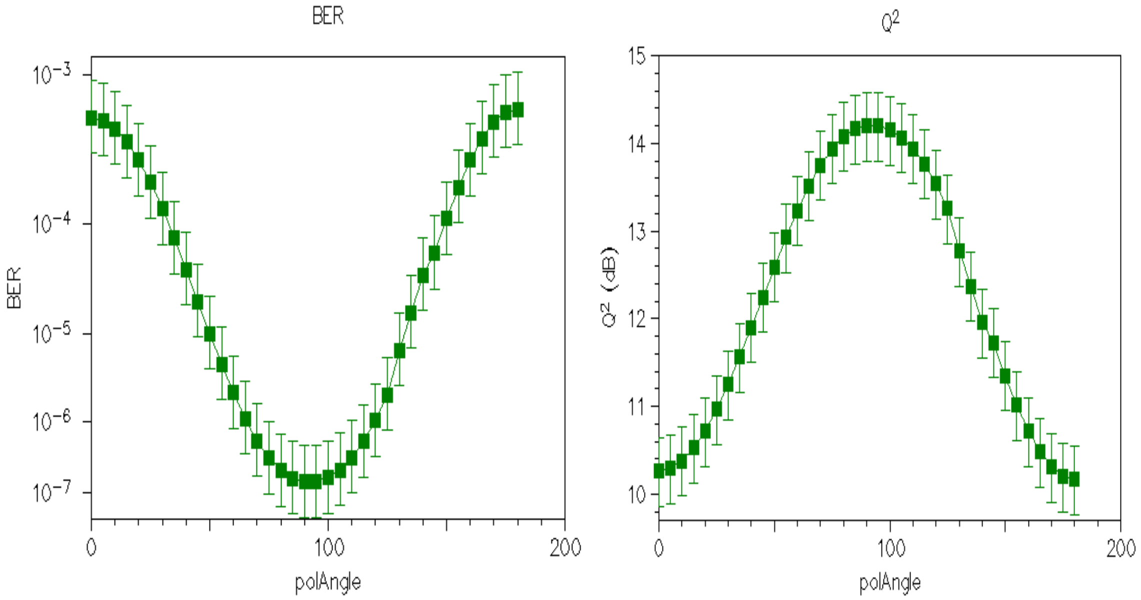


Fig 3.4: BER and Q-factor versus polarization angle for Odd channel (channel-1)

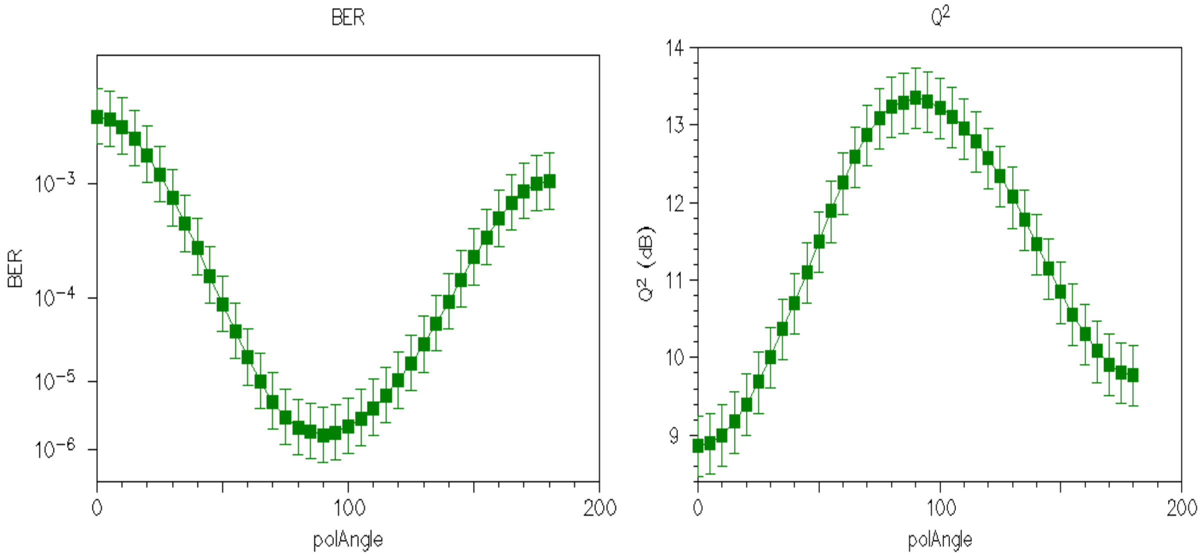


Fig 3.5: BER and Q-factor versus polarization angle for even channel (channel-2)

In Polarization State for fiber Length of 80 km, the polarization angle is scanned from 0 to 180 degrees with 5 degrees step and Q-factor is measured versus polarization angle. Figure 5 shows results for one odd channel-1) and Figure 6 one even channel (channel-2).It is observed that as the length of the fiber increases, the BER will increase and the Q-factor will decrease at zero polarization angle.

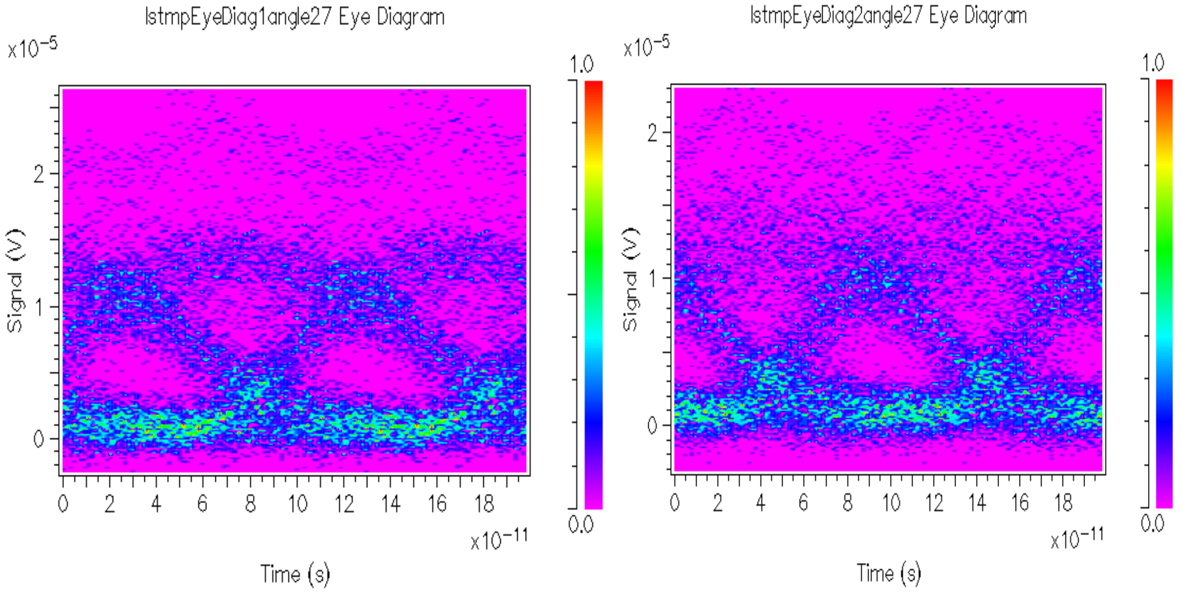


Fig 3.6: Eye diagrams of odd and even channels

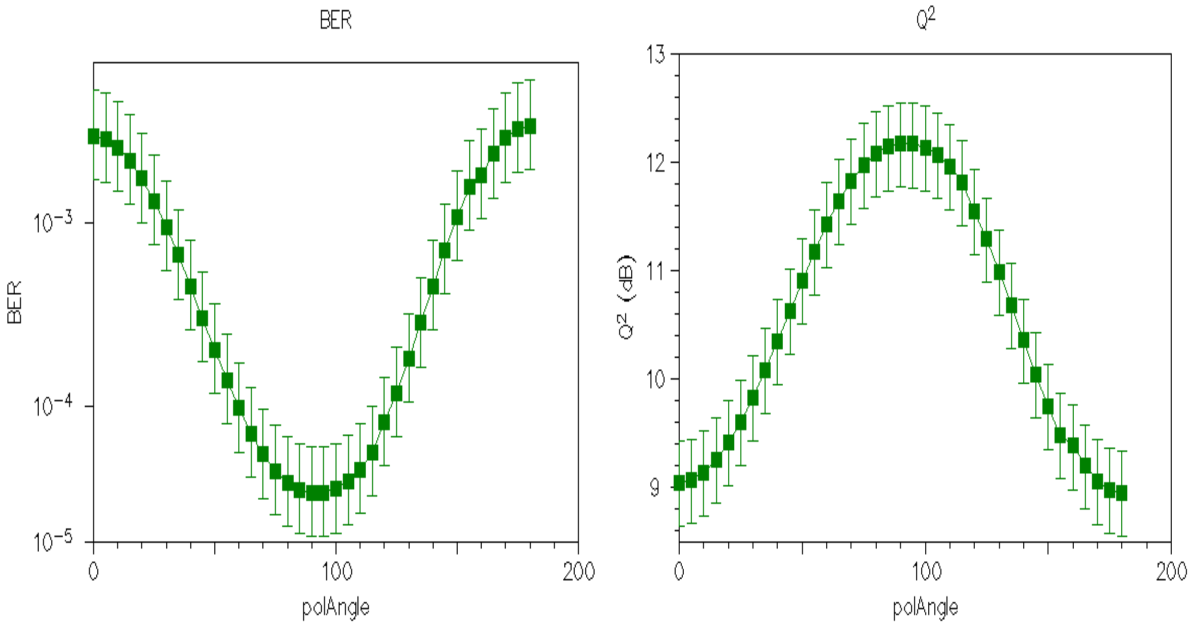


Fig 3.7: BER and Q-factor versus polarization angle for Odd channel (channel1)

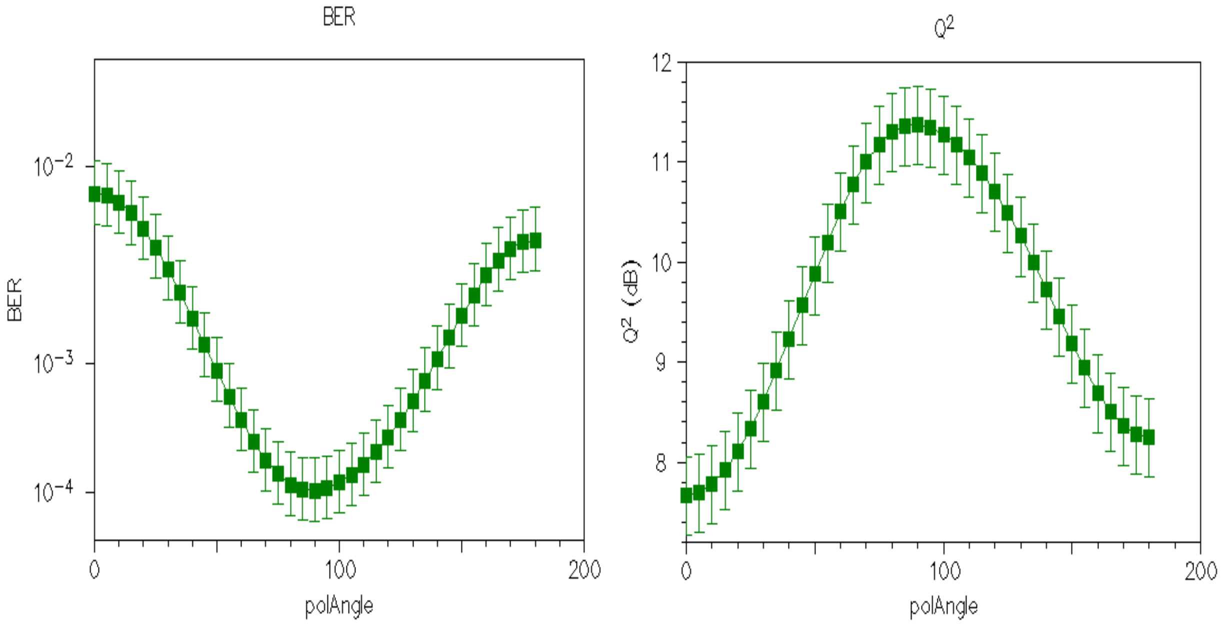


Fig 3.8: BER and Q-factor versus polarization angle for even channel (channel 2)

In Polarisation State for Fiber Length of 85 km, the polarization angle is scanned from 0 to 180 degrees with 5 degrees step and Q-factor is measured versus polarization angle. Figure 3.8 shows results for one odd (channel-1) and Figure 3.9 one even channel (channel-2).The eye opening is more in case of odd channels at zero polarization angle. It is observed that as the length of the fiber increases, the BER will increase and the Q-factor will decrease at zero polarization angle.

