Performance Analysis of Hybrid Amplifiers in Optical Communication Systems

Thesis submitted in the partial fulfillment of requirement for the award of degree of

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DECLARATION

I **Sanjiv Kumar** hereby certify that the work which is being presented in this thesis entitled "**Performance Analysis of Hybrid Amplifiers in Optical Communication Systems**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Hardeep Singh**.

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

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Date: 26/06/2012

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

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Abstract

The demand for high capacity long-houl telecommunication system increasing at a study rate, So that to satisfy the requirement on long distances, the communication channel must have a very low cost. Optical fiber is the only transmission medium offering such longer bandwidth with low loss communication links. Fiber optics has made a revolutionary change in telecommunication over the past few decades. The electronic regeneration has become expensive and also limited transmission rate, so that a means of optical amplifier was sought. Which increase transmission rate and eliminated the costly conversions from optical to electrical signals and vice–versa. Optical amplifiers amplify signals at different wavelength simultaneously. Basically here we discuss two types of Optical Amplifiers i.e. Semiconductor optical amplifiers and Fiber amplifiers and further classified into traveling wave semiconductor optical amplifier, fabry-perot semiconductor optical amplifier, Erbium doped fiber amplifier, Raman & Brillouin fiber amplifiers.

Optical amplifiers are the fundamental building blocks required for the development of future all optical networks. The amplifiers are based on semiconductor laser structures or doped optical fibre and in recent years there has been rapid and dramatic progress in their development. Currently fibre optical amplifiers are at a stage where they could be deployed in real networks.

In this thesis, I used 64 channel WDM systems at 10 Gbps and I have been investigated for the various optical amplifiers and hybrid amplifiers and the performance has been compared on the basis of transmission distance, presence and absence of nonlinearities and pumping. The amplifiers EDFA , RAMAN and SOA have been investigated independently and further compared with hybrid amplifiers like EDFA-EDFA, RAMAN-EDFA, RAMAN-SOA EDFA-SOA, EDFA-RAMAN, RAMAN-EDFA-SOA and SOA-RAMAN-EDFA. It is observed that optical hybrid amplifier RAMAN-SOA and SOA-RAMAN-EDFA provides the highest output gain (24.56 dB and 27.31 dB) ,least bit error rate (1×10^{-40} and 1×10^{-40}) and good eye diagram at 160 km for presence and absence of nonlinearities as compare to other optical amplifier as compare to other optical amplifier. Four types of pumping have been investigated independently and compared. It is observed that pump 3 of RAMAN-EDFA

provides the highest output power (10.64 dBm and 10.69 dBm) and least bit error rate (1 × 10^{-40} and 1 × 10^{-40}) at 160 km for presence and absence of nonlinearities respectively as compare to other pumping amplifier.

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List of Symbol

µm	Micro meter
nm	Nano meter
ps	Pico second
Km	kilometer
G	fiber path gain
i	modulating current
η	modulation sensitivity
β	group velocity dispersion coefficient
γ	self-phase modulation coefficient
T	pulse width
z	soliton period
N	soliton order
λ	Wavelength of light
c	Velocity of light
h	Plank constant
dB	Decibel
E1	lower energy state
E2	Higher energy state
E	Photon energy
N1	Population density of lower level
N2	Population density of higher level
N	carrier density
L	Run for fiber length

mW	Milli watt
$\Delta\lambda$	source line-width
D	fiber dispersion
L	the fiber length
ω	angular frequency

List of Abbreviations

APD	Avalanche photodiode
ASE	Amplified spontaneous emission
AWG	Arrayed waveguide gratings
BER	Bit error rate
DCF	Dispersion compensated fiber
DFA	Doped fiber amplifier
DFB	Distributed feedback
DRA	Distributed Raman amplifier
DS	Dispersion shifted
DWDM	Dense wavelength division multiplexing
EDFA	Erbium-doped fiber amplifiers
FDM	Frequency Division Multiplexing
FRA	Fiber Raman amplifier
FWM	Four-wave mixing
HA	Hybrid amplilifier
ISI	Inter symbol interference
LED	Light emitting diode
NA	Numerical aperture
NB-HA	Narrow band hybrid amplifier
NDS	Normal dispersion shifted
NF	Noise figure
OAMP	Optical amplifier

OFA	Optical fiber amplifier
PMD	Polarization-mode dispersion
PON	Passive optical network
RF	Radio frequency
RFA	Raman fiber amplifier
RZ	Return-to-zero
SBS	Stimulated Brillouin scattering
SMF	Single-mode fibers
SNR	Signal-to-noise ratio
SOA	Semiconductor optical amplifier
SRS	Stimulated Raman scattering
TDM	Time division multiplexing
VBR	Variable bit rate
WDM	Wavelength-division multiplexing
WLAN	Wireless local area networks

CHAPTER 1

Introduction

1.1 Introduction

Information revolution implies that multimedia networks need high bandwidth for realtime communication services. At present, optical fiber is the only transmission medium offering such large bandwidth with low loss communication links. One of the foundations of this information society is high capacity optical fiber communications, which has been one of the fastest growing industries since the 1980s and is the key technology to fulfil the demands for bandwidth for broadband systems. The early optical fiber had a very high attenuation up to 1000 dB/km and could not be used for commercial fiber optical communication systems. In 1970, the scientists at Corning Glass Works were successful in producing a fiber with 20 dB/km loss which opened the doors for optical fiber communications. Now a day, the optical fibers with losses up to 0.2dB/km are commercially available [1].

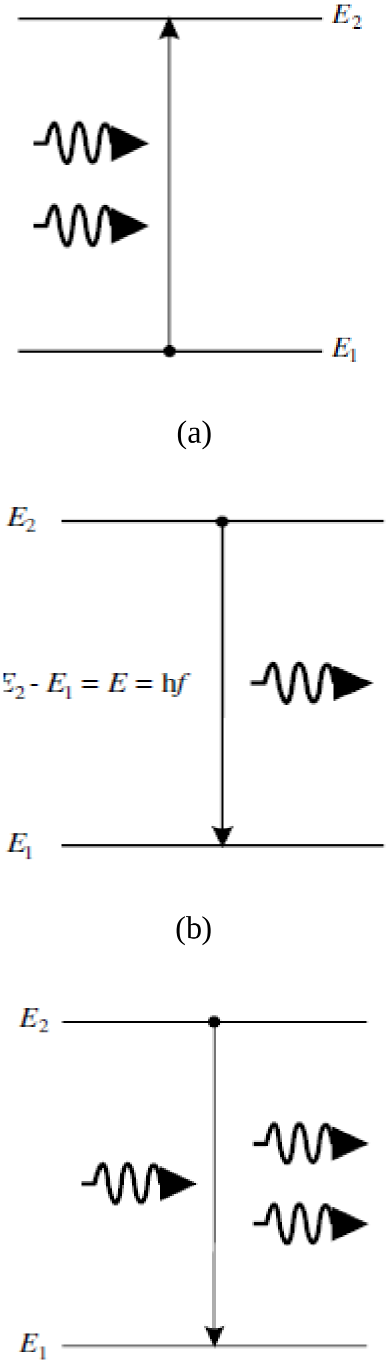
In fiber optic communication, there is degradation of transmission signal with increased distance. By the use of optoelectronic repeater, this loss limitation can be overcome. In optoelectronic repeater, optical signal is first converted into electric signal and then after amplification it is regenerated by transmitter. But such regeneration becomes quite complex and expensive for wavelength division multiplexing systems. So, to remove loss limitations, optical amplifiers are used which directly amplify the transmitter optical signal without converting it into electric forms. The optical amplifiers are used in linear mode as repeaters, optical gain blocks and optical pre-amplifiers. The optical amplifiers are also used in nonlinear mode as optical gates, pulse shaper and routing switches. The optical amplifiers are mainly used for amplification of all channels simultaneously in WDM light wave system called as optical in-line amplifiers. The optical amplifiers are also bit rate transparent and can amplify signals at different wavelengths simultaneously. The optical amplifier increases the transmitter power by placing an amplifier just after the transmitter called power booster. The transmission distance can also be increased by putting an amplifier just before the receiver to boost the received power. The optical amplifier magnifies a signal immediately before it reaches the receiver called as optical pre-amplifier.

In 1990, third generation 1.55 μm systems were developed using these approaches and the systems were operating at a bit rate of 2.5 Gb/s. Despite the better performance of third generation systems, they have a major drawback: the need to regenerate the signal periodically by using electronic repeaters typically spaced 60-70 km apart [1]. This problem was overcome with the advent of fiber amplifiers in the early 90s. The fourth generation systems were developed using fiber amplifiers to increase the repeater spacing and bit rate. The development of erbium doped fiber amplifier (EDFA) was a major impetus to the research on active-fiber technology in the 1.55 μm wavelength region and it had a great impact on ultra-long haul transmission. Erbium doped fiber has made it possible to transmit optical signals over thousands of kilometers without electrical repeaters, simply by cascading optical amplifiers and fiber sections in a chain [2]. By the early part of the 2000s, almost every long-haul (typically between 300 and 800 km) or ultra-long-haul (typically longer than 800 km) fiber-optic transmission system uses Raman amplification. Raman amplifiers were not deployed until the late 1990s. The problem was a relatively poor efficiency of Raman amplifiers at lower signal powers. Erbium-doped fiber amplifiers required powers in the range of 1 to 10 mW, whereas Raman amplifiers required powers in the range of 1 to 5 W. Therefore, to achieve a gain of 20 dB or more required almost three orders of magnitude more pump power in Raman amplifiers [3]. Now days Optical hybrid amplifier provides high power gain. Mohammed N.Islam described that the total amplifier gain (G_{Hybrid}) is the sum of the two gains [4]: $G_{Hybrid} = G_{EDFA} + G_{Raman}$ if we are using RAMAN-EDFA hybrid amplifier.

1.2 Principle & Theory

To achieve optical amplification, the population of upper energy level has to be greater than that of lower energy level, i.e. N2 > N1, where N1, N2 is population density of lower and upper state. This condition is known as population inversion. When photon energy E is incident on atom, it may be excited into higher energy state E_2 through absorption of photon called absorption as shown in figure 1.1(a). As atom in energy state E2 is not remain stable, atom returns to lower energy state in random manner by generating a photon as shown in figure 1.1(b). This is called spontaneous emission.

This can be achieved by exciting electron into higher energy level by external source called pumping. Stimulated emission occur, when incident photon having energy E= h_c/λ interact with electron in upper energy state causing it return to lower state with creation of



(c)

Figure 1.1: Absorption, spontaneous emission and stimulated emission process. [5].

second photon 1.1(c), where h is Plank constant, c is velocity of light and λ is the wavelength of light . So light amplification occurs, when incident photon & emitted photon are in phase and release two more photon, continuation of this process effectively creates avalanche multiplication. Therefore amplified coherent emission is obtained.

1.3 Types of optical Amplifiers

Optical amplifiers were classified on the basis of device characteristics i.e., whether it is based on linear characteristic (Semiconductor optical amplifier and Rare-earth doped fiber amplifiers) or nonlinear characteristic (Raman amplifiers and Brillouin amplifiers). Optical amplifiers were also classified on the basis of structure i.e., whether semiconductor based (SOAs) or fiber based (Rare-earth doped fiber amplifiers), Raman and Brillouin scattering amplifiers.

1.3.1 Semiconductor Optical Amplifiers

Semiconductor Optical Amplifiers (SOAs) uses the principle of stimulated emission to amplify an optical information signal. Optical input signal carrying original data enters to semiconductor's active region through coupling. The coupling is required because the mode field diameter of single mode beam is 9.3 Mm, while size of active region is less. Injection current delivers the external energy to pump elements at conduction band. The input signal stimulated the transition of electrons down to valence band & emission of photon with same energy & same wavelength as the input signal, so amplified optical signal is obtained [1]. SOA is of two types Fabry –Perot Amplifier (FPA) & Travelling Wave Amplifier (TWA). Fabry-Perot Amplifier (FPA) is same as SOA. In this, light entering the active region is reflected several times from cleaved face & amplified as it leaves the cavity. Travelling Wave Amplifier (TWA) is the SOA form. Here, TWA is an active medium without reflective facets, so that input signal is amplified by a single passage through active region. Practical active region without reflective facets was made by covering the facets of semiconductor material by antireflection coating, tilting the active region with respect to facet and using buffer material between active region & facet to also reduce reflectance R as small as 10-4. SOA's as shown in the figure 1.2.

- Used as power boosters following the source (optical PA)
- Provide optical amplification for long-distance communications (in-line amplification, repeaters).
- Pre-amplifiers before the photo detector

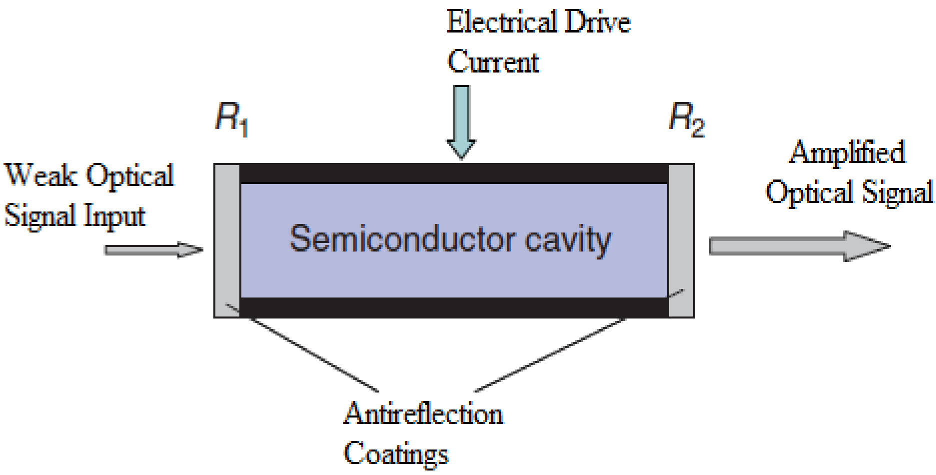


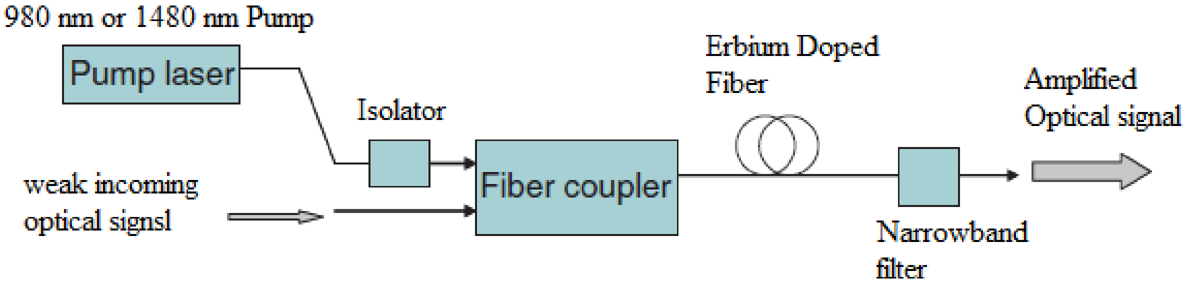
Figure 1.2 : Semiconductor Optical Amplifier[6]

1.3.2 Fiber Amplifiers

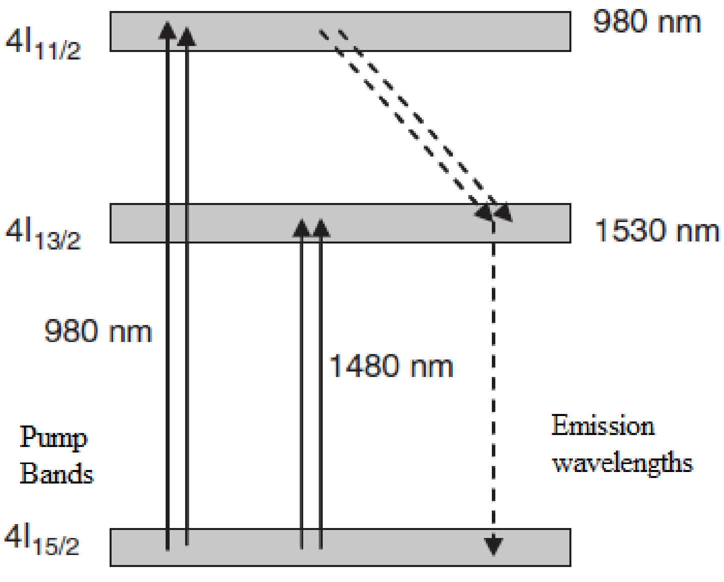
The fiber amplifiers also act as power amplifier, repeater, and a pre-amplifier. The gain medium comprises a length of single mode fiber connected to WDM coupler, which provides low insertion loss at both signal and pump wavelength [Agarwal, 2001]. The excitation occurs through optical pumping laser along with optical input signal within the coupler. The stimulated emission process occurs inside the fiber gain medium. The amplified optical signal is emitted from the other end of fiber made from heavily doped ions depending upon type of fiber amplifiers *i.e.* rare-earth doped fiber amplifier, Raman fiber amplifier and Brillouin fiber amplifier.

1.3.2.1 Eribium Doped Fiber Amplifier

The rare-earth doped fiber amplifiers are finding increasing importance in optical communication systems. The active medium consists of 10–30m length of optical fiber highly doped with a rare-earth element, such as erbium (Er), ytterbium (Yb), neodymium (Nd), or praseodymium (Pr). Erbium doped fiber amplifiers (EDFAs) can b extensively used in optical fiber communication systems due to their compatibility with optical fiber. An EDFA has a comparatively wide wavelength range of amplification making it useful as transmission amplifier in wavelength division multiplexing systems. Theoretically EDFA is capable of amplifying all the wavelengths ranging from 1500 to 1600 nm. However practically there are two windows of wavelength. These are C and L band. This allows the data signal to stimulate the excited atoms to release photons. Most erbium-doped fiber amplifiers (EDFAs) are pumped by lasers with a wavelength of either 980 nm or 1480 nm [7]. The 980-nm pump wavelength has shown gain efficiencies of around 10 dB/mW, while the 1480-nm pump wavelength provides efficiencies of around 5 dB/mW. Typical gains are on the order of 25 dB Typically noise figure lies between 4-5 dB with



(a)



(b)

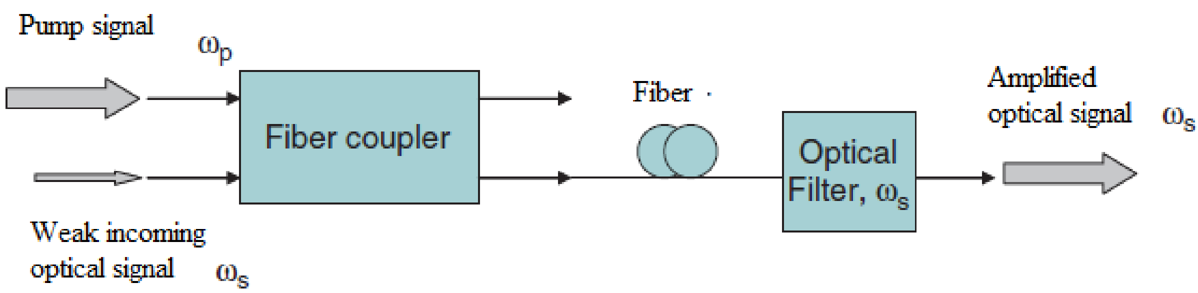
Figure 1.3 EDFA (a) The general EDFA configuration (b) The EDFA energy diagram[6]

forward pumping and equivalent figures for backward pumping are 6-7 dB assuming 1480 nm pumping light was used [1].The EDFA basic block diagram and energy diagram shown belowin Figure 1.3(a) and 1.3(b).

1.3.2.2 Raman Amplifier

A fiber based Raman amplifier uses stimulated Raman scattering (SRS) occurring in silica fibers when an intense pump beam propagates through it. In SRS, incident pump photon gives up its energy to create another photon & remaining energy is absorbed by the medium in the form of molecular vibrations (optical phonon). In Raman amplifier, standard single -mode optical fiber can be used generally. The main features of the Raman amplification were that it realized as continuous amplification along the fiber, bidirectional in nature and offers more stability, insensitivity to reflections [8]. The saturation optical power level was very high as it depends on the pump power. The main disadvantage of this amplifiers that pump power requirement is relatively high in comparison with SOAs and EDFAs.

Biswanath Mukherjee described in [7] fundamental advantages of Raman amplifier. First Raman gain exists in every fiber, which provides a cost-effective means of upgrading from the terminal ends. Second, the gain is nonresonant, which is available over the entire transparency region of the fiber. The third advantage of Raman amplifiers is that the gain spectrum can be tailored by adjusting the pump wavelengths. For instance, multiple pump lines can be used to increase the optical bandwidth, and the pump distribution determines the gain flatness.



Figuer 1.4 : The Raman operation principle in forword-pumping configuration[6]

1.3.3 Hybrid Optical Amplifier

The cascading an erbium-doped fiber amplifier (EDFA) and a fiber Raman amplifier is called a hybrid amplifier, the RAMAN-EDFA. The cascading a semiconductor optical amplifier (SOA) and a fiber Raman amplifier is called a hybrid amplifier, the RAMAN-

SOA. Hybrid amplifier provides high power gain. Mohammed N.Islam described that the total amplifier gain (G_{Hybrid}) is the sum of the two gains [4]:

$$G_{Hybrid} = G_{EDFA} + G_{Raman}$$

Gain partitioning in hybrid amplifier is as shown figure 1.5. Two kind of hybrid amplifier (HA) are: the narrowband HA (NB-HA) and the seamless and wideband HA (SWB-HA). The NB-HA employs distributed Raman amplification in the transmission fiber together with an EDFA and provides low noise transmission in the C- or Lband. The noise figure of the transmission line is lower than it would be if only an EDFA were used. The SWB-HA, on the other hand, employs distributed or discrete Raman amplification together with an EDFA, and provides a low-noise and wideband transmission line or a low-noise and wideband discrete amplifier for the C- and L-bands. The typical gain bandwidth ($\Delta\lambda$) of the NB-HA is 30 to 40 nm, whereas that of the SWB-HA is 70 to 80 nm.

