CHAPTER ONE

INTRODUCATION

1.1 Preface

Communication is import part of our daily life ,Every day , we are using different types of communication services , such as voice , video, image and data communication . As the needs for those services increase , the demand for large transmission capacity networks also increase.

In order to fulfill the increasing demand for higher data rate and larger bandwidth, light wave technology has been developed . The combination of photons and glass fibers provides a tremendous transmission capability improvement compared to the transmission through the electrons and copper wire .As result ,fiber optical transmission system are now widely develop in backbone network , clearly , fiber optic transmission technology will remain the key communication technology foreseeable future[1]

One of the major problems fiber optic in communication is the attenuation, dispersion and transmission loss of optical fibers. Attenuation mainly due to material absorption, material scattering, Others include bending losses, mode coupling losses and losses due to leaky modes , There are also losses at connectors and splices all these reduce the receiver power but solution by using optical amplifier ,In this work study performance evaluation of fiber optic by using Erbium Doped Fiber Amplifier (EDFA).

1.1 Problem Statement

When an optical signal is transmitted over a long distance, the signal loss from fiber attenuation, connectors, splices, dispersion, and bending causes the power reduction in optical fiber communication. Hence there are many amplification technology can be used to compensate these losses, and there is a need to evaluate their performance.

1.3 Proposed Solutions

The proposed solution is to use erbium doped fiber amplifier (EDFA) to enhance the performance in the transmission of optical fiber network , since Erbium Doped Fiber Amplifier is a devices that amplifier optical signal directly without need optic-electronic or electro-optical.

1.4 Aim and Objectives

The aim of this research is to evaluate the performance of a long length fiber optic communication system using EDFA scheme.

The detailed objectives include:

- Determining the suitable number and location of EDFA amplifier.
- Evaluate the performance of the optical fiber system using EDFA in terms of Q-factor , Bit Error Rate (BER), eye height , threshold all this parameters in eye diagram .

1.5 Scope of Work

This research works is limited to calculating the required number of EDFA and evaluate their improvement regarding various metrics using opticsystem.

1. 6 Methodology

Determine the number of EDFA amplifier depend on the length of optical fiber cable .This project is simulated using Optic-System software. Firstly, the performance of the optical fiber is evaluated when a stream of data is sent cross long distance without using an amplifier. The secondly, the data is transmitted along the optical fiber transmission line that using EDFA amplifier with different length optical fiber cable. Then, in this causes have three senor to location of EDFA pre , post , inline EDFA the performance of the two cases clear up best location of EDFA is inline that will be compared in terms of the value of Q-factor, bit error rate (BER), Eye height , and Threshold .

1.7 Thesis Outlines

This thesis contains of five chapters their outlines are as follows:

Chapter One is an Introduction that shows the problem statement, objectives, and the scope work of research.

Chapter Two a Literature Review which is gives the background and related works.

Chapter Three a simulation setup that shows the all causes of transmission data in fiber optical with EDFA by different length.

Chapter Four discusses the analysis results obtained from performance evaluated of optical fiber and then with EDFA result of simulation.

Chapter Five shows the conclusion for the whole research. It also provides suggestion for future recommendation.

CHAPTER TWO

LITERATURE REVIEW

This chapter consists of two parts ,the first part is Background to covers the fiber optical , losses of fiber , attenuation , all parameters causes the decrease of output power .The second part discusses an amplification the signal by using optical amplifier EDFA .

2.1 Background

Light-wave communication systems or fiber optics communication systems are one of the important features for today's communications, for years fiber optics has been merely a system for piping light around corners and into inaccessible places so as to allow the hidden to be seen. But now, fiber optics has evolved into a system of significantly greater importance and use. Throughout the world it is now being used to transmit voice, video, and data signals by light waves over flexible hair-thin threads of glass or plastics [1] .Figure 2.1 shows the components of optical fiber .

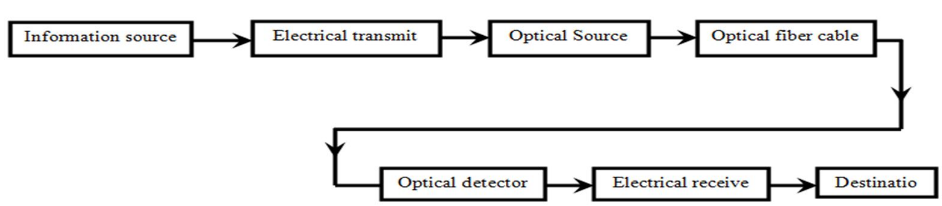


Figure 2.1 : Component of optical fiber communication

Information source provides electrical signal to the transmitter comprising of an electrical stage which drives an optical source to modulate the light wave carrier. The optical source which converts electrical to optical signal may be either a semiconductor injection laser diode (ILD) or light emitting diode (LED). Transmission medium consists of an optical fiber cable and the receiver consists of an optical detector. Photodiodes (PI, PIN, or avalanche) are utilized for the detection of the optical signal or the optical to electrical conversion. At present the signal processing is usually performed electrically. Input digital signal from information source is suitably encoded for optical transmission. Laser drive circuit directly modulates the intensity of the semiconductor laser with the encoded digital signal. A digital optical signal is launched into the optical fiber cable. Then the avalanche photodiode detector (APD) is followed by a front-end amplifier to provide gain, linear signal processing and noise bandwidth reduction. Finally the signal obtained is then decided to give the original digital information.

2.1.1 Advantages of Optical Fiber Communication

The optical fiber has many advantages such as transmission bandwidth of the fiber optic cables is higher than the metal cables , optical fiber are cheap than the conventional wire , and Optical fiber cables are flexible also easy to install . In addition optical fiber cables do not suffer from electromagnetic interference as they carry light. Optical fiber support bandwidth of up 40 Gbps to 100 Gbps and easily upgradable for higher speed and high bandwidth [1] .

2.1.2Fiber Losses

There are many factors contribute in signal loss within fiber like Dispersion which is the spreading of a light pulse as it propagates down the fiber. Absorption which is the process of converted light energy is into electrical energy and it occurs at wavelengths greater than 1.55μm due to infrared vibration. Scattering which is the spreading apart of light caused by interaction with material and it can be significant at shorter wavelengths. Bending which it occurs when total internal reflection deteriorates because of installation procedures and attenuation which it describes the total loss of an optical fiber system [2].

2.1.3 Applications of Fibre Optics

- Used in telephone systems.
- Used in sub-marine cable networks.
- Used in data link for computer networks, CATV Systems.
- Used in CCTV surveillance cameras.
- Used for connecting fire, police, and other emergency services.
- Used in hospitals, schools, and traffic management systems.
- They have many industrial uses and also used for in heavy duty constructions.

2.2 Optical Amplifier

An optical amplifier is a device which amplifies the optical signal directly without ever changing it to electricity the light itself is amplified .Reasons to use the optical amplifiers is reliability , flexibility , wavelength division multiplexing (wdm) , low Cost . In order to transmit signals over long distances (>100 km) it is necessary to compensate for attenuation losses within the fiber.

