DESIGNING A 40 CHANNEL DWDM NETWORK USING RAMAN-DPSK

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CERTIFICATE

This is to certify that the thesis report entitled, "**Design a 40 channel DWDM network using RAMAN-DPSK**" being submitted by **VINEET GUPTA** to the *Department of Electronics and Communication Engineering and Applied Physics*, Delhi Technological University in partial fulfilment of the requirement for award of Master of Technology degree in ***Microwave and Optical Communication*** is a record of bona fide work carried out by him under the supervision and guidance of **Dr. R. K. Sinha**. The matter embodied in this report has not been submitted for the award of any other degree.

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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own, unaided work. I have fully cited and referenced all material and results that are not original to this work. It is being submitted for the degree of Master of Technology in Engineering at the Delhi Technological University. It has not been submitted before for any degree or examination in any other university.

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ABSTRACT

With the advent of new technology in the field of optical communication system we had find numerous techniques to constraints the cost and to fulfill the challenging requirement of increasing capacity , now days carriers have two options first to install new fiber network second increase the effective bandwidth of existing fiber network. The dense wavelength-division multiplexing (DWDM) technology has recently resulted in a considerable increase in the transmission capacity of optical fiber communication systems up to several terabits per second. The high bit rate transmission improves spectral utilization which results in increased overall system capacity and reduces overall system cost. The further improvement of the transmission capacity of such systems can be achieved through the expansion of the spectral range of DWDM transmission toward the short-wavelength region. The goal of a WDM transmission network is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors.

Therefore in this report we have proposed and investigated the new trends and progress of fiber Raman amplification using DPSK modulation for dense wavelength division multiplexing photonic communication networks. In this we simulate a realistic scenario of 40 individual channel , 40 Gbps DWDM link with inter channel spacing of 50 GHz. Forty individual channel carrying PRBS data are modulated using DPSK and transmitted over ITU-T G.652 single mode fiber. The objective of this design is to utilize distributed backward pump raman amplification using unequal pump power to compensate for the link attenuation and Differential phase-shift keyed (DPSK) modulation, which carries the information by change in optical phase between bits, has been widely used in long-haul optical communication networks for its ~3dB lower optical signal-to-noise ratio (OSNR) requirement compare to on-off keying (OOK) signals when using balanced receiver.

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Last but not least, I take this opportunity to express my deepest thanks to my parents and my brother. Without their support, love and encouragement, it would not have been possible to pursue M.Tech. degree studies. I sincerely thank them.

VINEET GUPTA

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Communication means simply the exchange of information from one point (source) to another point (destination) through an algorithm of process, given here as:

1. The generation of information signal: data, voice, video, and image.
2. The explanation of information signal by asset of symbols: optical, electrical, or visual.
3. The encoding is done of these symbols that make it suitable for transmission over a transmission medium of interest.
4. The propagation of source symbols from source to desired destination.
5. The decoding of the transmitted symbols.
6. The reproduction of the original information signal, along with a desired degradation in quality.

Since, most important feature of the telecommunication industry is its information carrying capacity, but there are some other many important features. For example, in bank network security is more important to capacity while in television broadcasting, capacity is more important as compare to security. We cannot increase capacity as our requirement because capacity of a channel as Shannon-Hartley limit is given by -

$$C = BW \times \log_2(1 + SNR) \qquad (1.1)$$

Here C is information carrying capacity in bits/sec, BW is bandwidth in Hz, and SNR is the signal-to-noise power ratio.

From this above equation we can say that channel bandwidth is directly proportional to signal bandwidth, which can be defined as the range of frequencies which can be transmitted through the channel without attenuation. According to the rule of thumb, bandwidth is given as 10 percent of the carrier signal frequency.

A copper wire can transmit a signal upto 1MHz, while coaxial cable can transmit upto 100 MHz. A radio frequency has a range of 500 KHz to 100 MHz. Microwaves link and satellite channels operate upto 100 GHz.

Fiber optic communication system uses light wave as carrier signal whose frequency is between 100 to 1000 THz and estimated bandwidth is around 50 THz. Optical fiber communication systems played a vital role in the advent of the Information Age and have revolutionized the telecommunication industry. Because of it have advantages over electrical signal transmission; optical fiber has almost replaced copper wire communications in the telecommunication world. The most common type of channel for fiber-optic communication is optical fiber; however, other channels like optical waveguides are used within communication gear, and have formed the channel of very small distance links like in laboratory trials.

The demand for capacity increases due to the rapid growth of data traffic in all types of communication systems. The transmission systems mostly operate in the 1550nm wavelength window, where the capacity of fiber is being utilized with maximum possible efficiency using advanced modulation formats and dense wavelength division multiplexing (DWDM). Wide amplification bandwidths (> 100 nm) with low gain ripple (<1.5 dB) have been achieved using multi-pump configurations for DWDM applications [1], [2], however in these approaches either the number of pumps is high (e.g., more than 8 pumps) [1] and/or special attention in fiber management is required [2].

The scheme proposed in this paper combines various properties of Raman amplifiers exhibit high gain and noise characteristics,It also consider the following points as shown - (i) the progressive up gradation from 100 to 400 Gbps of DWDM technologies with aspiring to maintain a reasonable cost, and (ii) differential phase shift keying (DPSK) modulation format favored by 40 Gbps network. DPSK is highly utilized in current systems due to its resistance to nonlinearity and dispersion which is a major limiting factor in communication networks.

1.2 Dense Wavelength Division Multiplexing (DWDM) Technology

DWDM is an optical technology used to increase bandwidth over existing fiber optic backbones. DWDM network combines multiple signals of different wavelength and transmit them through same fiber or we can say, one fiber is transformed as many virtual fibers. For example, if we want to multiplex four OC-48 signals into a fiber, we have to increase the information carrying capacity of a fiber from 2.5 to 10 Gbps.

The important components of DWDM systems are transmitter which can be lasers source of particular wavelength, DWDM MUX to combine all the optical signal, optical fiber as a transmission channel, optical amplifier to amply the attenuated signal over long distance transmission, DWDM DEMUX to separate all the signals, photo-detector to detect the optical signal and error detector to analyze the signal. A DWDM system is shown below-

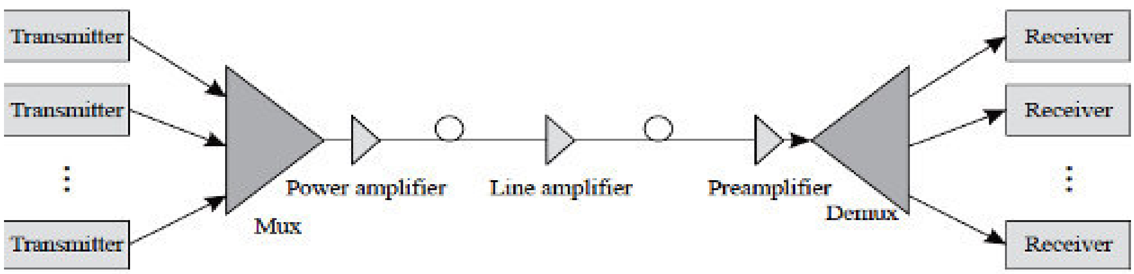


Fig. 1.1 Block Diagram of DWDM System

(Ref. Rajiv Ramaswami, Optical Networks, 3rd edition)

1.3 Objective of the Project

The objective of this project is to achieve the Ultra-High bit rate transmission in low loss optical window 1550-nm. For achieving this transmission, we have designed a 40 channel DWDM network with channel spacing 50 GHz(0.4-nm) and each channel is modulated by 1Gbps electrical signal. Mach-Zehnder modulator (MZM) phase modulator is used to modulate RZ-DPSK electrical signal. To increase signal to noise ratio RZ-DPSK modulation format is used [3]. Distributed Raman amplification using backward pumping is used for amplification because of less fluctuation and various advantages over EDFA.

1.4 Scope of the Project

DWDM is major area of research in fiber optics in the present scenario. Still, many research works are going on in the field of DWDM network to minimize the channel spacing below

50 GHz (0.4-nm), so that number of channels to be multiplexed can be increase and Ultra-High data rates can be achieved. Proposed project is designed for 40 channels with 50 GHz channel spacing but by the advancement in current technology in future, it can be extended for greater number channel with less spacing and high data rate. So this will result Ultra-High capacity (in the range of several Tbps) transmission channel.

1.5 Organization of Thesis

In **Chapter 2** Literature review of project is discussed. **Chapter 3** describes basic concepts of Raman amplification and use of Raman amplification in DWDM networks. In **Chapter 4** DPSK modulation is discussed. In C**hapter 5** Components description and operating principle is shown. In **Chapter 6** we have shown the methodology for project designing and Results. At the end **Chapter 7** includes summary and future scope of the project

CHEPTER – 2

LITERATURE REVIEW

In optical communication we can transmit multiple wavelengths simultaneously over a single optical fiber with high data rate up to several Gbps by using the dense wavelength division multiplexing technique. Because of smallest attenuation and various amplification techniques operate in 1550-nm window, it is widely used to design DWDM systems. By using algorithm approach a DWDM system is also designed in this wavelength window [4]. Wide amplification bandwidths (> 100 nm) with low gain ripple (<1.5 dB) have been achieved using multi-pump configurations for DWDM applications [1], [2], however in these approaches either the number of pumps is high (e.g., more than 8 pumps) [1] and/or special attention in fiber management is required [2].

Raman amplification exhibits benifits of self phase matching between the pump and signal together with a broad gain- bandwidth or high speed response compared to the other nonlinear processes [5]. The net gain increases with increasing fiber length up to a certain length of fiber, and then begins to decrease after a maximum point and it's higher for bidirectional pumping than counter pumping [6].Raman amplifier have shown various optimization techniques to stabilize the wide band gain by changing its parameters and applied pump power configuration to improve pumping efficiency and also improves systems bit error rate performance.

The combination of RZ and DPSK format can be used to enhance the transmission quality compare to simple DPSK and therefore has attracted much interest [7,8]. It also shows more resistance to cross-phase modulation compared to OOK [9]. The main advantage of using DPSK is that it improves 3-dB receiver sensitivity with compared to intensity modulation [10]. In a long distance DPSK network with optical amplifiers, nonlinear phase noise is also the limiting factor for phase shift keying optical signals [11]. Amplified spontaneous emission (ASE) noise which is generated by the optical amplifiers, are converted into phase noise through the Kerr effect nonlinearity in the transmission fiber. It disturbs the signal optical phase and causes waveform distortions [12].

Raman amplifiers have several advantages over EDFA, such as:

- It builds-up low noise.
- Simple to designed, because in the optical fiber it can directly amplify the optical signals, and no special medium is required.
- Compromising assignment of input signal frequencies.
- It has wide bandwidth and large gain.

