OPTICAL TRANSMISSION MODULE AND ITS ANALYSIS

A Dissertation submitted towards the partial fulfilment of
the requirement for the award of degree of

Master of Technology in
Microwave and Optical Communication Engineering

Submitted by
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2K14/MOC/19

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Delhi Technological University
(Formerly Delhi College of Engineering)
JUNE 2016

DELHI TECHNOLOGICAL UNIVERSITY

Established by Govt. of Delhi vide Act 6 of 2009
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CERTIFICATE

This is to certify that the work which is being presented in the dissertation entitled " **OPTICAL TRANSMISSION MODULE AND ITS ANALYSIS**" is the authentic work of **SUMIT KUMAR** under my guidance and supervision in the partial fulfilment of requirement towards the degree of Master of Technology in Microwave and Optical Communication Engineering jointly run by Department of Applied Physics and Department of Electronics & Communication Engineering in Delhi Technological University during the 2014-16.

As per the candidate declaration this work has not been submitted elsewhere for the award of any other degree.

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DECLARATION

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

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ABSTRACT

In this thesis, an optical module has been designed using band optical filter and the input binary sequence is generated by a pseudo random sequence generator and converted into its electrical equivalent by Gaussian pulse generator. Another transmission module is designed using Fiber brag grating based Hilbert transformer. NRZ pulse generator is used for FBG based transmission .NRZ pulse generator gives better BER performance than Gaussian pulse generatgor.

ACKNOWLEDGEMENT

I take this opportunity as a privilege to thank all individuals without whose support and guidance, I could not have completed my project successfully in this stipulated period of time.

First and foremost I would like to express my deepest gratitude to my supervisor **Dr. Sudipta Majumdar**, Asst. Professor, Department of Electronics & Communication, for his valuable support, patience, guidance, motivation and encouragement throughout the period this work was carried out. I am grateful to her for closely monitoring my progress and providing me with timely and important advice, their valued suggestions and inputs during the course of the project work.

I am deeply grateful to the **Prof. S. C. Sharma** (Head of the Applied Physics Department), **Prof. Prem R. Chadha** (Head of the Electronics and Communication Engineering Department), **Prof. R. K. Sinha**, **Prof. Rajiv Kapoor** and **DR. Priyanka Jain** for their support for providing best educational facilities.

I also wish to express my heartfelt thanks to the classmates as well as staff at Department of Applied Physics and Department of Electronics & Communication of Delhi Technological University for their goodwill and support that helped me a lot in successful completion of this project.

Finally, I want to thank my parents, brother sisters and friends for always believing in my abilities and for always showering their invaluable love and support.

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CHAPTER 1

INTRODUCTION

1.1 Thesis Approach

The transmission of information from one point to another is done through several medium. One of these mediums that really had a big impact on data transmission was coaxial-cable system. The first coaxial-cable system deployed in 1940 was a 3MHz system which could transmit 300 voice channels. But these coaxial cables hey mostly suffer from high cable losses and repeater spacing is also very limited and is costly for longer transmissions length. The optical fiber came into existence in 1988, which significantly change the telecommunication industry and played a major role in the information times. Optical fiber communication gives high performance and more reliable communication system over the previous one.

Information carrying capacity is related to the bandwidth and carrier frequency. The more the carrier frequency, greater will be the transmission bandwidth as well as information carrying capacity. The cost of cables is less. The cables are flexible and easy to install the generation of cross talk is absent inside the fiber optic cables. This thesis consists of implementation of a optical transmission module using optical band filter and its analysis in form of Bit Error Rate and Quality factor. For better result tuning is done over some frequency range. And also comparison is done here between the designed transmission module and another transmission module which uses Fiber Bragg Grating and Hilbert transformer.

1.2 Motivation and Objectives

In today’s life the communication system needs to be get more fast and user friendly. The demand of good communication system is highly required in the era when we count the distance on tip of our fingers not on the meter scale, it’s the era of globalisation. The main communication medium is shifted towards microwave and radio frequency range and that too required security. This is a matter of concern that we are having very less number of companies which deals in optical equipment. Here our aim to analyse the performance of optical component in microwave frequency range communication system. The bit error rate, quality factor are the parameters which determines the power losses and the signal strength. The research work is carried out here to analyse this parameters for a better communication set up in optical domain.

1.3 Thesis Organisation

The rest of the report is organised as follows:

Chapter 2 includes an introduction of fiber optics with description of optical communication system, optical element, parameters .

Chapter 3 deals with literature review, including all the papers that helped to implement my proposed work.

Chapter 4 discusses the software used for simulation of circuits and results.

Chapter 5 contains the experimental work and results of the circuit.

Chapter 6 deals with summary and conclude the thesis with the indication of future work.

CHAPTER 2

OPTICAL COMMUNICATION SYSTEM

2.1 Optical Fiber Communication System

An optical fibre communication (OFC) system has three basic components transmitter, receiver and the transmission path as shown in the fig. 2.1

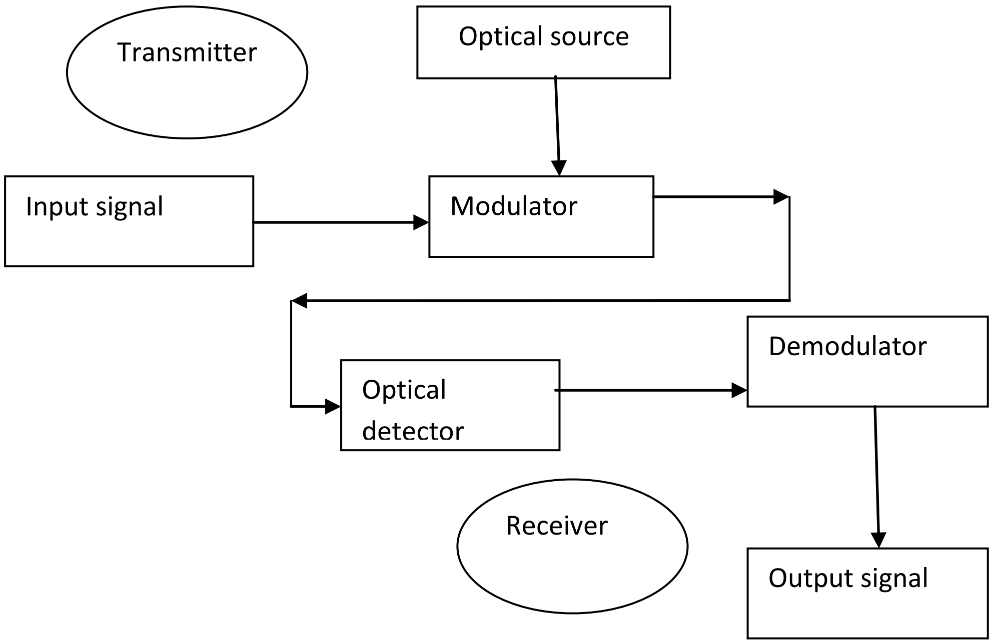


Fig. 2.1. Diagram of optical fibre communication system

In the transmitter side information to be conveyed enters the optical source. The optical source is a laser source which generates optical light signal at the certain wavelength. The data source and the optical signal are fed to the modulator and then the resulting modulated pulse signal propagates through transmission path which is an optical fiber . At the receiver side the optical signal is detected through an optical detector. The detector signal then passes through the demodulator to get the desired output signal. An optical fiber is flexible thin filament of silica glass that accepts electrical signals as input and converts them to optical signal. It carries the optical signal along the fiber length and reconvert the optical signal to electrical signal at the receiver side.

2.1.1 Advantages of OFC

- Optical fibers are cheaper than conventional wires.
- Optical fiber cables are flexible and easy to install.
- Optical fibers are less affected by fire.

- In optical fiber cables signal can propagate longer transmission distances like 50 km or more (single mode fiber cables) without the need to regenerate the signal.
- It is not affected by electronic noise and electromagnetic interference is absent.
- Easily upgradeable for higher speed and high bandwidth.
- Optical fiber cables support duplex communications, bidirectional transmission from transmitter to receiver and vice versa.
- Optical fiber cables do not suffer from electromagnetic interference as they carry light.
- Optical fiber support bandwidth of upto 40 Gbps.
- Even if many fibers run alongside each other, the chance of cross talk is very less and hence the signal loss is less compared to copper cables.

2.1.2 Challenges in Fiber Optic Communication

The key challenges in fiber optics communications (FOC)are: (i) Attenuation and (ii) Dispersion and bandwidth. Non-uniform effects in optical fibers are becoming increasingly important day by day.

- **Attenuation in Optical Fibers**

  Signal loss during transmission is the attenuation, which reduces the capability of the receiver to distinguish the signal from noise and also the transmission distance. Suppose optical power of 0dBm is coupled into an optical fiber, which has an attenuation of 1 dB/km at the transmission wavelength and the signal is collected at the receiver having noise floor corresponding to -60 dBm. If we ignore the effect of dispersion and assume that a signal-to-noise ratio of 20 dB is to be achieved for reliable detection, then the total length of the link is limited to 40 km.Attenuation is as a result of the partial transparency of the glass material constituting in optical fiber which will result in gradual reduction of amplitude of propagated signal and hence gain. In case of single mode fiber, effect dispersion can be neglected but the problem with attenuation is very serious issue. Transmission of signal in optical fiber ranges in between 1330nm and 1550 nm. Attenuation of silica fiber is in order of 0.2 db at 1550nm.

- **Dispersion and Bandwidth in Optical Fiber Communication**

  The other serious challenge in optical fiber communication is dispersion. Dispersion is the broadening of the input signal at the output side. Basically it is used to convey information. Dispersion is the main problem in digital transmission as it may cause intersymbol interference(ISI) Dispersion are of three types-(i)Intermodal dispersion(ii)Intramodel dispersion or chromatic dispersion (iii)Polarization mode dispersion. A single mode fiber carries only one mode and do not experience intermodal dispersion-the major benefactor to bandwidth limitation in multimode fibers.thus one would expect a single mode fiber to have very low dispersion or equivalently much higher bandwidth than a multimode fiber. This is absolutely true. However a single mode fiber is still a transmission medium, beacause of its nature of single mode fiber it dispersion is intermodal. The major mechanism that causes dispersion in singlemode fiber is “chromatic dispersion”

2.2 Introduction to Optical Amplifiers

Optical amplifiers are used to amplify an optical signal. An optical amplifier is capable of amplifying the attenuated optical pulses or signal. Optical amplifiers are divided in term of their function they perform.

The three basic types of optical amplifiers: power boosters, in-line amplifiers and preamplifiers.

a) Power booster amplifiers

   A booster is also called post amplifier. Boosters are power amplifiers that magnify transmitted signal before sending it to the fiber. Boosters increase the power of the optical signal to the highest level, which further increase the transmission distance. It produces maximum output power not the maximum gain , because the input signal is large.

b) Line amplifiers

   Its primary function is to compensate for power losses caused by fiber attenuation, connectors and signal distribution in networks. Hence the main requirement of this type of amplifier is stability over the entire WDM bandwidth.

c) Preamplifiers

   It magnifies a signal immediately before it reaches to receiver. Preamplifier operates with a week signal. Hence good sensitivity, high gain and low noise are the major requirement. Noise is the most important feature of preamplifiers because the performance of the receiver is limited not by its own noise but by the noise of the preamplifiers. Reasons to use the optical amplifier flexibility, reliability, wavelength division multiplex (WDM), low cost.

2.3 Working Principle of Optical Amplifiers:

Its main function is to amplifying the attenuated signal. When the number of charged particle rush at the higher energy level or the no of particle are high at the higher energy level that is called the population inversion. Population inversion is high at the higher energy level all due to the pumping of electrons to the upper level. When electrons at the metastable state has high decay period which lead to population inversion in metastable state with stable state, this leads to stimulated emission between metastable state and stable state.

- Applications
  a) Inline amplifiers
    - Input-25 to 20 dBm
    - Output~ 0 to 5 dBm
  b) Pre amplifiers
    - Input -35 to -35 dBm
    - Output~-15 to -10dBm
    - Gain ~20dB
    - Noise figure<5dB
  c) Power booster amplifiers
    - Input-5 to 0dBm
    - Output~10 to 20dBm
    - Gain~15dB
    - Noise figure<4dB

2.4 Classification of Optical Amplifiers

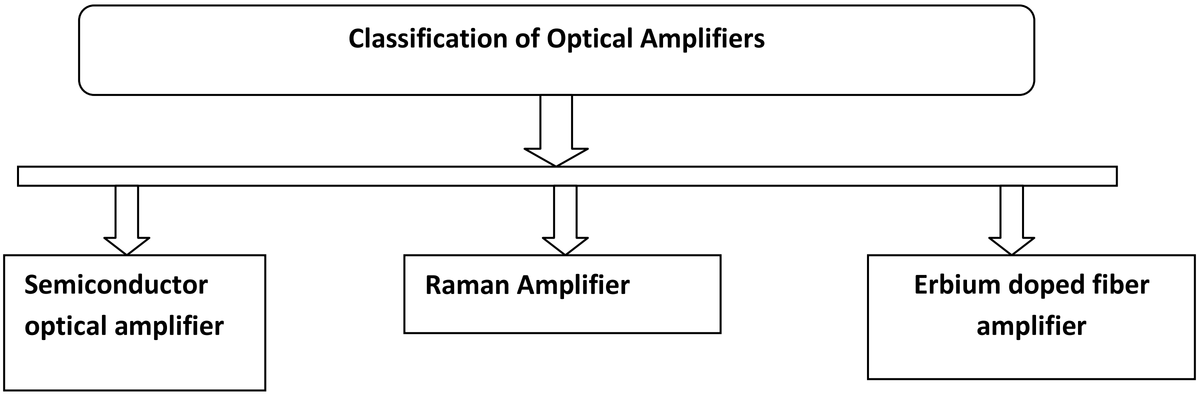


Figure 2.2 Classification of Optical Amplifiers

2.4.1 Semiconductor Optical Amplifiers

A semiconductor optical amplifier (SOA) works in a similar way to a basic laser. The structure is much the same, with two specially designed slabs of semiconductor material on top of each other, with another material in between them forming the “active layer.” An electrical current is set running through the device in order to excite electrons, which can then fall back to the non-excited ground state and give out photons (“particles ”of light).But there are two key differences. In a standard laser we want very reflective ends to keep light bouncing back and forth within the cavity. So the laser car has a rear-view mirror. With a semiconductor amplifier we need to get the optical signals straight into the cavity and then straight back out again, so we want to avoid light reflecting back into the cavity. This means that we do not want mirrors on the ends, and a semiconductor optical amplifier car has fuzzy dice obscuring the rear-view mirror. Also, in lasers we only want to get light out at one specific wavelength, and we design the device to make this possible (especially in Distributed Feedback DFB lasers). In a semiconductor amplifier we want to amplify light at as many wavelengths as possible. This is because we will have an incoming optical network signal that may have many different wavelengths that all need to be amplified at the same time.