Initially this was accomplished with an optoelectronic module consisting of an optical receiver, regeneration and equalization system, and an optical transmitter to send the data. Although functional this arrangement is limited by the optical to electrical and electrical to optical conversions [3] .

2.2.1 Different Places of Optical Amplifiers

According to the position in a fiber transmission link the optical amplifiers are typically used in three different places:

- Power Amplifiers

  Power amplifiers serve to boost the power of the signal before it is launched on the line, extending the transmission distance before additional amplification is required.
- Line Amplifiers

  Line amplifiers are located at strategic points along a long transmission link to restore a signal to its initial power level., thereby compensating for fiber attenuation.
- Preamplifiers

  Preamplifiers raises the signal level at the input of an optical receiver, which serves to improve signal detection performance (the receiver sensitivity).

  In each of the three cases, the desired properties are different. For power amplifiers, the important feature is high gain; preamplifiers require a low noise figure, and line amplifiers require both. Figure 2.2 shows the different places of optical amplifier [3].

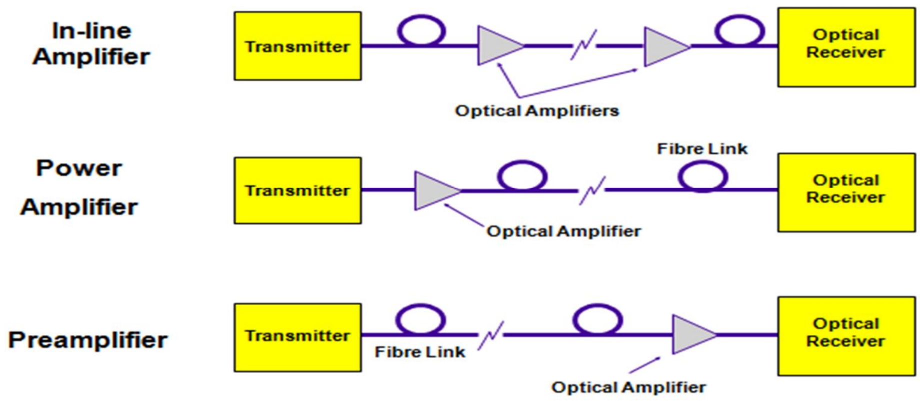


Figure 2.2: Different Places of Optical Amplifiers [3].

2.3 Types of Optical Amplifier

There are different types of optical amplifier such as

Optical fiber amplifiers (EDFA)**,** semiconductor optical amplifiers **and** distributed fiber amplifiers (Raman Amplifiers).

2.3.1 Erbium-Doped Fiber Amplifiers (EDFAs)

It is the most important version is erbium doped fiber amplifiers (EDFAs) due to their ability to amplify for example a signal at the low loss 1.55 nm wavelength range. A pump optical signal is added to an input signal by a WDM coupler. Within a length of doped fibre part of the pump energy is transferred to the input signal by stimulated emission, For operation circa 1550 nm the fiber doping is Erbium, Pump wavelength is 980 nm or 1480 nm, pump power circa 50 mW, Gains of 30-40 dB possible. Figure 2.3 shows the configuration of EDFA [4] .

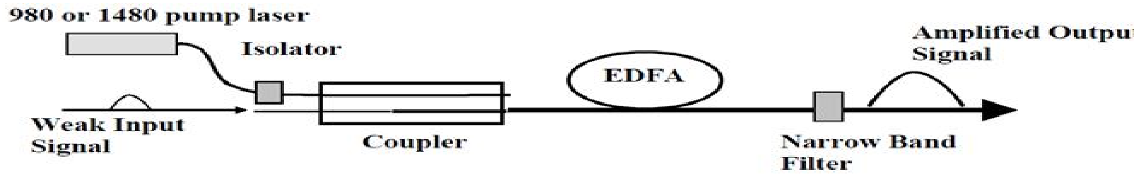


Figure 2.3: General EDFA Amplifier Configuration [4]

2.3.1.1 The Design and Operation EDFA

The design options are include Pump wavelength, dual or single pump modules, dual or single isolators and a microprocessor control with adjustable remote alarm. The (EDFA) products are available for both digital and analog systems . A (relatively) high-powered beam of light is mixed with the input signal using a wavelength selective coupler. The mixed light is guided into a section of fiber with erbium ions included in the core; this high-powered light beam excites the erbium ions to their higher-energy state.

When the photons belonging to the signal (at a different wavelength from the pump light) meet the excited erbium atoms and the erbium atoms give up some of their energy to the signal and return to their lower-energy state , significant point is that the erbium gives up its energy in the form of additional photons which are exactly in the same phase and direction as the signal being amplified, There is usually an isolator placed at the output to prevent reflections returning from the attached fiber, Such reflections disrupt amplifier operation and in the extreme case can cause the amplifier to become a laser[5]. Figure 2.4 shows the design of EDFA amplifier.

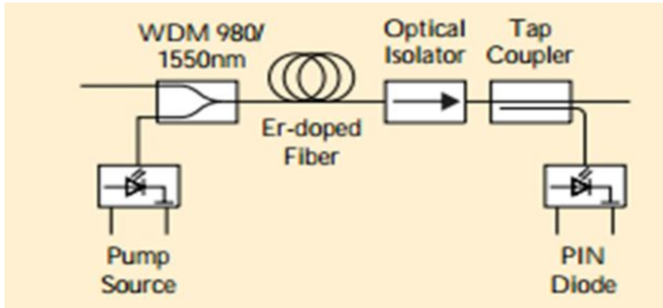


Figure 2.4: Design EDFA [5]

2.3.1.2 EDFA Three-Energy Level System

Like many other forms of amplifiers of electromagnetic radiation, the EDFA operates via a three-energy level system. The model representing this process is shown in the following Figure 2.5. Levels E_1, E_2, and E_3 are the ground and pump levels, respectively. The populations (fractional densities) of erbium ions in the three energy levels are denoted N_1, N_2, and N_3, where $N_1 > N_2 > N_3$ when the system is in thermal equilibrium (no pump or signal present). When pump and signals are present, these populations change as ions move back and forth between levels, accompanied by the emission or absorption of photons at frequencies determined by the energy-level difference. The wavelength λ for each transition is given by the quantum relation by equation

$$\lambda = {}^{hc}/_{\Delta E} \tag{2.1}$$

Where

h = The Planck's constant & ΔE = The difference in energy levels.

