Thesis Report

On

PEFORMANCE ANALYSIS OF MODULATION FORMATS IN DISPERSIVE OPTICAL COMMUNICATION SYSTEM

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

MASTER OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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HARMANJOT SINGH

CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, **"Performance Analysis of Modulation Formats In Dispersive Optical Communication System,"** in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communications Engineering submitted in Electronics and Communications Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. R.S. Kaler.**

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

With the increasing growth and demand for capacity in national, regional, and even metropolitan optical networks, high bit rate fiber transmission has recently become an essential part of communications. The high bit rate transmission improves spectral utilization which results in increased overall system capacity and reduces overall cost. The optical communication systems are used as high speed long–haul communication systems. To release the potential of optical communication systems and achieve higher transmission capacity at high bit rate, a lot of research on modulates on formats and dispersed managed systems has been done in recent years. The goal of an optical fiber communication system is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors. The objective of this thesis is, to analyse the performance of dispersed managed RZ system, different modulation formats and to study the different compensation techniques at high bit rate.

The dispersed managed system is a promising way to transmit data in optical communication networks. The performance of 10 Gbps optical communication system with the dispersion managed return-to-zero (RZ) pulse has been reported. The return-to-zero (RZ) pulse is efficient for long-distance, high-bit-rate, wavelength division multiplexed (WDM) transmission dispersion-managed systems. In RZ pulse, the power is transmitted only for fraction of bit period. In this thesis, predictions are made by varying the dispersion parameter of single mode fiber in optical communication system. It has been reported that the performance of the system is improved with increase in the value of dispersion parameter.

Using the different types of modulation formats, it is predicted that the novel modulation formats enhance the overall performance of the optical communication systems at high bit rate. The performance of non-return-to-zero (NRZ), carrier suppressed return-to-zero (CSRZ) and doubinary modulation format at 10 Gb/s for the optical communication system is analyzed. The performance evaluation of the modulation format has been analyzed in terms of the bit error rate (BER) against the accumulate dispersion and optical signal to noise ratio. The bit rate taken for all the modulation formats is 10 Gb/s. The dispersion tolerance of the modulation formats has been analyzed. The performance of the NRZ, CSRZ and doubinary is analyzed which shows that CSRZ is better for long optical communication system at 10 Gb/s.

To enhance the overall performance of the optical communication systems, various types of dispersion compensation techniques are used. By using these techniques, the effect of the dispersion can be reduced to great extent. The compensation techniques are fiber based and devices based. In this thesis, the performance of different dispersion compensation techniques with doubinary modulation format at high bit rates is reported. The compensation techniques proposed are dispersion compensation fiber (DCF), reverse dispersion fiber (RDF), negative dispersion fiber (NDF), fiber bragg grating (FBG) and optical phase conjugation (OPC). The comparison of different dispersion compensation techniques at different bit rate has been done. The bit rate is used upto 40 Gb/s. The comparison of different techniques has been analysed from the eye closure, bit error rate and Q-factor characteristics. It has been analysed that the dispersion compensation techniques using combination of standard single mode fiber (SSMF) with dispersion compensation fiber (DCF) and reverse dispersion fiber (RDF) is best suitable for long haul optical communication systems at high bit rates.

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CHAPTER 1

INTRODUCTION

Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber. Fiber-optic communication systems have revolutionized the telecommunications industry and played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, the use of optical fiber has largely replaced copper wire communications in the developed world. Optical fiber is the most common type of channel for optical communications; however, other types of optical waveguides are used within communications gear, and have even formed the channel of very short distance (e.g. chip-to-chip) links in laboratory trials. The main benefits of fiber are its exceptionally low loss, allowing long distances between amplifiers or repeaters and its inherently high data-carrying capacity, such that thousands of electrical links would be required to replace a single high bandwidth fiber. Another benefit of fiber is that even when run alongside each other for long distances, fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines.

With the explosive growth in demand for capacity in national, regional, and even metropolitan optical networks, high bit rate fiber transmission have recently become an essential part of state-of-the-art communications. Modern optical networks are now primarily based on 2.5 Gb/s and 10 Gb/s channels. 40 Gb/s channels have begun to be implemented in new product offerings [1]. In addition to increases in data rate per channel, the number of channels per fiber is also increased through wavelength division multiplexing (WDM) or dense WDM (DWDM) to further improve overall capacity. High-bit rate transmission is attractive for several reasons. First, it potentially enables lower capital expenditure by sharing transmitter/receiver cost between more data sources or users. Second, it eases wavelength management by reducing the number of WDM channels. Wavelength management, such as reconfigurable optical add/drop multiplexing, is essential to making optical networks transparent, scalable, and flexible, which ultimately reduces the operational expenditure of such networks. Thirdly, high spectral efficiency can be achieved in a WDM system that has a common channel grid through the use of high bit rate channels. Improving spectral utilization facilitates increased overall system capacity and lower overall cost.

1.1 Modulation Techniques

The optical signal used for the optical communication network can be generated with different modulation techniques. Their are four basic physical attributes that can be modulated to optically transmit information: intensity, phase, frequency, and polarization. The electrical signal is modulated by the carrier signal. Depending on depending on which parameter of signal is modulated, the modulation techniques can be divided into amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK) and polarization shift keying (PolSK).

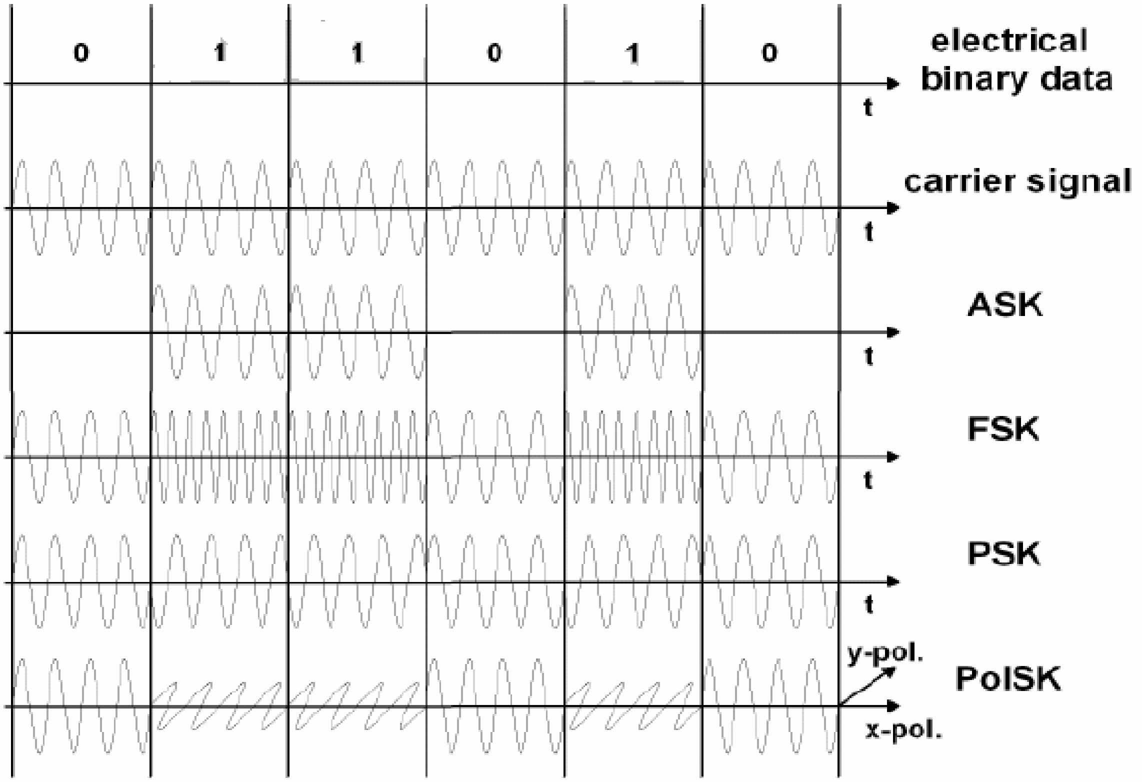

Figure 1.1: Principle of optical signal modulation

1.1.1 Amplitude Shift keying

Amplitude-Shift-Keying (ASK) known as"On-Off"-keying (OOK) is the technique of modulating the intensity of the carrier signal is shown in figure (1.1). In the simplest form, a source is switched between on and off states. The ASK modulation is characterized by the relation between the signal levels in on and off states called extinction ratio (ER). The ER value is dependent on the approach used for the signal generation: direct or external modulation of the laser source. In case of external modulation, the ER is limited by the extinction ratio of the external modulator. Typical ER values vary between 8-12 dB depending on the signal bit rate in use. The ASK-based modulation formats are characterized by simple signal generation and detection, due to which all currently deployed optical transmission systems employ ASK-based modulation formats. In the following section various ASK-based modulation formats is discussed. Due to the use of different modulation methods for generation of these formats, they posses different signal shapes (e.g. return-to-zero or non return-to-zero) and spectral characteristics, resulting in different transmission behaviours.

1.1.2 Frequency Shift Keying

Frequency Shift Keying (FSK) is realized by switching the laser light frequency between two frequency values as shown in figure (1.1). In FSK, the optical signal envelope remains unchanged and the complexity of signal generation and detection increases compared to ASK modulation. FSK modulation is characterized by the modulation index. By the variation of modulation index, different FSK-based modulation format can be realized. The differences between FSK formats are reflected in the optical signal spectra, whereby a smaller modulation index enables more compact optical spectra. The FSK-based formats are not used in already deployed transmission systems because of complex signal detection. More recently, FSK-based modulation known as Dispersion Supported Transmission (DST) [2] format was intensively investigated for the implementation in MAN networks [3]. The main drawback of this new technique is that the transmitter and receiver parameters have to precisely match the characteristics of the transmission line, requiring a detailed characterization of the dispersion in the transmission line.

1.1.3 Phase Shift Keying

Phase Shift Keying (PSK) uses the phase of the signal to encode information. Optical PSK signals posses a narrow spectrum and a constant signal envelope as shown in figure (1.1), which enables improved nonlinear tolerance, but on the other hand the PSK signals are sensitive to a phase modulation induced by multi-channel effects, which can result in decoding errors at the receiver side. At the same time, PSK-based modulation enables improved receiver sensitivity (up to 6 dB) compared to ASK-formats. Especially interesting method of PSK modulation is differential PSK

(DPSK). In DPSK signals, the information is encoded in the phase change between two successive bits. Basically, PSK signals only allow coherent detection, which require a local oscillator at the receiver to compare the phase of transmitted with the phase of the local signal, making the feasibility of this modulation more difficult. Also, a phase-locked-loop (PLL) is required to synchronize the local oscillator to the received signal. Pure PSK modulation is rather inapplicable for the system implementation, but some special binary and multilevel variants of PSK like DPSK [4] or differential quaternary PSK (DQPSK) [5] allow the use of direct detection methods. DQPSK enables a further improvement of the code efficiency using 4 different phases, where the signal symbol rate is half of that in DPSK case. The DQPSK bit stream must be differentially encoded using a digital pre-coder. The signal detection in DPSK formats can be made using MZI interferometer based configurations [5] which enable a reduced detection complexity compared to coherent detection. In spite of increased realization complexity of PSK modulation, recently presented DPSK and DQPSK system are as good alternatives to ASK-based modulation formats in future high speed WDM systems.

1.1.4 Polarization Shift Keying

Polarization Shift Keying (PolSK) is the most exotic modulation format among all already presented. The optical PolSK signals are generated by switching the signal polarization between two orthogonal states of polarization. The PolSK is characterized by a constant signal envelope enabling an improved nonlinear tolerance, an improved sensitivity (3 dB) [6] compared to ASK-based modulation, and enable a better utilization of the system bandwidth by the use of orthogonal polarization as an additional degree of freedom. The drawbacks of PolSK are an increased complexity of signal generation and detection, as well as, the sensitivity to polarization disturbances in the transmission line, whose impact increases with an increased channel data rate.

1.2 Modulation Formats

The ASK-based modulation formats are characterized by simple signal generation and detection, due to which all currently deployed optical transmission systems employ ASK-based modulation formats. The two basic modulation formats of are non-return-to-zero (NRZ) and return-to-zero (RZ). RZ pulse formats also have several variants, such as chirp-free RZ, chirped RZ (CRZ), CSRZ, RZ-DPSK, CSRZ-DPSK and π/2 alternate-phase (п/2-AP) RZ. Carrier suppressed RZ pulse is a special form of RZ pulse where the carrier is suppressed. A very interesting modulation format is optical duobinary, which offers high spectral efficiency and chromatic dispersion tolerance.

1.2.1 Non-return-to-zero (NRZ) Modulation format

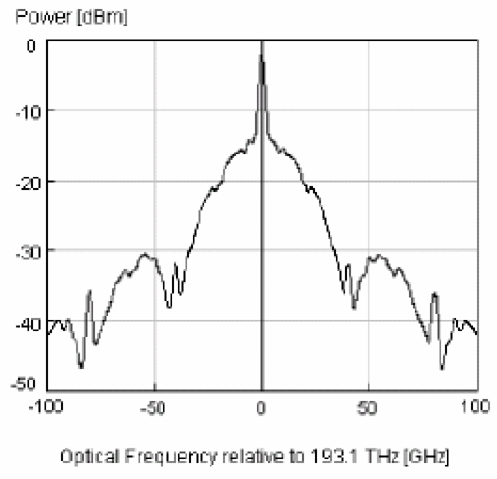

Figure 1.2: Optical spectrum of NRZ modulation format

The simplest modulation scheme is a non-return-to-zero (NRZ) format, where the pulse is on for the entire bit period. Most commercial systems use the NRZ modulation format [7]. The non-return-to-zero (NRZ) has been the most dominant modulation format in intensity modulated-direct detection fiber-optical communication systems for the last years. The reasons for using NRZ in the early days of fiber-optical communication as it is not sensitive to laser phase noise, requires a relatively low electrical bandwidth for transmitter and receivers compare with RZ and the simplest configuration of transmitter and receiver. The NRZ pulses have a narrow optical spectrum as shown in figure (1.2). The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference between the pulses this modulation format is not suitable when high bit rates and distance are considered. The narrow spectrum of NRZ pulses yields a better realization of dense channel spacing in DWDM systems.

1.2.2 Return-to-zero (RZ) modulation format

In return-to-zero (RZ) modulation format, power is transmitted only for a fraction of the bit period. A RZ signal with the same average power of a NRZ signal has a spectrum peak-power twice larger than the NRZ pulse. The main characteristic of RZ modulated signals is a relatively broad optical spectrum. The large spectral width results in a reduced dispersion tolerance and a reduced spectral efficiency of RZ-based WDM systems. The RZ pulse shape enables an increased robustness to fiber nonlinear effects and to the effects of polarization mode dispersion (PMD) [8]. The RZ system implementation improves the system receiver sensitivity up to 3 dB [9]. Due to its broader spectrum, RZ pulse has a reduced dispersion tolerance and spectral efficiency. The duty cycle of RZ pulse is less than unity. The reduced pulse width implies a broader signal spectrum making this technique less interesting for the implementation in DWDM systems. Higher optical powers per channel can be tolerated in a RZ-based WDM system, resulting in an improved maximum transmission length. The RZ modulation format is used for long haul optical communication systems working at higher bit rates.

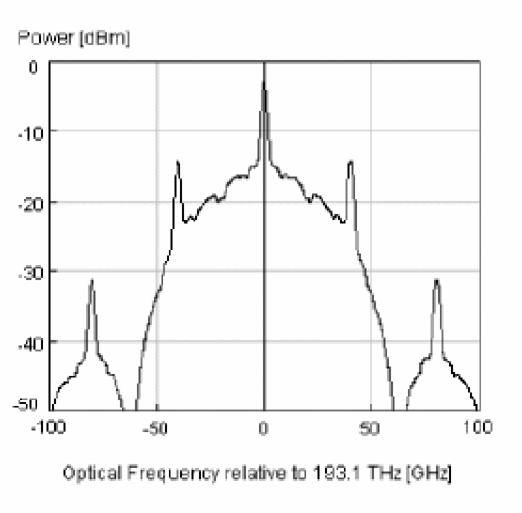

Figure 1.3: Optical spectrum of RZ modulation format

1.2.3 Carrier suppressed return-to-zero (CSRZ) modulation format

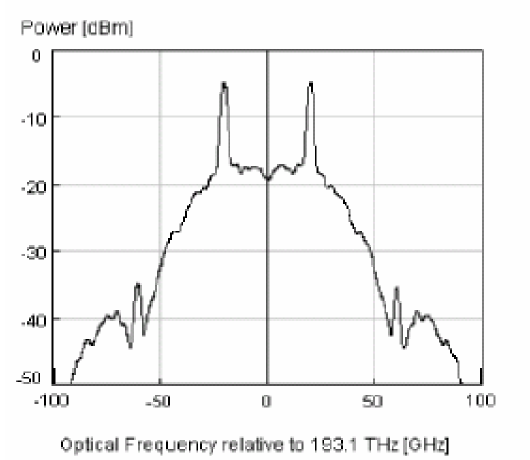

Figure 1.4: Optical spectrum of CSRZ modulation format

Carrier-suppressed RZ (CSRZ) modulation is one of the recently proposed modulation formats for high bit rate transmission systems, which has been intensively investigated in numerical and experimental works [10]. The main target of this modulation format is a reduction of the nonlinear impacts in a transmission line and an improvement of the spectral efficiency in high bit rate WDM systems. It can be expected that the dispersion tolerance of the transmission can be improved as well by CSRZ modulation, due to its reduced spectral width compared to conventional RZ modulation. Compared to the RZ case a spectral reduction with a factor of 2 occurs in CSRZ as shown in figure (1.4). The CSRZ pulses possess a RZ signal shape with an optical phase difference of π between adjacent bits. This inter-pulse phase condition can be beneficial for an increased nonlinear tolerance Carrier suppressed RZ pulse is a special form of RZ pulse where the carrier is suppressed. The difference between CSRZ and conventional RZ is that the CSRZ signal has a π phase shift between adjacent bits. This phase alternation, in optical domain, produces no DC component; thus, there is no carrier component for CSRZ. CSRZ modulation utilizes a return to zero modulation. It also alters the phase of the optical signal. CSRZ signal is far less sensitive to fiber nonlinear effects and provides better robustness against transmission impairments. The robustness of CSRZ modulation to narrow-band filtering can be improved, which can be beneficial for DWDM systems. By the use of an optimized narrow-band filtering in 40 GB/s CSRZ based DWDM transmission systems, a spectral efficiency beyond 0.4 bit/s/Hz can be realized.

1.2.4 Doubinary modulation format

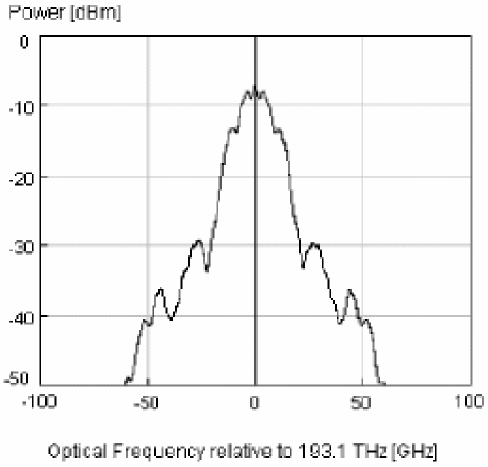

Figure 1.5: Optical spectrum of doubinary modulation format

A very interesting modulation format is optical duobinary, which offers high spectral efficiency and chromatic dispersion tolerance. Duobinary modulation can be described as a combination of a conventional ASK-based modulation and phase shift keying (PSK). Depending on the realization, optical duobinary transmission can be understood as a multilevel transmission with phase encoded bits and a reduced spectral width. Duobinary transmission technology was introduced for the first time by A. Lender in the 1960s as a mean of transmitting binary data over an electrical cable with high-frequency cut-off characteristics. Recently, duobinary modulation [11] has been applied to high-speed optical transmission systems with a channel data rate of 10 GB/s in order to improve their dispersion tolerance. In the duobinary format, the optical phases of “1” bits that are separated by an odd number of “0s” differ by π radians. The optical spectrum of the duobinary signal is very compressed as compared to many other binary formats. The optical duobinary format is generally realized via two possible methods, one through electronic low pass filter (LPF) and the other through optical filtering of a DPSK signal in a delay interferometer (DI). The LPF duobinary has recently received significant attention. One reason for this is that duobinary can be easily created using simple low-cost techniques. The spectral width of the signal is reduced twice compared to a conventional NRZ signal as shown in figure (1.4). The reduction of the spectral width of the optical duobinary signal is the reason for its better dispersion tolerance compared to NRZ signals and enables an improved spectral efficiency in WDM systems. A further advantage of duobinary modulation is the suppression of SBS-effect, since in the optical duobinary spectrum; the carrier is effectively suppressed [11]. The main disadvantage of duobinary signals, similar to NRZ signals, is a relatively strong impact of fiber nonlinearities, which represents the main limiting factor for the maximum transmission length and the achievable transmission quality. The new duobinary based modulation methods with the use of RZ-based signal enables the realization of WDM systems with dense channel spacing and with an improved transmission performance. Due to its large dispersion tolerance, the duobinary modulation is suitable for optical metro area networks (MANs) [12], in which the component costs and a signal generation realized in electrical domain play an important role.

1.3 Dispersion Compensation Techniques

The ideal dispersion compensator must have a quite stringent list of characteristics. Regarding the chromatic dispersion, it has to be well matched to the transport fiber, have a smooth dispersion profile (i.e. no dispersion ripples or group delay ripples), be tuneable, and potentially provide a high channel-to-channel variation in the dispersion. Furthermore, it has to be free of polarization effects (polarization dependent loss (PDL) and polarization mode dispersion (PMD). Regarding the wavelength, it has to be broadband, being usable over the whole wavelength range (high spectral efficiency) and should accommodate high signal bandwidths. The ideal compensator must also provide low insertion loss and being capable of handling high optical power. Finally it must be compact, consume no or low power and must be low-cost [13].

Obviously, such a long list of requirements is virtually impossible to fulfil. Trade-offs must be made between the different requirements. 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 [14].

1.3.1 Fiber based method

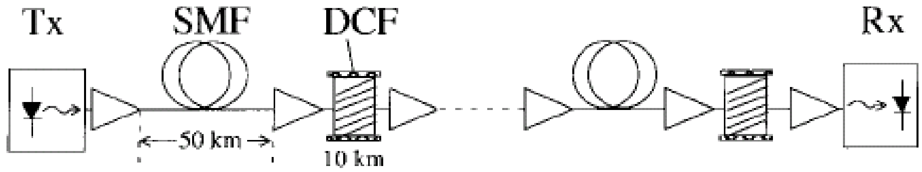

Figure 1.6: Dispersion compensation fibers in optical communication system

The fiber based method employs the dispersion compensation through a small section of fiber length. Their are various techniques such as dispersion compensation fiber (DCF), reverse dispersion fiber, negative dispersion fiber to compensate the dispersion of the system. 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. 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 [15].

The disadvantages of the fiber-based methods are the extra fiber loss in, high non-linearities 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.

1.3.2 Fiber Bragg Grating

The first in-fiber Bragg grating was demonstrated by Hill in 1978 [16]. A fiber Bragg grating (FBG) is a type of distributed bragg reflector is constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical fiber to block certain wavelengths, or as a wavelength-specific reflector.

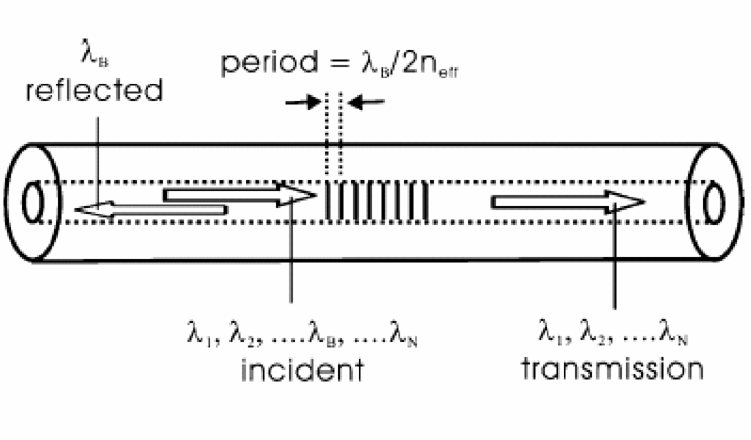

Figure 1.7: Basic structure of fiber bragg grating

The Bragg wavelength λ_B, of an FBG, which is given by the following relation:

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

where n_{eff} the modal refractive index and Λ is represents the index modulation period of the Bragg grating. Assume that the incident light fulfils the Bragg condition given by Eq. (1). The incident light will be Fresnel-reflected at one of the grating plane. Under the Bragg condition, the reflected light is exactly in-phase with reflected lights from other grating planes. Since all of these reflected lights would be constructively interfered at the incident edge of the FBG, the incident light is reflected as shown in Fig. (1.6). On the other hand, other wavelength components will pass through the FBG. Therefore, the FBG acts as a band-pass filter at the reflection port and a band-rejection filter at the transmission port. Such interferometric effect can exhibit a very narrow bandwidth characteristic of filters.

