“Performance Analysis of Optical Amplifiers in Optical Communication Systems”

A Thesis

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

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in
Electronics and Communication Engineering

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ABSTRACT

Information revolution implies that multimedia networks need high bandwidth real-time communication services. At present, optical fiber is the only transmission medium offering such large bandwidth with low loss communication links. With growing transmission rates, electronic regeneration becomes more and more expensive. Optical amplifiers are in general bit rate transparent and can amplify signals at different wavelength simultaneously. Optical amplifiers are mainly of two types 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 wavelength converters are the key components for multi-wavelength optical transport networks and provide wavelength conversion in optical domain with out distortion of input signal. Wavelength converters increase the flexibility and capacity of networks for a fixed set of wavelength. The electro-optic converter is a straight forward solution for conversion, but electro-optic converter has limitations such as large power consumption and complexity. Wavelength conversions based on semiconductor optical amplifiers (SOAs) and semiconductor lasers have been focused on research interests during the last few years. Semiconductor optical amplifiers used in cross gain modulation mode (XGM), cross phase modulation (XGM) and four wave mixing (FWM) mode for wavelength conversions. It is reported earlier by some authors that all optical up conversion use cross gain modulation of the SOA with high conversion efficiency, but it requires a large input optical power to saturate the gain of the SOA. Extinction ratio degradation problem is also presented in the XGM scheme.

In this thesis, the simulation results of cross phase wavelength conversion in semiconductor optical amplifiers have been presented. The cross gain modulation scheme shows extinction ratio degradation for conversion to longer wavelengths and this can be overcome using cross phase modulation in semiconductor optical amplifiers that are integrated into interferometric structures

It is seen that the BER values is very high at low current but as we increase the bias current, BER value continuously falls. It is observed from the results that minimum BER

value comes out around 10^{-40} at power 0.35 mW. It's also evaluated from results that BER has minimum value around 10^{-40} at power 0.35 mW for 0.3 A value of bias current for up conversion. It is noticed from the results that minimum BER value comes out around 10^{-30} at power 0.3 mW. It is also evaluated from the results that minimum BER comes out around 10^{-100} at power 0.3 mW for down conversion.

Furthermore in this thesis we studied about the optical amplifier for Dense Wavelength Division Multiplexing (DWDM). Erbium Doped Fiber Amplifier (EDFA) is used in the optical communications technology at the standard telecornmunication wavelength of I550 nm. We studied the simulation effects of gain value with pump power and wavelength of amplifier has been presented. The results of the various configurations for gain spectrum with pump power of the EDFA are enumerated. Variation in the noise figure with pump power and EDFA length is also depicted in this study. In order to observe the performance of gain compensation of EDFA, gain of EDFA verses pump power is studied for different lengths of EDFA. It is also seen that maximum gain value is 18.88 dB for pump power 3 mW and the minimum noise figure value comes out 0.0079 dB at pump power 3 mW.

CERTIFICATE

I hereby certify that the work, which is being presented in the thesis, entitled **"Performance Analysis of Optical Amplifiers in Optical Communication Systems"** in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering at Electronics and Communication Engineering Department of Thapar Institute of Engineering and Technology (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Dr. R.S. Kaler
I have not submitted the matter presented in the thesis for the award of any other degree of this or any other university.

(Aman Sanghi)

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

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Aman Sanghi

(8044102)

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CHAPTER 1

OPTICAL AMPLIFIERS

1.1 Introduction

Information revolution implies that multimedia networks need for high bandwidth real-time communication services. At present, optical fiber is the only transmission medium offering such large bandwidth with low loss communication links. With growing transmission rates, electronic regeneration becomes more and more expensive. Optical amplifiers have really revolurized the field of fiber optics communication. Optical amplifiers are in general bit rate transparent and can amplify signals at different wavelength simultaneously. Optical amplifiers are mainly of two types i.e. Semiconductor optical amplifiers and Fiber amplifiers. These are further classified into traveling wave semiconductor optical amplifier, fabry-perot semiconductor optical amplifier, Erbium doped fiber amplifier, Raman & Brillouin fiber amplifiers.

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. $N_2 > N_1$, where N_1, N_2 is population density of lower and upper state. This condition is known as population inversion. This can be achieved by exciting electron into higher energy level by external source called pumping. Stimulated emission occur, when incident photon having energy $E = hc/\lambda$ interact with electron in upper energy state causing it return to lower state with creation of second photon, 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 µm, 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 are typically used in the following ways as shown in the fig 1.1,

- 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.

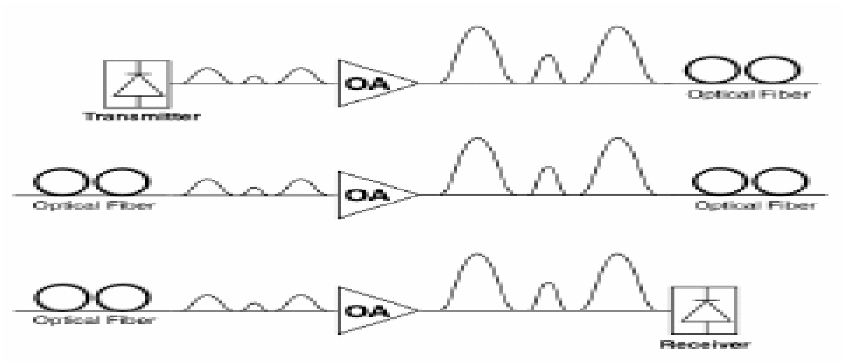


Fig 1.1 Optical Amplifiers (SOAs) applications.

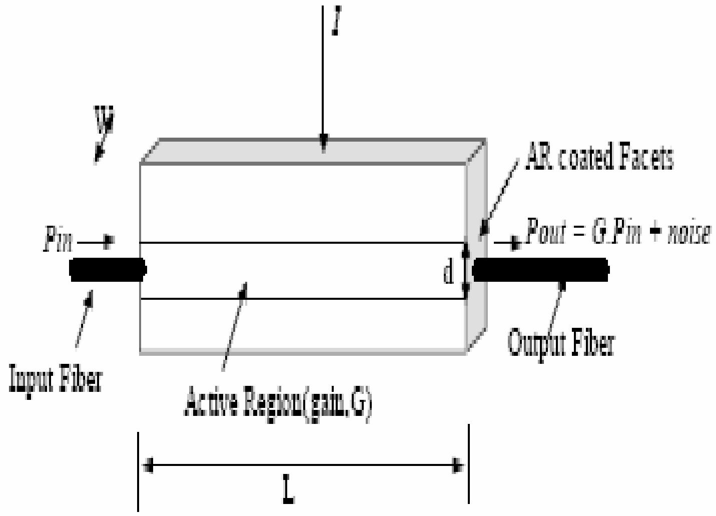


Fig 1.2 Semiconductor opticcal Amplifier

1.3.2 Fiber Amplifiers

Fibre amplifiers act as power amplifier, repeater, and a preamplifier. The gain medium comprises a length of single-mode fibre connected to WDM coupler, which provides low insertion loss at both, signal & pump wavelength. Excitation occurs through optical pumping laser combined with optical input signal within the coupler. Stimulated emission process occurred inside the fiber gain medium. The amplified optical signal is emitted from other end of fibre made from heavily doped ions depending upon type i.e. Rare-earth doped fibre amplifier, Raman fibre amplifier & Brillouin fibre amplifier.

1.3.2.1 Rare Earth Doped Fiber Amplifier

Different rare-earth ions, such as erbium, holmium, neodymium, praseodymium, thulium and ytterbium can be used to realize fiber amplifiers operating at different wavelength covering visible to infrared region. In rare earth doped fiber amplifier, erbium's dopant in silica based single mode fiber used, so called erbium doped fiber amplifier (EDFA). A piece of fiber gain medium as an active medium is heavily doped with ions of Erbium. In this, population inversion is stronger due to large number of erbium ions that fall to level *2* from various upper levels. When optical information pass through such populated erbium doped fiber, it would stimulate transition of erbium ions from level 2 to level 1 & generating photons of same wavelength with direction & phase as input photon . EDFA consists of three basic components: length of erbium doped fiber, pump laser and wavelength selective coupler to combine the signal and pump wavelengths. Optimum fiber length used depends upon pump power, input signal power, amount of erbium doping and pumping wavelength. The 980 nm wavelength with semiconductor laser pumping source has proved to be best in terms of efficiency (more than 10 dB gain per mw pump power) and better noise performance [2]. Typically noise figure lies between 4-5 dB and ή between 40-50% with forward pumping and equivalent figures for backward pumping are 6-7 dB and 60-70% assuming 1480 nm pumping light was used [3] .

In praseodymium-doped fluoride fiber amplifier similar to EDFA, But operated at 1300 nm with noise figure 3-5dB for best performance. Thulium-doped fiber amplifiers had extended transmission bandwidth of optical fibers beyond the range available from EDFA.

1.3.2.2 Raman Amplifiers

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 [4]. 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.

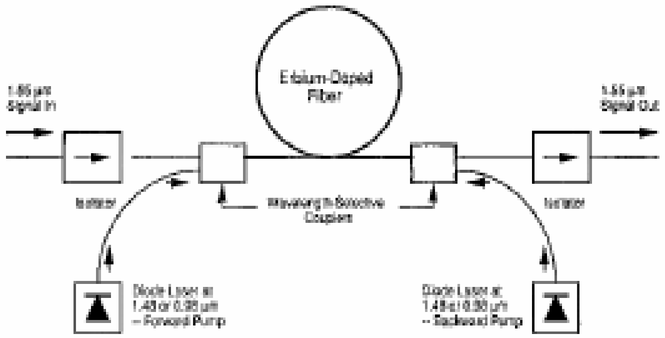


Fig .1.3 General Erbium-Doped Fiber Configuration

1.3.2.3 Brillouin Fiber Amplifier

The operating principle of this amplifier is same as Raman amplifiers except that optical gain is obtained by stimulated Brillouin scattering (SBS). In this, each pump photon creates signal photon and the remaining energy is used to excite an acoustic phonon. Amplification occurs only when the signal beam propagates in direction opposite to that of pump beam (backward pumping). Brillouin gain spectrum is extremely with bandwidth < 100MHz. The narrow bandwidth of this amplifier makes them less suitable as power amplifier, preamplifier or in-line amplifier in light wave systems. This amplifier used as channel selection by allowing amplification of a particular channel without boosting other nearby channels.

1.4 Optical Amplifiers Basic Parameters

Optical gain is the most important property of amplifiers. The two families of amplifiers discuss in this chapter, erbium doped devices and semiconductor-based devices, provide optical gain based on different but comparable interactions of light with matter. In erbium-based devices, light from a pump source elevates ions of the rare-Earth element erbium to an excited state (see Fig.1.5). Optical signals with wavelengths that fall within the gain spectrum of the erbium induce stimulated emission and are thereby amplified. In semiconductor devices, the energy levels of the erbium ion are replaced with the energy bands of the semiconductor crystal, but other than that the gain mechanism is similar. The semiconductor is brought into an excited state by pumping it electrically, populating the bands with electrons and holes. An optical signal propagating through the device gives rise to carrier recombination, and the associated stimulated emission amplifies the signal (see Fig. 1.6) Note that the device properties that are described in this paragraph apply to traditional optical amplifiers as well as amplets. After all, the characteristics distinguishing amplets from their larger cousins are not qualitative but rather quantitative.

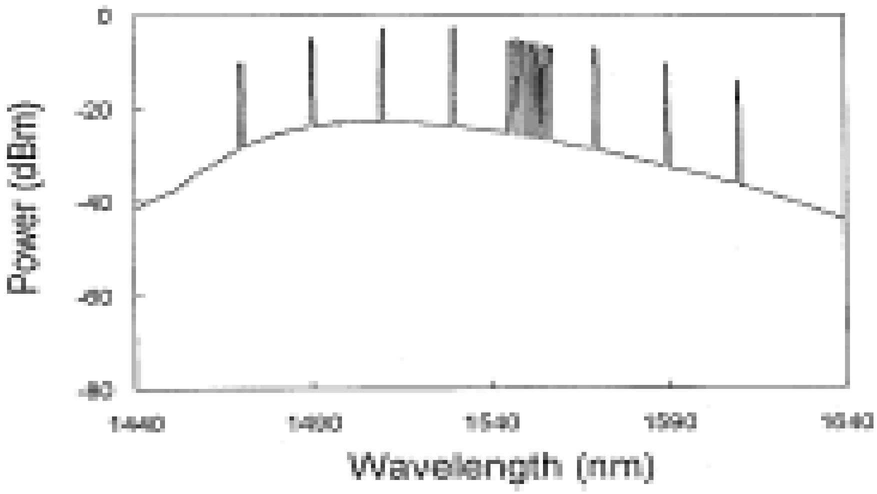


Fig 1.4 Output spectrum of a SOA amplifier

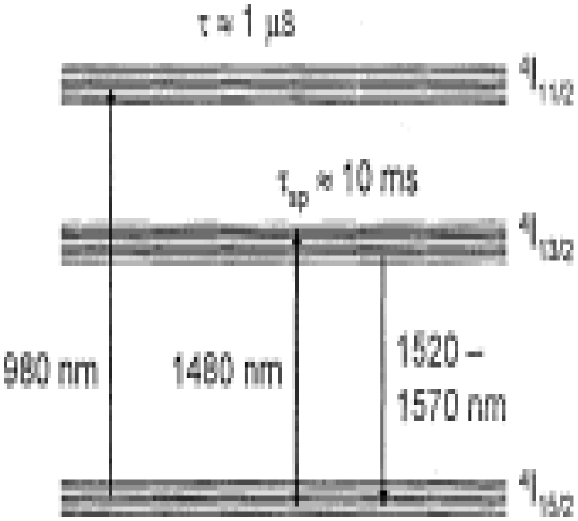


Fig.1.5 Energy level scheme of the Er^{++} ion.

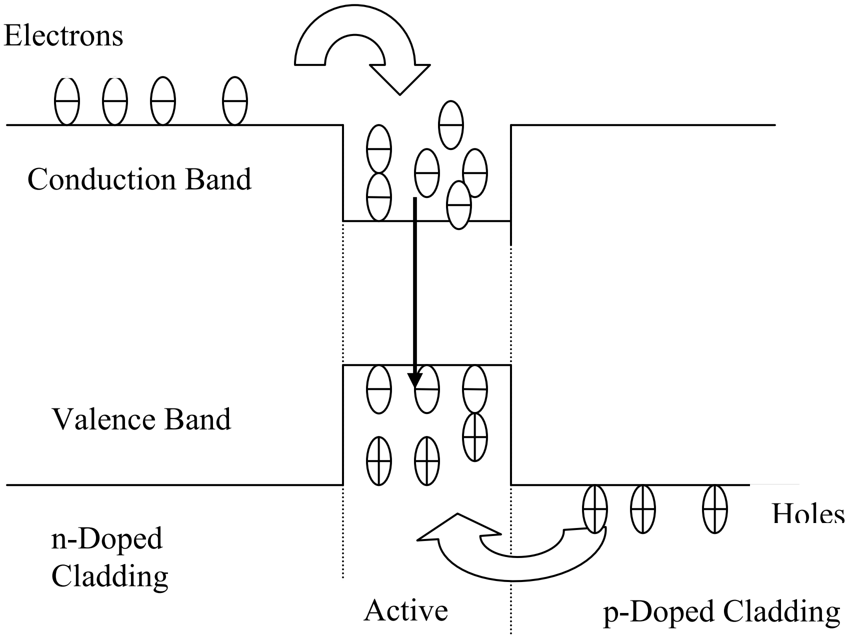


Fig 1.6 Carrier recombination in the active layer of a semiconductor amplifier.

1.4.1 Device Structure

In order to be amplified efficiently, the signal must propagate through the amplifier in a well-confined manner. Therefore, amplifiers are usually waveguides with gain. The EDFA is the most well-known example: a waveguide (the optical fiber) is heavily doped with erbium ions, which provide gain when optically excited by injection of pump light (Fig. 1.7). Erbium can also be implanted into a planar waveguide structure, forming an EDWA. Similarly, a SOA is formed by enclosing an amplifying active layer, usually indium gallium arsenide phosphide (InGaAsP) of an appropriate band gap, between cladding layers of lower refractive index, creating a waveguide structure [5]. Light is usually coupled into and out of it by means of lenses (see Fig. 1.8). The cladding layers of the SOA waveguide are p-and n-doped, respectively, allowing electrical pumping by current injection.

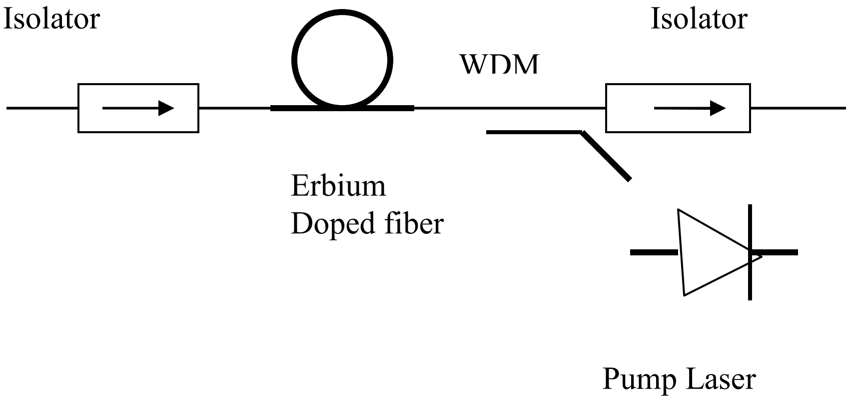


Fig 1.7 Basic EDFA configuration. A design with counter-propagating pump.

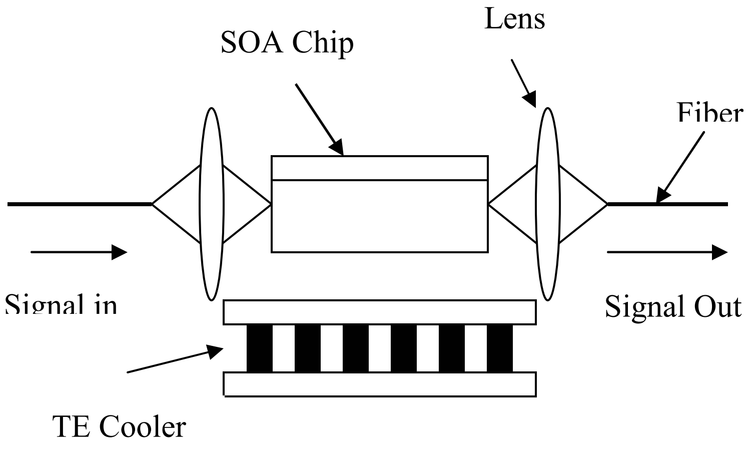


Fig. 1.8 Typical packaged SOA chip.

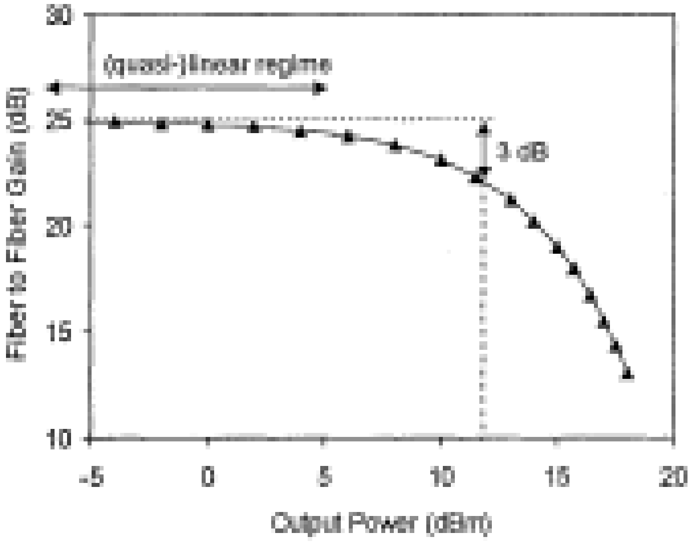


Fig.1.9 Typical gain versus output power curve of an optical amplifier.

1.4.2 Gain

The gain spectrum of the optical amplifier is determined by the energy levels of the erbium ion, or by the band gap of the semiconductor. The gain bandwidth of erbium extends from about 1525 to 1565 nm, covering a considerable part of the low-loss window of standard single-mode fiber. The spectral properties of a SOA are determined by the composition of the InGaAsP active layer, which can be varied to provide gain from 1200 to 1650 nm [6]. For a given composition, the gain bandwidth is about 80 nm. The gain spectrum is not the only difference between erbium and semiconductor devices. The lifetime of the excited state is another distinguishing characteristic. The excited state of erbium has an extremely long lifetime (10 ms), leading to slow gain dynamics. As a result, high-data rate signals do not cause any significant gain modulation even in deeply saturated amplifiers. In contrast, the carrier lifetime in a SOA typically is 100 s, i.e., of the order of the bit period in a 10-Gb/s modulated signal. Therefore, amplifying such a signal using a saturated SOA will normally lead to intersymbol interference (ISI). A third difference is the polarization dependence of the device. An erbium doped fiber has circular symmetry, and, therefore, the gain of an EDFA will exhibit negligible polarization dependence. EDFAs and SOAs based on asymmetric planar waveguides on the other hand may exhibit polarization-dependent gain. This is reduced to acceptable levels by proper waveguide design (EDFA) or by introducing crystal strain (SOA).