In actuality, the three levels in the simplified diagram are narrow bands, so each transition is actually associated with a band of wavelengths rather than a single line. Two pump wavelengths are typically used for EDFAs: 980 and 1480 nm. As shown in the above figure, by absorbing energy from a 980 nm pump, Er^{3+} ions in the ground state are raised to state E_3 . The rate at which these transitions occur is proportional to N_1P_p, where P_p is the pump power. These excited ions decay spontaneously to the detestable state E_2, and this transition occurs at a rate much faster than the rate from level E_1 to level E_3[6].This means that in equilibrium under the action of the pump, the ion population in the ground state is reduced and accumulates largely in state E_2. This process is referred to as population inversion because we now have $N_2 > N_1$, the reverse of the situation in thermal equilibrium .The transition rate from level E_2 to level E_1 is very slow compared with the other transitions, so that the lifetime τ, in the state E_2 (the reciprocal of its transition rate to E_1) is very long (approximately 10 ms). Similar pumping action can occur at 1480 nm, in which case the ions are raised directly to the upper edge of the E_2 band.

Reliable semiconductor laser pump sources have been developed for EDFAs at both the 980 and 1480 nm pump wavelengths. The wavelength band for transitions from state E_2 to the ground state is in the 1530 nm range, making it ideal for amplification in the lowest attenuation window of fibers. The dominant transitions from E_2 to E_1 are radioactive, which means that they are of two types: spontaneous emission and stimulated emission.

In the case of spontaneous emission, an ion drops spontaneously to the ground state, resulting in the emission of a photon in the 1530 nm band, and this appears as additive noise. Spontaneous emission noise is an unavoidable by-product of the amplification process, predicted by quantum theory. Its phase, direction, and polarization are independent of the signal [6].

In the case of stimulated emission, an incident photon in the 1530 nm range stimulates the emission of another photon at the same wavelength in a coherent fashion (with the same direction, phase, and polarization). If the incident photon is from a signal++, this produces the desired amplification of the optical field. However, the incident photon could also have originated as a spontaneous emission "upstream" on the fiber. In which case this is called amplified_spontaneous emission (ASE), which represents the major source of noise in amplified fiber transmission systems [7].

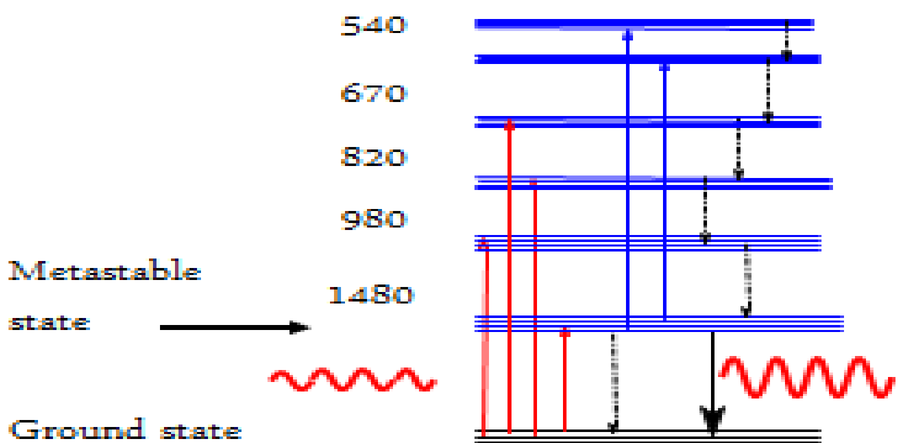


Figure 2.5: EDFA Energy level [6]

2.3.1.3 Technical Characteristics of EDFAs

EDFAs have a number of attractive technical characteristics , it has Low insertion loss , Efficient pumping , Minimal polarisation sensitivity , High output power (this is not gain but raw amount of possible output power) , Low noise, Very high sensitivity , Wide spectral band amplification with relative flat gain (>20 dB) useful for WDM applications .

2.3.1.4 Disadvantages of EDFAs

Not easily integrated with other devices, relatively large devices (km lengths of fiber) . Cross-talk effects in addition gain saturation effects also amplified spontaneous emission (ASE - there is always some output even with no signal input due to some excitation of ions in the fiber – spontaneous noise) [8] .

2.3.1.5 Saturation and Gain EDFAs

There are two main differences between the behaviour of electronic amplifiers and of EDFAs in gain saturation:

1. As input power is increased on the EDFA the total gain of the amplifier increases slowly.

An electronic amplifier operates relatively linearly until its gain saturates and then it just produces all it can. This means that an electronic amplifier operated near ssaturation introduces significant distortions into the signal.

2. An erbium amplifier at saturation simply applies less gain to all of its input regardless of the instantaneous signal level, thus it does not distort the signal. There is little or no crosstalk between WDM channels even in saturation.

EDFA is in saturation if almost all Erbium ions are consumed for amplification. Then the total output power remains almost constant, regardless of input power changes, shows as Figure 2.6.

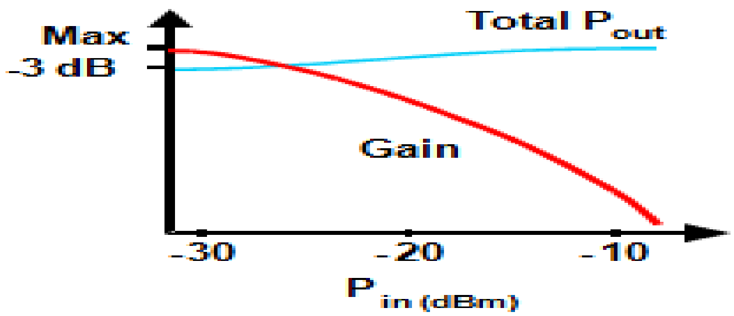


Figure 2.6: Gain EDFAs [8]

The ratio between output power to input power is defines as Amplification factor ,equation 2.1 shows this factor and the total output power is defines as Amplified signal with Noise (Amplified Spontaneous Emission ASE) , equation 2.2 shows total power

$$G = p_{out}/p_{in} \qquad (2.2)$$

$$P_{total} = X + Y \qquad (2.3)$$

Where

p_{out} The output power

p_{in} T he input power

X The amplified signal

Y Noise

2.3.1.6 Noise and Noise Figure

The ASE noise generated in an EDFA can be the limiting performance factor in an optical transmission link. It is therefore important to quantify this effect. For an amplifier with gain G, the ASE noise power spectral density at the output at optical frequency ν (in each polarization state) is where NSP, the spontaneous emission factor, is a function of the state population and approaches its minimum value of 1 with full population inversion. The ASE noise spectrum for an EDFA is roughly the same shape as the gain profile. The significance of the ASE noise is most clearly expressed in terms of SNRs and the amplifier noise figure F_n. These quantities are defined in terms of electrically detected signals in an ideal system [9] , as shown in the following Figure 2.7.