Fiber Bragg gratings (FBG) have been proposed for compensating the chromatic dispersion several years ago. Such a device reflects light when its wavelength corresponds to the grating period. When the grating is chirped, that is when its period varies linearly along the axis; the different spectral components of the light are reflected at different location along the grating. In such a way, a spectral component travelling faster in the transport fiber can be delayed by the FBG compared to a spectral component that travels slower. With a narrowband operation, FBG can now be operated over the full C-band though a multi-channel operation where the same portion of optical fiber reflects over many wavelength regions instead of only one. The multi-channel operation can be achieved by grating superposition or by a sampling approach. Dispersion compensation of 80 km of SSMF over 51 channels covering the full C-band has been reported with a good slope-matching. Each reflection region or grating component can be made independent on each other allowing for a large flexibility in the channel-to-channel variation of the optical characteristics. Such a device can provide a tunable dispersion by imposing a thermal gradient on the FBG. Multi-channel tunable dispersion compensation has been obtained in this manner [17]. FBG-based dispersion compensation provides a low loss and small footprint solution. Multi-channel FBGs are channelized devices that can be incompatible with a cascade of a large number of units. Furthermore, overall non-linearities in the group delay (group delay ripples) also increases with the square root of the number of cascaded units.

1.3.3 Optical phase conjugation method

Optical phase conjugation (OPC) is used as e generic term for a multitude of nonlinear optical processes. The common feature is that all these processes are capable of reversing both the direction of propagation and the phase factor for each plane wave component of an arbitrary incoming beam of light. This mean phase Conjugator can be considered as a kind of mirror with very unusual reflection properties. Unlike a conventional mirror, where a ray of light bits redirected according to ordinary law of reflection, a phase Conjugator mirror (PCM) retro-reflects all incoming rays back to the original path. When a conventional mirror only the wave vector component normal to the surface of the mirror reflects a ray changes sign the tangential components are unchanged. This means that the propagation direction of the reflected ray depends on the angle between the surface normal and the incident ray. A PCM, on the other hand, changes the sign of the complete wave vector so that the reflected ray is always anti parallel to the incident ray, independent of the orientation of the mirror surface. The concept here is to use a device in the middle of the link to invert the spectrum. This process changes the short wavelengths to long wave length and the long ones into short once. If the spectrum is inverted in the middle of the link (using standard single mode fiber) the second half of the link acts in the opposite direction. When the pulse arrives it has been rebuilt exactly compensated for by the second half of the fiber. Mid span spectral inversion is bit difficult to implement in all situations because active device have to be put in the middle of the link. This may or may not be practical. A process called “optical phase conjugation” performs this spectral inversion.

1.4 Optical amplifier

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Stimulated emission in the amplifier's gain medium causes amplification of incoming light. Optical amplifiers are important in optical communication and laser physics. The OA has made it possible to amplify all the wavelengths at once and without optical-electrical-optical (OEO) conversion. Besides being used on optical links, optical amplifiers also can be used to boost signal power after multiplexing or before demultiplexing, both of which can introduce loss into the system.

1.4.1 Semiconductor optical amplifier (SOA)

Semiconductor optical amplifiers are amplifiers which use a semiconductor to provide the gain medium. Recent designs include anti-reflective coatings and tilted waveguide and window regions which can reduce end face reflection to less than 0.001%. Since this creates a loss of power from the cavity which is greater than the gain it prevents the amplifier from acting as a laser. Such amplifiers are often used in telecommunication systems in the form of fibre-pigtailed components, operating at signal wavelengths between 0.85 μm and 1.6 μm and generating gains of up to 30 dB [18]. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc. However, the performance is still not comparable with the EDFA. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time. This originates from the short nanosecond or less upper state lifetime, so that the gain reacts rapidly to changes of pump or signal power and the changes of gain also because phase changes which can distort the signals. This nonlinearity presents the most severe problem for optical communication applications. However it provides the possibility for gain in different wavelength regions form the EDFA. "Linear optical amplifiers" using gain clamping techniques have been developed.

1.4.2 Doped fibre amplifier

Doped fibre amplifiers (DFAs) are optical amplifiers which use a doped optical fibre as a gain medium to amplify an optical signal. They are related to fibre lasers. The π signal to be amplified and a pump laser are multiplexed into the doped fibre, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where core of a silica fiber is doped with trivalent Erbium ions (Er^{+3}), can be efficiently pumped with a laser at 980 nm or at 1,480 nm, and exhibits gain the 1,550 nm region. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fibre. The pump laser excites ions into a higher energy. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fibre, and the wave length and power of the pump laser. The broad gain-bandwidth of fibre amplifiers make them particularly useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.

The **erbium-doped fibre amplifier** (EDFA) is the most deployed fibre amplifier as its amplification window coincides with the third transmission window of silica based optical fibre. Two bands have developed in the third transmission window, the Conventional, or C-band, from approximately 1525 nm - 1565 nm, and the long or L -band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands. The principal difference between C- and L-band amplifiers is that a longer length of doped fibre is used in L-band amplifiers. The longer length of fibre allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful quantity of gain. EDFAs have two commonly-used pumping bands – 980 nm and 1480 nm [19]. The 980nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stabilised laser sources are typically needed. The 1480nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980nm and 1480nm pumping is generally utilised in amplifiers. Doped fibre amplifiers for other wavelength ranges Thulium doped fibre amplifiers have been used in the S-band (1450-1490 nm) and Praseodymium doped amplifiers in the 1300 nm region. However, those regions have not seen any significant commercial use so far and so those amplifiers have not been the subject of as much development as the EDFA. However, Ytterbium doped fiber lasers and amplifiers, operating near 1 micron wavelength, have many applications in industrial processing of materials, as these devices can be made with extremely high output power (tens of kilo-watts).

1.5 Optsim

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

1.5.1 Simulation

Optsim provides multiple simulation engines that provide complementary simulation techniques. This enables the greatest flexibility in modeling and simulating systems ranging from short-distance data communication links, to ultra long-haul DWDM telecom systems, to large metro networks with feedback paths and EDFA transients due to adding and dropping of channels.

1.5.2 Analysis

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

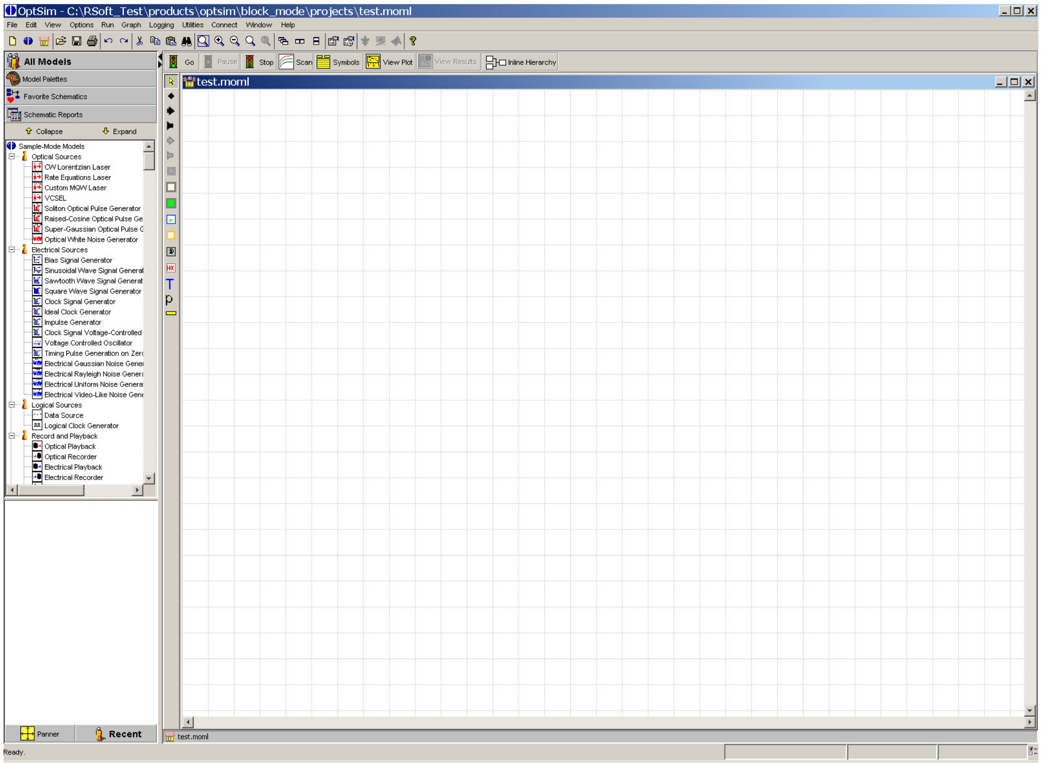

Figure 1.8: The Optsim graphical editor

Simulation results can be plotted in a number of forms including signal waveforms, eye diagrams, signal spectra, OSNR, Poincare sphere, dispersion maps, and more. A wide and complete choice of measurements is available including jitter, eye opening/closure, electrical/optical spectra, chirp, optical instantaneous phase/frequency and power.

CHAPTER 2

LITERATURE SURVEY

The optical communication systems are used as high speed long–haul communication systems. An optical modulation format is the method used to impress data on an optical carrier wave for transmission over optical fiber. The ideal modulation format for long haul, high speed, and WDM transmission links is the one that has a narrow spectral width, large dispersion tolerance and has a simple and cost-effective configuration for generation. The various modulation formats are non-return-to-zero (NRZ) and return-to-zero (RZ), Carrier suppressed RZ and duobinary. Dispersion is a big factor which degrades the performance of optical communication networks. Due to there are several fiber and devices based compensation techniques had been developed to limit this effect. The fiber devices based compensation techniques are dispersion compensation fibers, negative dispersion fiber and reverse dispersion fiber where as the devices based compensation techniques are fiber bragg grating and optical phase conjugator.

2.1 NRZ and RZ modulation format

Kwok, Chow, Tsang and Bjarklev el at. [20] had theoretically and experimentally the conversion bandwidth of the cross-polarization-modulation based wavelength conversion scheme with a dispersion-flattened highly nonlinear photonic-crystal fiber for signals with a nonreturn-to-zero (NRZ) modulation format. It was showed that the conversion bandwidth can be extended to cover a very wide band, including S-, C-, and L-bands for 10 Gbit/s NRZ signals (a total bandwidth of 120 nm is experimentally demonstrated). It was studied the theoretical bandwidth limit for 40 Gbit/s NRZ signals. A significant extension of the conversion bandwidth using the cross-polarization-modulation approach compared with the four-wave mixing approach previously reported is demonstrated.

Mob, Fiirst, Geiger and Flscher el at. [21] theoretically and experimentally analyses advantages of nonlinear RZ over NRZ on 10 GB/s single-span links. Griffin, Walker, and Johnstone el at. [22] 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 el at. [23] had proposed alternative modulation formats in N 40 Gb/s WDM standard fiber RZ-transmission systems.

Winzer and Leuthold el at. [24] experimentally demonstrate and discuss a new technique for variable duty cycle return-to-zero (RZ) modulation, employing a phase modulator driven by a single electrical nonreturn-to-zero signal, and an optical delay interferometer with no synchronization between two electrical driving signals is needed.

Park, Wiesenfeld, and Garret el at. [25] demonstrated the transmission of a 40-Gb/s signal over multiple (up to six) 120-km spans of conventional single-mode fiber (SMF). It is proposed to use a very low duty cycle return-to-zero (RZ) format which employs optical pulses much shorter than the bit-period. The resulting broad spectrum of these short pulses reduces nonlinear effects and enables the transmission of the signal over long distances. Tanaka, Moritd and Edagawa el at. [26] successfully demonstrated 5OGHz spaced 40Gbitis × 2 WDM transmission over 480km using band limited RZ signals and an SMF-based dispersion-flattened transmission line and the longest distance transmission for a spectral efficiency of 0.8 bits/Hz was achieved without using polai-isation multiplexing

Sunnerud, Karlsson and Andrekson el at. [27] 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 between power margin and acceptable PMD is studied.

2.2 CSRZ Modulation Format

Sano and Miyamoto el at. [28] demonstrated the transmission performance of prechirped return-to-zero (RZ) and prechirped carrier-suppressed return-to-zero (CS-RZ) signals over a periodically dispersion-compensated transmission line. The transmission characteristics of both formats was analysed, taking account the transmitter configuration expected, in which pulse chirping is generated by using both a phase modulator and a linear dispersion compensating device. The dependence of the transmission characteristics on phase modulation, pre- and postcompensating dispersion and receiver optical and electrical filter widths was discussed. In 100-GHz spaced 40-Gb/s-per-channel systems, it was shown that the phase modulation must be carefully optimized in order to minimize the linear crosstalk and waveform distortion induced by the intra- and interchannel nonlinear interaction in the transmission fiber.

Tsuritan, Agata, Shimomura, Morita and Taga el at. [29] theoretically and experimentally analysed the 70-GHz-spaced 40 42.7 Gb/s prefiltered carrier-suppressed return-to-zero differential phase-shift keying (CSRZ-DPSK) signals which have been transmitted over transpacific distances for the first time, using all-Raman repeaters with two pump-wavelengths, dispersion-managed fiber commercially available in volume, and an ETDM receiver. It was analysed that the nonlinear transmiss1on penalty was increased by band limitation; this penalty for CSRZ-DPSK signal was smaller than that for CSRZ-OOK signal. The long-term stability of the transmission performance was also evaluated with low-speed signal polarization scrambling without using any polarization mode dispersion (PMD) compensation.

Agarwal, Banerjee, Gurevich and Wood el at. [30] demonstrated an all-Raman single-band transmission of 5.12 Tb/s (128 42.7 Gb/s) with 50-GHz channel spacing over 1280 km of standard single-mode fiber with CSRZ modulation format. The ultra-high capacity for a spectral efficiency of 0.8 b/s/Hz was achieved by strong optical filtering of transmitted signals.

2.3 Doubinary Modulation Format

Lender el at. [31] demonstrated a new approach to digital data transmission, termed duobinary and correlative, substantially increases speed over any band-limited media owing to correlation between signal states. Specific codes are used with or without carrier modulation. In the error detection process, it has been found that with this type of system it is unnecessary to introduce redundant digits into the original data stream.

Price and Mercier el at. [32] demonstrated a reduced bandwidth optical digital intensity modulation with improved chromatic dispersion tolerance. In this a simple optical modulation scheme using a lithium niobate Mach-Zehnder modulator driven by a three level drive waveform is proposed. The two-level intensity modulated (IM) optical signal obtained possesses a smaller optical bandwidth and thus greater chromatic dispersion tolerance compared with existing two-level IM methods used for high data rate transmission. Yonenaga and Shibata el at. [33] demonstrated and experimentally analysed an optical duobinary transmission system with no receiver sensitivity degradation .In this a novel optical duobinary transmission system with no receiver sensitivity degradation is proposed. The transmitter yields a narrowband optical signal and the receiver configuration is as simple as a binary IM-DD receiver.

The feasibility of the proposed system is experimentally confirmed at 2.5,5 and 10 Gb/s.

Jansen, Spalter, Weiske, and Escobar el at. [34] demonstrated and experimentally analysed comparison between NRZ and Duobinary modulation at 43 Gb/s for MLSI-Based and DCF-based transmission systems. The performance of midlink spectral Inversion (MLSI) is compared with the performance of “conventional” dispersion compensation fiber (DCF)-based transmission for two data formats: 43-Gb/s ON–OFF keying nonreturn-to-zero (OOK-NRZ) and 43-Gb/s duobinary is analysed. In the MLSI-based system, a polarization-diverse subsystem was used for spectral inversion employing magnesium-oxide-doped periodically poled lithium niobate waveguide technology. The transmission link consists of 8 × 100 km standard single-mode fiber (SSMF) using erbium doped fiber amplifiers (EDFAs) for amplification. It was concluded that Compared to the DCF-based system, it was seen that the MLSI-based configuration enhances the dispersion tolerance for both the NRZ and the duobinary modulation formats

Ono, Yano, Fukichi and Emura el at. [35] demonstrated and analysed the characteristics of optical duobinary signals in Terabit/s capacity, high-spectral efficiency WDM systems.

2.4 Dispersion compensation fiber

Nutys and Park et al. [36] investigated theoretically and experimentally the transmission performance of a 10 GB/s repeater transmission system using dispersion compensating fibers (DCFs). The system configuration that we 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 demonstrate that the use of DCFs is an extremely effective method to overcome the chromatic dispersion in high-speed transmission systems.

Weinert, Ludwig, Pieper, Weber, Breue, Petermann, and Kuppers et al. [37] 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.

2.5 Fiber Bragg Grating

Li.M and Li.H et al. [38] presented a novel approach for the reflection equalization of a phase-only sampled fiber Bragg grating (FBG), where the grating is specially designed as a simultaneous dispersion and dispersion-slope compensator with channels up to 51. The sampling-function used is given with an analytical form with a linearly-chirped sampling period and is optimized by using the simulated annealing algorithm.

Ngo et al. [39] designed and developed a novel tunable dispersion compensator with fixed center wavelength that is based on the electrical adjustment of the chirp of a fiber Bragg grating (FBG). Both temperature gradient and strain gradient are employed to adjust the chirp of the FBG jointly. The electrical current flowing through the taper on-fiber thin-film heater will introduce a temperature gradient on the FBG. The center wavelength of the FBG will be kept fixed because the effect of temperature rise on the FBG and the effect of compression of the FBG will offset each other. Applying an electrical power of less than 0.68W, they demonstrate a linearly chirped FBG whose dispersion can be continuously adjusted from 178 ps/nm to 302 ps/nm with a central wavelength shift of as small as 0.16 nm.

Dai, Chen, Sun, and Xie el at. [40] demonstrated fiber dispersion by using uniform phase mask and conventional fabrication technology with sub micrometer rather than nanometerprecision, a pure third-order dispersion-compensating fiber Bragg grating (DCFBG) and a tunable slope DCFBG are demonstrated with high performance based on the combined reconstruction equivalent-chirp method and an error correction technique. The former DCFBG has a dispersion varying from 1000 to 1000 ps/nm in the 100-GHz passband and group delay ripple is less than 5 ps. The latter has a dispersion slope varying from 150 to 150 ps nm2 within the 3-nm passband, and its group delay ripple is less than 10 ps.

Eggleton, Ahuja and Rogers el at. [41] demonstrated integrated tunable fiber gratings for dispersion management in high-bit rate systems. They presented a comprehensive discussion of an emerging tunable dispersion compensating device, based on thermally actuated fiber gratings and present detailed analysis of the impact of group-delay ripple and polarization-mode dispersion on systems performance, and present results from systems experiments that demonstrate the performance of these devices at bit rates of 10, 20, 40 and 160 GB /s.

Garrett and Gnauck el at. [42] demonstrated wavelength-division-multiplexed transmission of 16×10-Gb/s non return-to-zero channels with 50-GHz spacing over 840 km of conventional single-mode fiber (SMF), or 14 times the 10-Gb/s dispersion limit, using a total of eleven chirped fiber gratings for dispersion compensation.

2.6 Optical phase Conjugator

Jansen, Borne and Waardt el at. [43] demonstrate Compensation of nonlinear phase noise impairments through optical phase conjugation in long-haul transmission systems**.** It has been shown that optical phase conjugation (OPC) is an effective compensation scheme for non linear phase noise (NPN) resulting from the ASE of EDFAs (ASE-NPN). In this the influence of NPN resulting from modulator imperfections (MI-NPN) was discussed and showed that MI-NPN can be compensated for through OPC, though shift the optimum location of the OPC towards the middle of the transmission link.

Chowdhury el at. [44] proposed recent advances in optical phase conjugation and its application to 40 GB/s transmission**.** Optical phase conjugation is effective in compensating intra-channel nonlinearities in pseudolinear systems. Results of optical phase conjugation in 40 Gb/s optical systems with different transmission distances and modulations formats, and varying conjugator locations is presented.

Tang and Wu el at. [45] proposed modulation instability (MI) limits the transmission capacity of fiber systems using optical phase conjugation (OPC). A midway OPC system with periodic dispersion compensation (DC) where fiber parameters and the local path-averaged power are distributed symmetrically with respect to the position of OPC is proposed to cope with the MI effect. The analytical solution for evaluating the effect of MI shows that the MI effect can be suppressed considerably in such an OPC system with a strong DC configuration.

2.7 Negative dispersion fiber

Chung and Y. G. Jang el at. [46] 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.

2.8 Reverse dispersion fiber

Lu el at. [47] proposed and demonstrated architecture of an externally modulated AM-VSB CATV 77-channel erbium-doped fiber amplifier (EDFA)-repeated system which uses the combination of single-mode fiber (SMF) and reverse dispersion fiber (RDF) as dispersion compensation device is proposed and demonstrated. Compared to the conventional externally modulated fiber optical CATV systems with or without dispersion compensation fiber (DCF), excellent performance of composite second order (CSO) 78 dB accompanied by satisfied carrier-to-noise ratio (CNR) 50 dB and composite triple beat (CTB) 65 dB was obtained in the proposed system.

2.9 Thesis objectives

- To study the performance of 10 Gbps optical communication with the dispersion managed RZ pulse
- To analyze the various modulation formats for optical modulation system
- To study the comparison of different dispersion compensation techniques with doubinary modulation format at high bit rate.

2.10 Thesis organization

This thesis is divided into six chapters. The first chapter describes the concept and evaluation of modulation formats and various types of dispersion compensation techniques. Various types of modulation techniques are discussed in this chapter like amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK) and polarization shift keying (PolSK). Various modulation formats like non-return-to-zero (NRZ), return-to-zero (RZ) and carrier suppressed RZ pulse and duobinary formats used optical networks are discussed. The study of dispersion compensation technique has also done .The fiber and devices based compensation is also discussed. Various optical amplifiers used in the functioning of optical networks are discussed. This chapter also describes the simulation tool known as OPTSIM that includes different simulation techniques for designing the system setup.

The second chapter includes the literature survey of various modulation formats and various dispersion modulation techniques.

The third chapter describes the performance of 10 Gbps optical communication with the dispersion managed RZ pulse. In the performance is analysed by varying the dispersion parameter of the standard single mode. The performance is based on the average eye opening, Q-factor, bit error rate (BER) and jitter characteristics.

In the fourth chapter, the performance of optical modulation system based on various modulation formats is analysed. The modulation formats used are non-return-to-zero (NRZ), carrier suppressed return-to-zero (CSRZ) and duobinary. The performance is described in terms of bit error rate (BER) and optical signal to noise ratio (OSNR) verse the dispersion.

The fifth chapter analysed the comparison of different dispersion compensation techniques with doubinary modulation format at high bit rate. The compensation techniques used are dispersion compensation fiber (DCF), reverse dispersion fiber (RDF), negative dispersion fiber (NDF), fiber Bragg Grating (FBG), optical phase conjugation (OPC). The performance is analysed at the different bit rates. The bit rate used is 5, 10, 20, 30 and 40 GB/s.

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

CHAPTER 3

PERFORMANCE OF OPTICAL COMMUNICATION SYSTEM WITH DISPERSION MANAGED RZ PULSE

In this chapter, the performance of 10 Gbps optical communication system with the dispersion managed RZ pulse has been reported. The return-to-zero (RZ) pulse is efficient for long-distance, high-bit-rate, wavelength division multiplexed (WDM) transmission dispersion-managed systems. In RZ pulse, the power is transmitted only for fraction of bit period. The effect of varying the dispersion parameter of single mode fiber on optical communication system has been noted. It is observed that with increase in the value of dispersion parameter, there is an increase in the average eye opening and Q-factor value. Also a good desirable bit error rate value has been achieved and reported. Timing jitters are reduced with increase in value of dispersion parameter. Also the performance of the optical communication system with the varying duty cycle of the RZ pulse for a fixed value of dispersion parameter has been analysed. It is demonstrated that the performance of the system is improved by reducing the duty cycle.