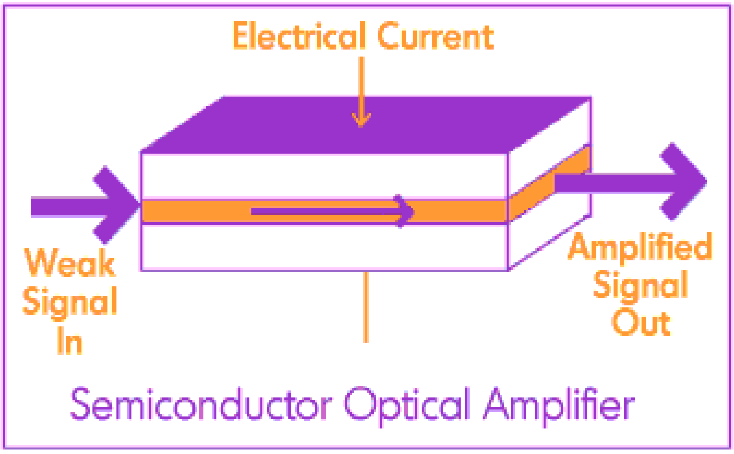


Fig 2.3: Semiconductor optical amplifier

The excited electrons in the semiconductor are now stimulated by incoming light from optical signals to move down to their ground states. The photon given out by an electron losing energy from its excited state exactly matches the photon that caused the emission in the first place. Therefore, there are now two photons representing one particular section of a signal where previously there was only one hence, the signal has been amplified. These two photons can now cause more stimulated emission as they travel down the device, until they all exit together as a successfully amplified signal. Semiconductor amplifiers do not currently give as much amplification as erbium doped-fiber amplifiers (EDFAs) can at the common 1550-nanometer region of wavelengths. However, they can be designed to amplify around the 1300nm transmission window, which may see them used in networks that use such wavelengths. In fact, as the demand for more wavelengths grows, systems may use both the 1300nm and 1550nm regions and semiconductor amplifiers may have an important role to play in such systems.

Key Points

- Similar to lasers, but with non-reflecting ends and broad wavelength emission
- Incoming optical signal stimulates emission of light at its own wavelength
- Process continues through cavity to amplify signal
- Can be designed for amplification around 1300nm or 1550nm

2.4.2 Raman Amplifiers

The Raman optical amplifier is based on an entirel different principle than EDFA’s or conventional lasers. In EDFA’s and conventional lasers, atoms are pumped to a high energy state and then drop to a lower state, releasing their energy, when a suitable wavelength photon passes nearby. Raman optical amplifiers utilize Raman scattering (the Raman effect, often called SRS - Stimulated Raman Scattering) to create optical gain. Initially SRS was considered to be a detriment to high channel count DWDM systems. In these systems, as light traveled down the fiber, energy would be "robbed" from the shorter wavelength channels, boosting the amplitude of the longer wavelength channels.

A Raman optical amplifier is not a "black box" like an EDFA. It consists of little more than a high-power pump laser, usually called a Raman laser, and a WDM or directional coupler. The optical amplification occurs in the transmission fiber itself. The optical amplification is distributed along the transmission line. Optical signals are amplified up to 10 dB in the network optical-fiber. The Raman optical amplifiers have wide gain bandwidth (up to 100 nm). They can use any installed transmission optical-fiber (single-mode optical fiber, TrueWave, etc.). In effect, they reduce the effective span loss and improve noise performance of the transmission line by boosting the optical signal in transit. They can be combined with erbium-doped fiber amplifiers (EDFA) to achieve very wide optical gain flattened bandwidth.

2.4.3 Erbium Doped Fiber Amplifiers (EDFA):

2.4.3.1 Introduction to EDFA Technology

Erbium doped fiber amplifiers came into existence in 1970, these type of fiber amplifiers are used as a power amplifiers. These amplifiers are located at the input of the transmitter in the optical communication system. EDFA is one of the common amplifiers used in optical communication.

2.4.3.2 Physical Principle of EDF Amplification

It works on the principle that the fiber itself acts as active medium for amplification.

EDFA is basically a heavily doped with Erbium ions during propagation of information pulse.

A separate pump laser is used to produce the optical light beam that co-propogates with the original information carrying optical pulse.

During the propagation the pumped pulse losses their energy like stimulated
and the energy is transferred to information carrying optical pulse.

- Working

  EDFA act as a waveguide when medium itself doped with erbium ions. The working can be explained on the basis of stark splitting .Stark splitting is uneven distribution of ions in the various energy levels.

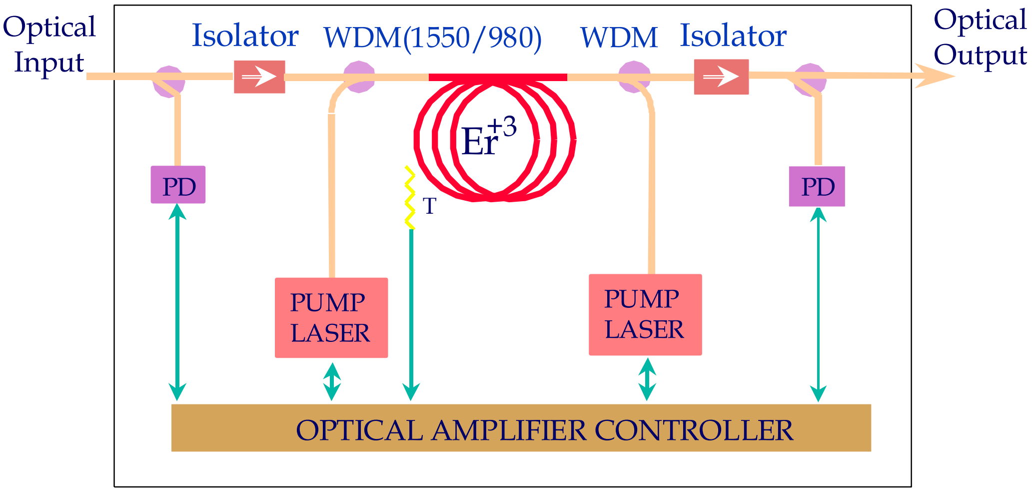


Figure 2.4. Basic block diagram of EDFA

Once EDFA is highly bombarded with optical beam produced from laser pump the excitation of the ions leads to formation of different energy levels containing different amount of charged ions. This process is called thermalisation. Because it involves unequal distribution of ions amongst the different energy levels , due to distribution of the thermal equilibrium.

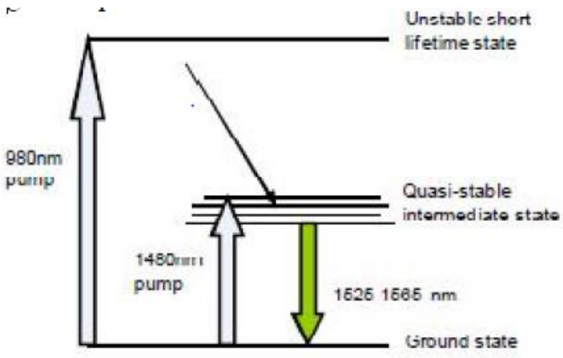


Figure 2.5: Energy levels of EDFA

Thermalization is the process in which we create a new energy level E2 or E3 which is highly semi stable state. This happens only when we apply an external energy to the system.

When the pump laser beam moves inside the fiber it carries the erbium ions to go to the excited state. Which leads to the formation of degenerate . This is energy level E2 and E3. If EDFA is further doped with floride ions then fourth energy level may also be possible E2 level being highly unstable and has small decay period and the charged particles immediately loose some part of energy to metastable state by spontaneous emission. As soon as laser pump leads to the formation of stimulated emission. The E2 level which is metastable state has high decay period(from E2to E1) which leads to population inversion in metastable state with respect to E1 state this leads to stimulated emission between E2 and E1 and the laser pump gives all its energy to the optical pulse producing waveguide amplification.

2.4.4 Basic EDFA Design

Basically EDFA consist of a length 10-30m EDF, a pump laser, and a WDM(wavelength division multiplexer) the main function of WDM is combining the input signal and light beam pumped by pump lase so that they co-propagate along the length of EDF. EDFA's can be designed such that pump energy propagates in the same direction along the signal is forward pumping and in the opposite direction to the signal is backward pumping but sometimes the energy propagates in both direction together with the signal. The pump energy may either be pumped by 980nm or 1480nm pump energy or a combination of both. The most common EDFA configuration is the forward pumping configuration 980nm pump energy, as shown in Figure below. Due to this forward pumping configuration they are cost effective and are reliable and have low power consumptions, thus providing the best design according to the performance level.

In a single stage EDFA , there are three main components EDF, pump and WDM combiner and additional optical components used to makes the performance level excellent and used to optimize the parameters of the EDFA and the performance. The signal enters the amplifiers through input port and then passes through the Tap which is used to convert the small percentage of the input power to the input detector. The signal then pass through the isolated before combining it with pump beam and the light beam is pumped bye 980nm pump laser diode. The input signal and the pump energy after being combined is passed along the length of the fiber and when the amplification takes place inside the fiber the amplified signal exist out through the fiber and the pump energy dies out and the amplified signal then pass through the second isolator. Which allow the signal to travel only in one direction and laser action does not takes place. The isolator also act as a filter for 980nm light travels in in the forward direction to stop the light existing out from the fiber from the output port. To optimize the performance and the gain in the EDFA we use gain flattening filter after the isolator. Which optimize the signal and remove the transient and the gain becomes flat.

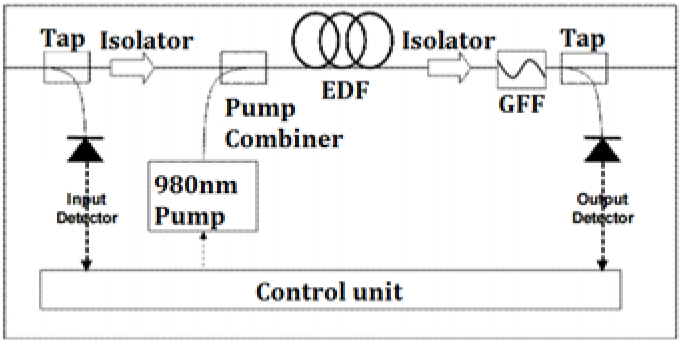


Fig. 2.6. Typical design of EDFA.

2.5 Pumping in EDFA

Our goal is to achieve population inversion, which means having more ions of erbium at the intermediate level (2) than at the lower level. To attain population inversion, we need to pump erbium ions at the intermediate level. There are two ways to do this: directly at the 1480 nm wavelength and indirectly 980nm wavelength. EDFA act as a waveguide when the medium itself doped with erbium ions. The working can be explained on the basis of STARK splitting.

Stark splitting refers to uneven distributions of ions into various energy levels, once edfa is highly bombarded with optical beam produced from laser pump. The excitation of ions lead to formation of different energy levels containing different amount of charged ions.this process is called thermalization because it involves unequal distributions of ions amongst the different energy levels due to distributions of the thermal equilibrium.

When the pump laser beam moves inside the fiber it causes the erbium ions to go into the excited state, which leads to formation of degenerates (this is called stark splitting or thermalization) energy level E and E3. If the EDFA is further doped with fluoride ions then fourth energy level may also be possible E3 level being highly unstable, has very small decay period and the charged particle easily and immediately loose some part of energy to reach to metastable state by spontaneous emissions soon as laser pump leads to the formation of stimulated emission. The E2 level which is metastable has very high decay period (from E2 to E1) which leads to population inversion in metastable state with respect to E1 state. This leads to stimulated emission between E2 and E1and the laser pump gives all of its optical energy to optical pulse producing waveguide amplification.

2.6 Gain and Noise in EDFA

Gain is the ratio of output power to the input light power, that is

Gain=P_{out} /P_{in}

Gain and noise are described as function of length of active fiber. Both gain and noise are higher for counter propagating pump .Gain and noise depends on the power of the input signal with an increase in the input power, gain decreases.

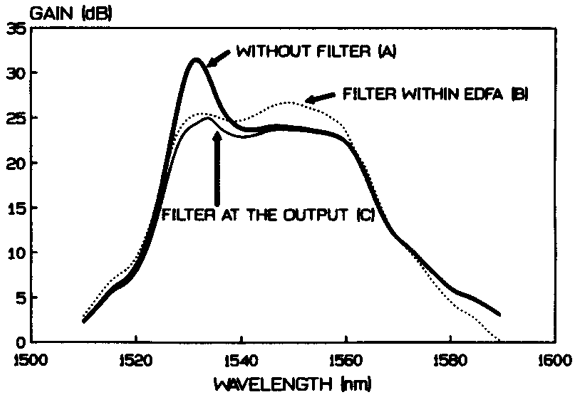


Figure 2.7 Gain vs Wavelength

While noise rises there is a specific input power where noise is minimum .The non-uniform gain profile with approximately peaks at 1530 nm, produces gain variation problems in a multi wavelength system when many amplifiers are travelling along a long transmission distance. Not only the non-uniform gain amplify different wavelengths indifferently, but it also causes a large problem of ASE noise at the peak of the gain profile, which can saturate the gain of the EDFA.

2.7 Gain saturations

Does gain depend on the power of input signal .A high power input signal mean huge number of photons per unit time will enter an erbium doped fiber .These photons will then stimulate a large number transitions per unit of time from the intermediate level(2) to the lower level (1). This means the intermediate level will rapidly depleted cofficients photons or we can say that greater the input light power, the less populated the intermediate level (2) will become. As the principle of stimulated emission tells us gain is directly proportional to the difference in population of level (2) and (1), depleting level (2) mean decreasing gain. This phenomenon is gain saturation. Gain saturation is important characteristics of EDFA.