1.4.3 Output Power

An optical amplifier driven with lots of input power will saturate, i.e., its gain will drop from its small- signal gain value. The reason is that the power source of the amplifier, the number of excited erbium atoms or the number of available electron-hole pairs, is depleted. The saturation of an optical amplifier is usually referenced to the output power at which the gain has been compressed by 3 dB [7], as indicated in Fig. 1.9. An EDFA can be operated deeply in saturation (when the input power does not slowly vary, i.e., when the number of optical channels remains constant). A saturated SOA, on the other hand, may give rise to ISI and in WDM systems to interchannel crosstalk due to the fast gain dynamics. Therefore, operation of the SOA is usually restricted to the quasi-linear regime, and consequently it is more difficult to get high output power out of a SOA.

1.4.4 Noise Figure

Besides the stimulated emission that creates gain, the gain medium also produces spontaneous emission, which gives rise to the amplified spontaneous emission (ASE) spectrum of the amplifier. This ASE noise limits the optical signal-to-noise ratio (SNR) of a cascade of amplifiers and is quantified in the amplifier's noise figure (NF) [8]. This can be denoted as NF =2 n_{sp} / n_i in which $n_{sp} = N_2 / (N_2\text{-}N_1)$ is the inversion parameter of the amplifier (i.e., the degree of population inversion, with N1 and N2 the fractional number of erbium atoms or carriers in the ground and excited states, respectively), and this is the input coupling loss. Both well-designed EDFAs and SOAs have inversion factors close to unity, but the fiber-chip coupling loss of the SOA puts it at a disadvantage. EDFA noise figures typically are 4–6 dB, while SOA noise figures are usually 6–8 dB.

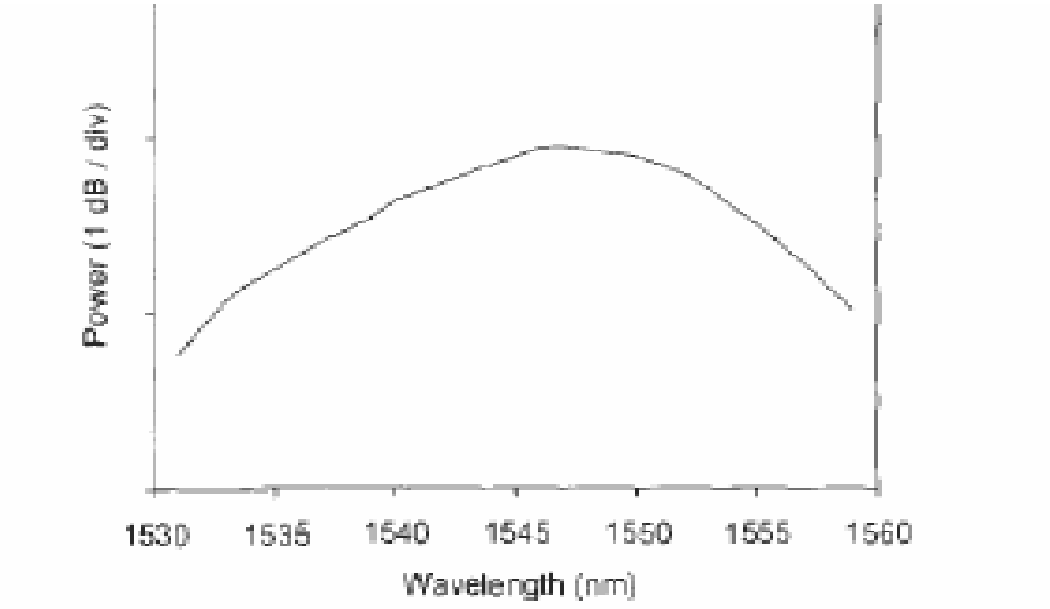


Fig 1.10 Type ASE spectrum of SOA

1.4.5 Gain Ripple

Different phenomena are denoted by the term gain ripple in EDFAs and in SOAs. Gain ripple in an EDFA refers to the shape of the gain spectrum which is determined by the wavelength- dependent emission and absorption coefficients of the erbium- doped fiber, weighed by the fractional populations of the excited and ground states of the erbium. Gain flattening filters are sometimes used to reduce this gain ripple. If channel loading or input levels are changed from their design center, inversion variation and spectral hole burning will affect the gain flatness of an EDFA. In-line attenuators are often used in DWDM line amplifiers to control the inversion and fix the erbium gain, thus, controlling the spectral tilt [8]. This degree of control is seldom used in amplifiers applications due to its added cost and complexity. The overall gain spectrum of a SOA is determined by the semiconductor bands, and has a smooth parabolic shape without the excursions seen in an EDFA gain shape. However, SOAs are extremely short devices (1 mm, compared to many meters for an EDFA), so that reflections at the end facets can give rise to round-trip resonances that lead to a ripple with a period of a few tenths of nanometers in the wavelength domain. With countermeasures like antireflection coatings and angled facets, the magnitude of this gain ripple can be reduced to 0.1 dB

1.5 SOA Design, Technology and Device Physics

SOA device design is similar to semiconductor laser design. The typical SOA is an MOCVD-grown layer structure consisting of an active layer sandwiched between p- and n-doped cladding layers which allow current injection. Lateral optical confinement is accomplished by etching a mesa, which is overgrown with a current blocking structure, which can be semi-insulating INP or a diode structure in reverse direction. As aforementioned, a SOA is supposed to deliver gain in a *traveling-wave* fashion [9-10]. Unlike a laser structure, that depends on facet reflections in a SOA reflections must be avoided as much as possible, which usually leads to an implementation with an angled gain stripe and facet antireflection coatings. Another important difference is that a laser emits in one (usually TE) polarization, while a SOA should amplify incoming signals independent of their polarization. This is accomplished by tuning the geometry and composition of the active layer. In particular, the type and amount of crystal strain has a large influence: Compressive strain leads to TE amplification, while a tensile strained layer mainly amplifies TM-polarized light. Careful tuning of the strain in alternating tensile and compressive quantum wells, or control of the amount oftensile strain in quantum wells or in a bulk active layer, can deliver mall (0.2 dB) polarization dependence.

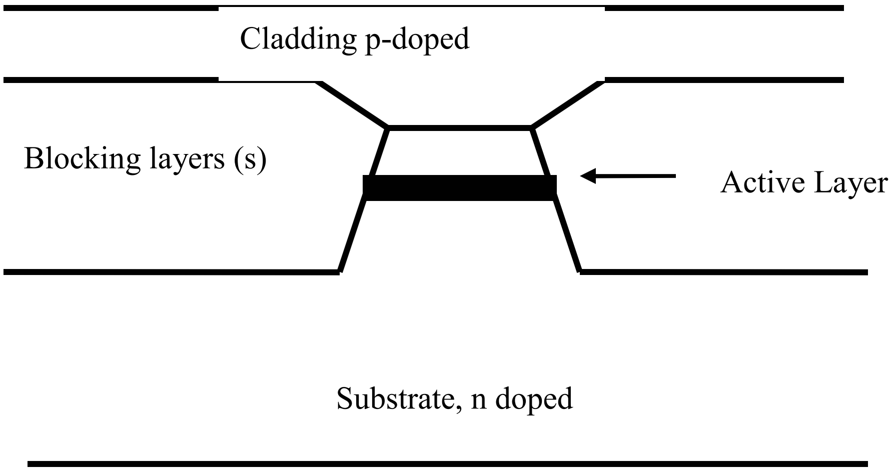


Fig 1.11 SOA device structure. Mesa, blocking layers, and cladding are often grown in three separate MOCVD runs

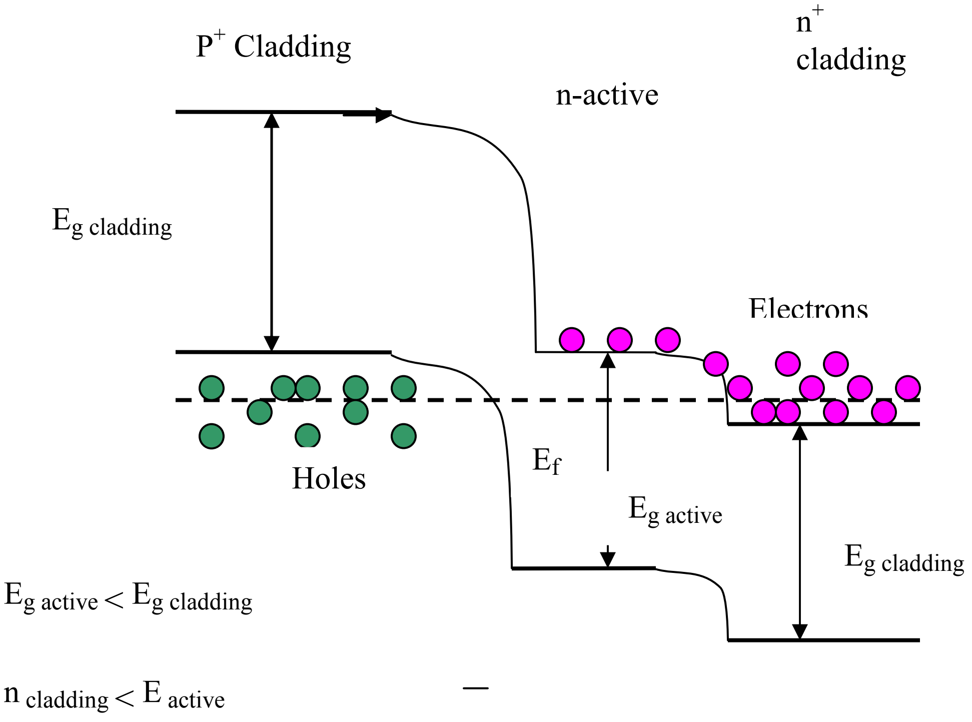


Fig.1.12 n doped region between two degenerated regions (n and p doped) at equilibrium.

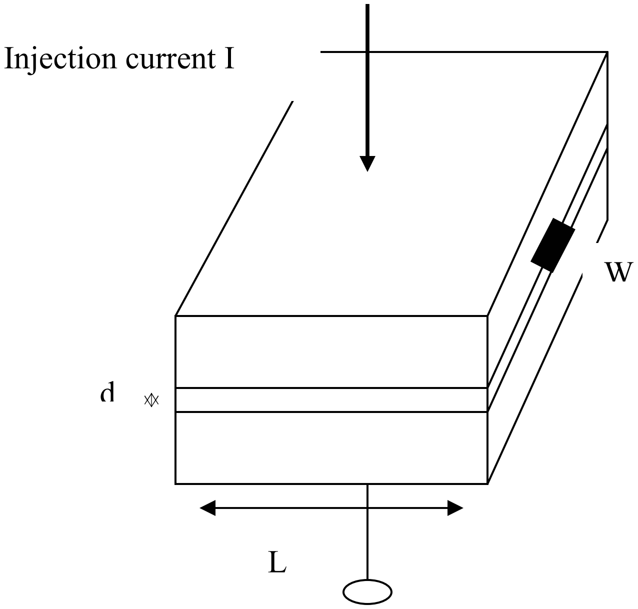


Fig 1.13 Example of SOA laser

1.6 Output Power and Gain Dynamics

The output power of a SOA is reported in terms of its P_{sat}, the power at which the gain is compressed by 3 dB. The highest powers SOAs that have been reported to date possess P_{sat} values of 17 dBm. For a single- polarization device, a value of 20 dBm has been reported. It must be noted that in amplification applications, the SOA can not be operated at its P_{sat}, since the fast gain dynamics of the device (carrier lifetime 100 ps) would cause its gain to be modulated by the bit pattern on the input signal [11]. Likewise, cross-gain modulation (XGM) will cause crosstalk in amplified WDM signals. When the device is operated in its nearly linear regime, the gain modulation is negligible and WDM operation is feasible.

1.7 Four-Wave Mixing

The phenomenon of four-wave mixing (FWM) occurs in the SOA as a result of intraband processes such as spectral whole burning and carrier heating. Compared to FWM in fiber, the interaction length in a SOA is so short that no walk off occurs between different wavelength signals, so the strength of the mixing products is solely determined by the power of the interacting signals ($P_{mix.}=P_1^2, P_2$) and by the FWM-efficiency, which strongly varies with the frequency spacing Δf of the interacting signals. The signals must be co polarized for FWM to occur. FWM mixing products appear one Δf above and below the interacting signals. In a WDM system, this usually means they interfere with other channel. Therefore, the power levels in a SOA- based WDM system must be controlled to minimize the occurrence of FWM [12]. Since the output power of the SOA must be confined to the (quasi) linear regime anyway to avoid XGM, this poses no additional limitation in WDM operation for current generation devices. However, in future higher power SOAs, FWM and not XGM may be the limiting phenomenon when designing the system power map.

1.8 Comparison between Optical Amplifiers

For SOAs and EDFAs gain are greater than 20dB, while for Raman fiber amplifiers gain is restricted to lower values. The SOAs need an electrical bias supply at levels of around 50mA, while the supply requirement is much more stringent in Erbium and Raman fiber amplifiers because of the high power pump laser requirement [13-14]. The difference in signal and pump frequency (stokes shift) for SBS (Brillouin amplifiers) is smaller by three order of magnitudes compared with SRS (Raman amplifier) .Inter modulation distortion and saturation induced crosstalk in WDM systems is negligible small in fiber amplifiers as compared to SOAs. The comparison characteristic & main features of optical amplifiers are given in table 1.1

Table 1.1 Comparison of Optical Amplifiers (NA: not applicable)

Property	**SOA**	**EDFA**	**Raman Amplifiers**	**Brillouin Amplifier**
Unsaturated device gain	>20dB	>20dB	5 - 15dB	>25dB
Optical pump power	NA	20 – 50mW	100 – 200mW	<10mW
Optical pump Wavelength	NA	820nm, 980nm 1400 – 1500nm	Stokes shift below signal	
Electrical bias current	50mA	>100mA	>500mA	<50mA
Wavelength of operation	any	1525 – 1565nm	Any, but subject to pump	
Bandwidth	20 – 50nm	10 – 40nm	20 – 40nm	0.001nm
Coupling loss	5 – 6dB	<1dB	<1dB	<1dB
Polarization sensitivity	> few dB	0dB	0dB	0dB
Saturated output	> few mW	few mW	Limited only by pump power	
Directions	bidirectional	bidirectional	bidirectional	unidirectional
Noise	low	low	Very low	Very low

1.9 OptSim Brief Introductions

OptSim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications. It can be used to design optical communication systems and simulate them to determine their performance given various component parameters. OptSim is designed to combine the greatest accuracy and modeling power with ease of use on both Windows and UNIX platforms. It includes the most advanced component models and simulation algorithms, validated and used for research documented in numerous peer reviewed professional publications, to guarantee the highest possible accuracy and real-world results. Many of these publications are listed and available on RSoft Design Group's website at www.rsoftdesign.com from a link on the OptSim page. OptSim represents an optical communication system as an interconnected set of blocks, with each block representing a component or subsystem in the communication system. As physical signals are passed between components in a real world communication system, “signal” data is passed between component models in the OptSim simulation. Each block is simulated independently using the parameters specified by the user for that block and the signal information passed into it from other blocks. This is known as a block-oriented simulation methodology. These blocks are graphically represented as icons in OptSim. Internally, they are represented as data structures and sophisticated numerical algorithms.

1.10 Short Description of OptSim GUI Elements.

- **Title Bar**

The title bar at the top of the OptSim window displays the name of the project currently opened. All projects must have filenames, therefore OptSim always asks you for a project to open or a name and location to save a new project when it is created.

- **Menu Bar**

Directly below the title bar, the menu bar groups most OptSim commands into Windows- style pull-down menus. Clicking on a pull-down menu will display a list of related commands.

- **Tool Bar**

The tool bar directly below the menu bar groups a set of buttons that serve as shortcuts for the most frequently used commands in the menu bar for editing related functions. Placing the cursor over a tool bar button causes a light-background box (tool tip) to popup with the name of the command executed by the button.

- **Explorer**

The explorer module provides access to the models library, models palettes, favorite schematics, user library, compound components library, and more. It also allows user to view a list of recent models or to see a panned view of the schematic in the design area.

- **Design Area**

The design area (layout pane) is the area below the tool bars where you may create the graphical network representing your design (either a compound component or complete OptSim project). The grid shown in the figure may optionally be turned off or on by the user.

- **Run Tools Bar**

The run tools bar is a set of shortcut buttons for simulation run-related commands. It is located directly above the design area. Placing the cursor over a tool bar button causes a light-background box (tool tip) to pop up with the name of the command executed by the button.

- **Toolbox**

The toolbox is another set of shortcut buttons to access tools that are used in schematic drawing. These are not accessible from the menu. The toolbox is located on the left side of the design area. Placing the cursor over a tool bar button causes a light-background box (tool tip) to popup with the name of the command executed by the button.

- **Status Bar**

The status bar at the bottom of the OptSim window is used to provide explanations and context-sensitive information regarding the status of the simulation that is currently running or other general project related information.

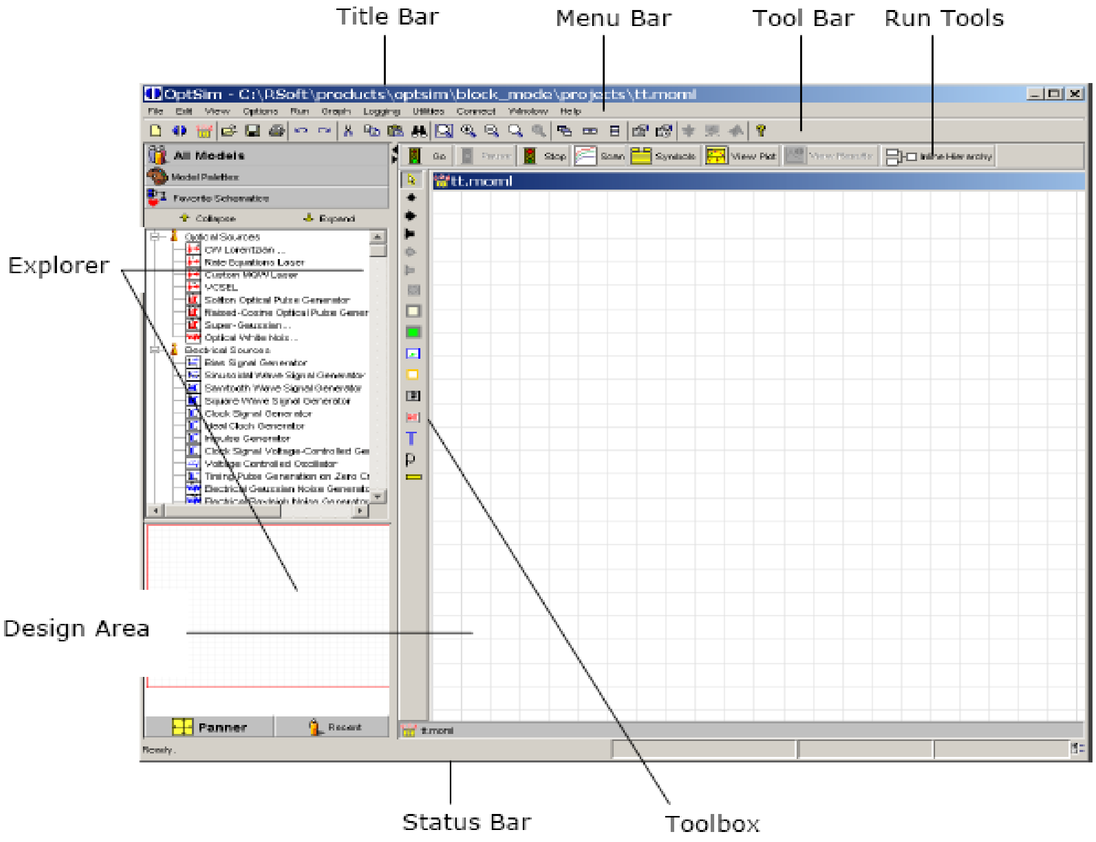


Fig.1.14 The OptSim graphical editor

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

All optical wavelength converters are expected to become key components in the future broadband net works. Their most important use will be for avoidance of wavelength blocking in optical cross connects in wavelength division multiplexed (WDM) networks, e.g., [15-18]. Thereby the converters increase the flexibility and the capacity of the network for a fixed set of wavelengths [19-20]. Equally important, the wavelength conversion function enables decentralized network management concerning the wavelength paths through the network and may facilitate easier protection switching [22-23]. The potential of wavelength converters has already been demonstrated in a number of system experiments.