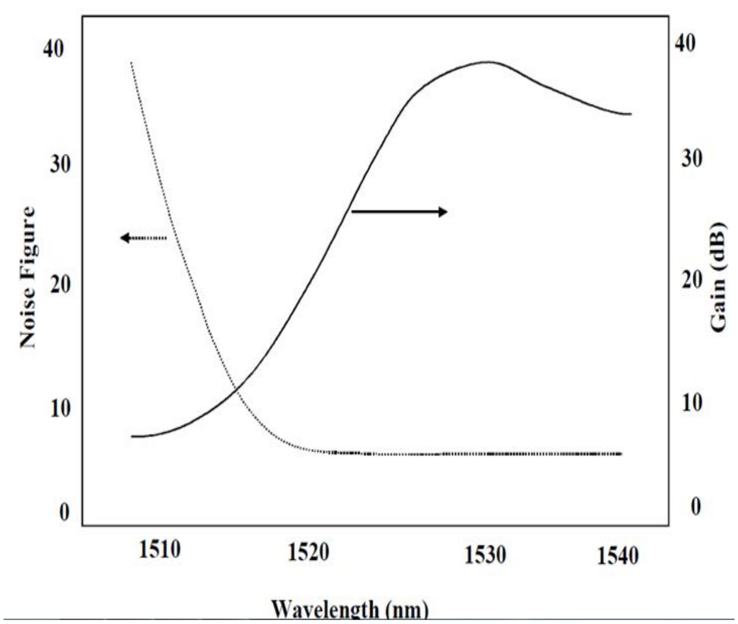


Figure 2.7: Noise Figure [9]

The noise figure is defined as where SNR_{in} is the electrical SNR seen when a signal of power Pin is converted to a photocurrent at the output of an ideal photo detector (PD) [10]. The noise in this case is shot noise due to the fact that the ideal detector is counting photons, which arrive randomly at the detector. (The detection process must be an integral part of any noise calculation, reflecting the quantum limits of light wave transmission.

2.3.2 Raman Amplifiers

Raman Amplifiers are based on the principle of Raman scattering. this nonlinear process occur when an atom absorbs a photon and then releases a photon with a slightly different energy .this energy could be slightly lower or higher depending whether the vibration energy is lost or gained .stimulated Raman scattering takes place when a strong pump beam and a longer wavelength signal simultaneously travel through the fiber. The pump beam excites the atoms to higher energy states while the signal stimulates atoms to emit an additional photon at the same signal wavelength .Similar to the EDFA process Stimulated Raman scattering allows for the amplification of the input signal through stimulated emission [11].

2.3.2.1 Advantages of Raman Amplifiers:

Can be used to amplifier variable wavelength with lower average power over a span, good for lower crosstalk, Compatible with SM fiber install and can be used to "extend" EDFAs.

3.2.2.2 Disadvantages of Raman Amplifiers

Requirement high pump power (high pump power lasers have only recently arrived) and Sophisticated gain control.

2.3.3 Semiconductor Optical/Laser Amplifiers (SOAs/SLAs)

Semiconductor optical amplifiers (SOA) achieve amplification by inserting a semiconductor diode laser between two fibbers. Both ends of the active region are cleaved and antireflection (AR) coated but the planar nature of the SOA makes coupling a bit more difficult than the straight through coupling used with EDFAs. Semiconductor diode lasers have already been developed for use in transmitters, so SOAs need only some minor modifications of an existing technology. Although SOAs are not without some drawbacks, they offer several important advantageous over other types of optical amplifiers [12].

2.3.3.1 Characteristics of SOA

Relatively high gain ~20 dB with output saturation power 5-10 dBm , Can operate at 800, 1300, and 1500 nm wavelength regions (Large BW) , it Compact and easily integrated with other devices (Can be integrated into arrays) , High noise figure and cross-talk levels due to nonlinear phenomenon such as 4-wave mixing. it Polarization dependent(require polarization maintaining fiber).

2.4 Optic System Simulator

Optic System is a comprehensive software design suite that enables users to plan, test, and simulate optical links in the transmission layer of modern optical networks. It is a system level simulator based on the realistic modeling of fiber optic communication systems. A Comprehensive Graphical User Interface (GUI) controls the optical component layout and net list , component models and presentation graphics .

Optic System allows for the design automation of virtually any type of optical link in physical layer , and the analysis of a broad spectrum of optical network, from Long –Haul Network , Metropolitan Area Network (MAN) and Local Area Network (LAN). Optisystem includes an extensive library of sample optical design (OSD) files that can be used as templates for optical design projects for learning and demonstration purposes , OptiSystem capabilities can be extended with addition of user components ,and can be seamlessly interact with a wide range of tools[13] .

2.4.1 Optic System Application

Optic system has a wide range of application which includes:

- Can be used to simulate has all system components.
- CATV or TDM/WDM/CDM network.
- Passive optical networks (PON) based FTTx .
- Amplified system BER and link budget calculations [14] .
- Transmitter, channel, amplifier, and receiver design.
- Dispersion map design.
- SONET/SDH ring design.

2.4.2 Optical System Components

An optical communication system consists of a: transmitter, communication channel and receiver

- The role of the optical transmitter is to convert the electrical signal into optical from, and launch the resulting optical signal into the optical fiber.
- The role of the communication channel is to transport the optical signal from transmitter to receiver without distorting it.
- The role of the optical receiver is to convert the optical signal receives at the output end of the optical fiber back into the original electrical signal [15].

2.4.3 A description of the key elements in the optisystem shows as Figure 2.8

Pseudo-Random Bit to generate sequence random bits (PRBS) : generates PRBS according to different operation modes. The bit sequence is designed to approximate the characteristics of random data. PRBS is used to scramble data signal in terms of bit rates. Pseudo- random bit sequence generator is used to scramble data signal in terms of bit rate.

NRZ Pulse Generator : Optical information signals get modulated with optical source signal and make two types of pulse RZ and NRZ. In the RZ format, each optical pulse representing bit 1 is shorter than bit slot, and its amplitude returns to zero before the bit duration is over. In the NRZ format, the optical pulse remains on throughout the bit slot and its amplitude dose not drop to zero between two or more successive 1 bits. As a bit pattern, pulse width varies whereas it remains the same in the case of RZ format. In optical communication the use of RZ format help the design of high-capacity light wave systems.

Mach-Zehnder Modulator : optical modulator are used for electrically controlling the output amplitude or the phase of the light wave passing through the device .To reduce the devices size and the driving voltage , waveguide-based modulators are used for communication application .

Continues Laser Diode (CW) : To generate optical signals supplies input signal with 1550 nm wavelength and input power of 0 dB which is externally modulated at 10 Gbits/s. With a non-return to zero (NRZ) pseudorandom binary sequence in Mach-Zehnder modulator .

Optical fiber : an optical fiber is a flexible, transparent fiber made of glass or plastic, the slightly thicker than a human hair. It functions as a waveguide or light pipe to transmit light between the two end transmitter and receiver. Optical fiber typically includes a transparent core surrounded by transparent cladding materials with a lower index of refraction. Light kept in core by total internal refraction this causes the fiber to act waveguide.

It is especially advantageous for long distance communication because light propagates through the fiber with little attenuation compared to electrical cable this allows long distance to be spanned with a few repeater Erbium Doped Fiber Amplifiers (EDFAs)

(EDFAs) : have received great attention due to their characteristics of high gains , bandwidth , low noise and high efficiencies .