3.1 Introduction

The goal of an optical fiber communication system is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors. There are many modulation schemes that are come into existence for long-haul systems, i.e., the format used to create the optical pulses. The simplest modulation scheme is a non-return-to-zero (NRZ) format, where the pulse is on for the entire bit period. Alternatively, a return-to-zero (RZ) format can be used where the pulse is on for only a portion of the bit period. Optical return-to-zero (RZ) signals are becoming increasingly important in optical communication systems. They have proven to be superior to the non return- to-zero (NRZ) format both in terms of receiver sensitivity [9], and in terms of fiber transmission performance. The RZ spectrum has a wider bandwidth than the NRZ spectrum. Receiver sensitivity is defined as the received optical power required in order achieving a certain bit error rate (BER) [48]. The electrical power of an RZ pulse with a 0.5 duty cycle will be twice that of an NRZ pulse. The RZ pulse has a 3 dB improvement in receiver sensitivity. The RZ format would be beneficial for systems with few channels but would require NRZ as the number of channels increase [7]. The RZ format has the better receiver sensitivity and nonlinearity tolerance due to which this modulation format is of great interest for research scholars these days. The work is going on achieving high bit rates which is above 40 Gb/s. Due to its relatively broad optical spectrum which results is results in reduced dispersion tolerance and a reduced spectral efficiency. RZ pulse is less susceptible to inter symbol interference and better nonlinear robustness. RZ modulation has become a popular solution for 10 Gb/s systems because it has a higher peak power, a higher signal-to-noise ratio, and lower bit error rate that NRZ encoding .The duty cycle of pulses used also has its effect on the performance of system. So best suitable value for duty cycle must be taken. Dispersion is a big factor which degrades the performance of optical communication networks. Due to this several compensation technique had been developed. Some of the techniques are dispersion shifted fibers and dispersion compensation fibers. In dispersion compensation fibers the negative value of dispersion parameter is given. The amplifiers also have an important role in optical communication systems. With the Erbium doped fiber amplifier, the number of spans of standard single mode fibers has been decreased to great extant.

Mob, Fiirst, Geiger and Flscher el at. [21] theoretically and experimentally analyses advantages of nonlinear RZ over NRZ on 10 GB/s single-span links. Griffin, Walker, and Johnstone el at. [22] 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 el at. [23] had proposed alternative modulation formats in N ×40 Gb/s WDM standard fiber RZ-transmission systems.

K. Ennser and K. Petermann et al. [49] had investigated theoretically and experimentally the performance of RZ- versus NRZ transmission on standard single-mode fibers. On the basis of computer simulations, the RZ-transmission for the optimum system performance taking into account the dispersion, Kerr nonlinearity, attenuation and ASE noise was investigated. The parameters such as bit rate, distance and power levels are estimated for the lowest system degradation. The work considers different duty ratios including NRZ-pulses.

Park, Wiesenfeld and Garret el at. [25] had demonstrated the transmission of a 40-Gb/s signal over multiple (up to six) 120-km spans of conventional single-mode fiber (SMF). They use a very low duty cycle return-to-zero (RZ) format which employs optical pulses much shorter than the bit-period. The resulting broad spectrum of these short pulses reduces nonlinear effects and enables the transmission of the signal over long distances. Tanaka, Moritd and Edagawa el at. [26] successfully demonstrated 50 GHz spaced 40Gbits × 2 WDM transmission over 480 km using band limited RZ signals and an SMF-based dispersion-flattened transmission line. The longest distance transmission for a spectral efficiency of 0.8 bits/Hz was achieved without using polai-isation multiplexing.

Upto now, various dispersed managed systems had been demonstrated by varying the different parameter like fiber length, input power of the laser. No such efforts have been done to vary the dispersion parameter of the standard single mode fiber for dispersed managed system. In this chapter, performance of optical communication system by varying the dispersion parameter of dispersed managed RZ system is analysed.

The figure (3.1) shows the block diagram for the optical communication system for simulation setup. The transmitter section consist of data source, laser source, adjustable duty cycle RZ pulse, electrical filter and amplitude modulator. The transmission medium consist of standard single mode fiber, dispersion compensation fiber, in line amplifier and pre amplifiers. The receiver section consists of electrical and optical filters, photodiodes and measurement devise.

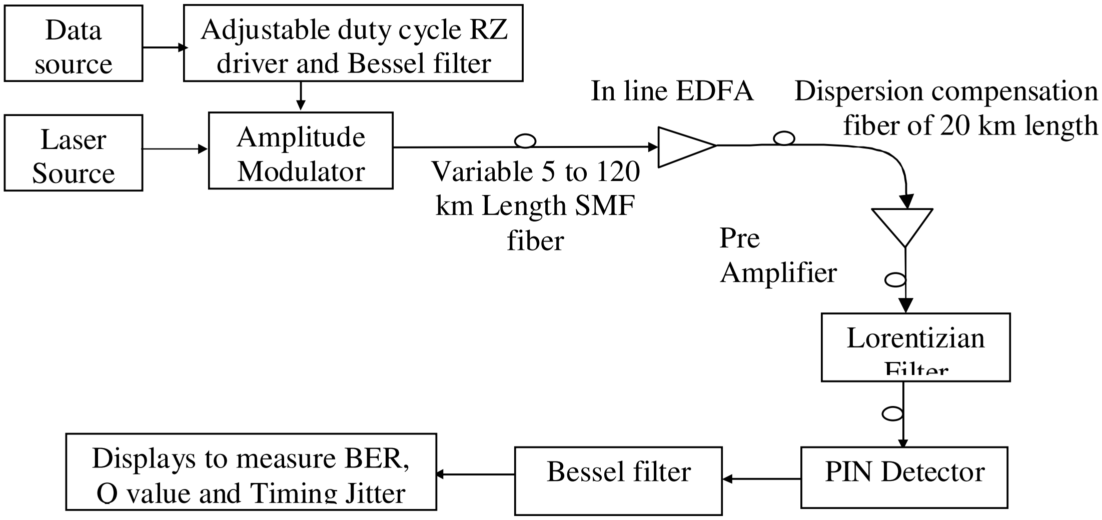

Figure 3.1: Block diagram for optical communication system for dispersed manage RZ pulse

The chapter is divided into different sections. In the first section, the brief introduction about the RZ pulse and its comparison with the NRZ pulse is given. The second section describes the simulation setup for the optical communication system. The third section includes the simulation results and its discussion. The fourth section gives the conclusion of this chapter.

3.2 Simulation setup for optical communication system to examine performance of dispersed manage RZ pulse

The particular system setup of optical communication system for dispersed manage RZ pulse is shown in figure (3.2). The component used in figure (3.2) are chosen from the Optsim Ver.4.7.0 component library palette and placed as per requirement in the design area of the Optsim editor. Then various simulation parameters are set. The parameter used for this particular simulation is as shown below in table (3.1).

	Simulation Bandwidth	
Lower Limit	193.349489032 THz	1549.47927297 nm
Lower Limit	193.349489032 THz	1550.52107715 nm
Center Frequency	193.414489032 THz	1550.00017506 nm
Bandwidth	0.13 THz	1.04180417799 nm
	Variable Bandwidth Simulation	
Lower Limit	193.349489032 THz	1549.47927297 nm
Lower Limit	193.349489032 THz	1550.52107715 nm
Center Frequency	193.414489032 THz	1550.00017506 nm
Bandwidth	0.104 THz	0.833443308505 nm
Reference Bit Rate	0.8 Gbps	
Simulated Bit Rate	0.802469135802 Gbps	
Total Simulated Time Span	512 ns	

Table 3.1: Simulation Parameter

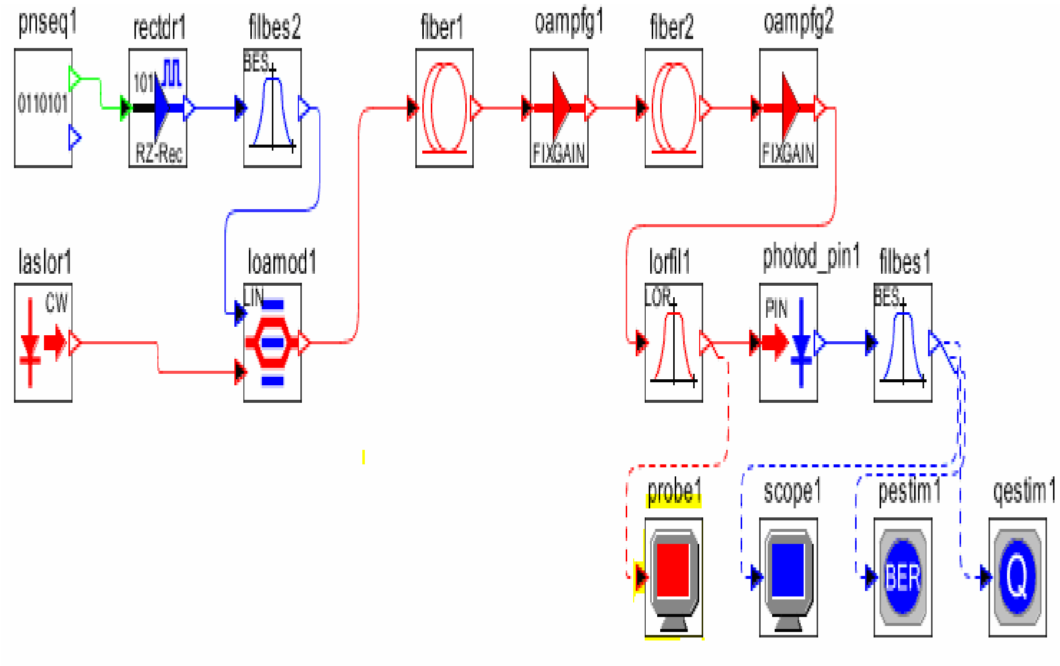

Figure 3.2: Simulation setup for optical communication system for dispersed manage RZ pulse

As shown in figure (3.2), the transmitter section consists of data source (pnseq1), modulator driver (rectdr1), electrical filter (filbes2), laser source (laslor1) and modulator (loamod1). Data source produces a pseudo-random sequence of bits at a rate of 10 Gbit/s. The output of data source is given to modulator driver which produces a RZ format pulse with duty cycle of 0.5. The property of modulator driver is shown in table (3.2). From this the signal goes to the electrical Bessel filter having lowpass type characteristics and -3dB bandwidth equal to 10 GHz. The output of laser source which is CW Lorentizan type having properties shown in table (3.3) and electrical filter is given to the modulator. The line-width was set to 10 MHz full width half maximum. The modulator is of amplitude modulator type which has $\sin^2$ shaped input-output characteristics. The properties are shown in table (3.4).

Parameter	Value
Low Level	0.0
High Level	5.0
Duty cycle	0.5

Table 3.2: Properties of Modulator driver

Parameter	Value
Center emission wavelength(nm)	1550
Center emission frequency(GHz)	193.41
CW power(mw)	0.0
CW power(dB)	1.0

Table 3.3: Properties of Laser

Parameter	Value
Excess loss(dB)	3.0
Transmission per applied voltage	20.0
Chirp factor	0.0

Table 3.4: Properties of Amplitude Modulator

The transmission medium used is a combination of standard single mode fiber (fiber1), dispersion compensation fiber (DCP), in line amplifier and pre-amplifier. The properties of standard single mode fiber and DCP (fiber2) is shown in table (3.5). In line amplifier (ampfg1) and pre-amplifier (oampfg2) is EDFA fixed gain amplifiers. Their are two types of fibers that are Semiconductor Optical Amplifier (SOA) and Erbium Doped Fiber Amplifiers (EDFA). Due to its high gain characteristics, EDFA are used these days. The shape of the gain graph is flat having a gain of 25 dB. The noise figure value is set at 4.5 dB. The standard single mode fiber used is of 120 km length and the length of dispersion compensation fiber is 20 km.

S. No.	Parameter	SSMF	DCF
1.	Core Effective Area (m^2)	80 x 10^{-12}	20 x 10^{-12}
2.	Loss @ λ = 1550 nm (dB)	0.2	0.55
3.	Non linearity refer. wavelength (nm)	1550	1550
4.	Zero dispersion wavelength (nm)	1391.5	3825.23
5.	Fiber Nonlinearity (1/W/km)	1.23	5.06
6.	Nonlinearity refractive index	2.5 x 10^{-20}	2.5 x 10^{-20}
7.	β_2 (ps^2/km)	-20.407	102.0358
8.	β_3 (ps^3/km)	0.14745	0.14116
9.	Fiber Birefringence	On	On
10.	1st order Dispersion- D (ps/nm/km)	16	-80
11.	2nd order Dispersion -D' (ps/nm^2/km)	0.07	0.19
12.	Fiber Average Beat Length (m)	5	5
13.	Fiber PMD (ps/$km^{0.5}$)	0.1	0.1

Table 3.5: Properties of Standard Single Mode Fiber and DCF

In the simulation setup there are some global parameters whose vales can be changed to get the desired graphs. In this the global parameters used are fiber length and dispersion value of standard single mode fiber and the duty cycle of modulator driver. The initial values for fiber length is, dispersion and duty cycle is 5 km, 8 ps/ns/km and .2 respectively. Table (3.6) given below shows the global parameters

Parameter	Value	Current Value
Fiber_length	5	5
Dis_parameter	8	8
Duty_cycle	0.2	0.2

Table 3.6: List of global parameter

At the receiver side, PIN photodiode (photod_pn1) is used as the receiver light energy to electric form. The pin photodiode simulated had 70% quantum efficiency. Its responsivety at 1550 nm was .875104401174 A/W. The dark current was simulated at 0.1 nA. The output from the transmission medium is given to band pass lorentizian filter having -3 dB two sided bandwidth of 52 GHz. The output of pin photodiode is passed through a bandpass Bessel filter (filbes1) with center frequency at 20 GHz. It is simulated to have 3 poles with -3 dB bandwidth of 10 GHz. The output from the filter is given to the measurement devices which are electrical scope (scope1), Q estimator (qesbm1), BER estimator (pesbm1) and optical probe (probe1) to get the results.

3.3 Result and Discussion

In previous section, various component and parameters used in simulation setup are discussed. Using some of these components, the value of bit error rate (BER), Q-factor, timing jitters, average eye opening are measured. Eye diagrams and optical spectrum at the receiver end is measured. The measurement component used are Q estimator to measure Q-factor, average eye opening values and timing jitters, BER estimator to measure to measure bit error rate (BER), electrical scope to measure eye diagrams and optical probe to measure optical spectrums. The graphs are taken by varying the values of global parameters at different stages of the simulation.

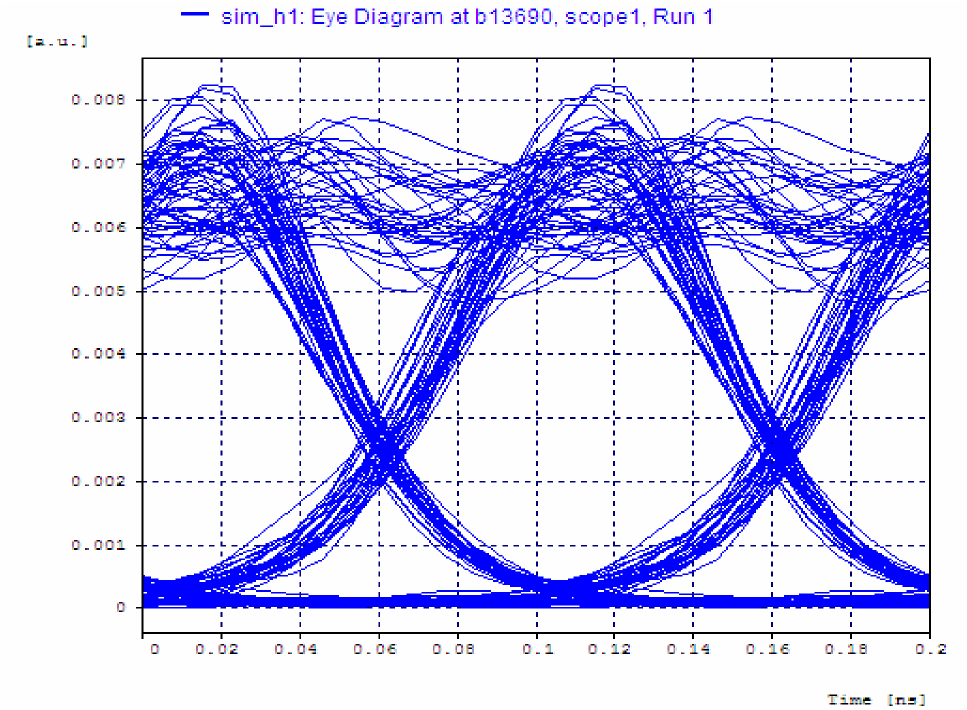

Figure 3.3: Eye-diagram of optical communication system for dispersion value = 8

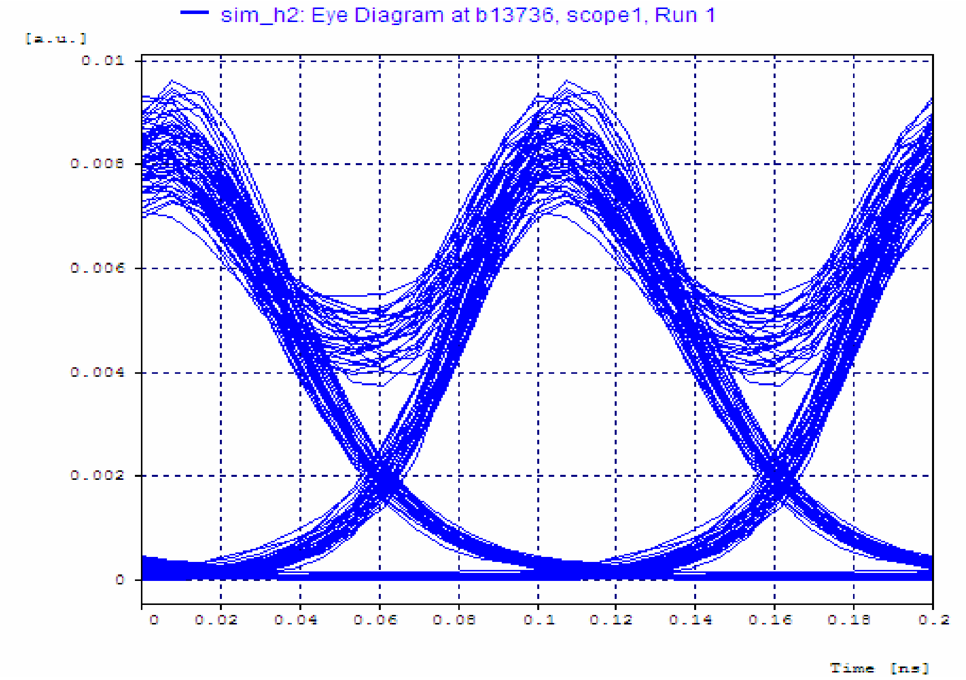

Figure 3.4: Eye-diagram of optical communication system for dispersion value = 10

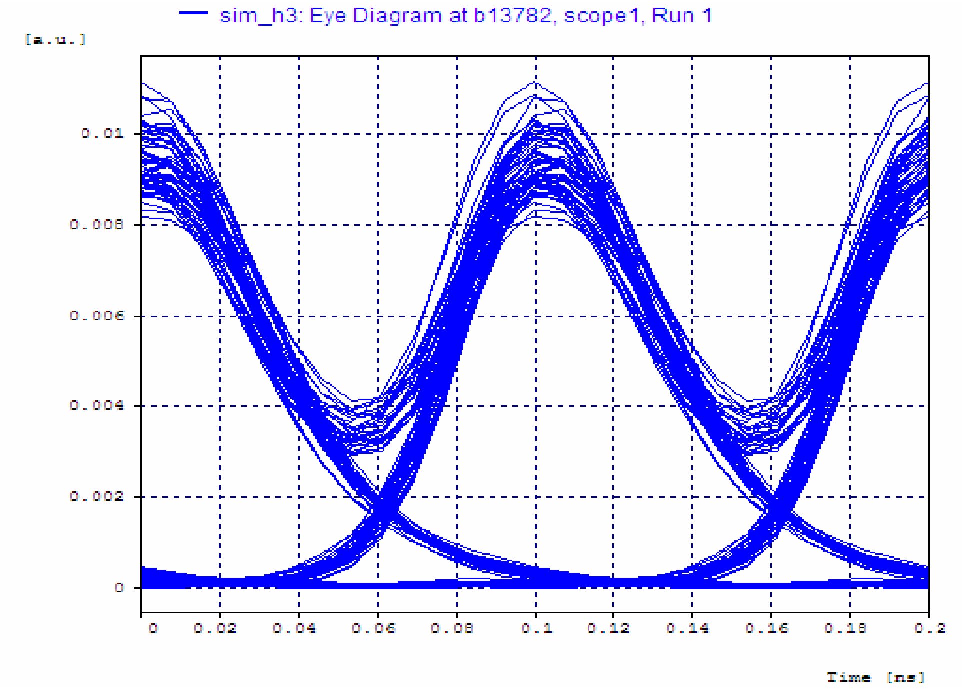

Figure 3.5: Eye-diagram of optical communication system for dispersion value = 12

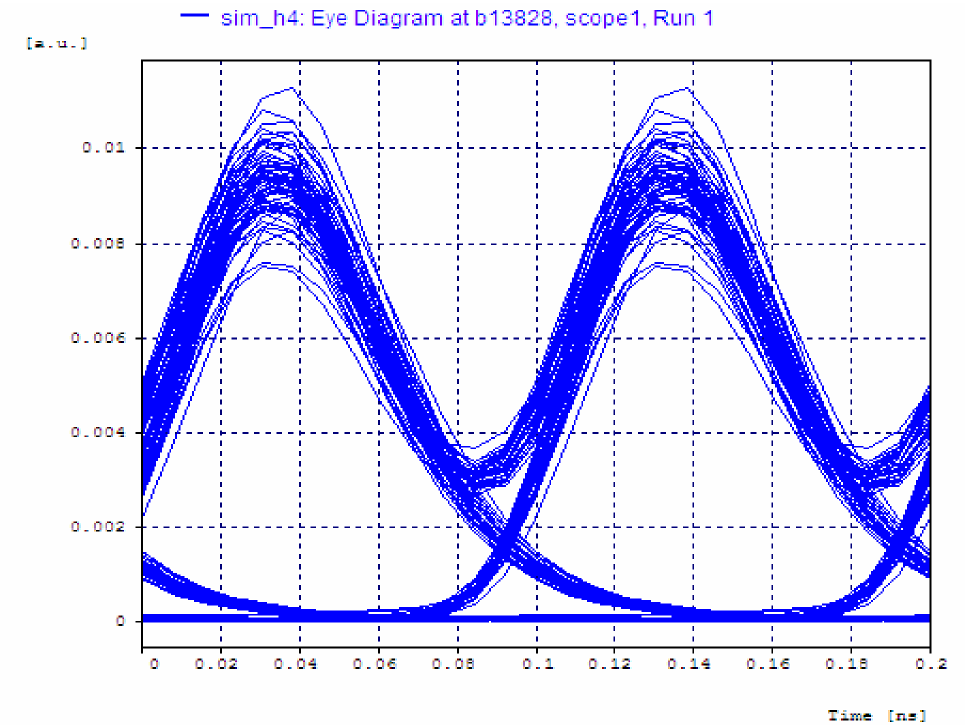

Figure 3.6: Eye-diagram of optical communication system for dispersion value = 14

The figures (3.3), (3.4), (3.5), and (3.6) show the eye diagrams taken for different values of dispersion parameter with standard single mode fiber length of 120 km and DCPF length of 20 km. It has been seen from the diagrams that as the value of dispersion parameter increases, the eye opening increased. Hence the performance of the optical communication system improves with increase in dispersion parameter. Figures (3.7), (3.8), (3.9), and (3.10) given below show the optical spectrums obtained at different values of dispersion parameter.