Efficient optical space switches can also be constructed using tunable wavelength converters together with an array of fixed output filters. This application of converters has for example been employed for internal routing in a complex 2.5 Gb/s optical ATM switch block experiment [25].

Clearly, wavelength conversion is a very useful function in advanced optical systems. The requirements to the converters will be system dependent, but preferably the converters should feature the following

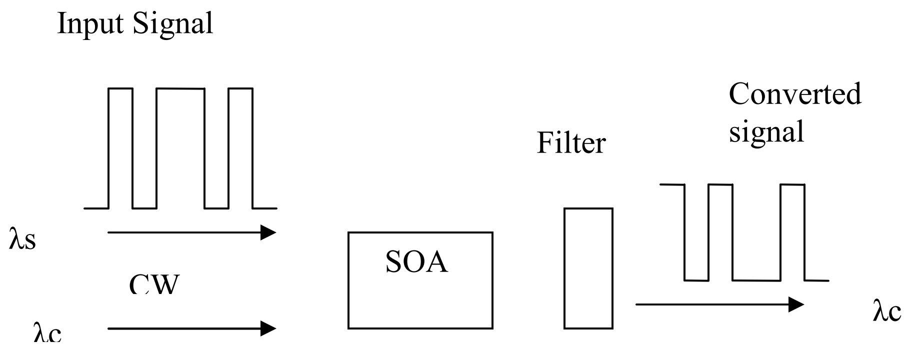
- Bit-rate transparency (up to at least 10 *Gb/s).*
- 1\0 extinction ratio degradation.
- High signal-to-noise ratio at the output (to ensure casead-ability).
- Moderate input power levels (~O dBm).
- Large wavelength span for both input and output signals.
- Possibility for same input and output wavelengths (no conversion).
- Low chirp.
- Fast setup time of output wavelength.
- Insensitivity to input signal polarization.

- Simple implementation.

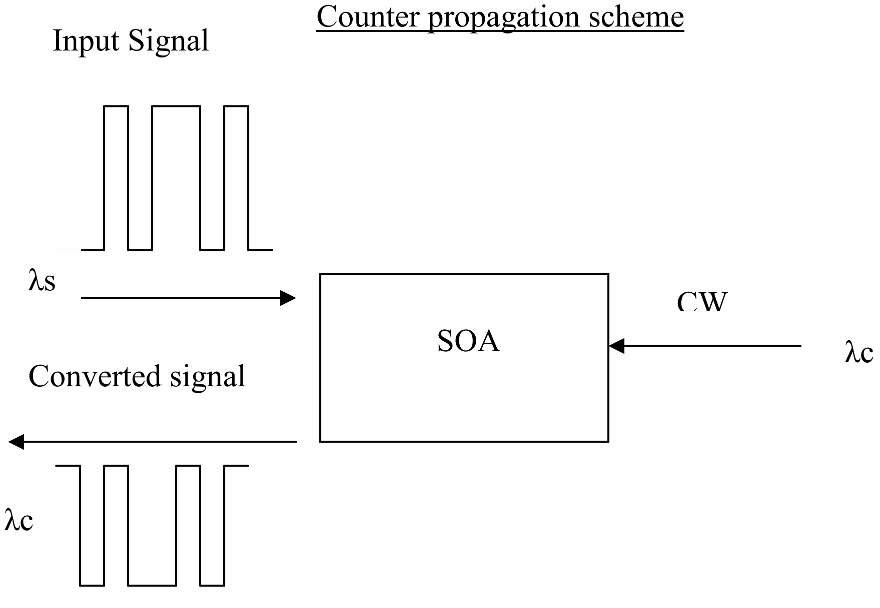
Several techniques have been proposed to achieve wavelength conversion. The straight forward solution is an electrooptic converter consisting of a detector followed by a laser that retransmits the incoming signal on the new wavelength. Disadvantages of the electro-optic converter such as complexity and large power consumption have, however, directed the interest to all optical wavelength converters. They enable direct translation of the information on the incoming wavelength to a new wavelength without entering the electrical domain. Examples of all optical wavelength converters are: Semiconductor optical amplifiers (SOAs) used in the cross gain modulation (XGM) mode [26-27] or the cross phase modulation (XPM) mode [13-15]; SOA's using four wave mixing (FWM) [16-19]; bistable lasers incorporating saturable absorbers [20-22]; injection locked Y-lasers [23-24]; and DBR lasers relying on optical frequency or intensity modulation [25-27]. Wavelength conversion based on four-wave-mixing in optical fibers [28] and quasi phase matching in $LiNb0_3$ waveguides [29], but the semiconductor based converters generally appear to be most efficient.

SOA converters using the XGM and the XPM conversion scheme presently seems to be well suited for system use. The important parameters such as input power levels, maximum bit-rate and wavelength dependency will be discussed. An explanation of the large bandwidth of SOA converters is also given based on modeling. Finally, transmission of wavelength converted signals is addressed.

Co propagation scheme



Counter propagation scheme



(a)

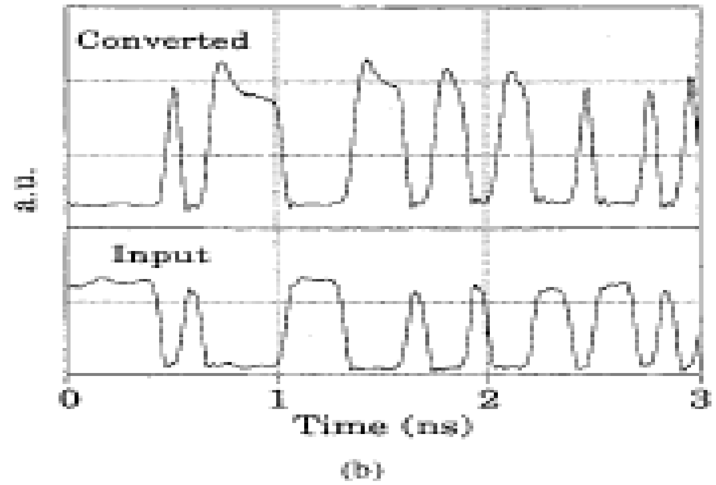


Fig.2.1. Schematic of the co- and counter-propagation XGM wavelength conversion principle (a) and measured waveforms for the converted signal (co-propagation) and the input signal at 10 Gb/*s* (b). The measurements are performed with a 1200 *pm* long SOA.

Another wavelength conversion technique is based on four wave mixing in SOA's as mentioned above. The scheme is attractive because of transparency to modulation format [34] as well as high bit rate capabilities [30]. Unfortunately the conversion efficiency for this scheme is not very high and it decreases swiftly with increasing conversion span. Consequently, it is difficult to retain a large signal to noise.

2.2 XGM SOA Converters

2.2.1 Basic Characteristics

An all optical wavelength converter is a device that transfers information from one wavelength to another without entering the electrical domain. A simple technique for the realization of this function is the use of cross gain modulation (XGM) in semiconductor optical amplifiers (SOA's). The principle is depicted in Fig 2.l (a) showing an intensity modulated input signal that modulates the gain in the SOA due to gain saturation. A CW signal at the desired output wavelength is modulated by the gain variation, so after the SOA it carries the same information as the intensity modulated input signal. As shown the input signal and the CW signal can be launched either co- or counter directional into the SOA. In the latter case the output filter that is needed for the co-propagation scheme can be avoided and it is possible to convert to the same wavelength.

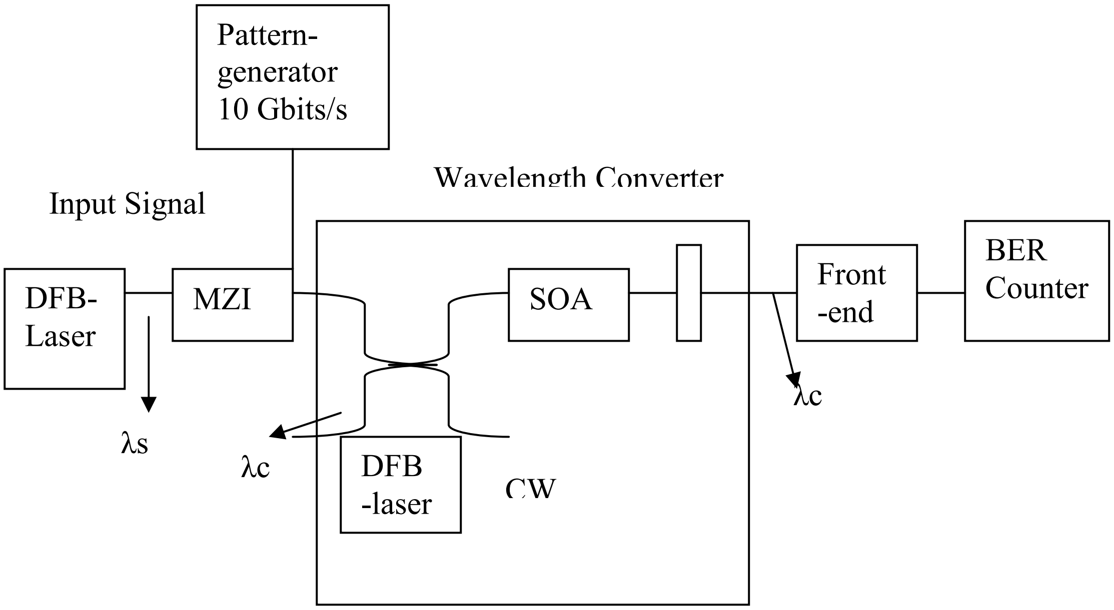


Fig 2 2.Setup for assessment of the performance for XGM SOA wavelength converters.

The XGM SOA converter is polarization independent if SOA's with a polarization independent gain are employed. Such amplifiers with high fiber-to-fiber gain are now fabricated in many laboratories [31]. Fig.2.l (b) gives an example of measured waveforms for input- and converted-signals at 10 Gb/s. As noted the XGM scheme gives a wavelength converted signal that is inverted compared to the input signal.

The influence of the dimensions of the amplifier on the converter performance is very important. The amplifiers that are fabricated by Alcatel Alsthom Recherche have buried active waveguides with tapers at the facets and give polarization insensitive fiber-to-fiber gains as high as 28 dB [31].

There are two reasons for the difference in conversion performance for the different cavity lengths. The first is the superior dynamic performance of the long SOA. The second is attributed to the difference in the optical bandwidth for the two amplifiers. The optical bandwidth of the long amplifier is only 30 nm whereas it is 60 nrn for the short amplifier. Therefore, a larger extinction ratio of the converted signal is expected for the long SOA since a smaller bandwidth gives larger differential gain at the short wavelength side of the gain peak.

2.2.2 Bandwidth of SOA Converters

The wavelength converters will be employed in high speed networks and must be able to handle signal bit rates of 10 G*b/s* and even higher bit rates can be foreseen in the future. Therefore a good understanding of the bandwidth limitations is important Both the XGM and XPM wavelength conversion schemes rely on inter-hand recombination, so the conversion speed is determined by the carrier dynamics.

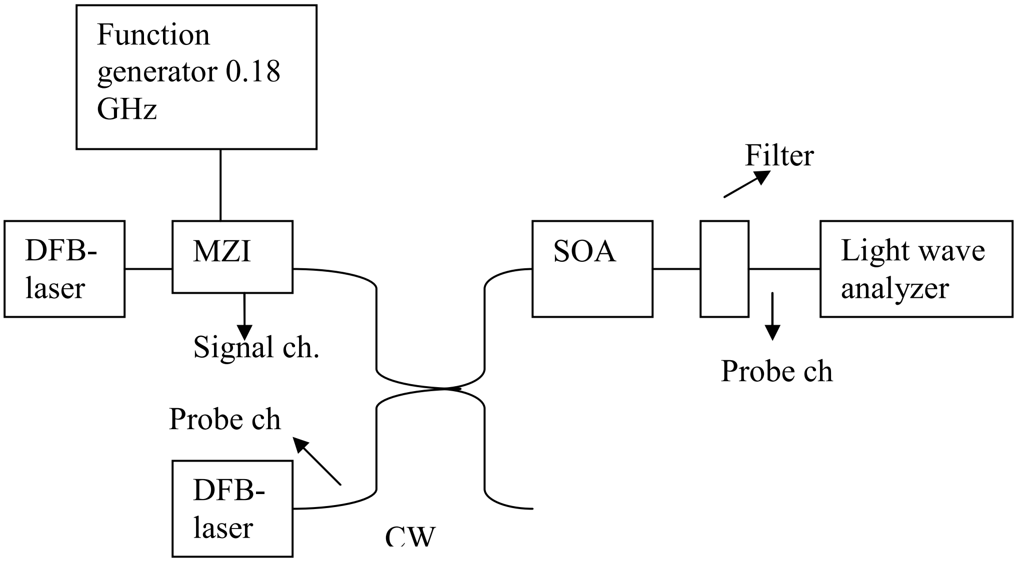
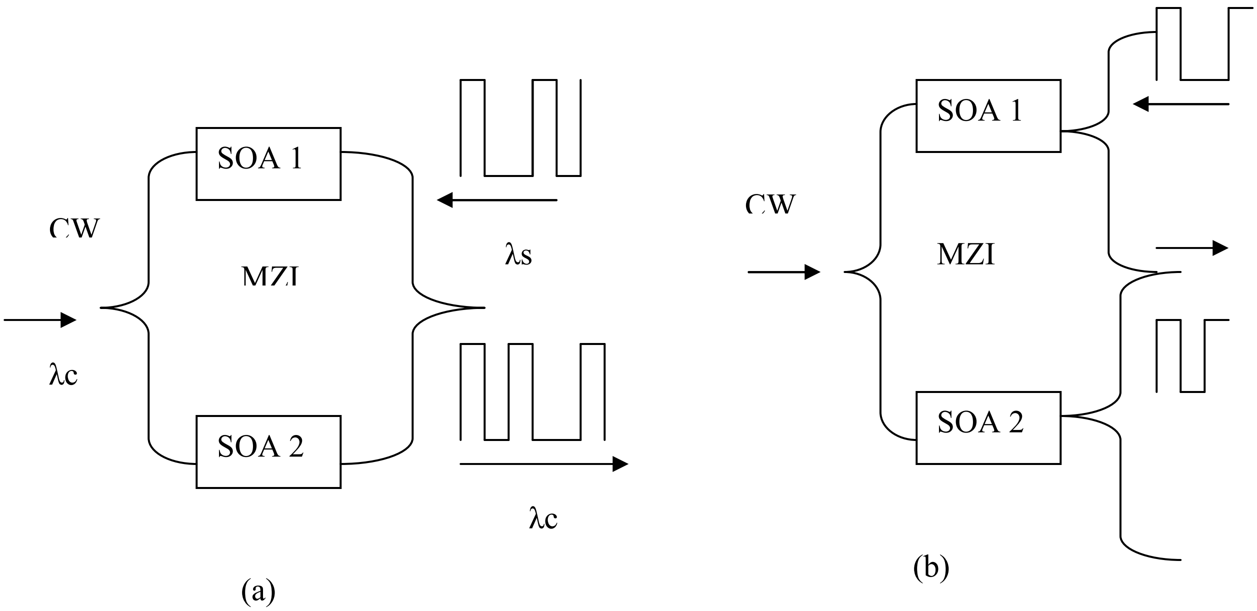


Fig 2.3. Block Diagram for measuring the small signal response or SOA’s.

The large modulation bandwidths cannot be accounted for by the simple low pass transfer function determined by the effective carrier lifetime [35]. The evolution of input signal and probe as they propagate through the amplifier has to be accounted for: Due to saturation, the low frequencies of the input signal will be filtered away as the signal propagates through the amplifier. Therefore, the modulation that is transferred to the probe signal in the rear part of the amplifier has a predominant high frequency content that equalizes the modulation experienced in the front part of the amplifier.

2.3 XPM SOA Converters

To overcome the problems with extinction ratio degradation for the XGM scheme, the SOA converter can be used in a cross phase modulation (XPM) mode [28-30]. The XPM scheme relies on the dependency of the refractive index on the carrier density in the active region of the SOA. An incoming signal that depletes the carrier density will modulate the refractive index and thereby result in phase modulation of a CW signal (wavelength λc) coupled into the converter. The phase modulated CW signal can be demultiplexed after the converter [31] or even better the SOA can be integrated into an interferometer so that intensity modulated signal format results at the output of the converter. Nonlinear loop mirrors [30], Mach-Zehnder interferometers (MZI) [28-34] and Michelson interferometers (MI) [32-35] have been proposed.



(a)

(b)

Fig 2.4 Schematic and principle of operation for interferometric wavelength converters based on XPM in SOAs. (a) Asymmetric MZI wavelength converter. (b) Symmetric MZI converter with additional coupler for the input signal.

The XPM scheme has the distinct feature that the converted signal can be either inverted or noninverted compared to the input signal depending on the slope of the demultiplexer (e.g., the interferometer slope used in the Mach-Zehnder configuration). Normally, it is advantageous for the converted signal to be noninverted (same polarity). Note that for the XGM scheme discussed above converted signal is inverted as seen from

Because of the small gain modulation the XPM scheme offers converted signals Fig. 2.1 (b). with a narrow spectrum compared to the XGM scheme. A narrow spectrum for the converted signal is attractive because it allows transmission over long distances. Moreover, the spectral crosstalk is reduced in WDM demultiplexers.

As an example, structures for Mach-Zehnder interferometric converters are shown in Fig. 2.4. The *SO*As are placed in asymmetric configurations so that the phase change in the two amplifiers is different. As a consequence, the CW light is modulated according to the phase difference. In the first configuration in Fig.2.4 (a), asymmetric splitters ensure that an intensity dependent phase difference is achieved between the interferometer arms due to the different saturation of SOAI and SOA2. In the second configuration in Fig 2.4 (b), the MZI is formed by symmetric splitters and the input signal is fed to only one of the SOA's through an additional coupler. The saturation is asymmetric since the other SOA is not affected by the input signal power. The converter could also be constructed with only one amplifier in one of the interferometer arms [38], but this scheme gives less output power and will be sensitive to changes in the polarization of the CW signal

Besides wavelength conversion the interferometric SOA configurations are also very well suited for all optical demultiplexing [35-36]. Moreover, it should he noted that the converters also feature polarization conversion since an arbitrarily polarized input signal is converted to the polarization state of the CW-light source. This could be important for switch block applications where polarization sensitive components can be employed after the wavelength converters.

2.4 Monolithically Integrated MZI Wavelength Converter

Even though fine results have been achieved with interferometric converters assembled from discrete components, monolithic integration is necessary to ensure long term stability.

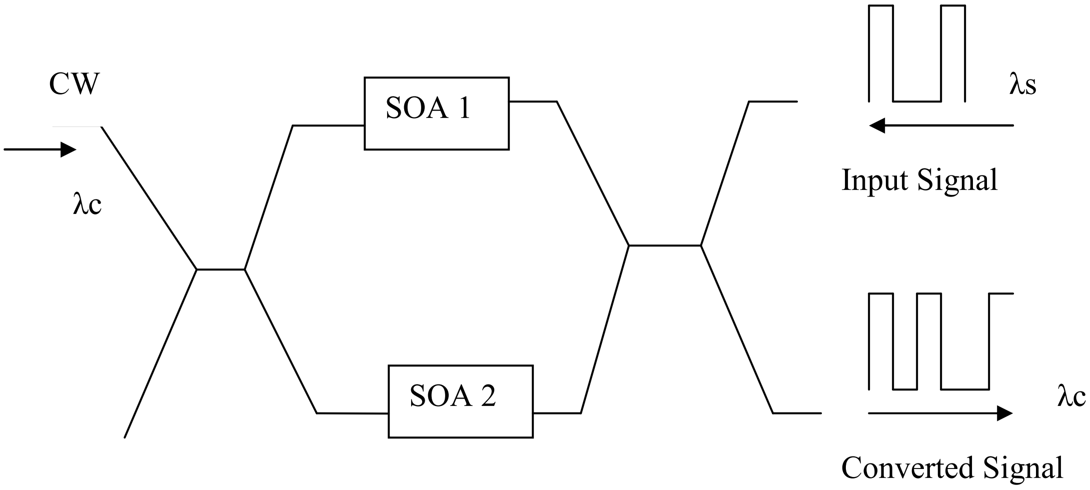


Fig.2.5. Schematic of monolithic integrated asymmetric MZI-SOA wavelength converter.