2.8 Gain Ripple

Gain ripple in EDFA refers to the uneven gain spectrum which is depends on the wavelength and absorption coefficients of the erbium doped fiber, the ground and the excited state of the erbium is measured by populations on each state. To reduce the gain ripple we use gain flattening filters. If channel is loaded and the traffic is increased due to the presence of ions leads to population inversion and also variations in the gain and the spectral hole which will burning the effect of the gain flattens of the EDFA. There are two types of appearance of uniform gain: Gain equalization and Gain flattening. Gain equalization means attain a non-comparable gain. Gain flattening means attaining a uniform gain bandwidth.

EDFA gain flattening techniques based on six different principles are gain clamping due to gain saturations, use of passive filters, use of external active filters, cascading EDFA with different optical gain spectra, spatial hole burning in twin core fibers, adjustment of signal powers[18]. Due to the increase in the signal traffic or the noise traffic the number of WDM channel are increased so the demand of EDFA also increased. EDFAs are now required to provide a uniform or a flat gain over a broad range of wavelength and also there are changes in optical power levels due to add and drop channels along the link, this is called dynamic gain flattening .There are different methods to flatten the gain spectrum of EDFA.

2.9 Gain Flattening

The Gain is mainly depend on the wavelength of the input signal and is mostly restricted by width of energy bands. Actually gain in the form of curves fluctuates between two frequency range 1525 nm to 1560 nm and from 1565 nm to 1610 nm. These two ranges are known as C-band and L-band. There are twin peaks at these frequency range which is the non-linearity of gain. We should have a flat gain in these two ranges. This property of EDFA amplifiers is called gain flatness. The clamping is the drop in the nonlinearity in the gain or fixed drop in Gain from fluctuating to stable gain.

2.10 Techniques for Flattening the Gain Spectrum for EDFA

There are different methods or techniques which are used to optimized and flatten the gain as classified below:

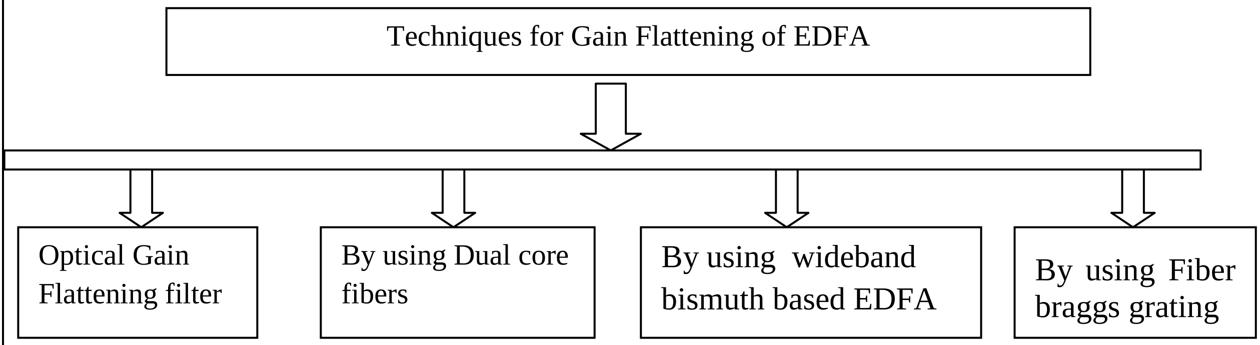


Figure 2.8 Techniques for gain flattening of EDFA

2.10.1 Optical Gain Flattening Filters

The uneven gain profile of an EDFA can be flattened by using optical filters to adjust the transients of gain or to remove the peaks of the gain. There are various optical filters used to flatten the gain are long period fiber grating, fiber acousto-optic tunable filter, Machzehnder filter etc. There are many filters to flatten the gain but we are using optical gain flattening filter to flatten the gain spectrum. The principles of optical gain flattening filter are shown in figure 2.9.

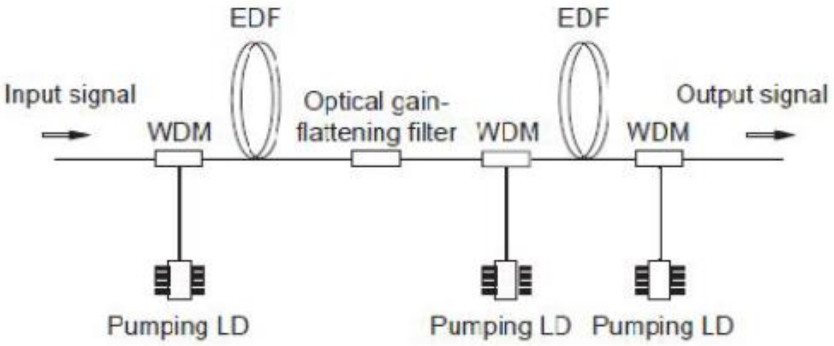
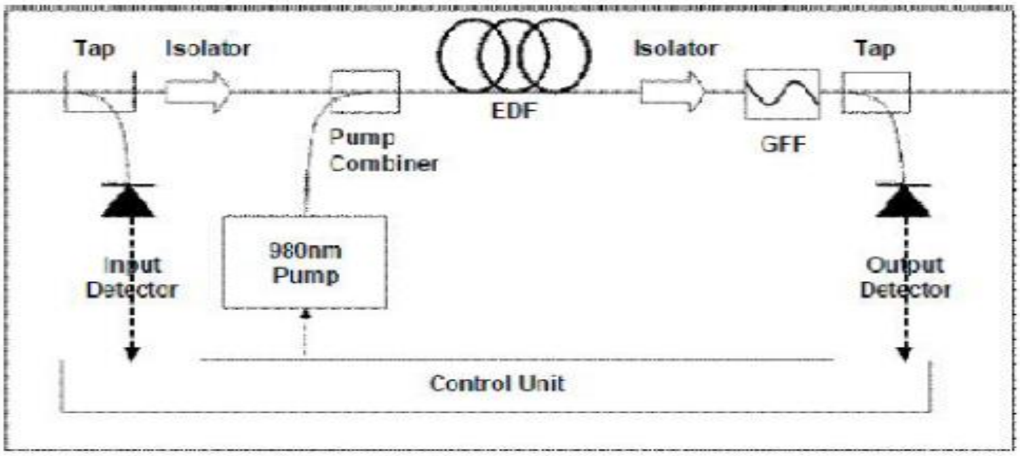


Figure 2.9 Gain flattening filter

In figure it is shown that gain of EDFA depends on wavelength. Due to the dependence of EDFA on wavelength flattened the gain profile of EDFA and the deviation is improved.



: Fig 2.10: Optical gain flattening filter

Gain flattening filter is placed in between the isolator and the tap. The GFF is incorporated in the middle stage of EDFA between two erbium doped fibers due to this filters the gain wavelength characteristics have asymmetrical twin peaks and a loss wavelength characteristics of a optical gain flattening filter to adjust the EDFA gain wavelength characteristics .

2.10.2 Dual Core Fiber

Most of the techniques use expensive components and complicated circuits or designs. The use of dual core fibers or twin core fibers is also obvious choice in which both the cores are identically doped with erbium ions. Gain flattening by twin core fiber was suggested by laming et al in 1993.it involves the concatenation of single core EDF with length of twin core EDF. The main purpose of edf twin core fiber is to introduce spatial hole burning which decreases the excessive gain at certain wavelength. Wu and chu has also suggested the use of twin core fiber for gain flattening by launching pump power in both cores. The power ratios have to be predetermined.

The EDFA with flat gain over a wide wavelength range can simply be constructed by means of a length of dual-core fiber. This fiber consists of twin cores which are closely spaced, one of which is doped with erbium and the other is non-doped.

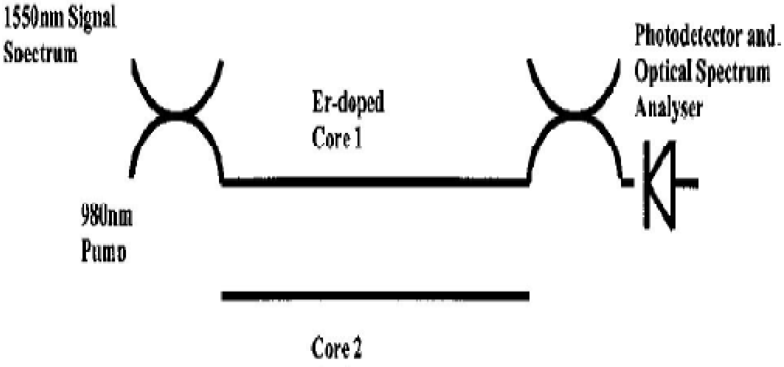


Fig. 2.11: Structure of dual core Fibers.

This diagram consists of three components: 1) the input fiber coupler which combines the 1480nm signal and the 980 nm pump power into one of the cores of the fiber; 2) the dual core fiber; and 3) the output fiber coupler which separates the amplified 1480 nm signal from the residual pump power. Only the erbium-doped core is used for connection to the two couplers. The other core which is un-doped is not used.

The principle of operation is that the coupling efficiency from core 1 to core 2 is very high at the wavelength where the gain is also very high, i.e., at 1533 nm. In this case, the excessive signal is coupled to core 2 which is not used. On the other hand, the coupling efficiency from core 2 to core 1 at this wavelength is minimum, so that this excessive signal that has been coupled to core 2 would not return to core 1.The doped core is an amplifying medium whereas the non-doped core is a passive medium.

2.10.3 Composite Filters.

Gain flattening is done by using composite filters which is the another method to flatten the gain of EDFA by incorporating isolator in between the erbium doped fibers. The active length of two erbium doped fiber with the isolator spliced in between. The amplifier is pumped by 980nm pump energy in the forward direction. Therefore the pump power and input signal co-propagate along the EDF length. Without the isolator, the backward ASE noise rises to a maximum value towards the input of the amplifier and depletes the population -inversion of the gain medium. Pump power is used to amplify signal travelling backward along ASE noise and the signal dies .this causes an increase in noise characteristics and gain becomes non-uniform.if the there is isolator in between the EDF improves the noise figure an increase in the gain spectrum and there is uniform gain. As the ASE effect is reduced. It is well known that an erbium-doped fiber has a strong absorption in the wavelength range 1500 – 1600 nm.

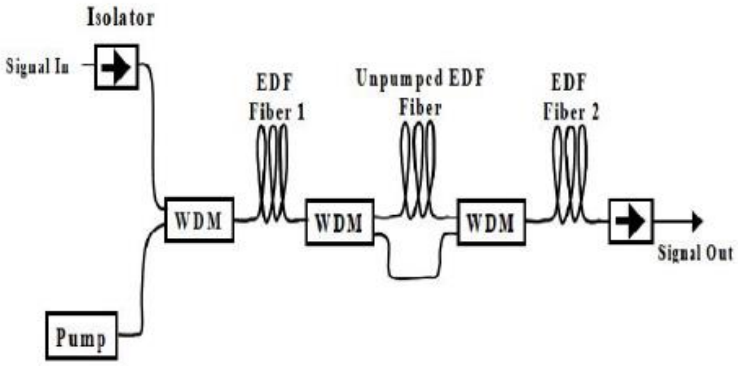


Fig 2.12: Structure of composite filter

It is well known that an erbium-doped fiber has a strong absorption in the wavelength range 1500 – 1600 nm, which is wavelength dependent.

2.10.4 Fiber Braggs Gratings:

One of the most commonly used and broadly deployed optical sensors is the fiber Bragg grating (FBG), which reflects a wavelength of light that shifts in response to variations in temperature and/or strain. FBGs are constructed by using holographic interference or a phase mask to expose a short length of photosensitive fiber to a periodic distribution of light intensity. The refractive index of the fiber is permanently altered according to the intensity of light it is exposed to. The resulting periodic variation in the refractive index is called a fiber Bragg grating.

When a broad-spectrum light beam is sent to an FBG, reflections from each segment of alternating refractive index interfere constructively only for a specific wavelength of light, called the Bragg wavelength, described in equation (1). This effectively causes the FBG to reflect a specific frequency of light while transmitting all others.

$$\lambda_b = 2n\Lambda \qquad (1)$$

In equation (1), λ_b is the Bragg wavelength, n is the effective refractive index of the fiber core, and Λ is the spacing between the gratings, known as the grating period.

Because the Bragg wavelength is a function of the spacing between the gratings (L in Equation 1), FBGs can be manufactured with various Bragg wavelengths, which enables different FBGs to reflect unique wavelengths of light.

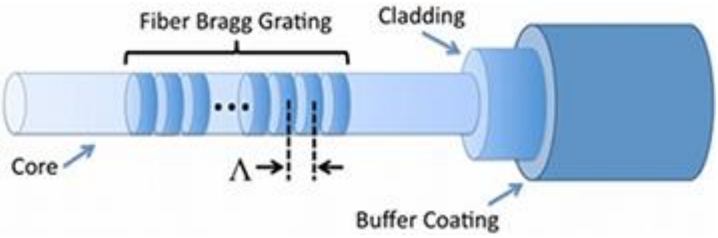


Fig 2.13: An expanded view of an FBG

Changes in strain and temperature affect both the effective refractive index n and grating period Λ of an FBG, which results in a shift in the reflected wavelength. The change of wavelength of an FBG due to strain and temperature can be approximately described by equation (2):

where $\Delta\lambda$ is the wavelength shift and λo is the initial wavelength.

The first expression describes the impact of strain on the wavelength shift, where p_e is the strain-optic coefficient, and ε is the strain experienced by the grating. The second expression describes the impact of temperature on the wavelength shift, where α_Λ is the thermal expansion coefficient and αn is the thermo-optic coefficient. αn describes the change in refractive index while α_Λ describes the expansion of the grating, both due to temperature.

Because an FBG responds to both strain and temperature, you need to account for both effects and distinguish between the two. For sensing temperature, the FBG must remain unstrained. You can use packaged FBG temperature sensors to ensure the FBG inside the package is not coupled to any bending, tension, compression, or torsion forces. The expansion coefficient α_Λ of glass is practically negligible; thus, changes in the reflected wavelength due to temperature can be primarily described by the change in the refractive index αn of the fiber.