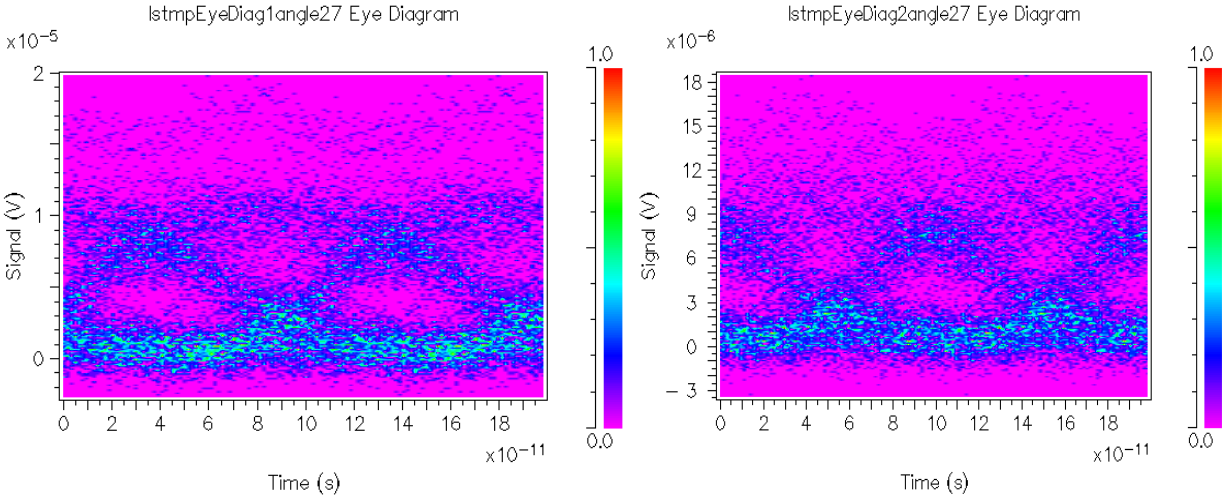


Fig 3.9: Eye diagrams of odd and even channels

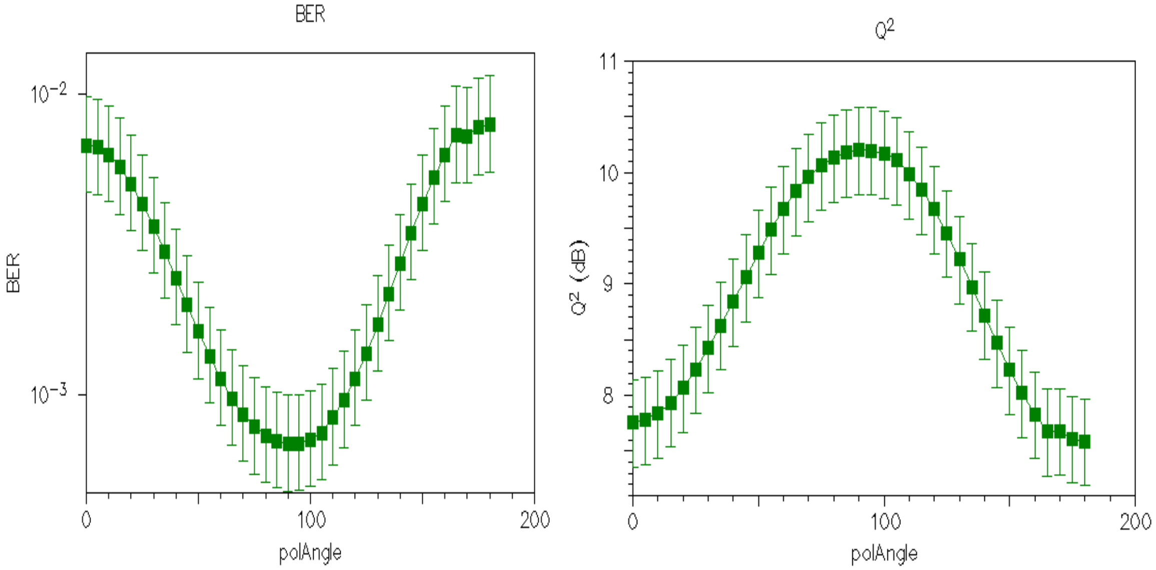


Fig 3.10: BER and Q-factor versus polarization angle for Odd channel (chanel-1)

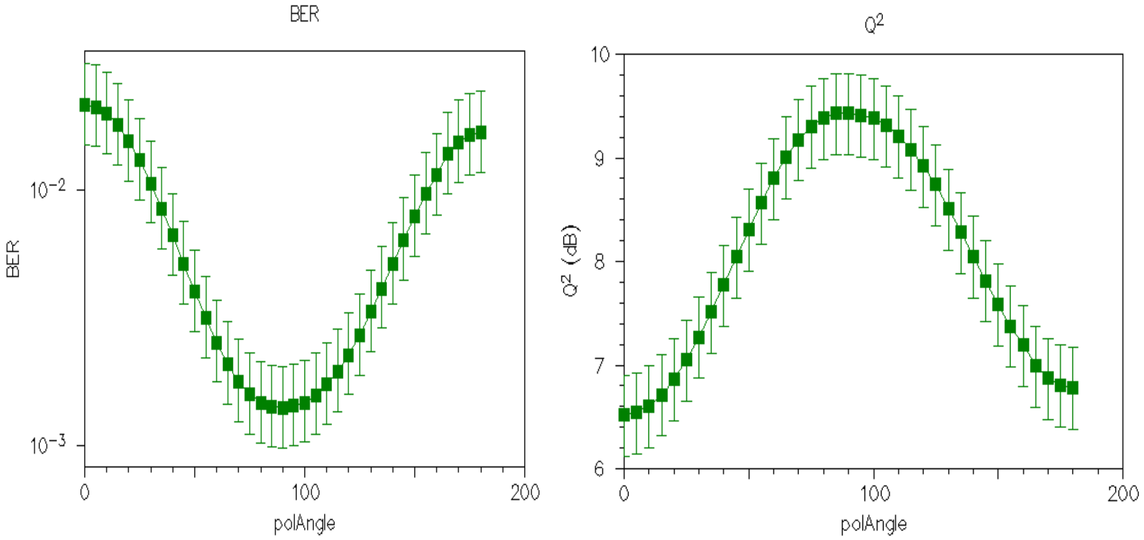


Fig 3.11: BER and Q-factor versus polarization angle for even channel (channel-2)