The interferometric transfer function is clearly observed by the periodical change in output power versus bias current, giving a ratio between constructive and destructive interference. The intensity dependent phase difference between the two MZI arms is achieved by the asymmetric power splitting (Fig.2.5) that gives asymmetric gain saturation of the SONs and thereby an increased phase difference with input power.

A CW signal at a chosen wavelength *(λc)* within the bandwidth of the SOAs is launched into the MZI (see Fig. 2.5) and will experience the phase modulation generated by the intensity modulated input signal (λs). This causes a modulation of the CW light according to the input signal. It should be noted that for the given biasing conditions the converted signal is noninverted relative to the input signal.

The wavelength dependency of the input signal and the CW signal is also an important issue. An ideal converter is expected to operate with equal performance at wavelengths within the EDFA window where it is likely that the future WDM systems will operate. The ability to convert the information to the same wavelength is an important feature for application in WDM switch blocks [35].

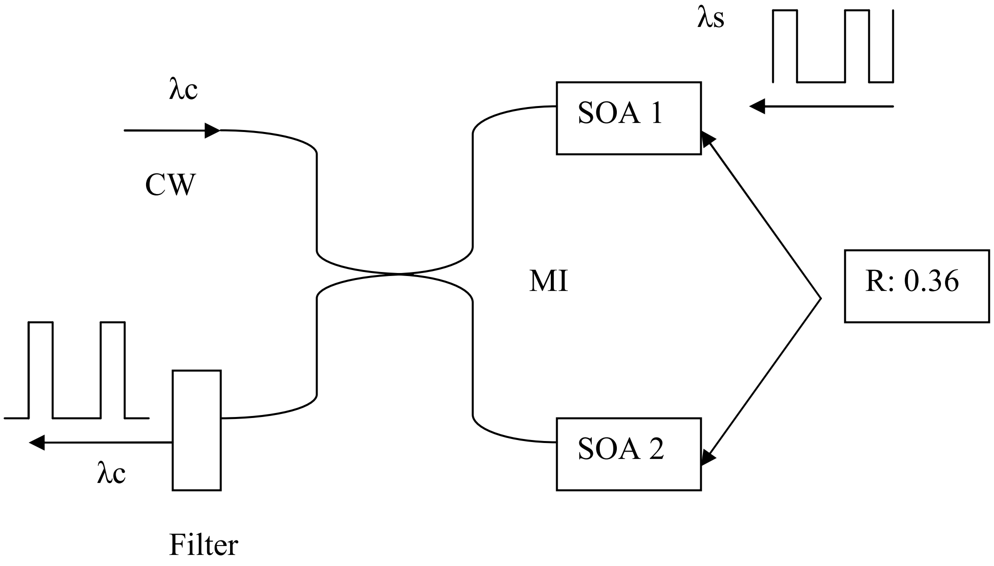


Fig.2.6.Conversion principle for the MI SOA wavelength converter

The MZ1 wavelength converter show good performance for both up and down-converted signals. This together with stable operation makes the integrated all optical MZI converter a strong candidate for the practical implementation of wavelength conversion in photonic switch fabrics. Additional important features for the interferometric converters are their ability to regenerate signals hath with respect to extinction ratio and spectral quality [34-36]. Similar to the MZI converter, the monolithically integrated Michelson interferometric SOA converter in Fig. 2.5 has shown excellent performance [35].

2.5 Gaps in present Study

- The draw back with the XGM conversion scheme is extinction ratio degradation for up-converted signals. This gives an excess penalty and limits cascadability of these converters.
- Semiconductors optical amplifiers have to be fully exploited for increased gain spectrum.
- There is need of work on L-band EDFA with reduction of crosstalk and gain improvement.

2.6 Objective of Studies

- To convert the wavelength for up and down conversion, in cross phase modulation-mach Zehnder configuration (XPM-MZI) mode.
- To optimize the bias current, average receiver power, and pump power in the SOA-MZI arrangements to achieve high signal-to-noise ratio. To investigate the BER and Q factor with variation of pump power, bias current and average receiver power.
- To investigate the optical amplifiers Erbium Doped Fiber Amplifier (EDFA) for effective performance.

2.7 Thesis organization

After carrying the introduction about optical amplifiers and literature review of all optical wavelength converters techniques of Semiconductor optical amplifiers (SOAs) in chapter I and II, the SOA technique has been discussed under the special case of cross phase modulation (XPM) mode in chapter III, which is followed by the simulation results on XPM wavelength converters for up and down converters. Then simulation results on Erbium Doped Fiber Amplifiers gain profile and nonlinearities have been covered in chapter IV and finally results have been concluded in chapter V.

CHAPTER 3

WAVELENGTH CONVERTERS BASED ON XPM

3.1 Abstract

Wavelength converter plays an important role for increasing the capacity and flexibility of future broadcast network. The XPM based converter has high conversion efficiency at low input power, in order to improve the efficiency and wideband conversion range, the XPM is increased by optimizing the SOA-MZI configuration. The XPM is improved by increasing the active region length and bias current of the SOA.

Wavelength converter based on cross-phase modulation is arranged as two semiconductor optical amplifier in Mach-Zehnder configuration. Performance characteristics are evaluated for NRZ signal at a bit rate of 10 Gb/s and converted signal power, BER are presented for different variable parameters in both up and down wavelength converter. Variation of average receiver power and input power can cause the BER performance and Q factor for both up and down wavelength converters. Variation of pump power and bias current with BER for up converter is also presented here. It is seen from the simulation results that the BER values is very high at low pump power but as we increase the input power from 0.1 mW to 0.001W, BER value continuously falls from input power 0.1 mW to 0.3 mW. The range of wavelength conversion can be increased by increasing the driving current and an optimum conversion performance can be achieved by choosing all suitable parameters.

Keywords: Semiconductor optical amplifier, Cross-phase modulation, Mach-Zehnder Interferometer, Bit Error Rate, Q factor, bias current.

3.2 Introduction

All optical wavelength converters are the key components for multi-wavelength optical transport network and are expected to provide wavelength conversion in optical domain with out significant distortion of the input signal [41].Wavelength converters offer the advantage of increased flexibility in wavelength routing and avoidance of wavelength blocking in a wavelength division multiplexing network node. As a consequence, the capacity of an optical multi-wavelength network can be considerably increased with the use of wavelength converters at different nodes [42-43].

To overcome the problems of XGM and FWM scheme, the SOA converters can be used in cross phase modulation (XPM) mode. The XPM scheme is based on the dependency of refractive index of the carrier density in the active region of the SOA [44-45-46]. Incoming signals deplete the carrier density and modulate the refractive index. Therefore phase modulation of a continuous wave (CW) signal couples into the converter. The phase modulated CW signal can be demultiplexed after the converter[47-48].

SOAs can be used for gating optical signals, i.e. signals can be either amplified or absorbed by SOAs. The blocking properties of SOAs at low bias currents are extremely useful because they enable channel routing functions, such as reconfigurable add/drop multiplexers (ROADM), to be produced with off-channel isolation better than 50 dB. Due to their nonlinear characteristics, SOAs can be used to convert an optical signal to another wavelength by Cross-Gain Modulation (XGM), Cross-Phase Modulation (XPM) or Four-Wave Mixing (FWM) to achieve all-optical cross-connects without OEO conversion. XPM can be used to provide 2R (re-amplification, pulse reshaping) or 3R (re-amplification, pulse reshaping and retiming) regenerations [55-56]. SOAs can provide a cost-effective solution that is physically small and has tremendous potential for integration with a wide variety of active and passive components

In this chapter, simulation approach is presented to find the performance of wave length conversion using cross phase modulation (XPM) in SOA pair configuration of an optical intensity modulation system. The converter is considered to be consisted of two semiconductor optical amplifiers arranged as Mach-Zehnder interferometer (MZI) configuration. The performance results are evaluated in terms of converted signal power, BER and Q actor due to wave length conversion and variation in input power, average receiver power, bias current. After giving the brief literature of SOA cross phase modulation technique we discuss about the simulation set up and parameters used for XPM-MZI configuration mode. The results are carried out on both up and down conversions, to determine the amount of changes in BER and Q with the variation of input power and average receiver power and then the variation of bias current and input power with BER is also presented here and finally the results have been concluded.

3.3 Simulation Setup and Parameters

In block diagram of fig 3.1, the signal with wavelength 1550 nm is send to lower port of SOA-MZI and the pump is applied at upper port with desired wavelength for up converter, which is required at the output. The same phase-change effect that creates pulse distortion in the cross-gain modulation can be used to create wavelength conversion. As the carrier density in the amplifier varies with the input signal, it produces a change in refractive index, which in turn modulates the phase of the probe [47-48]. This phase modulation can be converted into intensity modulation by using an interferometer such as a Mach-Zehnder interferometer (MZI). The upper semiconductor optical amplifier is represented by SOA_1 and lower is represented by SOA_2

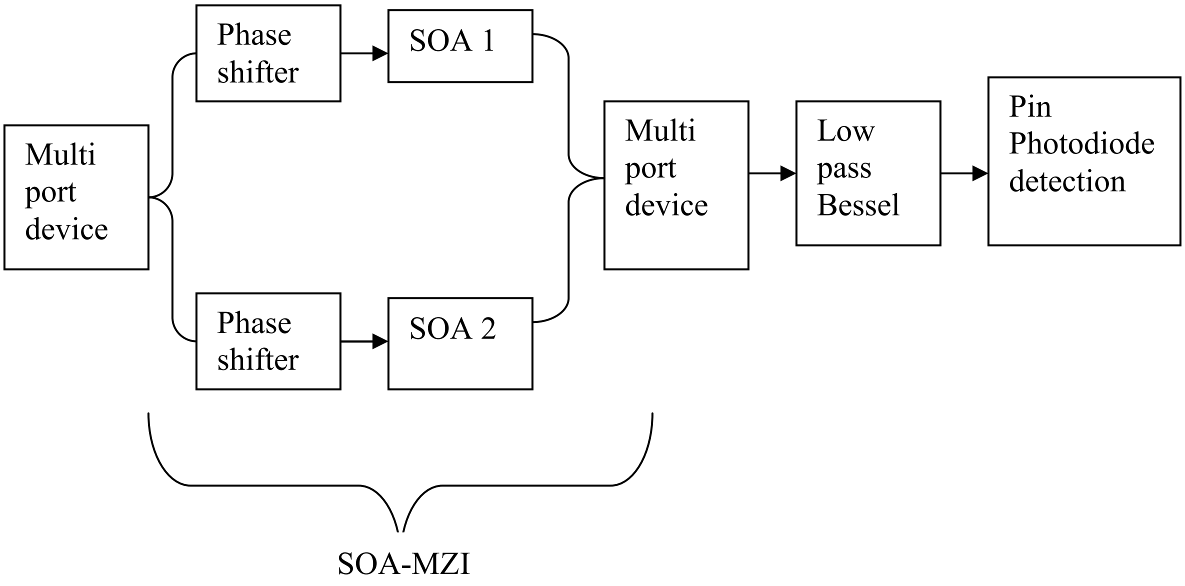


Fig3.1 Block diagram of wavelength converter based on cross phase modulation.

In the setup, shown in fig 3.2, firstly signal is generated with the help of PRBS generator (PRBS1), then it changes into the electrical signal with the help of electrical signal generator (siggen 1). The output from the electrical generator we can seen with the help of electrical signal analyzer (elecsig) The out put of the electrical signal generator is applied to the modulator (modulator 1). Here we use Mach-Zehnder type modulator. The output waveform of modulator can be seen with the help of modulator signal analyzer (modsig). The two multi-port devices (Multiport Dev 1,2) are used to set up the MZI configuration, one SOA in each arm of the MZI configuration. The upper semiconductor optical amplifier is represented by SOA_1(SOAT1) and lower is represented by SOA_2 (SOAT2). MZI can also transfer matrix data file for the multi-port device model. Actually the multi-port devices here can be easily replaced by optical couplers. The first multi-port device functions as a coupler, its transfer matrix data file name is multiport coupler. The second multi-port device functions as a summer; its transfer matrix data file name is multiport summer. We can find different coupling ratios in the two arms used, which will make the phase change in each amplifier different. Unlike in the cross-gain modulation wavelength conversion, in the cross-phase modulation wavelength conversion the added signal is in-phase with the original signal. In the two arms of the MZI, two optical phase shifters (PhaseShift1,2)are used to monitor the influence of the phases on the performance of the system though no phase shift was introduced in this setup. The output of the SOA-MZI is applied to the Fabry Perot filter (Filter1) with optimized bandwidth of 0.12 x 10^{-9}Hz, and then its output is detected by photo detector (Receiver 1) at converted wavelength. The output waveform of SOA1 can be seen with the help of SOA spectrum analyzer (soa_spectra) and out put waveform of SOA 2 can be seen with the help of signal plot (sigpit_3). We can see the output spectra waveform of filter with the help of filter spectrum analyzer (filter_spectra) and signal at the output port of receiver can be take with the help of signal receiver (recsig). Eye diagrams of the simulation result can be seen with the help of eye diagram analyzer (EyeDiag_1). Simulation results of BER and Q factor are easily seen with the BERT analyzer (BERT). The sensitivity of the receiver is -27 dBm and absorption coefficient 0.68 x10^6 luminous/m. The quantum efficiency of receiver is 0.8. The time domain simulation bandwidth is varied according to the conversion range. In up conversion input wavelength is taken as 1550 nm and converted wavelength chosen is 1555 nm for the validation of SOA_1. The spectrum waveform of converted wavelength is seen with the help of spectrum analyzer (SpecPit_3). The simulation is carried out at centre frequency of 193.THz for up converter. The receiver sensitivity is –25 dBm for 10^{-9} BER requirement. This sensitivity was achieved by adjusting the receiver parameters.

In the down conversion signal with wavelength 1553 m is send to lower port of SOA-MZI and the pump is applied at upper port with desired wavelength, which is required at the output. In the down conversion input wavelength is taken as 1553 nm and converted wavelength chosen is 1551 nm for the validation of SOA_1. The simulation is carried out at centre frequency of 193.1THz for down converter. The filter is used in down conversion is same with same bandwidth as used in up converter, and then its output is taken with photo detector at converted wavelength. The receiver sensitivity used is as almost same as used in up converter. In the down conversion the output spectrum of all components can easily seen as in the up converter.

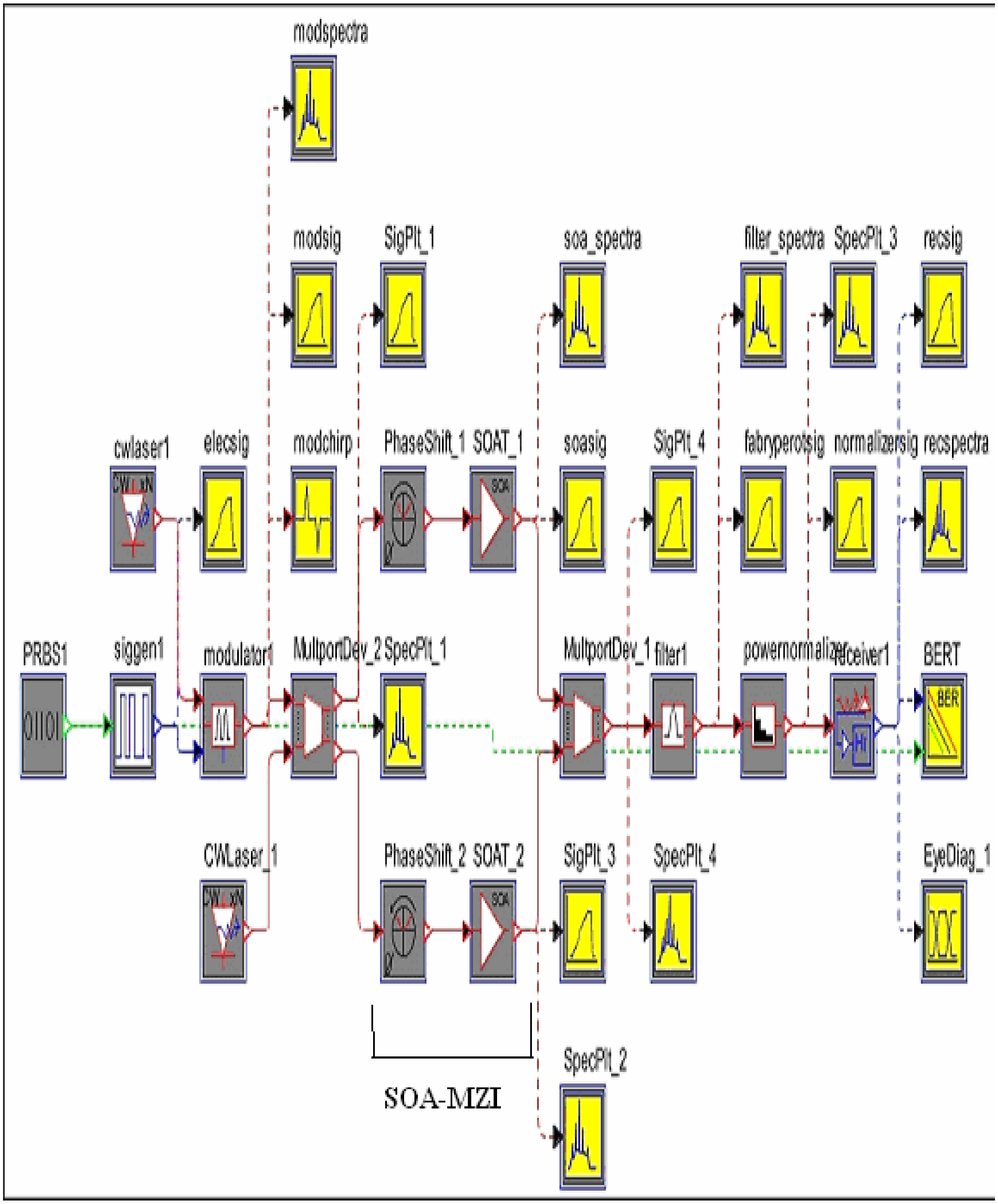


Fig.3.2 Simulation Setup of Wavelength Converters based on XPM for up and down conversion.

Table 3.1

Parameters of the SOA-MZI for Wavelength Converter Based on XPM of

Parameters	SOA1	SOA2
Bias current	.15 A	.18 A
Length of the active region	5.0e-4 m	5.0e-2 m
Width of the active region	3.0e-6 m	3.0e-6m
Thickness of the active region1	1.5e-7 µm	1.5e-7 m
Confinement factor	0.3	0.3
Carrier life time	0.19 ns	0.3 ns
Transparency carrier density	1.4 e24m^{-3}	1.4e24m^{-3}
Wavelength peak gain	1.55e-6	1.55e-6
Line enhancement factor	5.0	5.0
Internal Loss	1500.0m^{-1}	1500.0m^{-1}

Table 3.1 shows the optimized parameters of the SOA-MZI for wavelength up and down converters based on the XPM.

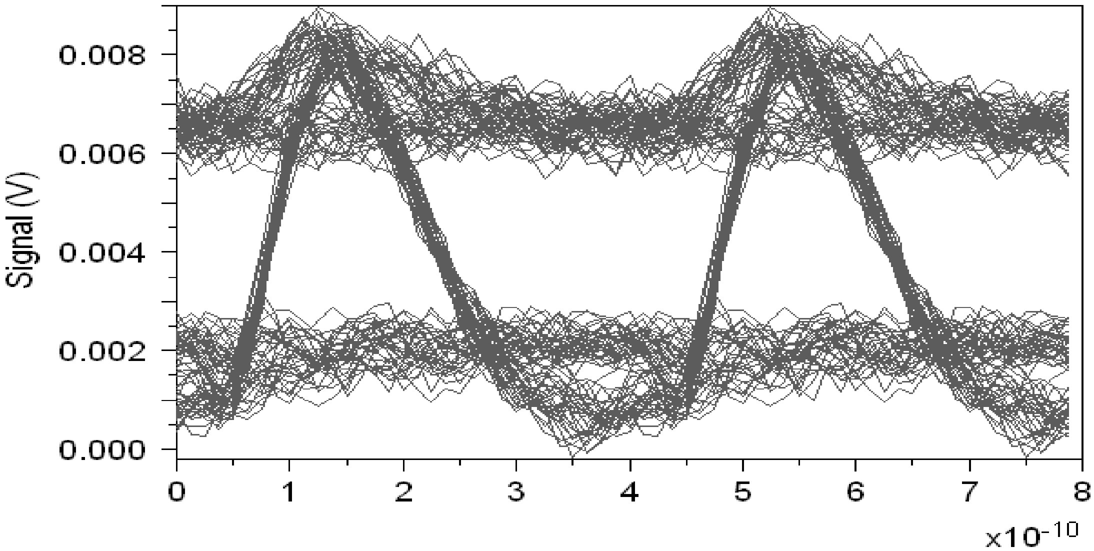
3.4 Results and Discussion

Results For UP conversions

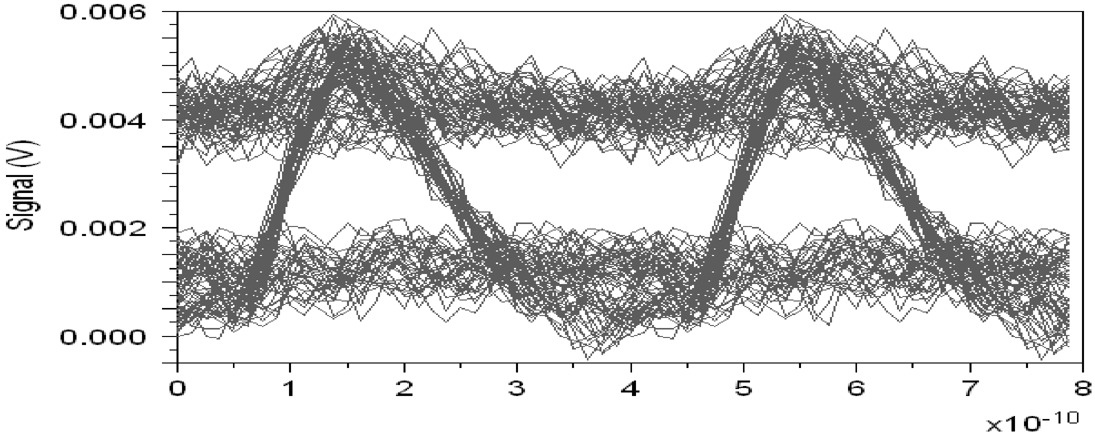
Results of eye diagrams for up conversion at different average receiver power are present in figure 3.3.