2.11 Electroabsorption Modulator

An electro absorption modulator (or electro-absorption modulator) is a semiconductor device which can be used for controlling (modulating) the intensity of a laser beam via an electric voltage (→ optical modulators). Its principle of operation is based on the *Franz–Keldysh effect* , i.e., a change in the absorption spectrum caused by an applied electric field, which changes the band gap energy (thus the photon energy of an absorption edge) but usually does not involve the excitation of carriers by the electric field.

Most electroabsorption modulators are made in the form of a waveguide with electrodes for applying an electric field in a direction perpendicular to the modulated light beam. For achieving a high extinction ratio, one usually exploits the quantum-confined Stark effect in a quantum well structure.

Compared with electro-optic modulator, electroabsorption modulators can operate with much lower voltages (a few volts instead of hundreds of thousands of volts). They can be operated at very high speed; a modulation bandwidth of tens of gigahertz can be achieved, which makes these devices useful for optical fiber communications. A convenient feature is that an electroabsorption modulator can be integrated with a distributed feedback laser diode on a single chip to form a data transmitter in the form of a photonic integrated circuit. Compared with direct modulation of the laser diode, a higher bandwidth and reduced chirp can be obtained.

The EA Modulator device is located in the **OptoElectric** library. It has 2 electrical ports for the bias and RF driving and 2 optical ports as an input and output. The EA modulator is driven with a voltage source device which is called ‘Vpulse’ and is located in the electrical library. The Vpulse generates a pulse with 2 ns duration, 0.4 ns rise and fall time from -1.5 to 0 V. The other electrical input of the EA modulator is grounded. The optical input to the EA modulator is from a CW laser device located in the **OptoElectronic** library and is called 'CW Source'. The wavelength of the laser is set to 193.1 THz.

2.12 Circulator

In fiber optical networks passive components such as optical isolators are essential for delivering of signals with minimum loss. Another type of passive element that is commonlyused in fiber optic system is the optical circulator. These devices that are used to direct the optical signal from one port to another port and in one direction only. This action prevents the signal from propagating in an unintended direction. Optical circulators have continued to increase their presence in a broad array of applications, including optical amplifiers, optical add and drop systems, dense wavelength-division multiplexing (DWDM Mux) networks and, optical time domain reflectometers (OTDRs).

In a 3-port circulator a signal is transmitted from port 1 to port 2, another signal is transmitted from port 2 to port 3 and, finally, a third signal can be transmitted from port 3 to port 1. This behaviour is represented by the following.

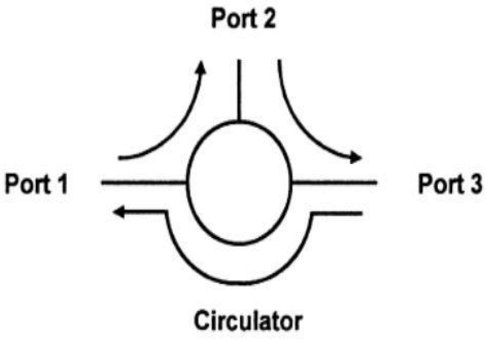


Figure 2.14: Conventional figure to represent the behavior of an optical circulator.

The name derives from the fact that a signal is transmitted from Port 1 to Port 2, another signal can be transmitted from Port 2 to Port 3 and, finally, a signal can be transmitted from Port 3 to Port 1. In practice, one or two ports are used as inputs and the third port is used as the output.

To simple examples of optical circulators can be considered. The first is an EDFA amplifier (erbium doped fiber amplifier) application to amplify a signal. The configuration to do this with a three-port optical circulator is shown in the following figure.

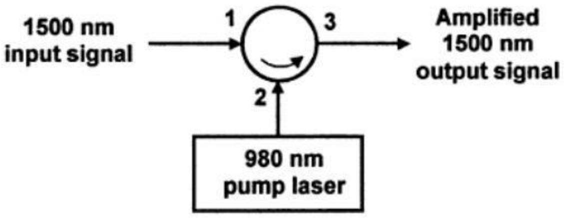


Figure 2.15: Amplification of an input optical signal by a pump laser.

In the fig 2.15, a weak optical signal at 1550nm is input to Port 1 and is directed to Port 2. The weak signal at Port 2 is pumped by a 980nm pump lasers and the amplified signal is then transmitted from port 2 to the output Port 3.In the second example, we consider the application of a Fiber-Bragg grating compensator to correct a distorted signal. This can also be done using a three-port optical circulator as shown in the following figure.

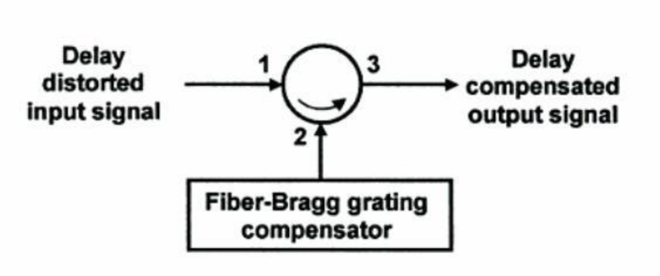


Figure 2.16 : Fiber dispersion compensation of a distorted signal.

In the fig. 2.16 the distorted signal at Port 1 is conditioned by transmitting the delay distorted input signal to the input of Port 2. At Port 2 dispersion compensation is applied and the compensated (corrected) signal is transmitted to Port 3. We now analyze the operation of the three-port optical circulator. We begin by considering the figure 2.17 shown below.

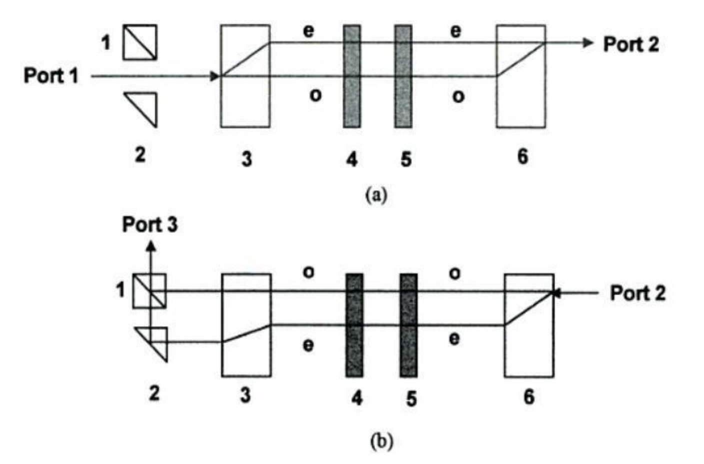


Figure 2.17: Configuration of a 3-port optical circulator.

The components are a beam splitting polarizer (1), a reflection prism (2), two birefringent crystals (3,6), a Faraday rotator (4), and a half-waveplate (5). The upper figure (a) describes the propagation from Port 1 to Port 2 and lower figure (b) describes the propagation from Port 2 to Port 3.

Optical circulators can be used to achieve bi-directional optical signal transmission over a single fiber. Optical circulators is commonly used in WDM networks, polarization mode dispersion, chromatic dispersion compensation, optical add-drop modules (*DWDM OADM*), optical amplifiers, OTDR and fiber sensing applications. Fiberstore offer 3/4 ports polarization-insensitive optical circulator and 1310/1550/1064 polarization-maintaining (PM) optic circulators. Our fiber optical circulators can provide high isolation, very low insertion loss, low polarization dependent loss (PDL), low polarization mode dispersion (PMD), and excellent environmental stability. Any other wavelengths, without or with any connector can customized according to our requirement.

2.13 Polarisation Controller

A **polarization controller** is an optical device which allows one to modify the polarization state of light. Polarization controllers can be operated without feedback, typically by manual adjustment or by electrical signals from a generator, or with automatic feedback. The latter allows for fast polarization tracking. A polarization controller can have the task of transforming a fixed, known polarization into an arbitrary one. Since polarization states are defined by two degrees of freedom, for example azimuth angle and ellipticity angle of the polarization state, such a polarization controller needs two degrees of freedom. The same holds for the task of transforming an arbitrary polarization into a fixed, known one.

More general is the transformation of an arbitrary polarization into another arbitrary polarization. This needs three degrees of freedom. Such a polarization controller can for example be obtained by placing on the optical path three rotatable waveplates in cascade: a first quarterwave plate ,which is oriented to transform the incident elliptical polarization into linear polarization, a halfwave plate, which transforms this linear polarization into another linear polarization, and a second quarterwave plate, which transforms the other linear polarization into the desired elliptical output polarization.

Polarization controllers can be implemented with free space optics, through a fiber pigtailed U-bench, for example. In that case, light exits the fiber, passes through the three waveplates, that can be freely rotated to allow polarization adjustment and then enters back into the fiber. Polarization controllers can also be implemented in an all-fiber solution. In that case, the polarization of light is changed through the application of a controlled stress to the fiber itself.

2.13.1 Features

- Smooth & Convenient control of State of Polarization
- Various Wavelength range & buffered fiber type

2.13.2 Applications

- Fiber Lasers
- Fiber Optic Interferometers
- Optical communication
- Fiber optic sensors

2.14 Power Splitter/Combiner

A Splitter/Combiner cable of module connect between dual-fiber and single-fiber optical signals, potentially doubling the data capacity of the installed fiber plant. Separate Tx and Rx signals from a dual-fiber optical device using the same wavelength over two fibers can be combined through the Splitter/Combiner onto a single bi-directional strand of fiber for the long and expensive run to the remote site. Another Splitter/Combiner at the remote site splits and combines the signals for the dual-fiber device at that location. Splitter/Combiners are fully passive, and they operate at a specific wavelength. They are transparent to networks and protocols. A pair of cables, as in the example above, attenuates an optical signal by no more than 7 dB on either single mode or multi-mode fiber. Signal reflections are effectively eliminated with angled polished connector (APC) at the single-fiber “common” interface.

2.15 Hilbert Transform

Fourier, Laplace, and z-transforms change from the time-domain representation of a signal to the frequency-domain representation of the signal.The resulting two signals are equivalent representations of the same signal in terms of time or frequency. In contrast, The Hilbert transform does not involve a change of domain, unlike many other transforms, the Hilbert transform is not a transform in this sense First, the result of a Hilbert transform is not equivalent to the original signal, rather it is a completely different signal Second, the Hilbert transform does not involve a domain change, i.e., the Hilbert transform of a signal x(t) is another signal denoted by in the same domain (i.e. time domain). The Hilbert transform of a signal x(t) is a signal whose frequency components lag the frequency components of x(t) by 90° has exactly the same frequency components present in x(t) with the same amplitude– except there is a 90° phase delay.

The Hilbert transform of x(t) = $A\cos(2\pi f_0 t + \theta)$ is $A\cos(2\pi f_0 t + \theta - 90°) = A\sin(2\pi f_0 t + \theta)$ There will be a delay of π/2 at all frequencies and

$e^{j2\pi f0t}$ will become

$$e^{j2\pi f_0 t - \frac{\pi}{2}} = -je^{j2\pi f_0 t}$$

and

$e^{-j2\pi f0t}$ will become

$$e^{-j(2\pi f_0 t - \frac{\pi}{2})} = je^{j2\pi f_0 t}$$

At positive frequencies, the spectrum of the signal is multiplied by –*j*.At negative frequencies, it is multiplied by +*j*.This is equivalent to saying that the spectrum (Fourier transform) of the signal is multiplied by -*j*sgn(*f*).

Assume that x(t) is real and has no DC component : $X(f)|_{f=0} = 0$, then

$$F[\hat{x}(t)] = -j\,\mathrm{sgn}(f)X(f)$$

$$F^{-1}[-j\,\mathrm{sgn}(f)] = \frac{1}{\pi t}$$

$$\hat{x}(t) = \frac{1}{\pi t} * x(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau}\,d\tau$$

The operation of the Hilbert transform is equivalent to a convolution, i.e., filtering. Obviously performing the Hilbert transform on a signal is equivalent to a 90° phase shift in all its frequency components. Therefore, the only change that the Hilbert transform performs on a signal is changing its phase. The amplitude of the frequency components of the signal do not change by performing the Hilbert-transform .On the other hand, since performing the Hilbert transform changes cosines into sines, the Hilbert transform of a signal x(t) is orthogonal to x(t) Also, since the Hilbert transform introduces a 90° phase shift, carrying it out twice causes a 180° phase shift, which can cause a sign reversal of the original signal.

CHAPTER 3

LITERATURE REVIEW

Optical communication includes many components and many research work are going on in optical communication system .Response is measured in the term of Q factor and Bit Error Rate and tuning of CW Laser is necessary to get a better response in the detector side. The analysis of these parameters is necessary to decide the behaviour and characteristics of the communication system.

1. **N Sindhu And P. K. Shafeena Et Al,"Gain Flattening In Erbium Doped Fiber Amplifier Based Optical Communication – A Review"(March,2013)**: It Is Just A Review Paper That Explain The Application Of EDFA. According To This Paper For Single Channel Systems, The Gain Variation Is Not A Problem. However, For A Multichannel System, The Transmission And The Gain Variations Problem Increases, Because EDFA Has Un-Even Gain. Tough The Typical Gain Is Obtained Between 1525nm And 1530 Nm And The Useful Gain Bandwidth May Be Reduced To Less Than 10 Nm. The Gain Of Edfas Depends On A Different Parameters Such As Erbium-Ion Concentration, Amplifier Length, And Core Radius And Pump Power.

2. **Sunil Kumar Panjeta Et Al,"Gain Optimization Of EDF Optical Amplifier By Stages Enhancement And Variation In Input Pumping Power"(2012) :** With A Similar Aim Of Keeping The Gain And Bandwidth Constant, The Author Worked By Enhancing And Comparaing The Stages And Varying The Input. This Paper Aims To Analyze The Performance Of Gain In EDF Amplifier By Increasing The Stages Of EDF Amplifier From Single Stage To Dual Stage By Adding CFBG(Chirped Braggs Grating). The Circuit Will Analyze The Performance Of The Network By Comparing The Stages And Also Comparing The For The Speed. It Is Evident That EDFA Improves The Performance. The Circuit Consists Of Components Such As An Input Source, Isolator, Pump Source, Erbium Fiber And WDM Coupler And Simulates The Performance Of EDFA By Changing The Values Of Different Parameters Such As Amplified Spontaneous Emission, Minimum Gain, Maximum Gain, Average Gain, Noise Figure, Gain Flatness, Gain Tilt Etc. Efficiently.