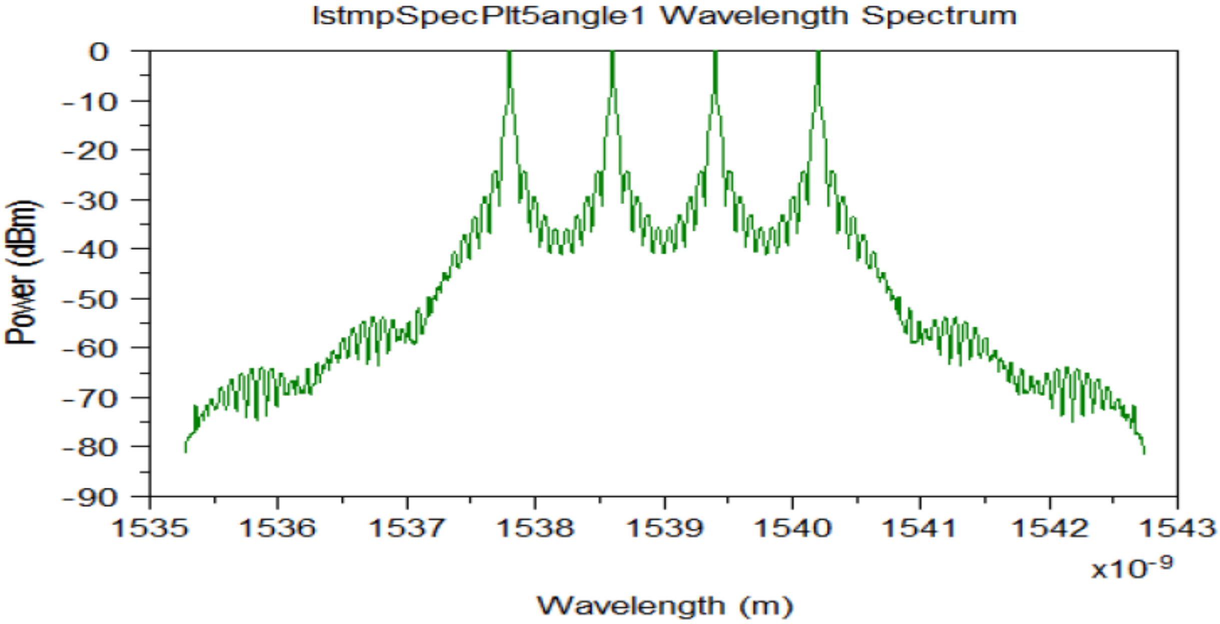


Fig 3.12: Wavelength spectrum after polarization transformer for odd channel

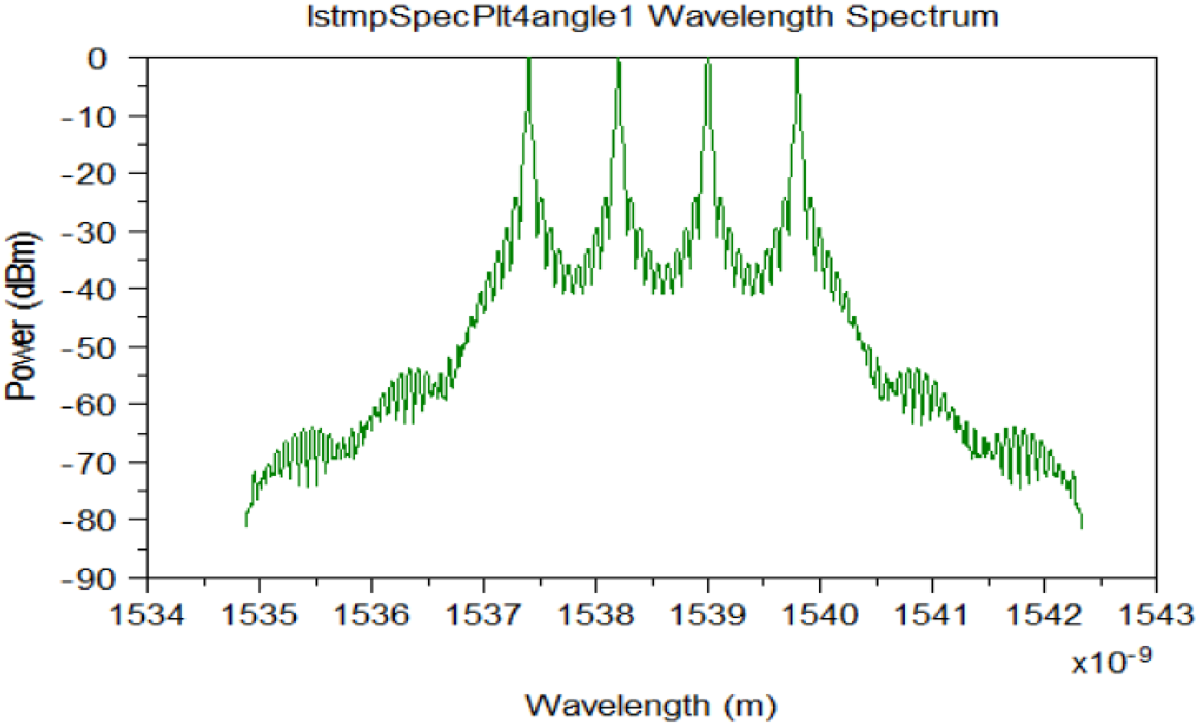


Fig 3.13: Wavelength spectrum for even channel

3.5 CONCLUSION

In this chapter, the design, implementation and performance analysis of polarization effect in WDM system for different values of fiber length and polarization angle is presented. The comparison of polarization effect at various values of fiber length and polarization revealed that as we increase the length of the filter, the bit error rate will increase and eye opening will also decrease and the Q-Factor will be reduced. In both even and odd channels, the Q-factor is minimal for polarization angles equal to 0 or 180 degrees, i.e. when all channels have parallel polarization states; and Q has maximum at 90 degrees, i.e. when adjacent channels polarization state is orthogonal to each other. The BER has minimum value at 90 degree, i.e. when adjacent channels polarization state is orthogonal to each other. It is also observed the spectrums of even and odd channels.

CHAPTER 4

DESIGN AND PERFORMANCE ANALYSIS OF PRE-COMPENSATING TECHNIQUE WITH DIFFERENT MODULATOR DRIVERS AND FIBER LENGTHS.

In this chapter, the design, implementation and performance analysis of pre-compensation technique in WDM system on changing the modulator drivers in the circuit is presented. Components involve with different modulator drivers like NRZ and RZ raised cosine, NRZ and RZ rectangular, Manchester and rectangular, Manchester and raised cosine. The investigations on pre-compensation technique has been carried out for 8 channels having bit rate of 10 Gbps and the performance has been evaluated in terms of eye diagrams, dispersion map and optical power map for different values of DCF and SMF length. The simulation results revealed that eye opening is maximum when NRZ rectangular modulator driver is used and is minimum when RZ Manchester modulation driver is used. The comparison of pre-compensation technique with uncompensated fiber is also investigated.

4.1 INTRODUCTION

The transmission of optical signals in an optical communication system may be limited by optical effects such as dispersion. The spreading of the optical pulse as it travels along the fiber limits the information capacity of the fiber. When light propagating within an optical fiber undergoes chromatic dispersion, the light is delayed within the optical fiber. The delay causes spreading of the light pulses, which may affect the performance of the system. Dispersion is the phenomenon in which the phase velocity of a wave depends on its frequency [32] or alternatively when the group velocity depends on the frequency. Media having such a property are termed dispersive media. The extent to which dispersion varies as a function of light wavelength is often referred to as dispersion slope. Various dispersion management techniques have been used to reduce dispersion and to manage dispersion slope by reducing dispersion at individual channel wavelengths. To combat dispersion and nonlinearities, each WDM channel can separately be either pre-compensated, post-compensated or dual-compensated (using a combination of pre- and post-compensation) in total accumulated dispersion [33].

Dispersion management is particularly important in wavelength division multiplexed (WDM) optical communication systems transmitting multiple channels at multiple wavelengths. Different technologies exist for compensating the chromatic dispersion. Each of them contains inherent trade-offs that render it more suitable for an application and less for another one. The main technologies are dispersion compensating fiber, fiber Bragg gratings, etalon filter and virtually imaged phased array. Furthermore, not truly dispersion compensation devices, electronic dispersion compensation and advanced modulation formats are attractive due to the high dispersion tolerance they provide [34].

Dispersion compensating fiber (DCF) is the predominant technology for dispersion compensation. It consists of an optical fiber that has a special design such as providing a large negative dispersion coefficient while the dispersion of the transport fiber is positive. A proper length of DCF allows the compensation of the chromatic dispersion accumulated over a given length of the transport fiber, although standard modules with predetermined dispersion values (with a typical granularity corresponding to the dispersion of 20 km of SSMF) are commercially available. The main advantage of this technology is the fact that it provides a broadband operation with a smooth dispersion property and good optical characteristics. In the first generation of DCF, only about 60% of the SSMF dispersion slope was allowed to be compensated. Now, 100% slope matching for both SSMF and E-LEAF is commercially available. However, dispersion compensation modules based on a first-generation DCF are largely deployed and their associated slope-mismatch is a problem we have to live with. DCF also presents a quite large insertion loss although improvements have been reported recently.

The fiber based method employs the dispersion compensation through a small section of fiber length. There are various techniques such as dispersion compensation fiber (DCF), reverse dispersion fiber, negative dispersion fiber to compensate the dispersion of the system.

DCF consists of an optical fiber that has a special design such as providing a large negative dispersion coefficient while the dispersion of the transport fiber is positive. A proper length of DCF allows the compensation of the chromatic dispersion accumulated over a given length of the transport fiber. The main advantage of this technology is the fact that it provides a broadband operation with a smooth dispersion property and good optical characteristics. DCF also presents a quite large insertion loss although improvements have been reported recently. Dispersion compensation modules based on DCF are also bulky and again, size reduction is expected in the future as bend loss reduction could allow a significant improvement in the compactness [35].

R.S. Kaler et. al.[10] described the various dispersion compensation techniques on the basis of eye opening, eye closure, bit error rate and Q-factor. The techniques have been applied to CSRZ system, which operates at bit rates of 2.5, 5, 10, 15 and 20 Gbps bit rates. They revealed that the technique using fiber Bragg grating (FBG) for dispersion compensation is the best technique as this technique gives larger values of eye opening, smaller values of eye closure, minimum value of BER and maximum value of Q-factor when compared with other techniques and the DCF is the next best technique as this technique gives maximum and minimum values of eye opening and eye closure at 20 Gbps (next best to FBG at 20 Gbps).

The transmission performance is dependent on the position of the DCF and the zero residual dispersion is not the best choice. In the case of full compensation, the dependence on the DCF position shows the pre compensation technique achieves the best results. Pre or post compensation when the DCF is located before or after the transmission fiber. Although the total dispersion over the entire SMF-DCF span can be minimal, net dispersion at any point along the span is non-zero, which keeps the nonlinear mixing effects at minimum levels.

Common for all dispersion compensation schemes enabling the full dispersion compensation is that the compensation of the accumulated dispersion in the transmission fiber has to be performed according to the following rule:

$$D_{DCF} .L_{SMF} + D_{DCF} .L_{DCF} =0 \tag{1}$$

Where D_{SMF} and D_{DCF} are the chromatic dispersion values of transmission and compensating fibers, respectively and L_{SMF} ,L_{DCF} the lengths of these fibers.

R.S. Kaler et. al.[13] described the simulative analysis of 40Gb/s long haul DWDM system with ultra high capacity upto 1.28 Tb/s for carrier-suppressed return-to-zero(CSRZ), duo binary return-to-zero(DRZ) and modified duo binary return-to-zero(MDRZ) modulation formats and analyzed DWDM system for the pre, post and symmetrical dispersion compensation schemes for 16 Channels with 25GHz channel spacing in order to find the optimum modulation format for a high bit rate optical transmission system. They reported that the symmetrical compensation is superior to pre and post dispersion compensation schemes. Symmetrical compensation scheme has been investigated for 32*40 Gbps MDRZ format for faithful transmission over 1450km.

The disadvantages of the fiber-based methods are the extra fiber loss in, high nonlinearity and the additional cost of the DCF. The maximum dispersion of such DCF is about -100 ps/nm/km, which is limited by the mismatching of the glass properties between the core and the cladding. Therefore, the up gradation of already installed systems is difficult with DCFs, as the dispersion in the 1550 nm region is 17 ps/nm/km. Hence very long lengths of dispersion compensating fiber will be required to compensate for the dispersion of even modest lengths of transmission.

4.1.1 DISPERSION MAPPING

The advent of optical repeaters based on erbium doped fiber amplifiers (EDFAs) has opened the new era of optical transmission technologies, allowing us to use wavelength division multiplexing (WDM) technologies with simple, compact and economical approaches [36]. In fact, the demonstrated capacity for long-haul optical transmission has been growing remarkably and more than a thousand fold increase in capacity has been achieved over the past ten years. The price we have to pay for such success is the combat with the accumulated impact of fiber nonlinearity, interplaying with the chromatic dispersion of the transmission fiber, which grows with transmission distance and, therefore, becomes significant for ultra-long-haul systems. Dispersion management technologies have been invented to overcome such inherent problems in optically amplified transmission systems [37].

The transmission of optical signals in an optical communication system may be limited by optical effects such as chromatic dispersion. Optical signals may be transmitted as pulses of light in an optical fiber. When light propagating within an optical fiber undergoes chromatic dispersion, the light is delayed within the optical fiber. The delay causes spreading of the light pulses, which may affect the performance of the system. The specific amount of dispersion that an optical signal undergoes varies depending upon the wavelength of the optical signal. The extent to which dispersion varies as a function of light wavelength is often referred to as dispersion slope. Various dispersion management techniques have been used to reduce dispersion and to manage dispersion slope by reducing dispersion at individual channel wavelengths. Dispersion management is particularly important in wavelength division multiplexed (WDM) optical communication systems transmitting multiple channels at multiple wavelengths.

Up till now, various methods to reduce dispersion effect have been proposed and theoretically compared. The performance of pre-compensation technique with 4 channels and dispersion map, eye diagram and power map have been shown [38]. According to literature survey, pre-compensation technique has been evaluated with 4 channels but no evaluation has been done for 8 channels. In this paper, the pre-compensation technique has been evaluated for different values of fiber length and comparison of modulator drivers. It is also reported the comparison of pre-compensation in wdm with without compensation in wdm.

This chapter is divided into different sections. In the first section, the introduction of pre compensation Technique is presented. In the second section, the schematic model is proposed. The third section describes the simulation setup for an WDM system implementing these requirements. In the fourth section, the comparison of performance of modulator drivers in transmitter and comparison is done for different values of DCF and SMF length in terms of eye diagrams. The fifth section gives the conclusion of this paper.

4.2 SCHEMATIC MODEL

The schematic model for WDM implementing the pre-compensation technique for various driver modulators between different users is presented in figure 1. N input channels/users are taken in this case for reference. The number of users can vary depending on various constraints like the bandwidth range.