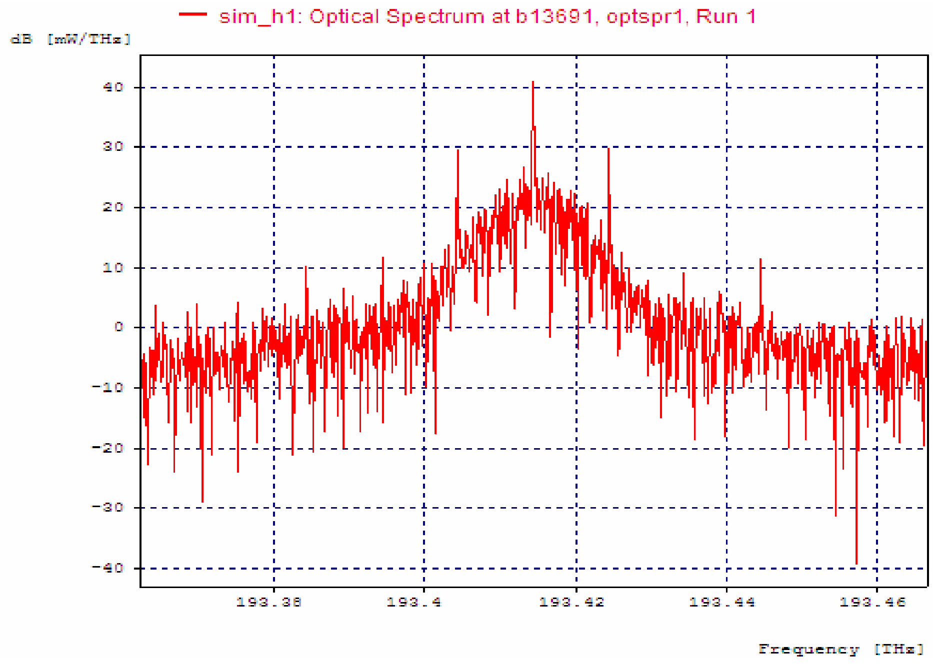

Figure 3.7: Optical spectrum of optical communication system for dispersion value = 8

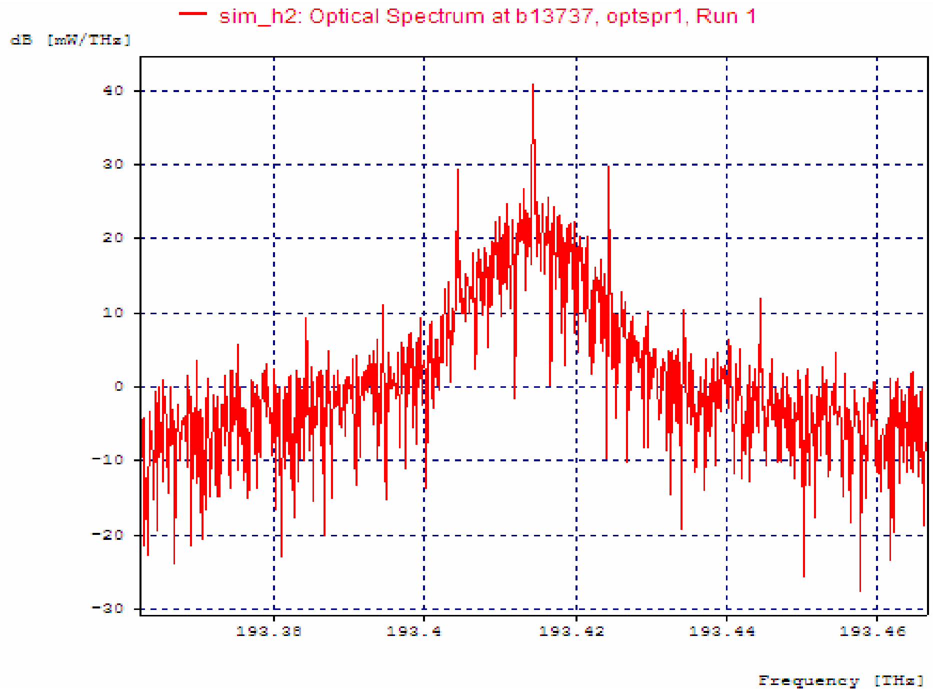

Figure 3.8: Optical spectrum of optical communication system for dispersion value = 10

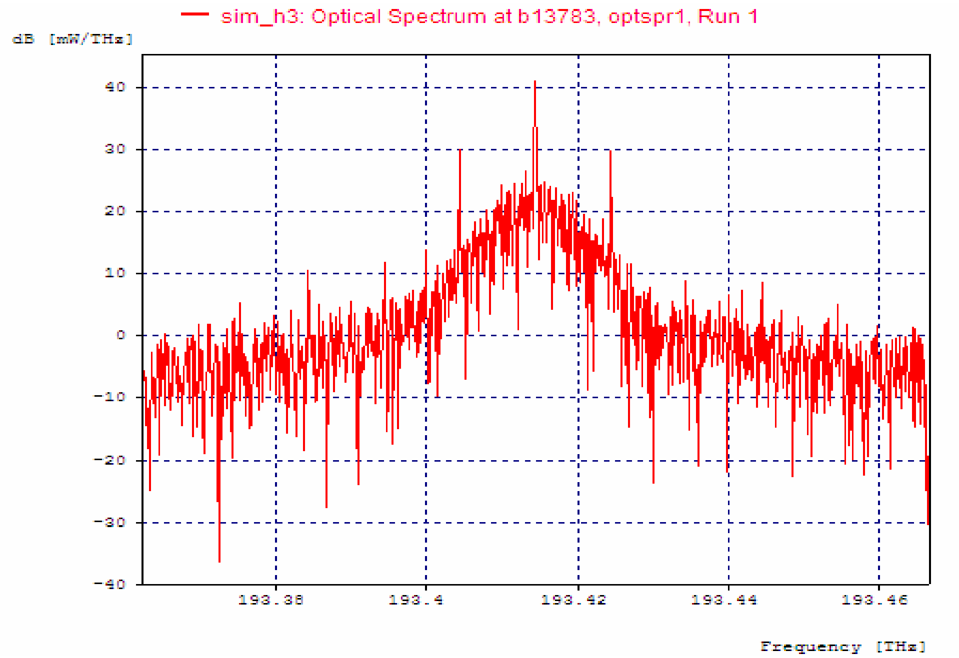

Figure 3.9: Optical spectrum of optical communication system for dispersion value = 12

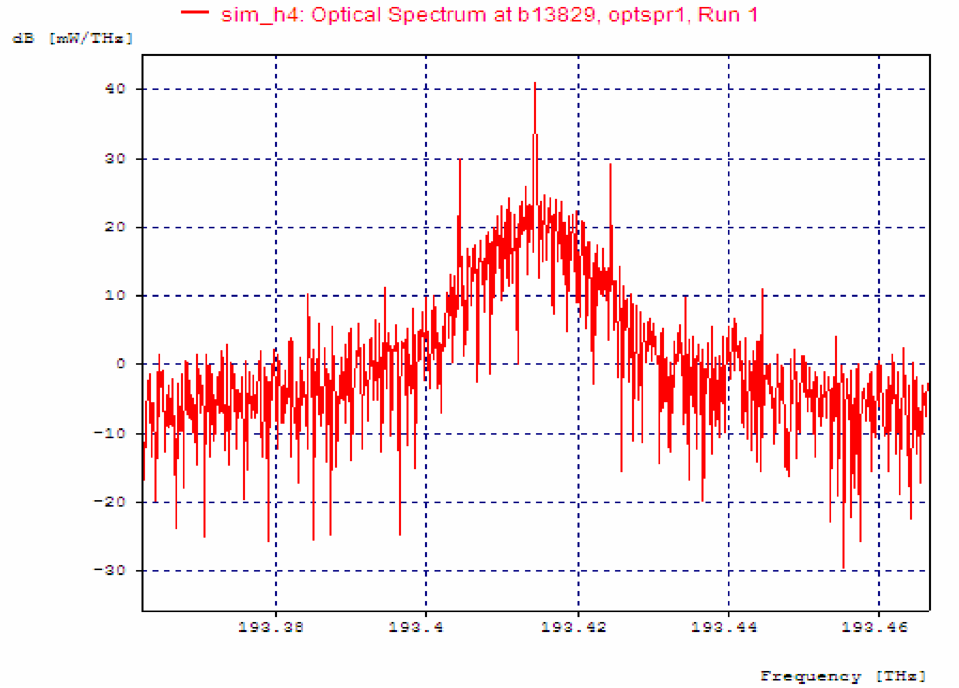

Figure 3.10: Optical spectrum of optical communication system for dispersion value = 14

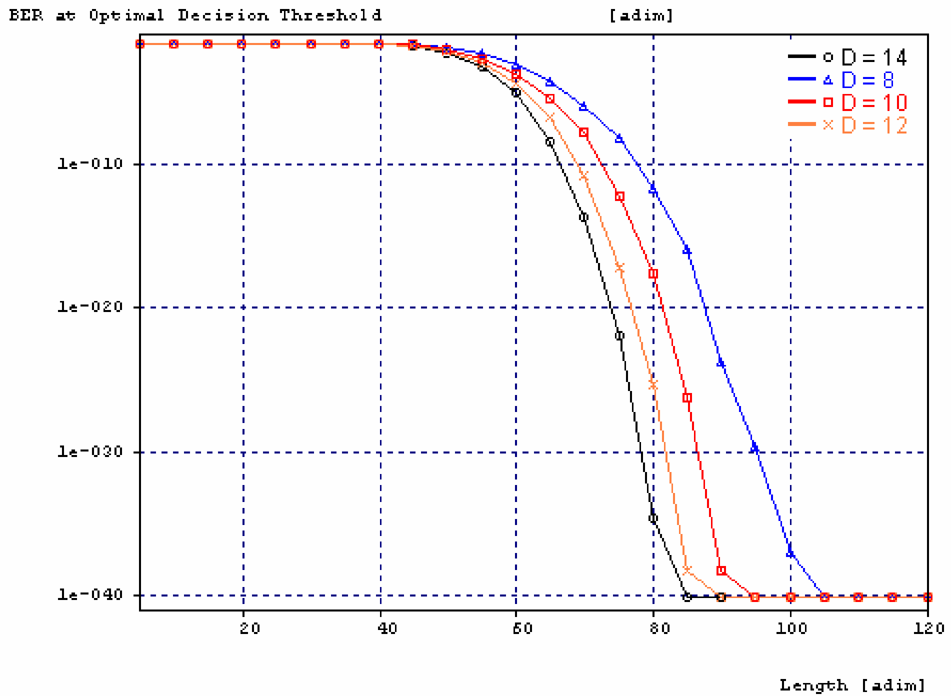

Figure 3.11: BER value versus single mode fiber length for variable dispersion parameter = 8, 10, 12, and 14 of RZ pulse.

Figure (3.11) shows the bit error rate (BER) for various values of dispersion parameters against the fiber length of standard single mode fiber. Upto a certain length of fiber the effect of dispersion parameter on BER is negligible but as the length of fiber increases, the effect can be noted. It can be seen that with dispersion value of 14, minimum BER is achieved. Hence with increase in dispersion parameter, the value of BER is decreased.

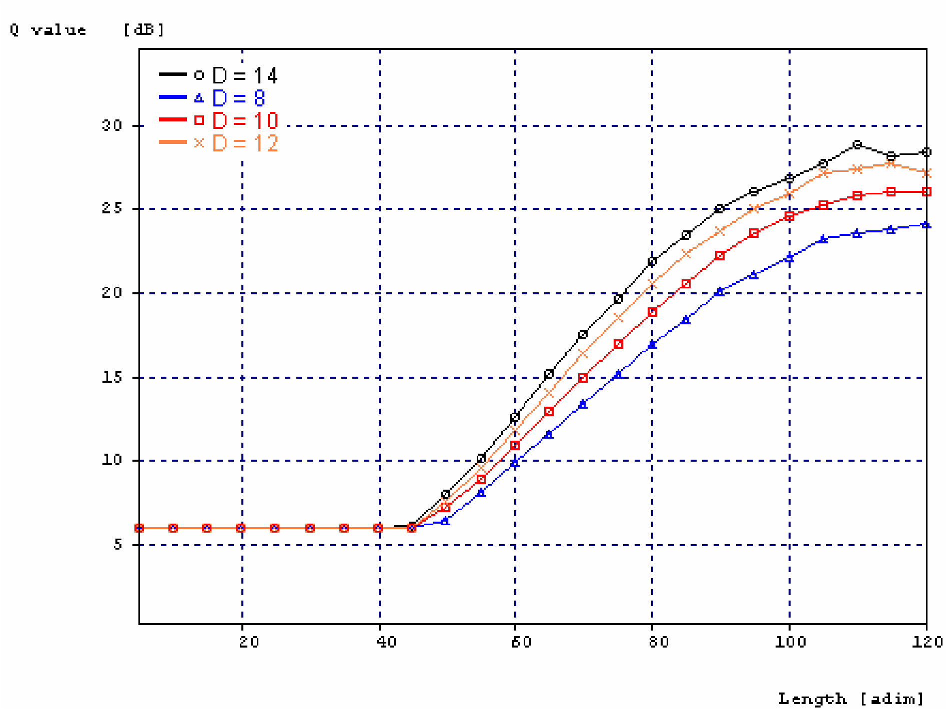

Figure 3.12: Q value versus single mode fiber length for variable dispersion parameter = 8, 10, 12, and 14 of RZ pulse.

Figure (3.12) shows Q-factor for various values of dispersion parameters against the fiber length of standard single mode fiber. It is seen that the Q-factor remains same for certain value of length. As the length of the fiber increases, the effect of dispersion parameter on Q-factor can be noted. The value of Q-factor at 120 km length for dispersion value 8, 10, 12, 14 is 24dB, 26dB, 27.1dB, 28.3dB respectively. Hence, the Q-factor of the system improves as the fiber length increases with increase in the value of the dispersion parameter for the dispersed manage RZ pulse system.

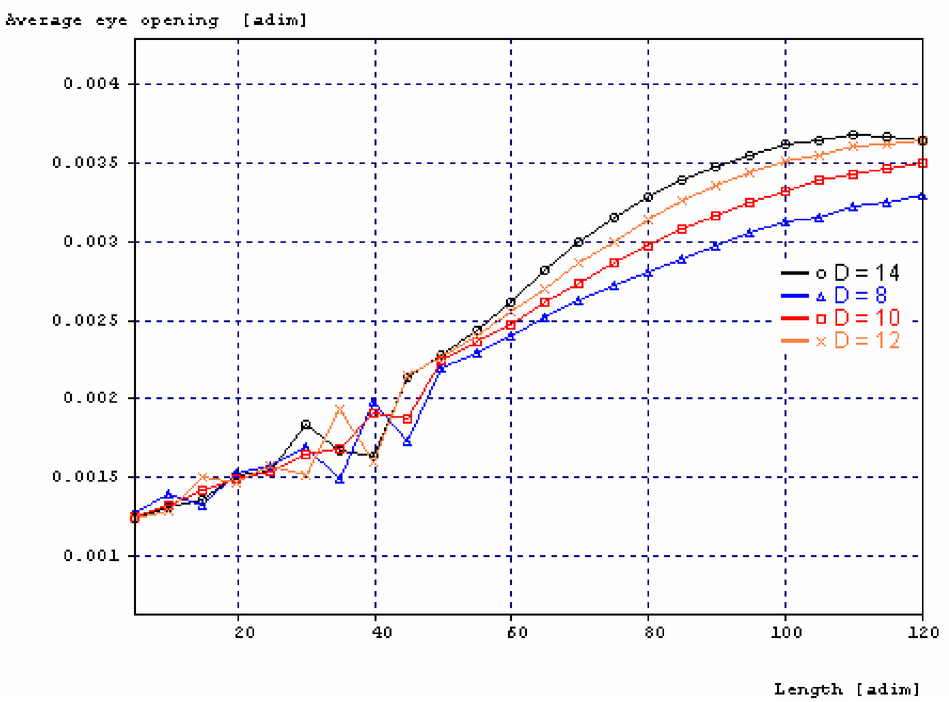

Figure 3.13: Average Eye opening value versus single mode fiber length for variable dispersion parameter = 8, 10, 12, and 14 of RZ pulse.

Figure (3.13) shows average eye opening for various values of dispersion parameters against the fiber length of standard single mode fiber .For the value of fiber length upto 40 km, the average eye opening for low dispersion parameters is more than the higher value of dispersion parameter. After that the average eye opening value is better for high values of dispersion parameter. The average eye opening value is almost same for dispersion value of 12 and 14 at fiber length of 120 km. Hence at low value of fiber length, the average eye opening is more for small values of dispersion parameters and vice-versa. Hence with increase in the valve of dispersion parameter, the performance of the system becomes better as there is increase in the value of average eye opening.

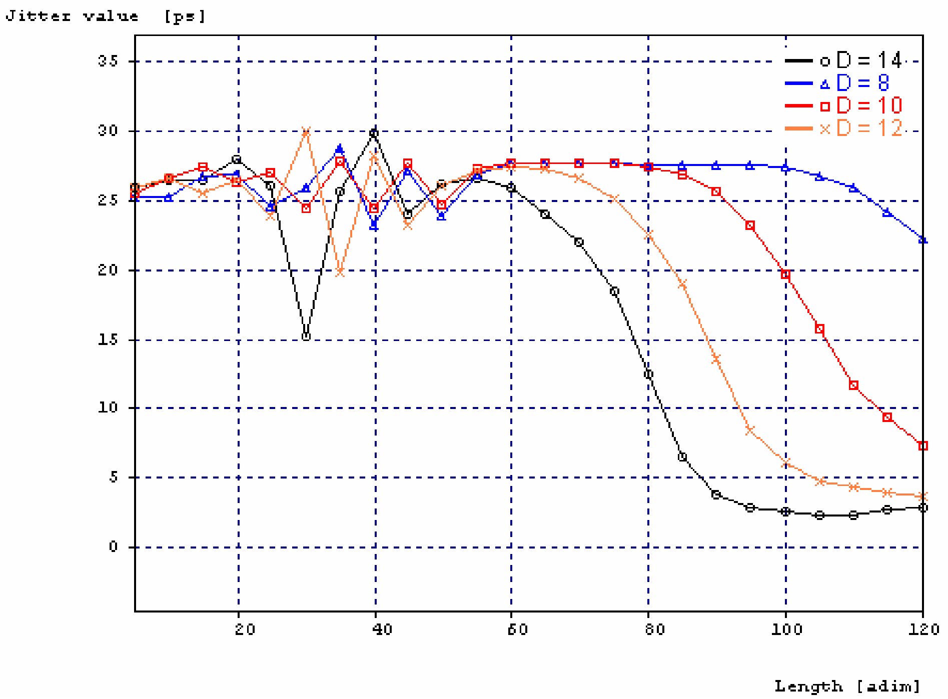

Figure 3.14: Jitter value versus single mode fiber length for variable dispersion parameter = 8, 10, 12, and 14 of RZ pulse.

Figure (3.14) shows timing jitter values for various values of dispersion parameters against the fiber length of standard single mode fiber. For the value of fiber length upto 60 km, there is a fluctuation in the values of timing jitter for all the values of dispersion parameter. After that the timing jitter value decreases with increase in the value dispersion parameter. The dispersion parameter with value of 14 has less timing jitter value. The values of timing jitter at 120 km length of single mode fiber for dispersion value of 8, 10, 12 and 14 is 22ps, 8ps, 4ps, 3.6ps respectively. It can be seen that for the values of 12 and 14 the jitter value is almost same. Hence, there is an improvement in the system performance with increase in the dispersion parameter. Figure (3.15), (3.16), (3.17), and (3.18) given below show the optical spectrums for the different values of duty cycle for RZ pulse.

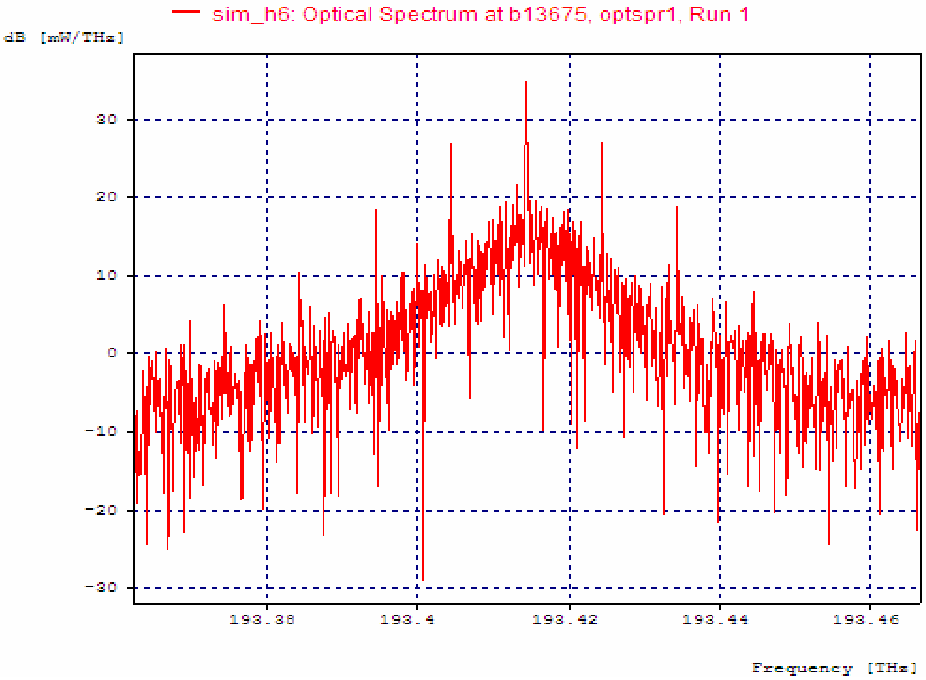

Figure 3.15: Optical spectrum of optical communication system for duty cycle = 0.2

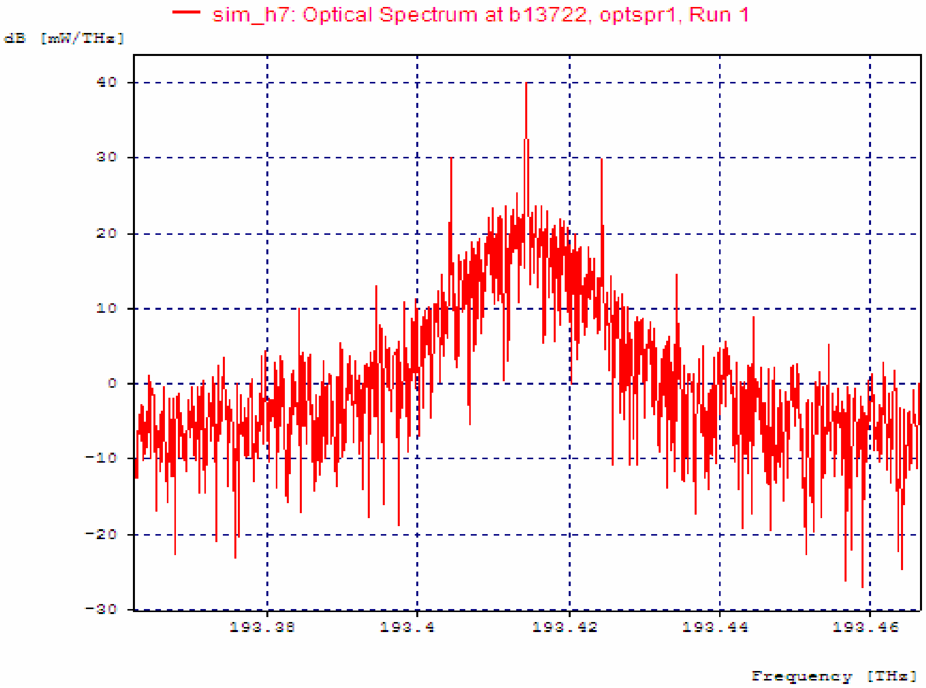

Figure 3.16: Optical spectrum of optical communication system for duty cycle = 0.4