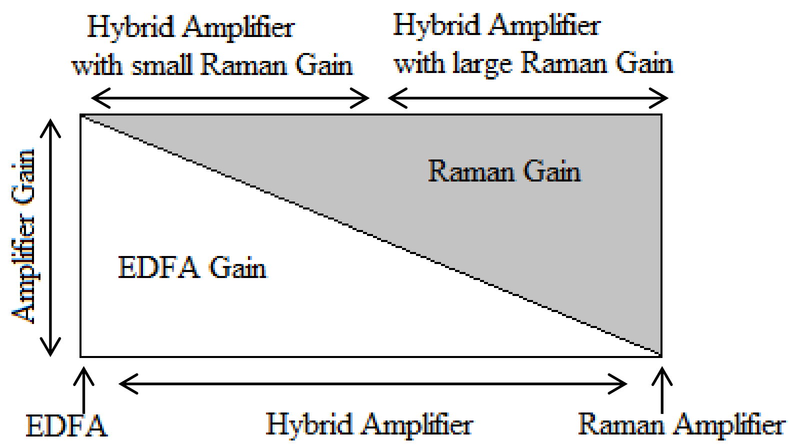


Figure 1.5 : Gain partitioning in Hybrid Amplifier[4]

1.4 Basic configuration of a transmission line with an inline Optical Amplifiers

We prefer different basic configurations of a transmission line with an inline optical amplifier. An EDFA is used as the repeater between two installed transmission fibers and amplifies the input signal light Figure 1.6(a). The signal light usually consists of wavelength-division multiplexed (WDM) multichannel and the EDFA offers C or L-gain

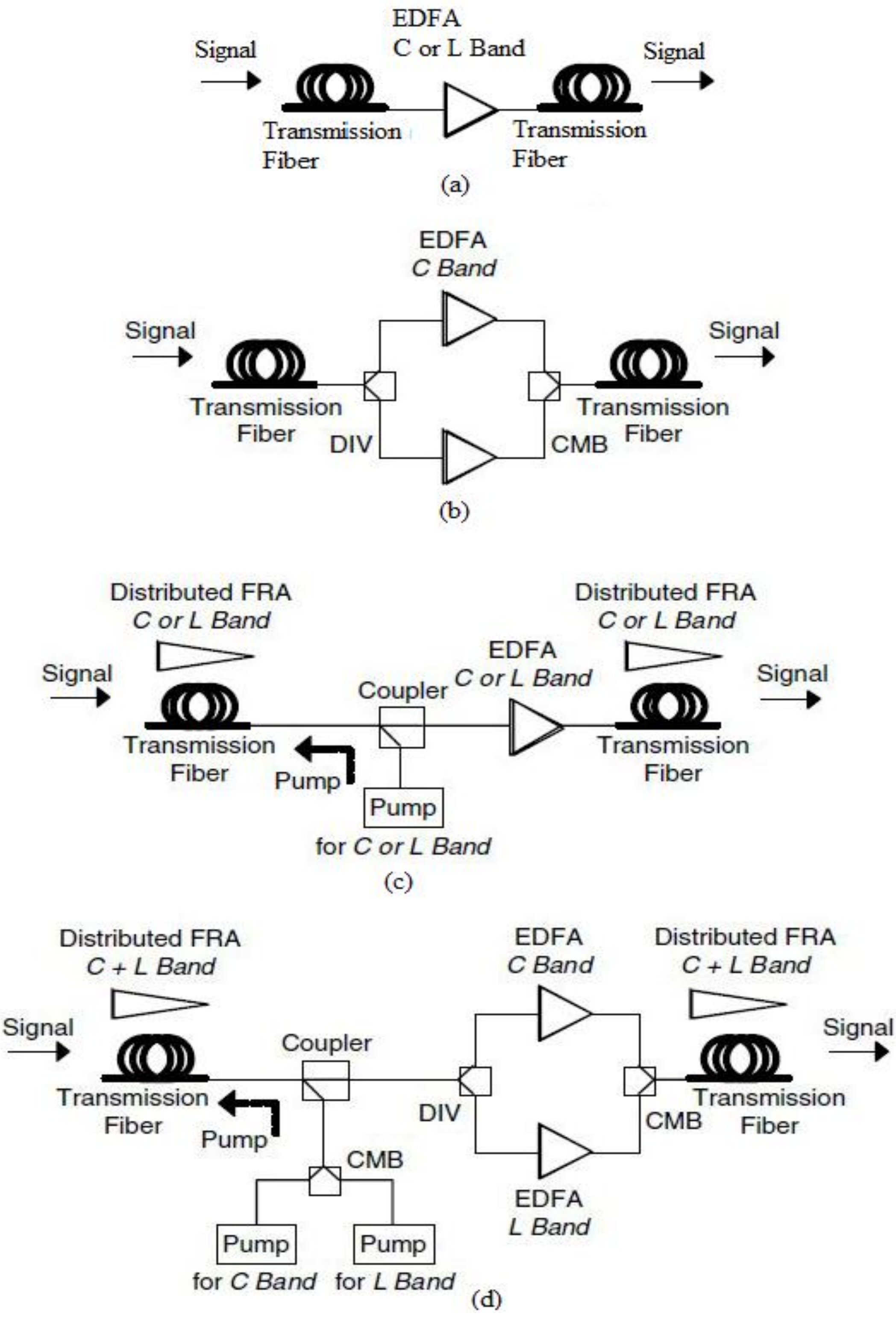


Figure 1.6: Basic configurations of a transmission line with an inline amplifier: (a) A EDFA (b) A two-gain band amplifier (EDFA) with C- and L-band EDFAs in parallel (c) A hybrid EDFA/distributed Raman amplifier with C- or L-band; and (d) A hybrid multipump raman/EDFA amplifier

band coverage [3]. The typical gain bands of C- and L-gain band EDFAs are the wavelength ranges of about 1530 to 1560 nm and 1570 to 1600 nm figure 1.6 (b) shows a two-gain band amplifier (EDFA) with C and L-band EDFAs in parallel with each other. The combiner and divider connected to the EDFAs multiplex and demultiplex the WDM signal channels according to their wavelengths. The two-gain band EDFA has a gain bandwidth that is about EDFA/distributed Raman amplifier with C- or L-band and (d) A hybrid EDFA/distributed Raman amplifier with C- and L-bands in parallel (CMB: combiner, DIV: divider) twice that of the C- or L-band EDFA figure 1.6 (b). However, its cost and the number of optical components are about twice those of the C- or L-band EDFA. The NB-HA that offers C- or L-band coverage is shown in figure 1.6 (c). The NB-HA consists of a C- or L-band distributed Raman Amplifier (DRA), which is a transmission fiber itself, and a C- or L-band EDFA set after the transmission fiber as a repeater. The figure 1.6 (d) shows a C and L-two-gain band HA. The two-gain band HA consists of a two-wavelength pumped DRA (C- and L-band) and a two-gain band EDFA. The pump lights for the C- and L-bands are multiplexed by a combiner and launched into the transmission fiber via a coupler.

1.5 Development of DWDM Technology

Early WDM began in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm (or 850 nm and 1310 nm) regions, sometimes called wideband WDM [9]. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were spaced at an interval of about 400 GHz in the 1550-nm window. By the mid-1990s, dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz. By the late 1990s DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even 25 GHz intervals, as shown in figure 1.7.

1.6 OptSim

The core version of OptSim was first developed in 1983 by the Optical Communication Group of Politecnico di Torino [10]. The optical simulation software was originally known as TopSim, a transmission system simulation package, which was developed for mobile and satellite communication. TopSim was furthered improved with the addition of

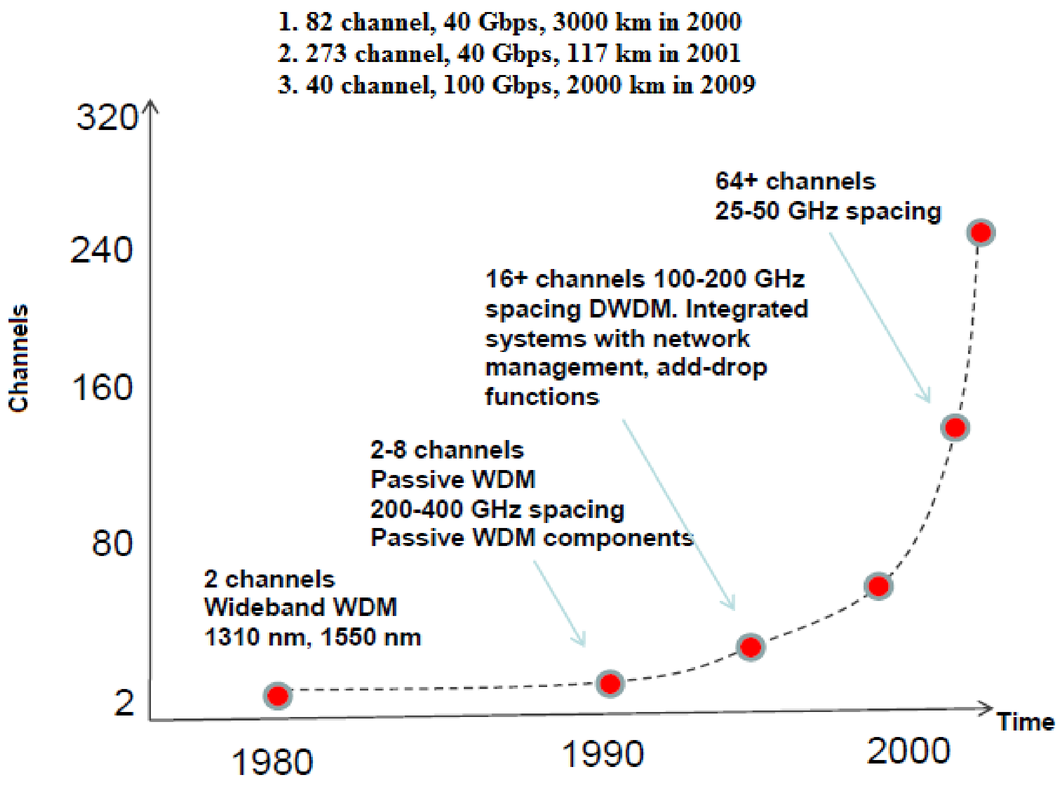


Figure 1.7: Developments in WDM Technology [9]

a library for optical systems and after continuous refinement efforts by the simulation specialists of Politecnico di Torino, the simulation software was later known as OptSim. OptSim is an advanced vectorial fiber simulator tool that takes into account all important phenomena including fiber loss, chromatic dispersion, birefringence, polarisation mode dispersion (PMD), Kerr non-linearity and amplified spontaneous emission accumulation. OptSim is one of the two high-end commercial system simulators that are capable of calculating more than 15,000 km of non-linear fiber with high precision in a reasonable time. The fiber is simulated by solving the nonlinear Schrodinger equation using a modified version of the standard Split-Step Fourier (SSF) method, which solve the problems related to the cyclical numerical convolution effects intrinsic to the standard SSF method by implementing a true linear numerical convolution by means of component processing techniques (overlap-and-add algorithm) [10]. This method has allowed extremely long fiber links to be simulated on a large window (thousands of bits at standard bit rates) with excellent accuracy. OptSim is actually the fastest simulator because all the simulation components are based on a time domain computation [11]. With OptSim, it is possible to model very closely a “real” ultra-long haul system and achieve realistic results. In addition, continuous refinement of the design parameters can be performed to achieve optimal results, which is difficult to perform in the hardware implementation environment because it can be costly, time consuming and relatively inflexible

1.6.1 System Requirements for Optsim

The Windows versions require for Optsim Windows 2000/XP. OptSim is not guaranteed to work under Windows 95/98/NT. OptSim will also run under Linux and various UNIX using X Windows or XFree86 and Motif. Hardware requirements areas follow [11] :

• Pentium II 400 MHz .

• Minimum of 64 Mbytes of RAM for data processing. 128 Mbytes of RAM for faster processing time.

• 100 Mbytes of free space for complete OptSim installation.

• A PostScript compatible printer to print the schematics or graphs created with OptSim.

• A Color graphic display with resolution of 1024x768 pixels or higher.

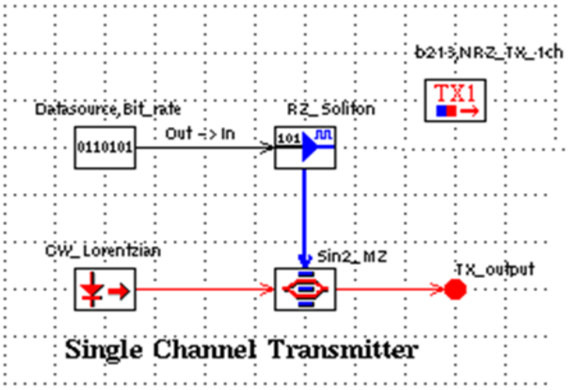
1.6.2 Creating Optical Transmitter, Receiver and Hybrid Amplifier using Compound Component:

When designing a complex optical transmission link (i.e. WDM) that is made up of a large number of components, it is a tedious process to draw all the components in the provided drawing block. The solution to these problems is to use the compound component. The advantage of implementing the compound component is that it makes the whole design look simpler and pleasant. The compound component can be used as a standard block in OptSim that can have any number of inputs and outputs. Input and output will of any type (optical, electrical and logical). The compound component can also be used to group the transmitter section, optical link and the receiver sections. In this thesis, the 16 channel transmitter, receiver, and optical hybrid amplifier has been used as compound component shows in the figure 1.8. The procedures for creating the compound component for optical 16 channel transmitter, receiver and hybrid amplifier are as follows:

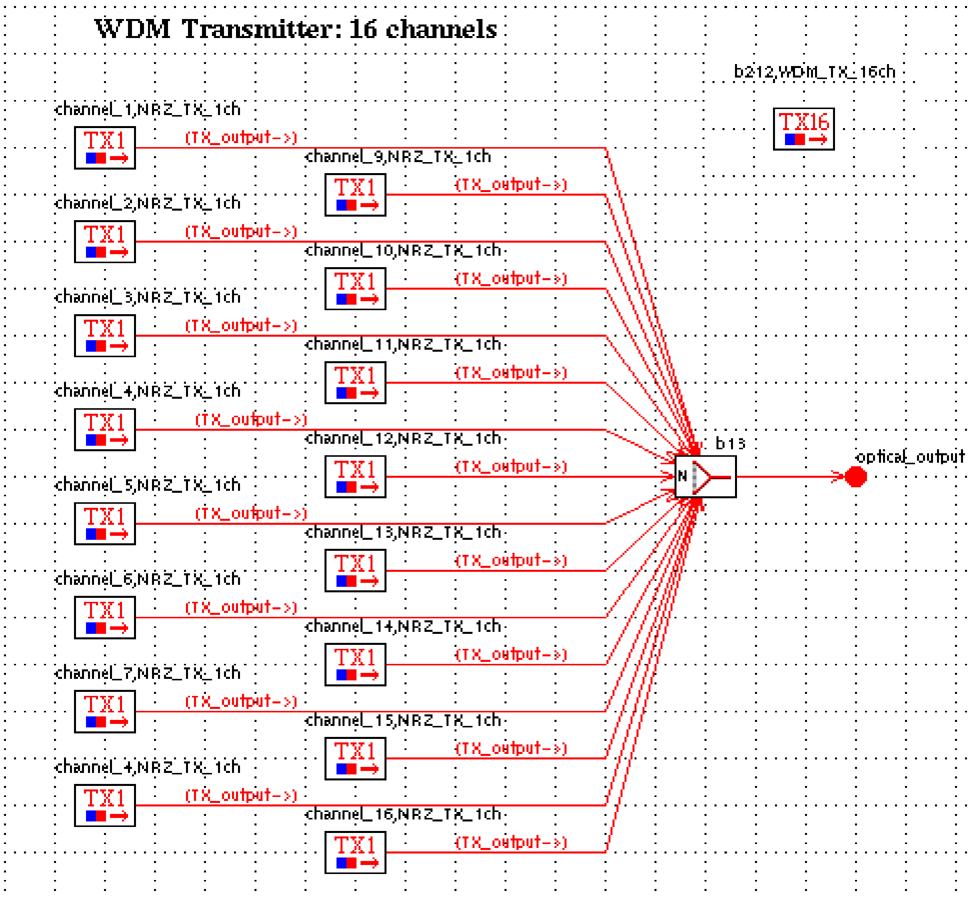
1. Click on the compound component icon on the menu bar and select “compound component” under the unit type.

2. Type the filename with extension .opm,.

3. Under the simulation parameters, select dual polarization and click “Ok”.



(a)



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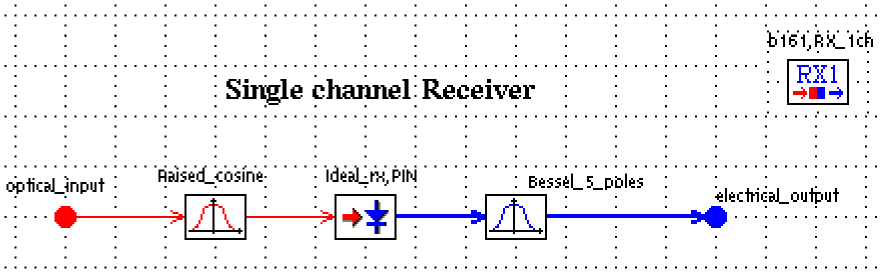

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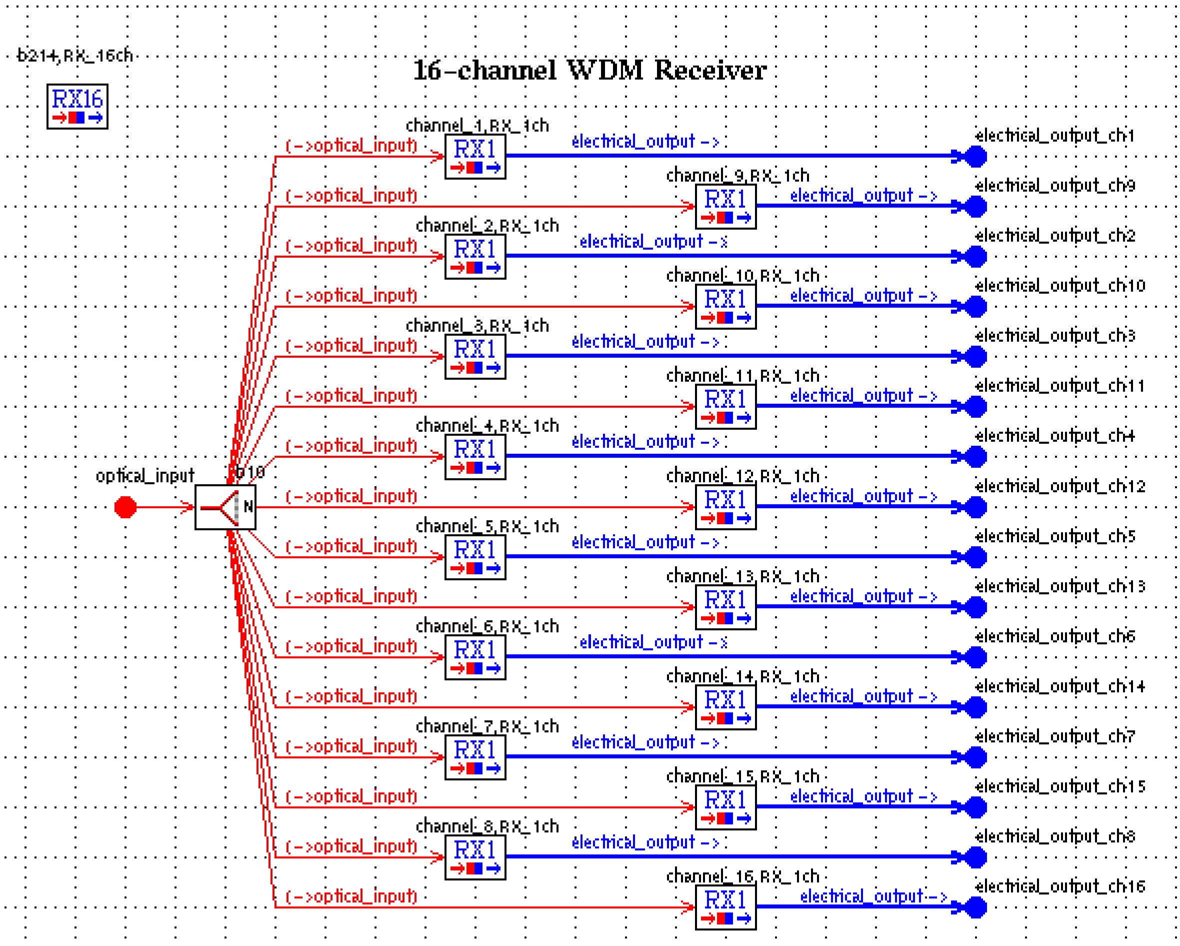

(d)

Figure 1.8: Compound Compponent of (a) Single channel Transmitter; (b) 16 channel Transmitter; (c) Single channel Raciver; (d) 16 channel Reciver

4. Drag and place the required component for transmitter (laser diode, amplitude modulator, driver and data source), receiver (photo diode, optical and electrical filter). we also create compound component for optical hybrid amplifier (EDFA, SOA, RAMAN) into the drawing board and link all transmitters, receivers as shown in Figure 1.8.

5. Save the file.

6. To change the number of transmitters, receivers and optical amplifiers, right click the compound component and select open from the dialog box and it would bring the user to the drawing board of current hybrid amplifier simulation setup. After the changes have made, save the file.

1.6.3 Creating .DAT file for Raman Co and Counter propagating pumping

All files used for the specification of fiber loss or dispersion versus frequency or wavelength must have the extension .DAT (i.e. in capital letters). The syntax used for these files must satisfy the following rules:

1. Files must be written in plain ASCII text.

2. A mandatory first line contains the keyword that identifies the file type and version. This keyword is OptSimFdisp for dispersion files, OptSimFloss for loss files and OptSimFRaman for Raman profile files (or nothing for kscale files).

3. All comment lines must begin with a '#' character.

4. Comment lines are allowed only between the starting line and the '##' line.

5. Two separated data sections must contain co-propagating and counter-propagating pumps. The co-propagating pumps section must begin with the keyword Coprop and the number of co-propagating pumps, the counter-propagating pumps section must begin with the keyword Counterprop and the number of counter-propagating pumps. Almost one of the two sections is mandatory.

6. Each data section must contain two-column entries, the first column contains the frequencies or wavelengths of pumps, the second column contains the corresponding

value of power in mW or dBm. .DAT files for Pump 1, Pump 2, Pump 3, Pump 4 and attenuation are as follows:

Table 1.1 .DAT files for verious pump

Pump1.DAT OptSimFPump 1 # frequency in nm # Power in mW ## Coprop 1 1365 500 Counterprop 1 1453 500	**Pump2.DAT** OptSimFPump 2 # frequency in nm # Power in mW ## Coprop 1 1365 400 Counterprop 1 1453 500
Pump3.DAT OptSimFPump 3 # frequency in nm # Power in mW ## Coprop 1 1365 300 Counterprop 1 1453 500	**Pump4.DAT** OptSimFPump 4 # frequency in nm # Power in mW ## Coprop 1 1365 250 Counterprop 1 1453 500
(e) Attenuation.DAT OptSimFloss 1 # frequency in nm # attenuation in dB/km ## 1365 0.3 1450 0.3 1465 0.3	

CHAPTER 2

Literature Survey

2.1 Motivation

Optical amplifiers will play an important role in the development of future optical systems and networks as they allow the direct amplification of light with a minimum of electronics. The key thrust in optical transmission in the coming years will be the development of a transparent optical network in which the use of electronic hardware is minimised, thus improving the network reliability and flexibility. In this context, for example, amplifiers can be used to replace optoelectronic regenerators in the long haul sections of the network, provide increased fan out in local passive networks and provide optical switching and routing. The use of optical amplifiers to realise practical non-linear transmission is also now being demonstrated. Such non-linear systems will allow the multi-gigabit transmission of data over large distances without dispersion.

In optoelectronic regenerators, the optical signal is first converted into electric current and then regenerated by using a transmitter. But such regenerators become quite complex and expensive for wavelength division multiplexing systems. This reduces the reliability of networks as regenerator in an active device. Therefore, up gradation of multichannel WDM network will require optical amplifier. The optical amplifiers are mainly used for WDM (Wavelength division multiplexing) light wave systems as all channels can amplify simultaneously. Optical amplifier increases the transmitter power by placing an amplifier just after the transmitter and just before the receiver.

2.2 Literature Survey

The progress of optical fiber communication has been advancing rapidly for the past two decades. Optical fiber communication systems have a long history and it was realized during the second half of the twentieth century that a greater transmission bandwidth could be achieved by employing optical waves as the carrier [1]. Increasing the gain-bandwidth of fiber amplifiers is the most effective way to increase the number of WDM channels. The gain-bands have been increased by (a) employing new fiber host materials for erbium-doped fiber amplifiers (EDFAs), (b) gain-equalizing optical filters [12] (c) parallel configurations for the two gain-bands of the EDFA [13] and (d) Raman amplifier with multiple wavelengths [14] (e) with multiple pump-wavelengths combination of EDFA with the distributed Raman amplification in the transmission fiber [15].

Shien-Kuei Liaw [16] proposed a hybrid EDFA/RFA for simultaneously amplifying the C-band EDFA and L-band RFA. The hybrid amplifier has many advantages: (1) the required DCF length for chromatic dispersion compensation is 50% safe. (2) By embedding the WDM-FBG at appropriate positions along the DCF, the dispersion slope mismatch values are -240 and +240 ps/nm at 1530 and 1595 nm, respectively, could be precisely dispersion compensated. (3) The reduction in gain variation from 9.8 dB to less than ±0.5 dB could be realized after optimizing the reflectivity of each FBG. (4) Pumping efficiency is improved by recycling the residual pumping power.

Lee et al. [17]–[19] have experimentally compared the performance of hybrid Raman+EDFA amplifiers, in which the Raman gain is provided in a dispersion compensating fiber (DCF) section of fiber. In their works the residual Raman pump power is recycled to pump the EDFA stage. Several different configurations based on a single pump laser over DCFs were studied. They found that by recycling the residual Raman pump in a cascaded erbium-doped fiber (EDF) section, as a secondary signal amplification stage, pump conversion efficiency can be increased. The amplifier characterization has been calculated in terms of global gain, and noise figure (NF). However, it has been restricted to the single channel characterization only, disregarding the ripple parameter within the amplifier effective gain bandwidth, which is a very important issue in WDM optical communication systems.

The configuration based on Lee et al. [20], experimentally demonstrate a novel concept of the dispersion-compensating Raman/erbium-doped fiber amplifier hybrid amplifier recycling residual Raman pump for increase of overall power conversion efficiency. A Raman amplifier using a 12.6 km DCF with effective area of 15.3 um^2 with attenuation coefficient of 0.5 dB/km, at 1550 nm, dispersion coefficient of −98 ps/(nm.km) composes the first stage. The second stage is given by an EDFA using a 10 m of EDF section (Er doping radius = 2.2 µm, core area = 15.2 um^2 and Er concentration = $1 \times 10^{25}\ m^{-3}$).

Surinder Singh et al. [21] investgated 20 chennel at 10Gb/s WDM transmission over 1190km using SOA at a span of 70km for RZ-DPSK modulation format by using

100GHz channel spacing and also show RZ-OOK format a transmission distance of up to 1050km with Q factor more than 15dB,without any power drops. SOA model for inline amplifier having minimum cross-talks and ASE (amplified spontaneous emission) noise power with sufficient gain.At optimal bias current of 400 mA, a high constant gain of 36.5 dB is obtained up to a saturation power of 21.36 mW. The DPSK modulation format has less cross-talk as compared to OOK format for nonlinearities and saturation case. The bit error rate (BER) for all channels observed is less than 10^{-10} up to gain saturation for both DPSK and OOK systems.