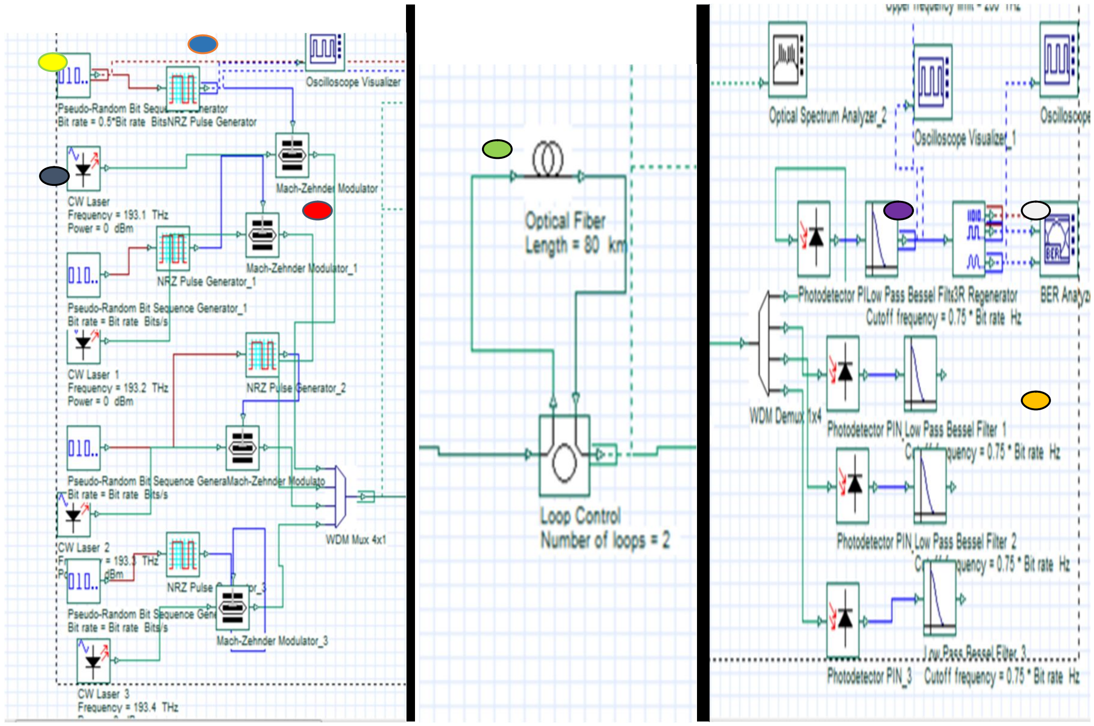
Optical amplification is required to overcome the fiber loss and also amplify the signal before receiver.

Receive signal by photo- detector PIN at the receiver part also include low pass filter and demodulator.

Photo- detector : photo detector or photo sensors are sensors of light or other electromagnetic energy , photo detector has p-n junction that converts the light photons in to current .

Low pass filter : is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency.

3 Regeneration : an act or the process of regenerating , renewal or restoration of body , also define the created a gain regenerate in a sentence



Transmitter **Channel** **Receiver**

Figure 2:8 general component optic system

2.5 Related Works

There are many related works in the area of optical amplifier such as :

- The author in [1] study the fiber optics communication industry is an ever evolving one , the growth experienced by the industry has been enormous this past decade but problem in losses in signal of optical fiber
- The authors G.Ivanovs , V. Bobrovs, L. Gegere , S.Olonkins study the characteristics of EDFA are investigated the amplification and noise figure dependences on different EDFA parameters[3].
- The authors Nitesh Reddy , Aarthi G and Tushar Krishna study the optical fiber amplification using EDFA with different wavelength [5].
- The author Christian Hentschel study the instrument for measuring EDFA with respect to gain, noise figure and BER , then discussed performance[8].
- The author in [10] study the performance analysis of optical communication system using Erbium Doped Fiber Amplifier, the simulated transmission system have been analyzed on the basic of different parameters. By simulating a model of communication system and using the most suitable settings of the system which include input power (dBm), fiber cable length (km) , EDFA length (km) , attenuation coefficient (dB/km) at cable section and extinction ratio of Mach–Zehnder modulator all the results are analyzed using optisystem.

CHAPTER THREE

SIMULATION SETUP

This chapter describes the details explanation of methodology that has been used in this research. The most important aspects during the methodology stage is design of the optical network with and without using EDFA. Simulation composed of two parts , part I, include the general optical network without EDFA with different length and parameters(gain , power), part II, include optical networks with using EDFA with different position pre EDFA, post EDFA , and inline the fiber cable .The system consists of transmitter, receiver and the basic optical communication components.

There simulation parameters in which all optical networks system involved in the research and illustrate in following tables. Table 3.1 shows the parameters of continuous wave laser (CW),table 3.2 shows the parameters of optical fiber , table 3.3 shows the parameters of EDFA (Ideal) , in addition, table 3.4 shows the parameters of Pseudo-Random bit sequence generator

Table 3.1 Simulation parameters for continuous wave (CW)

Frequency	193.1 , 193.2 , 193.3 , 193.4 THz
Power	0 dBm
Line width	10 MHz

Table 3.2 Simulation parameters for optical fiber

Reference wavelength	1550 nm
Length	80 Km , 120 km
Attenuation	0.20 dB/Km
Dispersion	16.76 ps/nm/km

Table 3.3 Simulation parameters for EDFA (Ideal)

At length 80 km	
Gain	5 dB
Power	2 dBm
Noise Figure	0 dB
At length 120 km	
Gain	3 dB
Power	2 dBm
Noise figure	0 dB

Table 3.4 Simulation parameters for Pseudo-Random bit sequence generator

Bit rate	0.2 * bit rate bits/s

3.1 Design of Optical Networks

Optical network consist of transmitter, optical fiber, and receiver.
On the transmitter section consists of data source, laser source and Mach-Zehnder modulator. The data source is then converted to Non –Return to Zero (NRZ) format. The Data source and laser signal are fed to and Mach-Zehnder modulator, where the inputs generated from data source are modulated with the laser signal are transmitted. The output from the modulated is now an optical signal .then multiple optical signals are transmitted in fiber using multiplexer .The multiplexed signal is the passed through the fiber. At the receiver side it pass through detector, de multiplexer, and low pass filter [16]. As Figure 3.1 shows the main component of optical networks.