CHAPTER-3

RAMAN AMPLIFICATION

Raman amplifiers are based on the stimulated Raman scattering (SRS), which is a non-linear phenomenon in optical fiber communication. It results in amplification of signal if optical pump signal with appropriate wavelength and power are applied into the fiber [13].

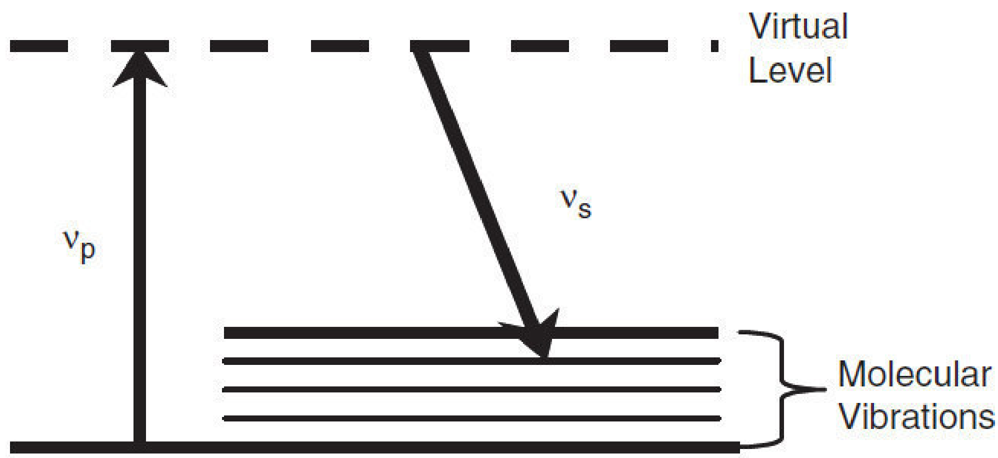


Fig.2.1 Quantum mechanical process of Raman scattering

(Ref. Govind P. Agarwal, Raman amplification in fiber optic communication)

In Raman scattering, light is an incident on a medium and it is converted to a lower frequency signal [14]. This is also shown in Figure 2.1. When a pump signal with photon energy v_p collides with a molecule up to a imaginary level (non resonant level). The molecule immediately drop to a lower energy state by emitting a signal photon v_p. The energy difference between pump and signal photons is converted into the molecular vibrational energy of the host material. The frequency shift and shape of the Raman gain curve is determined by these vibrational levels. the Raman gain curve is passably broad in optical fibers Due to the unstructured nature of silica. Figure 2.2 shows the Raman gain curve in three different types of fibers [15]. “The wavelength (or frequency) difference between pump and signal photon ($v_p - v_s$) is called the Stokes wavelength shift, and in standard optical fibers with a Ge-doped core, the peak of stokes frequency shift is about 13.2 THz”.

For enough high pump powers, the scattered light can grow fast the pump energy and converted into scattered wave. This process is called SRS (stimulated raman scattering), and it is the gain mechanism utilized in Raman amplification process. Three important points of this process are shown as

i. Stimulated Raman Scattering can occur in any type of fiber;
ii. Raman gain can occur at any signal wavelength by choice of the pump wavelength properly, because the pump photon is excited to a exited level,;
iii. This gain process is very fast.

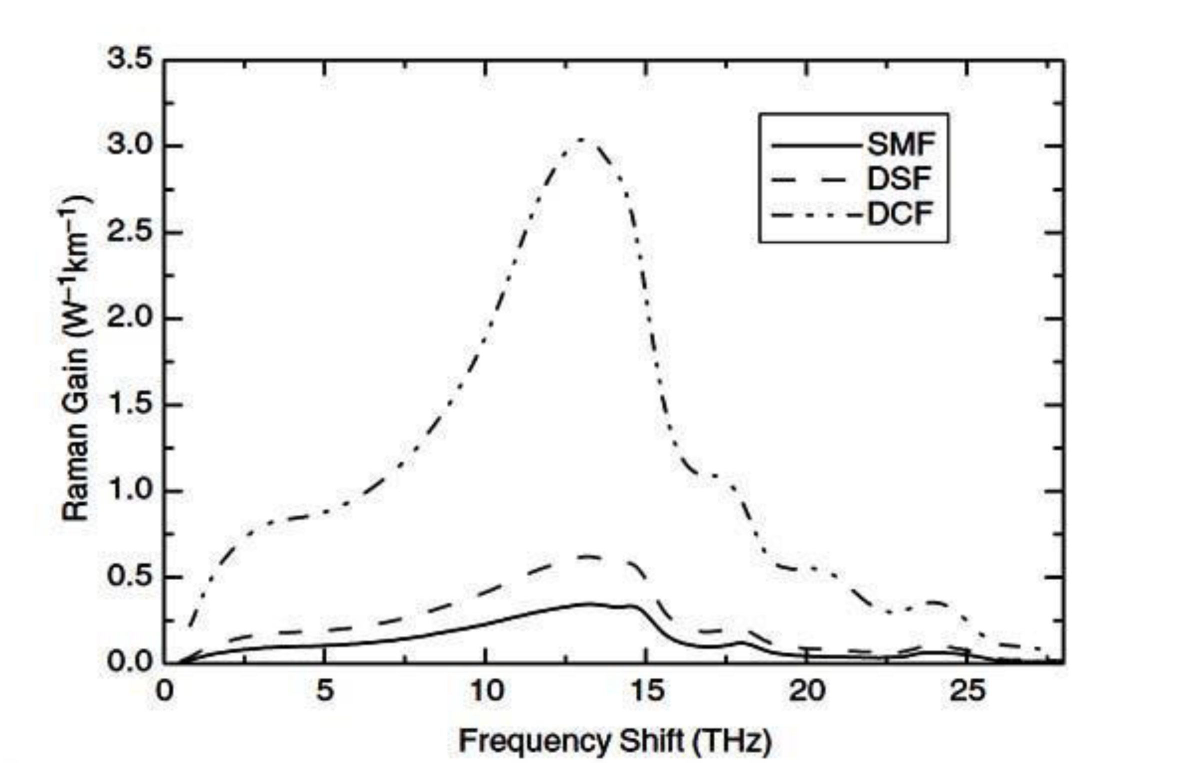


Fig. 2.2 Gain profiles in three different fiber types as follows :- standard single mode fiber; dispersion shifted fiber; dispersion compensating fiber.

The Raman only amplifier has now become an indispensable amplification technology with its distinctive benifits—such as flexible and wide gain bandwidth and intrinsically lower noise characteristics [16]. For the optimal design of the Raman amplified transmission systems, various approaches have been developed for the efficient modeling of the Raman amplifier. Although these have different algorithms, convergence speed and accuracies but still all the approaches have common platform of ordinary coupled mode equations that must be solved along the length of fiber axis.

Raman amplifiers have shown the strong capability to improve the system BER performance and various optimization techniques to stabilize the wideband gain bandwidth spectrum by changing the Raman amplifier parameters and pump power to improve the pumping efficiency. Significant enhancements in the field of Raman gain and effective gain bandwidth are shown not only to give better performance in terms of noise, but also to results in lower gain ripple.

CHAPTER-4

DIFFERENTIAL PHASE SHIFT KEY (DPSK) MODULATION

We can represent digital signal by changing optical power level called as amplitude shift key. Similarly, by changing phase of an optical carrier we can also represent digital signal and it is referred as optical phase shift key (PSK). The phase of optical signal was not enough stable in the early days of optical communication for phase based modulation schemes, because semiconductor laser sources was not mature at that time. Now, with the fast growth of coherent laser sources and active optical phase locking, Phase Shift Keying modulation now becomes stable in optical communication. So now differential phase shift key (DPSK) becomes most commonly used modulation format [17].

"DPSK modulation is an encoding format which records changes in the binary stream." In DPSK information is encoded on the change of phase between adjacent bits as: 1-bit is represented as π phase change, whereas 0-bit is encoded by no phase change. Like on-off key (OOK), DPSK can also be represented in RZ and NRZ format. DPSK has advantage of 3-dB signal to noise ratio improvement over intensity modulation. Earlier it has been shown that RZ-DPSK has better transmission performance than simple DPSK [10].

4.1 DPSK Principle

To generate the RZ-DPSK signal we use two MZM, First MZM is used to generate pulse curved bipolar electrical signal second MZM is used for electrically encoding process. In this approach we have to generate phase modulated signal by using MZM as phase modulator, where 1-bit is represented as π phase change, whereas 0-bit is represented as no phase change.

4.2 Non Return to Zero DPSK (NRZ-DPSK)

The block diagram of NRZ-DPSK modulator and demodulator is shown in figure below. As shown in the block diagram, NRZ electrical signal is firstly DPSK encoded by phase modulator. Then this electrical signal is used to drive another Mach-Zehnder modulator to generate DPSK modulated optical signal. A 1-bit in digital is represented by π phase change between adjacent bits of optical carrier, where for 0-bit in digital is represented by no phase change between adjacent bits of optical carrier. NRZ-DPSK has an important characteristic that its optical power is always constant [17].

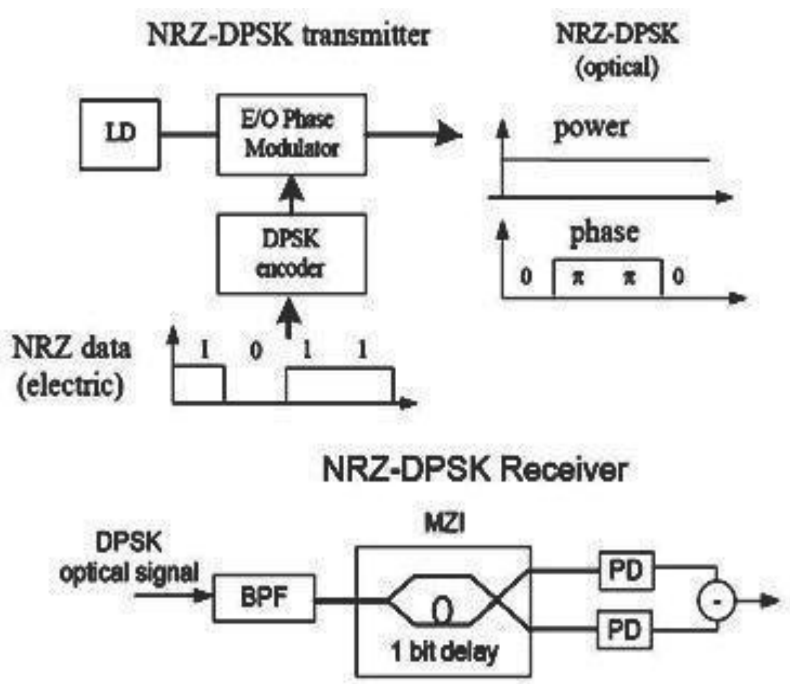


Fig. 4.1 Block diagram of NRZ-DPSK transmitter and receiver

In DPSK receiver shown in Figure 4.1, a one bit delay Mach-Zehnder Interferometer (MZI) is used to correlates current bit with previous bit and makes it phase to intensity conversion, as if the two adjacent bits are in-phase with each other they are added constructively in the MZI and results in high level, similarly, if the two bits are opposite in phase they cancel each other in the MZI and results in a low level signal. The two photocurrent from each photodiode used at each MZI output are combined to double the level of signal. So by increasing the signal level the sensitivity of receiver is improved by 3 dB compared to using a single photodiode only. Since signal amplitude change from “1” to “-1” in a DPSK system when a matched filter and balanced detection is used, then sensitivity of receiver is 3 dB grater than a simple NRZ system, where the signal changes only from “1” to “1”.