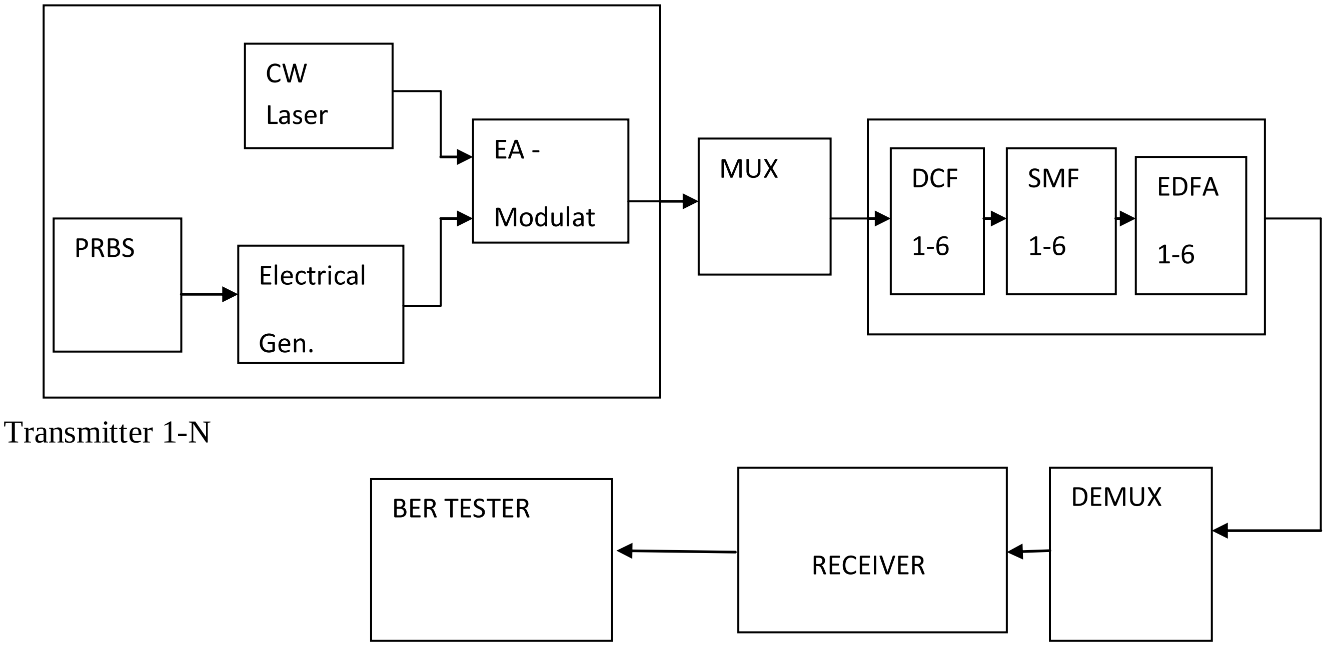


Figure 4.1 Schematic model

The transmitter section consists of a laser, modulator driver, p-n-sequence generator i.e. data source and modulator. The wavelength of various channels is set by keeping the difference equal to the spacing required. Then all these transmitted signals are multiplexed together. After that DCF(dispersion compensating fiber) is attached to reduce the dispersion effects and then send to non linear fiber. Then the signal is amplified so that it can be transmitted over long distances without its degradation. This section is repeated 6 times. At the receiver side, the signal is demultiplexed and analyzed with the help of eye diagram analyzer.

4.3 SIMULATION SETUP FOR PRE-COMPENSATION IN WDM

The simulation setup for showing the pre-compensation technique by changing the fiber length on WDM is shown in figure 4.2. The continuous wave laser is used to create the carrier signal. In this setup, eight users are taken in account whose wavelengths have a specific difference i.e. spacing between them. The frequency of first user is kept at 1525nm. The data source is used to generate the random input data bit sequence at the rate of 10 Gbps. The light signal modulates the input data. The modulator is driven by the modulator driver which decides the input data format. The input data format used is changed here and reported the best. The modulated data is combined using a multiplexer. After that DCF, SMF and EDFA combination is repeated 6 times. Dispersion compensating fiber is used to reduce the dispersion effect from single mode fiber. At the receiver, the signal is demultiplexed and sent to 8 receivers followed by eye diagram analyzer to measure channel performance for changing lengths of DCF and SMF. Property mapper is also attached to take dispersion map and optical power map.

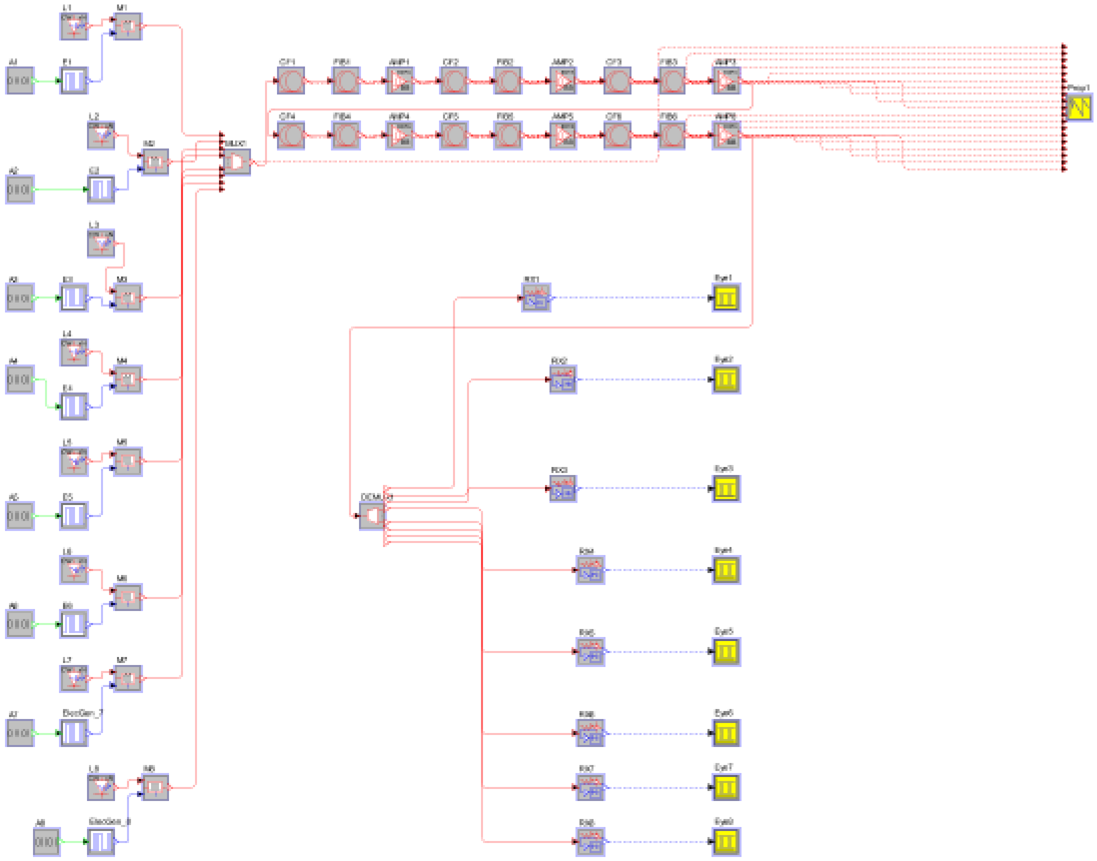
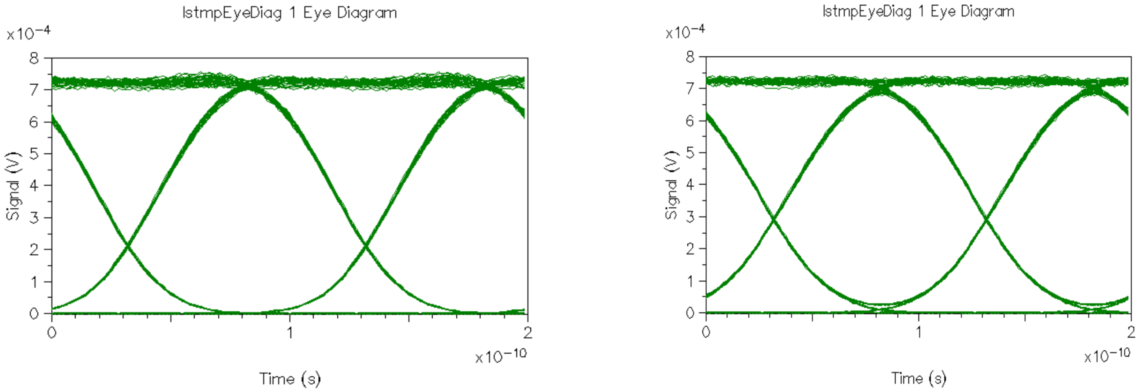


Fig 4.2: Simulation setup for pre-compensation technique in wdm.

4.4 RESULTS AND DISCUSSIONS

We have observed the eye diagrams for the different driver modulators. The eye diagrams for this circuit is given below and compares the eye diagrams for the best results. The rectangular

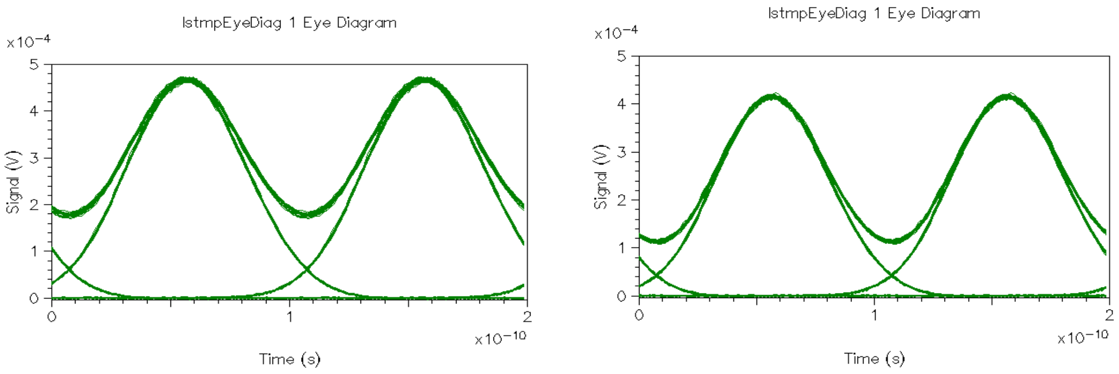
NRZ driver modulator is best as eye opening is maximum in this case. The eye opening in rectangular NRZ modulation is more than raised cosine NRZ modulation.



(a) (b)

Fig 4.3(a) Rectangular NRZ modulation (b) Raised Cosine NRZ modulation

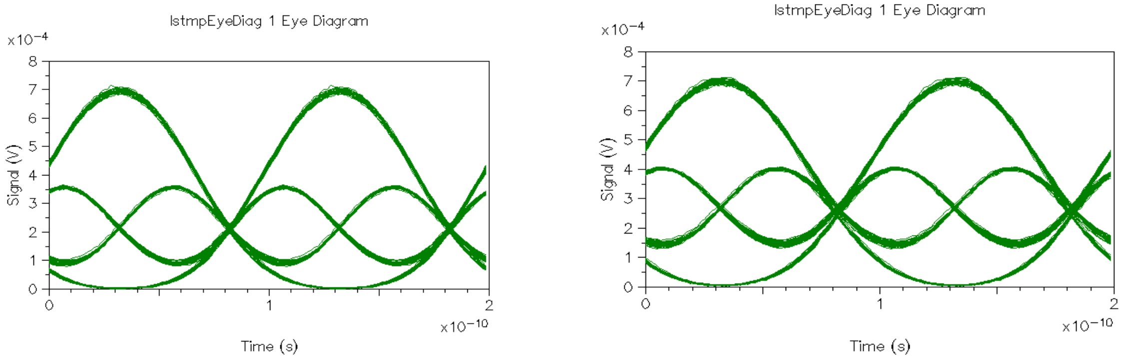
Fig 4.4 reveals that the eye opening in rectangular NRZ modulation is more than raised cosine NRZ modulation.



(a) (b)

Fig 4.4(a) Rectangular RZ modulation (b) Raised cosine RZ modulation

Fig 4.4 reveals that the eye opening in rectangular RZ modulation is more than raised cosine RZ modulation.