Shien-Kuei Liaw et al. [22] They propose a hybrid C-band erbium-doped fiber amplifier (EDFA) and L-band Raman fiber amplifier (RFA) using a single pump laser diode. The optimum pump sharing ratio to EDFA/RFA is 1/10 with a total pump power of 660 mW. Using multiple fiber Bragg gratings (FBGs) with various reflectivities at different positions along the dispersion compensation fiber, the optimum dispersion compensation and power equalization for C + L-band channels are simultaneously realized. With an input power of -20 dBm/ch the signal power variation among the channels is reduced from 9.8 dB to less than ±0.5 dB. Two pump reflectors are introduced to increase the pumping efficiency.

Ramandeep Kaur et al.[23] In this paper 10 Gbps WDM systems at 16, 32 and 64 channels have been investigated with EDFA, RAMAN and SOA amplifiers individually by varying transmission distance (40–200 km) and dispersion (2–10 ps/nm/km) in the term of output power, BER, Q factor and eye closure and the performance has been compared on the basis of transmission distance and dispersion with and without nonlinearities. when the dispersion is 2 ps/nm/km then SOA provides better results but as we increase the number of channels it degraded the performance but EDFA provides better results than SOA. They also observed that RAMAN amplifier gives low output power than other existing amplifiers and it can give better results for higher wavelengths.

As far as Raman+EDFA hybrid amplifiers under residual Raman pump recycling are concerned, Lee et al. [24]-[25] have experimentally compared the performance of different configurations based on a single pump laser over dispersion compensating fibers. It has been found that by recycling the residual Raman pump in a cascaded EDF section, as a secondary signal amplification stage, pump conversion efficiency can be increased. The amplifier characterization has been carried out in terms of global gain and noise figure. However, it has been restricted to the single channel characterization only, disregarding the ripple parameter within the amplifier "effective gain" bandwidth, which is a very important issue in WDM optical communication systems.

M.M.J.Martimi et al.[26] have experimentally compared EDFA/Raman hybrid amplifier configuration in which the recycling of the residual Raman pump is utilized. This optimi zation was made by adjusting the Raman gain profile in order to equalize the EDFA gain spectrum. Simulations with two and three pumps were performed and for both cases a flat global gain has been successfully obtained for a bandwidth of around 30nm. The Raman+EDFA hybrid amplifier under recycling residual Raman pump, allied with the properly chosen of the pump wavelengths and powers, enables the construction of broadband amplifiers with enhanced power conversion efficiency and high and flat gains.

A.K.Srivastava et al.[27] demonstrated a long haul, 64- channel WDM transmission system in the Lband with 50 GHz channel spacing over 500 km of dispersion shifted fiber using gain-flattened EDFAs which have high power and wide optical bandwidth for a broad range of operating gains.

C. R. Davidsou et al. [28] first time demonstrated the transmission of two hundred and fifty six 10Gbps WDM channels over 11,000 km in 80 nm of continuous optical bandwidth using a simple combination of distributed Raman gain and single-stage EDFA. The channel spacing across the bandwidth from 1527 nm to 1606.6 nm was 0.31 nm. This error free performance is achieved with the use of concatenated Reed-Solomon FEC coding. They have achieved the error free communication with least bit error rate ($< 10^{-10}$) good quality factor (> 9.1 dB).

Theoretically EDFA is capable of amplifying all the wavelengths ranging from 1500 to 1600 nm. However practically there are two windows of wavelength. These are C and L band. The C band ranges from 1530 nm to 1560 nm and L band from 1560 nm to 1610 nm. The semiconductor laser pumping source at 980 nm wavelength has proved to be the best in terms of efficiency (more than 10 dB gain per mW pump power) and better noise performance [29].

To get higher OSNR Tuan Nguyen Van et al. [30] proposed three calculating models of Terrestrial cascaded EDFAs Fiber optical communication links using Hybrid amplifier.

P.P.Iannone et al. [31] demonstrate SOA-Raman amplifiers have broad gain bandwidth(>80 nm) and can be designed to operate any of wavelength region compatible with single mode fiber.

Bergano et al. [31] successfully demonstrated transmission of 160 Gb/s over 930000 km by using a recirculating loop while Vareille et al. [1999] demonstrated the transmission capacity of 340 Gb/s over 6380 km on a straight-line test bed. Erwin et al. [32] demonstrated 24,000 km transmission of dispersion-managed solitons at 40 Gb/s.

Manoj kumar et al. [33] demonstrated 10 Gbps optical soliton transmission link using in-line semiconductor optical amplifiers (SOAs) for already installed standard single mode fibers (SMF) at 1.3 mm wavelength has been reported upto 400km.

2.3 Thesis Scope

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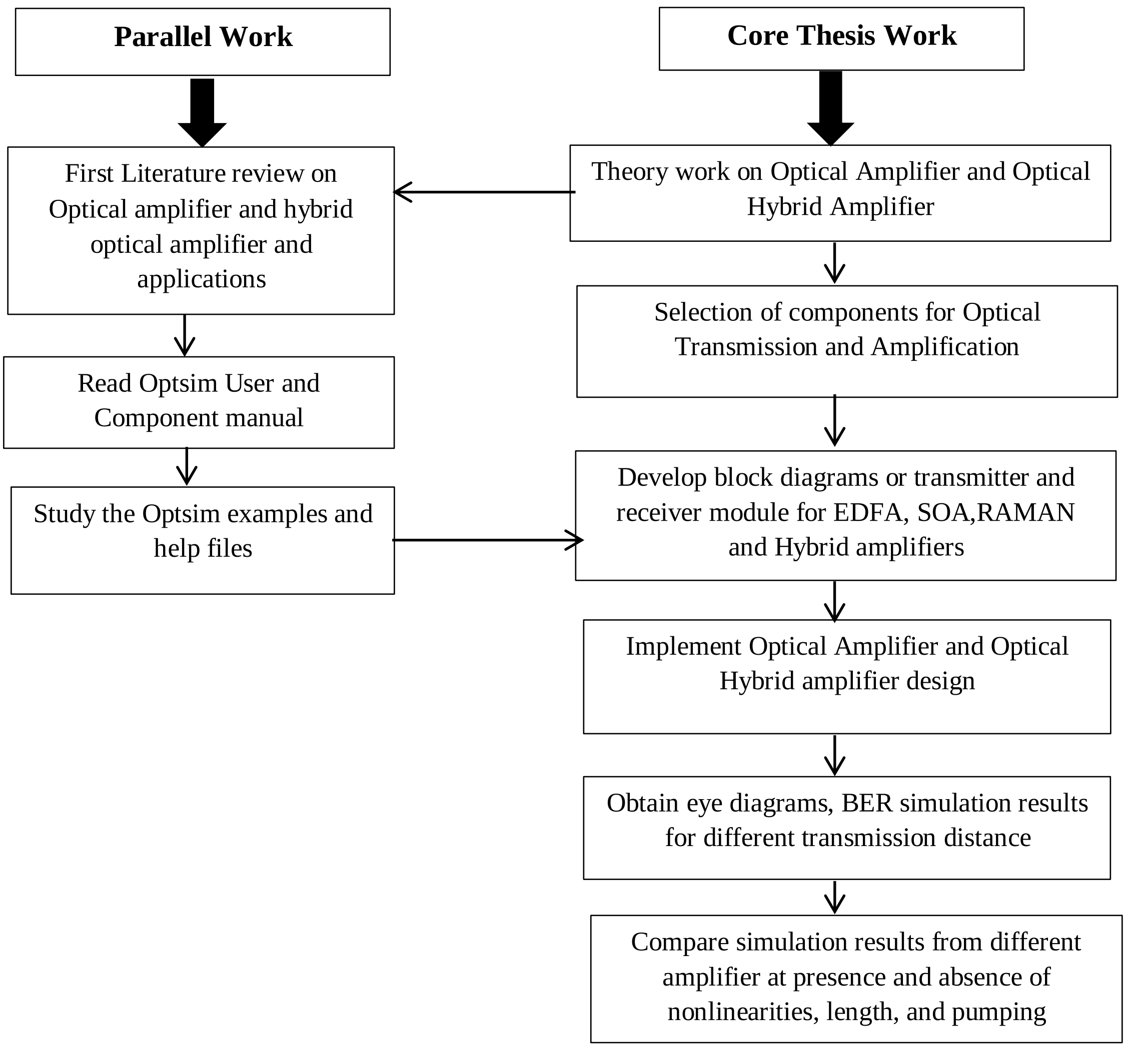


Figure 2.1 : Guide line of Thesis

The Optical amplifier is the Key of optical Transmission systems with Wavelength Division Multiplexing (WDM). Optical hybrid amplifiers is now hot research, many of books do not mention this and much of the effort was spent reading and extracting information from relevant journal articles. Following that, a literature review of the optical amplifier and hybrid optical amplifier has been done. The literature review was beneficial in understanding the operation of optical transmission using optical amplifier Selected the component which was able to support 10 Gb/s optical transmission. We have been developed a block diagram of the hybrid optical amplifier so as to enable the designer to have a better visualization of the whole system structure and components to be used. Then, the optical amplifiers design model was implemented into OptSim whereby the eye diagrams, BER, power, Q factor and eye opening results were obtained. These are represented in the figure 2.1.

2.4 Objectives

1. To examine the performance of optical amplifier EDFA, RAMAN, SOA amplifiers for presence and absence of nonlinearities in the fiber at different transmission distance. Compare all amplifiers and find which one is provide better result in the term of high output power, least BER, high Q factor and large eye opening.
2. To examine placements of hybrid amplifier after source in 64×10 Gb/s WDM optical communication system.
3. To examine the effect on hybrid amplifier by varies the fiber length. Find the optimize fiber length before which hybrid amplifiers provide maximum power, acceptable BER and Q factor.
4. To examine the effect on RAMAN-EDFA hybrid amplifier by using co-counters pumping with various power level in the raman fiber. Find the optimize raman fiber power level for which hybrid amplifier provide maximum power, acceptable BER and Q-factor.

CHAPTER -3

Simulation of 64×10Gbps WDM System Based on Optical Amplifiers

3.1 Abstract

In this chapter, we demonstrate the sixty four channel WDM system, which have been investigated for the various optical amplifier and hybrid amplifiers and the performance has been compared on the basis of presence and absence of nonlinearities at different distance. The amplifiers EDFA, RAMAN and SOA have been investigated independently and further compared with hybrid amplifiers like EDFA-EDFA, RAMAN-SOA, RAMAN-EDFA,EDFA-SOA,EDFA-RAMAN,RAMAN-EDFA-SOA, and SOA-RAMAN-EDFA. It is observed that optical hybrid amplifier RAMAN-SOA and SOA-RAMAN-EDFA least bit error rate (0.999×10^{-40} and 1×10^{-40}) for presence and absence of nonlinearities at 160 km for dispersion 2ps/nm/km compare to other optical amplifier.

3.2 Introduction

The rapid expansion of optical communication networks has created a requirement to increase the transmission capacity of these networks. The high capacity of optical networks basically depends on a high-speed transmitter, a high-capacity optical fiber, and a high-speed receiver. To increase the capacity of such networks, several techniques are utilized. One of the most popular techniques is wavelength division multiplexing(WDM). Currently the optical amplifiers are used which directly amplify the transmitter optical signal without conversion to electric forms as in-line amplifiers [35]. It amplifies the signals simultaneously and decreases the attenuation.

Erbium-doped fiber amplifiers (EDFAs), which have been widely, used in the actual optical transmission systems now in service. EDFAs is the more mature technology, mainly used in 1.5~1.6μm band amplification. EDFAs are of low noise, compact, highly efficient with high gain, and capable of amplifying multichannel signals on different wavelengths at a time, and hence quite economical for WDM transmissions. But it working under deeper saturation or having steeper saturation characteristic would result in smaller BER [36]. A Raman Amplifier was used to enhance the OSNR and extend the repeater less transmission distance with low receiver penalty but requires high pump power, and induce unstable system performance [37]. Therefore, if Raman amplifier cascaded with Erbium doped fiber amplifier called hybrid amplifier (HA), the SNR, Q factor and output power can be improved and bit error rate will be decreases. SOA-Raman amplifiers have broad gain bandwidth (> 80 nm) and can be designed to operate in any wavelength region compatible with single-mode optical fiber[38].

Mohammed N.Islam [4] described that the total amplifier gain is the sum of the two gains

$$G_{Hybrid} = G_{EDFA} + G_{Raman}$$

Also other important hybrid amplifier is the RAMAN-SOA. Yihong chen et.al [39] demonstrated a hybrid SOA-Raman amplifier scheme with over 40 nm operational bandwidth. Hiroji Masuda at al. achieves the widest seamless 3.0-, 1.3-, and 1.0-dB bandwidths of 80, 76, and 69 nm with a novel discrete Hybrid amplifier [40]. Due to the

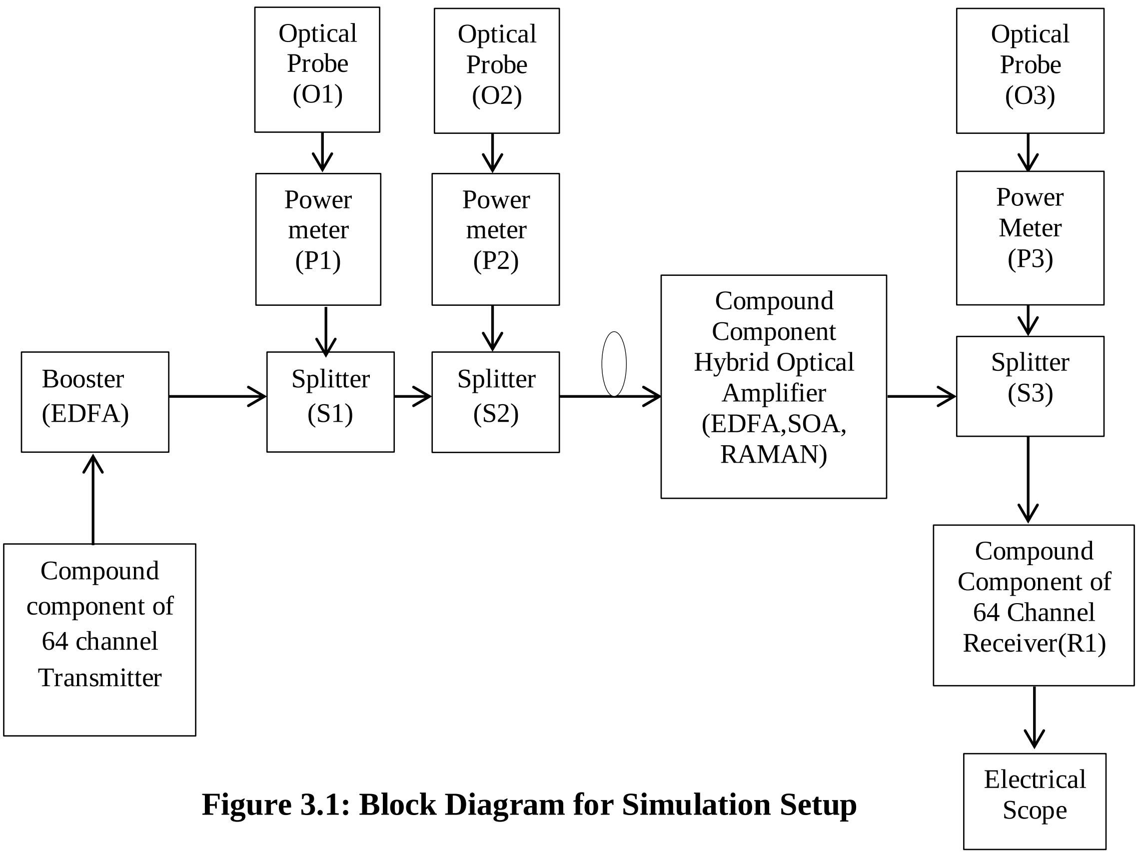


Figure 3.1: Block Diagram for Simulation Setup

nonlinear nature of the propagation, the system performance depends upon power levels and good power level is achieved by hybrid optical amplifier as compare to EDFA and SOA. The sufficient power levels depend upon the placement of the optical amplifier in optical communication [41].

In this chapter, the previous work in the context of 64 channels for existing amplifiers used as pre-amplifiers has been extended. Further the performance comparison of SOA, RAMAN EDFA and also for different hybrid optical amplifier for with and without nonlinearities in the term of bit error rate (BER), Q-Factor, eye closure and output power has been investigated.

The chapter is organized into five sections. After discussion of abstract and introduction of this chapter, the optical simulation setup is described in Section 3.3. In Section 3.4, comparison results have been reported for the different modulation formats and finally in Section 3.5, conclusions are made.

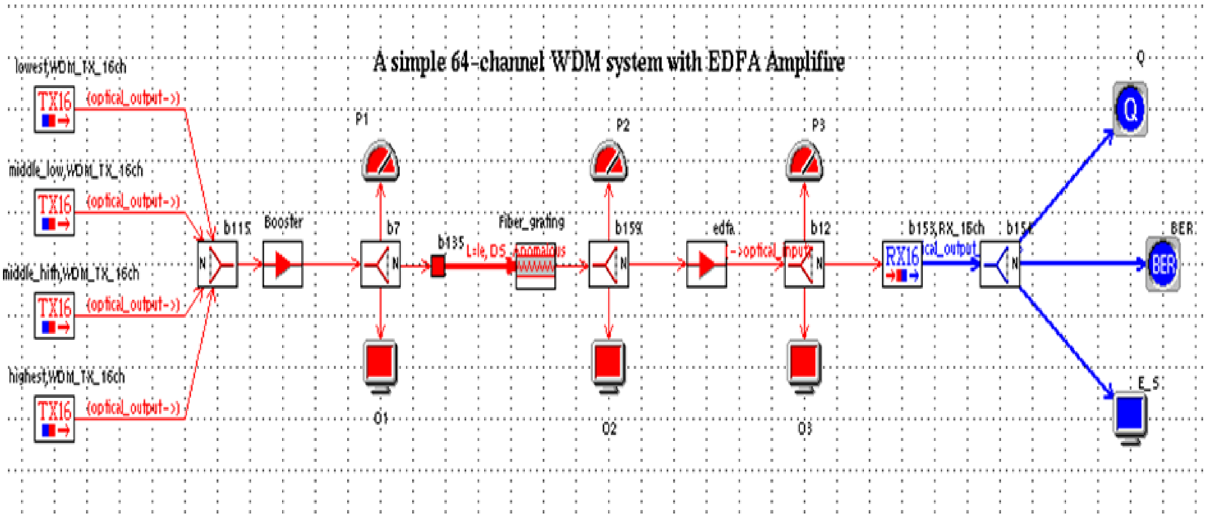
3.3 Simulation Setup

We used 64 channel transmitter and receiver model. In this model we have been transmitted at 10 Gb/s data rate with channel spacing of 100 GHz. Each input signal is modulated in RZ-soliton format (electrical driver) and Mach-Zehnder modulator is used for modulation of input signal. The amplitude modulator is a sine square with an excess loss of 3 dB. A modulated signal pre-amplified by a booster. The amplified signals send to the channel where these signal are transmitted over DS-anomalous fiber of different transmission distance. A transmitter compound component is built up using sixty-four transmitters.

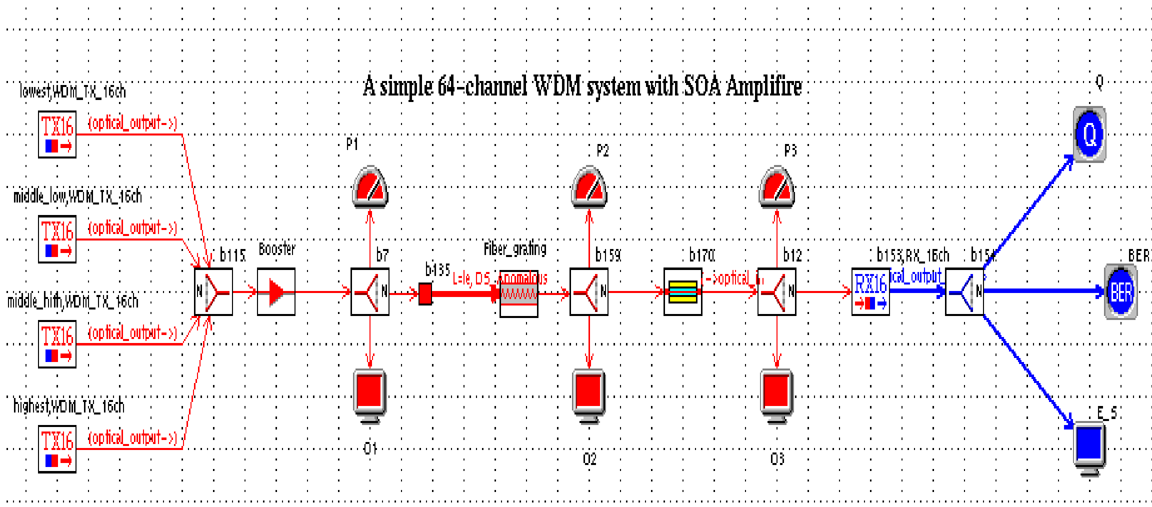
This transmitter compound component consists of the data source, electrical driver, laser source and external Mach-Zehnder modulator in each transmitter section. The data source is generating signal of 10 Gb/s with pseudo random sequence. The electrical driver converts the logical input signal into an electrical signal. The CW laser sources generate the 64 laser beams at 188.28–194.72 THz with 100 GHz channel spacing. These beams have random laser phase and ideal laser noise bandwidth. The signals from data source and laser are fed to the external Mach–Zehnder modulator (sin^2 _MZ for all configurations), where the input signals from data source are modulated through a carrier (optical signal from the laser source).

The simulations setup of EDFA, SOA, RAMAN and Hybrid Optical amplifiers using compound component at different transmission distance are shown in Fig. 3.1. The output optical signal of the modulator is fed to the channel where a booster is used to boost the signal. This optical signal is transmitted and measured over different distance for 40,80,120,160,200 and 240 km (R1) with and without nonlinearities individually. we used fiber grating device to dispersion compensate over a fiber span. Optical power meter (P1, P2, P3) and optical probe (O1, O2, O3) with splitters (S1, S2, S3) are used for measuring the signal power and spectrum at different levels. The modulated signal is converted into original signal with the help of PIN photodiode and filters. A compound receiver (R1) is used to detect all 64 signals and converts these into electrical form. Different types of optical amplifiers are also applied at the receiver side. The setup is repeated for measuring the signal strength by using different amplifiers i.e. EDFA, SOA, RAMAN, EDFA-EDFA, EDFA-RAMAN, RAMAN-EDFA,RAMAN-SOA and SOA-RAMAN-EDFA, RAMAN-EDFA-SOA. Different results like eye diagram, Q-factor and BER show that RAMAN-EDFA AND SOA-RAMAN-EDFA is the most suitable amplifiers in the all proposed amplifiers.

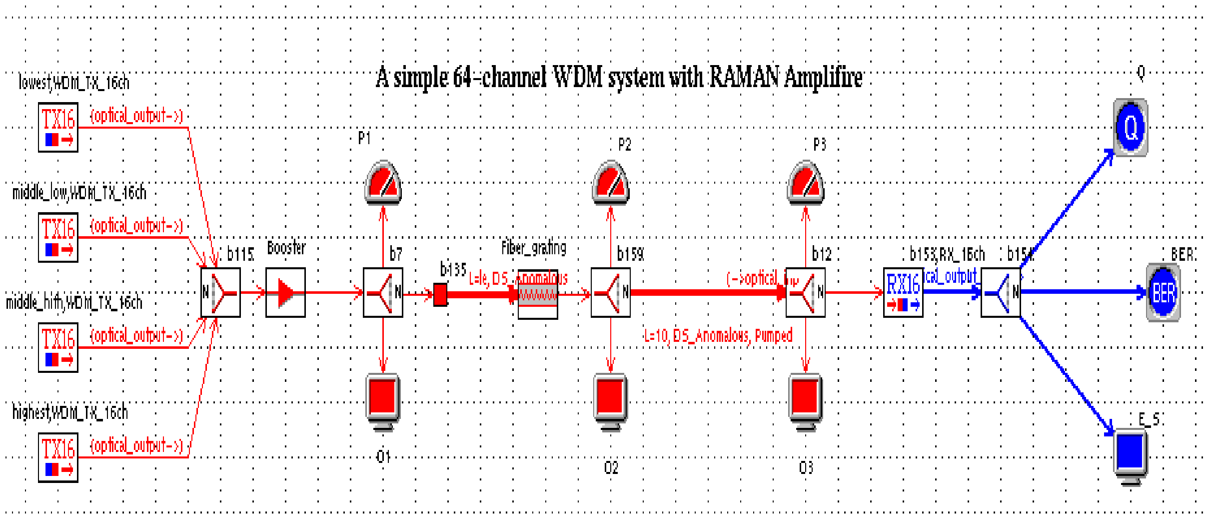
Different components have different operational parameters. The DS anomalous fiber is used to transmit the optical signal. Its various parameters are reference frequency is 193.414 THz attenuation is 0.2 dB/km and fiber polarization mode 0.1 ps/km$^{0.5m}$. The fixed output power EDFA is used for amplification and its parameters are output power is 15 dBm, gain shape is flat and noise figure is 4.5 dB. The various parameters for SOA are biased current is 100 mA, amplifier length is 300 $\times 10^{-6}$ m, confinement factor is 0.35, insertion loss is 3 dB and output insertion is 3 dB. The various parameters for RAMAN are Raman fiber length is 10 km, operating temperature is 300 K, pump wavelength is 1480 nm and pump power is 300 mW.with counter propagation pumping.