It is observed from the simulation results that the BER value continuously falls from input power 0.1 mW to 0.3 mW as shown in figure 3.4. It is seen from the simulation results that minimum BER value comes out around 10^{-30} at power 0.3 mW. The pump power changes from 0.1 mW to 0.001 W with increment of 0.25 mW. It is seen from the simulation results as we increase average receiver power changes from -23 dBm to -19 dBm with increment of -1 dBm, BER value decreases as shown in fig 3.4. It is also seen that the value of Q factor remains same with the same variation in the input power and average receiver power as shown in figure 3.5. It is concluded from the above results that BER has minimum value around 10^{-30} at power 0 .35 mW when the average receiver power is increases from -23 dBm to -19 dBm.

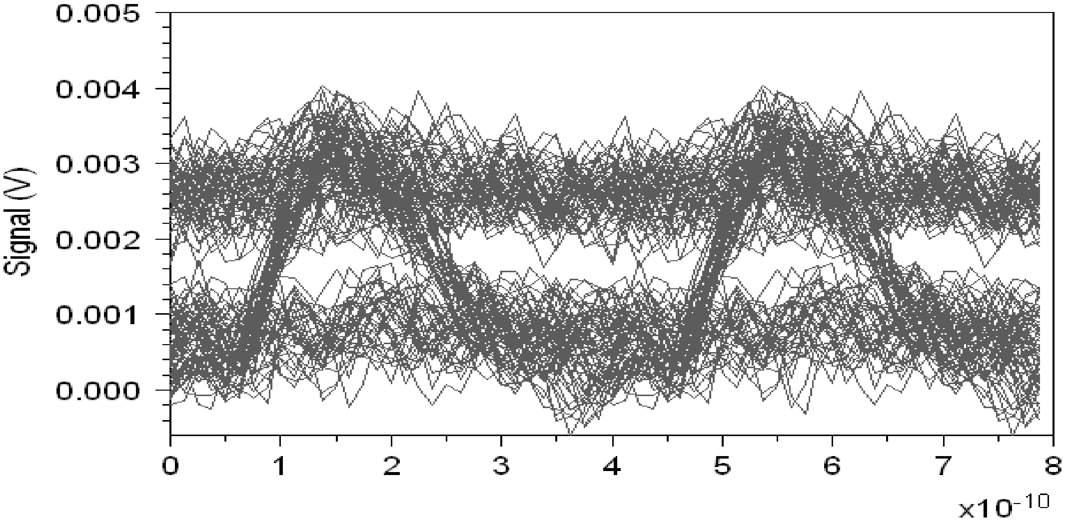
Wavelength spectrum observed for the up conversion is shown in figure 3.6. We can see clearly that the wavelength is converted from 1550 nm to 1555 nm. Base Band spectrum observed for the up conversion is shown in fig 3.7.



Eye diagram at average power -19 dBm



Eye diagram at average power -21 dBm



Eye diagram at average power -23 dBm

Fig 3.3 Clear eye pattern observed for up conversion at different receiver power values from -19 dBm to -23 dBm respectively.

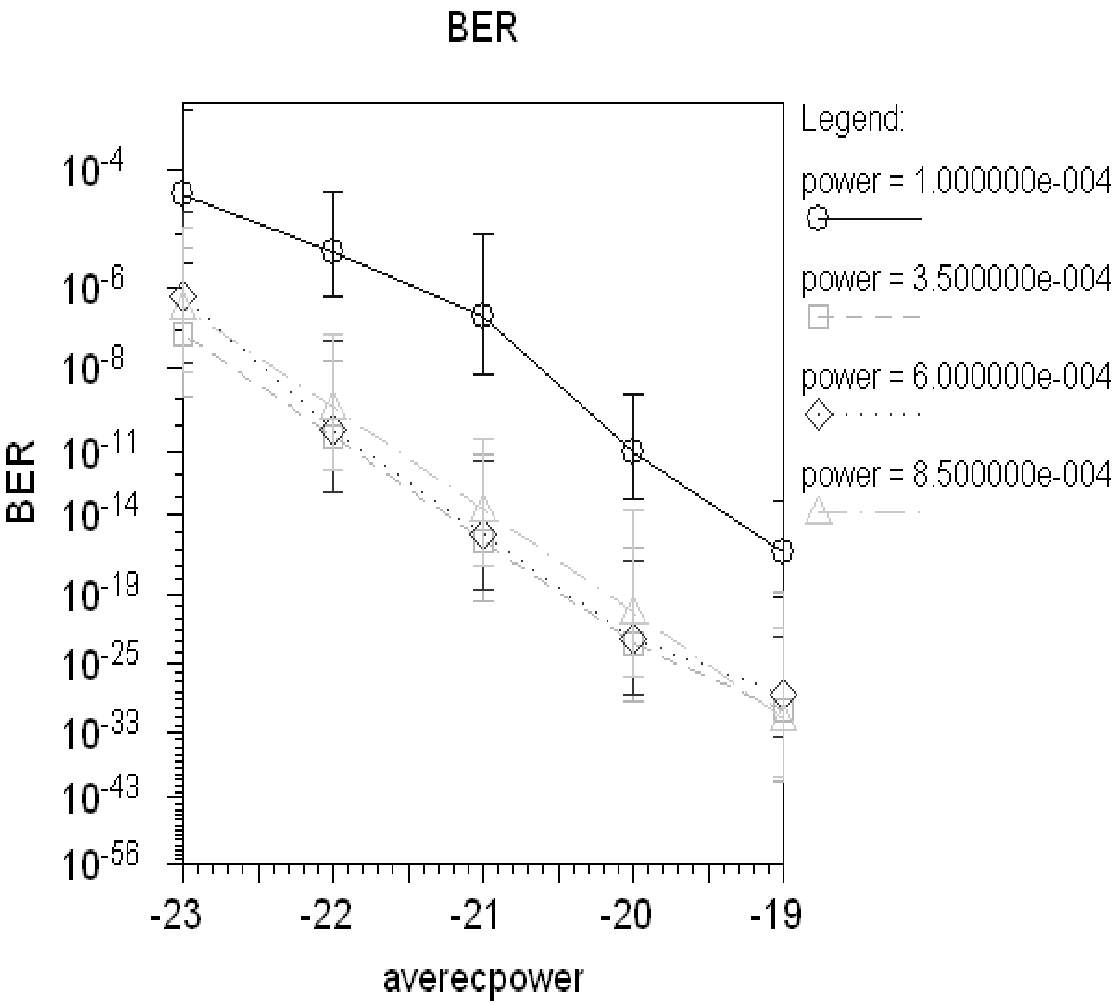


Fig 3.4 The variation in BER with input power and average receiver power

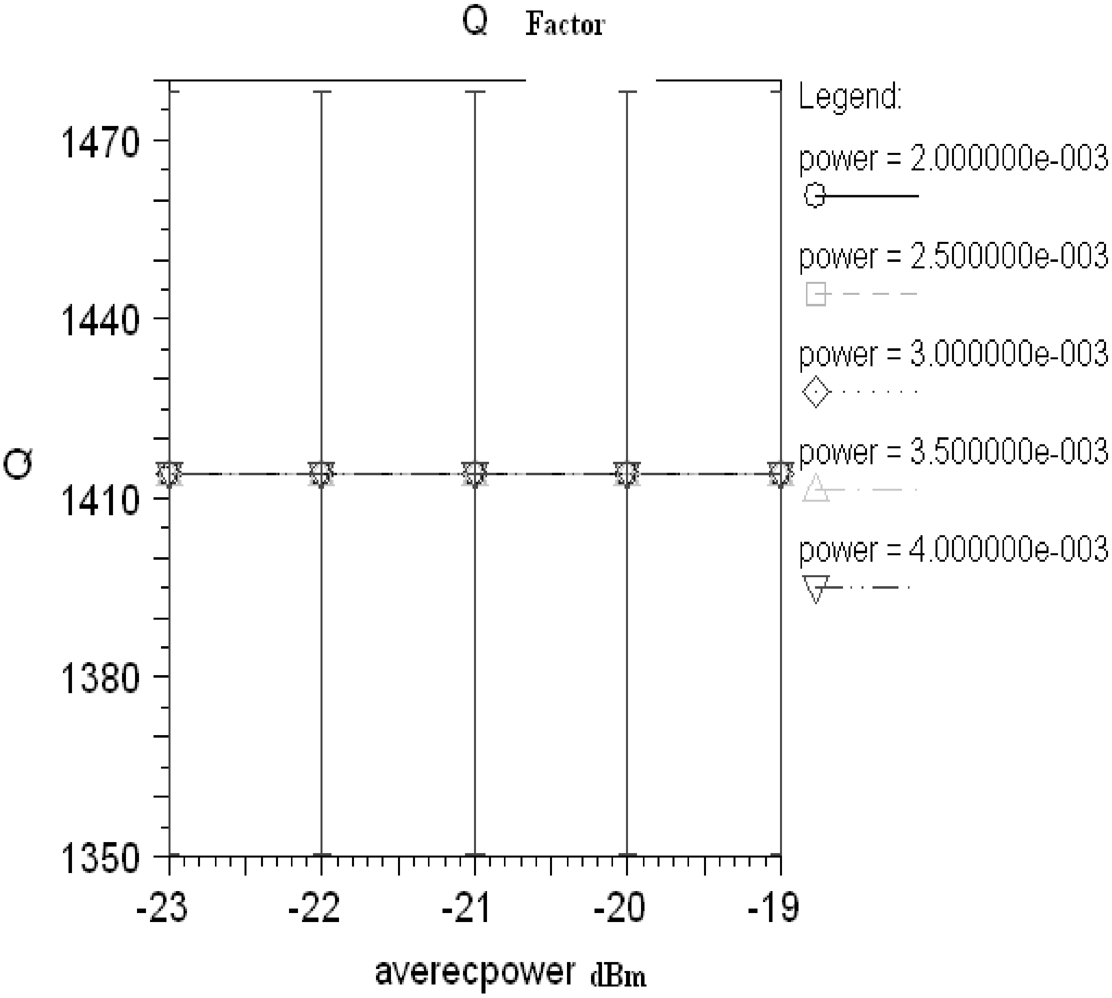


Fig.3.5 Q factor versus input power and average receiver power (dBm).

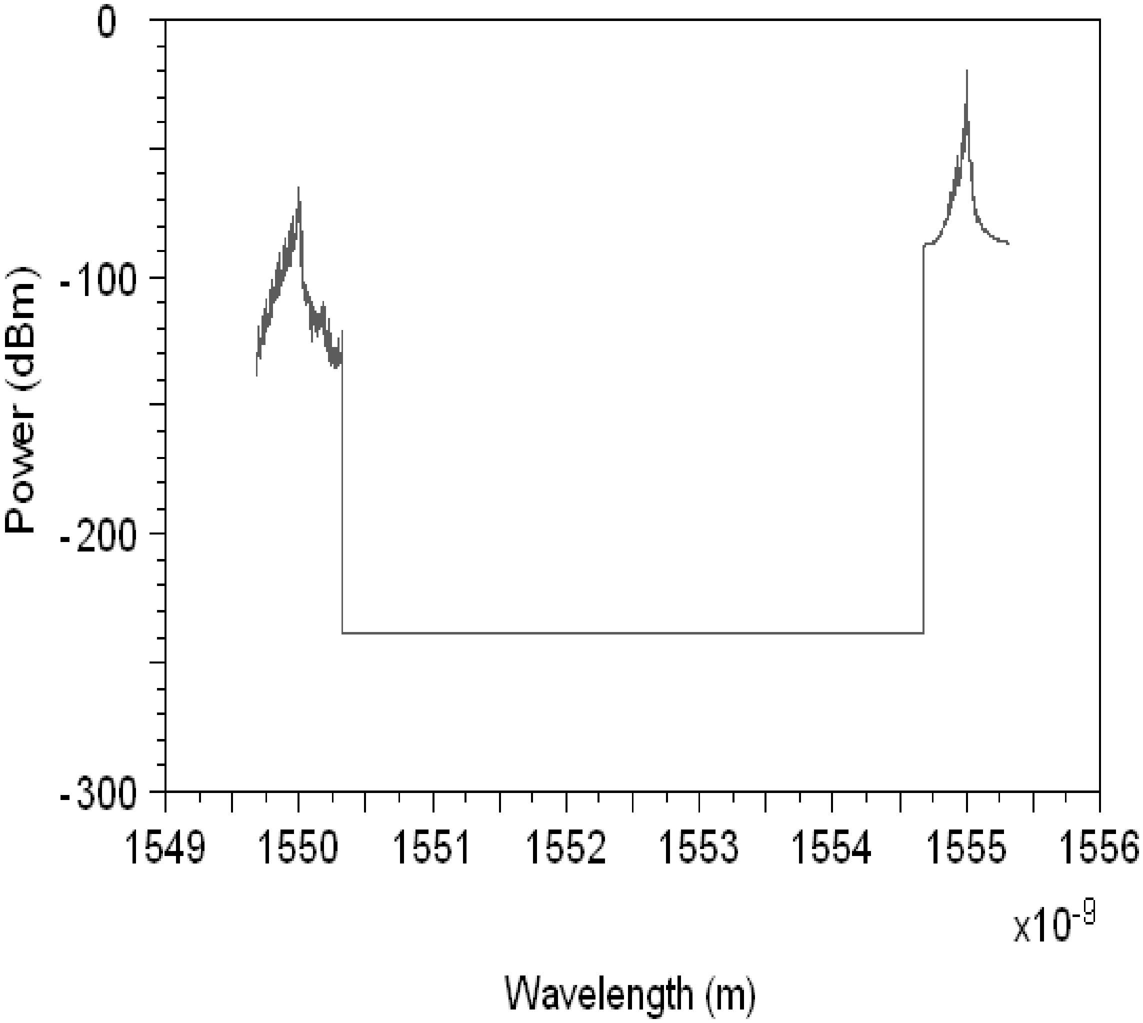


Fig 3.6 Wavelength Spectrum observed signal wavelength for up conversion.

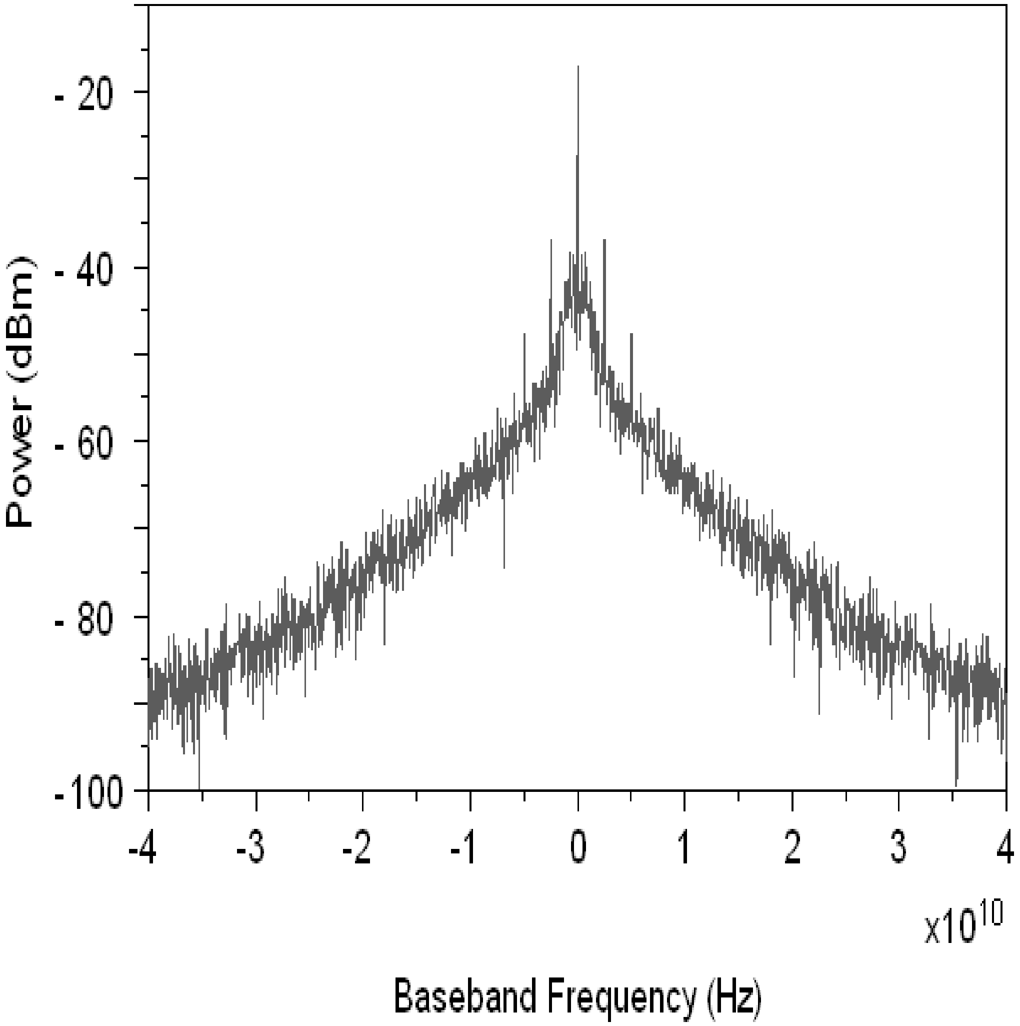


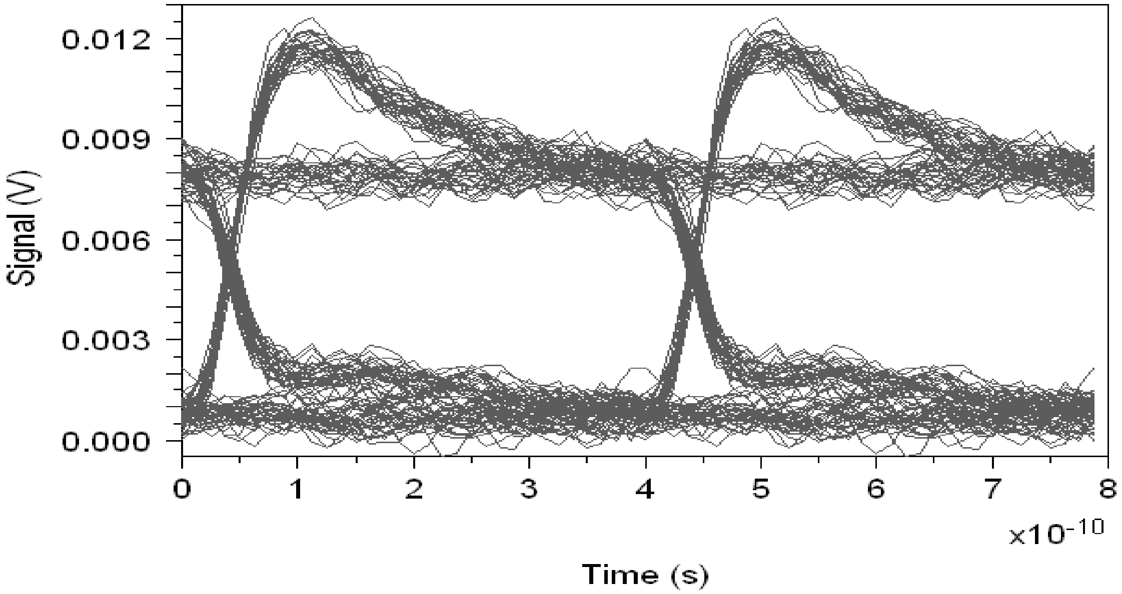
Fig. 3.7 Base band Spectrum observed signal wavelength for up conversion

Results For Down conversion

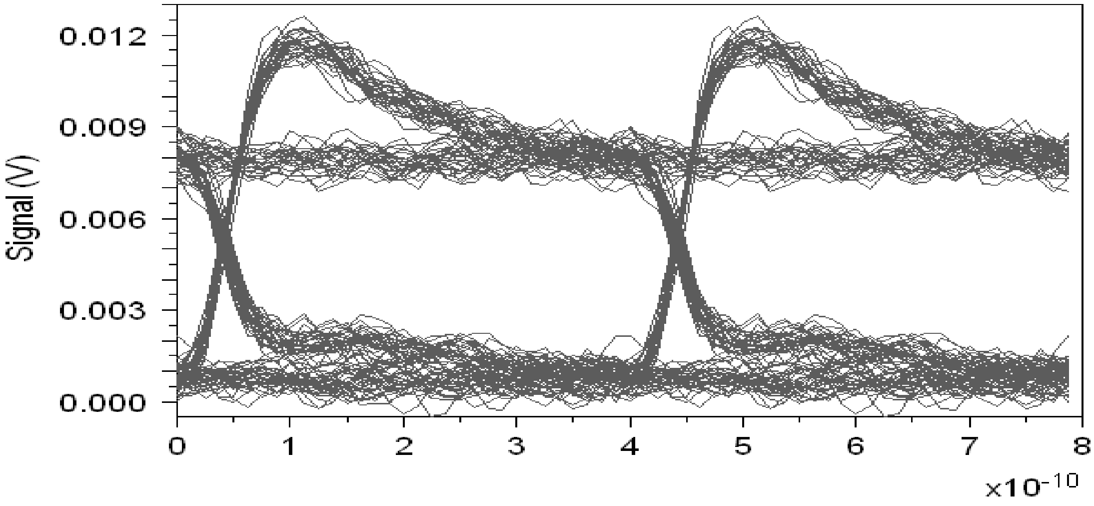
Results of eye diagrams for up conversion at different average receiver power are present in figure 3.8.