3. **Naveen Kumar, Ramachandran K Et Al,"Sagnac And Mach-Zehnder Interferometer Based Gain Flattening Of EDFA"(2012,December):** The Paper

Aims At Obtaining The Gain Flattening By Using Sagnac And Mach-Zehnder Interferometer.Due To The Need Of High Capacity Of Data Transmission Over A Long Haul Opticalcommunication ,. Different Methods For Gain Flattening Has Been Defined. Polarizations Maintain PMF Or Over Coupled Coupler Based Loop Mirror Configuration Easily Flatten The EDFA Gain Over A Range Of 30nm. But These Techniques Suffer From High Insertion Losses Due To Splicing Between Polarization Maintain Fiber (PMF) And Single Mode Fiber (SMF) Or The Use Of Over Coupled Coupler. Long Period Fiber Grating (LPG) Based Methods For EDFA Gain Equalization Has The Drawback Of Polarization Dependent Filtering Action And Are Suitable Only For A Specific State Of Polarization (SOP) Communication. Recently Mach-Zehnder Interferometer (MZI) Based Thermally Tunable Gain Flattening Technique Employing Planar Light Wave Circuit (PLC) Platform Was Proposed . The Gain Spectrum Of An Erbium Doped Fiber Amplifier Has Been Flattened Over A Range Of 35nm With An Accuracy Of -0.4 Db By Using A Novel All-Fiber Interferometric Configuration.

4. **M. H. AI. Mansoori Et Al “Performance Evaluation and Optimization of Dual-stage L-band EDFA Utilizing Short gain Medium”(2012, October) :** In this paper a High sensitivity dual stage L-band erbium doped fiber amplifier (L-EDFA) has been optimized using different performance parameters such as gain and noise figure for different erbium doped fiber (EDF) ions concentration, EDF pump power, input signal power , pump wavelength, power and directions. When these parameters are used , the dual-stage module will give a better performance of gain and noise figure by using short gain medium. The EDF amplifier obtain high gain of 50 dB with noise figure less than 4 dB using 7 meters length of EDF.

5. **X. S. Cheng[1] and B. A. Hamida[2] Et Al,” Compact and wideband bismuth based erbium doped fiber amplifier based on two stages and double pass approaches”(January 2012):** in this paper, a wideband erbium doped fiber amplifier (EDFA) working in C-Band and L-Band wavelength region is described and based on two stages and double pass configuration. The amplifiers employs two EDFs of 21cm and 46 cm which act as a gain medium in both C-Band and L-Band region respectively, which are pumped at 1480 nm laser diode and its performance are noticed or analysed in both parallel and linear configurations wideband operation is

attained by both the configurations that covers the wavelength form 1525 to 1620 nm. The parallel Bi-EDFA provides a higher attainable gain than linear Bi-EDFA especially for small input signal. At input power signal of -30 dB, the total gain of parallel Bi- EDFA achieved is approximately 20 dB with gain variations of +_2.5 dB with in wavelength rages from 1525nm to 1605 nm. At the input signal power of 0 dBm, the total gain of approximately 10 dB with gain variations of +_ 2 Db within 1540 to 1620 nm range achieved by both parallel and linear Bi-EDFAs. The noise figure achived for both parallel and linera Bi-EDFAs are below 10 dB at wavelength range from 1535 to 1620 nm. the noise figure is due to spurious reflection in cavity and high reflections of amplified spontaneous emission(ASE) from the end face.

6. **Wang Hui and Wang Jialiang Et Al, "Characteristic analysis of two-stage Erbium-Doped superflourescent fiber Source" (2012):** The research and exploration of Erbium-Doped superflourescent Fiber source (EDSFS) has been an important issue in two stage proposed EDSFS but there are no more details , structures and comparative analysis for the two structures of EDSFS.in this paper the single stage and the two stages were detailed and simulated by EDF fiber simulation software. The relationship between different parameters (Total pump power, Er-doped fiber length, output ASE , mean wavelength and spectral width) are analysed. The mean wavelength were falttened against the total pump power through the simulation. Finally the conclusion come out that optimizing the fiber length ratio and pump power ratio can attain a SFS with greater Spectral width, higher input power and high stability.

7. **N. Md. Yusoff ,Z. Abd. Rahman Et Al,"Gain-flattened Dual-stage L-band EDFA by Using Pump Power Distribution"(2011) :** In this paper An L-band erbium doped fiber amplifier(EDFA) with dual stage module was proposed that gives a flatten wavelength responses of less than 3 dB gain variations or fluctuations. Gain of 26 dB was attained throughout the l-band region (1570-1605nm) and noise figure of less than 4.5 dB when pump power was same for two different stages with different length of erbium doped fiber(EDF) without using any gain equalizing filter, the module is able to give a flat gain spectrum when input signal power is varied from -30 dBm to -15 dBm.

8. **R**. K. **Varshney, A. Singh, K. Pande, B. P. Pal Et Al," Side Polished Fiber-Based Gain Flattening Filter for Erbium-Doped Fiber Amplifiers"(2006,October):** In this paper a simple and accurate noval method is demonstrated the main process of the effect of non-uniform depth of polishing it means the study of transmission characteristics of optical waveguide device based on side polished fiber with multimode planar guide. We use the same method for the gain flattening of EDFA. The filtering actions of over all device could maintain the gain flattening within ±0.7 dB over a wavelength range of 32nm. in C-Band.

9. **Ni, Na, Chan. Chi Chiu, Tan Khey Ming Et Al,"Broadband EDFA Gain Flattening by using an embedded Long Period Fiber Grating Filter"(2006):** The Main Aim of this Paper is to faltten the gain by using a technique called embedded long period fiber grating. By using this technique a flattened gain at the range 34 nm with gain ripple of 1 dB. This method is proved to be simple and feasible.

10. **Naveen Kumar,M. R. Shenoy,B. P. Pal Et Al,"A Standard Fiber-Based Loop Mirror as a Gain Flattening Filter for Erbium Doped Fiber Amplifiers"(2005, October):** we investigate the gain flattening of ASE spectrum from an EDF by using fiber based loop mirror. By introducing bend induced birefringence in a loop,the ASE spectrum of edf is flattened within ±0.5 dB over a range of 32nm wavelength in C-Band.
11. **Ik. Bu Sohn,Jang Gi- Baek,Nam Kwon Lee,Hyung Woo Kwon and Jae Won Song Et Al,"Gain Flattened and Improved EDFA by using microbending Long Period Fiber Gratings"(Electrronic letter 2002, October):** In this letter the gain is flattened and EDFA is improved by using microbending long period fiber grating filter.in this paper the gain variation achived by this is <1 dB over wavelength range of 34 nm with two different pump power 34 and 86 mW. The gain is improved to 1.94 and 5.32 dB by using LPFG filter which is all depend on both the pump powers.

12. **Uh. Chan Ryu Et Al,"Inherent Enhancement of Gain Flatness and Achievement of Broad Gain Bandwidth in Erbium Doped Silica Fiber amplifiers(2002,February):** The main of this paper is to inherently increase the gain flatness and bandwidth of erbium doped silica fiber by three methods: the first perspect is to achieve the control on the gain spectrum inherently. The proposed

structure of composite fibers with Er-doped core and sm-doped cladding is experimentally analysed.in this Sm-doped cladding is used to control the gain fluctuations in EDFA C-band. Secondly by optimizing the spectral characteristics of WDM coupler over L-band of edfa. The gain above 21 db was obtained with 0.9 Db fluctuations and a gain tilt of ±0.5 dB/nm.no filtering device is used and a dynamic gain of 11.5 db was obtained under saturation condition.

13. **Seok Hyun Yun, Bong Wen Lee, Hyang Kyun Kim Et Al , " Dynamic EDFA Based on Active Gain Flattening with Fiber Acoustooptic Tunable Filter"(1999,October):** in this paper we first describe the analysis of dynamic EDFA by using technique of active gain flattening. The filters are all fber based acoustooptic used for controllable fiter configurations. Due to this Wide dynamic range of gain and power contol are achieved with <0.6 dB ripples over the wavelength range of 30 nm.

14. **Seo Yeon Park, Hyang Kyun Kim, Sun Mo Kang, Sang Yung Shin Et Al , "Dynamic Gain and Output Power Control in a Gain Flattened Erbium Doped Fiber Amplifiers"(1998,June):** In this paper we investigate an erbium doped fiber amplifier with flat gain spectrum over the wave length range of 18 nm with constant per channel of output power. The gain flatness is achived by costant output power by changing pump power and attenuation.

15. **M. Tachibana, R. I. Laming, P. R. Morkel, D. N. Pyne Et Al , " Erbium-Doped Fiber Amplifier with Flattened Gain Spectrum"(1991, February):** In this paper the main aim is to flatten the gain spectrum by placing the notch filter within the length of EDFA. Due to this we will enhance the gain with different parametes like wavelength , input power, output power etc. By using the notch filter technique to flatten the gain spectrum.Due to this 27 dB gain with 3 db bandwidth over the wavelength range of 33 nm are obtained with 38 mW pump power pumped at 980 nm pump wavelength. More efficiency is improved by further fiber optimizations.

CHAPTER 4

SOFTWARE USED

4.1 Optisystem

Optisystem is a famous optical communication system software simulation package for designing, testing and optimization of any of the optical link of the transmission of broad spectrum of optical networks. A system level simulator is a realistic designing of fiber optic communication system.

Optisystem is a standalone product that doesn't rely on any other simulation framework. Optisystem possesses a very good environment of simulation of different components in the system and a hierarchical definition of testing of each components module and system. Its capabilities can be easily expanded with the additions of user components and interference to the use of widely used software. There are many models and tools in optisystem. The description of basic and relevant tools to be used in my project or in any project.

4.1.1 Benefits

1. Rapid, low cost prototyping
2. Global insight into system performance
3. Straight access to extensive set of system characterization data.
4. Automatic parameter scanning and optimizations.

4.1.2 Starting Optisystem

To start optisystem, performs the following Action

From the start menu, select Programs> Optiwave software>Opisystem >optisystem.

Main part of GUI

The optisystem GUI contain the following main windows

1. Project layout
2. Dockers
    2.1 Component library
    2.2 Project browse.

    2.3 Description.

3. Status bar

4.1.3 Optical Spectrum Analayzer

It displays the modulated optical signal in frequency domain .

4.1.4 Optical Sources

- a) CW laser
- b) Pump laser
- c) White light source
- d) Laser measured
- e) Laser rate equation

CHAPTER 5

EXPERIMENTAL SET UP AND RESULTS

5.1 Experimental set up

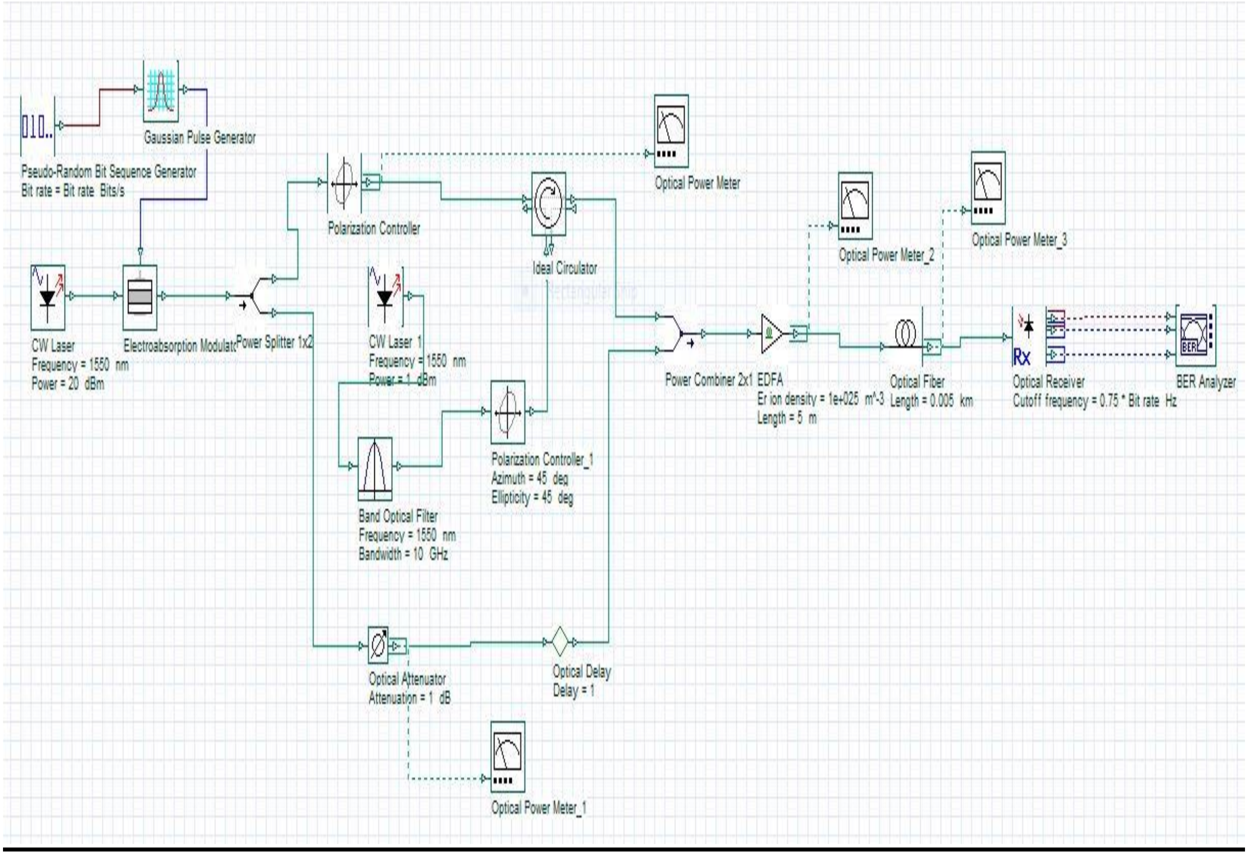


Figure 5.1(a) Schematic circuit diagram of transmission module using band optical fiber