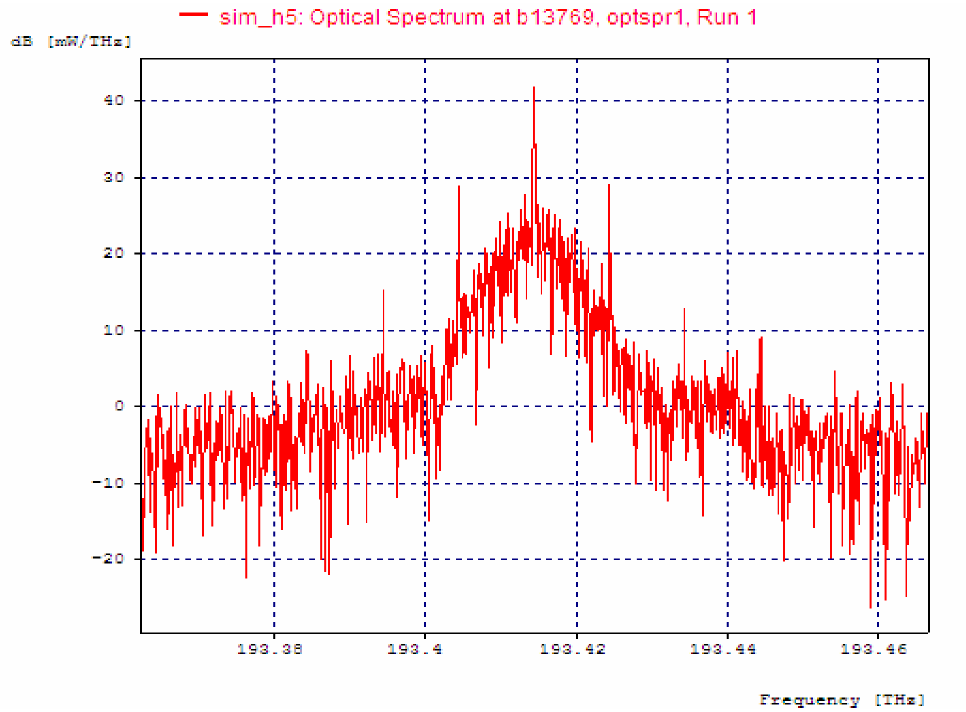

Figure 3.17: Optical spectrum of optical communication system for duty cycle = 0.6

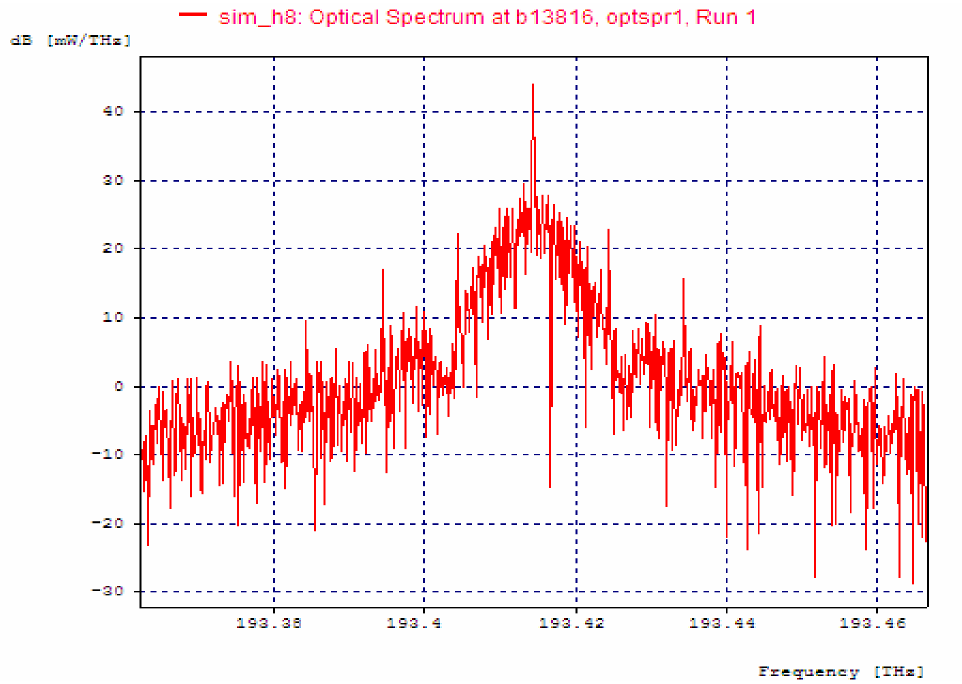

Figure 3.18: Optical spectrum of optical communication system for duty cycle = 0.8

3.4 Conclusion

In this chapter, the performance of 10 Gbps optical communication with the dispersion managed RZ pulse has been reported. The effect of varying the dispersion parameter of single mode fiber on optical communication system has been noted. It is observed that with increase in the value of dispersion parameter, there is an increase in the average eye opening and Q-factor value. The best result is achieved at the dispersion value of 14. It is reported that timing jitters decreased with increase in the vales of dispersion parameter. Also a good desirable bit error rate value is achieved as the value of dispersion parameter is increased in the dispersed manage system. It is observed that by reducing the duty cycle, the performance of the system is improve.

CHAPTER 4

PERFORMANCE OF OPTICAL COMMUNICATION SYSTEM WITH DIFFERENT MODULATION FORMATS

In this chapter, the performance of NRZ, CSRZ and doubinary modulation format at 10 Gb/s for the optical communication system at 10 Gb/s is analyzed. The performance evaluation of the modulation format has been analyzed in terms of the bit error rate against the accumulate dispersion and optical signal to noise ratio. The dispersion tolerance of the modulation formats has been analyzed. It is observed that doubinary modulation format provides the maximum dispersion tolerance. It is shown that CSRZ has the lowest bit error rate BER value. It is reported that CSRZ modulation format has the edge over NRZ and doubinary modulation format. The performance of the NRZ, CSRZ and doubinary has been observed which shows that CSRZ is better for long optical communication system at 10 Gb/s.

4.1 Introduction

The optical communication systems are used as high speed long haul communication system. Due to high data rates, limitation due to dispersion and nonlinearities in the optical communication system has been of great concern as these parameters limits the overall efficiency of the system. An optical modulation format is the method used to impress data on an optical carrier wave for transmission over optical fiber. The ideal modulation format for long haul, high speed and WDM transmission links is the one that has a narrow spectral width, low susceptibility to fiber nonlinearity, large dispersion tolerance and good transmission performance and has a simple and cost-effective configuration for generation. In Intensity-modulated direct-detection (IM/DD) systems, there are two possible modulation formats, non return-to-zero (NRZ), in which a constant power is transmitted during the entire bit period, and return-to-zero (RZ), in which power is transmitted only for a fraction of the bit period. Most commercial systems use the NRZ modulation format [7]. The non-return-to-zero (NRZ) has been the most dominant modulation format in intensity modulated-direct detection fiber-optical communication systems for the last years. The reasons for using the NRZ in the early days of fiber-optical communication as it is not sensitive to laser phase noise, requires a relatively low electrical bandwidth for transmitter and receivers compare with the RZ and the simplest configuration of transmitter and receiver. The NRZ pulses has a narrow optical spectrum .The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference. The RZ pulse occupies just a part of the bit slot, so it has a duty cycle smaller than 1 and a broad spectrum. The RZ pulse shape enables an increased robustness to fiber nonlinear effects and to the effect of polarization mode dispersion (PMD). Due to its broader spectrum, the RZ pulse has a reduced dispersion tolerance and spectral efficiency [23]. The RZ achieves a 1-2 dB advantage in optically pre-amplified receiver sensitivity compared to the NRZ .Carrier suppressed RZ pulse is a special form of the RZ pulse where the carrier is suppressed. The difference between the CSRZ and conventional RZ is that the CSRZ signal has a π phase shift between adjacent bits. The CSRZ signal is far less sensitive to fiber nonlinear effects and provides better robustness against transmission impairments. Optical duobinary format s a very interesting modulation format, which offers high spectral efficiency and chromatic dispersion tolerance. In the duobinary format, the optical phases of "1" bits that are separated by an odd number of "0s" differ by π radians. The optical spectrum of the duobinary signal is very compressed as compared to many other binary formats [32]. The LPF duobinary has recently received significant attention. One reason for this is that duobinary can be easily created using simple low-cost techniques [50]. So different types of modulation techniques are used these days to enhance the performance of optical communication system. Each modulation format has its own advantages and disadvantages. Depending upon the required application, the modulation format is used.

Lender el at. [31] demonstrated a new approach to digital data transmission, termed duobinary and correlative, substantially increases speed over any band-limited media owing to correlation between signal states. Specific codes are used with or without carrier modulation. In the error detection process, it has been found that with this type of system it is unnecessary to introduce redundant digits into the original data stream.

K. Ennser and K. Petermann et al. [49] had investigated theoretically and experimentally the performance of RZ- versus NRZ transmission on standard single-mode fibers. On the basis of computer simulations, the RZ-transmission for the optimum system performance taking into account the dispersion, Kerr nonlinearity, attenuation and ASE noise was investigated. The parameters such as bit rate, distance and power levels are estimated for the lowest system degradation.

Yannick Keith Lizé, Xiaoxia Wu, Moshe Nazarathy, Yuval Atzmon, Louis Christen, Scott Nuccio, Mathieu Faucher, Nicolas Godbout, Alan E. Willner el at. [51] has demonstrated chromatic dispersion tolerance in optimized NRZ, RZ and CSRZ-DPSK demodulation.

Upto now, the non-return-to-zero (NRZ) has been demonstrated as the most dominant modulation format in intensity modulated-direct detection. The NRZ modulation format has its limitation at higher bit rates. In the recent years, work has been done on the novel modulation formats. In this chapter, the performance of the NRZ, CSRZ and doubinary modulation format at 10 Gb/s for the optical communication system is analyzed.

The chapter is divided into different sections. In the first section, the brief introduction about the different types of modulation formats is provided. The brief view about the NRZ, RZ, CSRZ and doubinary pulses is given. The second section describes the simulation setup for the optical communication system for the comparison of NRZ, CSRZ and doubinary modulation. The third section includes the simulation results and the different types of graphs obtained from that result has been discussed. The fourth section gives the conclusion of this chapter.

4.2 Simulation set up to examine the comparison of NRZ, CSRZ and Doubinary modulation formats.

Figure (4.1) shows the schematic diagram for different modulation techniques. The transmitter section consists of NRZ transmitter, CSRZ transmitter and Doubinary transmitter. Each transmitter has its own configuration to produce the desired modulation format. The figure (4.2) given below show how the NRZ modulation format is produced. It consists of pseudo random sequence (PRSB) source, NRZ CODER, continuous wave pump, Bessel filter and machzender modulator(MZM). The light of the continuous wave (CW) pump is externally modulated in a MZM. The two inputs to the MZM modulator is output of filter and pump. The input power is set at -30dB.The output of the modulator is NRZ pulse. The figure (4.3) shows how the CSRZ modulation format is produced. It consists of two machezender modulator, continuous wave pump, clock generator and NRZ pulse source. The first MZM modulator (MZM 1) generates NRZ optical signal by external modulation of the CW-pump light. The CSRZ signal forming is realized in the second MZM (MZM 2), which is biased at the”zero”point. The figure (4.4) shows how the doubinary signal is

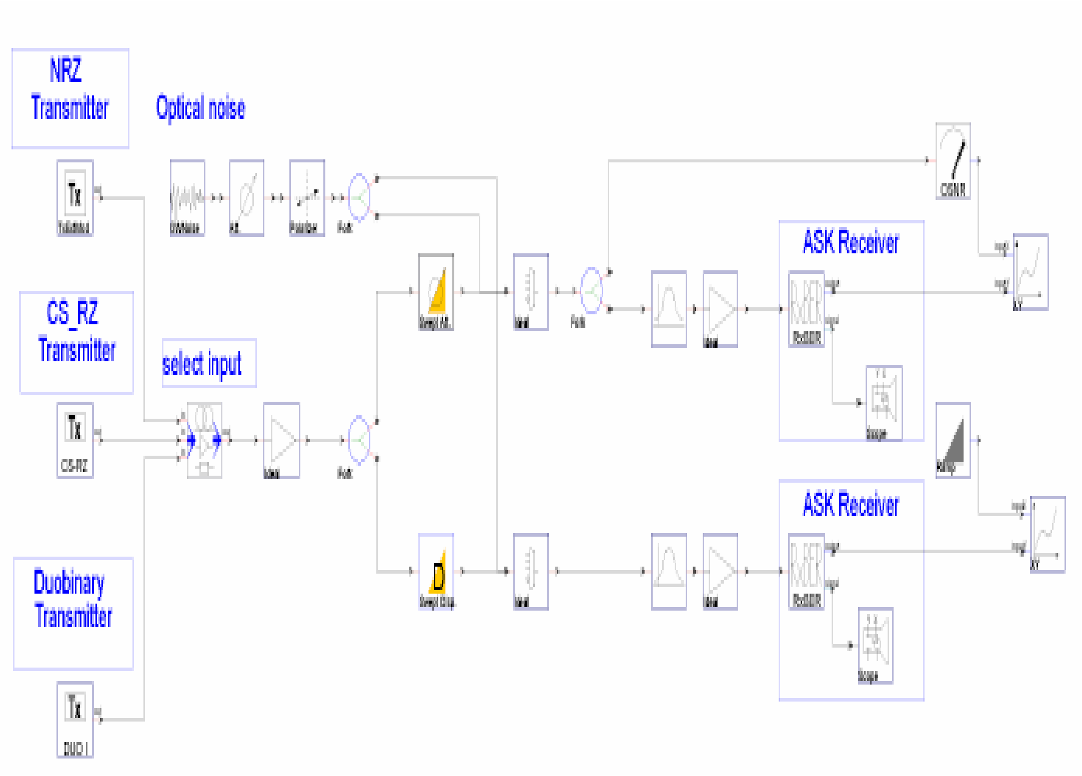

Figure 4.1: Simulation set for comparison of different modulation formats

produce. For duobinary generation, electrical NRZ signals are pre-coded in an encoder (EX-OR circuit).The pre-coded binary signals are converted pump light. The CSRZ signal forming is realized in the second MZM (MZM 2), which is biased at the"zero"point. The figure (4.4) shows how the doubinary modulation format is produce. For duobinary generation, electrical NRZ signals are pre-coded in an encoder (EX-OR circuit).The pre-coded binary signals are converted to 3-level duobinary signals by band-limiting electrical filters. The transmission section consists of amplifiers, filters and splitter. The receiver is of ASK type. The various devices are used to measure BER, OSNR and eye diagrams.

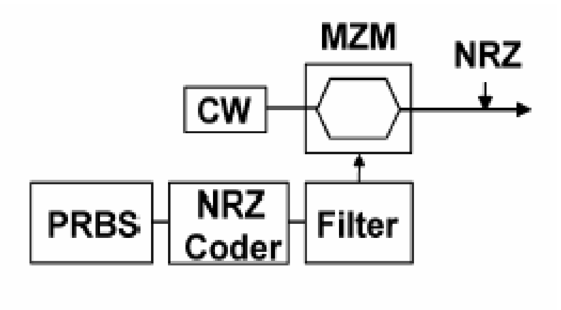

Figure 4.2: NRZ Transmitter

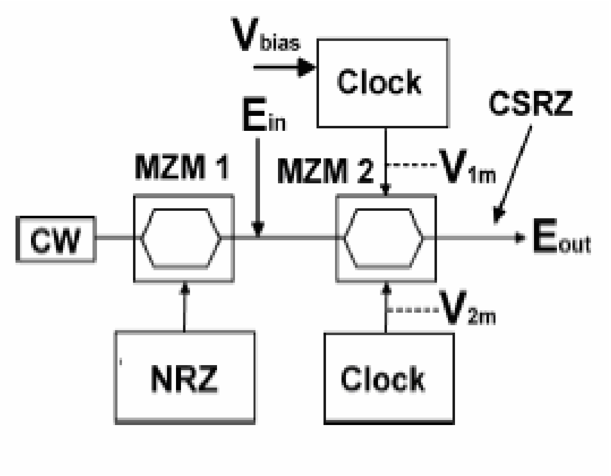

Figure 4.3: CSRZ transmitter

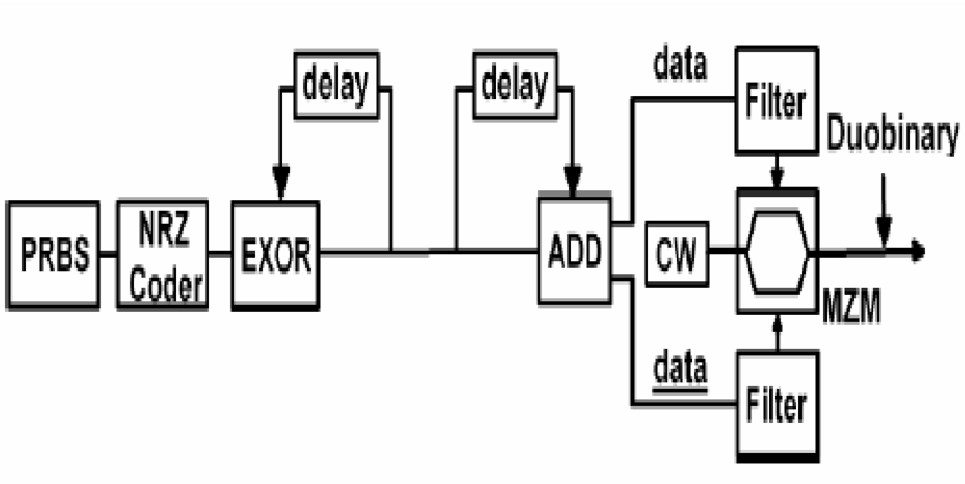

Figure 4.4: Doubinary Transmitter

4.3 Result and Discussion

In previous section, various component and parameters used in simulation setup are discussed. Using some of these components, the bit error rate (BER), optical signal to noise ratio and eye-diagrams is measured at the receiver end.

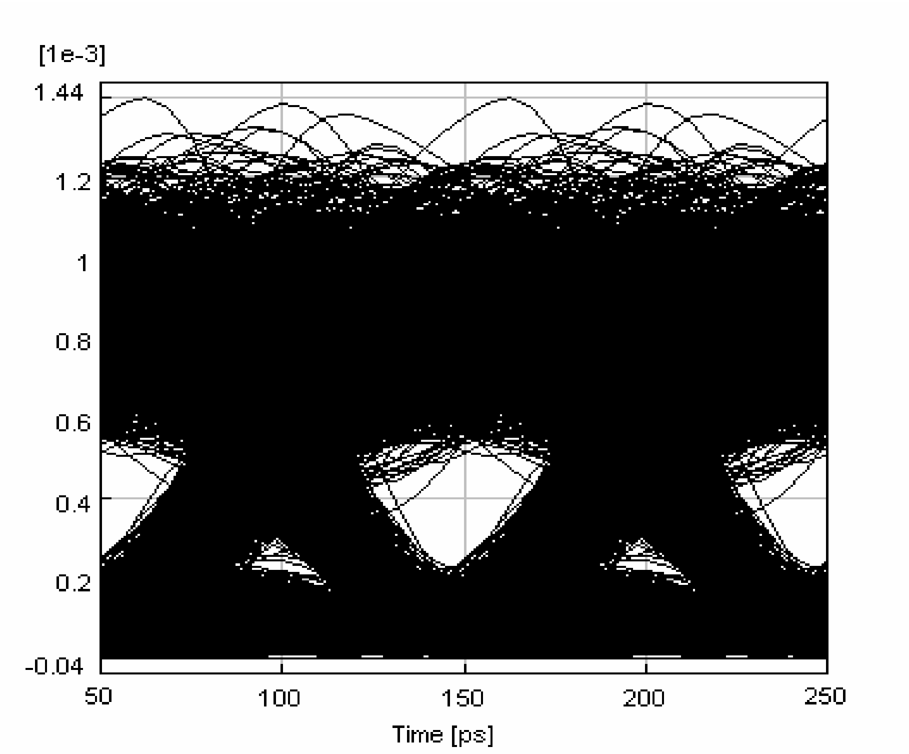

Figure 4.5: Eye diagram of NRZ modulation format for BER vs. acc_dispersion

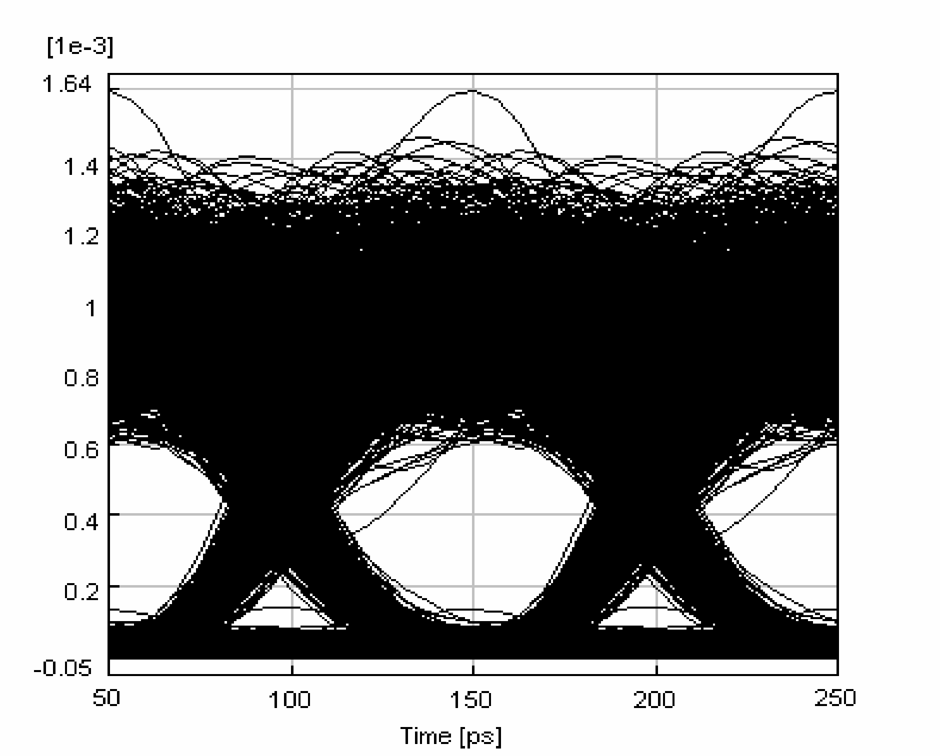

Figure 4.6: Eye diagram of CSRZ modulation format for BER vs. acc_dispersion

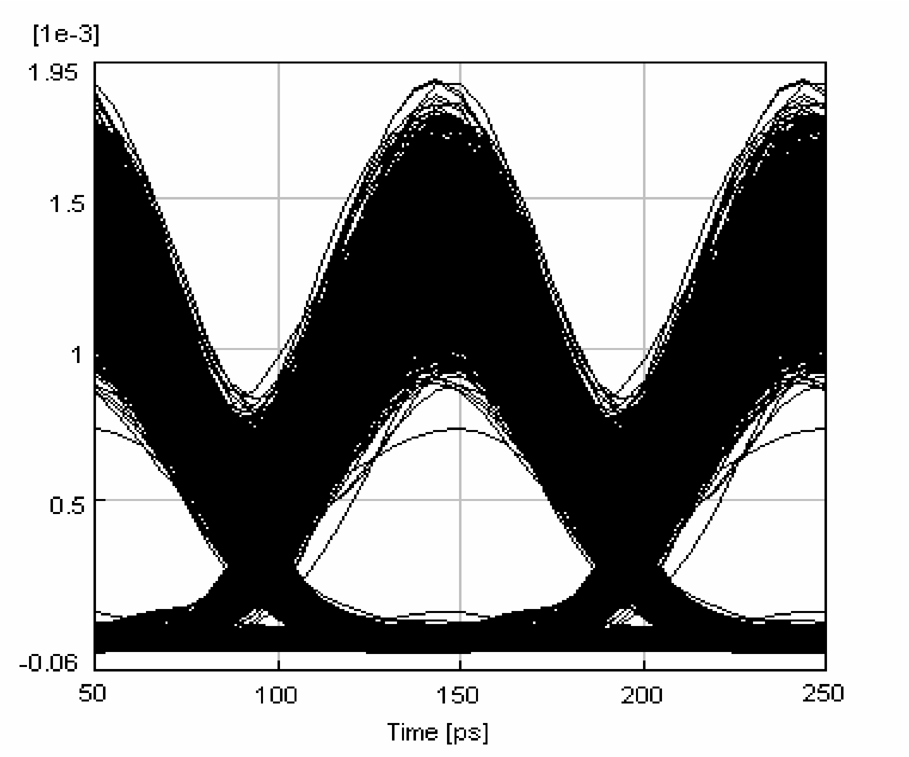

Figure 4.7: Eye diagram of Doubinary modulation format pulse for BER vs acc_dispersion

The above figures (4.5), (4.6), (4.7) show the eye diagrams of NRZ, CSRZ and doubinary modulation format for BER vs. acc_dispersion. It can be analyzed that the eye opening for doubinary modulation format is more than the NRZ and CSRZ modulation formats. So the tolerance to the dispersion by the doubinary modulation format is better. NRZ modulation format provided the least tolerance to the dispersion. So doubinary modulation format can be recommended for very long haul optical communication system at vary high bit rates. The effect of dispersion is quite high at high bit rates, therefore NRZ modulation format is not used for very large distance communication system at high bit rates although the cost of implementation of NRZ transmitter and receiver are less as compare to the CSRZ and doubinary modulation formats. CSRZ modulation format can be implemented for high bit rates but the distance of communication can be limited due to dispersion effect. Hence the doubinary modulation format gives the best tolerance to the dispersion.