A simple 64-channel WDM system with EDFA Amplifire

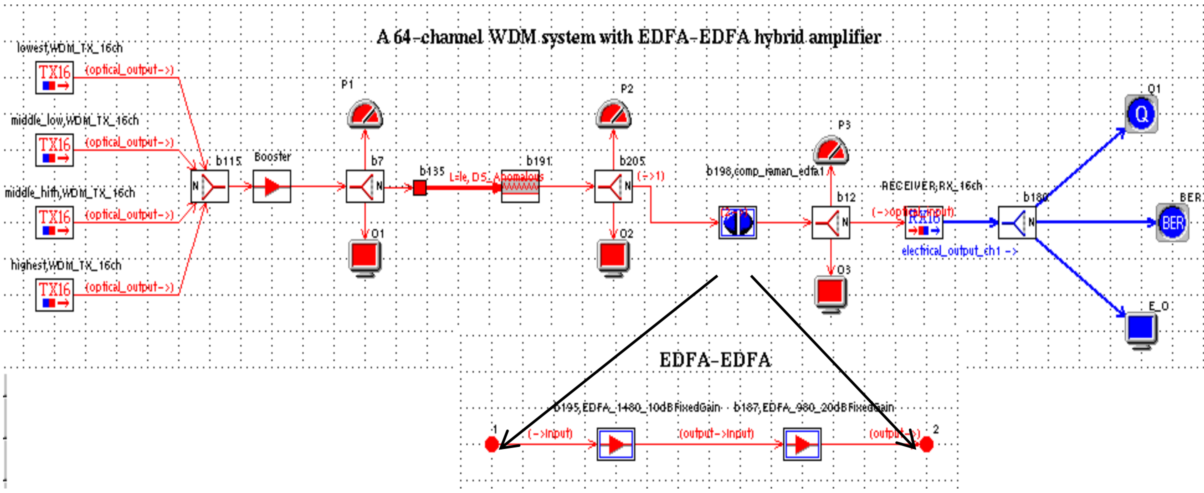
(a)


A simple 64-channel WDM system with SOA Amplifire

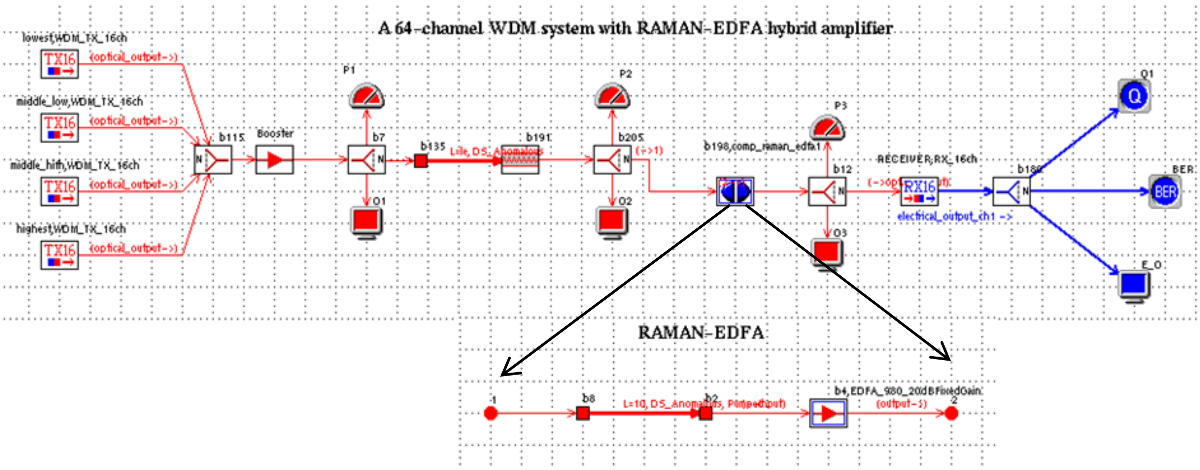
(b)


A simple 64-channel WDM system with RAMAN Amplifire

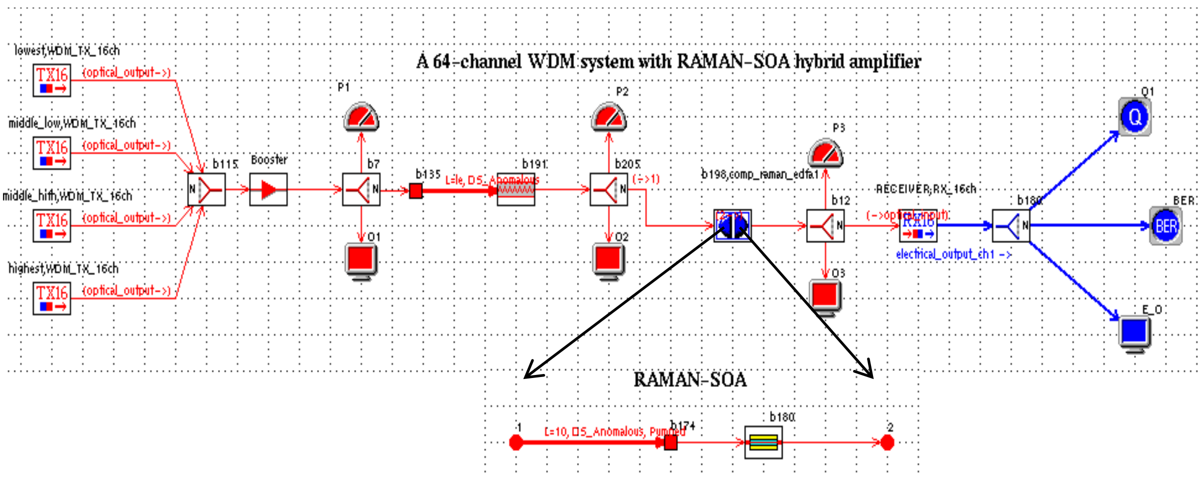
(c)


A 64-channel WDM system with EDFA-EDFA hybrid amplifier
lowest,WDM_TX_16ch
middle_low,WDM_TX_16ch
middle_hith,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
Booster
P1
P2
P3
O1
O2
O3
b198,comp_raman_edfa1
RECEIVER,RX_16ch
Q1
BER
E_O
EDFA-EDFA
b195,EDFA_1480_10dBFixedGain
b187,EDFA_980_20dBFixedGain

(d)


A 64-channel WDM system with RAMAN-EDFA hybrid amplifier
lowest,WDM_TX_16ch
middle_low,WDM_TX_16ch
middle_hith,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
Booster
P1
P2
P3
O1
O2
O3
b198,comp_raman_edfa1
RECEIVER,RX_16ch
Q1
BER
E_O
RAMAN-EDFA
b4,EDFA_980_20dBFixedGain

(e)


A 64-channel WDM system with RAMAN-SOA hybrid amplifier
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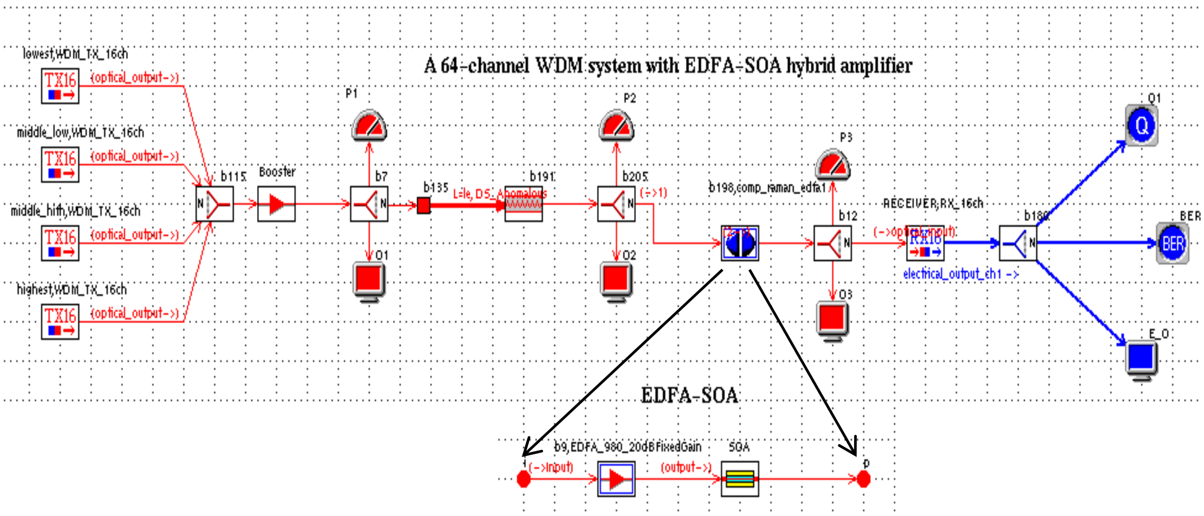
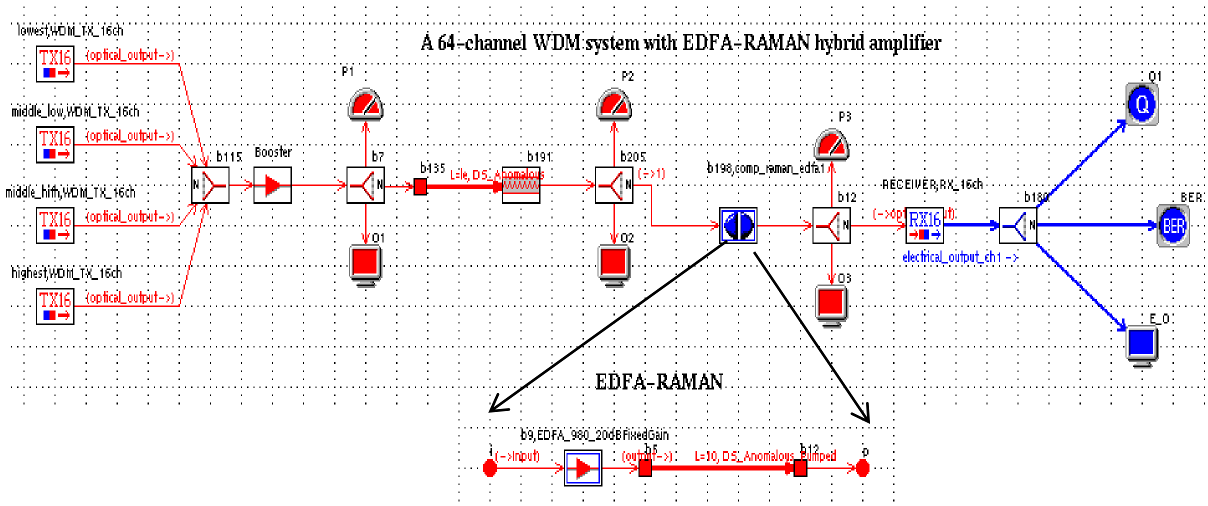
middle_hith,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
Booster
P1
P2
P3
O1
O2
O3
b198,comp_raman_edfa1
RECEIVER,RX_16ch
Q1
BER
E_O
RAMAN-SOA

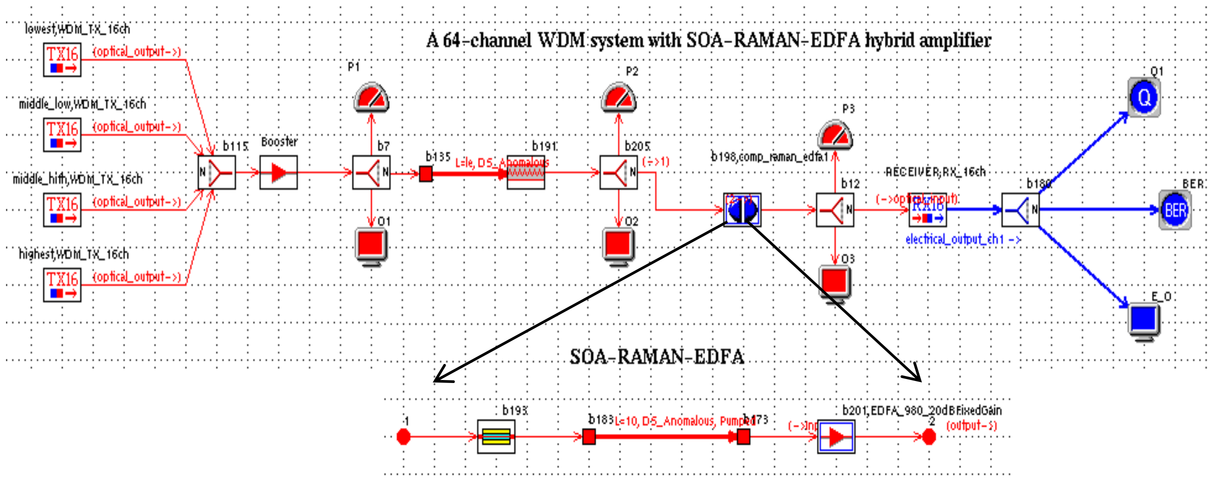
(f)


A 64-channel WDM system with EDFA-SOA hybrid amplifier
lowest,WDM_TX_16ch
middle_low,WDM_TX_16ch
middle_high,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
(optical_output->)
b115
Booster
P1
b7
O1
b135
L=le, DS_Anomalous
b191
P2
b205
O2
b198,comp_raman_edfa1
P3
b12
O3
RECEIVER,RX_16ch
RX16
electrical_output_ch1 ->
b180
Q1
Q
BER
E_O
EDFA-SOA
b9,EDFA_980_20dBFixedGain
SOA
(->input)
(output->)

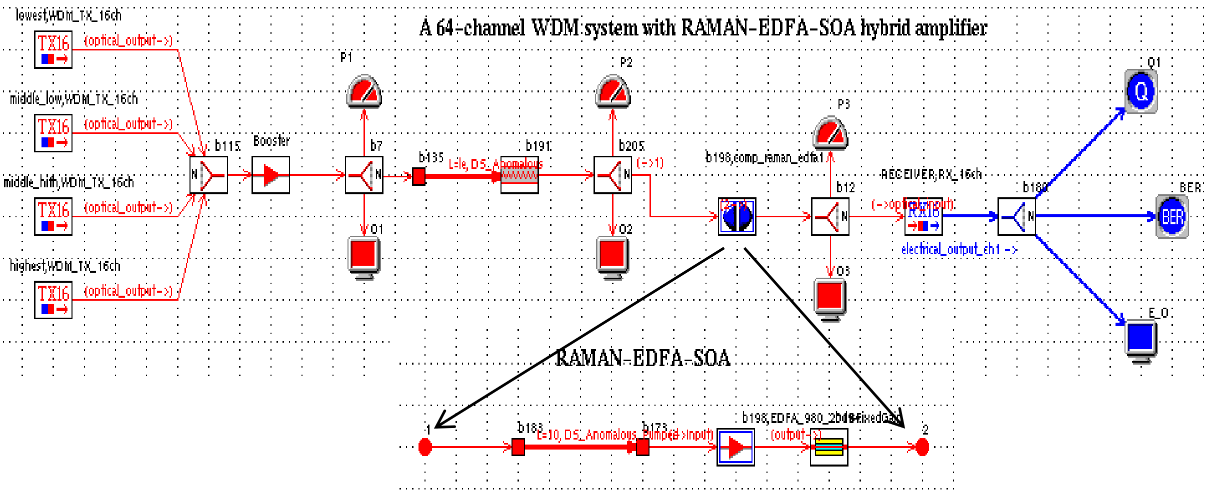
(g)


A 64-channel WDM system with EDFA-RAMAN hybrid amplifier
lowest,WDM_TX_16ch
middle_low,WDM_TX_16ch
middle_high,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
(optical_output->)
b115
Booster
P1
b7
O1
b135
L=le, DS_Anomalous
b191
P2
b205
O2
b198,comp_raman_edfa1
P3
b12
O3
RECEIVER,RX_16ch
RX16
electrical_output_ch1 ->
b180
Q1
Q
BER
E_O
EDFA-RAMAN
b9,EDFA_980_20dBFixedGain
(->input)
L=10, DS_Anomalous, Pumped

(h)


A 64-channel WDM system with SOA-RAMAN-EDFA hybrid amplifier
lowest,WDM_TX_16ch
middle_low,WDM_TX_16ch
middle_high,WDM_TX_16ch
highest,WDM_TX_16ch
TX16
(optical_output->)
b115
Booster
P1
b7
O1
b135
L=le, DS_Anomalous
b191
P2
b205
O2
b198,comp_raman_edfa1
P3
b12
O3
RECEIVER,RX_16ch
RX16
electrical_output_ch1 ->
b180
Q1
Q
BER
E_O
SOA-RAMAN-EDFA
b193
b183
L=10, DS_Anomalous, Pumped
b173
b201,EDFA_980_20dBFixedGain
(output->)

(i)



(j)

Figure 3.2 : Simulation setup for (a) EDFA, (b) SOA, (c) RAMAN, (d) EDFA-EDFA, (e) RAMAN-SOA, (f) RAMAN-EDFA, (g) EDFA-SOA, (h) EDFA-RAMAN, (i) SOA-RAMAN-EDFA, (j) RAMAN-EDFA-SOA.

Figure 3.2 shows the various simulation setups for different amplifiers. In figure 3.2 (a) optical signals are amplified using EDFA amplifier. The signal power, Q-factor, BER and eye opening is measured by power meter, optical probe, electrical scope, Q-meter, and BER meter. This set up is repeated for different distance from 40 km to 240 km by varying the fiber length. These set ups are further repeated for SOA,RAMAN, EDFA-EDFA, RAMAN–EDFA,RAMAN-SOA EDFA-SOA,EDFA-RAMAN,SOA-RAMAN-EDFA and RAMAN–EDFA-SOA. The modulated signal is converted into original signal with the help of PIN photodiode and filters. A compound receiver is used to detect all sixteen signals and converts these into electrical form.

3.4 Result and Discussion for EDFA, RAMAN, SOA

The different optical amplifiers configurations have been compared for 64 × 10Gbps WDM system in the term of received maximum Q Factor (dB), Average eye opening, minimum BER and maximum output power (dBm). The optical signal is connected to different optical amplifier through a splitter. Different components have different operational parameters. The parameters for external Mach-Zehnder modulator are described in the table 3.1.

Table 3.1: Parameters for amplitude Modulator

Maximum transmissivity offset voltage	2.5 V
Average power reduction due to modulation	3dB
Excess loss	3dB

The electrical filter is of raised cosine band pass filter with 40 GHz bandwidth, raised cosine exponent is 1 and raised cosine roll off is 0.1. The responsively of the PIN detector is 1A/W and quantum efficiency is 0.79819. The DS Anomalous fiber is used to transmit the optical signal. Its various parameters are shown in Table 3.2.

Table 3.2 : Parameters for DS Anomalous fiber

Reference frequency	193.414THz
Attenuation	0.2 dB/km
Dispersion correlation lenght	20km
Fiber nonlinearity index	1.841/W/km
Nonlinear refractive index	$2.5e^{-20}$ $m^{2/w}$
Fiber Polarization made dispersion	$0.1ps/km^{0.5}$

The EDFA is used to amplify the optical signal. Its various parameters are shown in Table 3.3

Table 3.3 : Parameter for EDFA

Output power	15dBm
Gain shape	Flat
Maximum small signal gain	35dB
Noise figure	4.5 dB

The SOA is used to amplify the optical signal. Its various parameters are shown in Table 3.4

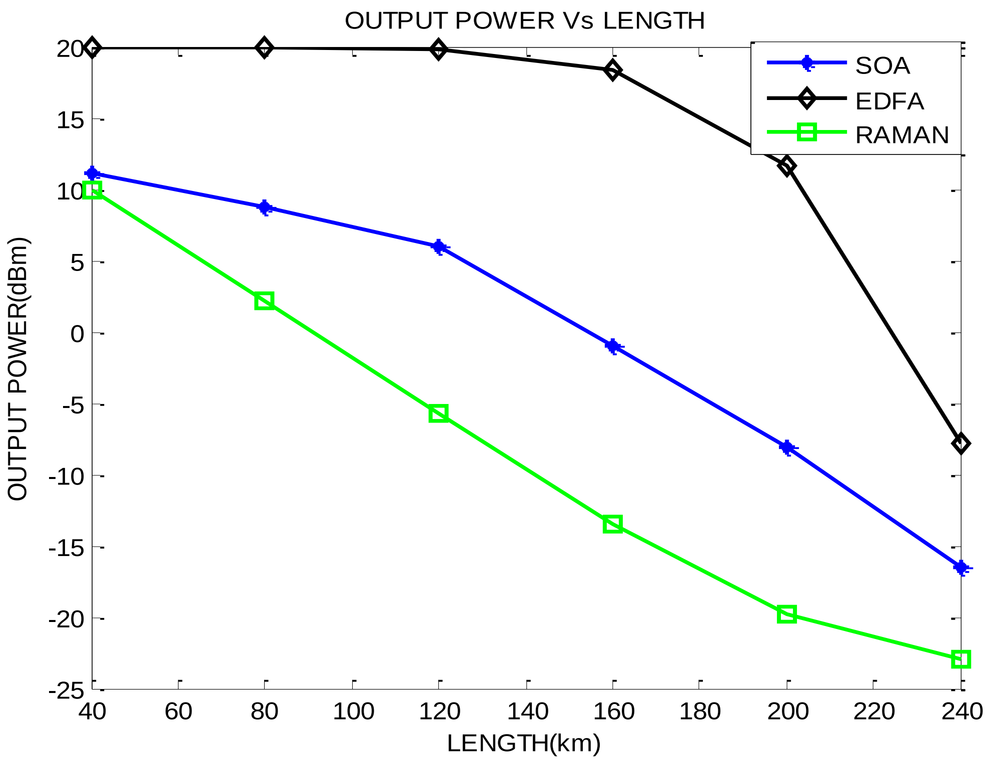
Table 3.4 : Parameter for SOA

Biased current	100mA
Amplifier length	300×10^{-6m}
Active layer width	1.5×10^{-6m}
Active layer thickness	0.15×10^{-6m}
Confinement factor	0.35
Spontaneous carrier lifetime	0.3ns
Insertion loss	3dB
Output insertion	3dB

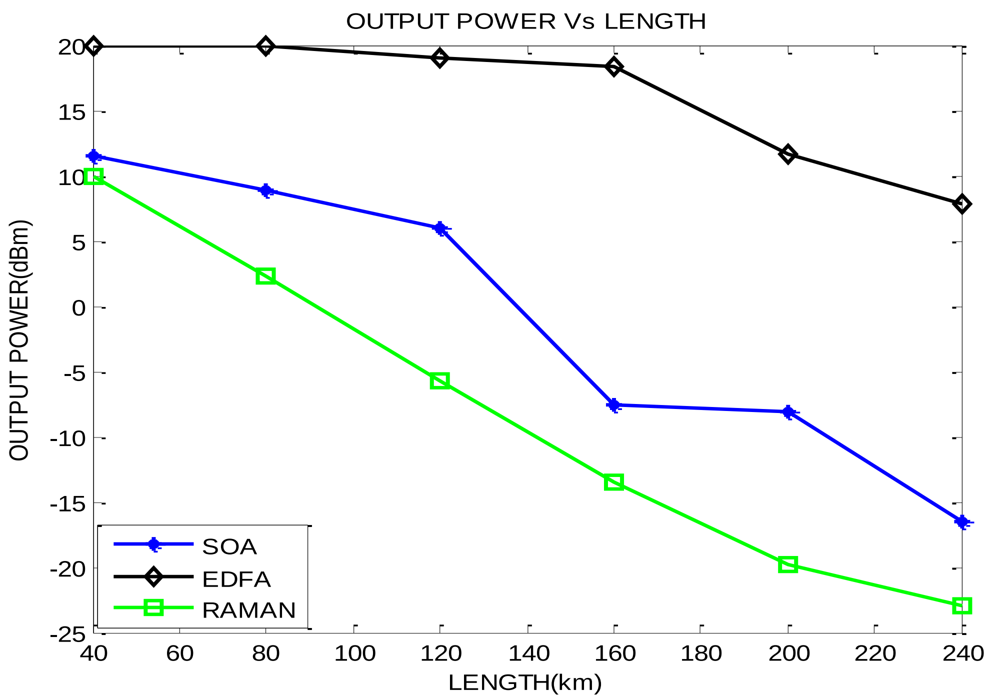
Table 3.5 : Parameter for RAMAN fiber amplifier

RAMAN fiber length	10km
Operating temperature	300K
Pump power	24.771dBm
Pump wavelength	1480nm
Pump attenuation	1.2dB/km

To analyse the system, the results for the presence of nonlinearities in the first channel, the graph between output power vs distance have been taken. These graphs show that as we increase the transmission distance from 60 to 240 km, the output power decreases simultaneously. The variation in output power from different optical amplifiers is 20 to 7.89 dBm for EDFA, 9.96 to -23.00 dBm for RAMAN, 11.50 to -16.51 dBm for SOA.