(a) (b)

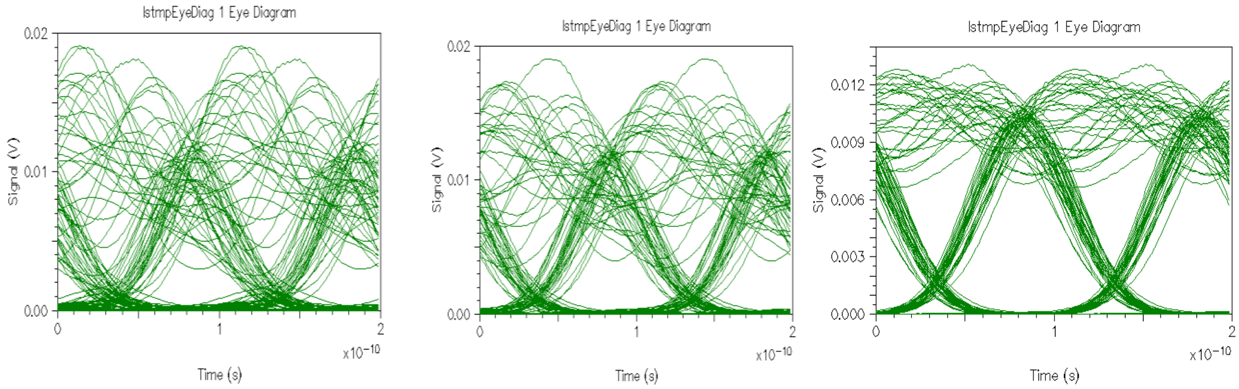
Fig 4.5 (a) Rectangular with Manchester modulation (b)Raised cosine with Manchester modulation

The above eye diagrams show that the eye opening in Manchester rectangular modulation is more than raised cosine Manchester modulation.

Taking all these eye diagrams in account, it can be concluded that the rectangular NRZ modulation gives the best results as the eye opening is maximum in the case of rectangular NRZ modulation.

The results of eye diagrams are shown in figures for different length. Eye opening decreases and eye closure increases with increase the length of SMF i.e. eye opening penalty increases as the length of single mode fiber increases. We have observed the comparison of the length of SMF and DCF. The best result is for 20km for DCF and 80 km for the SMF.

In fig 4.6, We have taken the length of DCF 10 km and we have varied the length of SMF from 40 to 80 km and observed the eye diagrams.

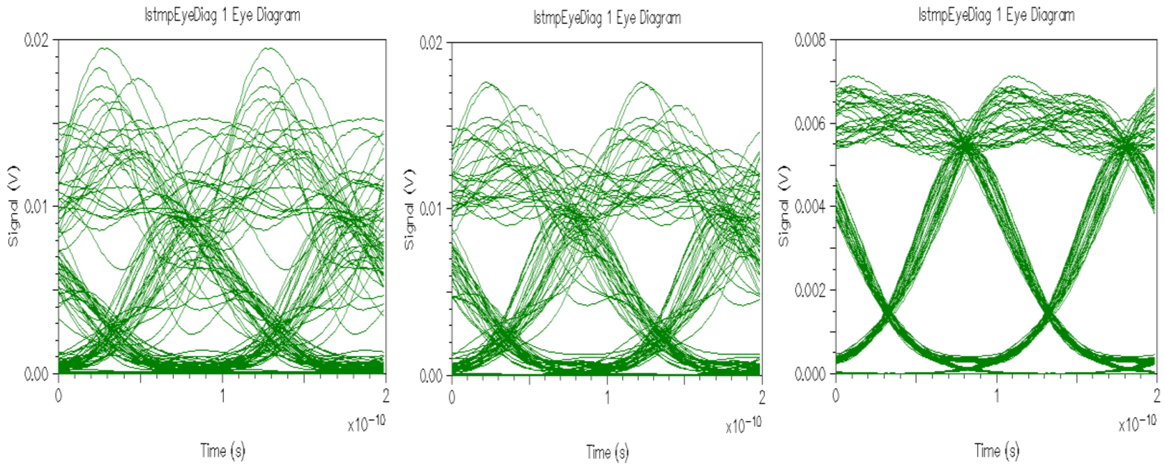


(a) (b) (c)

Fig 4.6 (a) DCF length of 10 km and SMF of 40 km (b) DCF length of 10 km and SMF of 60 km (c) DCF length of 10 km and SMF of 80 km

Fig 4.6 shows that as the length increase, the eye opening increases. The eye opening is maximum for fiber length of 80 km. this is because dispersion compensating fiber is based on negative dispersion coefficient. Thus, the dispersion decreases and the eye opening increases on increasing the fiber length.

In fig 4.7, We have taken the length of DCF 15 km and we have varied the length of SMF from 40 to 80 km and observed the eye diagrams.

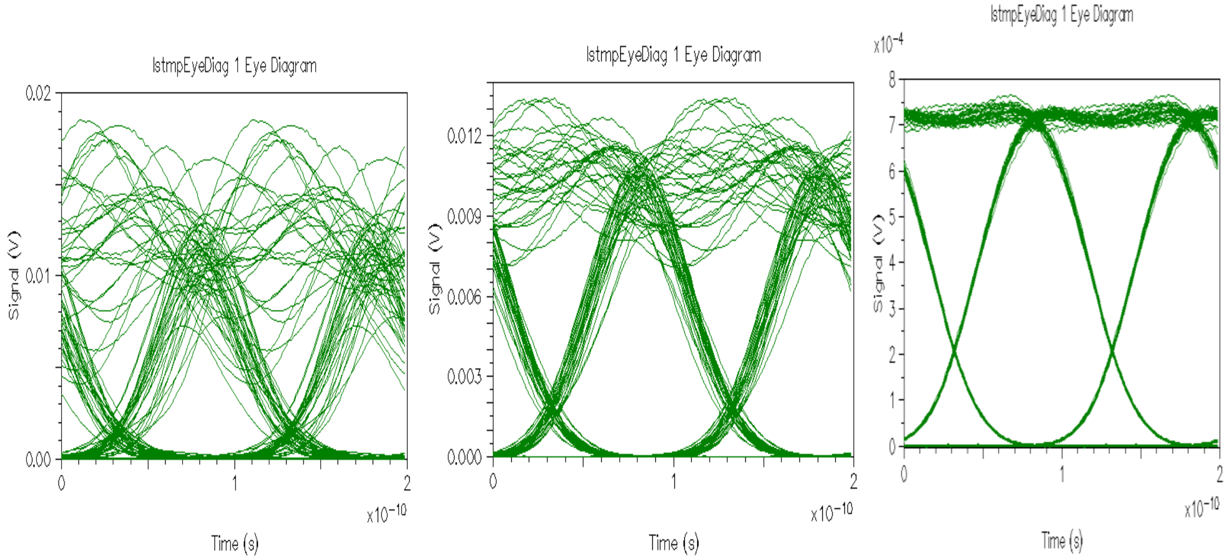


(a) (b) (c)

Fig 4.7 (a) DCF length of 15 km and SMF of 40 km (b) DCF length of 15 km and SMF of 60 km (c) DCF length of 15 km and SMF of 80 km

Fig 4.7 shows that as the length increase, the eye opening increases. The eye opening is maximum for fiber length of 80 km. This is because dispersion compensating fiber is based on negative dispersion coefficient. Thus, the dispersion decreases and the eye opening increases on increasing the fiber length.

In fig 4.8, We have taken the length of DCF 20 km and we have varied the length of SMF from 40 to 80 km and observed the eye diagrams.



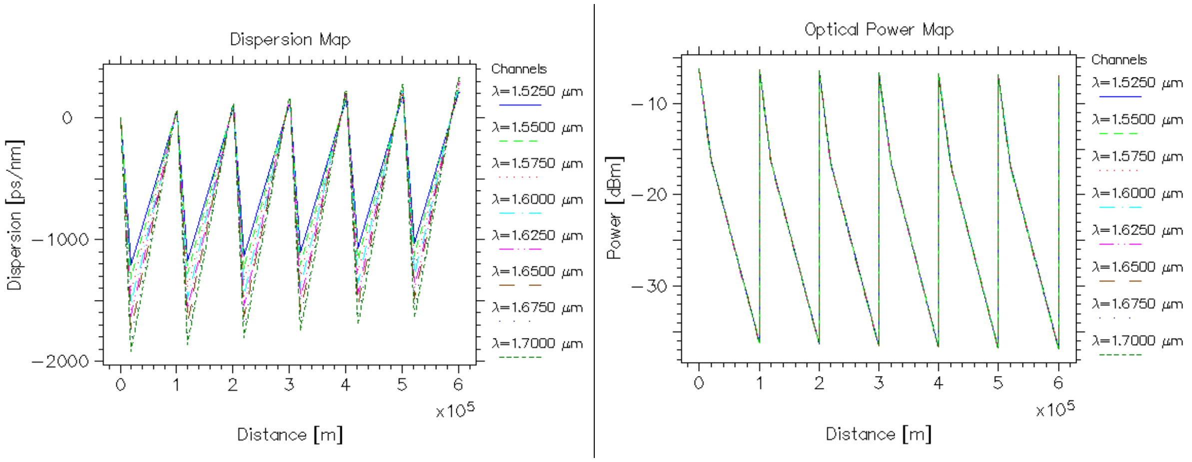
(a) (b) (c)

Fig 4.8(a) DCF length of 20 km and SMF of 40 km (b) DCF length of 20 km and SMF of 60 km (c) DCF length of 20 km and SMF of 80 km

Fig 4.8 shows that as the length increase, the eye opening increases. The eye opening is maximum for fiber length of 80 km. this is because dispersion compensating fiber is based on negative dispersion coefficient. Thus, the dispersion decreases and the eye opening increases on increasing the fiber length.

From the above eye diagrams, it can be observed that the DCF of length 20km and SMF of length 80 km give the best results amongst all other fibers.

The dispersion map and optical power map are shown in fig 4.9 and We have observed the improvement due to pre-compensation. The power map shows that the power falls more rapidly in the DCF section than in the SMF section because of the larger attenuation typically associated with the DCF.



(a) (b)

Fig 4.9(a) Dispersion map (b) Optical Power Map

Figure 4.10 and 4.11 shows performance for an uncompensated (*i.e.*, SMF span = 100km, and DCF span = 0km) link. The power map rises with the link length because the amplifier over-compensates for the attenuation at each span. Since there is no dispersion scheme employed, the accumulated dispersion for each wavelength produces a closed eye at the receiver even if the link is not power-limited.