The BER versus signal result is observed for different average receiver power values for down converters as shown in figure (3.9). It is observed from simulation results that the BER values are very high at low pump power. BER value continuously falls from input power 0.1 mW to 0.3 mW as shown in fig 3.9. It is evaluated from the results that minimum BER comes out around 10^{-100} at power 0.3 mW for down conversion. In this simulation we change the input power from 0.1 mW to 0.001 W with 0.25 mW increments. The simulation results of average receiver power verses BER is also observed here. It is observed that as we increase average receiver power from changes -23 dBm to -19 dBm with increment of -1 dBm the BER values falls as shown in fig 3.9. Wavelength spectrum observed for the down conversion is shown in figure 3.11. We can see clearly that the wavelength is converted from 1553 nm to 1551 nm. Base Band spectrum observed for the down conversion is shown in fig 3.11.

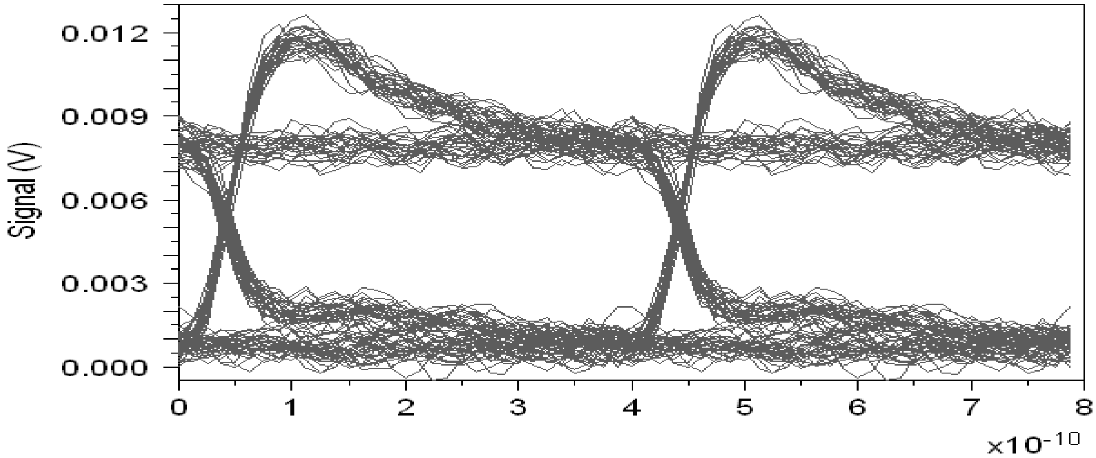
Results of different eye diagrams for down conversion at different average receiver power are present.



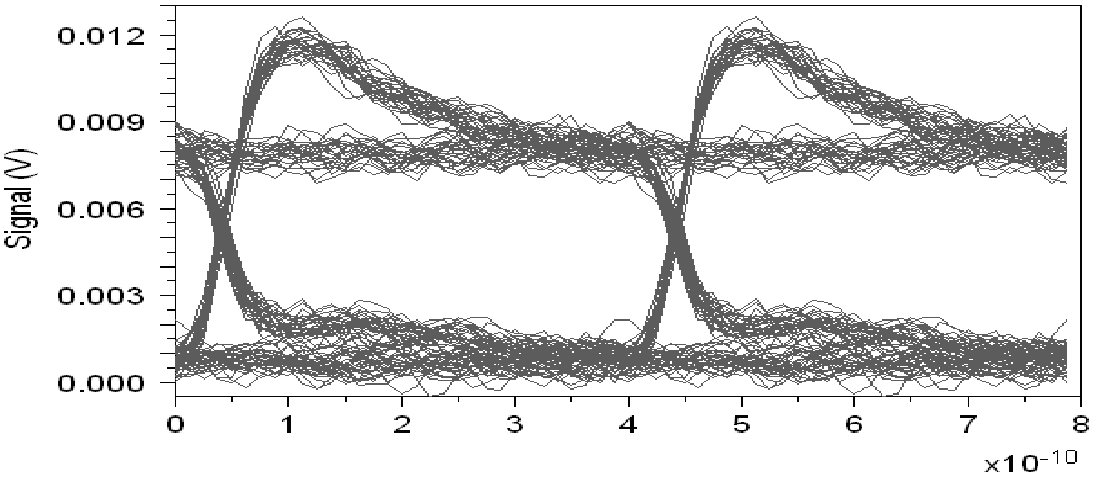
Eye diagram at average power -19 dBm



Eye diagram at average power -20 dBm



Eye diagram at average power -21 dBm



Eye diagram at average power -22 dBm

Fig. 3.8 Results of different eye diagrams for down conversion for different receiver power from -19 dBm to -22 dBm respectively

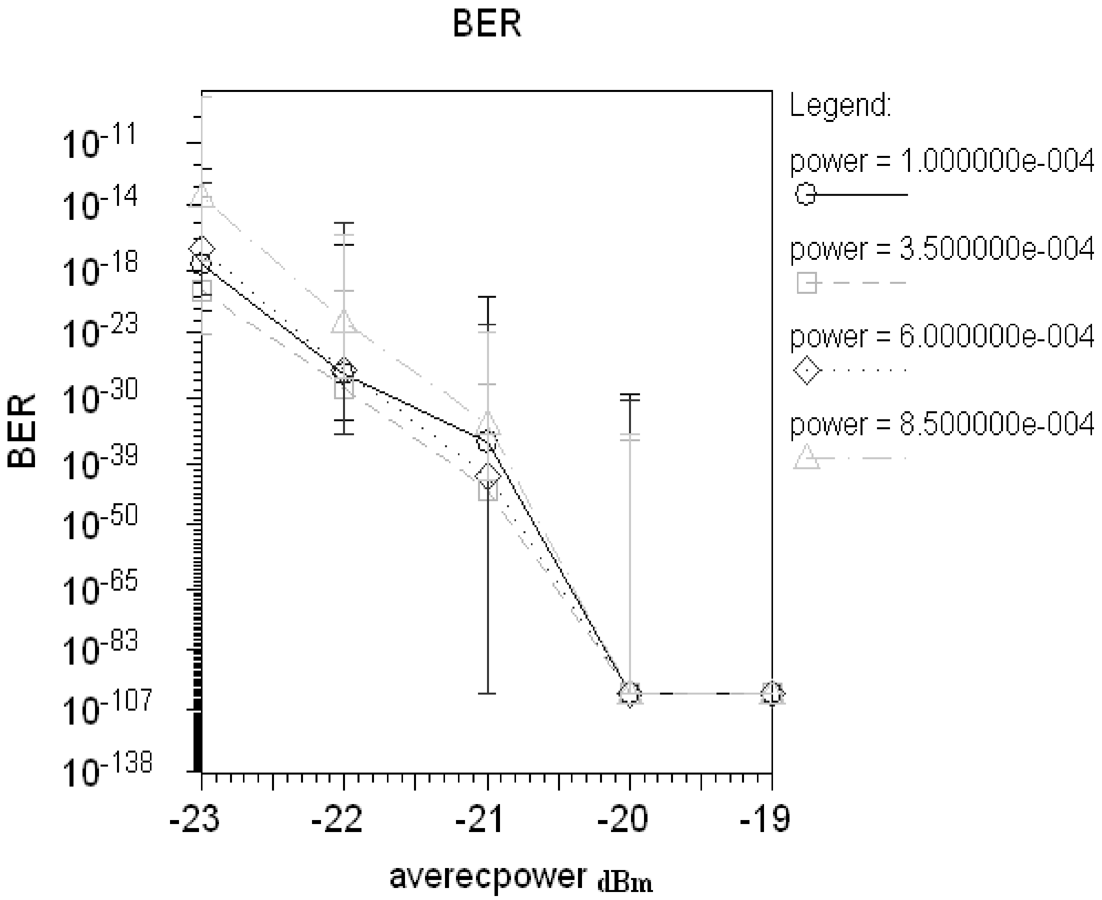


Fig.3.9 Variation in signal with the BER with different values of average receiver Power

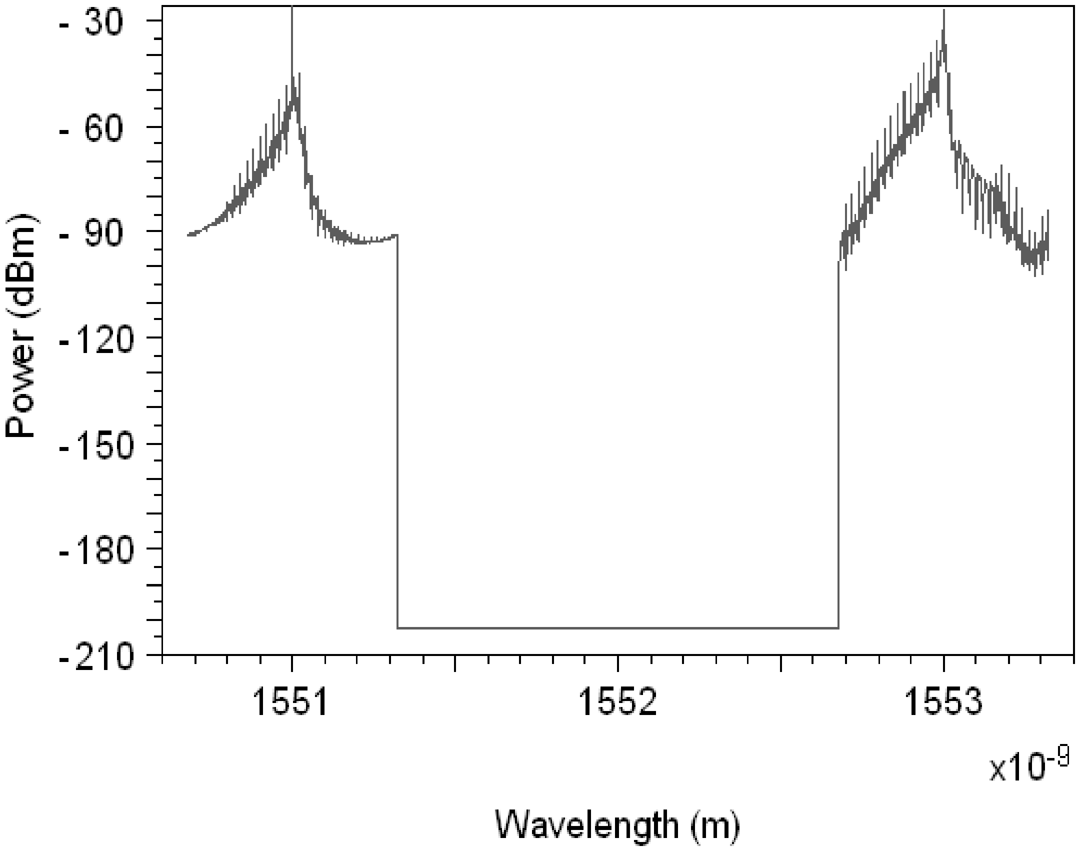


Fig.3.10 Wavelength Spectrum observed signal wavelength for down conversion

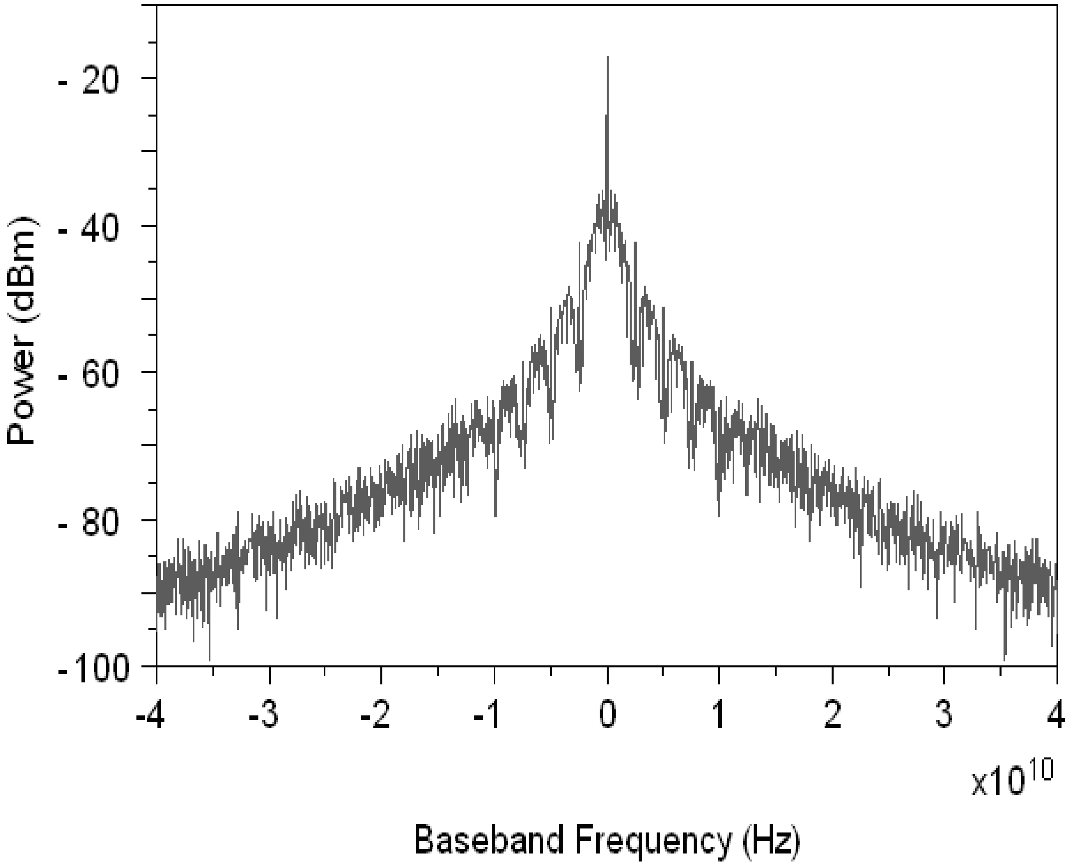


Fig. 3.11 Base band Spectrum observed signal wavelength for down conversion

3.5 Conclusion

Simulation results are presented to determine the performance of a wavelength converter based on semiconductor amplifiers arranged in the two arms of an MZI configuration for both up and down converters. We have observed the variation in the value of BER, as we increase the input power from 0.1 mW to 0.001 W, BER values continuously falls. It is observed from simulation results that minimum BER value comes out around 10^{-30} at power 0.35 mW for up conversion. It is also observed that as we increase the average receiver power from -19 dBm to -23 dBm, Q factor remains same for up converter. It is concluded from the above results that BER has minimum value around 10^{-100} at power 0.35 mW when the average receiver power is increased from -23 dBm to -19 dBm for down conversion. Simulation results of eye diagrams are also show the variation in up and down converters.

CHAPTER 4

OPTIMIZATION EDFA AMPLIFIERS

4.1 Abstract

The optical amplifier is the key of optical transmission systems with Dense Wavelength Division Multiplexing (DWDM). Erbium Doped Fiber Amplifier (EDFA) is used in the optical communications technology at the standard telecornmunication wavelength of I550 nm.

In this chapter, the analysis of gain value with pump power and wavelength of EDFA amplifier has been presented. The results of the simulation of the various configurations for gain spectrum with pump power of the EDFA are enumerated here. Variation in the noise figure with pump power and EDFA length is depicted in this study. It is evaluated that maximum gain value is 18.95 dB for EDFA length 14 m at wavelength 9.8 nm. We observed that as we increase the pump power from 1.5 mW to 3 mW with wavelength 9.6 nm to 9.9 nm, gain rises at wavelength 9.8 nm. It is evaluated from the simulation results that maximum gain value is 18.88 dB for pump power 3 mW. We have seen that as we increase the pump power from 1mW to 3 mW with wavelength 9.6 nm to 9.9 nm, noise figure value falls at wavelength 9.8 nm. It is evaluated from simulation results that minimum noise figure comes out 0.0079 dB at pump power 3 mW

Key words: EDFA cascades, gain, EDFA length, wavelength division multiplexing, noise figure.

4.2 Introductions

The recent exponential growth in data communication and the internet places urgent demand on high-capacity communication networks. The need for greater transmission capacity through optical fiber has encouraged the increase of Wavelength Division Multiplexing (WDM) channels and the data rate per channel, and furthermore promotes the expansion of the optical band. To increase total capacity, research and development teams must work on the data speed and channel spacing that has been limited by the speed of the electronic devices and fiber nonlinearity.

As the optical amplifiers have overcome on the speed limitation of the optical links, they are one of the most essential components of telecommunications networks and the development of the Erbium Doped Fiber Amplifiers (EDFAs) in particular is affecting all areas of optical communications networks [49]. Indeed as the EDFA gain bandwidth is not spectrally uniform, and exhibit some ripples, gain differences accrue between optical channels having large bandwidth. As the number of channels in wideband and long distance WDM systems increase, broadband and spectrally flat amplification is required.

The optical amplifier is the key of optical transmission systems with Dense Wavelength Division Multiplexing (DWDM). Erbium Doped Fiber Amplifier (EDFA) is used in the optical communications technology at the standard telecornmunication wavelength of I550 nm.

Erbium doped fiber amplifiers have attracted most because they operate in the wavelength region near 1.55 μm, the wavelength region in which fiber attenuation is small. EDFA amplified simultaneously all channels when a WDM signal was amplified [50]. The shape of the gain spectrum was affected by the amorphous nature of silica & by presence of other codopants within the fiber core such as Germina & Alumina. EDFA, whose core was doped with Germina, the gain spectrum is quite broad & has a double-peak structure. The gain of EDFA depends upon erbium-ions concentration, amplifier length, and core radius & pump power [51]. The gain of modern EDFA range changes from about 20 dB to 40 dB depending as they act as booster or preamplifier. The optical filter placing before the amplifier increased the noise while placing it after the amplifier reduced the output power. A combination of several long period fiber grating were acting as the optical filter which can flat the gain within 1dB over the 40 nm bandwidth in wavelength range of 1530-1570 nm[53]. It is found that the usage of gain equalizer filter was the most applicable technique for gain broadening EDFAs, but the hybrid Raman amplifier & EDFAs had the maximum accessible bandwidth without any power consuming in optical filter.