(a)



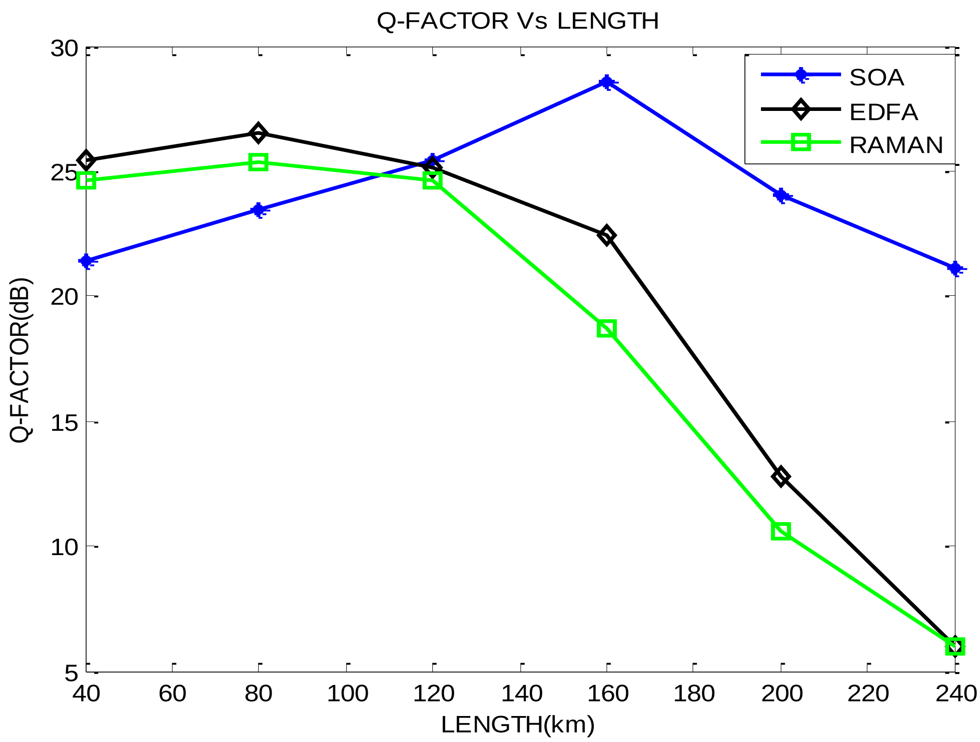
(b)

Figure 3.3 : Power vs Distance for (a) Presence of nonlinearities; (b) Absence of nonlinearities

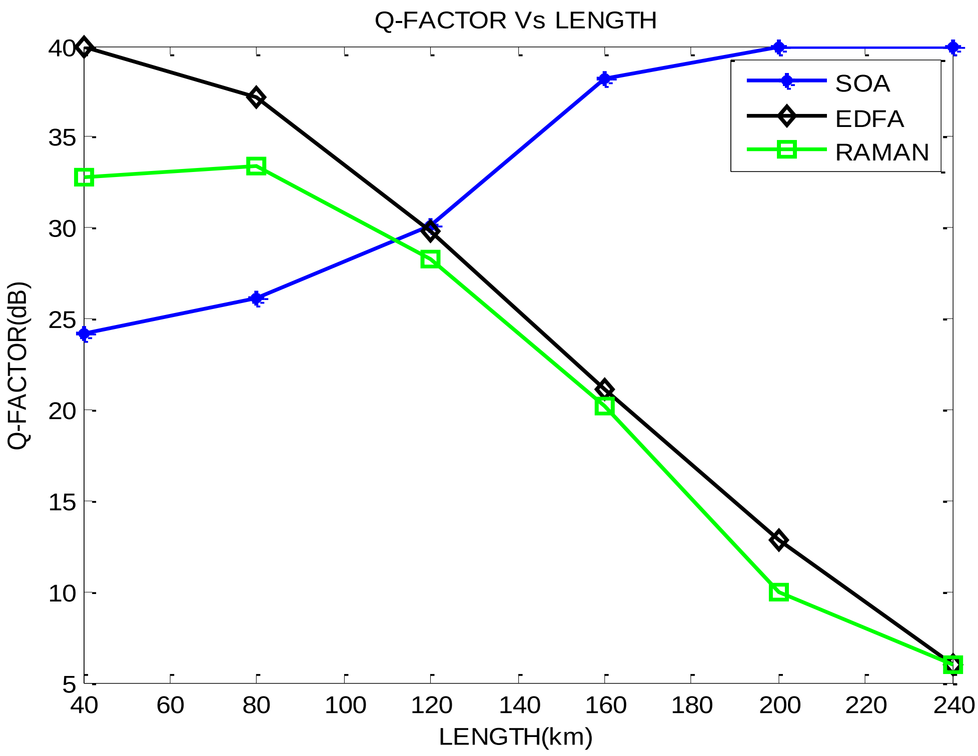
The figure 3.3(a) shows the variation in output power for different amplifiers at absence of nonlinearities is 20 to 7.90 dBm for EDFA, 9.973 to -23.20 dBm for RAMAN, 11.50 to -16.51 dBm for SOA. If the nonlinearities not considered, better output power is provided by the EDFA amplifier (20 dBm) and also for the worst case (at 200 Km) it becomes 7.90 dBm as compare to other amplifiers as shown in figure 3.3(b).

The figure 3.4(a) shows the graphical representation of Q Factor as a function of Length in the Presence of non-linearity. The least value of Q Factor is provided by the SOA amplifier (21.39 dB) but in the worst case it will becomes (at 240 Km) 32.74dB, which is better than others. In the distance range 40 to 120 km, RAMAN and EDFA amplifier have comparable Q-factor .Also at 120 km EDFA,RAMAN and SOA have almost the same Q-factor.

The variation in Q-factor for different amplifiers at absence of nonlinearities is 25.45 to 6.02 dB for EDFA, 24.65 to 6.20 dB for RAMAN, 21.39 to 32.43 for SOA. SOA provides the better result as compare to other amplifiers means improvement in Q-factor up to 160 km and then decrement.



(a)



(b)

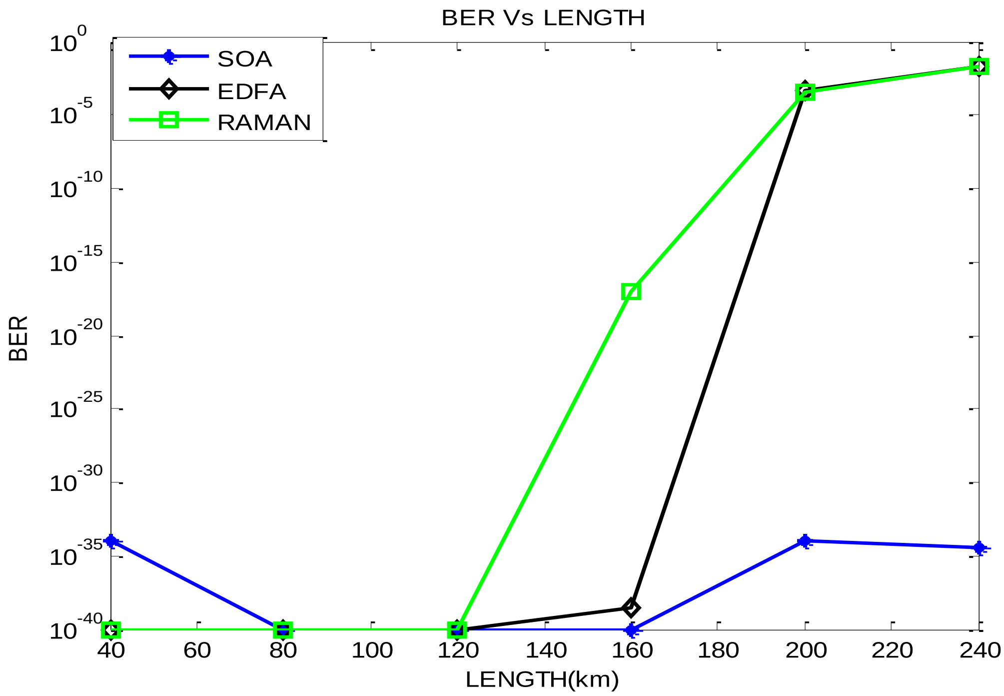
Figure 3.4 : Q-factor vs Distance for (a) Presence of nonlinearities; (b) Absence of nonlinearities

If nonlinearities are not considered, better Q Factor is provided by the RAMAN amplifier up to 120km and at 240 onwards SOA has highest Q-factor as shown in figure 3.4(b).

The variation in Q-factor for EDFA, RAMAN and SOA are 40 to 6.20 dB, 32.78 to 6.20 dB and 24.26 to 40 dB respectively. At 120 km EDFA, SOA and RAMAN have comparable Q-factor.

The acceptable bit error rate (BER) for optical transmission is 1×10^{-9}. The BER versus transmission distance for presence and absence of nonlinearities is shown in figure 3.5. It is observed that by increasing the transmission distance from 40 to 240 km, BER is also increasing.

The figure 3.5(a) shows the graphical representation of BER as a function of Length in the presence of nonlinearities. It is observed that for distance from 40 to 120 km RAMAN and EDFA have almost same BER of the order of 1×10^{-40} .SOA has high BER of the order 10^{-35} at 40km and then it decreases linearly up to 80 km.At 80 to 120 km SOA have



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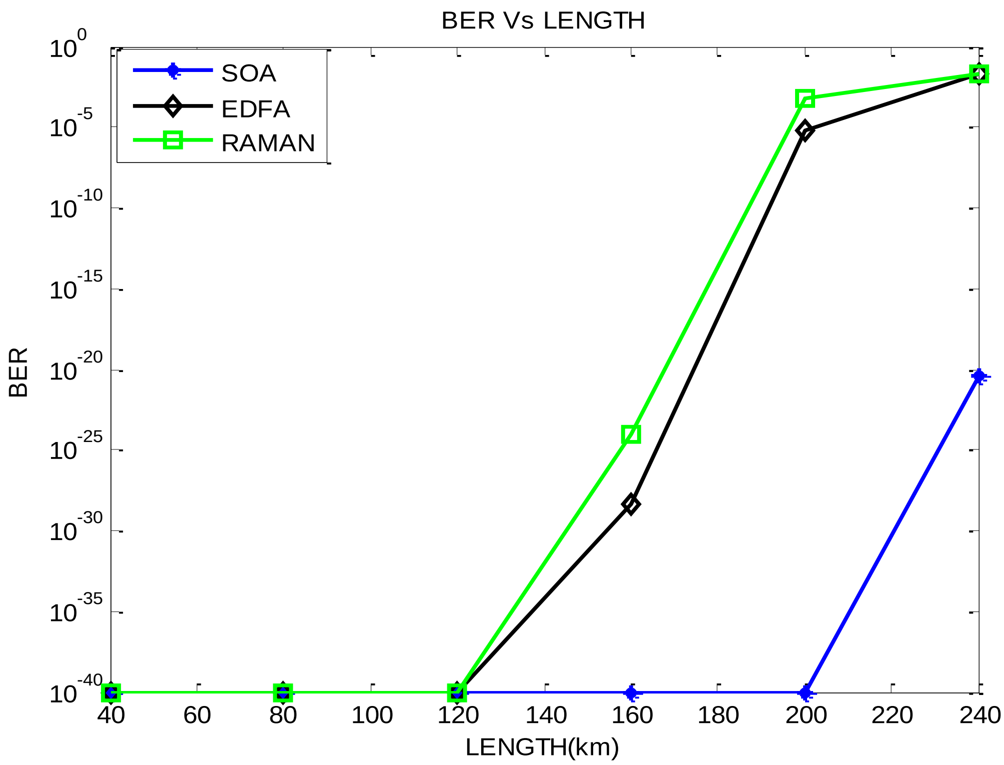
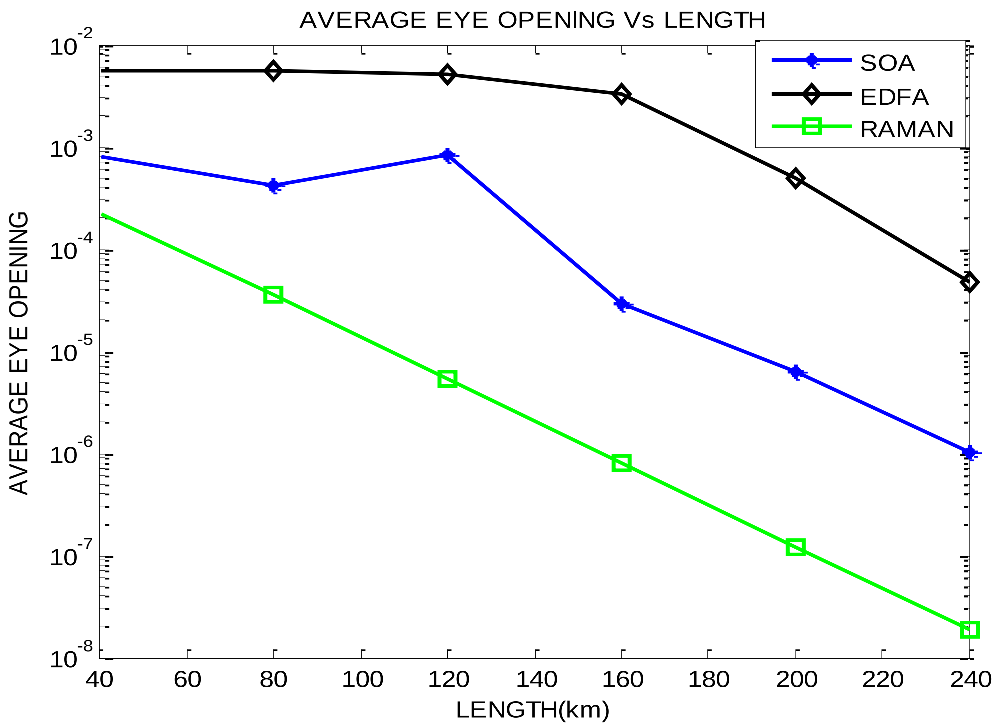


(b)

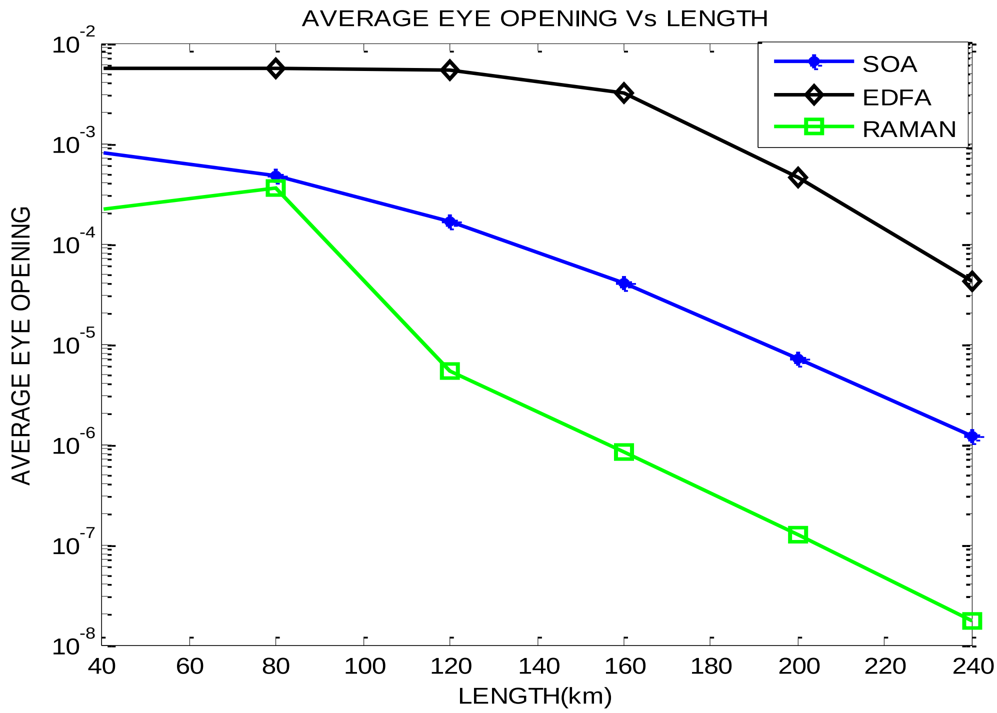
Figure 3.5 : BER vs. Length (a) Presence of nonlinearities (b) Absence of nonlinearities

comparable BER with RAMAN and EDFA. After 120km BER for RAMAN,EDFA starts increases but SOA start increases at 160 km. At 200km only SOA have BER less than 10^{-34} .It is observed that RAMAN and EDFA provides highest Q-factor among all in distance range from 40 to 80 km. The variation in BER for EDFA, RAMAN and SOA are 1×10^{-40} to 0.227×10^{-01}, 1×10^{-40} to $0.227\times10^{-01}$and 0.261×10^{-37} to 1×10^{-40} respectively.

If the nonlinearities not considered, better BER is provided by the SOA amplifier (1×10^{-40}) and also for the worst case (at 240 Km) it becomes 1.05×10^{-20}. But there is very much variation in BER in RAMAN and EDFA after 120km,So to mitigate this problem we required gain equalizer which increase the complexity and cost of the setup, so that SOA provides better results as shown in figure 3.5(b). The variation in Q-factor for RAMAN, EDFA and SOA are 1×10^{-40} to 0.227×10^{-01}, 1×10^{-40} to 0.227×10^{-01} and 1×10^{-40} to 1.05×10^{-20} respectively.



(a)



(b)

Figure 3.6 : Average Eye Opening vs Distance (a) Presence of nonlinearities (b) Absence of nonlinearities

The eye opening from different amplifiers verses transmission distance at presence of nonlinearities is shown in figure 3.6(a). Large eye opening means less BER and good communication. It is observed that by increasing the transmission distance from 40 to 240 km, eye opening is also decreasing. The variation in average eye opening at different distance is 0.563 × 10^{-02} to 0.480 × 10^{-04} for EDFA, 0.224 × 10^{-03} to 0.1857 × 10^{-07} for RAMAN, 0.786 × 10^{-03} to 0.1030 × 10^{-05} for SOA.

As figure 3.6(b) If the nonlinearities not considered, the variation in average eye opening at different distance is 0.557 × 10^{-02} to 0.415 × 10^{-04} for EDFA, 0.214 × 10^{-03} to 0.1757 × 10-^{07} for RAMAN, 0.806 × 10^{-03} to 0.1230 × 10^{-05} for SOA.

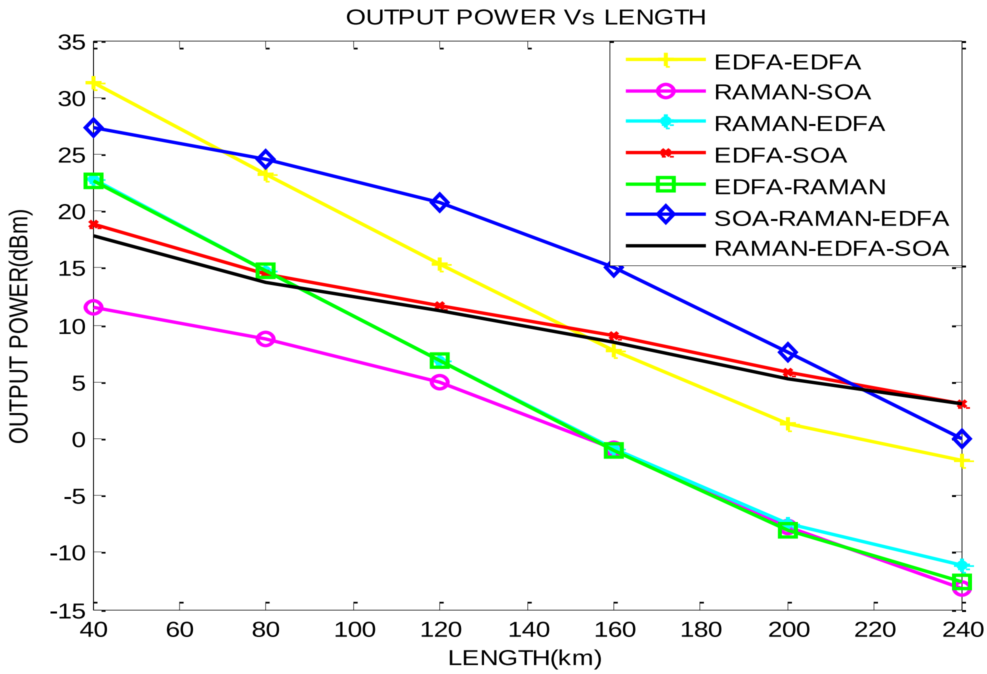
3.5 Result and Discussion for Hybrid Optical Amplifiers

The Performance of different hybrid amplifiers EDFA-EDFA, RAMAN-EDFA,RAMAN-SOA, EDFA-RAMAN, SOA-RAMAN-EDFA and RAMAN-EDFA-SOA are evaluated and compared for 64 × 10Gbps WDM system in the term of received maximum Q Factor (dB),Average eye opening, minimum BER and maximum output power(dBm) for with and without nonlinearities at different transmission distance . The distance varied from 40 to 240 km in steps of 40 km. To analyse the system, the results of the first channel have been taken.

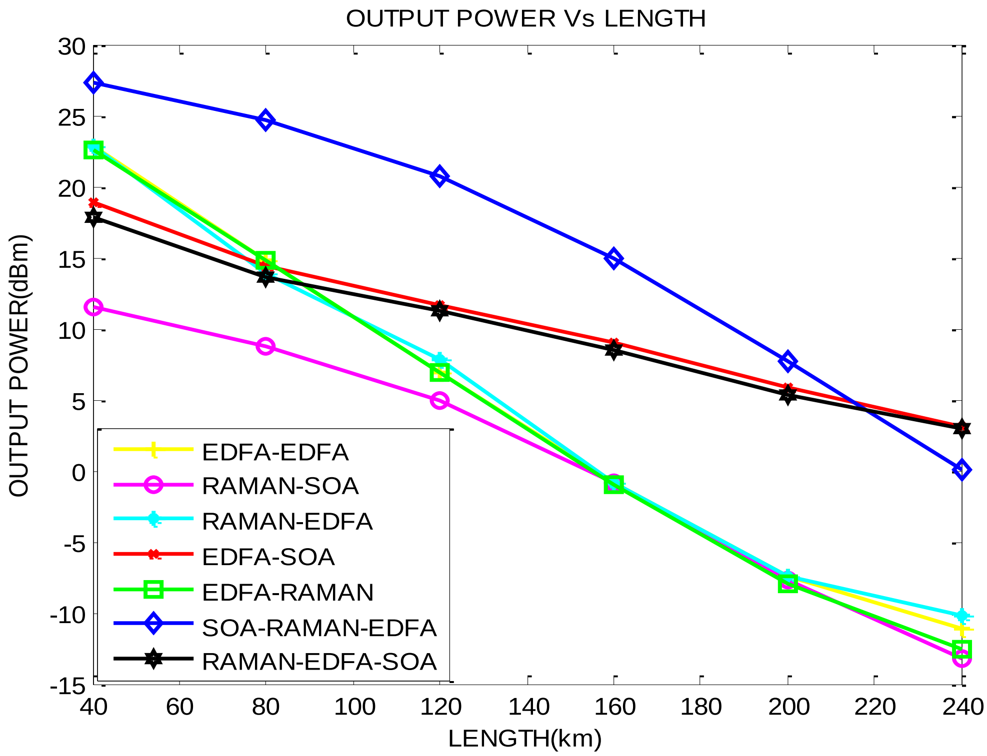
The figure 3.7(a) shows the graphical representation of output power as a function of length in the presence of nonlinearities. The output power is decreased due to the fiber nonlinearities and fiber attenuation. The better output power is provided by the RAMAN-EDFA-SOA and EDFA-SOA amplifier for entire distance range. At 40km output power provided by RAMAN-EDFA-SOA and RAMAN-SOA are 17.84 dBm and 18.90 dBm and also for the worst case (at 240 Km) it becomes 2.99 dBm and 3.09 dBm, But for other configuration power decreases linearly with distance upto negative range.

The variation in output power is 31.28 to -1.949 for EDFA-EDFA, 11.49 to -13.24 dBm for RAMAN-SOA, 22.82 to -11.13 dBm for RAMAN-EDFA, 18.90 to 3.09 dBm for EDFA-SOA, 22.60 to -12.59 dBm for EDFA-RAMAN,27.30 to 0.001 dBm for SOA-RAMAN-EDFA.

If the nonlinearities not considered, the better output power is provided by the RAMAN-EDFA-SOA and EDFA-SOA amplifier for entire distance range shows in figure 3.7(b).