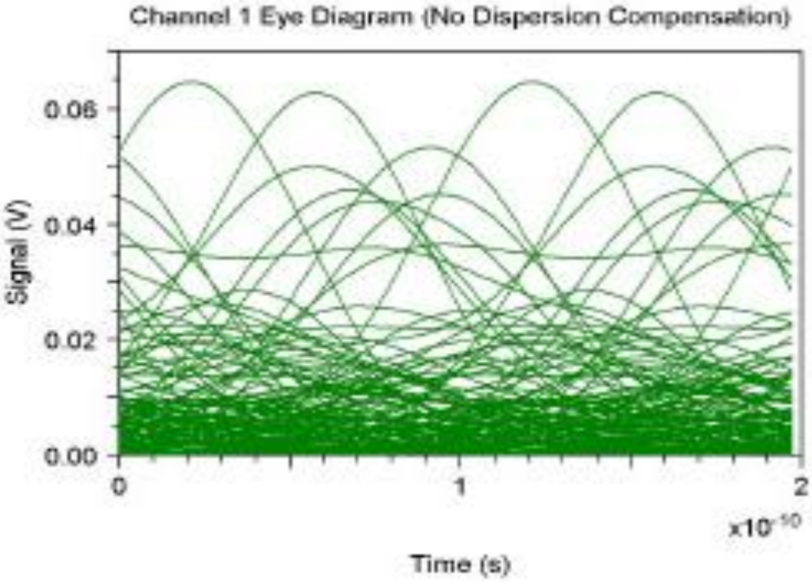
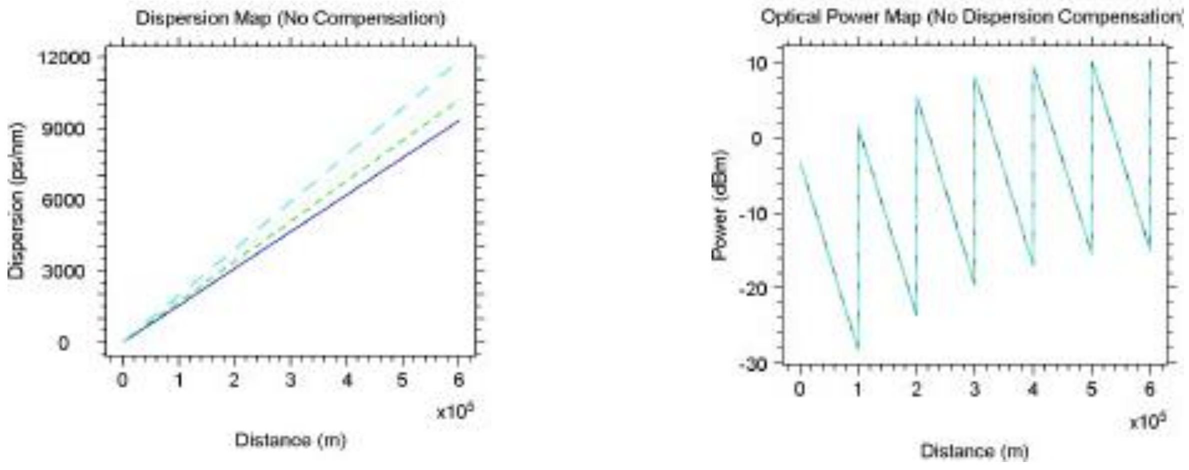


Fig 4.10: Eye Diagram with no dispersion compensation



(a) (b)

Fig 4.11: Dispersion map and optical power map of uncompensated fiber

4.5 CONCLUSION:

In this chapter, the design, implementation and performance analysis of pre-compensation technique in WDM system on changing the different transmitter components in the circuit is presented. Components involve different modulator drivers like NRZ and RZ raised cosine, NRZ and RZ rectangular, Manchester and rectangular, Manchester and raised cosine. The investigations on pre-compensation technique has been carried out for 8 channels having bit rate of 10 Gbps and the performance has been evaluated in terms of eye diagrams, dispersion map and optical power map for different values of DCF and SMF length. The simulation results revealed that eye opening is maximum when NRZ rectangular modulator driver is used and is minimum when RZ Manchester modulation driver is used. Also, it has been observed that pre-compensated fiber gives better results than the uncompensated fiber. Moreover, the DCF of length 20km and SMF of length 80 km give the best results amongst all other fibers.

CHAPTER 5

INVESTIGATION OF PERFORMANCE OF DWDM AT DIFFERENT FIBER LENGTH AND CHANNEL SPACING

In this chapter, the investigations on DWDM has been carried out for 96 channels by varying channel spacing and the performance has been evaluated in terms of output spectrums, eye diagrams, BER, eye opening, graphs and Q-factor for different values of fiber length. The simulation results reveal that Q-factor decreases and BER will increase on increasing the fiber length. It has been investigated that eye opening decreases on increasing the fiber length and the eye opening decreases on decrease in channel spacing.

5.1 INTRODUCTION:

Owing to the rapidly growing capacity requirements for long distance transmission, fiber optic telecommunications are advancing into high data rate and dense channel schemes enabled by wavelength division multiplexing (WDM). In order to maximize the system capacity and to minimize the performance degradation caused by transmission impairments the system investigation and optimization are very important [39]. DWDM technology is known as a kind of technology coupling and transmitting optical signals of different frequency (wavelength) to an optical fiber by using the tremendous bandwidth of SMF’s low-loss area in DWDM system, which is not only conducive to the realization of switching and recovery in optical networks but also convenient to the expansion and upgrade, and thus the further realization of transparent and high survivability optical networks [40].

DWDM technology is now in a mature development period. With the development of the society, the requirement of people to communication quality and speed is higher and higher. How to use the optical bandwidth huge resources and to upgrade the capacity of fiber-optic communications systems is an important theoretical and technical subject [40].Simulation software takes all kinds of parameters into account for DWDM system, through which the measurement results of various instruments can be get, and it can simplify design process and save a lot of time and funding for theoretical research.

To maximize the WDM network capacity, the system's design and optimization have to take into account all the contributing factors - such as the channel data rate, transmission distance, signal optical power, fiber linear and nonlinear effects and of course the channel interval. In a HDWDM system the latter factor the most important for high quality solution [41].

An optical communication system consists of transmitter, communication channel and receiver. Optical transmitter is the core equipment of fiber optic transmission system [42], and consists of optical source, electrical pulse generator and optical modulator. DWDM system requires very high accuracy and stability of wavelength, and high performance requirements in dispersion.

Designing a channel, an EDFA was added after a period of 50 meters SMF to compensate for the linear loss. The most fundamental reason that restrict the transmission of high-speed signals on the 1550nm optical fiber is the linear dispersion[43], the dispersion of SMF in the 1550nm window is 17ps/(nm·km), therefore the DFC should be used for compensating their dispersion performance.

At the receiving end these different wavelengths of light signals carrying different carrier is separated by the wave of sub-use device. As different wavelengths of light carrier signal can be seen as independent of each other (without regard to fiber nonlinear time), optical fiber can be achieved in multichannel optical signal the use of transmission [44]. The use of different sub multiplexer can be used several different wavelengths, from two to several hundred range.

Optical receiver is composed of the photoelectric detectors and filters and demodulator. Its performance impacts on the optical fiber communication system transmission (relay) distance, which is one of the most important part of the entire fiber-optic communication systems and its design to a large extent depends on the transmitter used modulation[43, 44].

Kaler et. al. [14] numerically simulated the ten channels at 10 Gb/s DWDM transmission faithfully over 17,227 km using 70km span of SMF and DCF using optimum span scheme at channel spacing 20 GHz. For this purpose, they have used inline optimized semiconductor optical amplifiers (SOA's) and differential phase shift keying (DPSK) format.

Up till now, various methods to reduce channel spacing have been proposed and theoretically compared. The performance of DWDM with 16 channels using Mach-zender modulator and eye diagrams has been shown [45]. According to literature survey, DWDM has been evaluated with 64 channels and on the basis of this work; it has been done for 96 channels. In this paper, the DWDM has been evaluated for different values of fiber length and channel spacing. It is also reported the BER and Q-factor by varying fiber length.

This chapter is divided into different sections. In the first section, the introduction of DWDM is presented. The second section describes the simulation setup for a DWDM system implementing these requirements. In the third section, the comparison of performance of DWDM on the basis of different fiber length and channel spacing in terms of eye diagrams and graphs. The forth section gives the conclusion of this chapter.

5.2 SIMULATION SETUP

The simulation setup for showing system performance by changing the fiber length and channel spacing on WDM is shown in figure 1. The continuous wave laser is used to create the carrier signal. In this setup, 96 users are taken in account whose wavelengths have a specific difference i.e. spacing between them. The wavelengths of next users are changing on the basis of channel spacing. The data source is used to generate the random input data bit sequence at the rate of 10 Gbps. The light signal modulates the input data. The modulator is driven by the modulator driver which decides the input data format. The input data format used here is NRZ Rectangular. The modulated data is combined using a combiner. After that it is amplified by booster and sent over different fiber lengths. After that it is further amplified and sent to the fiber of varying length. At the receiver, the signal is demultiplexed by using a splitter which splits this signal into the same number of signals as were transmitted. The photodiode is used for optical to electrical conversion. Then the signal is passed through the Bessel filter which is made to work as low pass filters and the final output signal is received. An optical scope is attached at the output of combiner to examine the input signal.

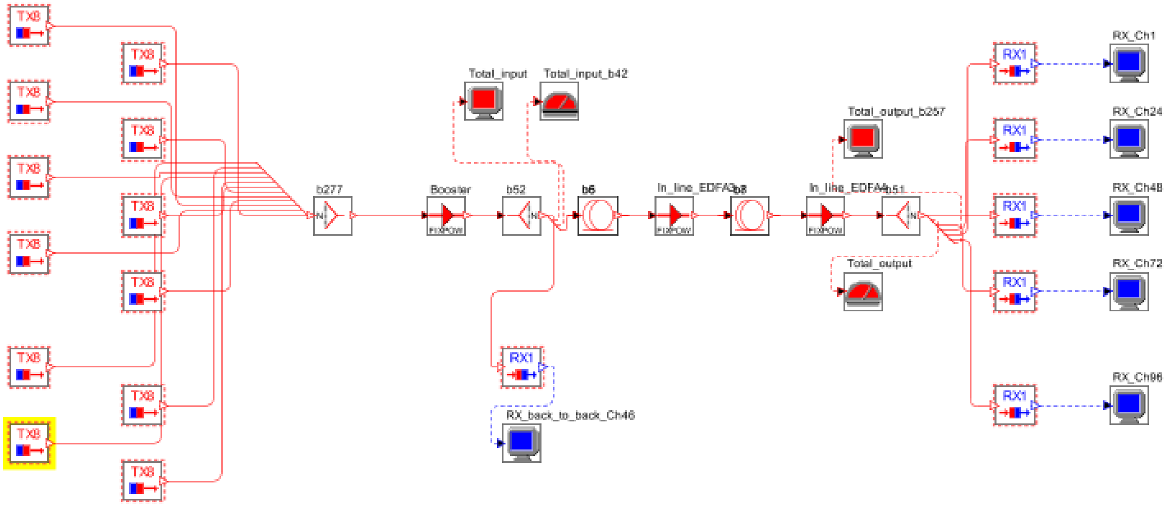


Fig 5.1: 96 channel WDM System

Here Tx8 and Rx8 is a combination of 8 single channel transmitter and receiver respectively and is shown in fig 2.

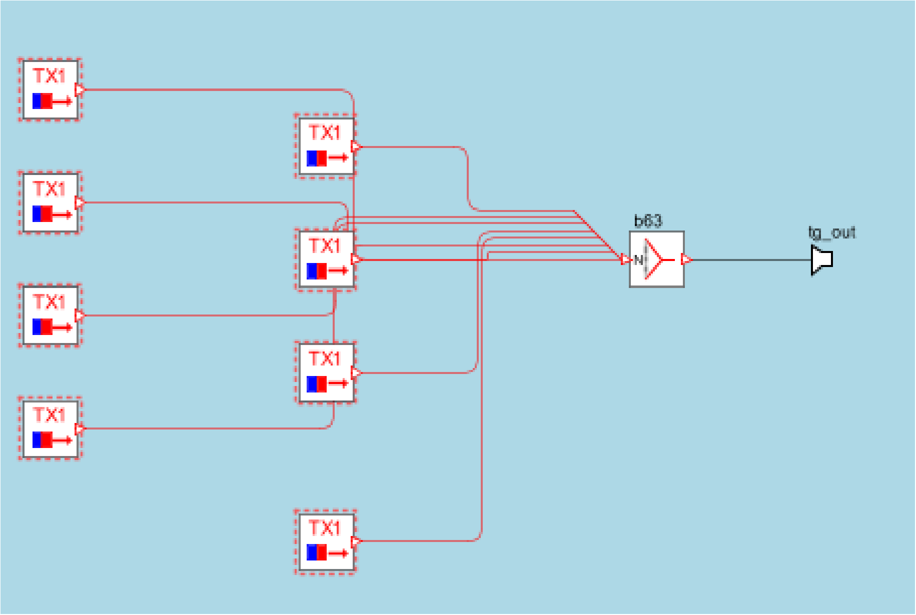


Fig 5.2: Transmitter with 8- channels.