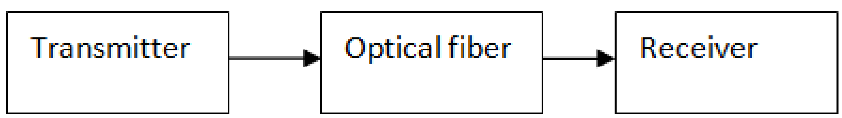


Figure 3.1: General Block Diagram of Optical Networks

3.1.2 Simulation of Optical Networks

Pseudo-random bit to generate sequence random bits : Generates a Pseudo Random Binary Sequence(PRBS) according to different operation modes .NRZ Pulse Generator the optical pulse remains on throughout the bit slot and its amplitude doesn't drop to zero between two or more successive 1 bits . In the optical communication the use of RZ format help the design of high capacity light wave.

(CW) : to generate optical signals supplies in put signal with 1550 nm wavelength and input power of with a non-return to zero (NRZ)Pseudo-random binary sequence in Mach-Zehnder modulator with 30 dB of extinction ratio .

MACH-ZEHNDER modulator: optical modulator is used for electrically controlling the output amplitude or the light wave passing through the device to reduce the device size and waveguide- based modulator is used for communication application.

Optical fiber: an optical fiber is a flexible, transparent fiber made of glass or plastic, the slightly thicker than a human hair

It function as waveguide or light pipe to transmit light between the two end transmitter and receiver. Optical fiber typically includes a transparent core surrounded by transparent cladding materials with a lower index of refraction. Light kept in core by total internal refraction this causes the fiber to act waveguide .Receive signal by photo- detector PIN at the receiver part and also include low pass filter [16] . As Figure 3. 2 show the block diagram of optical networks.

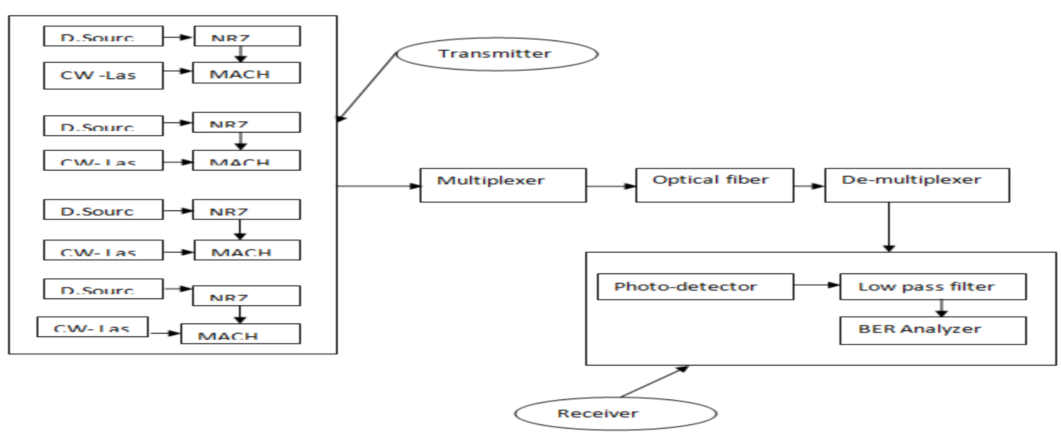


Figure 3.2: Block Diagram of Optical Networks

The Simulation composed of three parts , first part is the transmission which consists of four inputs with different frequencies (193.1 , 193.2 , 193.3 , 193.4)THz with addition continuous wave laser (CW), each CW laser connect with modulated (NRZ) bit sequence via Mach-Zehnder modulator . The four inputs combined together via WDM multiplexer

Second part is fiber which in this case consists of 80 km. The third part is the receiver which contains the WDM de-multiplexer then the photo-detector for each output followed by low pass filter to remove the un wanted high frequency, shows that as Figure 3.3.

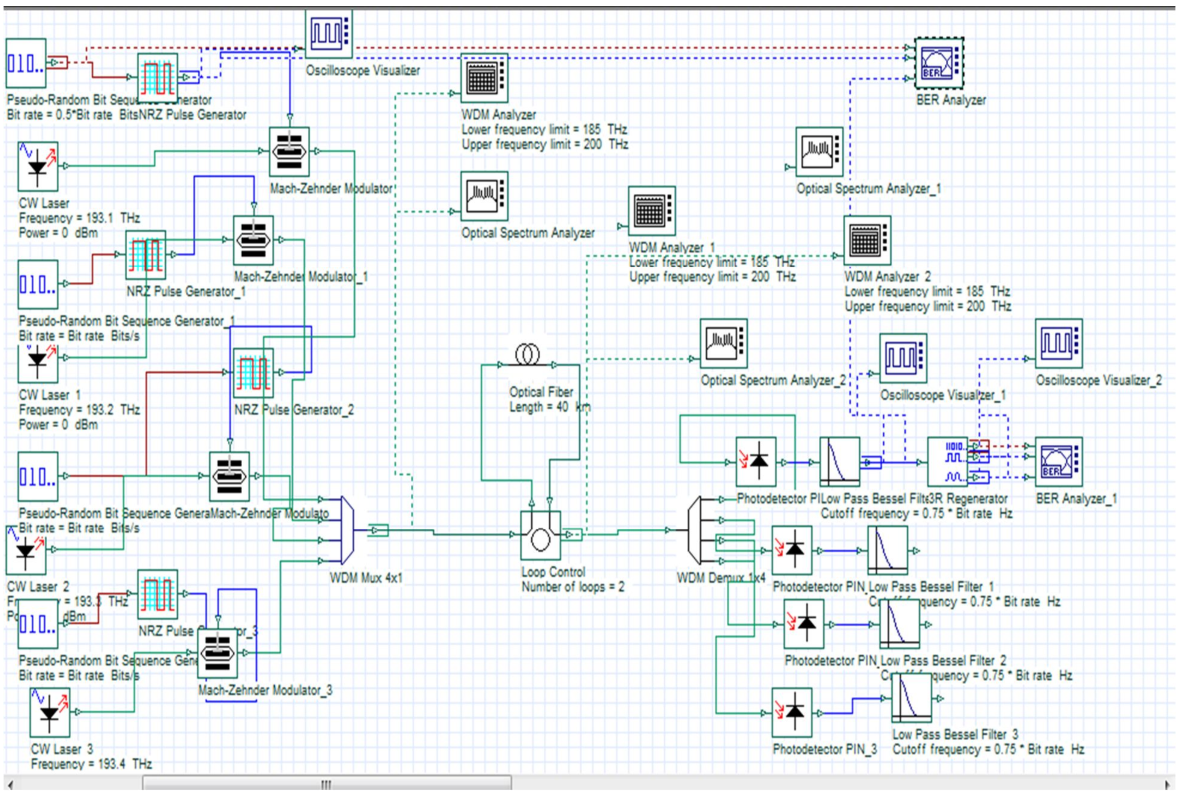


Figure 3.3: Simulation of Optical Fiber

3.2 Design at 80 km Length Optical Networks with EDFA

Consist all the component of optical fiber the explain above in addition consist optical amplifier EDFA.