(a)

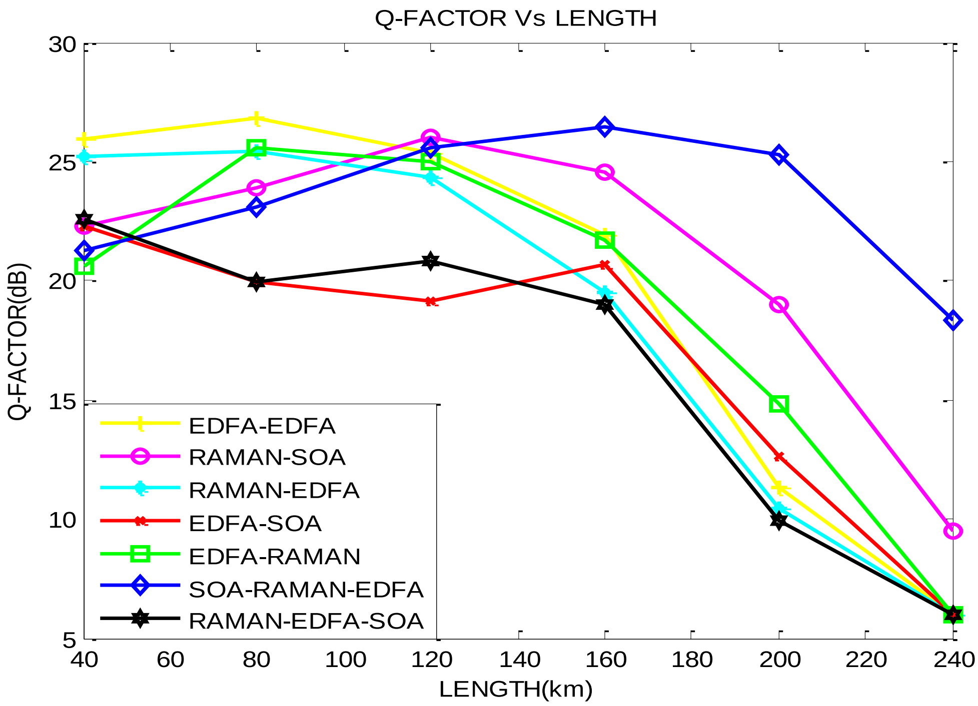


(b)

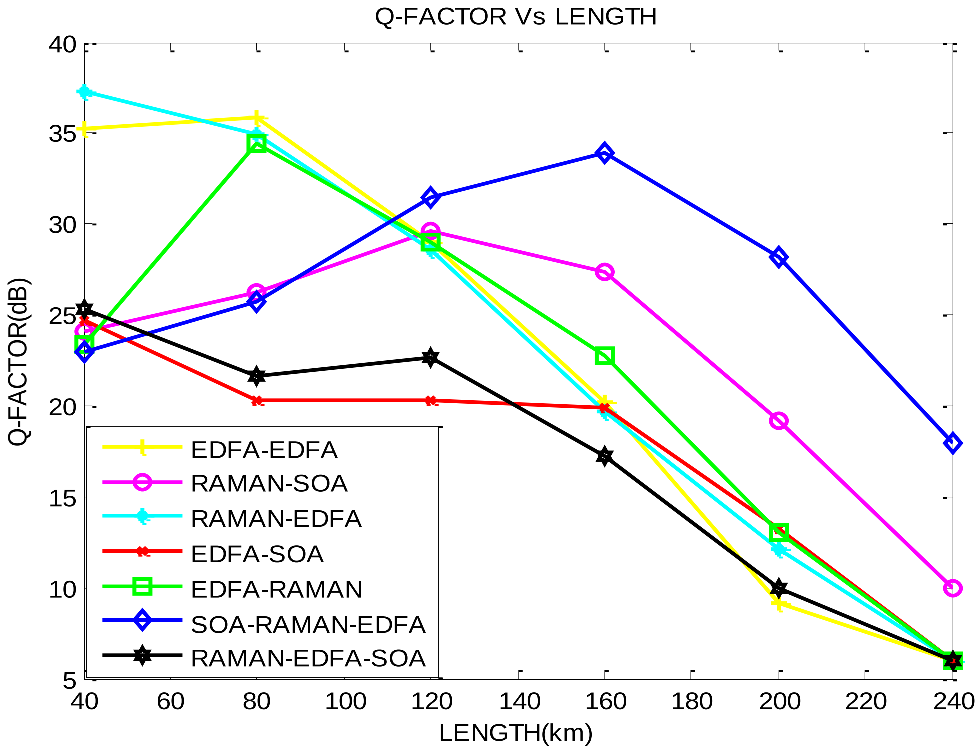
Figure 3.7 : Power vs Distance (a) Presence of nonlinearities (b) Absence of nonlinearities

At 40 km output power provided by RAMAN-EDFA-SOA and RAMAN-SOA are 18.84 dBm and 19.20 dBm and also for the worst case (at 240 Km) it becomes 3.00 dBm and 3.20 dBm, which is shows there is improvement in the power level without nonlinearities. The output power for other configuration is 22.84 to -11.15 dBm for EDFA-EDFA, 11.49 to -13.24 dBm for RAMAN-SOA, 22.84 to -11.15 dBm for RAMAN-EDFA, 22.61 to -12.60 dBm for EDFA-SOA, 27.32 to 0.019 dBm for SOA-RAMAN-EDFA.

The figure 3.8(a) shows the graphical representation Q-factor vs. Length for 64 channels in the presence of nonlinearities. The Q factor for SOA-RAMAN-EDFA and RAMAN-SOA amplifier is linear as compare to other which is 21.91 dB and 22.31dB at 40 km and also for the worst case (at 240 Km) it becomes 18.39 dB and 9.56 dB respectively.
The Q-factor for other configuration is 25.93 to 6.02 dB for EDFA-EDFA, 25.23 to 6.020 dB for RAMAN-EDFA, 22.36 to 6.02 dB for EDFA-SOA, 20.67 to 6.02 dB for EDFA-RAMAN, 22.62 TO 6.02 dB for RAMAN-EDFA-SOA.



(a)



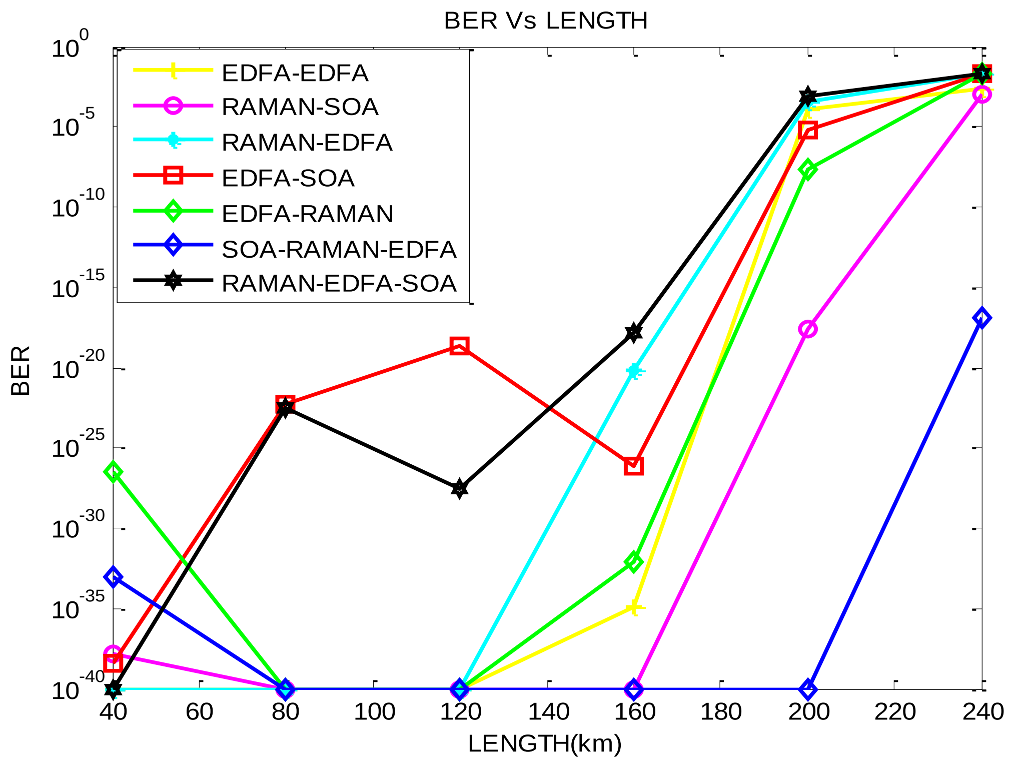
(b)

Figure 3.8 : Q-Factor vs Distance (a) Presence of nonlinearities (b) Absence of nonlinearities

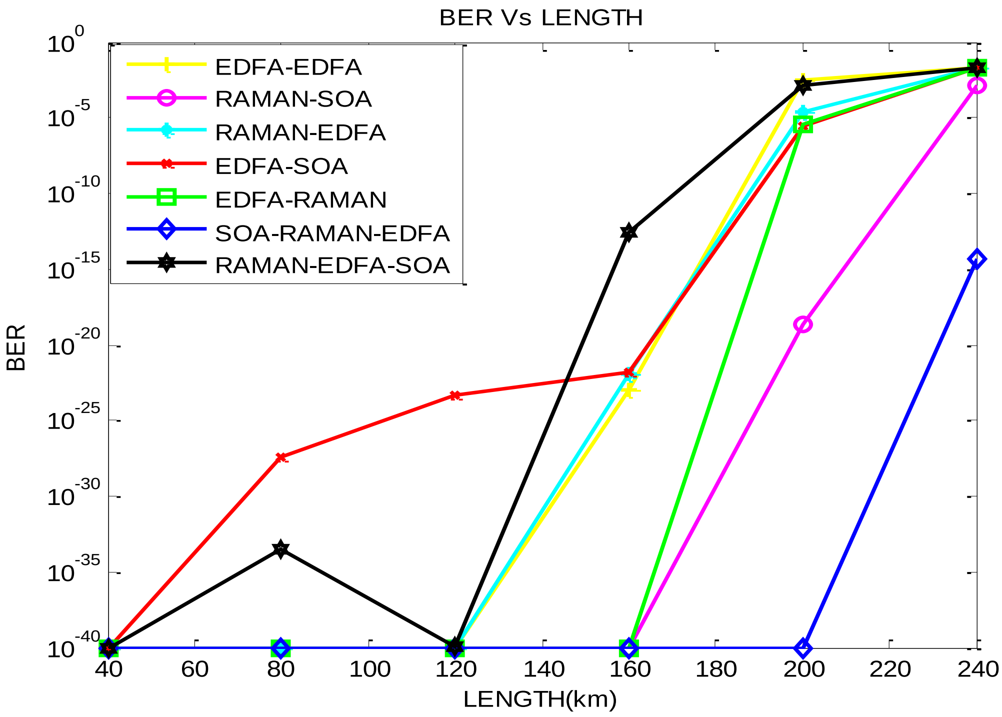
If the nonlinearities not considered, the better Q-factor is provided by the SOA-RAMAN-EDFA and RAMAN-SOA amplifier for entire distance range. The SOA-RAMAN-EDFA and RAMAN-SOA are 22.94 dB and 24.11 dB.

The figure 3.8(b) shows the graphical representation If nonlinearities not considered the Q-factor will be improved and up to 160 km all hybrid amplifiers provided better Q-factor and then decreased linearly. The Q-factor for other configuration is 35.28 to 6.02 dB for EDFA-EDFA, 37.82 to 6.020 dB for RAMAN-EDFA, 24.66 to 6.02 dB for EDFA-SOA, 23.37 to 6.02 dB for EDFA-RAMAN, 25.32 TO 6.02 dB for RAMAN-EDFA-SOA.

The figure 3.9(a) shows the graphical representation of BER as a function of distance in the presence of nonlinearities. At 80km the better BER is provided by the SOA-RAMAN-EDFA and RAMAN-SOA amplifier (1×10^{-40} and 1×10^{-40}) and also for the worst case at 240 Km it becomes 0.124×10^{-16} and 0.218×10^{-02}. Other hybrid amplifiers also provides the acceptable result but there is very much variation in BER. It is also observed that at 200km only SOA-RAMAN-EDFA has BER $<10^{-40}$.



(a)



(b)

Figure 3.9 : BER vs Distance for (a) Presence of nonlinearities (b) Absence of nonlinearities

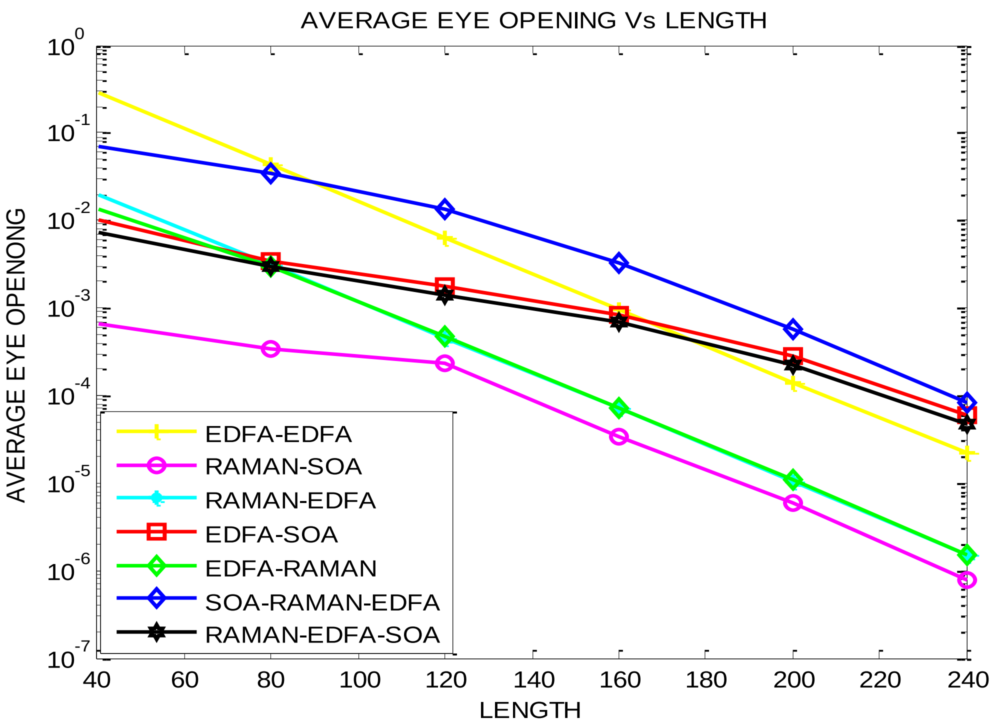
The variation in BER for other is 1 × 10^{-40} to 0.218 × 10^{-02} for EDFA-EDFA, 1 × 10^{-40} to 0.277 × 10^{-01} for RAMAN-EDFA, 0,379 × 10^{-38} to 0.227 × 10^{-01} for EDFA-SOA, 0.337 × 10^{-26} to 0.227 × 10^{-01} for EDFA-RAMAN, 1 × 10^{-40} to 0.227 × 10^{-01} for RAMAN-EDFA-SOA.

The figure 3.9(b) shows the graphical representation if nonlinearities not considered the BER will be improved and up to 160 km SOA-RAMAN-EDFA and RAMAN-SOA amplifiers provided better BER and then increased linearly. At 40 km the better BER is provided by the SOA-RAMAN-EDFA and RAMAN-SOA amplifier (1 × 10^{-40} in both case) and also for the worst case (at 240 Km) it becomes 0.533 × 10^{-14} and 0.132 × 10^{-02} . The variation in BER for other is 1 × 10^{-40} to 0.218 × 10^{-02} for EDFA-EDFA, 1 × 10^{-40} to 0.277 × 10^{-01} for RAMAN-EDFA, 1 × 10^{-40} to 0.227 × 10^{-01} for EDFA-SOA, 1 × 10^{-40} to 0.227 × 10^{-01} for EDFA-RAMAN, 1 × 10^{-40} to 0.227 × 10^{-01} for RAMAN-EDFA-SOA.

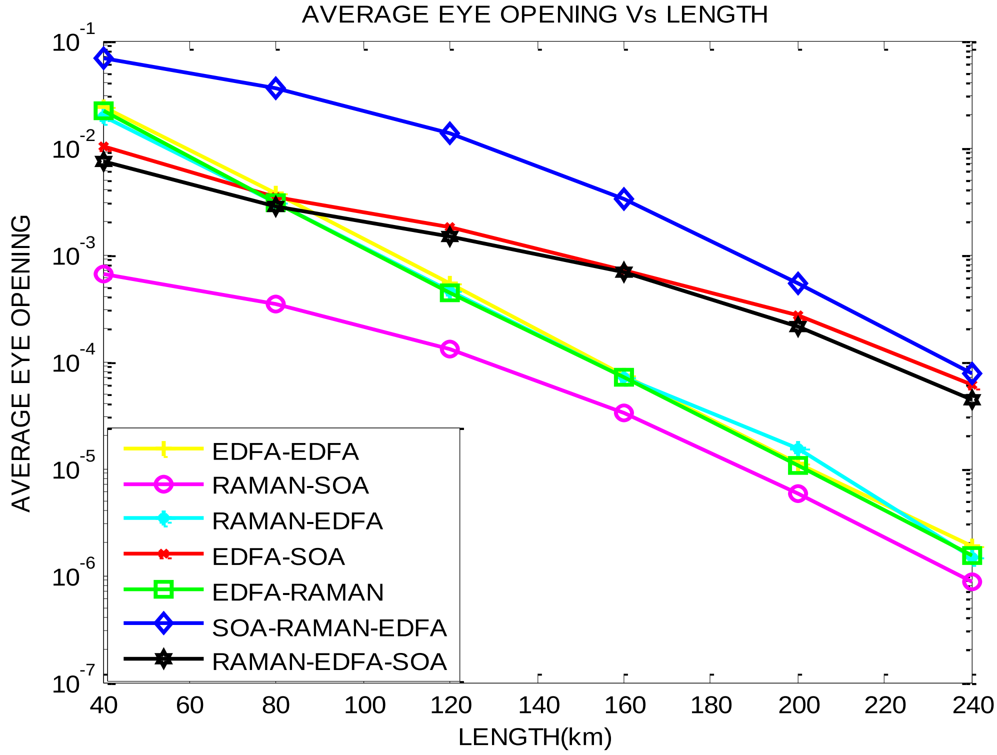
The figure 3.10(a) shows the graphical representation of Average eye opening as a function of distance in the presence of nonlinearities. The maximum eye opening is provided by the SOA-RAMAN-EDFA amplifier for all distance range. Other hybrid amplifiers also provide the acceptable result but there is variation in value. It is also observed that at 200km only SOA-RAMAN-EDFA has maximum value (0.8130×10^{-04}).

The variation in eye opening for other is 0.283 to 0.218×10^{-04} for EDFA-EDFA, 0.661×10^{-03} to 0.776×10^{-06} for RAMAN-SOA,0.196 × 10-01 to 0.152×10^{-05} for RAMAN-EDFA, 0.103×10^{-01} to 0.590×10^{-04} for EDFA-SOA, 0.133×10^{-01} to 0.152×10^{-05} for EDFA-RAMAN, 0.721×10^{-02} to 0.459×10^{-04} for RAMAN-EDFA-SOA.

The figure 3.10(b) shows the graphical representation of Average eye opening as a function of distance in the absence of nonlinearities. The maximum eye opening is provided by the SOA-RAMAN-EDFA amplifier for all distance range. There is improvement in eye opening in absence of nonlinearities. Other hybrid amplifiers also provide the acceptable result but there is variation in value. It is also observed that at 200km only SOA-RAMAN-EDFA has maximum value is (0.7661 × 10-04).



(a)



(b)

Figure 3.10 : Average eye opening vs Distance for (a) Presence of nonlinearities (b) Absence of nonlinearities

The variation in eye opening for other is 0.243×10^{-01} to 0.183×10^{-05} for EDFA-EDFA, 0.641×10^{-03} to 0.876×10^{-06} for RAMAN-SOA,0.195×10^{-01} to 0.149×10^{-05} for RAMAN-EDFA, 0.101×10^{-01} to 0.595×10^{-04} for EDFA-SOA, 0.127×10^{-01} to 0.150×10^{-05} for EDFA-RAMAN, 0.729×10^{-02} to 0.449×10^{-04} for RAMAN-EDFA-SOA.

3.6 Conclusion

The optical amplifiers and hybrid optical amplifiers design models were successfully designed and implemented into OptSim. The main motivation of this work is to optimize the optical amplifiers for different transmission distance and study the nonlinearities effect. The performance of optical amplifiers was evaluated using the eye patterns, BER measurement, average eye opening and Q factor. The simulation results show that RAMAN-SOA and SOA-RAMAN-EDFA performed better than EDFA, SOA, EDFA-RAMAN, RAMAN-EDFA, EDFA-EDFA optical amplifier. RAMAN-SOA and SOA-

RAMAN-EDFA provide high power (27.30 to 0.01 dBm with nonlinearities and 27.32 to 0,19 dBm for without nonlinearities), least BER (1×10^{-37} to 0.108×10^{-02} and 1×10^{-33} to 9.16×10^{-16} for with nonlinearities and 1×10^{-40} to 0.132×10^{-02} and 1×10^{-40} to 0.533×10^{-14} for without nonlinearities), large Q factor (22.32 to 9.521 dB and 21.62 to 18.62 dB for with nonlinearities and 24.11 to 9.960 dB and 22.91 to 17.97 for without nonlinearities) and good eye diagram for different transmission distance ranging from 40 to 240 km. These results are valid upto 160 Kms. Above 160 km distance, there is more distortion in the detected signal. The output power, Q factor and eye opening are decreasing above this. Also, there is an increment in BER after 160 Km. So, this proposed model is best suited for 160 km distance.

In conclusion, this model has demonstrated that RAMAN-SOA and SOA-RAMAN-EDFA is a promising alternative to EDFA, SOA, RAMAN, EDFA-EDFA,RAMAN-EDFA ,EDFA-RAMAN and RAMAN-EDFA-SOA in optical transmission when using a RZ-Soliton pulse format for transmission.

CHAPTER 4

Simulation of 64×10Gbps WDM System Based on RAMAN-EDFA Hybrid Amplifier at Different Pumping

4.1 Abstract

In this chapter, the 64 channel WDM systems at 10 Gbps have been investigated for the various RAMAN–EDFA optical amplifiers pumping and its power. The performance has been compared on the basis of different fiber length and effect of nonlinearities. Four types of pumping have been investigated independently and compared. It is observed that when using a RZ-Soliton data format pump 2 of RAMAN-EDFA provides the highest output power (10.04 dBm to 10.55 dBm and 10.01 to 10.68 dBm) and least bit error rate (1×10^{-40} to 0.140×10^{-10} and 1×10^{-40} to 0.277×10^{-07}) at 160 km for with and without nonlinearities respectively as compare to other pumping amplifier.

4.2 Introduction

There has been a strong interest in high capacity lightwave transmission systems and networks in recent. To increase data transmission capacities, several methods are investigated by adding more channels in the wavelength division multiplexing (WDM) system, so that spectral efficiency need to be upgraded. To overcome these problems, the WDM systems have been demonstrated using several types of wideband amplifiers. EDFA,SOA,RAMAN and hybrid amplifiers are the main amplifiers having good amplification response and good gain bandwidth.[4,40]

Due to its low convert efficiency, Raman Amplifier which is one of the key components of the high-speed and high-capacity communications systems can only assist EDFA but can be substituted in commercial operation [1], [2] and [3]. Therefore, it is an ideal application to combine the RAMAN with EDFA. During designing the hybrid amplifier of RAMAN EDFA, there is a question that how to configure the gain parameters of both amplifiers to get the optimum performance. However the optimization designing for the hybrid amplifier, firstly, requires a clarification of how the noise of RA and EDFA affects the performance of hybrid amplifier.

This chapter focuses on RAMAN-EDFA at different pumping and pumping power, which are an emerging technology and in fact being gradually deployed for the commercial services. Raman amplifiers are better to any other alternatives for optical amplification in terms of high signal transmission performance. Erbium-doped fiber amplifiers (EDFAs), which have been widely used in the actual optical transmission systems now in service. EDFAs are of low noise, compact, highly efficient with high gain, and capable of amplifying multichannel signals on different wavelengths at a time, and hence quite economical for WDM transmissions. Another alternative of optical amplification is the semiconductor optical amplifier (SOA), which is nominally an optical amplifier device with an active waveguide integrated onto a compound semiconductor. SOA is superior in the sense of high integration and additional functionality such as wavelength conversion and all-optical regeneration.

4.3 Simulation Setup

The block diagram of different configuration of RAMAN-EDFA for pumping is shown in figure 4.1. In this model, sixty four users transmitted their data over a bandwidth of 6.8 THz at 10 Gb/s speed with channel spacing of 100 GHz. Each input signal is modulated in RZ-Soliton format and preamplified by a booster. The amplified signals send to the channel where these signal are transmitted over DS-anomalous fiber of different transmission distance. A transmitter compound component is built up using four sixteen transmitters. This transmitter compound component consists of the data source (RZ-Soliton), electrical driver, laser source and external Mach-Zehnder modulator in each transmitter section. The data source is generating signal of 10 Gb/s with pseudo random sequence. The electrical driver converts the logical input signal into an electrical signal. The CW laser sources generate the 16 laser beams at 191.9 THz to 193.4 THz with 100 GHz channel spacing. These beams have random laser phase and ideal laser noise bandwidth. The signals from data source and laser are fed to the external Mach-Zehnder modulator (sin^2_MZ for all configurations), where the input signals from data source is modulated through a carrier (optical signal from the laser source).