EDFA have a high gain, operating at low pump power and its performance are better in comparison with other similar amplifiers and optical devices [49] Using EDFA in optical networks is possible to extend transmission distances and the capacity in optical network [49]. Also, the EDFA have a large bandwidth, a low noise figure and polarization insensitivity [50]. The size and the complexity of DWDM networks growth and appear transient effect, which may become significant for system performances and reliability. The EDFA have the same mechanism as a laser with three levels [50-51]. The EDFA is suited for modern optical transmissions systems because the EDFA have the maximum gain at 1550 nm wavelength, which is used for optical fibers. Wavelength-division multiplexing (WDM) and erbium-doped fiber amplifiers (EDFA's) have revolutionized high-capacity long-distance transmission systems. However, the EDFA gain is wavelength dependent causing severe signal power and SNR differential are among several WDM channels after a cascade of amplifiers [52].

After giving the brief literature of EDFA amplifiers, we discuss about the simulation setup used for the EDFA gain compensation. In the simulation results, analysis of gain value with pump power and wavelength of amplifier has been presented. The simulation results for the various configurations of gain spectrum with pump power of the EDFA are enumerated here. Variation in the noise figure with pump power and EDFA length is depicted and finally the results have been concluded.

4.3 Basic simulation setup

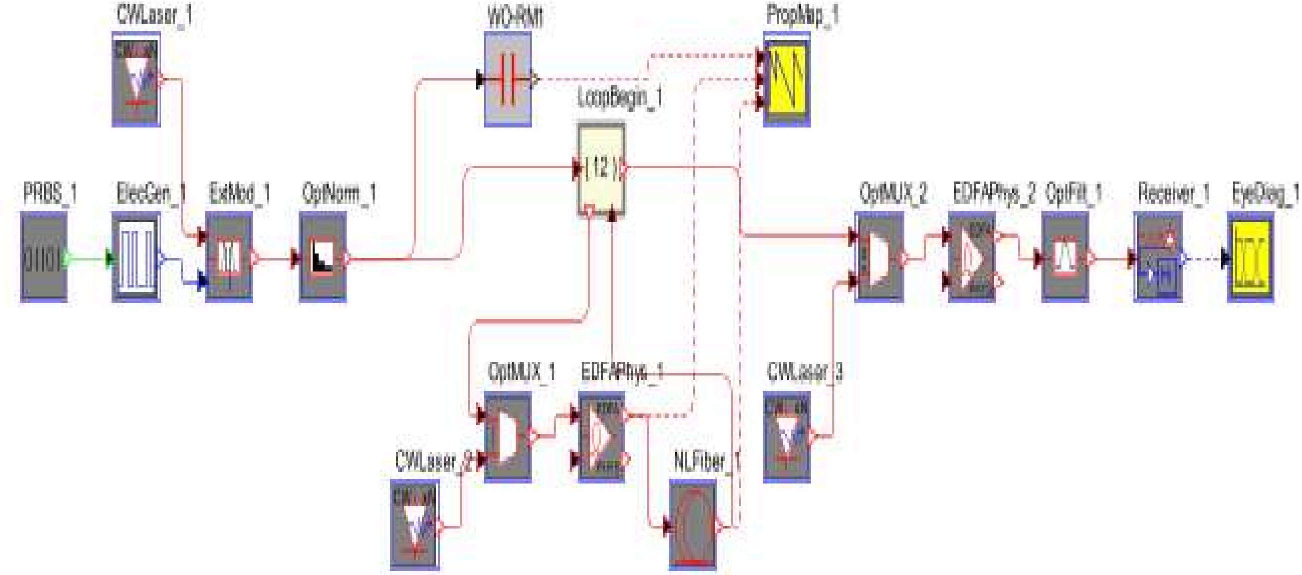


Fig 4.1 Basic Simulation Setup for EDFA Gain _Compensation

In the setup, shown in fig 4.1, we demonstrate the use of EDFA's in an optical link to minimize the degradation of an optical signal's average power. Firstly signal is generated with the help of PRBS generator (PRBS1), and then it changes into the electrical signal with the help of electrical signal generator (Elecgen1). In this design, two spans (LoopBegin_1) of 81 km optical fiber (NL-Fiber1) are amplified by 100 mW 980 nm pumped EDFA's (CW_laser1,2) and the photo receiver is also preamplified by an EDFA (CW_laser3). The output of the electrical generated is applied to the modulator (ExtMod_1). Here we use the Mach Zehnder type modulator. In this setup, we have used two optical multiplexers (Optmux 1,2), it accepts multiple optical signal at its input ports and produces a WDM optical signal at its output port which include all the input WDM signals. The output of EDFA at receiver is applied to the Gaussian type filter (Optfilt1) with optimized bandwidth of 0.12 x 10^{-9} m and center frequency 1550 nm, and then its output is detected by photo detector (receiver1). The eye diagram output waveform results are can be seen very easily with the help of eye diagram analyzer (EyeDia). The sensitivity of the receiver is -27 dBm and absorption coefficient 0.68 x10^{6} luminous/m. The quantum efficiency of receiver is 0.8 and the simulation is carried out at centre frequency of 193.THz. The receiver sensitivity is –25 dBm for 10^{-9} BER requirement. This sensitivity was achieved by adjusting the receiver parameters.

4.4 Results and Discussion

In order to observe the performance of gain compensation of EDFA, gain of EDFA verses pump power is observed for different length of EDFA as shown in fig 4.2, as we increase the pump power from 0.1 mW to 0.001 W, we seen that variation in the gain value is increases with the power, but when we increase the length of the EDFA from 1 m to 16 m, gain of EDFA continuously falls. It is observed from the simulation results that maximum gain value is 1.118 (dB).

In fig 4.3, we have seen that as we increase the wavelength from 9.6 nm to 9.9 nm with EDFA length 2 m to 14 m, gain rises at wavelength 9.8 nm. It is evaluated that maximum gain value is 18.95 dB for EDFA length 14 m at wavelength 9.8nm. In fig 4.4, we observed that as we increase the pump power from 1.5 mW to 3 mW with wavelength 9.6 nm to 9.9 nm, gain rises at wavelength 9.8 nm. It is evaluated from the simulation results that maximum gain value is 18.88 dB for pump power 3 mW. It is conclude from the results, EDFA has high gain at wavelength 9.8 nm when the pump power and EDFA length is high.

In order to observe the performance of noise figure, noise figure verses pump power is observed at different length of EDFA as shown is fig 4.5, as we increase the pump power from 0. 1 mW to 0.001 W with EDFA length 1 m to 16 m, noise figure value increases. It is observed from the simulation results that minimum noise figure value comes out 1.97 dB at EDFA length 1m. In fig 4.6, we have seen that as we increase the pump power from 1mW to 3 mW with wavelength 9.6 nm to 9.9 nm, noise figure value falls at wavelength 9.8 nm. It is evaluated from simulation results that minimum noise figure comes out 0.0079 dB at pump power 3 mW. In the fig 4.7, we observed that as we increase the wavelength 9.6 nm to 9.9 nm with EDFA length 2 m to 14 m, noise figure value falls at wavelength 9.8 nm. It is evaluated from the simulation results that minimum noise figure value comes out 0.0566 dB at EDFA length 14 m. It is concluded from the above results that noise figure has minimum value at wavelength 9.8 nm and EDFA length is 14 m.

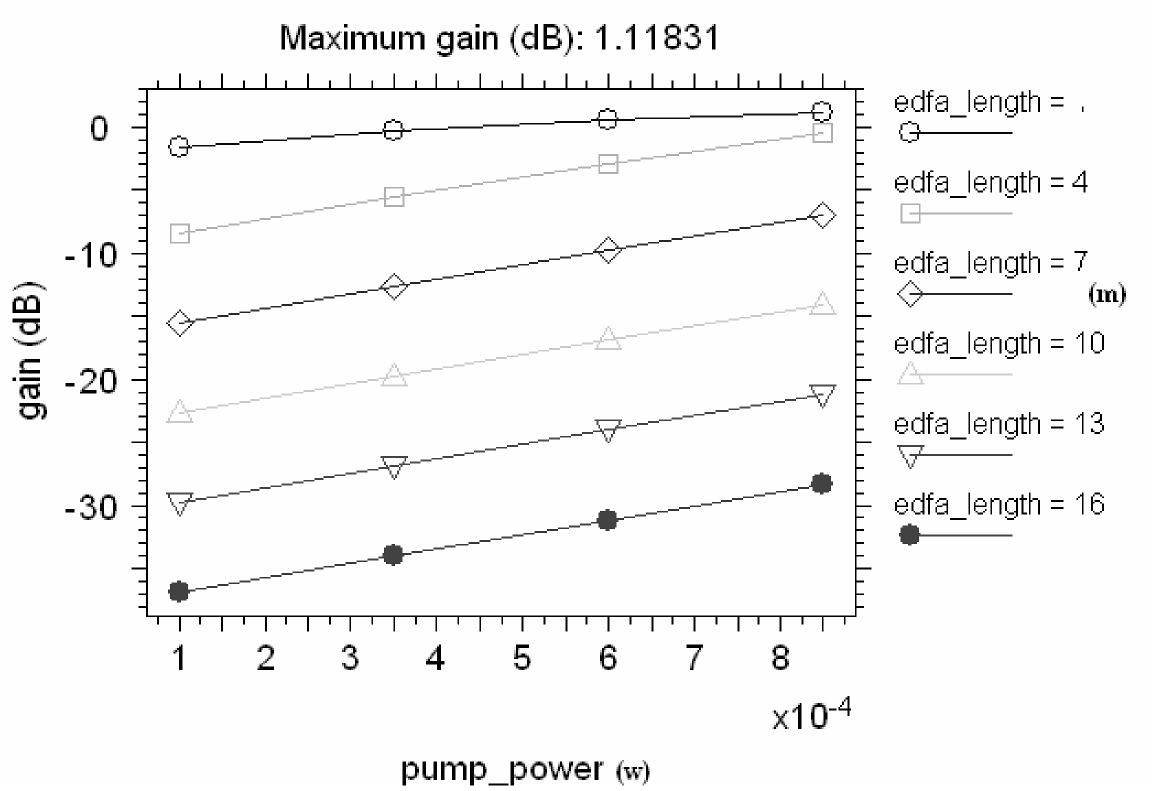


Fig 4.2 Gain variation with pump power and EDFA length.

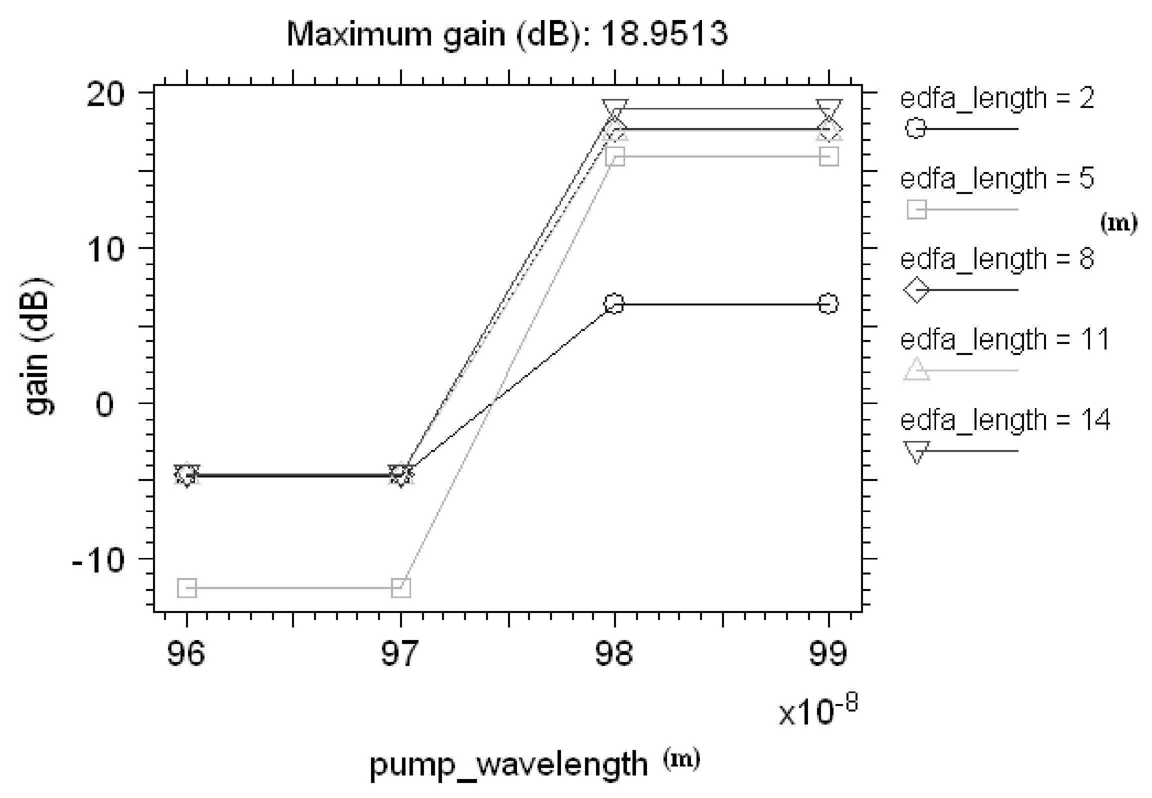


Fig.4.3. Gain variation with wavelength and EDFA length

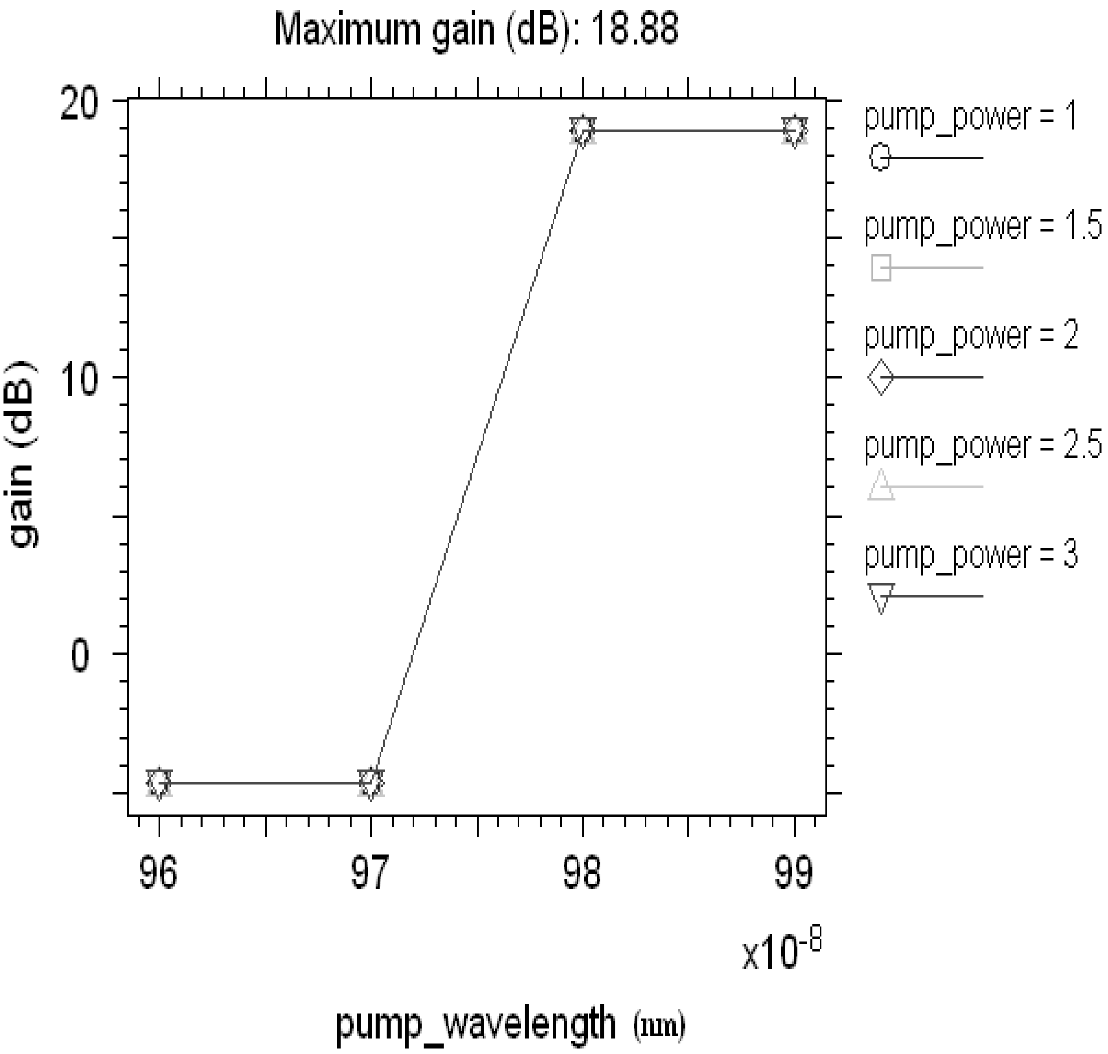


Fig 4.4 Gain variation with wavelength and pump power

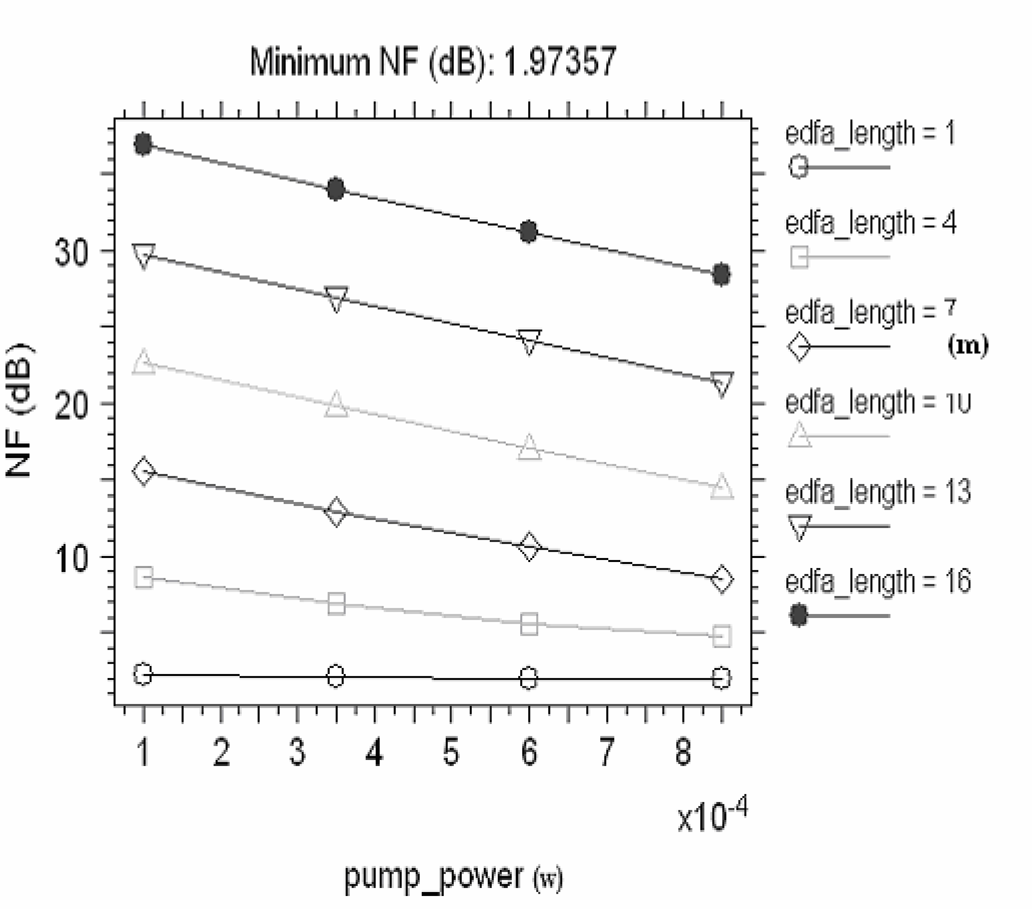


Fig 4.5 Noise figure variation with pump power and EDFA length.