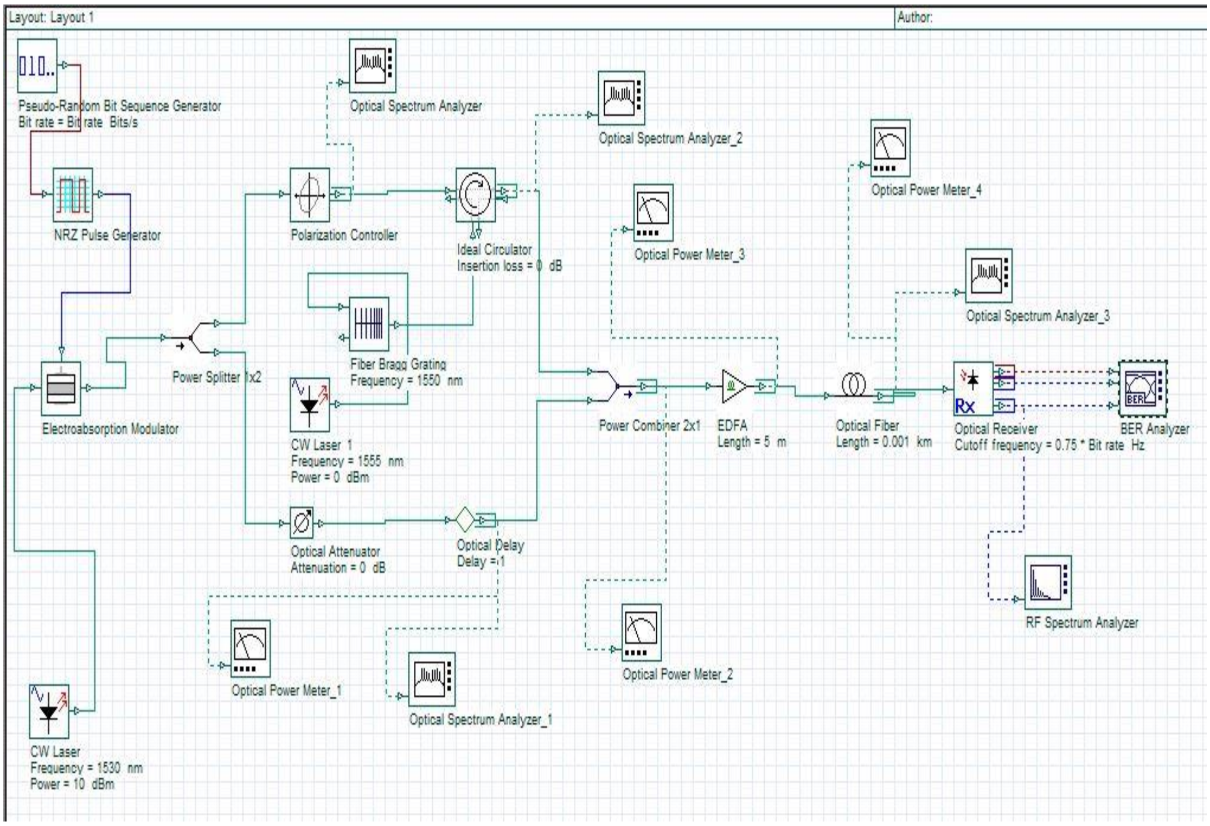


Figure 5.1(b) Schematic circuit diagram of transmission module using Hilbert transformer

The performance of the transmitter is carried out and verified by optisystem simulation .The experimental setup is shown in Fig. 5.1(a) A continuous wave (CW) light generated by a tuneable laser source of power 10 dbm and 10MHz linewidth (noise dynamic 3db, noise threshold -100db) is sent to a Electro-absorption modulator (modulation index 0.95) to which a Gaussian pulse with a temporal width of 50 ps generated by the pseudo random sequence generator which is encoded into it’s electrical equivalent by gaussian pulse generator is applied. The optical wavelength is set at 1550 nm which is centered at the notch wavelength of the band optical filter. The signal at the output of the electro-absorption modulator is divided into two paths by 1x2 power splitter. In the upper path, the optical signal is sent to the polarization controller (azimuth angle 0 degree and ellipticity 0 degree) followed by a ideal circulator (insertion loss 0 db). The lower part is send through an optical attenuator (0 db attenuation) then it is passed by 1 unit optical delay. The upper path works as a optical transformer and the purpose is maintaining polarization . Here we are using two parallel path and the purpose of doing such is to make the transmission free from fading. In any case at least one path will give fading free transmission. These two signals are then combined through 2x1 power combiner. Along the transmission channel there will be attenuation so we need to amplify the transmitted signal, Here we are using EDFA for the purpose of amplification .The length of EDFA is 5 meter and then the signal is transmitted by fIber (length 5 meter). At the receiver end, where we are using photodiode as receiver, we will do analysis of received signal. The cut off frequency of photodiode is 0.75THz. Frequency tuning is done here between wavelength range of 1530nm to 1550nm. In figure 5.1(b) we are using fiber brag grating instead of band optical filter. By using FBG instead of band optical fiber the upper path will work as a Hilbert transformer and if we change the refractive index of fiber then it will work as fractional Hilbert transformer. Here we are not changing the refractive index of the fiber. The input binary sequence is coded using NRZ pulse generator instead of Gaussian pulse generator. NRZ pulse generator gives less BER than Gaussian pulse generator.

The quality factor and the Bit Error Rate is analysed to conclude the simulation of the designed circuit. The duration of bits determines the bit error rate, the more the duration of bits during noise the more probability of getting corrupt. The maximum value of any probability can be 1, so, the BER may attain its maximum value as 1 and the logarithmic value of the BER will start from 0. For minimum BER the time span at 0 logarithmic value of BER should be minimum. Quality factor varies inversely with the bandwidth of the circuit, i.e. for larger bandwidth the quality factor will be low and for smaller bandwidth quality factor will be high. For a notch filter response the quality factor should have high value.

5.2 Component parameters

Table 5.1 Layout parameters

/* Layout 1 Parameters */										
Simulation window	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate	Set bit rate
Reference bit rate	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bit rate	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
Time window	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08
Sample rate	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11
Sequence length	128	128	128	128	128	128	128	128	128	128
Samples per bit	64	64	64	64	64	64	64	64	64	64
Number of samples	8192	8192	8192	8192	8192	8192	8192	8192	8192	8192

Table 5.2 CW Laser parameters

/* CW Laser Parameters */										
Frequency	1530	1532.22	1534.44	1536.67	1538.89	1541.11	1543.33	1545.56	1547.78	1550
Power	20	20	20	20	20	20	20	20	20	20
Linewidth	10	10	10	10	10	10	10	10	10	10
Sample rate	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11	6.40E+11
/* Electroabsorption Modulator Parameters */										
Modulation ind	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

Table 5.3 Bit rate of Bit sequence generator (in bits/second)

Pseudo-Random Bit Sequence Generator									
/* Pseudo-Random Bit Sequence Generator Parameters */									
Bit rate	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10

Table 5.4 Attenuation in optical attenuator (in db)

/* Optical Attenuator Parameters */										
Attenuation	1	1	1	1	1	1	1	1	1	1

Table 5.5 Delay in optical delay unit

/* Optical Delay Parameters */										
Delay	1	1	1	1	1	1	1	1	1	1

Table 5.6 Insertion loss in circulator (in dB)

/* Ideal Circulator Parameters */										
Insertion loss	0	0	0	0	0	0	0	0	0	0

Table 5.7 CW Laser1 Parameter

/* CW Laser_1 Parameters */										
Frequency	1530	1532.22	1534.44	1536.67	1538.89	1541.11	1543.33	1545.56	1547.78	1550
Power	1	1	1	1	1	1	1	1	1	1
Linewidth	10	10	10	10	10	10	10	10	10	10
Noise threshold	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Noise dynamic	3	3	3	3	3	3	3	3	3	3

Table 5.8 EDFA parameters

/* EDFA Parameters */										
Core radius	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Er doping radius	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Er metastable lifetime	10	10	10	10	10	10	10	10	10	10
Numerical aperture	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Er ion density	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25	1.00E+25
Loss at 1550 nm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Loss at 980 nm	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Length	5	5	5	5	5	5	5	5	5	5
Forward pump power	100	100	100	100	100	100	100	100	100	100
Backward pump power	0	0	0	0	0	0	0	0	0	0

Table 5.9 Optical fiber parameters

/* Optical Fiber Parameters */										
User defined reference	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Reference wavelength	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Length	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

Table 5.10 Optical receiver parameters

/* Optical Receiver Parameters */										
Photodetector	PIN	PIN	PIN	PIN	PIN	PIN	PIN	PIN	PIN	PIN
Gain	3	3	3	3	3	3	3	3	3	3
Ionization ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Responsivity	1	1	1	1	1	1	1	1	1	1
Dark current	10	10	10	10	10	10	10	10	10	10
Cutoff frequency	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09	7.50E+09
Insertion loss	0	0	0	0	0	0	0	0	0	0

Table 5.11 BER analyzer results

/* BER Analyzer Results */										
Total Power (dBm)	8.802446	8.82032	8.824868	8.818291	8.817473	8.824895	8.835373	8.844737	8.850552	8.854584
Total Power (W)	0.00759	0.007621	0.007629	0.007618	0.007616	0.007629	0.007648	0.007664	0.007675	0.007682
Signal Power (dBm)	8.802443	8.820317	8.824865	8.818289	8.817471	8.824893	8.835371	8.844735	8.85055	8.854582
Signal Power (W)	0.00759	0.007621	0.007629	0.007618	0.007616	0.007629	0.007648	0.007664	0.007675	0.007682
Noise Power (dBm)	-53.239304	-53.248355	-54.052915	-53.808339	-53.735597	-54.652126	-54.883267	-54.438198	-53.767882	-54.329032
Noise Power (W)	0	0	0	0	0	0	0	0	0	0
Signal Delay (s)	0	0	0	0	0	0	0	0	0	0
Signal Delay (samples)	101	101	101	100	100	100	100	100	100	100
Bit Rate (Bits/s)	1E+10	10000000000	10000000000	10000000000	10000000000	10000000000	10000000000	10000000000	10000000000	10000000000
Max. Q Factor	52.999276	52.770378	52.997942	53.153906	52.887178	53.486787	53.067755	52.82704	53.074339	52.980924
Q Factor from Min. BER	100	100	100	100	100	100	100	100	100	100
Min. BER	0	0	0	0	0	0	0	0	0	0
Min. log of BER	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000

Table 5.12 Band optical filter parameters

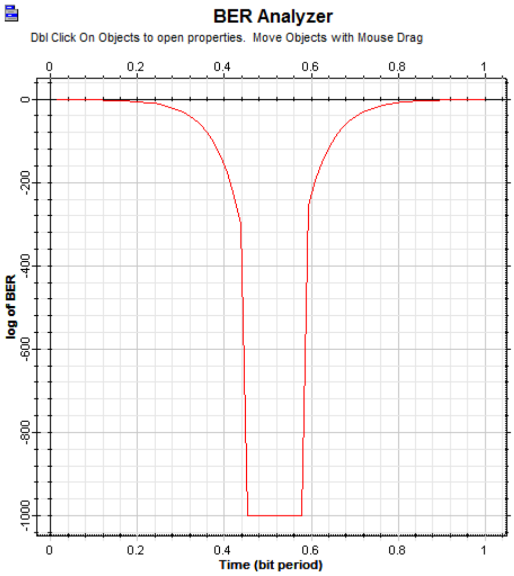
/* Band Optical Filter Parameters */										
Frequency	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Bandwidth	10	10	10	10	10	10	10	10	10	10
Insertion loss	0	0	0	0	0	0	0	0	0	0

Table 5.13 Polarization controller 1 parameters

/* Polarization Controller_1 Parameters */										
Azimuth	45	45	45	45	45	45	45	45	45	45
Ellipticity	45	45	45	45	45	45	45	45	45	45
Symmetry factor	0	0	0	0	0	0	0	0	0	0

5.3 Simulation Result

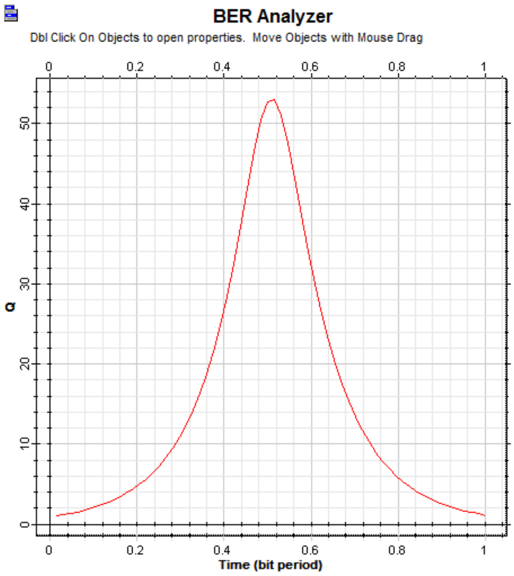
5.3.1 Using Band optical filter



(a)

Fig. 5.2 (a) Log of BER vs Time (bit period) at 1530nm

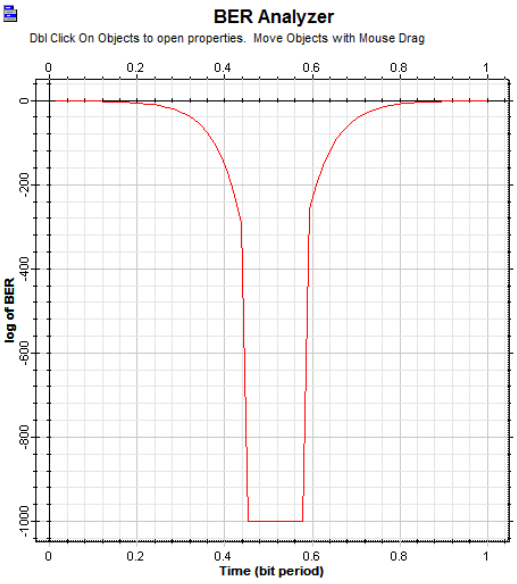
Min BER= 0



(b)