The optical power for NRZ-DPSK is invariable, while the optical amplitude changes between “1” and “-1” (and the phase change between “0” and “π”) or the average optical amplitude is zero. So in the optical field spectrum of NRZ-DPSK there is no carrier component [18].

Because of the constant optical power of NRZ-DPSK, its performance is not affected by nonlinear effect of optical power modulation such as XPM and SPM, while affected from chromatic dispersion. The group velocity dispersion (GVD) can convert phase modulation into intensity modulation and then XPM and SPM may contribute to distortion in waveform.

4.3 Return to Zero DPSK (RZ-DPSK)

Return-to-zero DPSK (RZ-DPSK) has been used to improve system to tolerate nonlinear distortion and to achieve a longer distance transmission. The binary data encoded as either "0" or "π" phase shift between consecutive bits of digital signal similar to NRZ-DPSK modulation format. Generally, optical pulse width is narrower than the bit slot, so at the edge of each bit slot optical power of signal returns to zero.

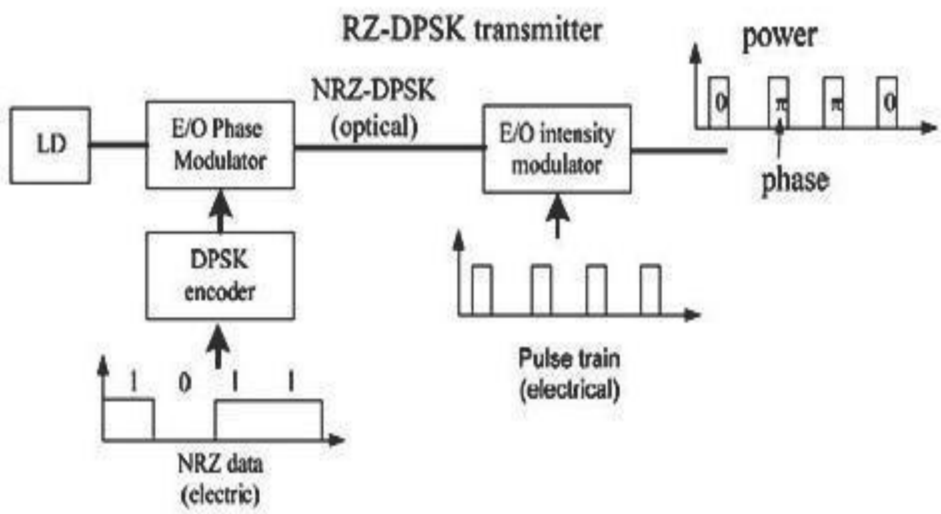


Fig. 4.2 Block diagram of RZ-DPSK transmitter

The block diagram of a RZ-DPSK modulator is shown in figure 4.2. As shown in the block diagram, RZ electrical signal is firstly DPSK encoded by phase modulator. Then this electrical signal is used to drive another Mach-Zehnder modulator to generate DPSK modulated optical signal. A 1-bit in digital is represented by π phase change between adjacent bits of optical carrier, where for 0-bit in digital is represented by no phase change between adjacent bits of optical carrier. The optical spectrum of RZ-DPSK is wider than NRZ-DPSK due to its narrow pulse intensity, so it causes more susceptibility to chromatic dispersion.

CHAPTER-5

COMPONENTS DESCRIPTION AND PRINCIPAL OF OPERATION

5.1 Introduction

In this chapter we will discuss the entire optical and electrical components model which we have used in our experimental setup. The main optical and electrical components are given below:

(1) Pseudo-random bit sequence (PRBS) generator

(2) Electrical signal generator

(3) Continuous wave (CW) laser

(4) Mach-Zehnder modulator

(5) WDM MUX and DEMUX

(6) Bi-directional Nonlinear Fiber (Raman Amplifier)

(7) PIN photo detector

(8) Fiber Delay

5.2 Pseudo-random bit sequence (PRBS) generator

This model produces a maximal length pseudo random binary sequence. In this a single model may be used to provide multiple pattern outputs, to drive different channels of a WDM or parallel optical bus simulation, offset from each other. Otherwise, each channel may have its own model configured to provide a different pattern than the any other model provides.

5.3 Electrical Signal Generator

This model takes a binary signal as input and converts it into an electrical signal at output. The output signal can be given as either current or voltage. The two different type of user parameters, that are used to configure the electrical signal output are describe below.

5.3.1 NRZ pulse generator

It generates a Non Return to Zero (NRZ) coded signal. It is the most common signal format and in fiber optics binary 1 is the active signal element while binary 0 is passive element.

5.3.2 RZ pulse generator

It generates a Return to Zero (RZ) coded signal. It is also common signal format in which binary 1 is active element for have period and passive element for another half and binary 0 is always passive element.

5.4 Continuous wave (CW) laser

This model produce continuously laser light and is most commonly used in conjunction with the external modulator to modulate a binary signal upon the CW laser source.

In this model, the CW source is characterized by its optical power, frequency, linewidth, RIN noise and phase. These are controlled directly through the parameters peakPower, wavelength, linewidth, RIN and phase. The laser can also be assigned a random phase by setting randomPhase=*YES*.

5.5 Multi-Line Multi-Node Output

It is frequently necessary to produce several CW signals with similar properties but different wavelengths.

In DWDM simulations especially, a series of regularly spaced optical sources is common. The CW Laser model provides a number of convenient facilities so that many or all required lines can be generated from a single icon. To produce a series of lines spaced equally in wavelength or frequency, set the parameter mode=LambdaGrid or mode=FreqGrid, respectively. The number of sources is controlled by noSources, and in both modes the parameter wavelength specifies the first line in a series of ascending wavelengths or ascending frequencies, respectively. The source separation in wavelength or frequency is specified with deltaFreq.

The comb of sources may be emitted either through a single node (the default) or with one channel per output node. To achieve the latter behavior, first set multiNodeOutput=*YES*. Then select the cw laser icon and open the menu item *Properties*. In the Ports tab, number_output_ports field, enter the number of lines that the model will generate (i.e. either noSources or the number of lines in the user data file if mode=*File*). Figure 5.1 indicates the use of multi-node output mode to produce a series of WDM sources.

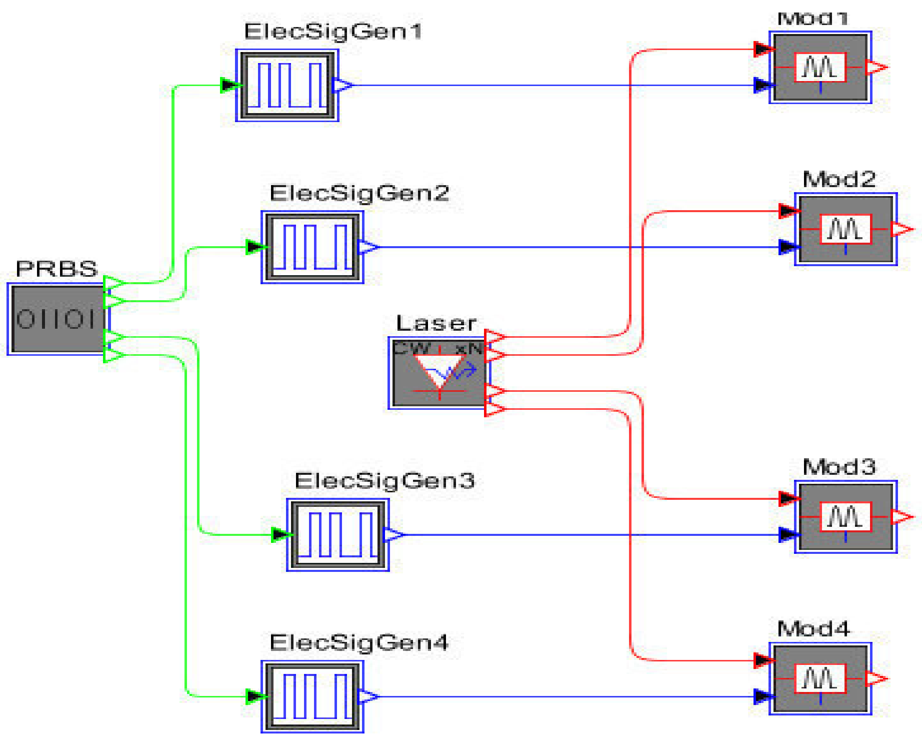


Fig. 5.1 CW Laser used in multi-node output mode configuration

5.6 Mach-Zehnder modulator

It is also an intensity modulator based on an interferometric principle and electro-optic effect, shown in figure below. It has two 3 dB couplers, which separate input power in two waveguides of equal length connected at output. An externally applied electrical field can be used to change the refractive indices in the waveguide, by means of electro-optic effect.

In different path, velocity will be different, so output leads to constructive or destructive interference, depending on the applied voltage. So the output signal intensity can be modulated according to the applied electric field.

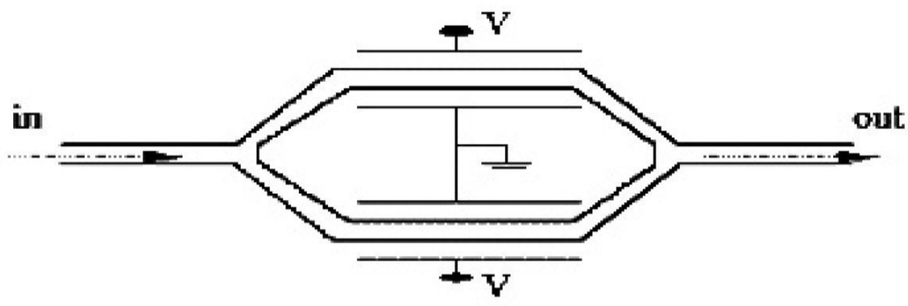


Fig. 5.2 Signal flow diagram of Mach-Zehnder Modulator

5.7 WDM MUX and DEMUX

A WDM multiplexer converts multiple optical signals of different wavelengths at its input ports into a single optical signal at its output port which includes all the input WDM optical signals**.** While a WDM DEMUX is just opposite, it converts a WDM optical signal at its input port into N different optical signals at its output ports, one channel per port. This is done by using the filter of appropriate wavelength to the input signal for each of the output port. Applied optical filter can be a Gaussian, Bessel, Rectangle, optical filter. The WDM MUX internal function is shown in Fig. 5.3.