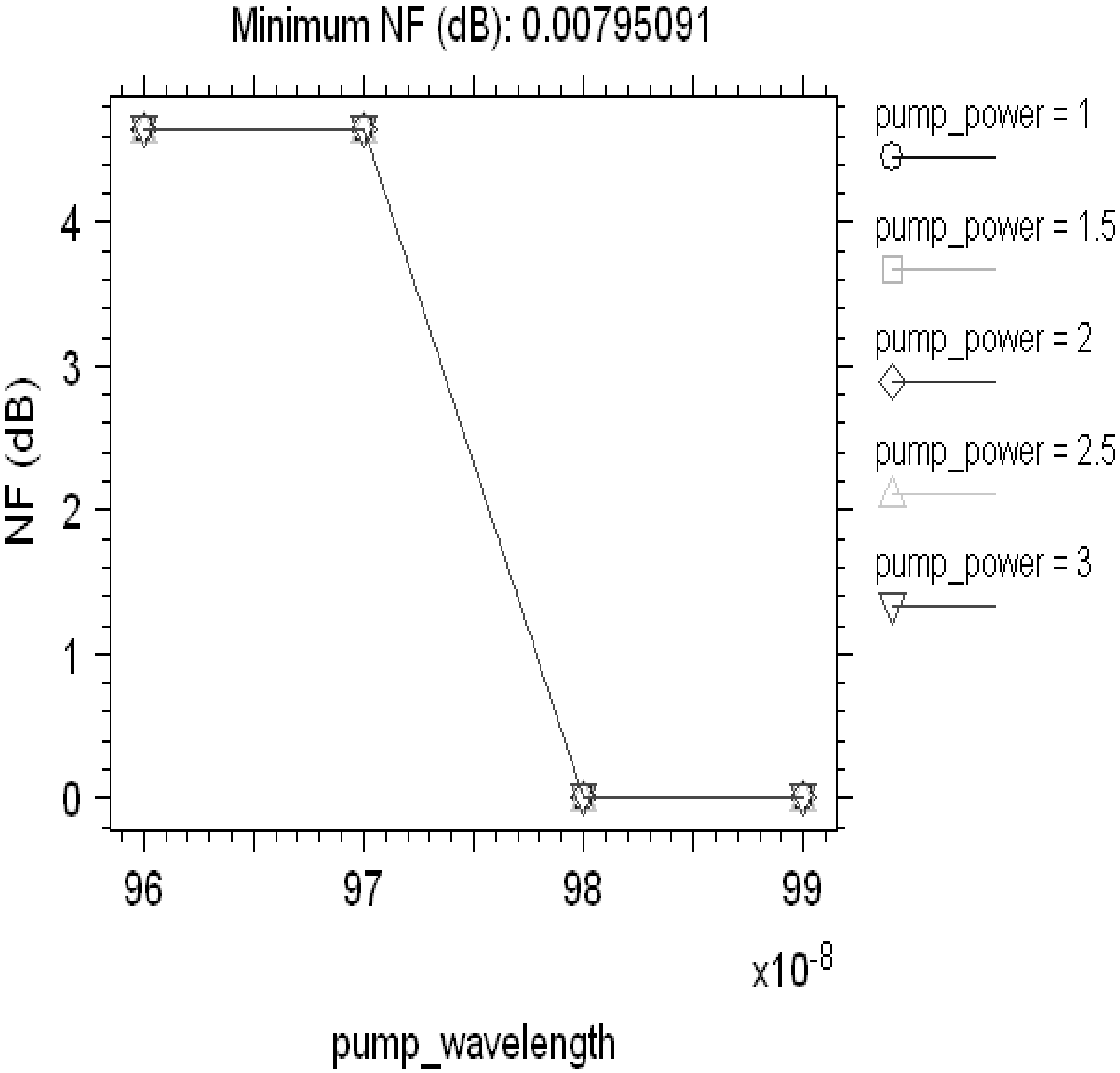


Fig 4.6 Noise figure variation with wavelength and pump power

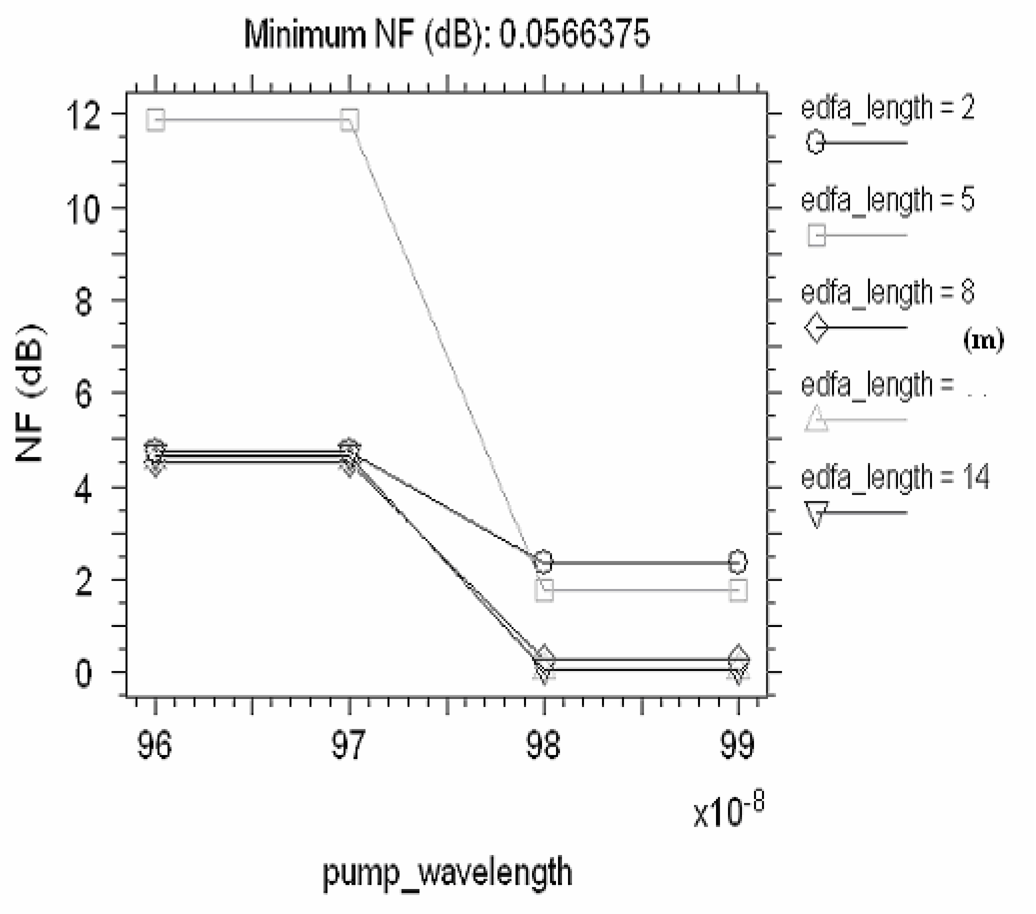
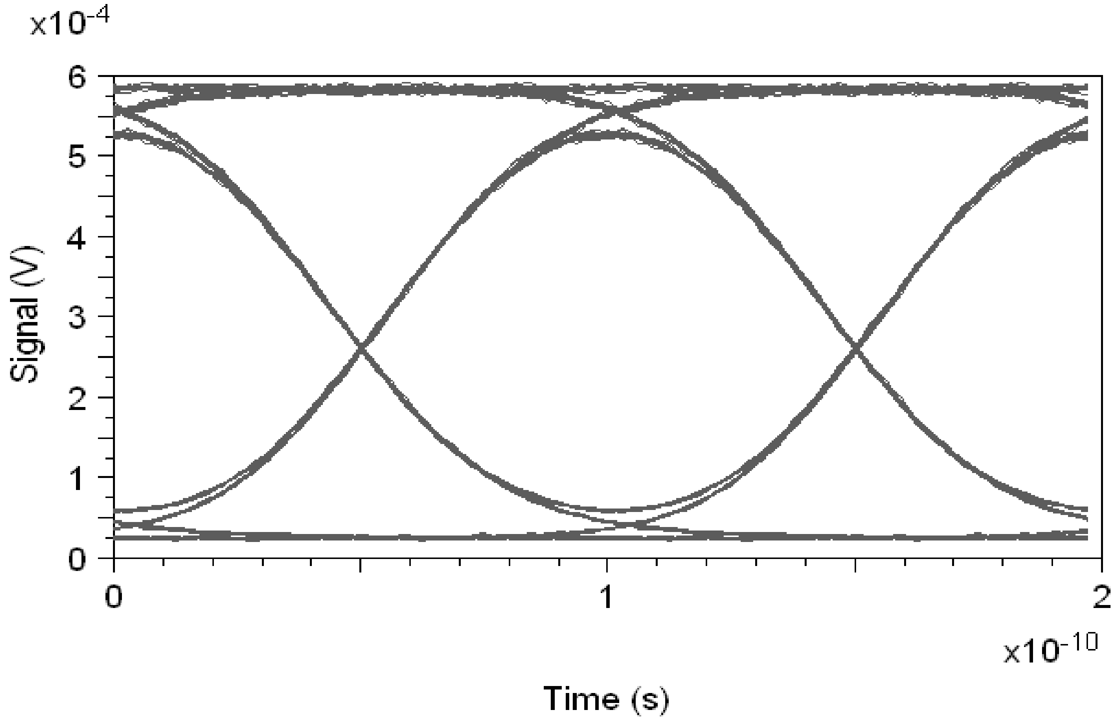
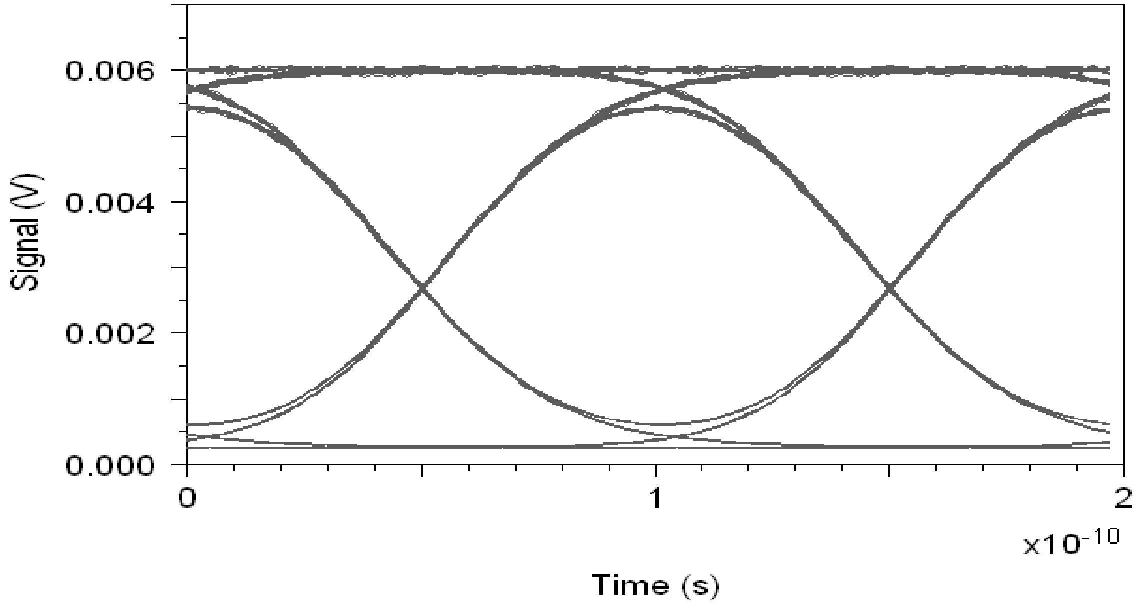


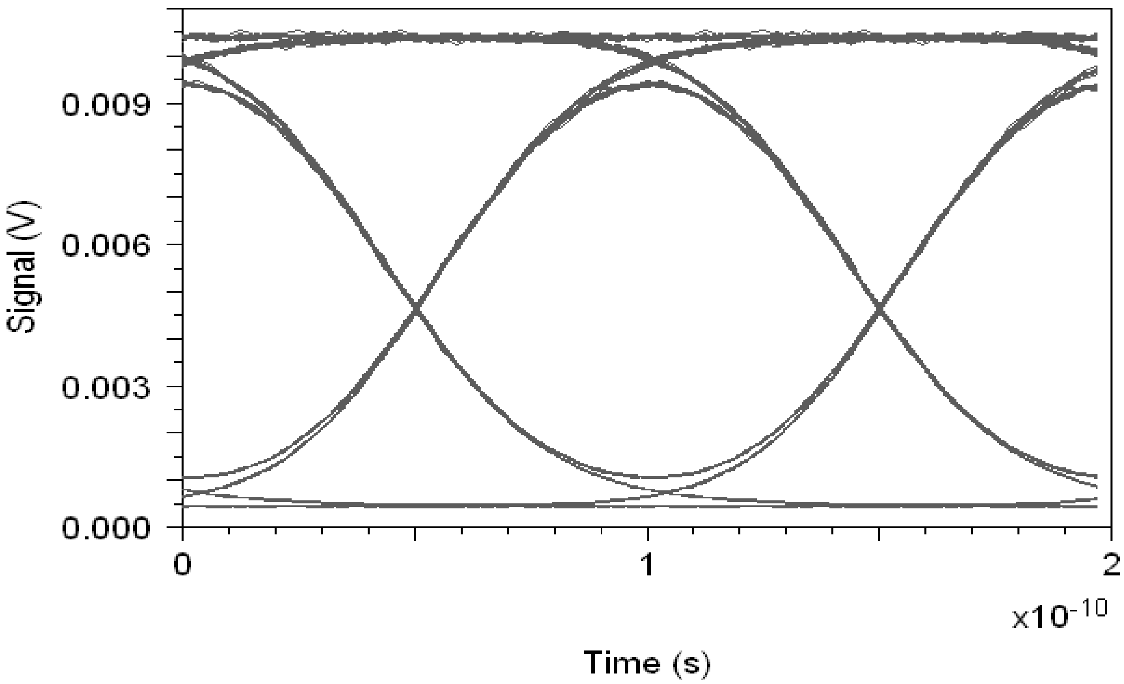
Fig.4.7 Noise figure variation with wavelength and EDFA length.



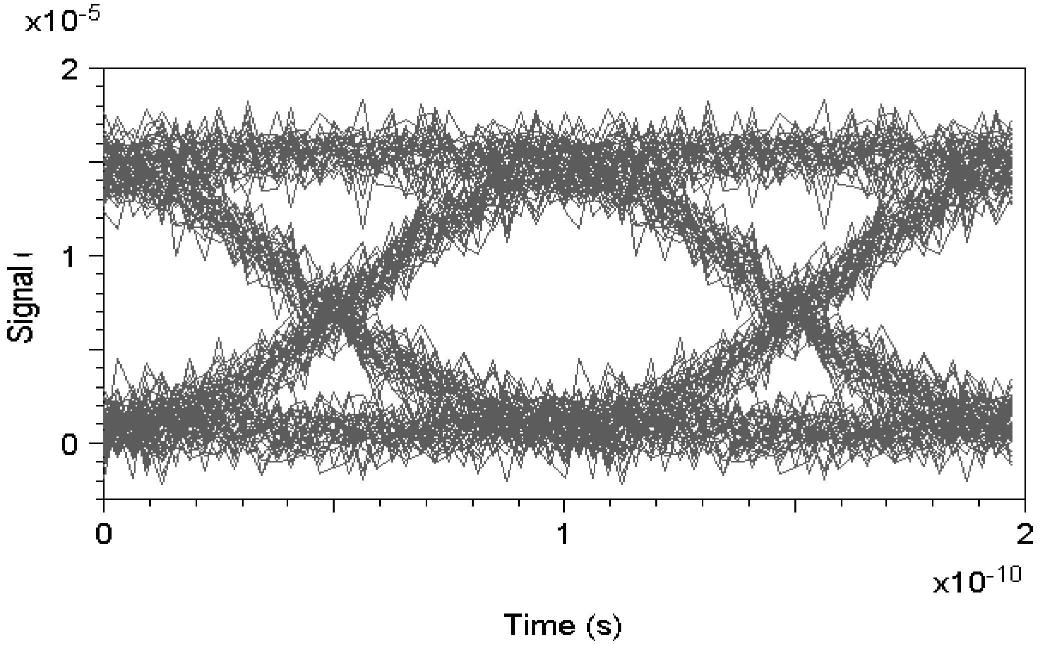
Eye Diagram at EDFA length 14 m



Eye Diagram at EDFA length 20 m and pump power 0.1 mW



Eye diagram at pump power 0.2 mW



Eye Diagram at EDFA length 14 m with repetition span increased

Fig 4.8 variation in eye diagram with EDFA length and pump power

In order to observe the performance of EDFA gain, as if we increase the length and pump power, gain flatness turns out to be directly proportional to the gain and to the flatness of the gain profile. Results of different eye diagrams for different iteration and length are shown here. The results of eye diagram shown in fig 4.8 that as we increase pump power and EDFA length, opening of eye is increased

4.5 Conclusion

In order to observe the performance of gain compensation of EDFA, gain of EDFA verses pump power is observed for different length of EDFA. It is demonstrated that the shape of the gain profile is determined by the average gain per unit fiber length. The optimum fiber length for maximum gain flatness turns out to be directly proportional to the gain and to the flatness of the gain profile. Furthermore it is concluded that from the simulation results EDFA has high gain at wavelength 9.8 nm when the pump power and EDFA length is high. It is concluded from the simulation results that noise figure has minimum value at wavelength 9.8 nm and EDFA length is 14 m.

As can be seen, the longest-wavelength signal with its relatively low amplification, is least able to overcome the effects of noise in the link's photo receivers, resulting in a closed eye. The well amplified shorter wavelength channels, however, exhibit open eyes. This discrepancy highlights the need to account for an EDFA's non-uniform spectral gain when designing an optically amplified link.

CONCLUSIONS AND FUTURE SCOPE

All optical wavelength converters are the key components for multi-wavelength optical transport network and are expected to provide wavelength conversion in optical domain with out significant distortion of the input signal. Wavelength converters offer the advantage of increased flexibility in wavelength routing and avoidance of wavelength blocking in a wavelength division multiplexing network node. As a consequence, the capacity of an optical multi-wavelength network can be considerably increased with the use of wavelength converters at different nodes.

To overcome the problems of XGM and FWM scheme, the SOA converters can be used in cross phase modulation (XPM) mode. The XPM scheme is based on the dependency of refractive index of the carrier density in the active region of the SOA.. Incoming signals deplete the carrier density and modulate the refractive index. Therefore phase modulation of a continuous wave (CW) signal couples into the converter. The phase modulated CW signal can be demultiplexed after the converter. The converter is considered to be consisted of two semiconductor optical amplifiers arranged as Mach-Zehnder interferometer (MZI) configuration. The performance results are evaluated in terms of converted signal power, BER and Q actor due to wave length conversion and variation in input power, average receiver power, bias current

For up conversion, it is observed from the simulation results that minimum BER value comes out around 10^{-30} at power 0.35 mW. It is concluded from the simulation results that BER has minimum value around 10^{-40} for bias current 0.3 A. For down conversion, it is concluded from the simulation results that BER has minimum value around 10^{-100} for power 0.35 mW. The effects of XPM are visible as an enlargement of the received probe spectrum, a distortion of the eye diagram of the probe signal, and an increase of the power measured by the Receiver Sensitivity. The analysis can be easily extended to include the effects of dispersion in fiber on the converter performance.

The optical amplifier is the key of optical transmission systems with Dense Wavelength Division Multiplexing (DWDM). Erbium Doped Fiber Amplifier (EDFA) is used in the optical communications technology at the standard telecornmunication wavelength of I550 nm. EDFA have a high gain, operating at low pump power and its performance are better in comparison with other similar amplifiers and optical devices Using EDFA in optical networks is possible to extend transmission distances and the capacity in optical network . Also, the EDFA have a large bandwidth, a low noise figure and polarization insensitivity. In order to observe the performance of gain compensation of EDFA, gain of EDFA verses pump power is observed for different length of EDFA. It is demonstrated that the shape of the gain profile is determined by the average gain per unit fiber length. Furthermore it is concluded from the simulation results EDFA has maximum gain value comes out 18.95 dB for EDFA length 14 m at wavelength 9.8 nm. It is observed t from the simulation result hat maximum gain value is 18.88 dB for pump power 3 mW. It is observed from the simulation results that minimum noise figure comes out 0.0079 dB at pump power 3 mW. It is also observed from the simulation results that minimum noise figure value comes out 0.0566 dB at EDFA length 14 m. It is concluded from the above results that noise figure has minimum value at wavelength 9.8 nm and EDFA length is 14 m.

Future Scope

In this thesis, we observe the performance of a wavelength converter based on semiconductor optical amplifiers arranged in two arms of an MZI, BER has minimum value around 10^{-40} at power .35 mW and for .3 A bias current for up conversion. The observation can be easily extended to include the effects of dispersion in fiber on the converter performance. We can improve the performance of all wavelength converters using fiber grating. Fiber Bragg Grating (FBG's) has emerged as important component in a variety of light wave technology. Their unique filtering property can do the optimization of the frequency response of a semiconductor optical amplifier wavelength converter. Furthermore, the SOA –MZI technology and combined FSK/IM modulation format for optical labeling of signal are scalable to higher bit rate.

We have only investigated erbium-doped fibers but the methods also work with other gain media, including combinations of fibers doped with different rare earths (e.g., Nd and Yb). Moreover, the principle is readily extended to more than two types of gain media, thereby enhancing the possibilities of compensating spectral loss variations. Although not studied here, we also believe that an alternating cascade provides some immunity to changes in the spectral gain-tilt of EDFA's that temperature variations bring about.

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