EDFA is Optical amplification which it required to overcome the fiber loss and also amplify the signal before receiver , it have received great attention due to their characteristics of high gains , bandwidth , low noise and high efficiencies ,.It is especially advantageous for long distance communication because light propagates through the fiber with little attenuation compared to electrical cable this allows long distance to be spanned with a few repeater Erbium Doped Fiber Amplifiers (EDFAs) [17]. As Figure 3.4 shows optical fiber with EDFA .

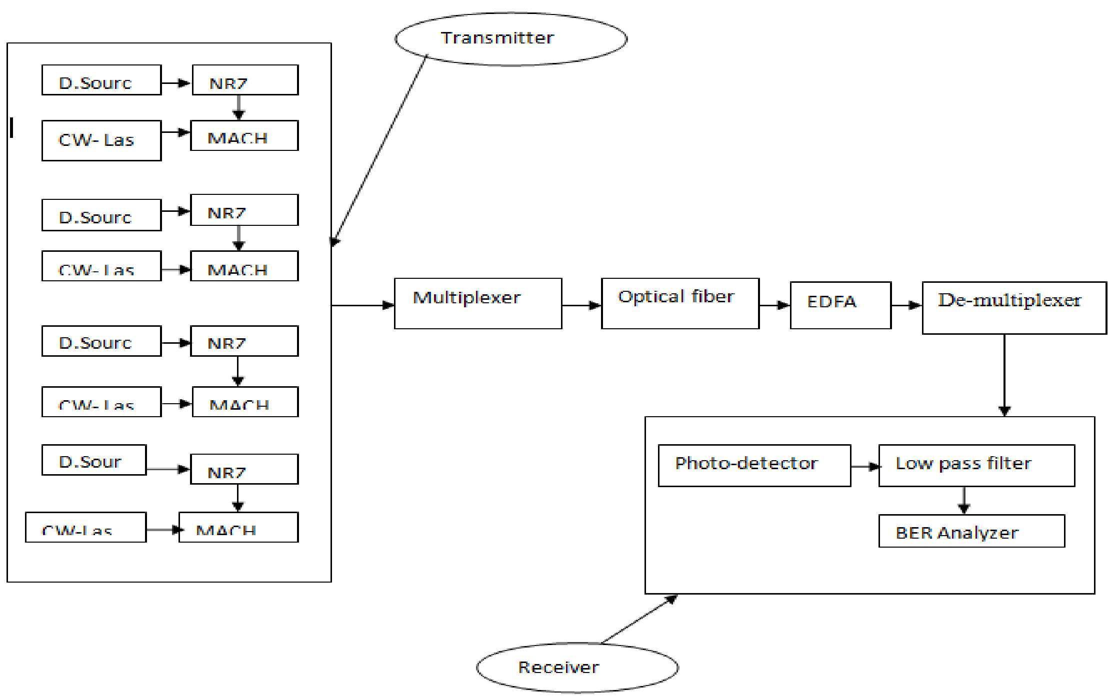


Figure 3.4: block diagram of Optical Networks with EDFA

3.2.1 Design Inline EDFA of 80 km Length

The Simulation composed of three parts, first part is the transmission which consists of four inputs with different frequencies (193.1 , 193.2 , 193.3 , 193.4)THz with addition continuous wave laser (CW), each CW laser connect with modulated (NRZ) bit sequence via Mach-Zehnder modulator . The four inputs combined together via WDM multiplexer .Second part is EDFA which has gain of 5 dBm with fiber which in this case consist of 80 km divided in to two 40km and between it EDFA . The third part is the receiver which contains the WDM de-multiplexer then the photo-detector for each output followed by low pass filter to remove the un wanted high frequency , as Figure 3.5 shows the simulation of inline EDFA fiber .

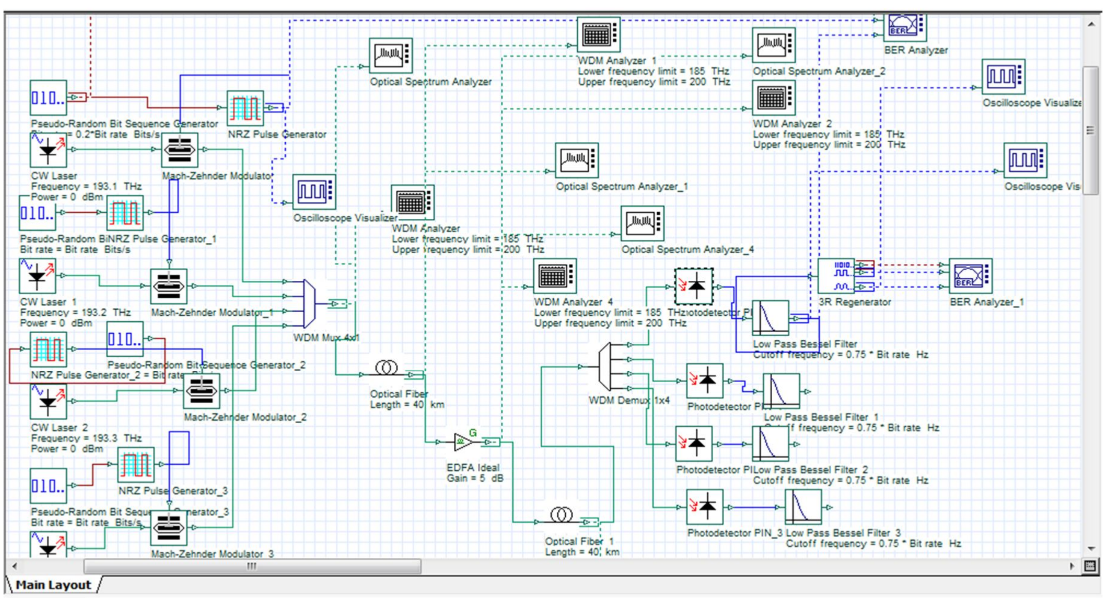


Figure 3.5 : Simulation of 80km Inline EDFA

3.2.2 Design Pre EDFA of 80 km Length

In this cause, the EDFA is located at the beginning of 80 km length of optical fiber cable shows as Figure 3.6.