Similarly, the receiver of 8-channels can be sketched. The single channel transmitter and receiver is shown below.

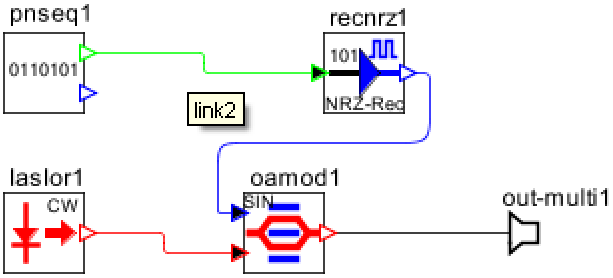


Fig 5.3 optical transmitter with single channel

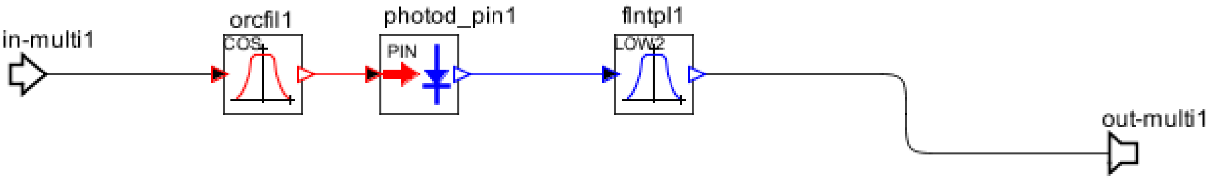
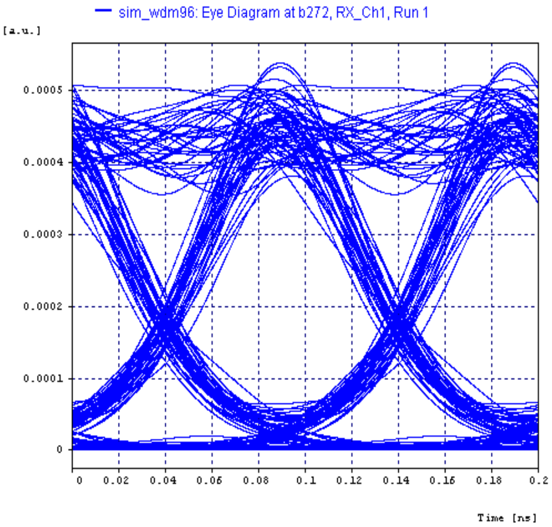


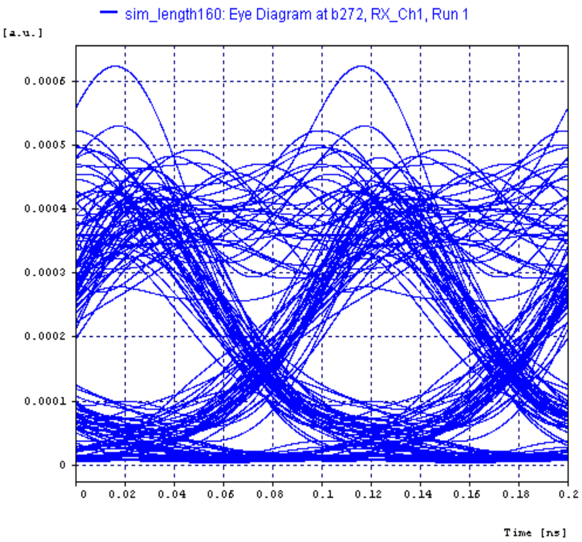
Fig 5.4 Optical receiver with single channel

5.3 RESULTS AND DISCUSSIONS

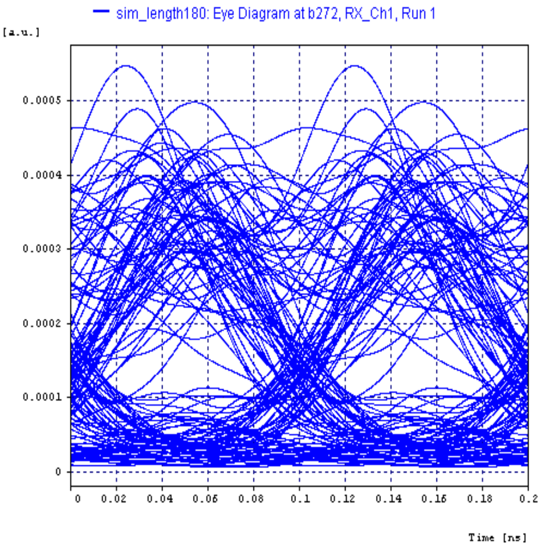
It has been observed the eye diagrams for different length of the fiber and for different channel spacing. As we increase the length of the fiber, eye opening decreases. That means BER will increase and Q factor will be reduced. The eye diagrams are given below.


sim_wdm96: Eye Diagram at b272, RX_Ch1, Run 1
[a.u.]
0.0005
0.0004
0.0003
0.0002
0.0001
0
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time [ns]

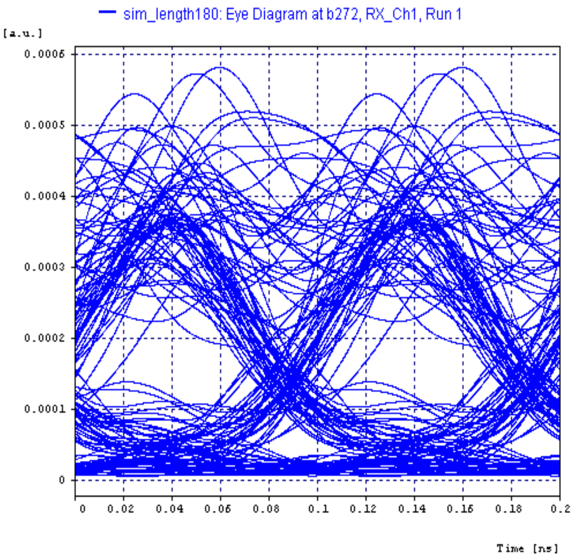
(a)


sim_length160: Eye Diagram at b272, RX_Ch1, Run 1
[a.u.]
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time [ns]

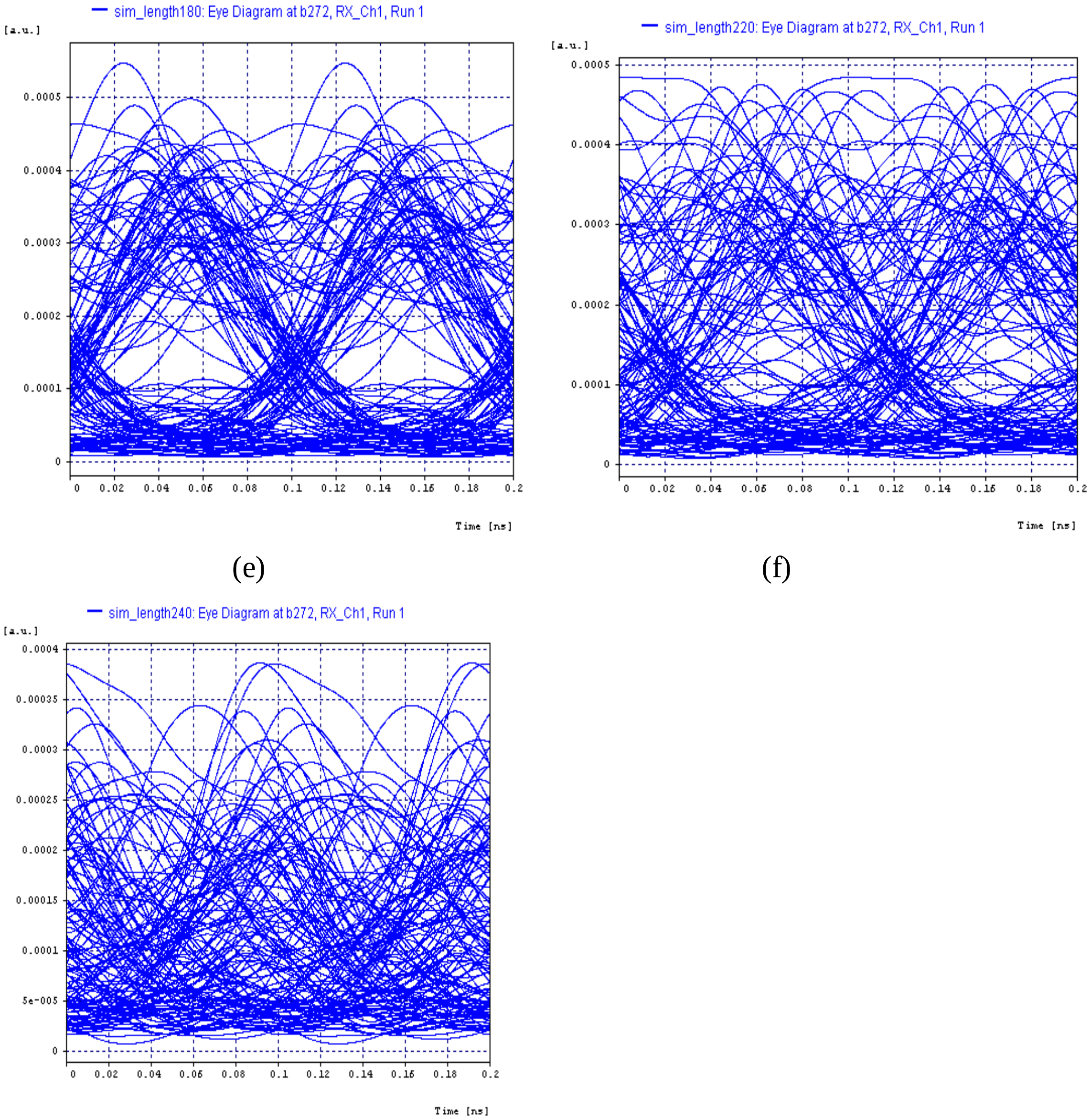
(b)


sim_length180: Eye Diagram at b272, RX_Ch1, Run 1
[a.u.]
0.0005
0.0004
0.0003
0.0002
0.0001
0
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time [ns]

(c)


sim_length180: Eye Diagram at b272, RX_Ch1, Run 1
[a.u.]
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
Time [ns]

(d)

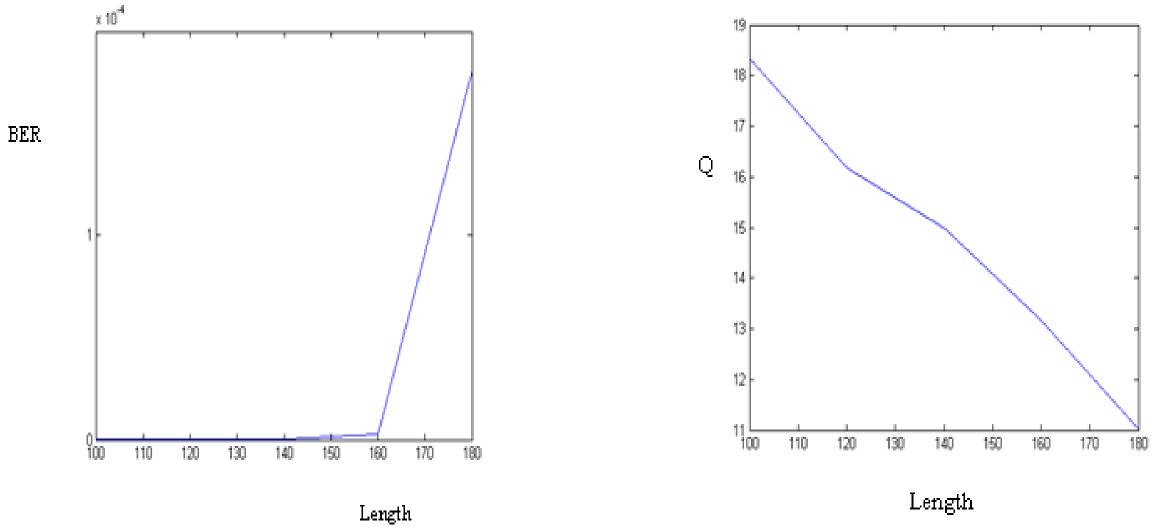


(e) (f)

(g)

Fig 5.5 (a) length of 120 km (b) 140 km (c) 160 km (d) 180 km (e) 200 km (f) 220 km (g) 240 km

The above eye diagrams show the effect of different length of the fiber on the wavelength division multiplexing. Taking all these eye diagrams in account, it can be concluded that the eye opening decreases by increasing the length of the fiber.