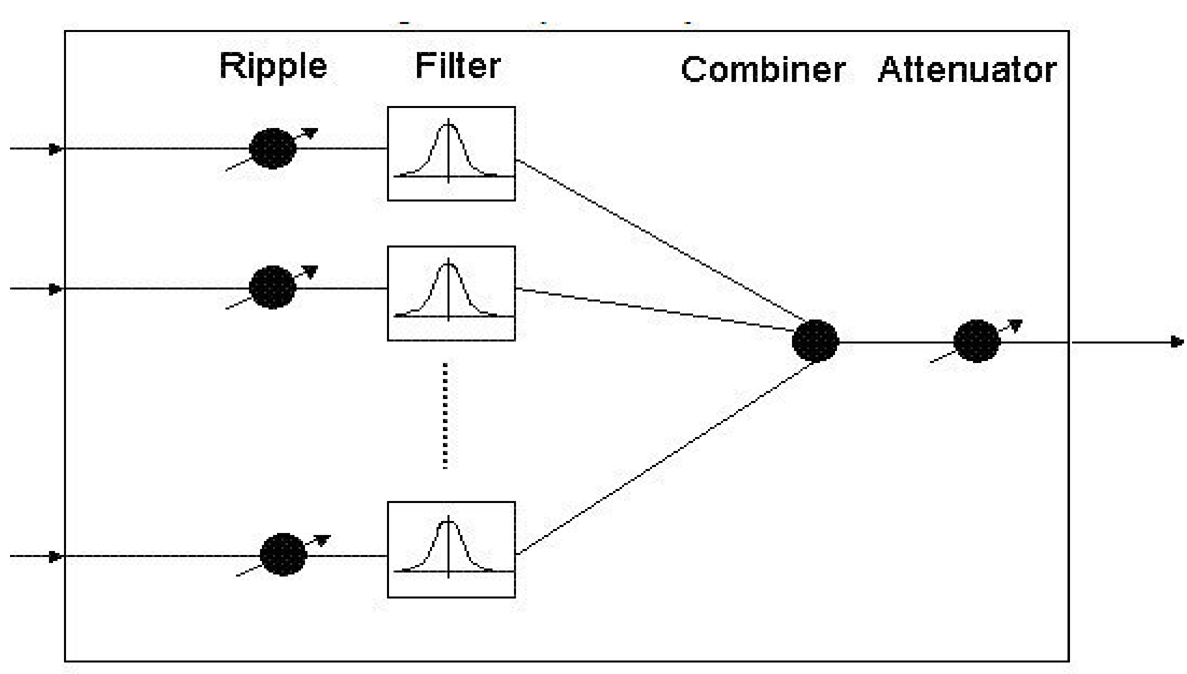


Fig. 5.3 Signal flow diagram in WDM-MUX

5.8 Bi-directional Nonlinear Fiber (Raman Amplifier)

In this we provide a detailed discussion of a bidirectional fiber with all nonlinear, dispersive, and Raman effects. CW pump lasers may be attached traveling both forwards and backwards to simulate Raman amplification of a forward traveling signal. Spontaneous emission and Rayleigh back-scatter effects are fully described. The problem is solved in two stages: a bi-directional power solution that solves for the pump and noise distributions, followed by an extended implementation of the standard Nonlinear Fiber Model that adds the influence of the pump waves to the dispersive and nonlinear effects experienced by the signal. For strictly uni-directional problems with no pumps, this is identical to the Nonlinear Fiber. The documentation for that model should be read before the following.

All the parameters of the standard Nonlinear Fiber are also parameters of the present Bidirectional Fiber. The Parameter Descriptions section below indicates all parameters of Bidirectional Nonlinear fiber.

Most of fiber propagation applications require the field which is traveling in both directions. The simulation of Raman amplification of signals by CW pumps is most obvious and important. Raman amplification is a bidirectional problem because of two things. first, the pump signal can be applied from either sides and second, the noise component in the field travels in both directions – Rayleigh backward scattering couples fields in both directions, and a single pump generates spontaneous emission in both directions. These effects are summarized in fig. as shown below. The (forward propagating) red signal is amplified by blue (pumps) propagating in both sides. Spontaneous emission, generated by the pumps (green crosses) is back-scattered. The signal directly contributes to the noise through double Rayleigh backscattering shown by the red loop.

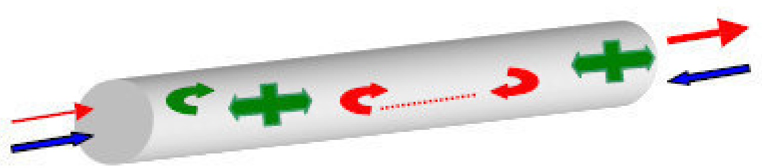


Fig. 5.4: Bidirectional fiber effects of Raman amplification.

Incoming signal (red) is directly amplified by both co-propagating and counter-propagating pumps (blue).

5.9 Origin of Raman effects

Raman effects may be viewed phenomenological as a result of delayed third-order nonlinearity, in contrast to effects such as self-phase modulation which arise from the instantaneous nonlinearity. Microscopically, a Raman scattering event occurs when a pump photon of frequency ω_p scatters off a phonon (vibrational quantum). A transfer of energy and momentum between the particles converts the incoming photon to a new frequency $\omega_s=\omega_p + \Omega$, with $\Omega <<\omega_p$. If $\Omega < 0$, the new photon is referred to as a "Stokes" wave. The opposite case of a positive frequency shift produces an "anti-Stokes" wave. This is very much less likely and can be largely neglected in fiber systems. Raman gain occurs when the Stokes shift corresponds to the separation between a pump and signal wave, so that the incoming signal is amplified. Stokes photons may also appear spontaneously at frequencies with no pre-existing signal. Subsequently amplified they contribute to the ASE noise of the system.

5.10 Input and output ports

The Bidirectional Nonlinear Fiber icon has three input and one output nodes. The first input and the output node function identically to the ports of the standard Nonlinear Fiber – the input node accepts an arbitrary set of optical signals, and the output node contains these signals after propagation through the fiber. The second and third input nodes denote incoming CW pump waves and are interpreted in a different manner. The second node represents pumps launched at the front of the fiber and co-propagating with the forward-traveling signal; the third node represents counter-propagating pumps launched at the rear of the fiber. The second and third nodes do **not** accept arbitrary optical signals. Their inputs must come from a series of CW Laser components. Using the Optical MUX, any number of CW Lasers may be connected to each input node. The restriction to CW Laser inputs serves as a reminder to the user that the pumps are completely specified by their wavelength, power and propagation direction.

The example topology in Fig. 5.5 should help to make this convention clear. A two-channel signal is generated by modulating the output of two CW Lasers with a random binary sequence, and is connected to the first node of the bidirectional fiber. A single CW Laser is connected to the second node representing a forward-traveling pump. Three additional CW Lasers are multiplexed (in multi-channel mode) and connected to the third input node to denote backward-going pumps. The single output node holds the modified version of the signals that enter on the first input node.

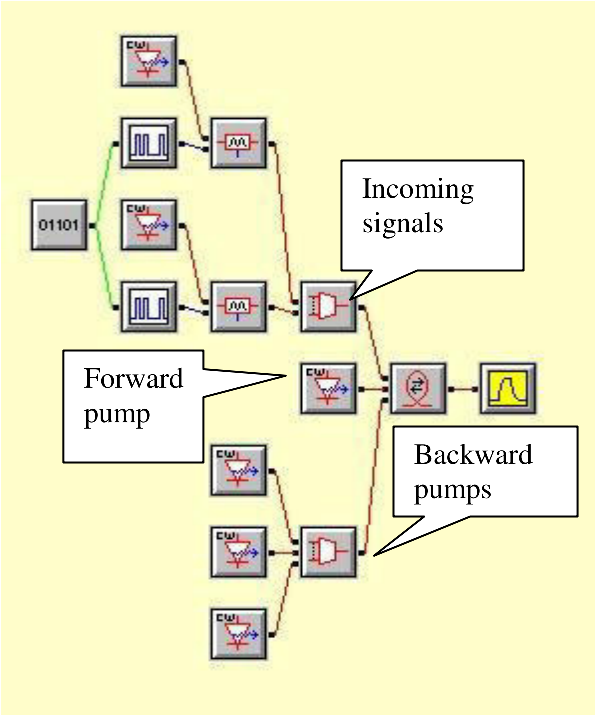


Fig. 5.5 Input and output ports connection for bidirectional fiber model

5.11 PIN photo detector

In PIN photo detector, a very lightly doped intrinsic semiconductor is introduced between the two heavily doped p-type and n-type semiconductors to improve the efficiency of the photo detector. The depletion region in these photodiodes covers completely this intrinsic semiconductor region. In comparison to the intrinsic semiconductor the width of the p-type and n-type semiconductors is small. So that most of the light absorption takes place in this intrinsic region. It increases the responsivity and efficiency of the photodiode.

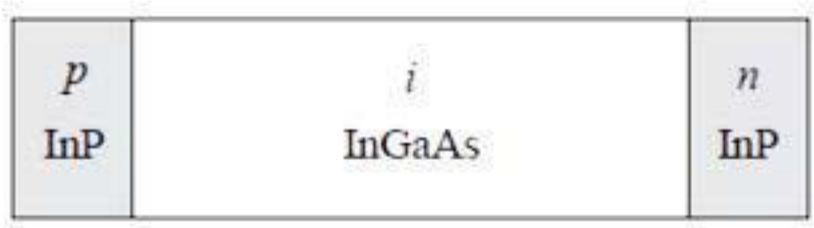


Fig. 5.6 A PIN photo detector model

To use a semiconductor material for the p-type and n-type regions that is transparent at the wavelength we applied is a more efficient method of increasing the responsivity, so no absorption of light takes place in these regions because the wavelength of interest is larger than the cutoff wavelength of this semiconductor. This is shown in Figure 5.6, where the material InGaAs is used for the intrinsic region the material and, InP is used for the p-type and n-type regions. These type of pin photodiode structure is called as a double heterojunction or a heterostructure since it has two junctions of different semiconductor materials.

5.12 Fiber Delay

It delays the input optical signal by the given amount to model an ideal fiber delay. This can be used anywhere in the topology where a specified optical signal time delay is desired.