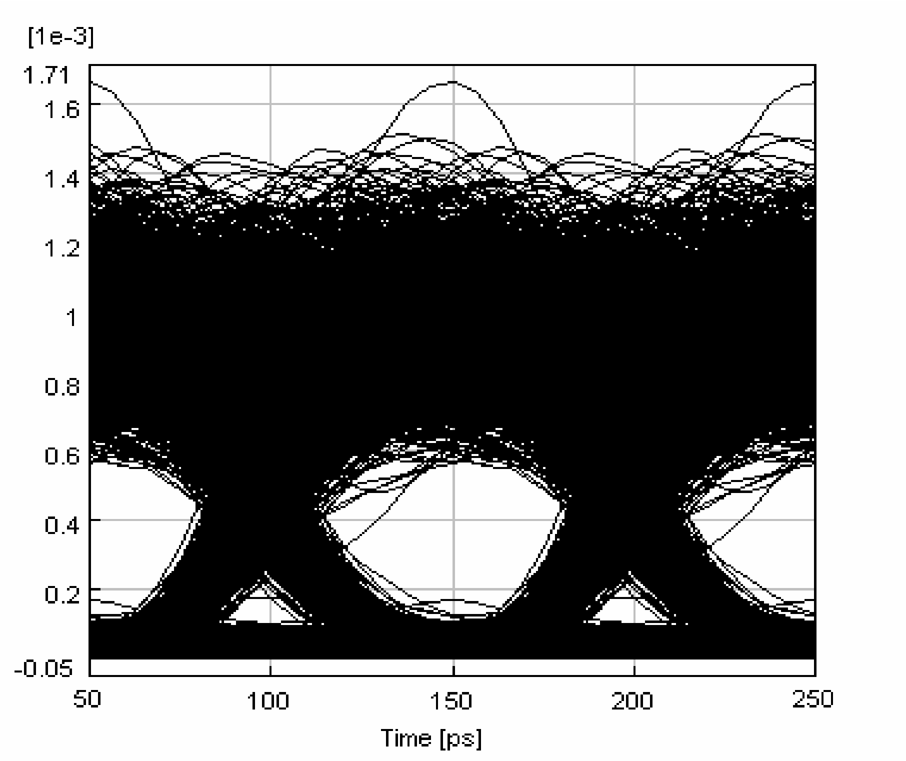

Figure 4.8: Eye diagram of NRZ modulation format for BER vs. OSNR

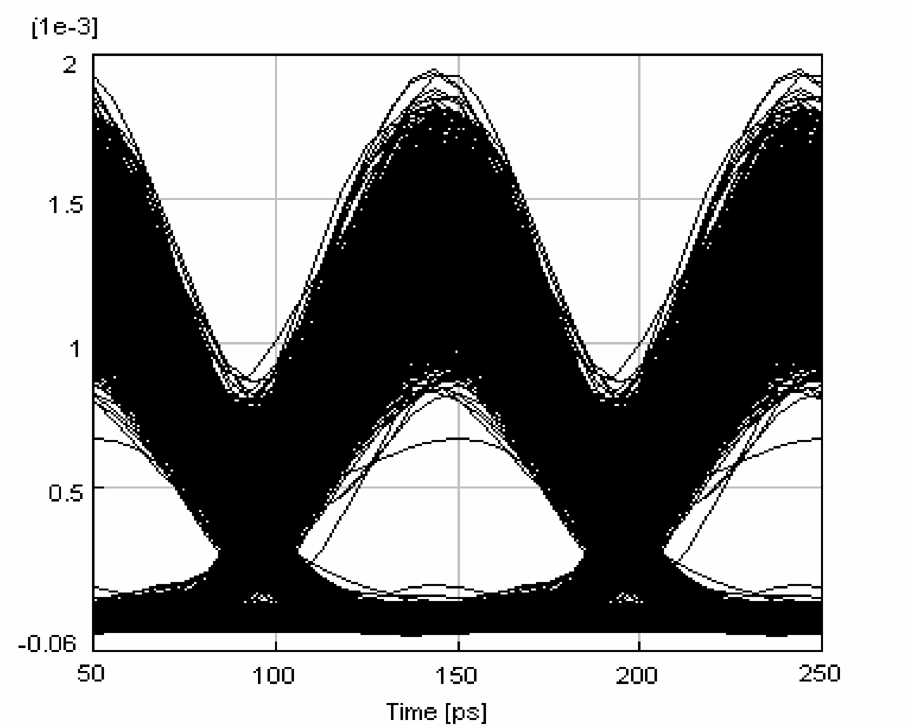

Figure 4.9: Eye diagram of CSRZ modulation format for BER vs. OSNR

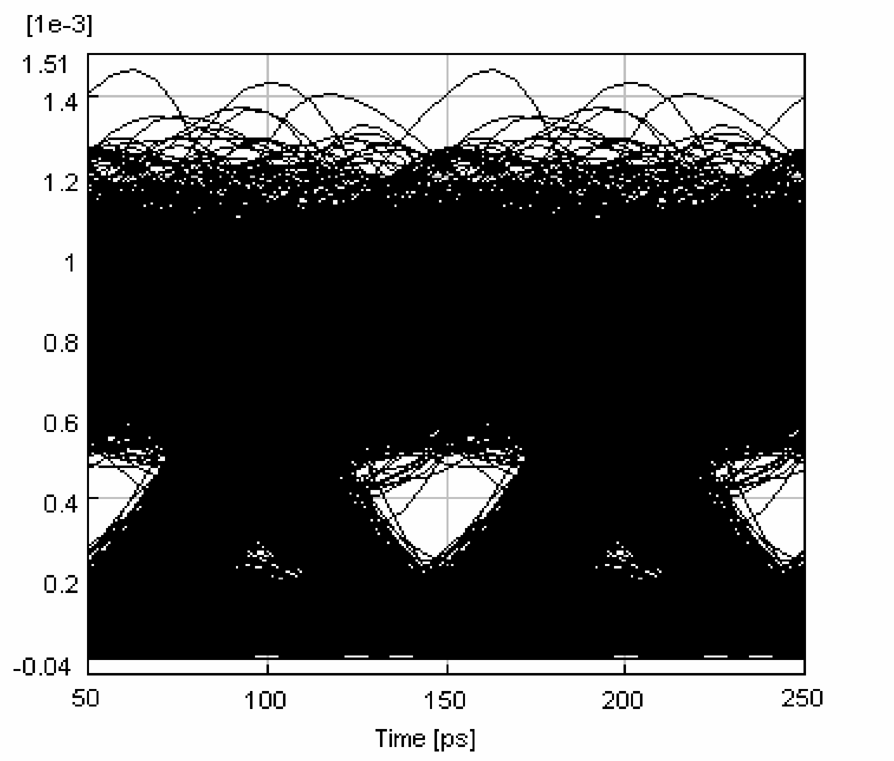

Figure 4.10: Eye diagram of doubinary modulation format for BER vs. OSNR

The above figure (4.8), (4.9), (4.10) show the eye diagram for BER vs. OSNR for the different modulation format used. It can be analyzed that the eye opening is more for CSRZ modulation format as compared to the NRZ and doubinary modulation format. The worst case can be seen for the doubinary modulation format. The OSNR can be understood as a measure of the ratio of the signal to noise power in an optical channel. Due to the narrow spectrum of the doubinary system, the intersymbol interference has quite a large effect on the doubinary modulation format. The effect of intersymbol interference reduces the OSNR of the doubinary modulation format. Due to this effect the optical communication systems with dobinary modulation format has some limitation while using for long distance at high bit rates. The CSRZ format has the maximum eye opening values so it can be considered for the optical communication system for long distance at high bit rates since it provided the best OSNR value .It is observed that the NRZ modulation format has a better OSNR than the doubinary so it can be used for small distance et high bit rates but not for large distance due to other limitations.

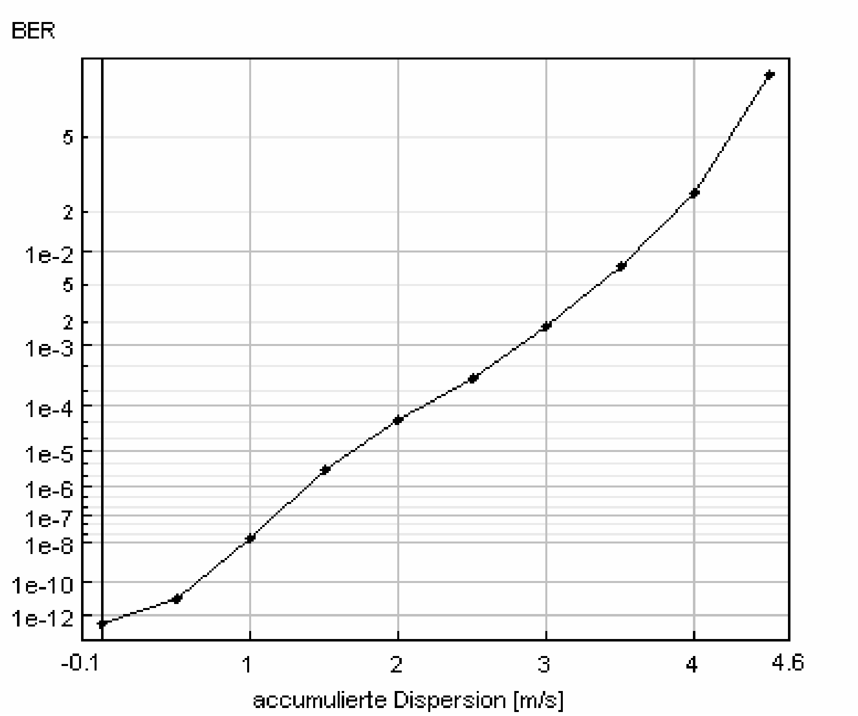

Figure 4.11: BER vs. acc_dispersion for NRZ modulation format

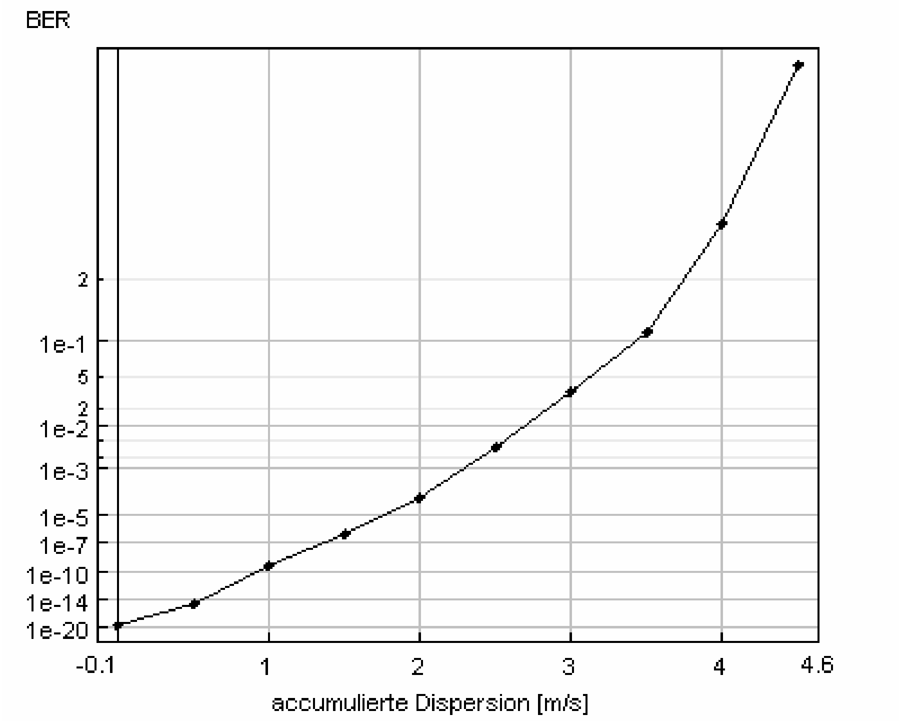

Figure 4.12: BER vs. acc_dispersion for CSRZ modulation format

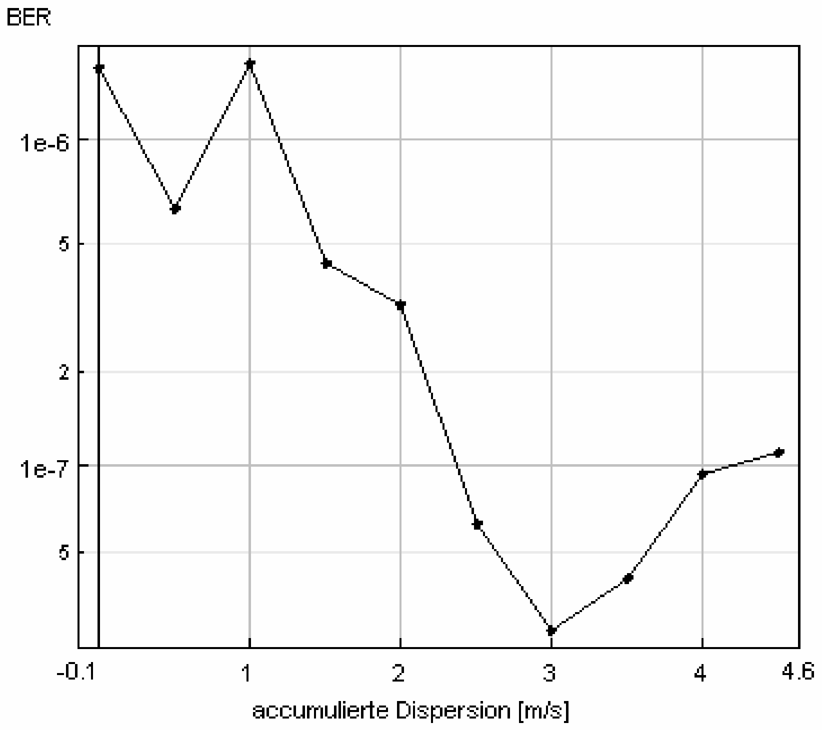

Figure 4.13: BER vs. acc_dispersion for Doubinary modulation format

The above figures (4.11), (4.12), (4.13) show the graphs for BER vs. accumulate dispersion for the NRZ, CSRZ and doubinary modulation format. It can be seen that for NRZ and CSRZ format the value of bit error rate is quite high as compare to doubinary modulation format. The value of BER for NRZ, CSRZ, and doubinary modulation format at the accumulierte dispersion of 4.6 m/s is 0.075dB, 0.056dB and 0.00000014db.Hence the doubinary format has the best tolerance to the dispersion since it has less value of BER low for given value of acc. Dispersion.

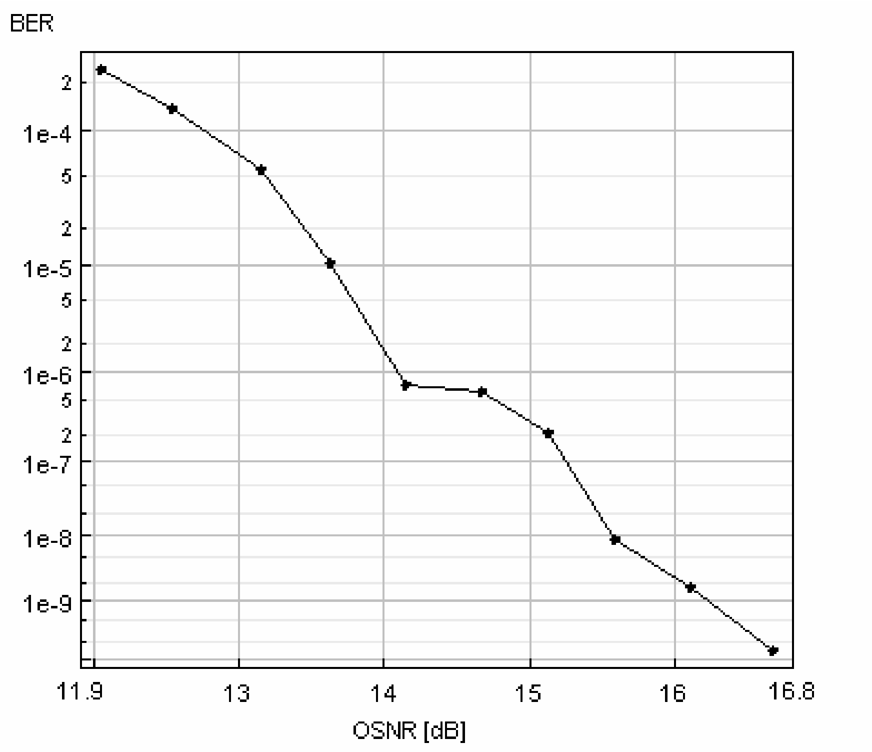

Figure 4.14: BER vs. OSNR for NRZ modulation format

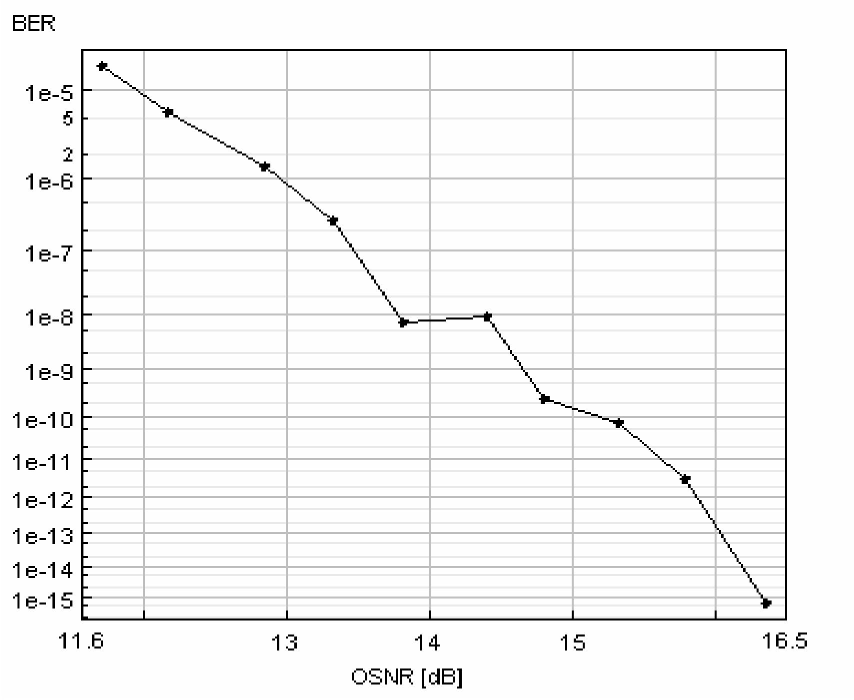

Figure 4.15: BER vs. OSNR for CSRZ modulation format

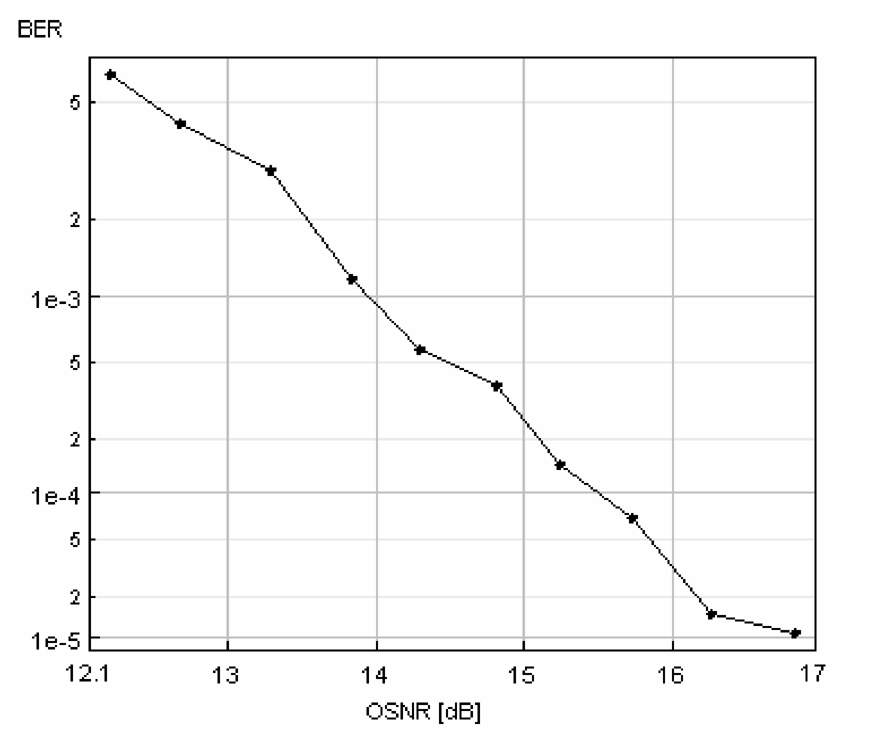

Figure 4.16: BER vs. OSNR for doubinary modulation format

The above figure (4.14), (4.15), (4.16) show the graphs for BER vs. OSNR for the NRZ, CSRZ and doubinary modulation format. It can be seen from all the three graphs that the value of BER is decreased with increase in the OSNR value. The value of BER for the NRZ, CSRZ doubinary modulation format at OSNR value of 16 is $1e^{-9}, 1e^{-14}, 1e^{-5}$ respectively. The CSRZ modulation format has the best BER value from the entire different modulation format at. a given value of OSNR where as doubinary has the worst BER value. Hence the doubinary system requires a high input power to achieve the desired BER value which limits the performance of the doubinary modulation format to some extent. It is observed that the CSRZ provides a good performance at high bit rate. The CSRZ modulation can be used for long distance communication system at high bit rates.

4.4 Conclusion

In this chapter, the performance of NRZ, CSRZ and doubinary modulation format at 10 Gb/s for the optical communication system is analyzed. It is observed that the CSRZ modulation format has the edge over the NRZ and doubinary modulation format. It is shown that the CSRZ has the lowest BER value. It is reported that the Doubinary modulation format provides the higher dispersion tolerance among the three modulation formats. The doubinary modulation format can be recommended for long distance communication systems at high bit rates but its performance are limited by the low OSNR value. It is observed that the NRZ modulation format has the worst performance in terms of dispersion tolerance. It is reported that the NRZ modulation format has a better OSNR value than the doubinary modulation format. The NRZ modulation format can be used for small distance communication system a high bit rates. It is concluded that the CSRZ modulation format is best for the long distance optical communication system due to its low value of BER and tolerance to the dispersion at high bit rates.

CHAPTER 5

COMPARISON OF DIFFERENT DISPERSION COMPENSATION TECHNIQUES AT HIGH BIT RATE

In this chapter, the performance of different dispersion compensation techniques with doubinary modulation format at high bit rates is analysed. The compensation techniques proposed are dispersion compensation fiber (DCF), reverse dispersion fiber (RDF), negative dispersion fiber (NDF), fiber Bragg Grating (FBG), optical phase conjugation (OPC). The comparison of different dispersion compensation techniques at different bit rate has been done. The comparison of different techniques has been analysed from the eye closure, bit error rate and Q- factor characteristics. The different bit rates used are 5, 10, 20, 30 and 40 Gb/s. It is observed that NDF is best suited for bit rate of 5 Gb/s bit whereas FBG and OPC can be recommended for bit rate of 10 Gb/s and 20 Gb/s. It is reported that the dispersion compensation techniques using combination of standard single mode fiber (SSMF) with dispersion compensation fiber (DCF) and reverse dispersion fiber (RDF) is best suitable for long haul optical communication systems at higher bit rates.