The output optical signal of the modulator is fed to the channel where a booster is used to boost the signal. This optical signal is transmitted and measured over different distance for 40,80,120,160,200 Km at presence and absence of nonlinearities individually. Optical Power meter (P1, P2, P3 etc.) and Optical probe (O1, O2, O3 etc) with splitters (S1, S2, S3 etc) are used for measuring the signal power at different levels. RAMAN EDFA amplifier is used for amplifying the optical signal. Different types of pumping in RAMAN EDFA are applied at the receiver side. The setup is repeated for measuring the signal strength by using different four pumps named Pump1, Pump2, Pump3, Pump4. Different results like Average eye opening, Q-factor, Eye diagram and BER show that Pump 2 in RAMAN–EDFA amplifier is the most suitable pump in the all proposed pumps. Polarization mode dispersion, birefringence and fiber nonlinearities (optional) are considered in simulation but raman crosstalk is not consider.

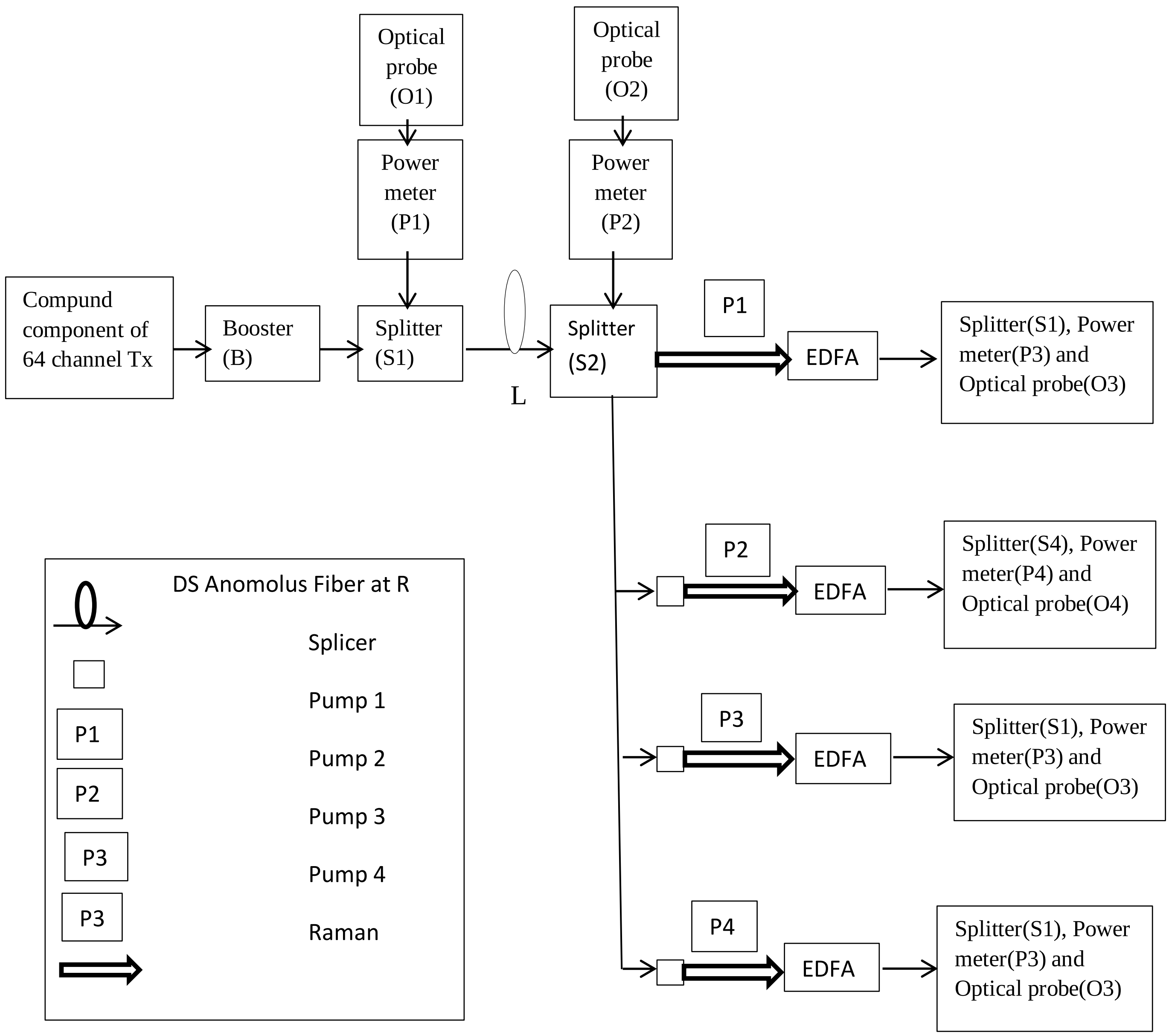


Figure 4.1 : Block Diagram of RAMAN-EDFA with different pumping system

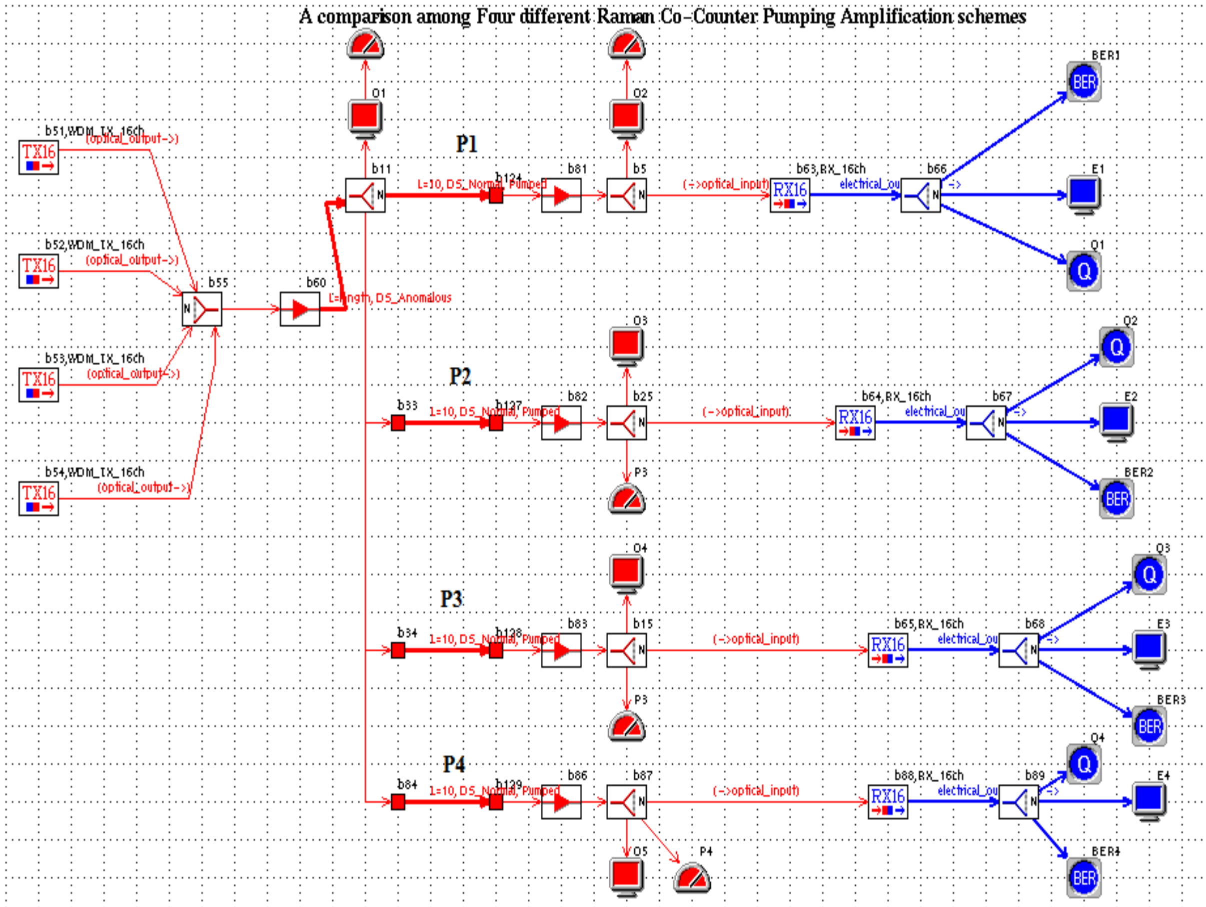


Figure 4.2 : Simulation Setup for RAMAN-EDFA at different Pumping

The simulation set up for different pumps is shown in figure 4.2. The optical signals are generated by sixty four transmitter compound component and this signal is fed to RAMAN EDFA via booster and DS-Anomalous fiber. The signal power is measured by power meter and optical probe. This set up is repeated for different distance from 40 km to 200 km by varying the fiber length i.e. L. The modulated signal is converted into original signal with the help of PIN photodiode and filters. We used four sixteen signal compound receiver to detect sixty four signals individual and converts these into electrical form.

4.4 Result and Discussion

In this chapter, the 64 channels are used to transmit the data with the speed of 10Gbps which is amplified by hybrid optical amplifier (RAMAN-EDFA) after covering the single span distance. The optical signal is connected to different pumps through a splitter.

Different components have different operational parameters. The parameters for external Mach-Zehnder modulator are described in the table 4.1. The DS Anomalous fiber is used to transmit the optical signal. Its various parameters are shown in Table 4.2.

Table 4.1 : Amplitude modulator parameter

Maximum transmissivity offset voltage	2.5V
Average power reduction due to modulation	3dB
Excess loss	3dB

Table 4.2 : DS Anomalous fiber parameter

Reference frequency	193.414THz
Attenuation	0.2dB/km
Dispersion correlation length	20km
Fiber nonlinearity coefficient	1.841/W/km
Nonlinear refractive index	2.5e-20 $m^{2/w}$
Fiber polarization mode dispersion	0.1ps/$km^{0.5}$

The EDFA amplifier is used to amplify the optical signal. Various parameters for EDFA are shown in Table 4.3.

Table 4.3 : EDFA parameter

Output Power	20dB
Gain shape	Flat
Maximum small signal gain	35dB
Noise figure	3.8dB

The Booster or pre-amplifier amplifier is used to amplify the optical signal. The various parameter for Booster or pre-amplifier are shown in Table 4.4

Table 4.4 : pre-amplifier parameter

Output Power	15dB
Gain shape	Flat
Maximum small signal gain	35dB
Noise figure	4.5dB

The RAMAN amplifier is used to amplify the optical signal. The various parameter for RAMAN are shown in Table 4.5(a) and 4.5(b).

Table 4.5(a) : RAMAN amplifier parameter

RAMAN fiber length	10km
Operating temperature	300K
Pump attenuation (1365nm,1450nm)	0.3dB/km

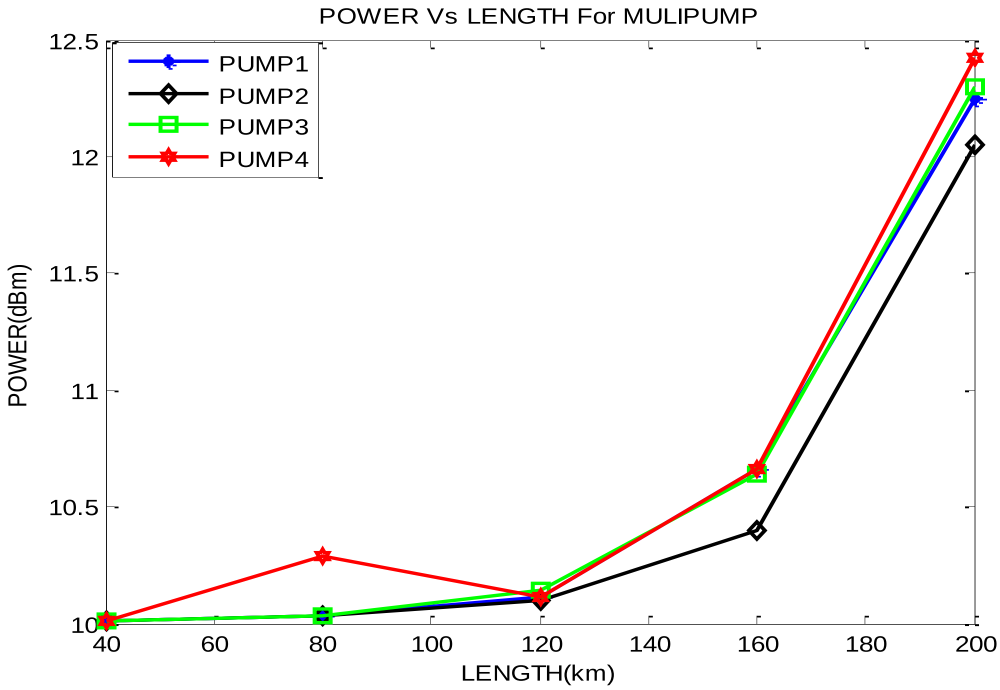
Table 4.5(b) : RAMAN amplifier Pump parameter

Pump	**co-propagating pumping (nm)**	**co-propagating pump power (mW)**	**counter propagating pumping (nm)**	**counter propagating pump power (mW)**
Pump 1	1365	500	1453	500
Pump 2	1365	400	1453	500
Pump 3	1365	300	1453	500
Pump 4	1365	250	1453	500

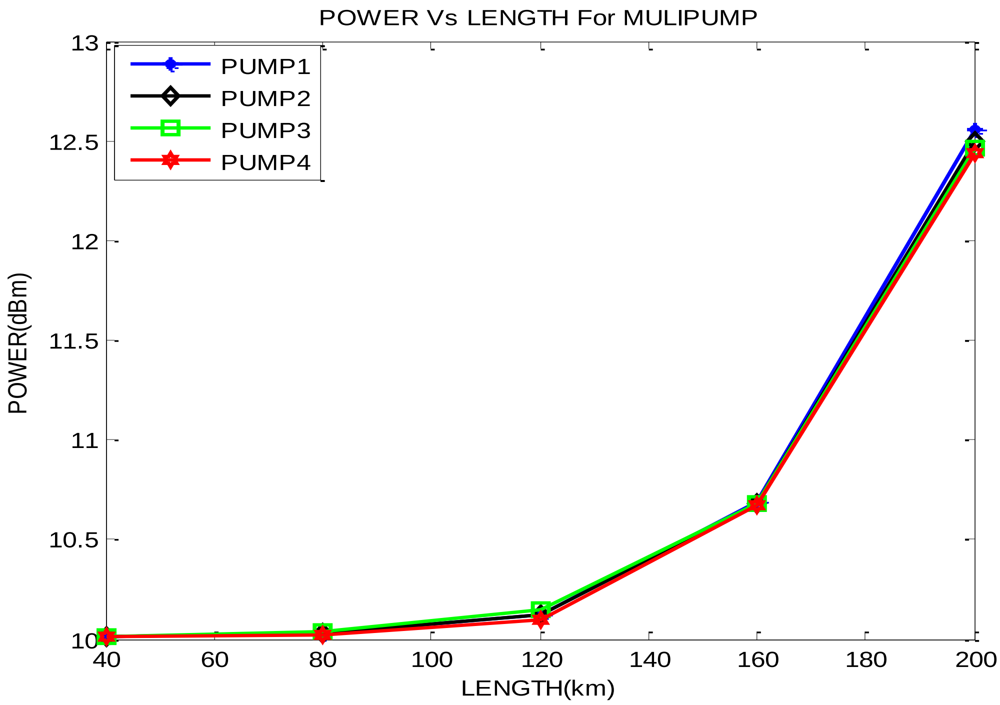
The electrical filter is of raised cosine band pass filter with 40 GHz bandwidth, raised cosine exponent is 1 and raised cosine roll off is 0.1. The responsively of the PIN detector is 1A/W and quantum efficiency is 0.79819.

In order to observe the performance of different pumps, the output power versus transmission distance graph is shown for with and without nonlinearities. When we used

RZ-soliton data pules format first power increased at particular range end then decreases.



(a)



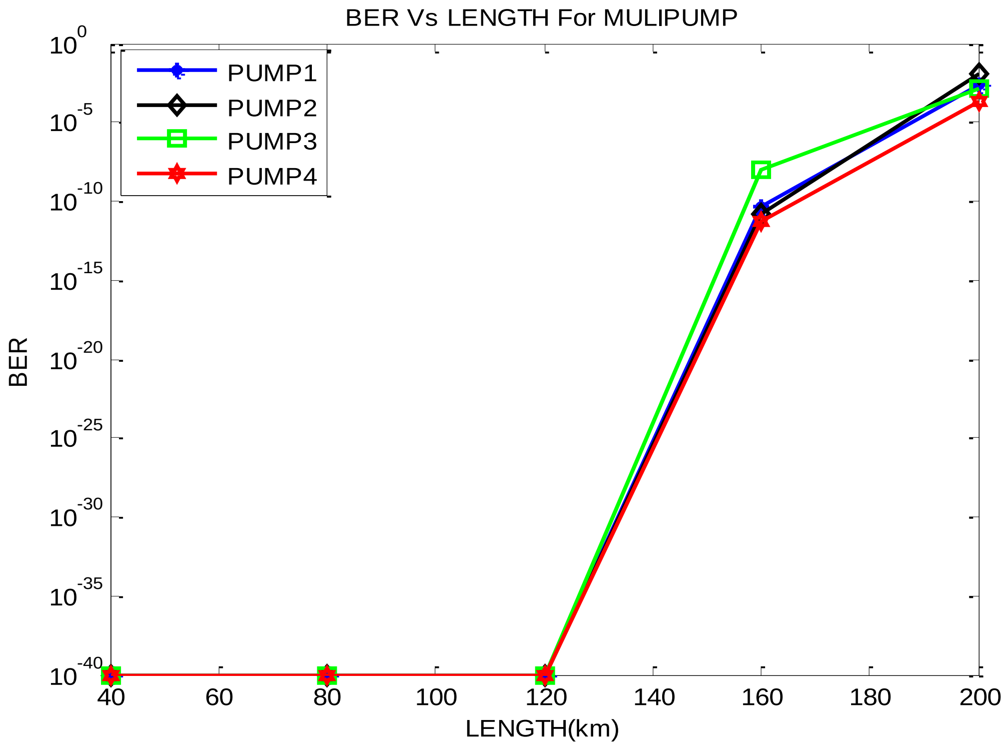
(b)

Figure 4.3 : Power vs Distance at (a) Presence of nonlinearities (b) Absence of nonlinearities

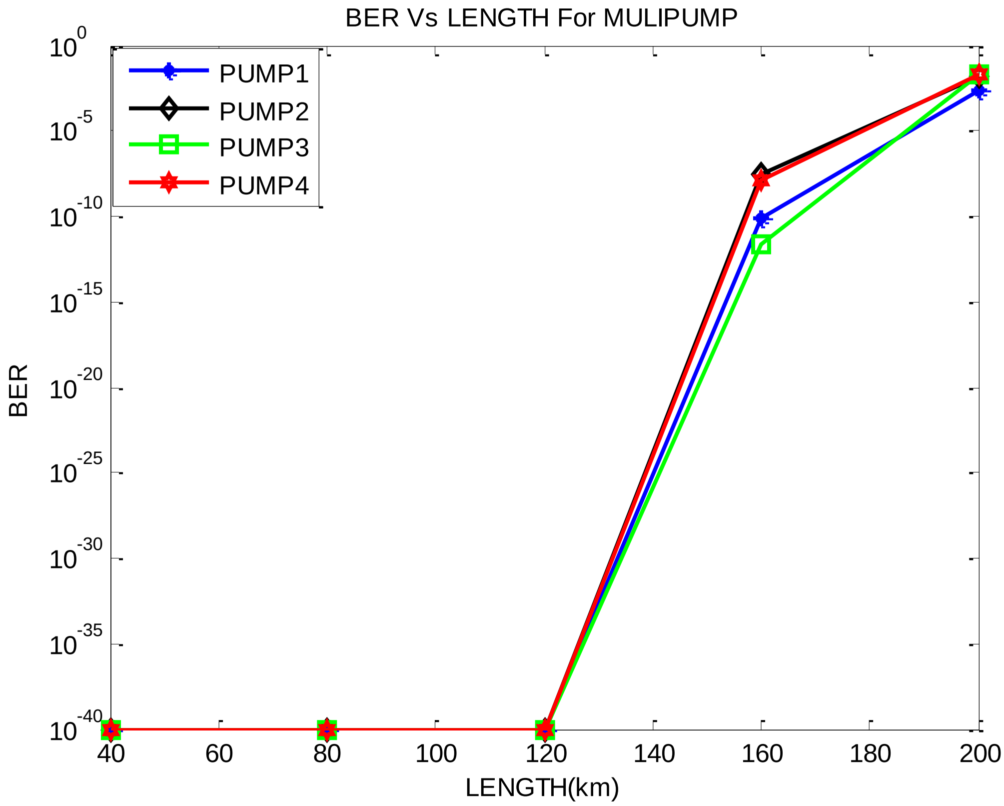
There is graphs show that as we increase the transmission distance from 40 to 200 km, the output power increased simultaneously but after 200km its start decreasing. The variation in output power from different pumps presence of nonlinearities for pump 1 is 10.01 to 12.05 dBm, for pump 2 is 10.01 to 12.30 dBm, for pump 3 is 10.01 to 12.42 dBm and for pump 4 is 10.01 to 12.42 dBm as shown in figure 4.3(a).

The variation in output power from different pumps at absence of nonlinearities is 10.01 to 12.56 dBm for pump 1, 10.01 to 12.56 dBm, for pump 2, 10.01 to 12.46 dBm for pump 3,10.01 to 12.44 dBm for pump 4 as shown in figure 4.3(b). This comparison shows that output power of 12.44 dBm at 200 km transmission distance is the maximum output power obtained by pump3.

The acceptable bit error rate (BER) for optical transmission is 1×10^{-9}. The BER versus transmission distance at presence and absence of nonlinearities is shown in figure 4.4. It is observed that by increasing the transmission distance from 40 to 200 km, BER is also increasing. The variation in BER from different pumps at presence of nonlinearities is 1×10^{-40} to 0.227×10^{-02} for pump 1, 1×10^{-40} to 0.107×10^{-01} for pump 2, 1×10^{-40} to 0.127×10^{-02} for pump 3 and 1×10^{-40} to 0.183×10^{-03} for pump 4 as shown in the figure 4.4(a).



(a)

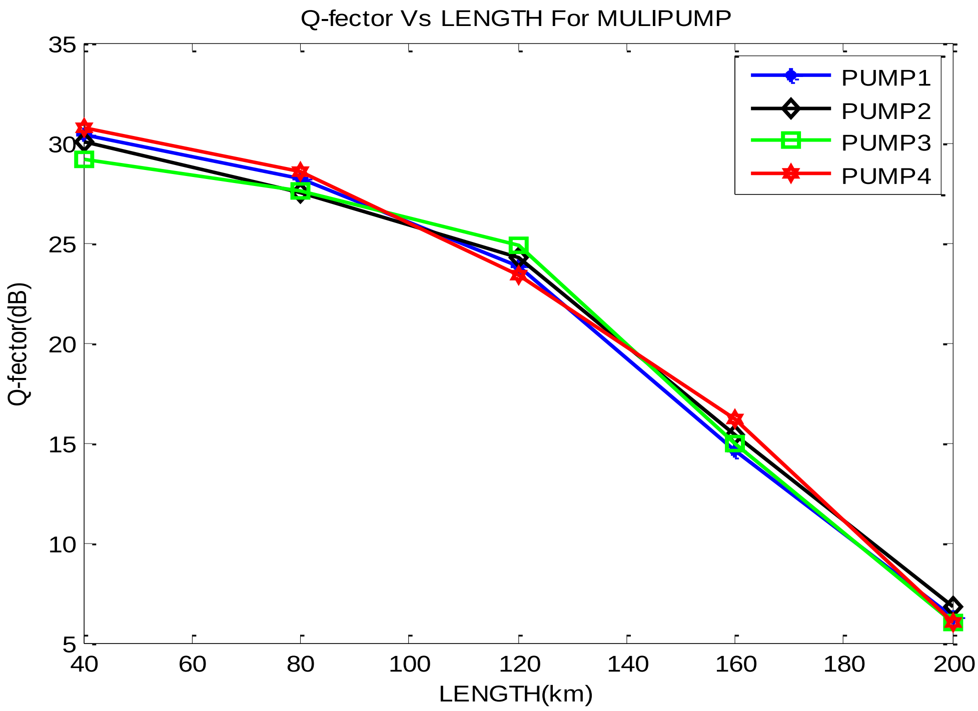


(b)

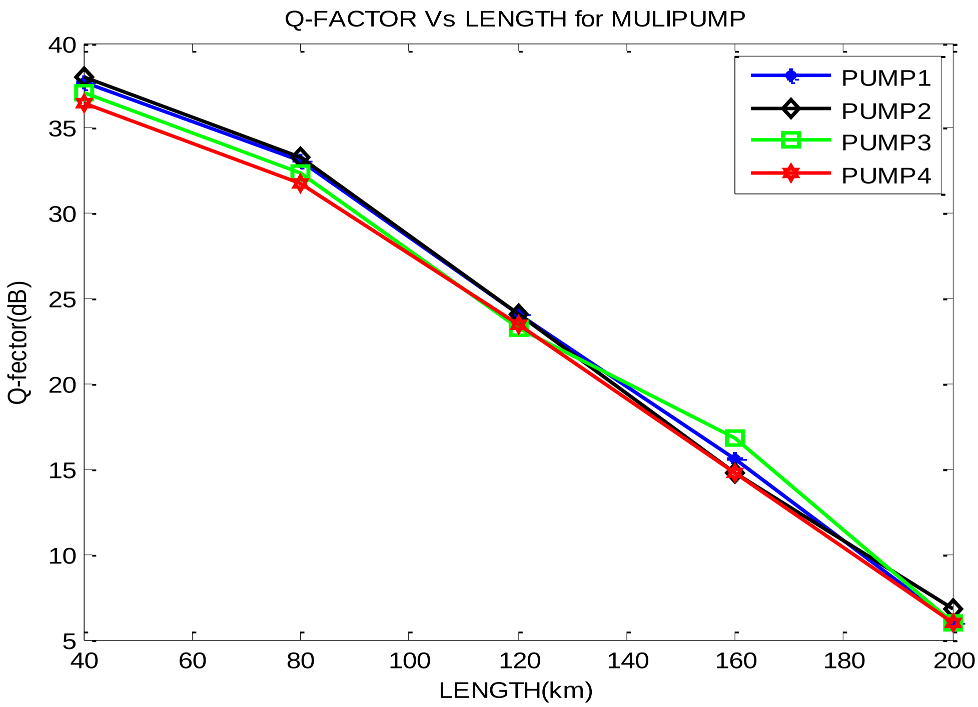
Figure 4.4 : BER vs Distance at (a) Presence of nonlinearities (b) Absence of nonlinearities

Figure 4.4(b) shows, The variation in BER from absence of nonlinearities is 1×10^{-40} to 0.227×10^{-02} for pump 1, 1×10^{-40} to 0.147×10^{-01} for pump 2, 1×10^{-40} to 0.217×10^{-01} for pump 3 and 1×10^{-40} to 0.227×10^{-02} for pump 4. It is observed from the simulation result that minimum BER value is obtained from pump 3 is show higher variation in BER at presence and absence of nonlinearities (0.888×10^{-08} to 0.213×10^{-11}) at 160 km transmission distance. The results show that the minimum BER is provided by pump 4 for all distance. Minimum BER and maximum output power both are achieved from pump 3 at distance 160km.