Fig. 5.2(b) Q value vs Time (bit period) at 1530 nm

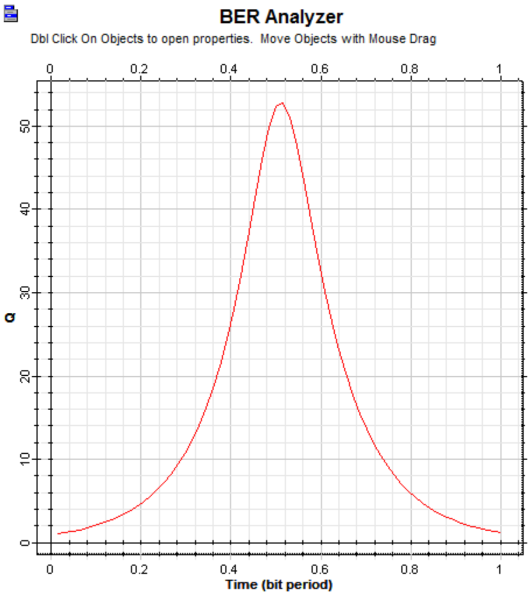
Q value =52.9993



(a)

Fig. 5.3(a) Log of BER vs Time (bit period) at 1532.22 nm

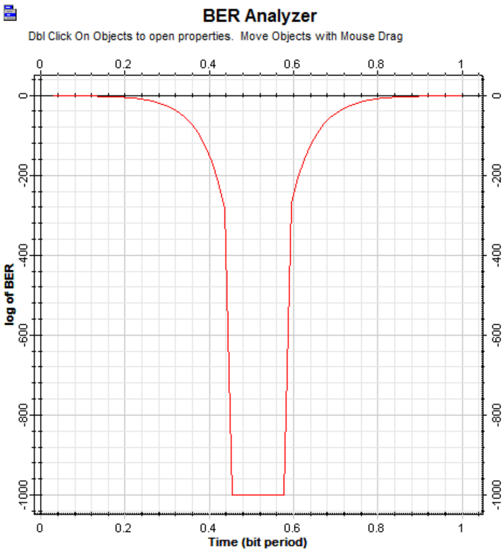
Min BER= 0



(b)

Fig. 5.3(b) Q value vs Time (bit period) at 1532.22 nm

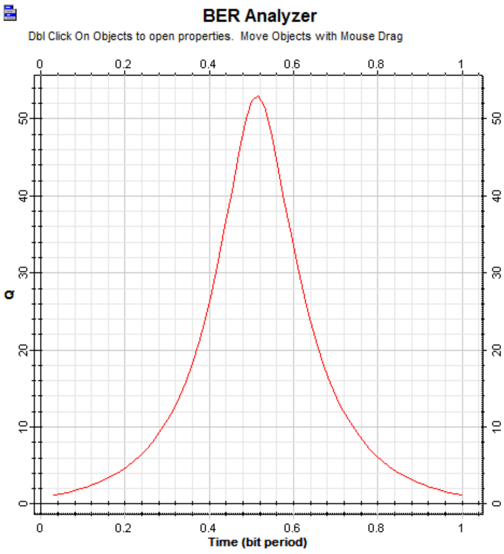
Q value =52.7704



(a)

Fig. 5.4(a) Log of BER vs Time (bit period) at 1534.44 nm

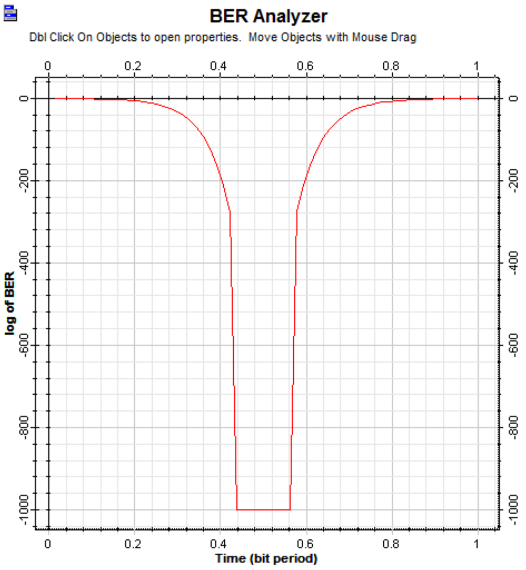
Min BER= 0



(b)

Fig. 5.4(b) Q value vs Time (bit period) at 1534.44nm

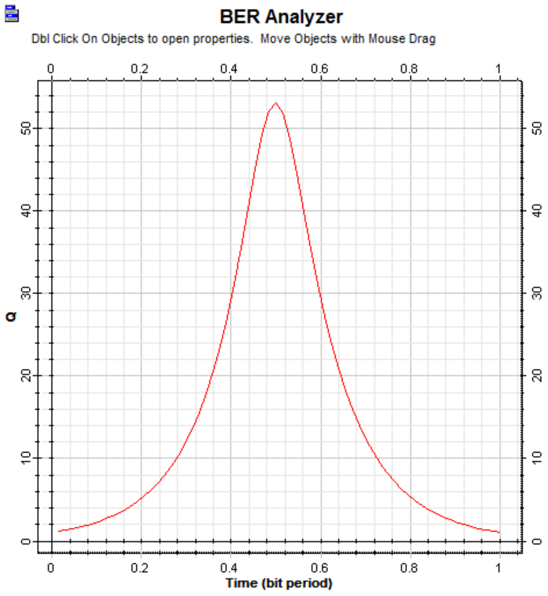
Q value =52.9979



(a)

Fig. 5.5(a) Log of BER vs Time (bit period) at 1536.67nm

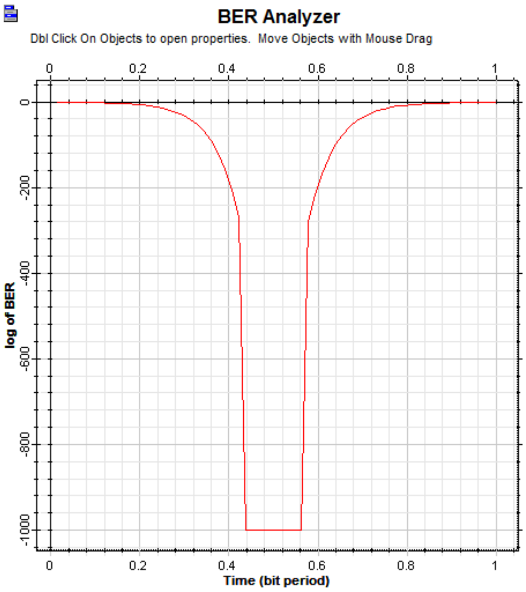
Min BER= 0



(b)

Fig. 5.5(b) Q value vs Time (bit period) at 1536.67nm

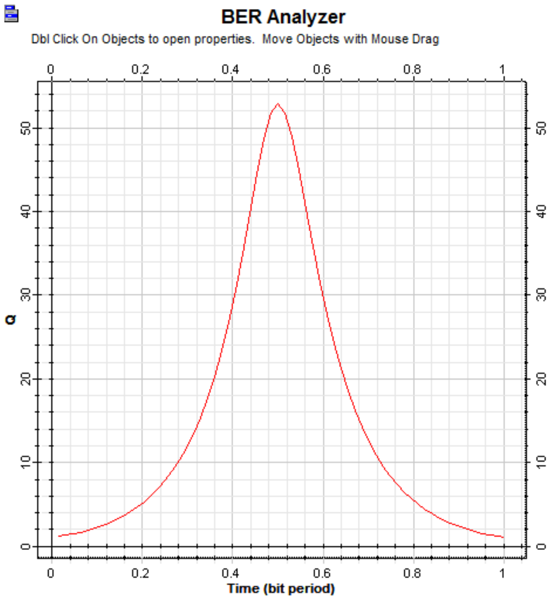
Q value =53.1539



(a)

Fig . 5.6(a) Log of BER vs Time (bit period) at 1538.89 nm

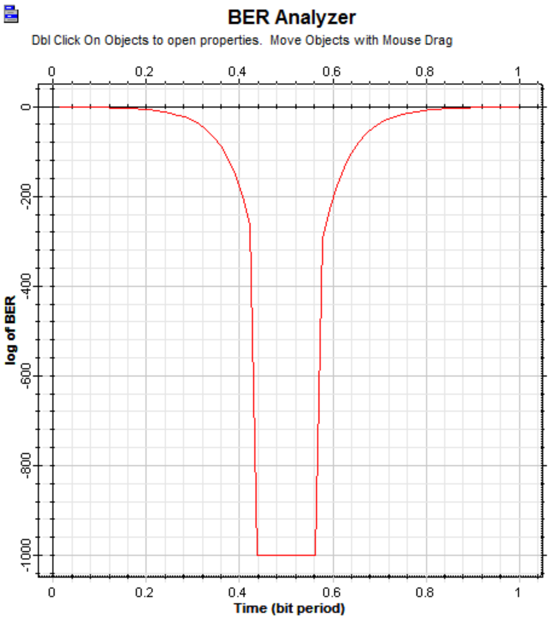
Min BER= 0



(b)

Fig. 5.6(b) Q value vs Time (bit period) at 1538.89 nm

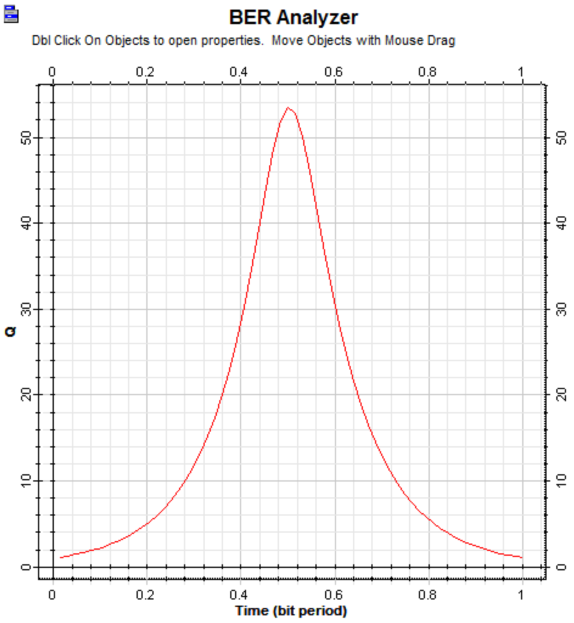
Q value =52.8872



(a)

Fig. 5.7(a) Log of BER vs Time (bit period) at 1541.11nm

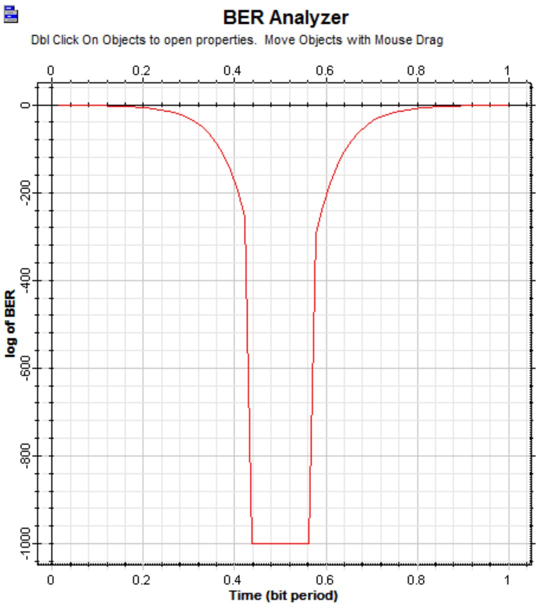
Min BER= 0



(b)

Fig. 5.7 (b) Q value vs Time (bit period) at 1541.11 nm

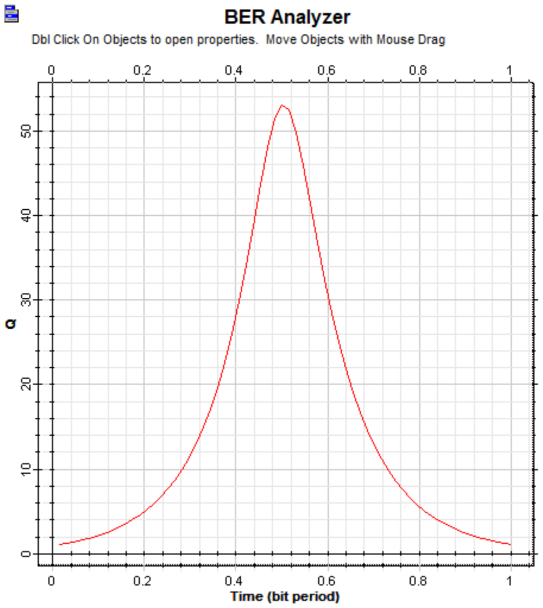
Q value =52.4868



(a)

Fig. 5.8(a) Log of BER vs Time (bit period) at 1543.33nm

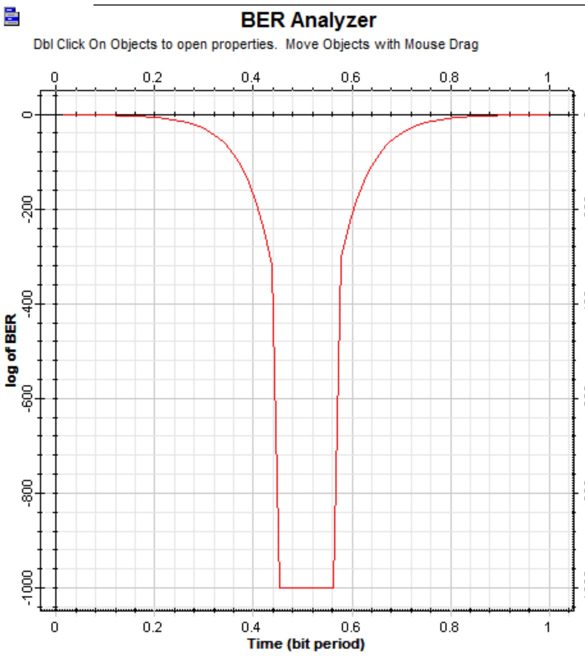
Min BER= 0



(b)