5.1 Introduction

The goal of an optical fiber communication system is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors. It is efficiently used to transmit the data to long distance at high bit rates. Their are many modulation formats used to transmit the data at high rates. Each of these modulation formats has their own advantages and disadvantages. To transmit data at very high bit rate, some special types of modulation formats are used. A very interesting modulation format is optical duobinary, which offers high spectral efficiency and chromatic dispersion tolerance. Duobinary transmission technology was introduced for the first time by A. Lender [31]. Duobinary modulation can be described as a combination of a conventional ASK-based modulation and phase shift keying (PSK). The reduction of the spectral width of the optical duobinary signal is the reason for its better dispersion tolerance compared to NRZ signals and enables an improved spectral efficiency in WDM systems. A further advantage of duobinary modulation is the suppression of SBS-effect; since in the optical duobinary spectrum the carrier is effectively suppressed [11]. At higher bit rate, the effect of chromatic dispersion is quite high. It limits the overall performance of the optical communication system at high bit rates. There are various types of dispersion compensation techniques used to limit this effect. The fiber based compensation techniques, fiber bragg grating and optical phase conjugator are some of the techniques used for dispersion compensation. In this chapter, performance of various compensation techniques with doubinary modulation format at high bit rate upto 40 GB/s is analysed.

Weinert, Ludwig, Pieper, Weber, Breue, Petermann, and Kuppers et al. [37] 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 is 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 is shown numerically that improvement is achieved by employing the newest type DCF which also compensates the dispersion slope of the SMF.

Price and Mercier el at. [32] demonstrated a reduced bandwidth optical digital intensity modulation with improved chromatic dispersion tolerance. In this, a simple optical modulation scheme using a lithium niobate Mach-Zehnder modulator driven by a three level drive waveform was proposed. The two-level intensity modulated (IM) optical signal obtained possesses a smaller optical bandwidth and thus greater chromatic dispersion tolerance compared with existing two-level IM methods used for high data rate transmission.

Garrett and Gnauck el at. [42] demonstrated wavelength-division-multiplexed transmission of 16 $\times$10-Gb/s non return-to-zero channels with 50-GHz spacing over 840 km of conventional single-mode fiber (SMF), or 14 times the 10-Gb/s dispersion limit, using a total of eleven chirped fiber gratings for dispersion compensation

Chowdhury el at. [44] proposed recent advances in optical phase conjugation and its application to 40 GB/s transmission**.** Optical phase conjugation is effective in compensating intra-channel nonlinearities in pseudo linear systems. Results of optical phase conjugation in 40 GB/s optical systems with different transmission distances and modulations formats, and varying conjugator locations is presented.

Upto now, various decomposition techniques for optical communication system has been demonstrated to limit the effect of the dispersion at bit rate up to 10 Gb/s. In the recent years, the demand to transmit data at high rate upto to many Gb/s has been increased and study is doing on this aspect. In this chapter, the comparison of different compensation techniques with doubinary modulation format at bit rate up to 40 Gb/s is analysed.

The chapter is divided into different sections. In the first section, the brief introduction about the doubinary modulation format and the various types of dispersion compensation techniques is given. The second section describes the simulation setup for the optical communication system for the comparison of different compensation techniques. The third section includes the simulation results and the result has been discussed. The fourth section gives the conclusion of this chapter.

5.2 Simulation setup of different compensation technique at high bit rate using Doubinary modulation format

The general set up for generation of doubinary signal is shown in figure (5.1). The transmitter section consists of data source (pnseq1), non-return-to-zero (NRZ) modulation driver (recnrz1, recnrz2), electrical filter (filbes1, filbes2), and logical not gate (logical_not1), modulator (oamod2_1) and laser source (laslor1). The data source was simulated to generate pseudo-random sequences with bit rate as variable. The bit rates taken were 5, 10, 20, 30 and 40 Gigabit per second. The data source feeds two drivers one directly and other through not gate that generates the NRZ signal. These two signals are passed to electrical filter of Bessel type. The Bessel filters have 5 poles. The laser source chosen is simulated at a centre frequency of 1550 nm (i.e. 193.4144890342 THz). All the signals i.e. two from the filter and the light of continuous wave (which is generated from the CW laser) are fed to the three arm machzender modulator. The 40 GHz doubinary signal is produced by the transmitter. The transmission medium consists of standard single mode fiber (SSMF) (fiber1), erbium doped fiber amplifier (EDFA) (oamfp1, oampfp2) as in line amplifiers and dispersion compensation fiber (DCF) (fiber2), and dispersion shifted fiber (DS) (fiber2) as dispersion compensation devices. The length of transmission medium is 100 km. At the receiver side PIN photodiode (photod_pin1) is used as the receiver that converts light energy to electric form. The pin photodiode simulated had 70% quantum efficiency. Its responsivity is 0,875104401174 A/W. The dark current is simulated at 0.1 nm. The Bessel electrical filter (filbes3) has 4 poles with -3db bandwidth of 7.5 GHz. The Bessel filter's output is fed to an electrical splitter (espl) that splits the electrical signal to electrical power scope (scope1), Q estimator (qestim1) and BER estimator (pestim1).

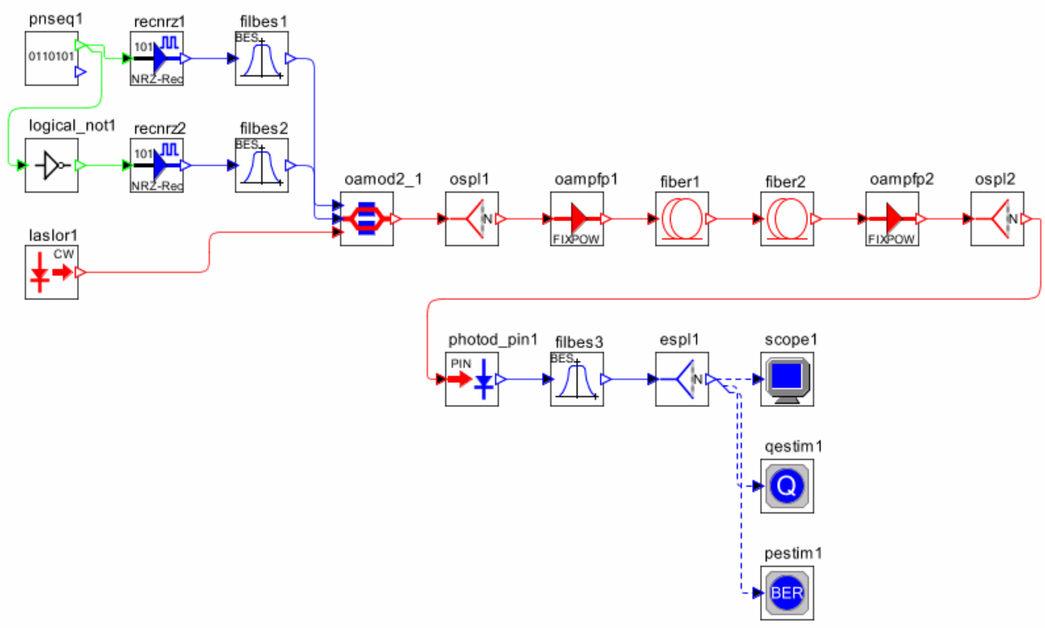

Figure 5.1: Setup for generation of Doubinary format and its compensation using SSMF and DCF

Figure (5.1) shows the schematic diagram of dispersion compensation using combination of standard single mode fiber (SSMF) and dispersion compensation fiber (DCF).The characteristics of the fibers used in figure (5.1) are given in table (5.1) and (5.2)

Transmission Loss @ $\lambda = 1550$ nm (dB)	0.2
Dispersion- D (ps/nm/km)	16
Nonlinearity refractive index	2.5×10^{-20}
Core Effective Area (m^2)	80×10^{-12}
Fiber PMD ($ps/km^{0.5}$)	0.1

Table 5.1: Parameter of SSMF

Transmission Loss @ λ = 1550 nm (dB)	0.2
Dispersion- D (ps/nm/km)	-80
Nonlinearity refractive index	2.5 x 10^{-20}
Core Effective Area (m^2)	20 x 10^{-12}
Fiber PMD ($ps/km^{0.5}$)	0.1

Table 5.2: Parameter of DCF

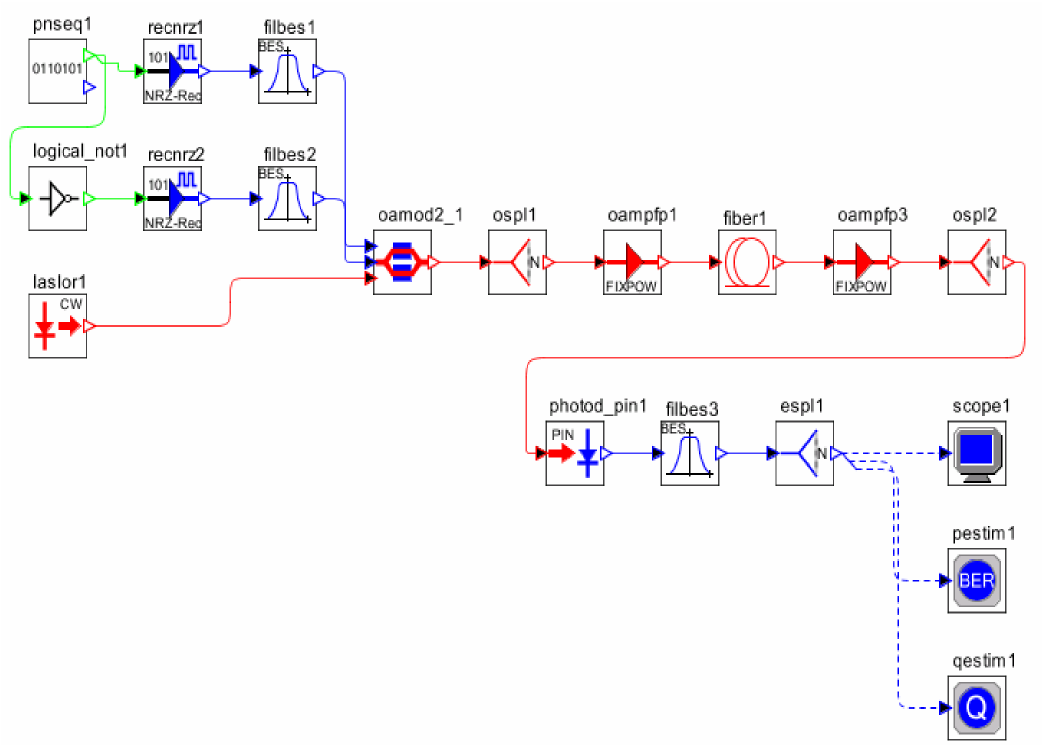

Figure 5.2: Setup for generation of Doubinary format and its compensation using NDF

Figure (5.2) shows the schematic diagram of dispersion using a negative dispersion fiber (NDF). The NDF (fiber1) simulated had an attenuation of 0.212 dB/Km and a negative dispersion of -2.5 ps/nm/Km. Fiber polarization mode dispersion (PMD) is 0.1 ps/ $km^{1/2}$. Nonlinear refractive index was taken as 2.5× 10^{20} m^2 /W. This setup is simulated using fiber length of 100 km.

Figure (5.3) shows the schematic diagram of dispersion using a standard single mode fiber (SSMF) and a reverse dispersion fiber (RDF). The RDF (fiber2) simulated had an attenuation of 0.24 dB/Km and a negative dispersion of -16 ps/nm/Km. Fiber polarization mode dispersion (PMD) is 0.03 ps/$km^{1/2}$. Nonlinear refractive index was taken as 2.8×10^{-18} m^2/W. For dispersion compensation using SSMF and RDF, the ratio of optical fiber lengths must be 1:1. The total simulation length is 100 km.

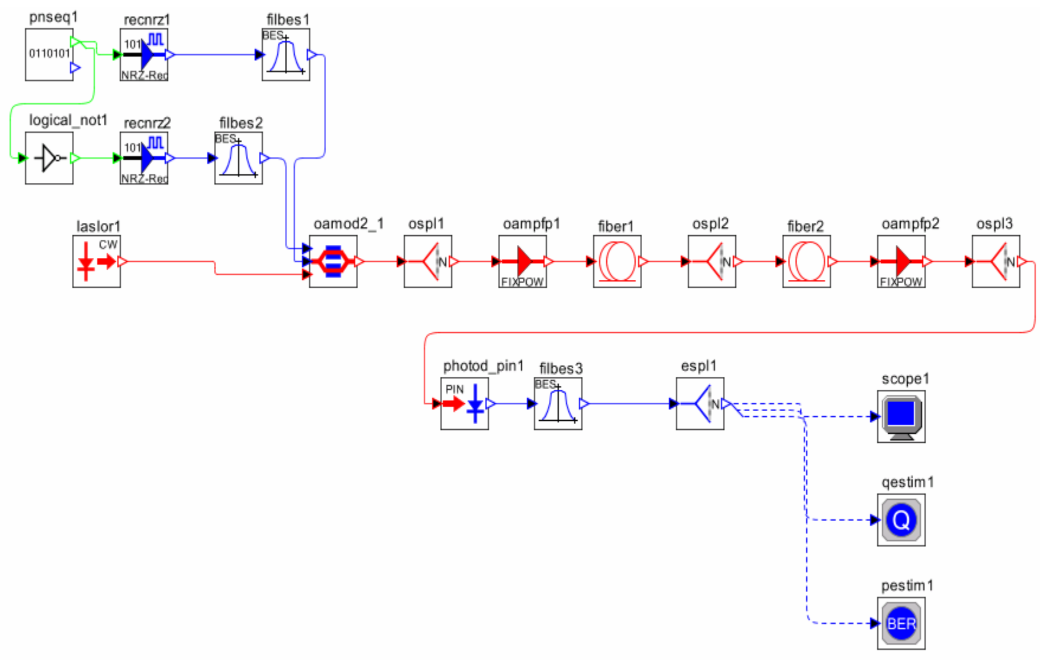

Figure 5.3: Setup for generation of Doubinary format and its compensation using RDF

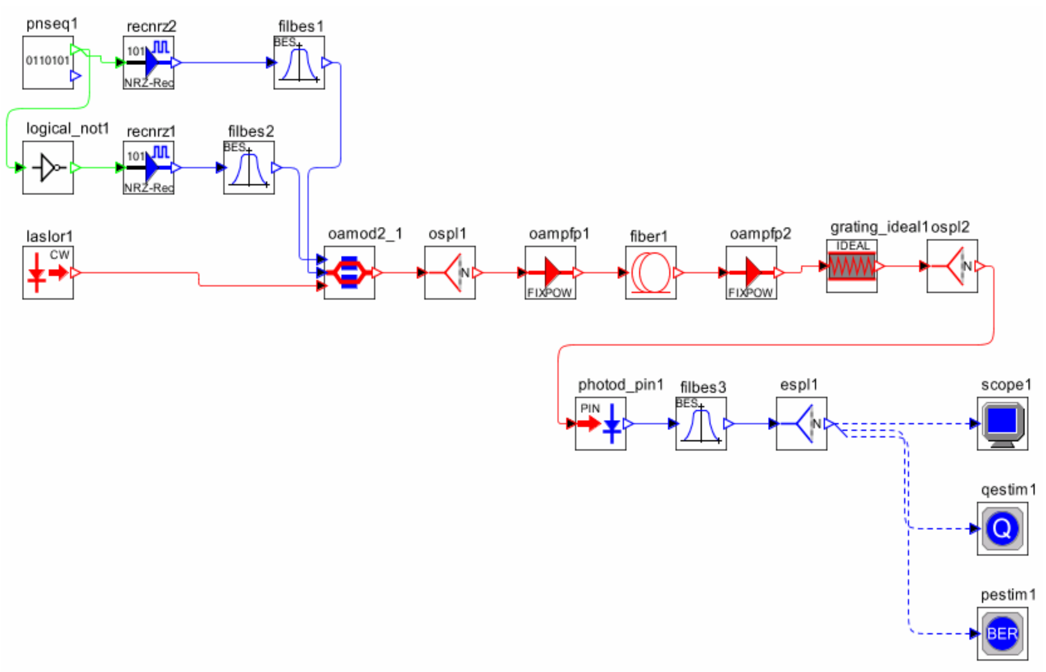

Figure 5.4: Setup for generation of Doubinary format and its compensation using FBG

Figure (5.4) shows the schematic diagram of dispersion using a fiber Bragg Grating (grating_ideal1) (FBG). The fiber optic link used in this set was dispersion shifted normal fiber (fiber1). This fiber had an attenuation of 0.2 dB/Km at 1550 nm and a negative dispersion of -2 ps/nm/Km. Fiber polarization mode dispersion (PMD) is 0.1 ps/$km^{1/2}$. Nonlinear refractive index was taken as 2.5×10^{20} m^2/W. This setup is simulated using fiber length of 100 km.

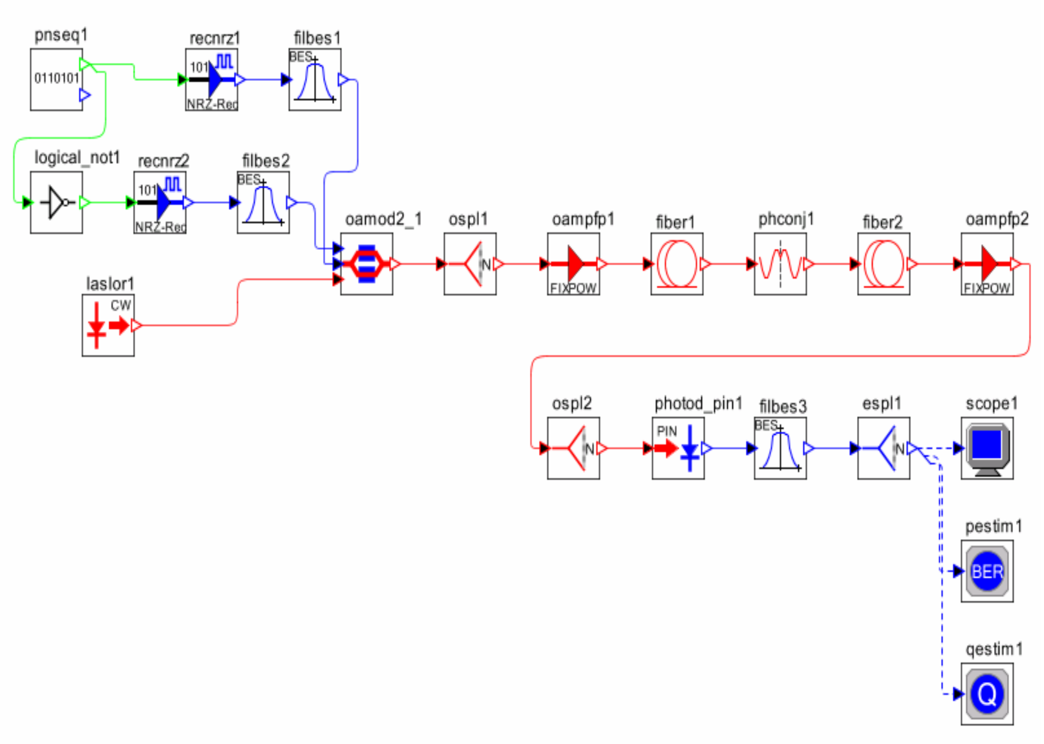

Figure 5.5: Setup for generation of Doubinary format & its compensation using OPC

Figure (5.5) shows the schematic diagram of dispersion using an Optical Phase Conjugation (OPC). The optical phase conjugator (phconj1) is simulated to give a phase shift of 2.57070796 at 100% efficiency. The fiber optic link used in this set was dispersion shifted normal fiber. This fiber had an attenuation of 0.2 dB/Km at 1550 nm and a negative dispersion of -2 ps/nm/Km. Fiber polarization mode dispersion (PMD) is 0.1 ps/ $km^{1/2}$. Nonlinear refractive index was taken as 2.5× 10^{20} m^{2} /W.This setup is simulated using fiber length of 100 km. For OPC, the setup is simulated using two section of fiber of equal length at either side of OPC.

5.3 Result and Discussion

In previous section, various component and parameters used in simulation setup are discussed. Using some of these components, the values of bit error rate (BER), Q-factor, eye closure has been measured. Eye diagrams and optical spectrum at the receiver end is measured. The measurement component used are Q estimator to measure Q-factor, BER estimator to measure to measure bit error rate (BER), electrical scope to measure eye diagrams. These graphs are taken by varying the values global parameters at different stages of the simulation. The bit rate is taken as variable global parameter with the values of 5, 10, 20, 30, and 40 GB/s. The figures

(5.6), (5.7), (5.8), (5.9), (5.10) shows the eye diagram of dispersion compensation fiber (DCF), fiber bragg grating (FBG), Negative dispersion fiber (NDF), optical phase conjugation (OPC) and reverse dispersion fiber (RDF) at bit rate of 30 GB/s.