The Q-fector versus transmission distance at presence and absence of nonlinearities is shown in figure 4.5. There is graphs show that as we increase the transmission distance from 40 to 200 km, the Q-factor decreased simultaneously. The variation in Q-factor from different pumps presence of nonlinearities for pump 1 is 30.38 to 6.30 dB, for pump 2 is



(a)



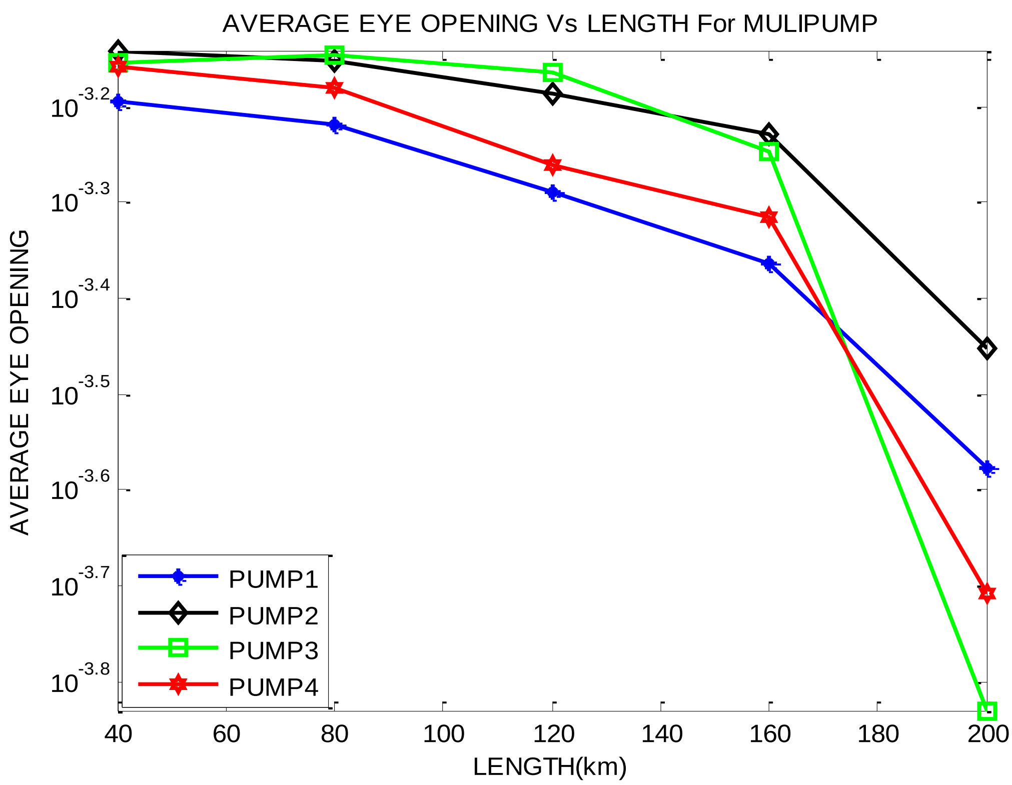
(b)

Figure 4.5 : Q-factor vs Distance at (a) Presence of nonlinearities (b) Absence of nonlinearities

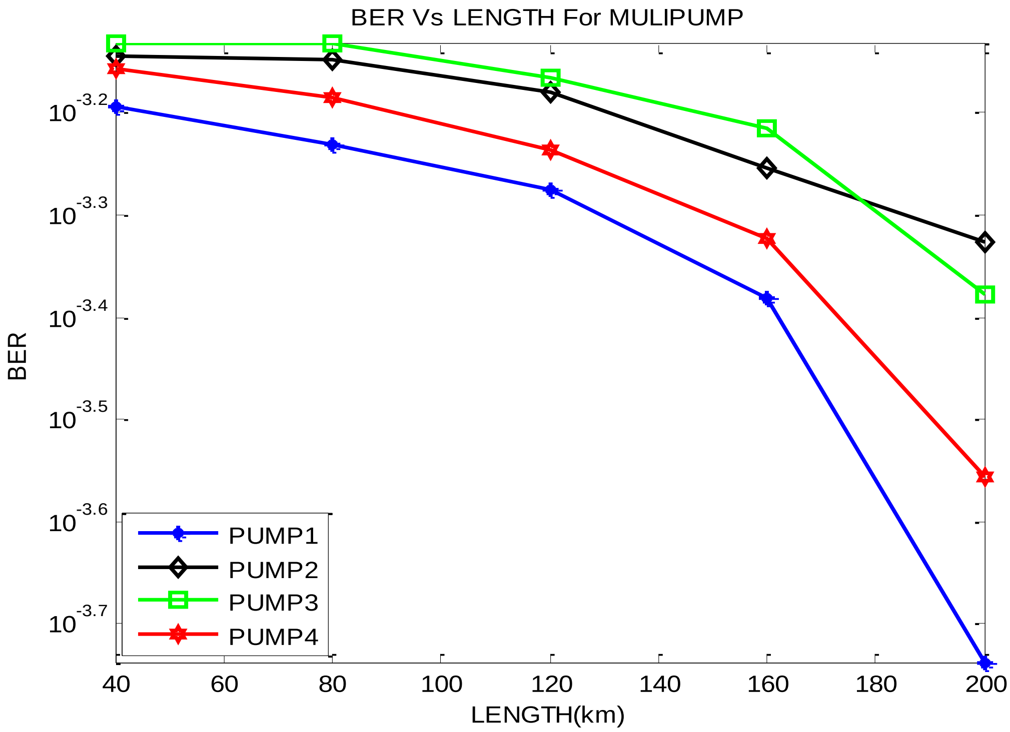
30.06 to 6.83 dB, for pump 3 is 29.15 to 6.02 dB and for pump 4 is 31.78 to 6.02 dB as shown in figure 4.5(a).

The variation in Q-factor from different pumps at absence of nonlinearities is 37.71 to 6.02 dB for pump 1, 37.11 to 6.76 dB for pump 2, 37.11 to 6.02 dB for pump 3, 36.76 to 6.02 dB for pump 4 as shown in figure 4.5(b). This comparison shows that 24.84 dB at 160 km transmission distance and presence of nonlinearities the maximum Q-factor obtained by pump 3.

The Average eye opening versus transmission distance at presence of nonlinearities is shown in figure 4.6(a). It is observed that by increasing the transmission distance from 40 to 200 km, eye opening is also minimum value. The variation in eye opening from different pumps at presence of nonlinearities is 0.640×10^{-03} to 0.265×10^{-03} for pump 1, 0.772×10^{-03} to 0.353×10^{-01} for pump 2, 0.700×10^{-03} to 0.147×10^{-03} for pump 3 and 0.695×10^{-03} to 0.196×10^{-03} for pump 4.



(a)



(b)

Figure 4.6 : Average Eye Opening vs Distance at (a) Presence of nonlinearities (b) Absence of nonlinearities

Figure 4.6(b) shows, The variation in eye opening at absence of nonlinearities is 0.640×10^{-03} to 0.183×10^{-03} for pump 1, 0.707×10^{-03} to 0.472×10^{-03} for pump 2, 0.736×10^{-03} to 0.419×10^{-03} for pump 3 and 0.697×10^{-03} to 0.278×10^{-03} for pump 4. It is observed from the simulation result that maximum eye opening value is obtained from pump 3 at presence and absence of nonlinearities.

Eye diagram of signal after pump 1 at 160 km distance with and without nonlinearities is shown in figure 4.7. The eye opening with and without nonlinearities is 2.85×10^{-04} and 2.35×10^{-04} respectively.

Eye diagram of signal after pump 2 at 160 km distance with and without nonlinearities is shown in figure 4.8. The eye opening with and without nonlinearities is 2.87×10^{-04} and 3.15×10^{-04} respectively.

Eye diagram of signal after pump 3 at 160 km distance with and without nonlinearities is shown in figure 4.9. The eye opening with and without nonlinearities is 3.42×10^{-04} and 3.51×10^{-04} respectively.

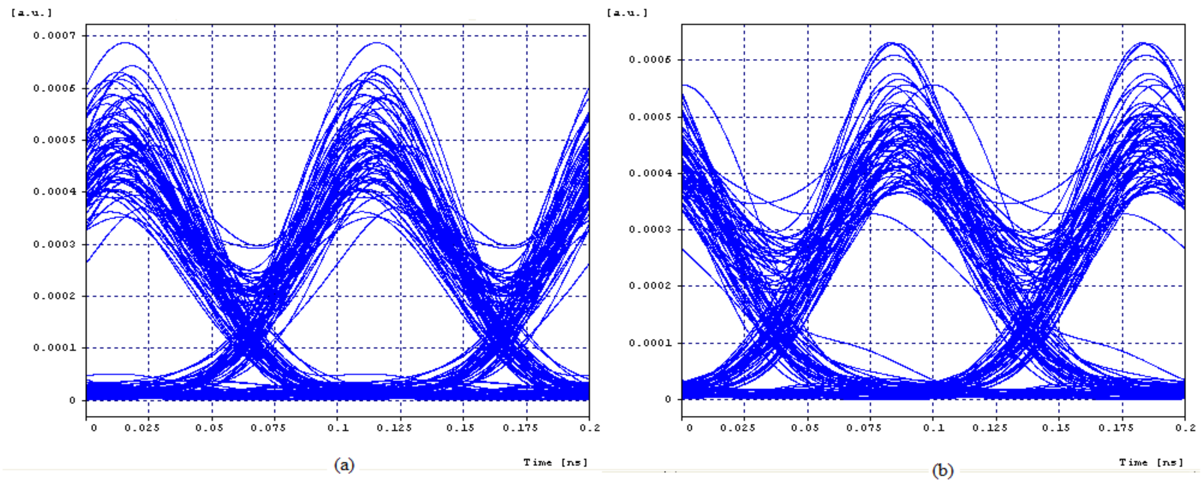


Figure 4.7 : Eye Diagram for Pump 1 at 160 km (a) Presence of nonlinearities (b) Absence of nonlinearities

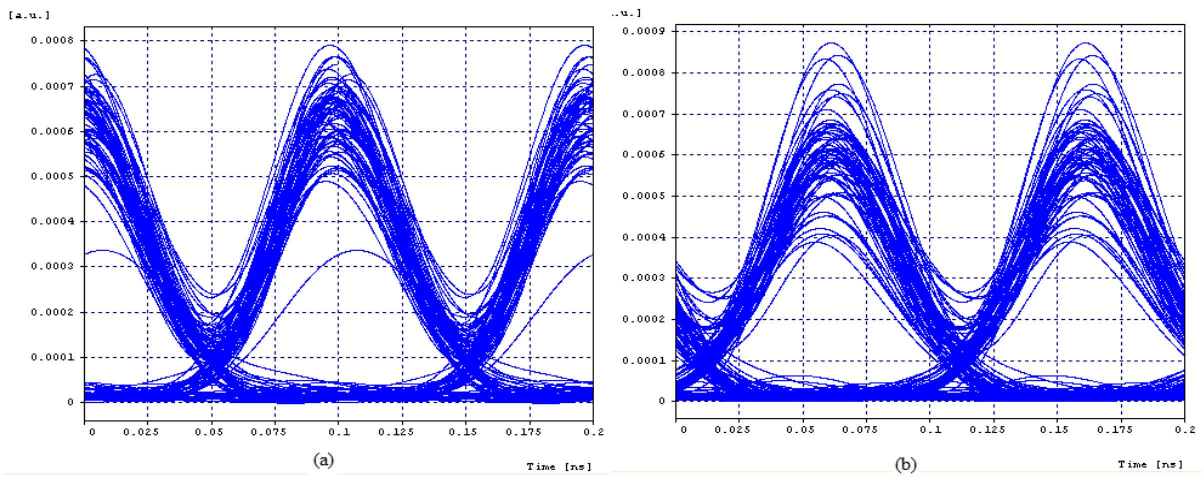


Figure 4.8 : Eye Diagram for Pump 2 at 160 km (a) Presence of nonlinearities (b) Absence of nonlinearities

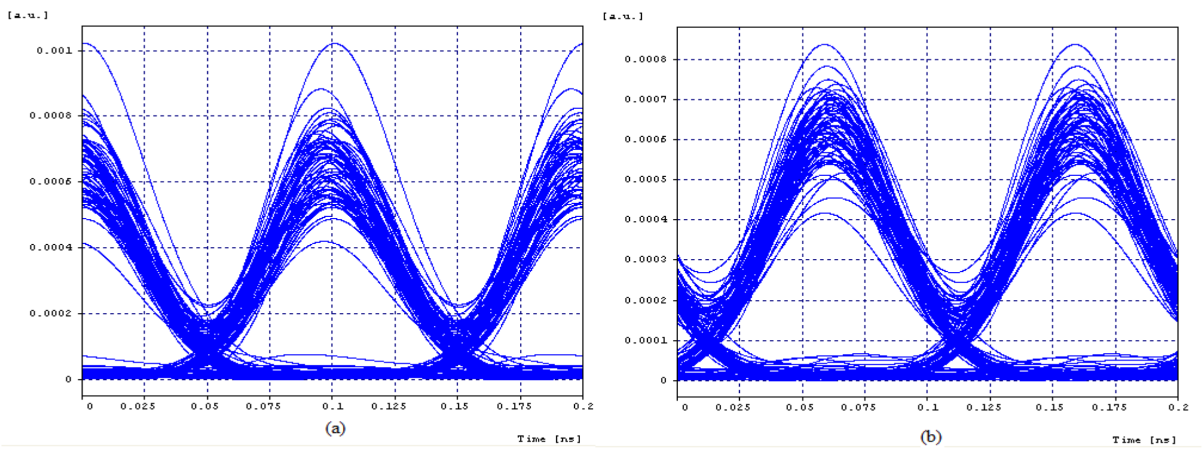


Figure 4.9 : Eye Diagram for Pump 3 at 160 km (a) Presence of nonlinearities (b) Absence of nonlinearities

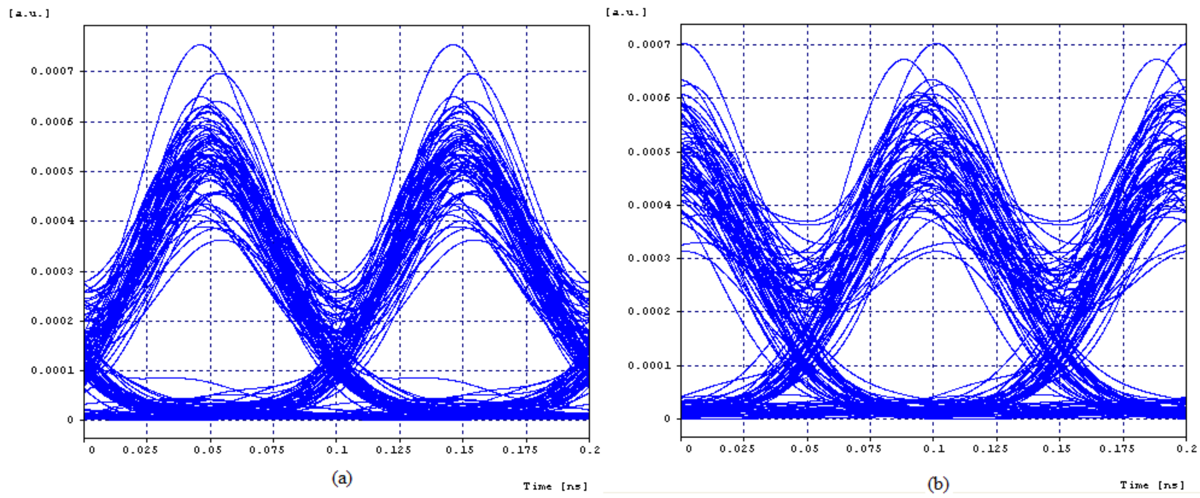


Figure 4.10 : Eye Diagram for Pump 4 at 160 km (a) Presence of nonlinearities (b) Absence of nonlinearities

Eye diagram of signal after pump 4 at 160 km distance with and without nonlinearities is shown in figure 4.10. The eye opening with and without nonlinearities is 2.91×10^{-04} and 2.71×10^{-04} respectively.

4.5 Conclusion

The hybrid optical amplifiers (RAMAN-EDFA) design model were successfully designed and implemented into OptSim. The main motivation of this work is to study the behaviour of nonlinearities in the fiber with the optical amplifiers for different pumping, raman fiber length and transmission distance.

The performance of RAMAN-EDFA HA is evaluated using the eye patterns, BER, average eye opening and Q-factor measurement. The simulation results have shown the variation in output power, BER, Q Factor and eye opening with respect to transmission distance and different pumping (Pump 1, Pump2, Pump 3, Pump 4). The variation in output power with presence and absence of nonlinearities is (10.01 to 10.66 dBm, 10.02 to 10.69 dBm) for pump 1, (10.01 to 10.05 dBm, 10.01 to 10.68 dBm) for pump 2 , (10.01 to 10.05 dBm 10.01 to 10.68 dBm) for pump 3 and for pump 4 is (10.01 to 10.62 dBm , 10.02 to 10.69dBm). The variation in Eye opening is (0.640×10^{-03} to 0.433×10^{-03}, 0.640×10^{-03} to 0.415×10^{-03}) for Pump 1, (0.722×10^{-03} to 0.591×10^{-03}, 0.717×10^{-03} to 0.556×10^{-03}) for Pump 2, (0.700×10^{-03} to 0.567×10^{-03}, 0.736×10^{-03} to 0.610×10^{-03}) to for Pump 3 and (0.695×10^{-03} to 0.484×10^{-03}, 0.697×10^{-03} to 0.476×10^{-03}) for Pump 4. The variation in BER is (1×10^{-40} to 0.410×10^{-10}, 1×10^{-40} to 0.855×10^{-10}) for pump 1, (1×10^{-40} to 0.140×10^{-10}, 1×10^{-40} to 0.277×10^{-07}) for pump 2, (1×10^{-40} to 0.888×10^{-08}, 1×10^{-40} to 0.213×10^{-11}) for pump 3 and (1×10^{-40} to $0,499 \times 10^{-12}$, 1×10^{-40} to 0.137×10^{-07})for pump 4. The variation in Q Factor is (30.38 to 14.58 dB, 37.71 to 15.61 dB) for pump 1, (30.06 to 15.42 dB to 37.97 to 14.76 dB) for pump 2, (29.18 to 14,98 dB to 37.11 to 16.78 dB) for pump 3 and (31.78 to 16.16 dB to 36.50 to 14.81 dB) for pump 4. This variation is acceptable upto 160 km transmission distance.

CHAPTER 5

Conclusion and Future scope

5.1 Conclusion

The main motivation of this work is to increase the long haul and ultra-broadband transmission distance, cascadability and flexibility of the optical networks. In order to achieve these goals, it is of utmost importance to optimize the optical hybrid amplifier and placement of optical amplifiers in optical communication systems and networks.

This thesis focuses on the investigation effect of the nonlinearities in the output characteristics when we increases the transmission distance. The performance of hybrid optical amplifiers was evaluated using the eye patterns, BER measurement, eye opening and Q factor. From the comparison of hybrid amplifier it is conceded that increasing the distance RAMAN-SOA and SOA-RAMAN-EDFA provide better result but after same range it degraded the performance because nonlinearities effect problem arises. It is observed that optical hybrid amplifier RAMAN-SOA and SOA-RAMAN-EDFA provides the highest output gain (24.56 dB and 27.31 dB) ,least bit error rate (1×10^{-40} and 1×10^{-40}) and good eye diagram at 160 km for presence and absence of nonlinearities as compare to other optical amplifier. These results are valid upto 160 Km. Above 160 km distance, there is more distortion in the detected signal. The output power, Q factor and eye opening are decreasing above this. Also, there is an increment in BER after 160 Km. So,This proposed model is best suited for 160 km distance.

The investigate RAMAN–EDFA with respect to pump system. The various results show that pump 3 gives the best performance up to 160 km at presence and absence of nonlinearities in comparison of all proposed pumps. The variation in output power is (10.01 to 10.66 dBm, 10.01 to 10.69 dBm) for pump 1 and for pump 2 is (10.01 to 10.65 dBm, 10.01 to 10.68 dBm,), for pump 3 is (10.02 to 10.64 dBm, 10.01 to 10.69 dBm) and for pump 4 is (10.01 to 10.66 and 10.01 to 10.67 dBm). The variation in Eye opening is (0.640×10^{-03} to 0.433×10^{-03}, 0.640×10^{-03} to 0.415×10^{-03}) for Pump 1, (0.722×10^{-03} to 0.591×10^{-03}, 0.717×10^{-03} to 0.557×10^{-03})for Pump 2, (0.700×10^{-03} to 0.567×10^{-03}, 0.736×10^{-03} to 0.610×10^{-03}) for Pump 3 and (0.695×10^{-03} to 0.484×10^{-03}, $0.697 \times 10^{-}$

^{03} to 0.476×10^{-03}) for Pump 4. The variation in BER is (1×10^{-40} to 1.01×10^{-40}, 1×10^{-40} to 0.855×10^{-10}) for ump 1, (1×10^{-40} to 0.999×10^{-40}, 1×10^{-40} to 0.277×10^{-07}) for pump 2,(1×10^{-40} to 0.888×10^{-08}, 1×10^{-40} to 0.013×10^{-11}) for pump 3 and (1×10^{-40} to 0.499×10^{-12}, 1×10^{-40} to 0.134×10^{-07}) for pump 4. The variation in Q Factor is (30.38 to 14.58 dB, 37.71 to 15.61 dB) for pump 1, (30.06 to 15.42 dB, 37.97 to 14.768 dB) for pump 2, (29.15 to 14.98 dB, 37.11 to 16.58 dB) for pump 3 and (31.78 to 16.16 dB, 37.50 to 14.58 dB) for pump 4. These variations are for presence and absence of nonlinearities acceptable upto 160 km transmission distance.

5.2 Future Scope

In this thesis, the hybrid optical amplifiers are used as in cascaded form and various combinations of EDFA, SOA, RAMAN. We can extend this work by using other gain media, including combination of RAMAN with fiber doped with different rare earths (e.g., Nd and Yb). There is need of detailed study for the XGM, XPM, and FWM in hybrid amplifier for multichannel WDM transmission system. The structural parameter optimization of hybrid amplifier is evaluated by reducing theses nonlinearities in doped fiber amplifiers for long haul WDM transmission at higher bit rate. The setup is demonstrated for transmission of 64-channel WDM system at 10 Gb/s channel data rate but this simulation can be implemented for increasing number of channel at very high data rate. The channel spacing is also a major concern. We can also investigate the system by changing the RAMAN and EDFA fiber length.

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