CHAPTER-6

PROJECT DESIGNING AND RESULTS

6.1 Introduction

In this chapter we will discuss the methodology for designing 40 channel DWDM network using bidirectional nonlinear fiber in 1550-nm wavelength window. For designing the proposed system Optsim-4.7, advanced optical communication system simulation package is used. Optsim is designed for cutting-edge research of optical LAN, parallel optical bus, WDM, DWDM, TDM, CATV, or other rising optical systems in datacom, telecom, and many communication applications. Optsim represents an interconnected set of models, with each model representing a subsystem or component in the optical communication system. In the Optsim simulation signal is passed between component models, as signals are passed between components in a real communication system.

6.2 Block diagram and Description

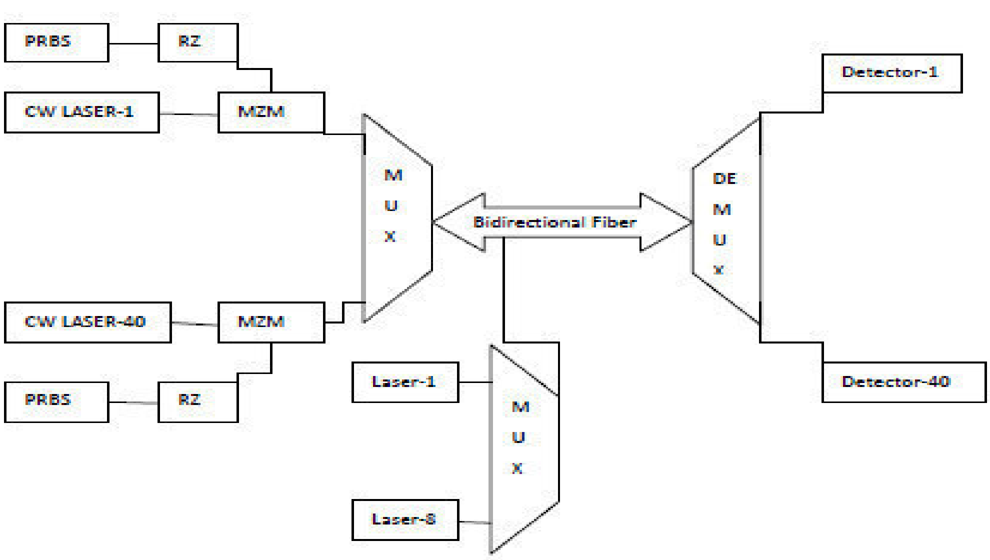


Fig. 6.1 Block diagram of DWDM Network

Here we will discuss the experimental setup of DWDM Network, which we have designed. In the transmitter section, a continuous wave laser is used to generate 40 different wavelengths from 1546 nm to 1532 nm with 0.4nm spacing (50 GHz) and -1 dBm power.

Each channel is modulated by RZ-DPSK signal generate by PRBS generator and MZM. Then after modulating all the 40 channels are multiplexed by WDM Multiplexer, with bandwidth 50 GHz and depth 100dB Gaussian filter is used to minimize the losses and interference. After multiplexing signal power per channel dropped, then this multiplexed signal is passed through Bidirectional Nonlinear fiber of variable length from 30 to 70 km. At the counter propagating probe of bidirectional fiber we have applied 8 CW laser with unequal pump power multiplexed by WDM multiplexer. The parameter of pump signal shown in table 6.1. After applied the pump signal, the signal amplification takes place using Raman amplification. Then de-multiplexer is used to separate all channels and then DPSK receiver is used to detect the optical signal. The responsivity of both PIN photo-detectors is 1A/W and dark current is 10na. After that optical analyzers are used to analyze the different parameter like Q factor, BER, Eye diagram etc.

Table 6.1

Wavelength(nm)	Frequency(THz)	Average power(W)	Power(dBm)
1370	218.83	0.5	26.98
1360	220.32	0.3	24.77
1350	222.07	0.2	23.01
1340	223.72	0.2	23.01
1335	224.56	0.5	26.98
1328	225.75	0.5	26.98
1323	226.60	0.5	26.98
1320	227.11	0.5	26.98

Table 6.1 Parameters of pump signal

6.3 Simulation Diagram of DWDM Network

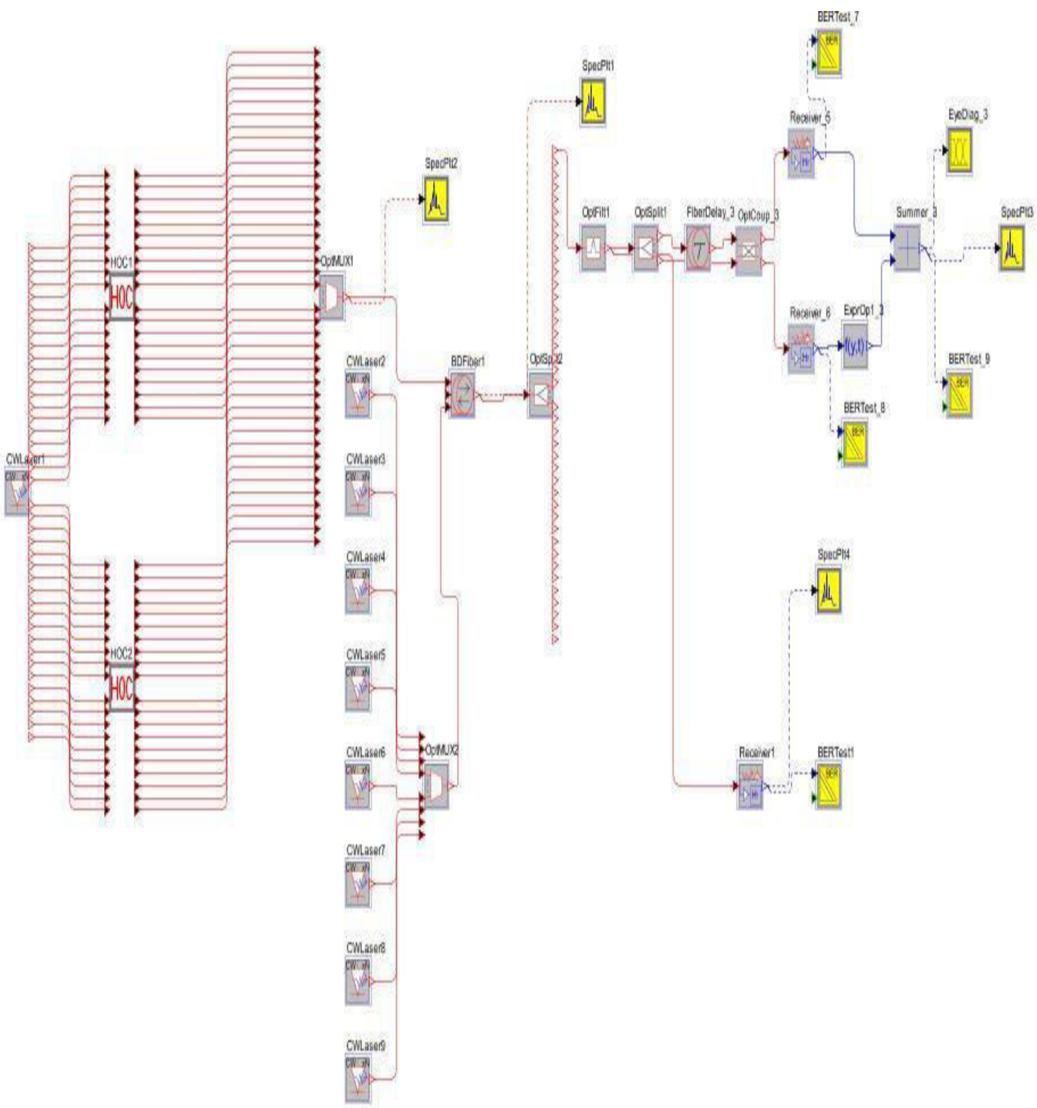


Fig.6.2 Optsim simulation diagram of DWDM Network

Optsim simulation diagram of DWDM Network is shown in fig. 6.2 and description is given in section 6.2. Now we have shown the parameter of each component used in simulation setup.

Data_Source

Parameter	Value	Units	Range	Std. Dev.	Distribution
patternType	"PRBS"				
filename	""				
bitRate	= 1e+09	bps	[1, 1e+015]	0.0	None
patternLength	= 7	2^x_bits	[0, 18]		
startTime	0.0	sec	[-1e+032, 1e+032]	0.0	None
offset	0	bits	[0, 262144]		
shift	0	bits	[0, 262144]		
preBits	2	bits	[0, 1024]		

Fig.6.3 Simulation parameter for PRBS generator

CWLaser1

Parameter	Value	Units	Range	Std. Dev.	Distribution
peakPower	1.0E-3	Watts	[0, 1e+018]	0.0	None
wavelength	1.5456E-6	meters	[0, 1e+018]	0.0	None
mode	"FreqGrid"				
multiNodeOutput	"YES"				
noSources	40	none	[1, 1000]		
deltaFreq	50E9	meters or ...	[0, 1e+018]	0.0	None
filename	""				
azimuth	0.0	degrees	[-90, 90]	0.0	None

Fig.6.4 Properties of CW Laser

Fig. 6.4 shows the properties of CW laser, which generate 40 different frequencies from 193.96 THz to 195.91THz with channel spacing 0.05 THz.

Sig_2

Parameter	Value	Units	Range	Std. Dev.	Distribution
driveType	"on_off_ramp"				
signalType	"VOLTAGE"				
modulationType	"RZ"				
pointsPerBit	= 5	2^x_points	[1, 27]		
Vmax	1.0	volts or a...	[-1000, 1000]	0.0	None
Vmin	0.0	volts or a...	[-1000, 1000]	0.0	None
tr	= 1e-10	sec	[0, 100]	0.0	None
tf	= 1e-10	sec	[0, 100]	0.0	None

Fig. 6.5 Simulation parameter of electrical signal generator

Mod_2

Parameter	Value	Units	Range	Std. Dev.	Distribution
modulationType	"Phase"				
phaseShift	180.0	degrees	[-180, 180]	0.0	None
vPi	1.0	Volts	[-1e+032, 1e+032]	0.0	None
vBias	0.0	Volts	[-1e+032, 1e+032]	0.0	None
vOffset	0.0	Volts	[-1e+032, 1e+032]	0.0	None
onOffRatio	15.0	dB	[0, 1e+006]	0.0	None
insertionLoss	0.0	dB	[0, 1e+006]	0.0	None
ChirpFactor	0.0	none	[-1e+032, 1e+032]	0.0	None

Fig. 6.6 Mach-Zehnder Modulator used as phase modulator

Fig 6.6 shows mach-Zehnder modulator used as phase modulator with phase shift of 180 degrees and on-off ratio 15 dB.