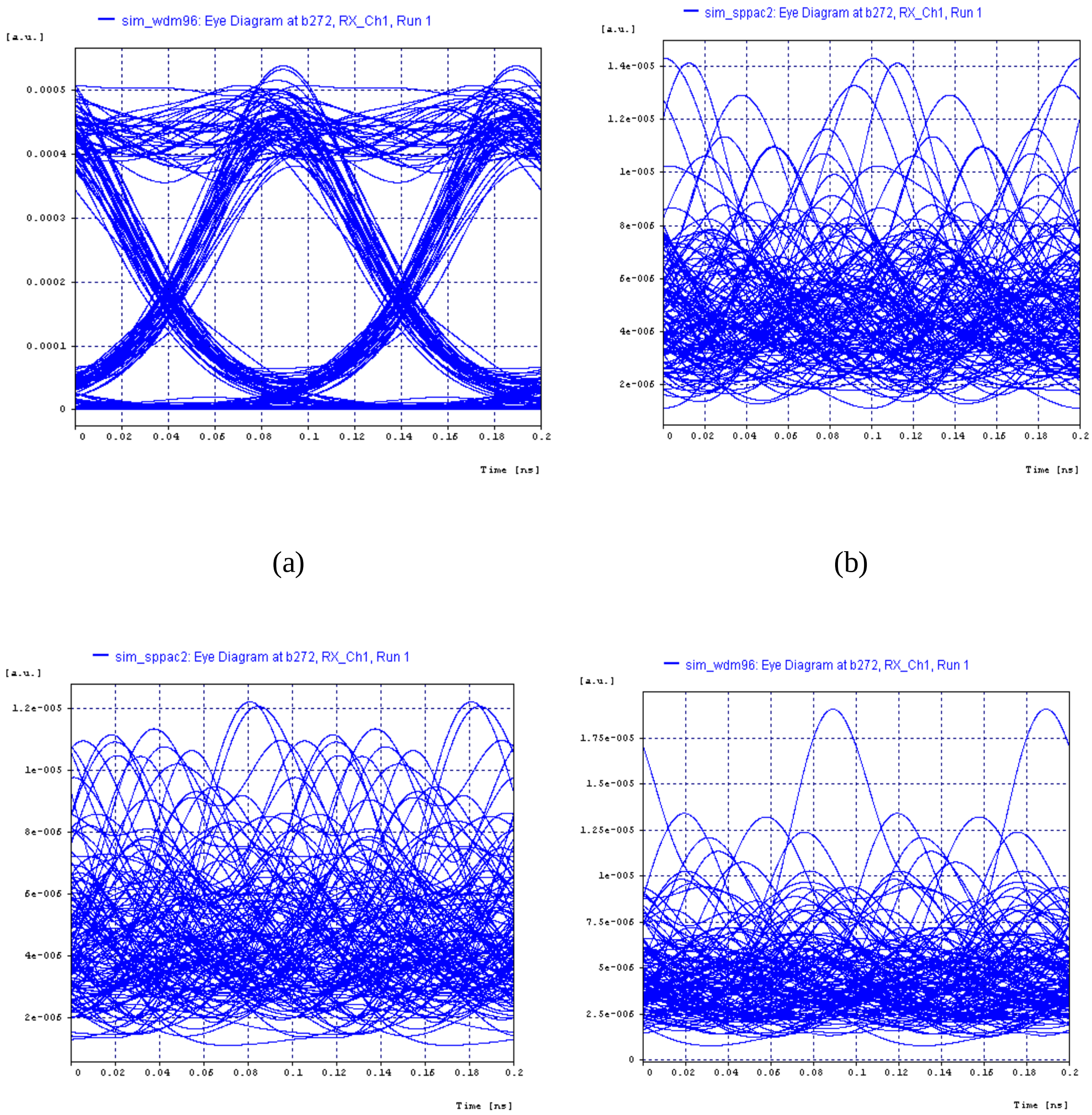


(a) (b)

Fig 5.6(a) BER v/s length (b) Q v/s length

Fig 5.6 shows the effect of increase in fiber length on BER and Q-factor. Taking these graphs in account, it can be concluded that the BER will be increased on increasing the fiber length and Q-factor will be reduced on increasing the fiber length.

It has been observed the eye diagrams for different for different channel spacing. As we decrease the channel spacing, eye opening decreases. It has been investigated that there is no change on BER and Q-factor by varying the channel spacing. The eye diagrams are given below.

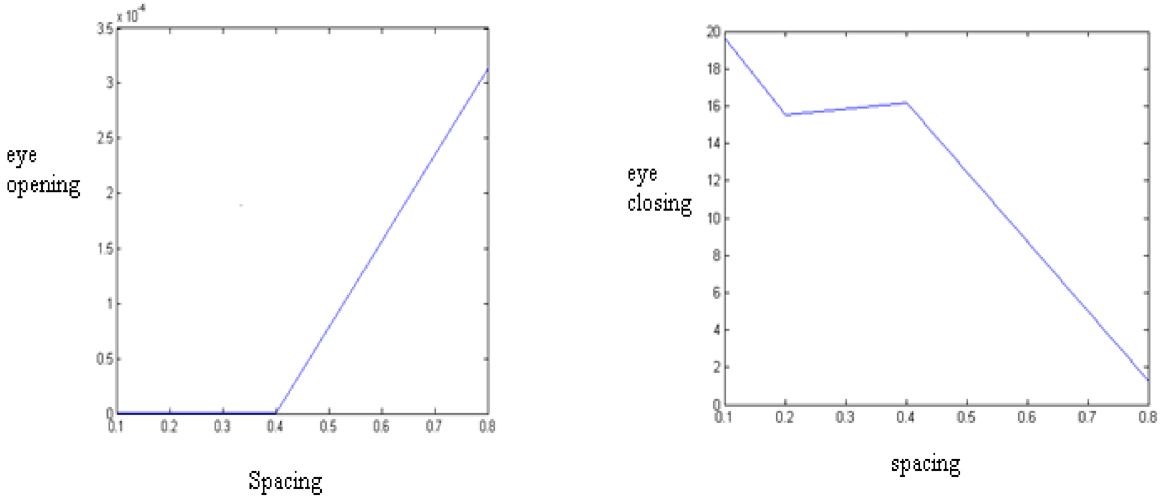


(a) (b)

(c) (d)

Fig 5.7 (a) eye diagram with channel spacing of 0.8nm (b) spacing of 0.4 nm
(c) spacing of 0.2 nm (d) spacing of 0.1 nm

The above eye diagrams show the effect of different length of the fiber on the wavelength division multiplexing. Taking all these eye diagrams in account, it can be concluded that the eye opening decreases by increasing the length of the fiber.



(a) (b)

Fig 5.8 (a) eye opening v/s spacing (b) eye closing v/s spacing

Fig 5.8 shows the effect of decrease in channel spacing on eye opening and closing. Taking these graphs in account, it can be concluded that the eye opening will be increased on increasing the channel spacing and eye closing will be reduced on increasing the channel spacing.

5.4 CONCLUSION:

In this chapter, the design, implementation and performance analysis of DWDM system for different values of fiber length and channel spacing is presented. The comparison of DWDM at various values of channel spacing revealed that 100 GHz spacing has the lowest BER and better system performance. Hence, the higher spacing values between the input channels is recommended for long distance transmission without dispersion. It can be seen from the graphs of BER, Q-factor and eye opening that higher channel spacing gives the best performance as compared to lower channel spacing. The comparison of DWDM at various values of fiber length revealed that as we increase the length of the filter, the bit error rate will increase and the Q-factor will be reduced.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

This chapter provides a summary of finding of the study which have been done so far. Also in this the scope for future research in WDM is given.

6.1 CONCLUSION

The field of optical wave division Multiplexing has experienced explosive growth over the past few years. As the WDM have many advantages over the all multiplexing techniques. This growth has been fuelled mainly by the demands for enormous bandwidth on our networks, namely the Internet, to satisfy the high applications of the network users. WDM has proven to be the current favourite technology for building optical network. The WDM advent of new information technology has created both opportunity and challenges. These opportunities and challenges are both economic and engineering in nature. Internet information travels through optical fibers.

The first objective of this thesis is the design, implementation and performance analysis of polarization effect in WDM system for different values of fiber length and polarization angle. The comparison of polarization effect at various values of fiber length and polarization revealed that as we increase the length of the filter, the bit error rate will increase and eye opening will also decrease and the Q-Factor will be reduced. In both even and odd channels, the Q-factor is minimal for polarization angles equal to 0 or 180 degrees, i.e. when all channels have parallel polarization states; and Q has maximum at 90 degrees, i.e. when adjacent channels polarization state is orthogonal to each other. The BER has minimum value at 90 degree, i.e. when adjacent channels polarization state is orthogonal to each other. It is also observed the spectrums of even and odd channels.

Second objective of thesis is the design, implementation and performance analysis of pre-compensation technique in WDM system on changing the different transmitter components in the circuit. Components involve different modulator drivers like NRZ and RZ raised cosine, NRZ and RZ rectangular, Manchester and rectangular, Manchester and raised cosine. The investigations on pre-compensation technique has been carried out for 8 channels having bit rate of 10 Gbps and the performance has been evaluated in terms of eye diagrams, dispersion map and optical power map for different values of DCF and SMF length. The simulation results revealed that eye opening is maximum when NRZ rectangular modulator driver is used and is minimum when RZ Manchester modulation driver is used. Also, it has been observed that pre-compensated fiber gives better results than the uncompensated fiber. Moreover, the DCF of length 20km and SMF of length 80 km give the best results.

Third objective of thesis is the design, implementation and performance analysis of DWDM system for different values of fiber length and channel spacing. The comparison of DWDM at various values of channel spacing revealed that 100 GHz spacing has the lowest BER and better system performance. Hence, the higher spacing values between the input channels is recommended for long distance transmission without dispersion. It can be seen from the graphs of BER, Q-factor and eye opening that higher channel spacing gives the best performance as compared to lower channel spacing. The comparison of DWDM at various values of fiber length revealed that as we increase the length of the filter, the bit error rate will increase and the Q-Factor will be reduced.

6.2 FUTURE SCOPE

In this thesis, the work is limited to less number of channels and small bit rate. Only experimental work has been done. Analytically it has not been done to calculate the power penalties and bit error rate. Moreover, Channel spacing is the main limiting factor of WDM system. Non linearities increases by decreasing the channel spacing. Further work can be done to reduce channel spacing.

Today, optical fibers are being installed where a single fiber has the ability to carry information as much as 200 times faster than was possible just five years ago. This revolutionary capability is being achieved with technology known as wavelength division multiplexing WDM.A single fiber can carry many separate wavelength signals or channels simultaneously. The communications industry is at the onset of new expansion of WDM technology necessary to meet the new demand for bandwidth.

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