Fig. 5.8(b) Q value vs Time (bit period) at 1543.33

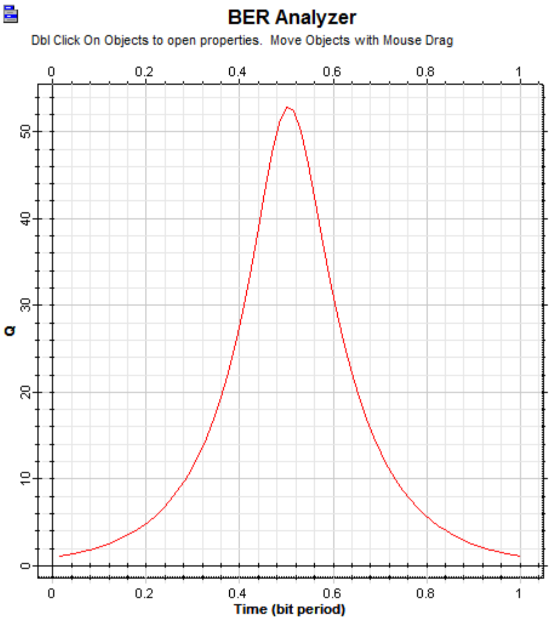
Q value =53.0678



(a)

Fig. 5.9(a) Log of BER vs Time (bit period) at 1545.56nm

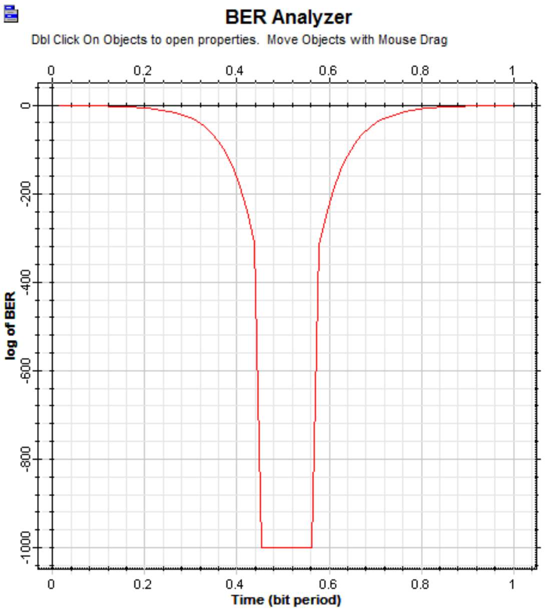
Min BER= 0



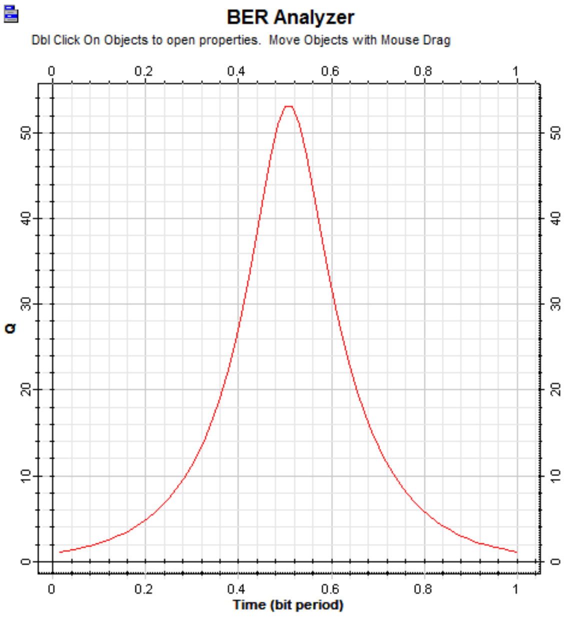
(b)

Fig. 5.9(b) Q value vs Time (bit period) at 15445.56nm

Q value =52.812



(a)



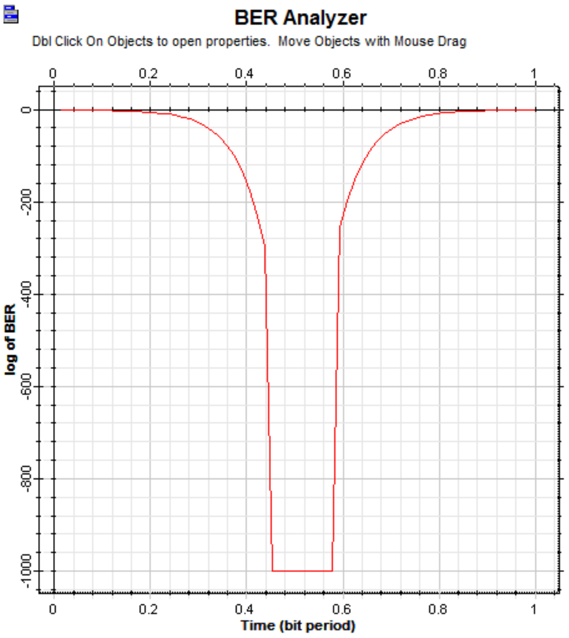
(b)

Fig. 5.10 (a) Log of BER vs Time (bit period) at 1547.78nm

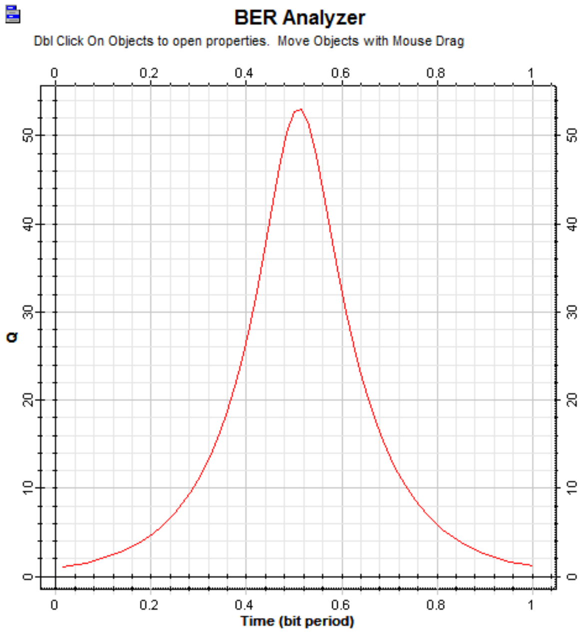
Min BER= 0

Fig. 5.10(b) Q value vs Time (bit period)at 1547.78 nm

Q value =53.0743



(a)



(b)

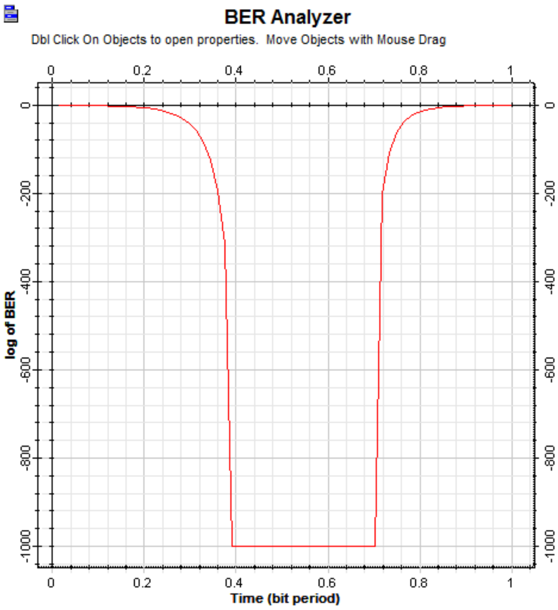
Fig. 5.11(a) Log of BER vs Time (bit period) at 1550nm

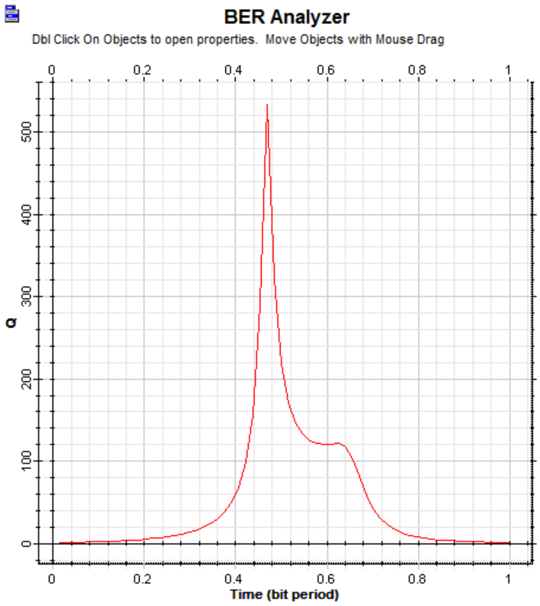
Min BER= 0

Fig. 5.11(b) Q value vs Time (bit period) at 1550 nm

Q value =52.9809

5.3.2 Using Hilbert transformer





(a)

Fig. 5.12(a) Log of BER vs Time (bit period) at 1550nm

Min BER= 0

(b)

Fig. 5.12(b) Q value vs Time (bit period) at 1550 nm

Q value = 532.998

5.4 Discussion

From all the above graphs we can say that in the case of band optical filter the time span for which the log of BER is 0 is almost same at all wavelengths , the period is shifted somewhere but the duration is almost same at all the frequency whereas Q value has different value at all the frequencies. The highest value of Q factor is 53.1539 at 1536.67 nm wavelength, whereas, the minimum value of Q factor is 52.4868 at 1541.11 nm wavelength.

While in the case of Fiber brag grating (i.e. Hilbert transformer) maximum value of Q factor 532.998 at 1550 nm wavelength. Which is very much higher (almost 10 times) than in the case of band optical filter. And the time span for any BER value is wider than in the case of band optical filter.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The demonstrated transmission module which uses has a narrower time span than in the case of FBG i.e. the BER is very much high in the case of FBG and we have seen that we are using Gaussian pulse generator in the case of band optical filter while NRZ pulse generator in the case of FBG. NRZ pulse generator has advantage of less BER than Gaussian pulse generator. But we are getting better BER performance in the case of band optical filter which uses Gaussian pulse generator. So we can say that the transmission module designed with band optical filter has much better BER performance than transmission module designed with FBG. Quality factor observed in the case of FBG is 10 times greater than the band optical filter. As we know quality factor is inversely proportional to bandwidth, i.e. for larger value of Q factor the bandwidth will be less and for lower value of Q factor bandwidth will be higher. So in the case of band optical filter there will be larger bandwidth.

REFRENCES

1. *Cheng, X. S., Parvizi, R., Ahmad, H., & Harun, S. W. (2009). Wide-Band Bismuth-Based Erbium-Doped Fiber Amplifier With A Flat-Gain Characteristic. Photonics Journal, IEEE, 1(5), 259-264.*

2. *Sunil Kumar Panjeta, Onkar Chand And Danvir Mandal (2012), "Gain Optimization Of EDF Optical Amplifier By Stages Enhancement And Variation In Input Pumping Power", International Journal Of Scientific And Research Publications, Vol. 2, Issue 11, November 2012.*

3. *Kumar, N., & Kasu, R. (2012, December). Sagnac And Mach-Zehnder Interferometer Based Gain Flattening Of An EDFA. In International Conference On Fibre Optics And Photonics. Optical Society Of America.*

4. *Hamida, B. A., Latiff, A. A., Cheng, X. S., Ismail, M. A., Naji, W., Khan, S., ... & Harun, S. W. (2012, May). Flat-Gain Single-Stage Amplifier Using High Concentration Erbium Doped Fibers In Single-Pass And Double-Pass Configurations. In Photonics And Optoelectronics (SOPO), 2012 Symposium On (Pp. 1-5). IEEE.*

5. *Marques, C. A., Oliveira, R. A., Pohl, A. A., André, P. S., & Nogueira, R. N. (2011, April). Adaptive Gain Equalization On Optical Amplifiers Based On The Acousto-Optic Effect Using A Single Long Period Grating. In EUROCON-International Conference On Computer As A Tool (EUROCON), 2011 IEEE (Pp. 1-3). IEEE.*

6. *Ezra Ip, "Gain Equalization For Few-Mode Fiber Amplifier Beyond Two Propagating Mode Groups", IEEE Photonics Technology Letters, Vol. 24, No. 21, November 1, 2012.*

7. *Ip, E. (2012). Gain Equalization For Few-Mode Fiber Amplifiers Beyond Two Propagating Mode Groups.*

8. *Ip, E. (2012, July). Gain Equalization For Few-Mode Fiber Amplifiers With More Than Two Propagating Mode Groups. In Photonics Society Summer Topical Meeting Series, 2012 IEEE (Pp. 224-225). IEEE.*

9. *T. Subramaniam, S. W. Harun, M. A. Mahdi, P. Poopalan & H. Ahmad, "Simulation Of EDFA System Using EDFA_Design Software "Jurnal Teknologi 40(D), Jun. 2004, Universiti Teknologi Malaysia, Pp. 17–24.*

10. *N Sindhu And P. K. Shafeena, "Gain Flattening In Erbium Doped Fiber Amplifier Based Optical Communication – A Review" .*

11. *SINDHU, N., & SHAFEENA, P. Gain Flattening In Erbium Doped Fiber Amplifier Based Optical Communication-A Review.*

12. *Frazão, O., Rego, G., Lima, M., Teixeira, A., Araújo, F. M., André, P., ... & Salgado, H. (2001). EDFA Gain Flattening Using Long-Period Fibre Gratings Based On The Electric Arc Technique. In Proceedings Of The London Communications Symposium-LCS2001.*

13. *Stephen Z. Pinter (2003), "EDFA Simulink Model For Analyzing GAIN Spectrum And ASE", December 2003.*

14. *Pinter, S. Z. (2003). EDFA Simulink Model For Analyzing Gain Spectrum And ASE.*

15. *M. Tachibana, R.I. Laming, P.R. Markel And D.N. Payne, "Erbium Doped Fiber Amplifier With Flattened Gain Spectrum", IEEE Photonics Technology Letters, Vol. 3, No. 2, February 1991.*

16. *Wegmuller, M., Oberson, P., Guinnard, O., Huttner, B., Guinnard, L., Vinegoni, C., & Gisin, N. (2000). Distributed Gain Measurements In Er-Doped Fibers With High Resolution And Accuracy Using An Optical Frequency Domain Reflectometer. Lightwave Technology, Journal Of, 18(12), 2127-2132.*

17. *Mynbaev D.H. And Scheiner L.L., ‘Fiber-Optic Communications Technology’, Pearson Education, 4th Edition, 2004, Pages 546-547.*

18. *Mynbaev D.H. And Scheiner L.L., ‘Fiber-Optic Communications Technology’, Pearson Education, 13th Edition, 2013, Pages 560-569.*

19. *Senior, J. M., & Jamro, M. Y. (2009). Optical Fiber Communications: Principles And Practice. Pearson Education.*

20. *Finisar white paper.(june2009) “Introduction to EDFA technology”.*