BDFiber1

Parameter	Value	Units	Range	Std. Dev.	Distribution
simulation_mode	"Full"				
length	= 60000.0	m	[0, 1e+032]	0.0	None
loss_model	"Constant"				
loss	0.25	dB/km	[0, 1e+032]	0.0	None
loss_filename	""				
signal_spectrum	"Incoming"				
sig_fixed_lambda_lo	1.4E-6	m	[1e-010, 1e+032]	0.0	None
sig_fixed_lambda_hi	1.6E-6	m	[1e-010, 1e+032]	0.0	None

Fig. 6.7 Bidirectional fiber properties

OptFilt1

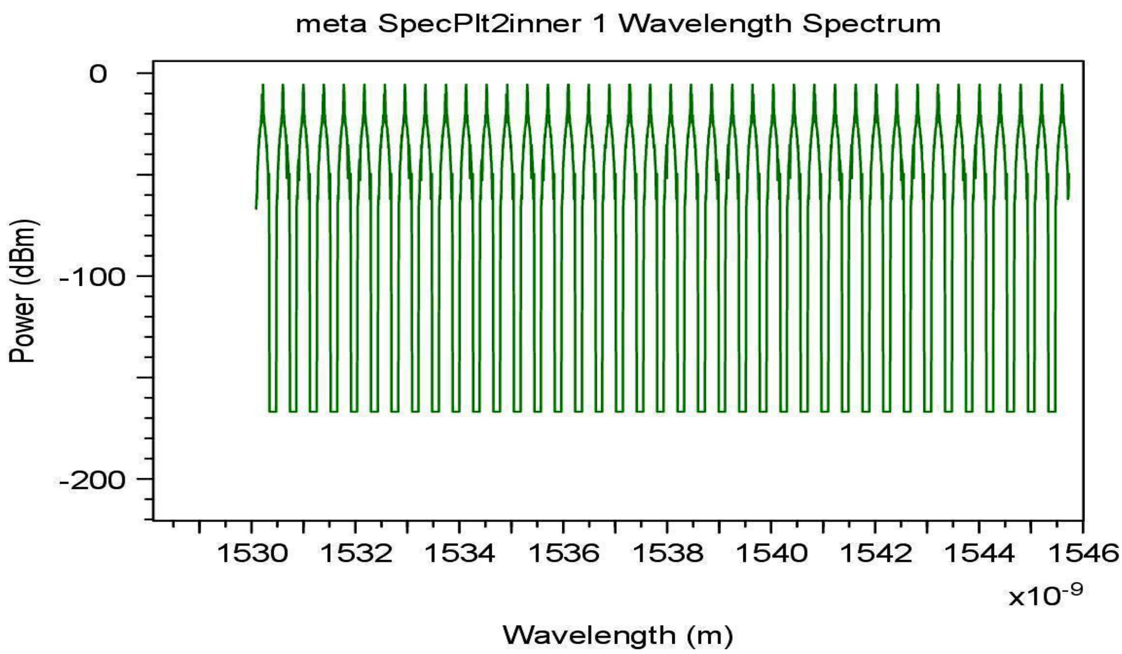
Parameter	Value	Units	Range	Std. Dev.	Distribution
loss	0.0	dB	[0, 1e+032]	0.0	None
type	"Gaussian"				
filename	""				
filterSpecMode	"Wavelength"				
filterCenter	1.542E-6	Hz or mete...	[1e-032, 1e+032]	0.0	None
reflectivity	0.0	none	[0, 1]	0.0	None
FSR	1.0E-7	Hz or mete...	[1e-032, 1e+032]	0.0	None
BW	1.0E-10	Hz or mete...	[1e-032, 1e+032]	0.0	None

Fig. 6.8 Properties of optical filter

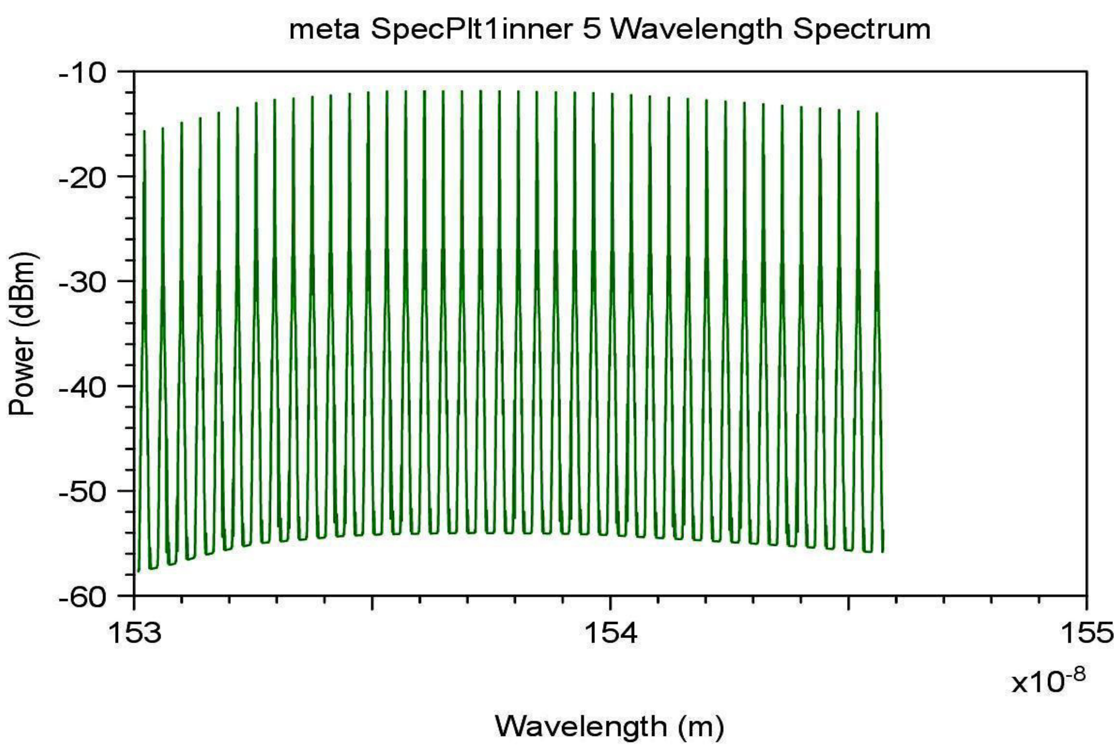
Fig. 6.8 shows the properties of optical filter of Gaussian type at 1542 nm.

6.4 Optical Spectrum

We have shown the optical spectrum of input channels applied to bidirectional fiber and output spectrum of Raman amplified channels. Since backward pumping helps in averaging out power ripples at the receiver end, the attenuation is now reduced to -4 dB with a spread of ± 2 dB.



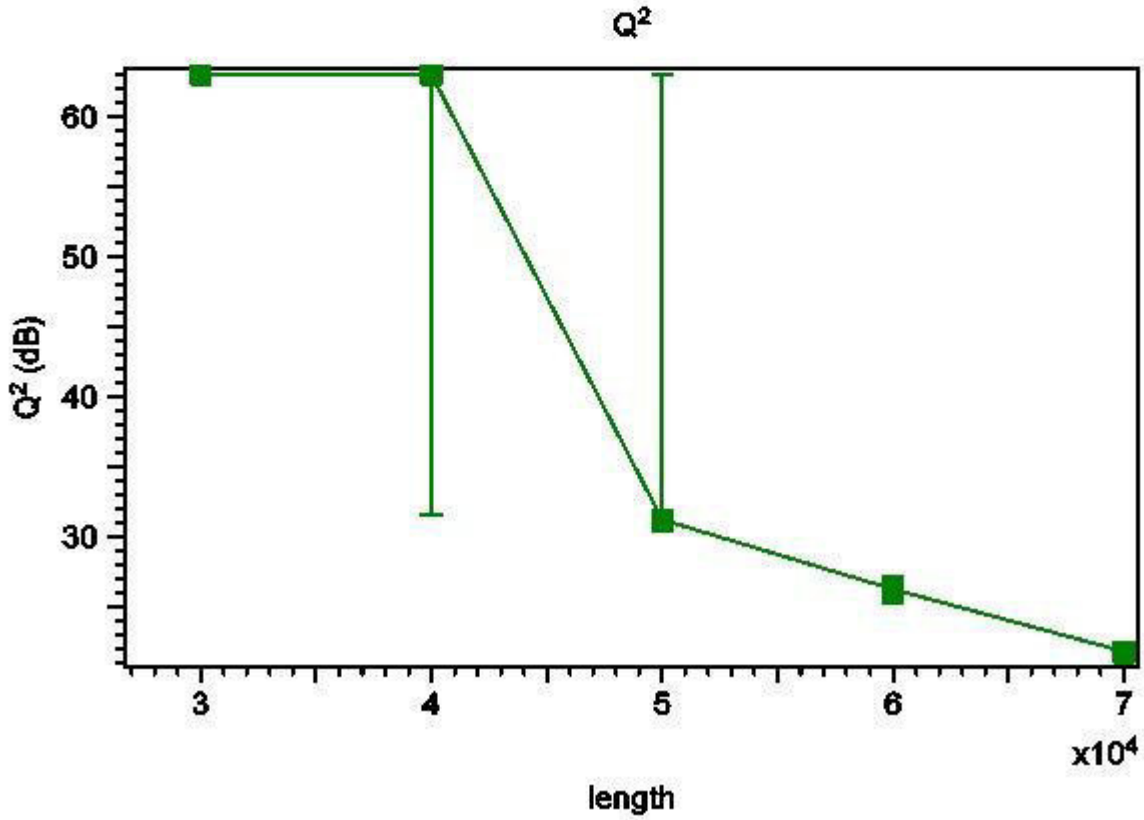
(a)