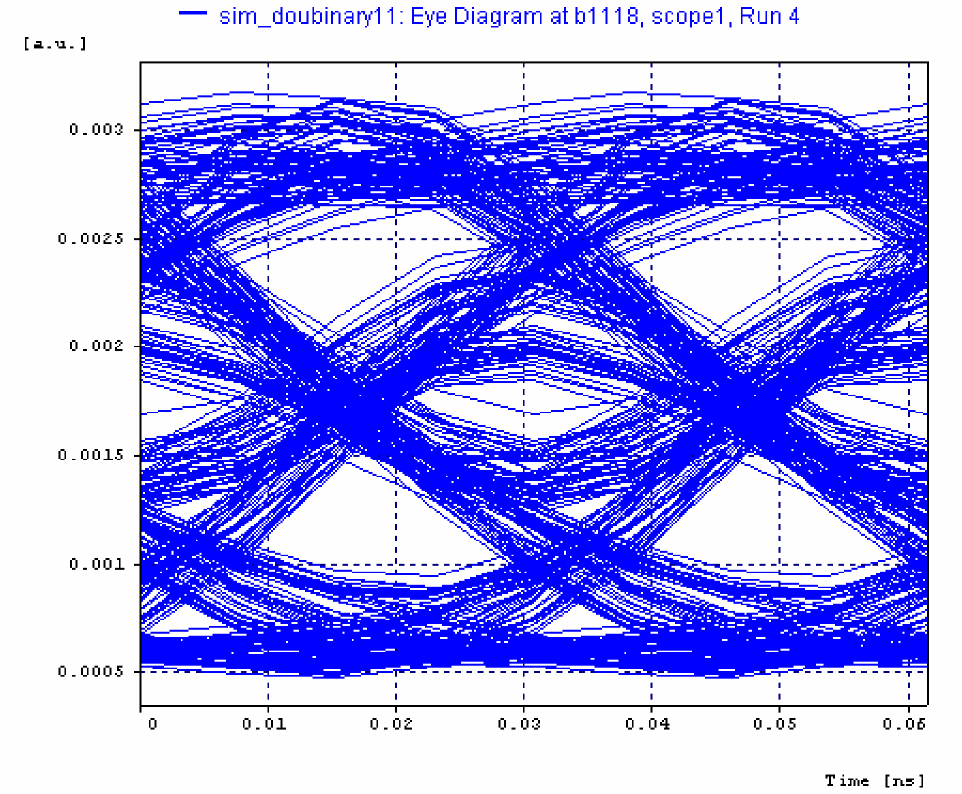

Figure 5.6: Eye diagram of DCF at 30 GB/s

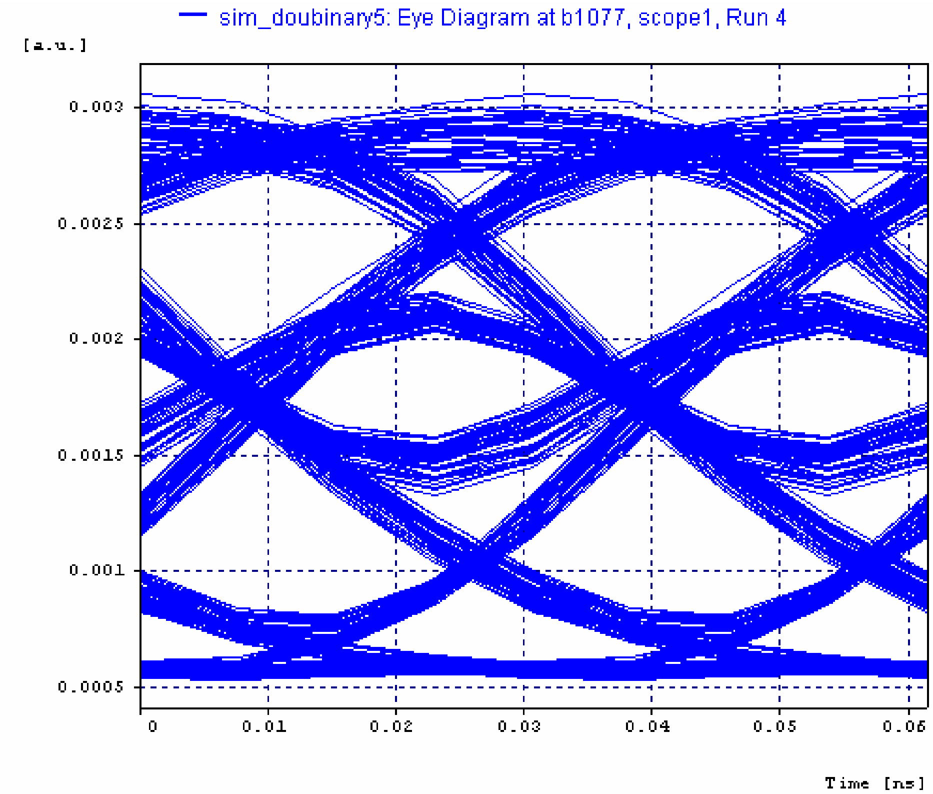

Figure 5.7: Eye diagram of FBG at 30 GB/s

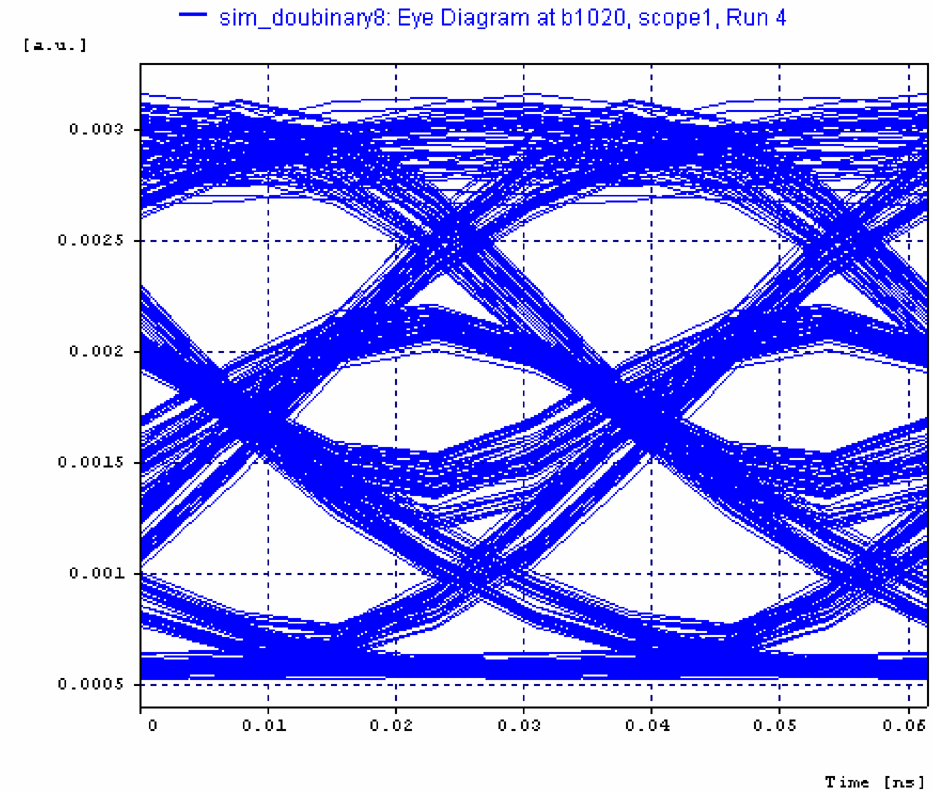

Figure 5.8: Eye diagram of NDF at 30 GB/s

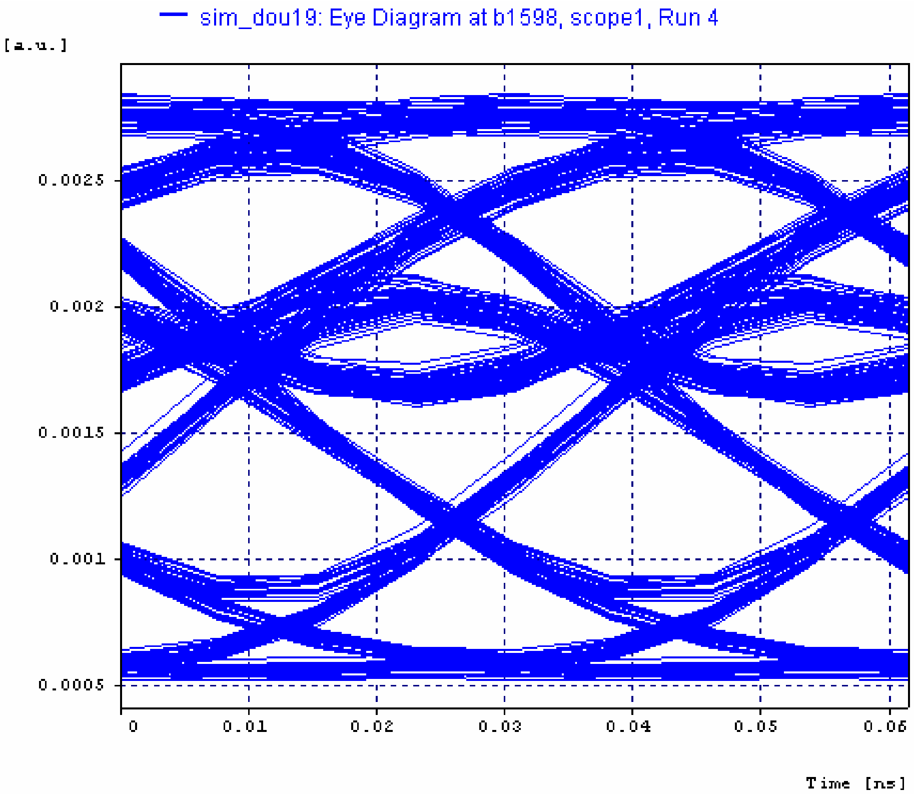

Figure 5.9: Eye diagram of OPC at 30 GB/s

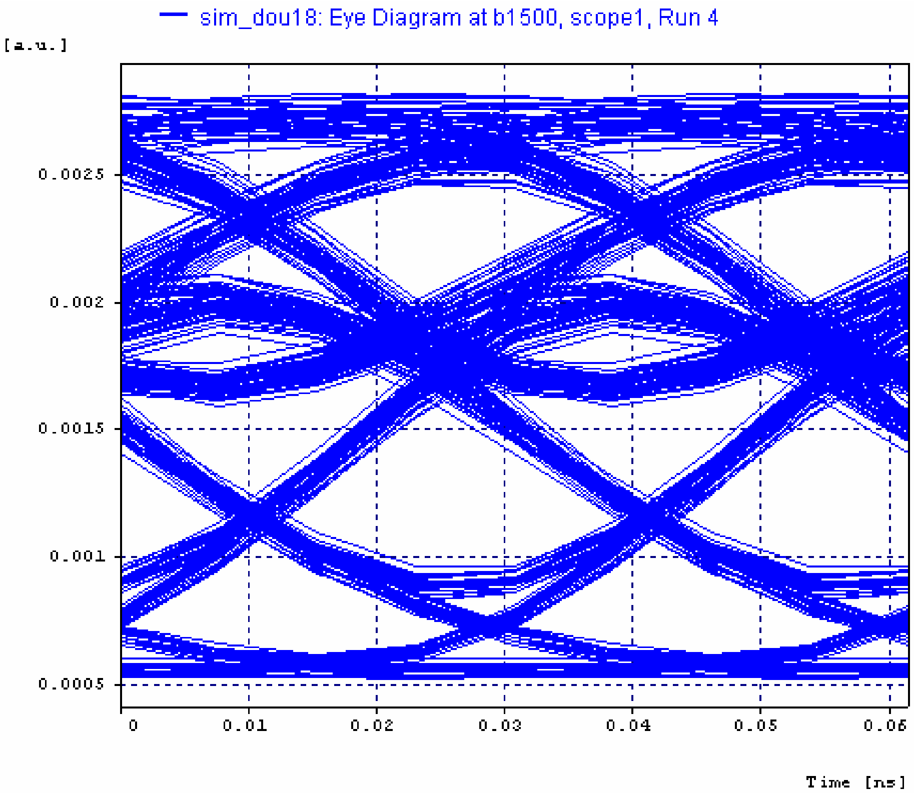

Figure 5.10: Eye diagram of RDF at 30 GB/s

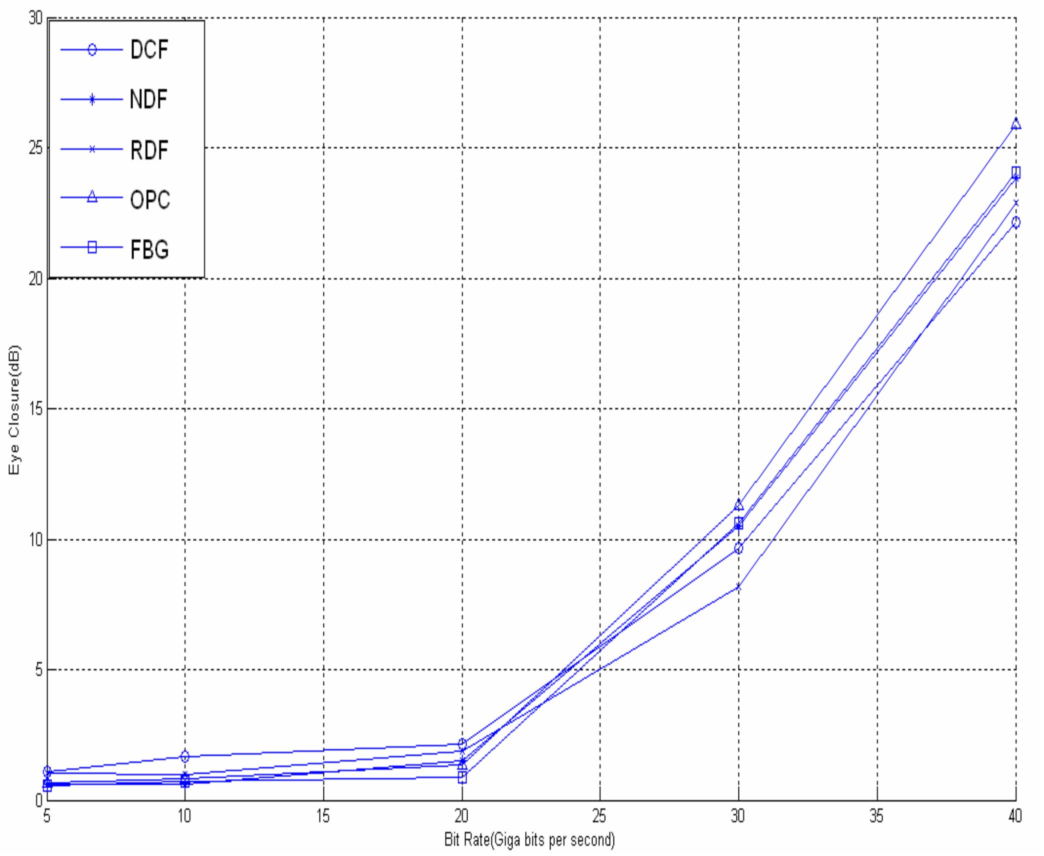

Figure 5.11: Comparison of eye closure at different bit rates for different dispersion compensation techniques

Figure (5.11) shows the eye closure characteristics of different compensation techniques at different bit rates. As seen from diagram NDF and OPC have low value of eye closure at 5 Gb/s. At 10 Gb/s all the dispersion compensation techniques except from DCF have low values of eye closure. FBG have less eye closure value at 20 Gb/s as compared to the other compensation techniques. The dispersion compensation techniques using SSMF and RDF and DCF shows the minimum value of eye closure at higher bit rates i.e. at 30 and 40 Gb/s. Overall the NDF, OPC and FBG dispersion compensation techniques are more useful at bit rates of 5, 10 and 20 Gb/s whereas DCF and RDF are favourable at 30 and 40 Gb/s.

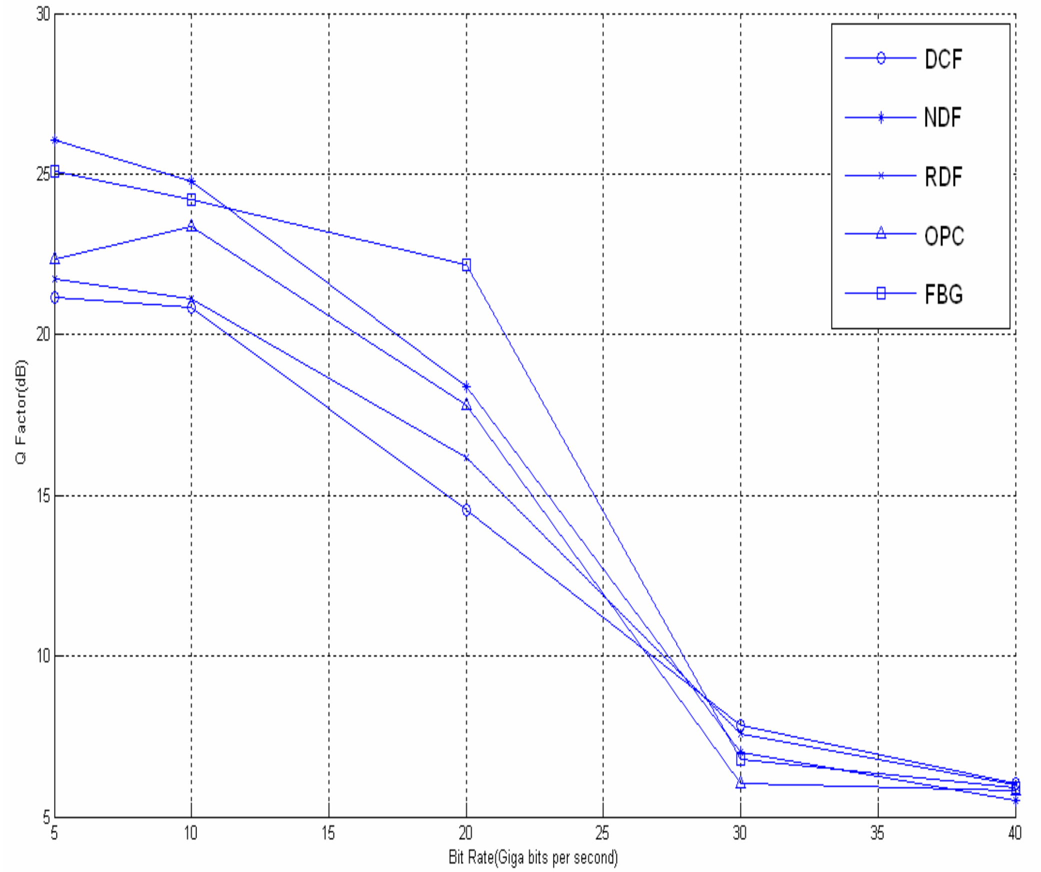

Figure 5.12: Comparison of Q-factor at different bit rates for different dispersion compensation techniques

Figure (5.12) shows the Q-factor of different compensation techniques at different bit rates. NDF dispersion compensation technique gives a better Q-factor as compared to the other compensation techniques at bit rate values of 5 and 10 Gb/s. FBG has better Q-factor at 20 Gb/s. OPC dispersion compensation techniques shows the better Q-factor when compared to the DCF and RDF at bit rate value of 5, 10 and 20 Gb/s. At the higher bit rate of 30 and 40 Gb/s the dispersion compensation techniques employed using DCF and RDF shows better Q-factor. Hence RDF and DCF can be used for longer distance optical communication system at high bit rates.

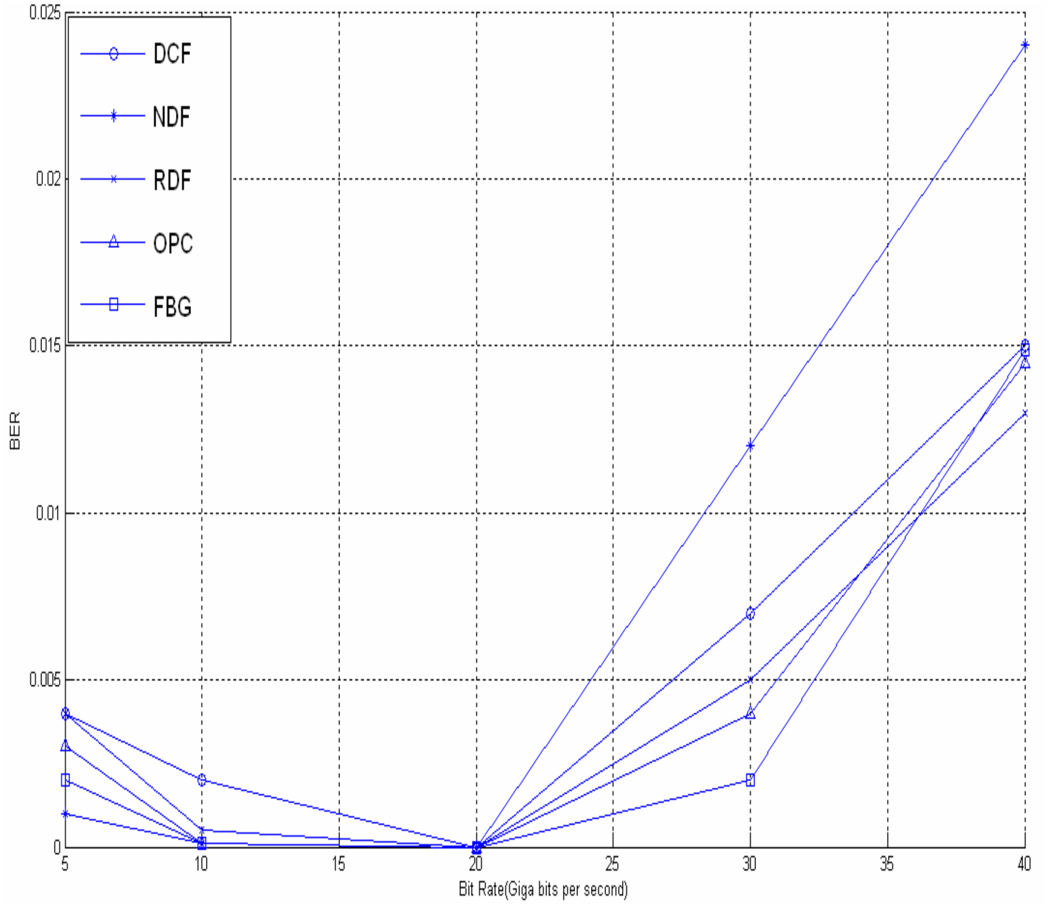

Figure 5.13: Comparison of BER at different bit rates for different dispersion compensation techniques

Figure (5.13) shows the bit error rate (BER) of different compensation techniques at different bit rates. NDF has the minimum bit error rate at 5 Gb/s .At 10 Gb/s the value of BER for all the compensation techniques are almost same except from DCF. At the 20 Gb/s, all the dispersion compensation techniques show their minimum bit error rate. OPC and FBG are the best compensation techniques at bit rate value of 30 Gb/s. RDF is the most suitable technique at bit rate of 40 Gb/s. NDF has the highest bit error rate at 40 Gb/s, hence it is not recommended at higher bit rates.

5.4 Conclusion

In this chapter, the comparison of different dispersion compensation techniques with doubinary modulation format at different bit rates has been reported. It has been concluded that various dispersion techniques can be recommended at different bit rates. From the eye closure, bit error rate (BER) and the Q-factor characteristics, it is clear that the dispersion compensation technique using negative dispersion compensation (NDF) is suitable at 5 Gb/s. The dispersion compensation techniques using fiber bragg grating (FBG) and optical phase conjugator (OPC) as dispersion compensation devices can be used at bit rate values of 10 Gb/s and 20 Gb/s. At high bit rate values of 30 Gb/s and 40 Gb/s, the dispersion compensation techniques using combination of standard single mode fiber (SSMF) with dispersion compensation fiber (DCF) and reverse dispersion fiber (RDF) can be used for long haul optical communication systems.

CHAPTER 6

CONCLUSION AND FUTURE PROSPECTS

6.1 Conclusion

This chapter provides a summary of the findings of the study which has done so far. Included in the summary are conclusions from observations made during the execution of this study. The study of following objectives is reported.

The first objective of the thesis is, to observe the performance of 10 Gbps optical communication with the dispersion managed RZ pulse. The RZ pulse is efficient for long-distance, high-bit-rate, wavelength in division multiplexed (WDM) transmission dispersion-managed systems. The effect of varying the dispersion parameter of single mode fiber on optical communication system has been noted. It is observed that with increase in the value of dispersion parameter, there is an increase in the average eye opening and Q-factor value. Also a good desirable bit error rate value has been achieved and reported. Timing jitters are reduced with increase in value. The effect of varying duty cycle of the RZ pulse for a fixed value of dispersion parameter has been performed. It has been shown that by reducing the duty cycle, the performance of the system is improved. It is concluded that dispersed managed RZ pulse system enhance the performance of optical communication networks at high bit rate.

The second objective of thesis is, to observe the performance of optical communication system with different modulation formats. The modulation formats consider for observations are non-return-to-zero (NRZ), carrier suppressed return-to-zero (CSRZ) and doubinary. It is reported that the Doubinary modulation format provides the higher dispersion tolerance among the three modulation formats. The NRZ has the worst performance in terms of dispersion tolerance. It is observed that the NRZ modulation format has a better optical signal to noise ratio (OSNR) value than the doubinary modulation format. It has been shown that CSRZ has the lowest bit error rate BER value. CSRZ modulation format has the edge over NRZ and doubinary modulation format. Doubinary modulation format can be recommended for long distance communication systems at high bit rates but its performance is limited by the low OSNR value which results from the intersymbol interference effect. The NRZ modulation format can be used for small distance communication system a high bit rates. It is concluded that the CSRZ modulation format is best for the long distance optical communication system due to its low value of BER and tolerance to the dispersion at high bit rates.

The third objective of the thesis is, to study the dispersion compensation techniques which are used to reduce the effect of dispersion at high bit rate. So, the comparison of different dispersion compensation techniques with doubinary modulation format at different bit rates has been reported .It has been concluded that various dispersion techniques can be recommended at different bit rates. From the eye closure, bit error rate (BER) and the Q-factor characteristics, it is clear that the dispersion compensation technique using negative dispersion compensation (NDF) is suitable at 5 Gb/s. The dispersion compensation techniques using fiber bragg grating(FBG) and optical phase conjugator (OPC) as dispersion compensation devices can be used at bit rate values of 10 Gb/s and 20 Gb/s. At high bit rate values of 30 Gb/s and 40 Gb/s, the dispersion compensation techniques using combination of standard single mode fiber(SSMF) with dispersion compensation fiber(DCF) and reverse dispersion fiber(RDF) can be used for long haul optical communication systems.

6.2 Future prospects

In this thesis, the work is reported on WDM system with different modulation formats and dispersion compensation techniques at high bit rate. The DWDM system and OTDM system have large bandwidth as compared to the WDM system. So this work is further extended to DWDM and OTDM system. The nonlinear effects such as four-wave mixing (FWM) and cross-phase modulation (XPM) are not included in this work. But these nonlinear effects can degrade the overall performance of the optical communication system. So these nonlinearities can be further included so that their effect can be reduced by different modulation formats and dispersion compensation techniques at high bit rate.

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