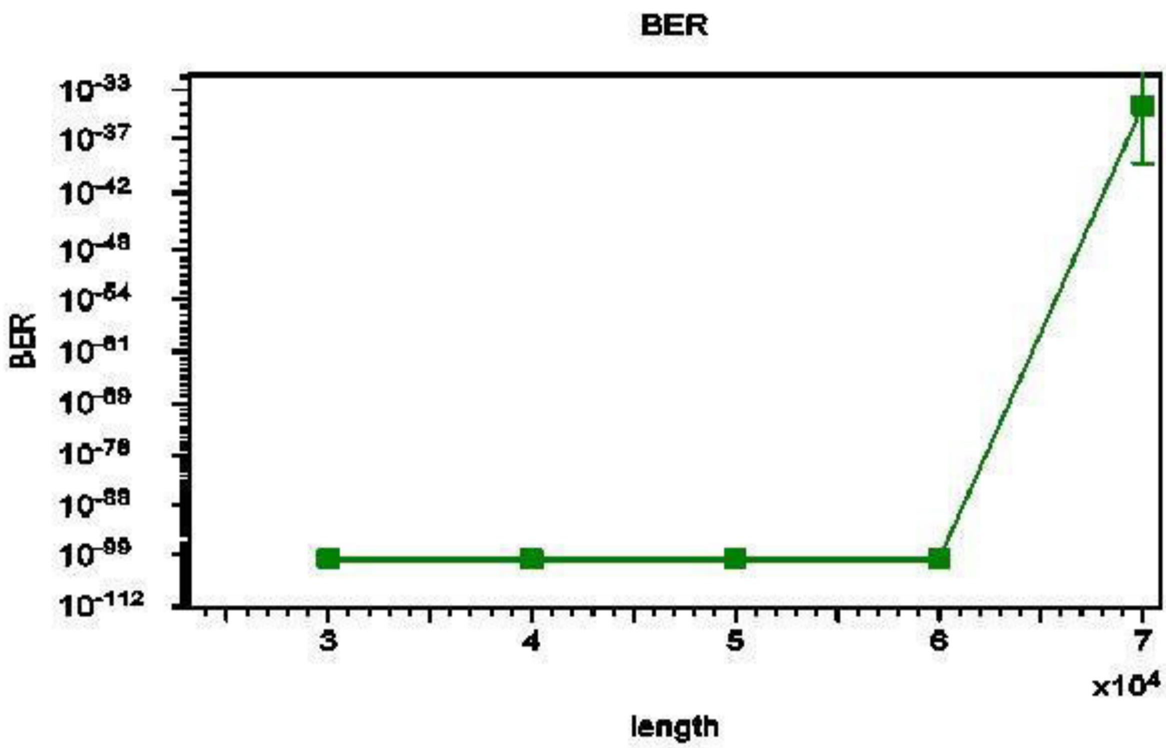
(b)

Fig. 6.9 optical spectrum of (a) input signal (b) amplified signal

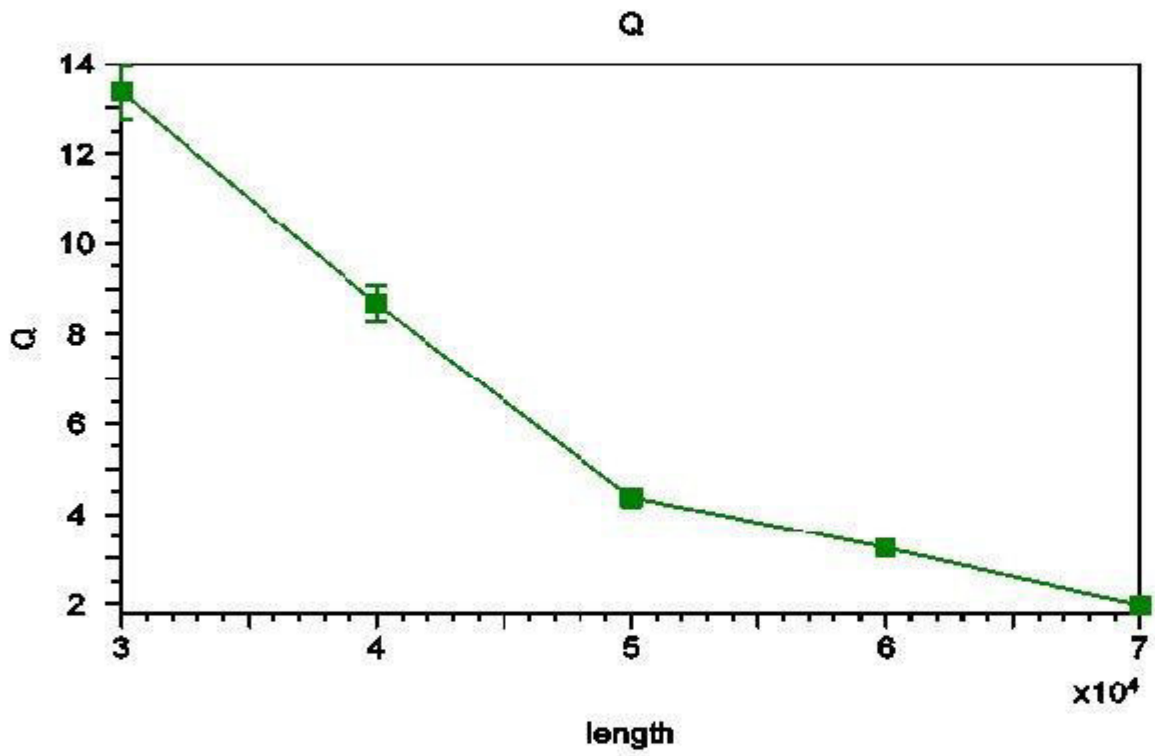
6.5 BER and Q factor analysis



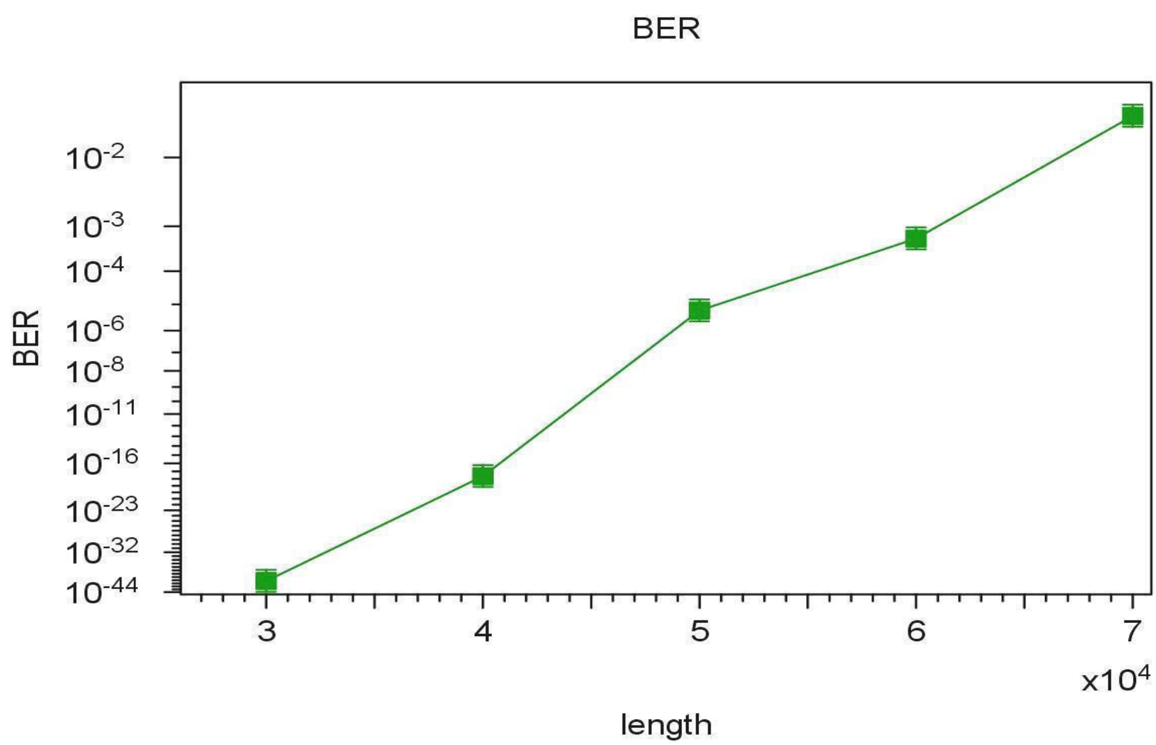
(a)



(b)



(c)



(d)

Fig. 6.10 Result of (a) Q-factor (b) BER with DPSK modulation (c) Q-factor (d) BER without DPSK modulation for different length

In Fig. 6.10 we have shown the result of Q-factor and BER measurement v/s length of our DWDM network with DPSK and without DPSK. It is clearly shows from graphs that Q-factor and BER both improves using DPSK. BER value and Q-factor value numerically at different with and without DPSK are also given in table 6.2 and 6.3 shown below:

Table 6.2

Length(m)	BER	Q^2(dB)
300000	0.0000e+000	63.010
400000	0.0000e+000	63.010
500000	2.1631e-288	31.192
600000	1.3936e-093	26.230
700000	5.4121e-035	21.788

Table 6.2 Length, BER, Q-factor with DPSK

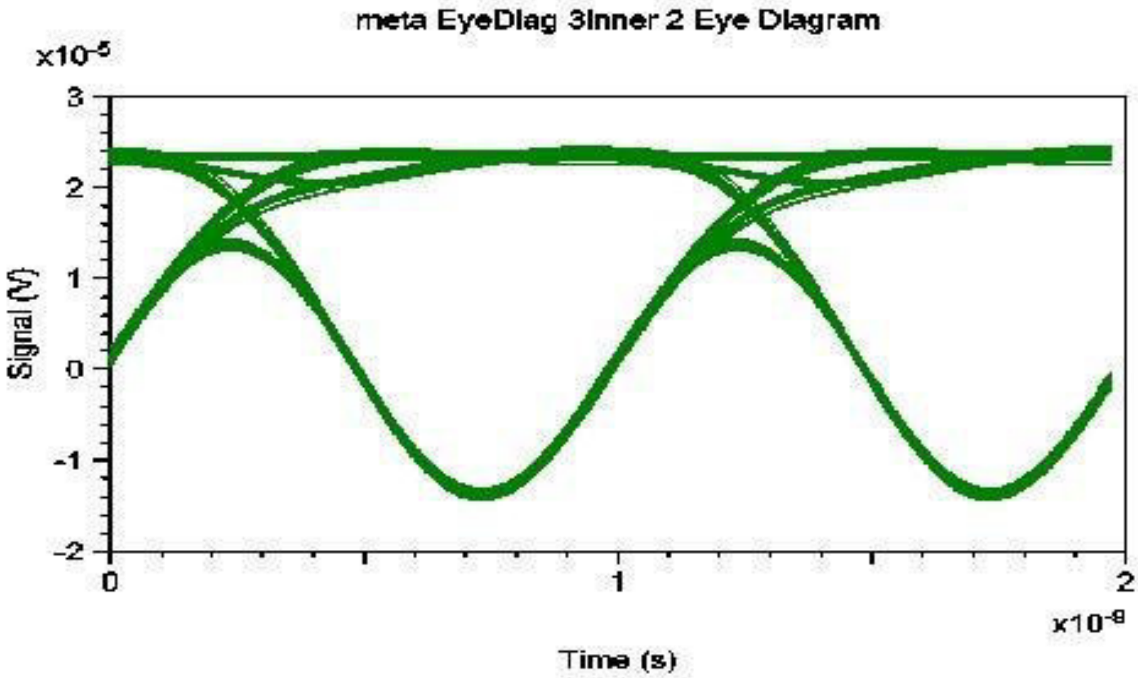
Table 6.2

Length(m)	BER	Q^2(dB)
300000	5.2983e-041	13.358
400000	2.2190e-018	8.667
500000	6.0300e-006	4.376
600000	5.7444e-004	3.251
700000	2.4917e-002	1.961

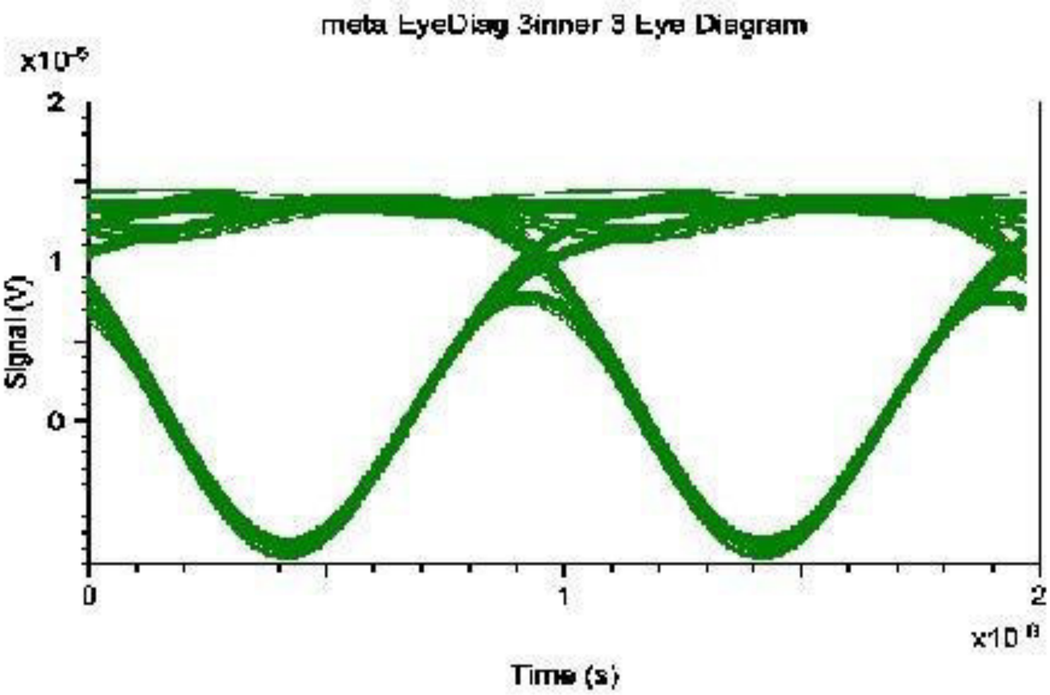
Table 6.3 Length, BER, Q-factor without DPSK

6.6 Eye Diagram analysis

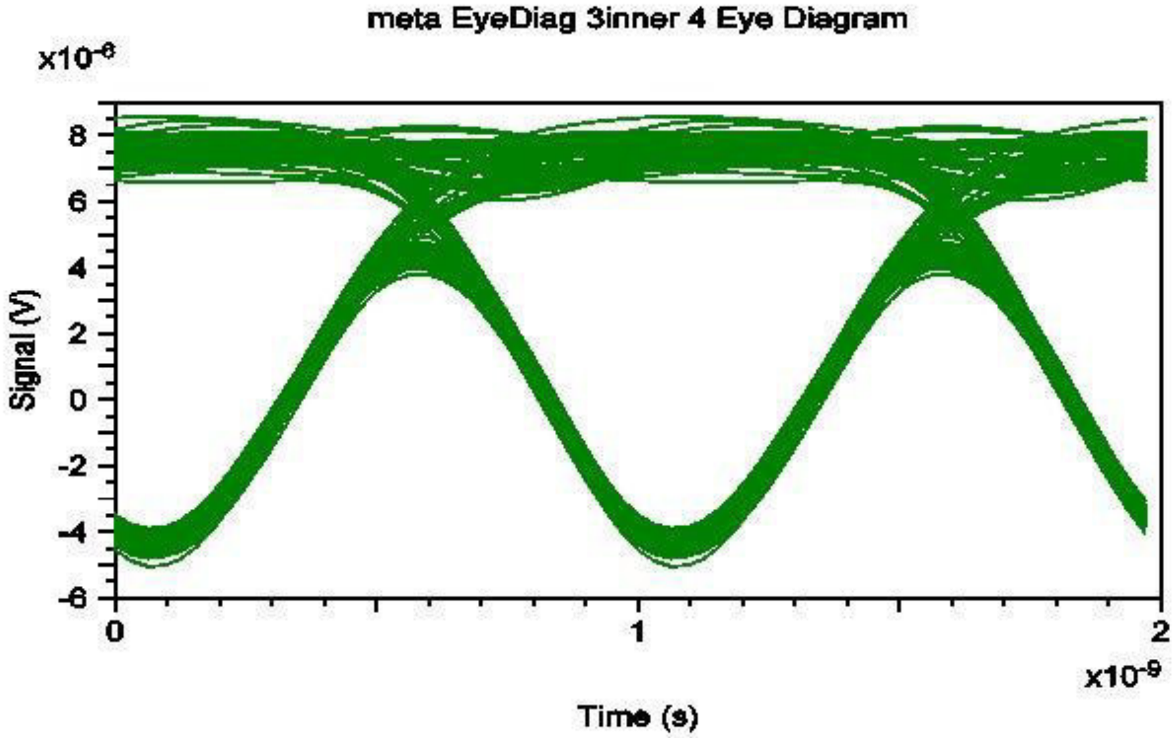
Eye diagrams at different length are shown below; as transmission distance increases the opening of eye decreases means nonlinear distortion increases.


meta EyeDiag 3inner 2 Eye Diagram
x10⁻⁵
3
2
1
0
-1
-2
Signal (V)
0
1
2
x10⁻⁹
Time (s)

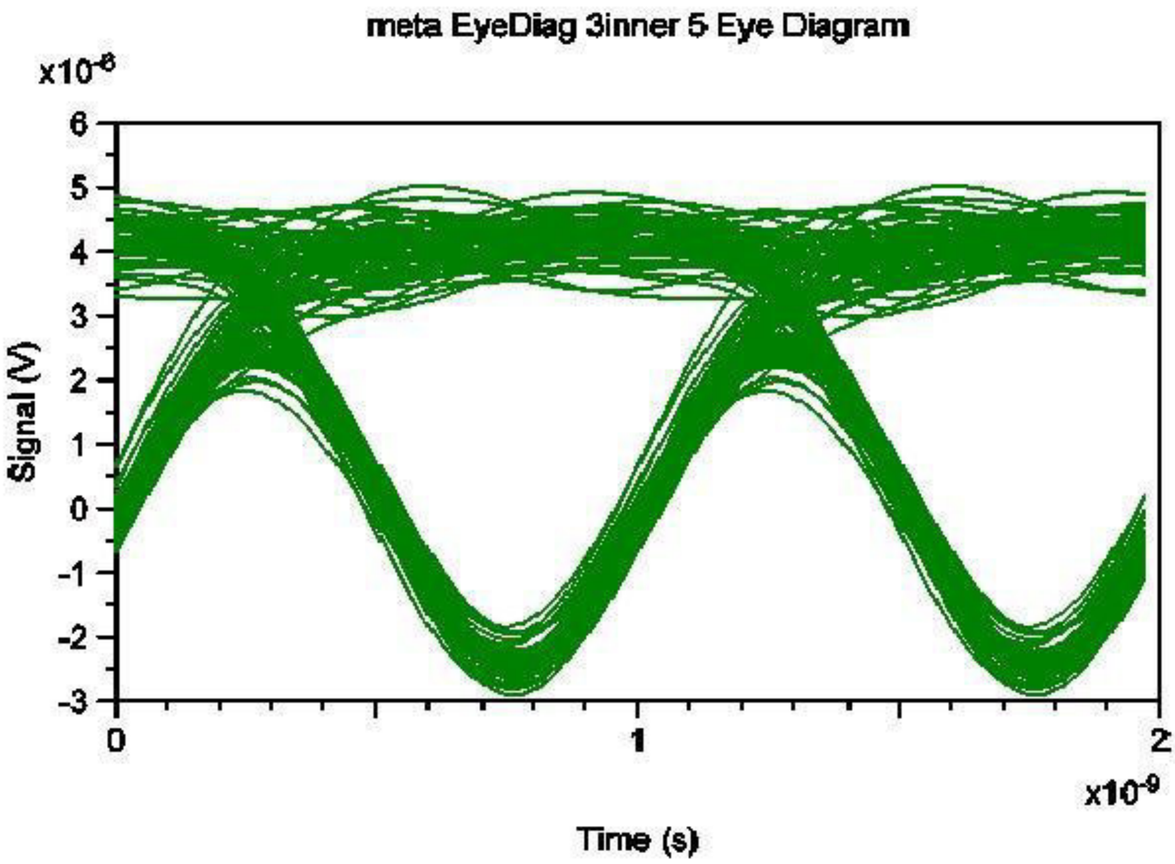
(a)


meta EyeDiag 3inner 3 Eye Diagram
x10⁻⁵
2
1
0
Signal (V)
0
1
2
Time (s)

(b)



(c)



(d)

Fig. 6.11 Eye diagrams at (a) 40 km (b) 50 km (c) 60 km (d) 70 km

CHAPTER-7

CONCLUSION AND FUTURE SCOPE

This chapter provides a summary of the findings of the study which has done so far. In this designed system, we have shown high capacity 40 channel DWDM system over 80 km in 1550-nm wavelength domain using DPSK modulation and Distributed Raman amplification. The proposed system shown excellent performance in terms of Q-factor, bit error rate, eye opening etc . The Q-value of designed system is obtained from and BER is from. The system is designed to operate on 50 GHz channel spacing which shows better performance for this small spacing, we can also design system for less channel spacing. As we know channel spacing and input power results nonlinearity such as four-wave mixing (FWM) and cross-phase modulation (XPM), as channel spacing is decreased nonlinear effects increase which degrade signal quality. By compensating nonlinear effects Ultra High data rate (upto several Tbps) can be obtained by these system. To increase the transmission distance of the proposed system, channel spacing can be increase up to 100 GHz.

It is an important issue in DWDM system that how many wavelengths can be multiplexed. Currently, various system use 64, 80 and 128 channels (wavelengths) using single mode fiber. Raman amplifier used for power booster, which was shown to have superior noise and BER performance. It made possible by combining the high power conversion efficiency, low-noise and flat gain properties of Raman amplifiers, and residual pump recycling. The separation of channel determines the difference of the wavelength of each channel, or how close (in terms of wavelength) the channels are. Forty channel DWDM systems can transmit over a single fiber an aggregate bandwidth of 400 Gbps (10 Gbps per channel).

Still DWDM technology is evolving and technologists as well as standards bodies are having so many issues, Systems are being authorized for few tens of wavelengths in same fiber. However in the near future DWDM systems will have several 100 wavelengths in a single Fiber or 1000 channels may be multiplexed within same fiber. Still 200 channels at 40Gbps per channel with an aggregate bandwidth of 8 Tbps per fiber are equal to feasible.

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