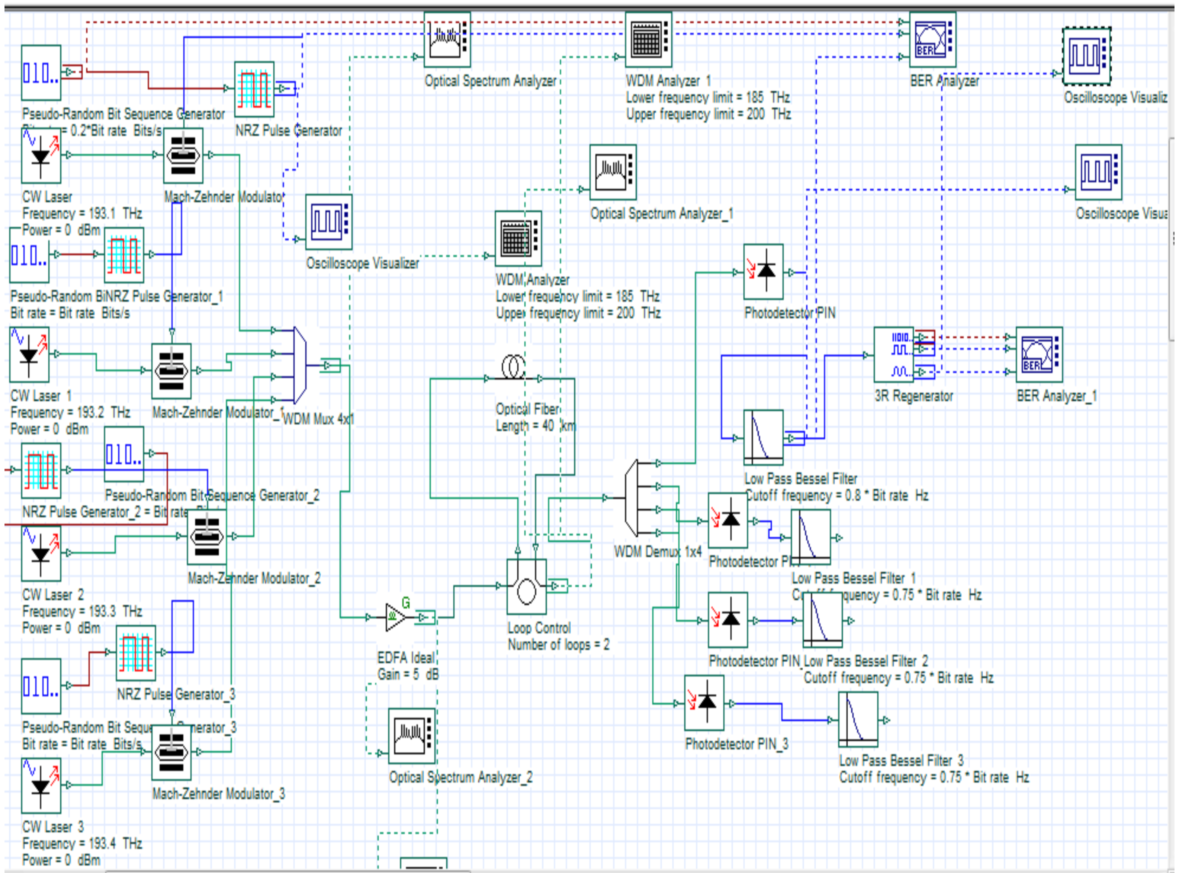


Figure 3.6: Simulation of 80km Pre EDFA

3.2.3 Design Post EDFA of 80 km Length

In this cause, the EDFA is located at the end of t80 km length of optical fiber cable shows as Figure 3.7.

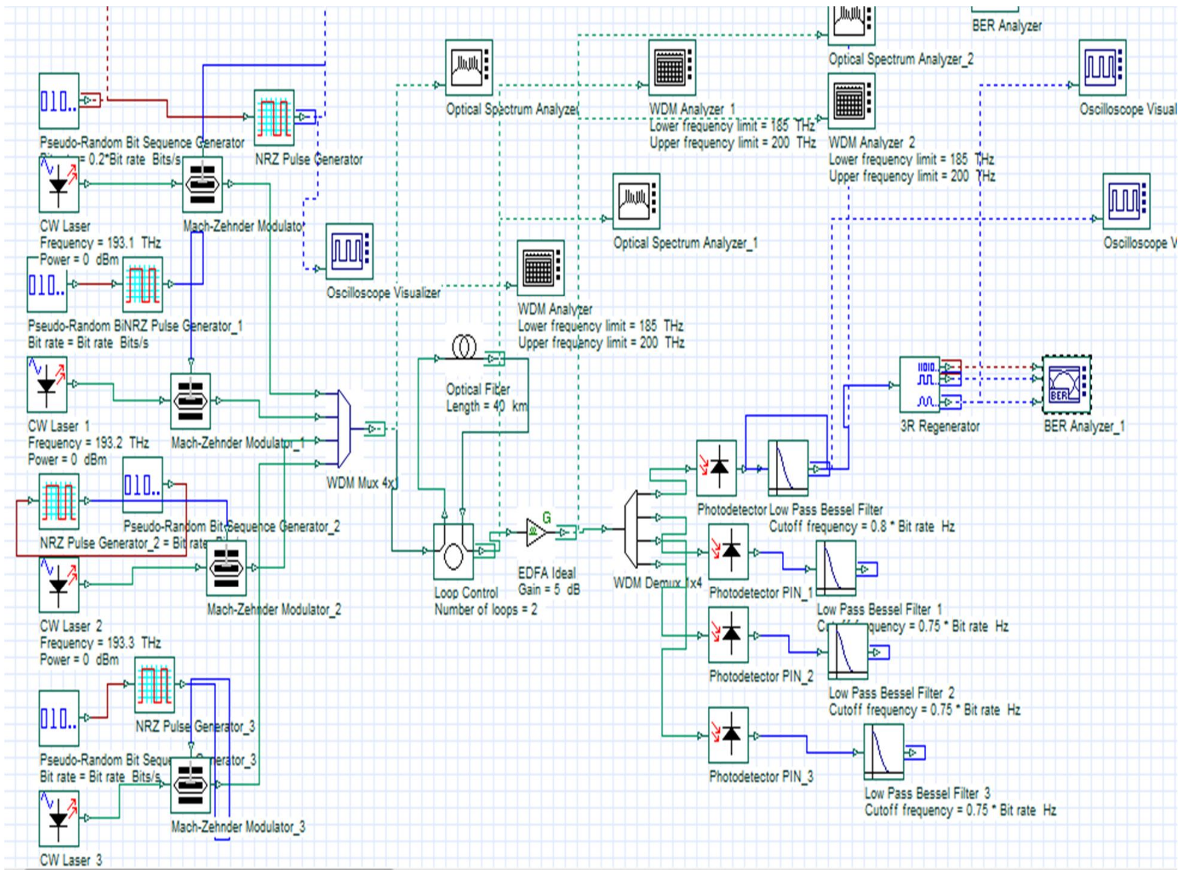


Figure 3.7: Simulation of 80km Post EDFA

3.3 Design Inline EDFA of 120 km Length

The Simulation composed of three parts, first part is the transmission which consists of four inputs with different frequencies (193.1 , 193.2 , 193.3 , 193.4)THz with addition continuous wave laser (CW), each CW laser connect with modulated (NRZ) bit sequence via Mach-Zender modulator . The four inputs combined together via WDM multiplexer. Second part is EDFA which has gain of 3 dBm with fiber which in this case consist of 120 km divided in to three 40km and two EDFA . The third part is the receiver which contains the WDM de-multiplexer then the photo-detector for each output followed by low pass filter to remove the un wanted high frequency [17]. As Figure 3:8 shows the simulation of inline EDFA .

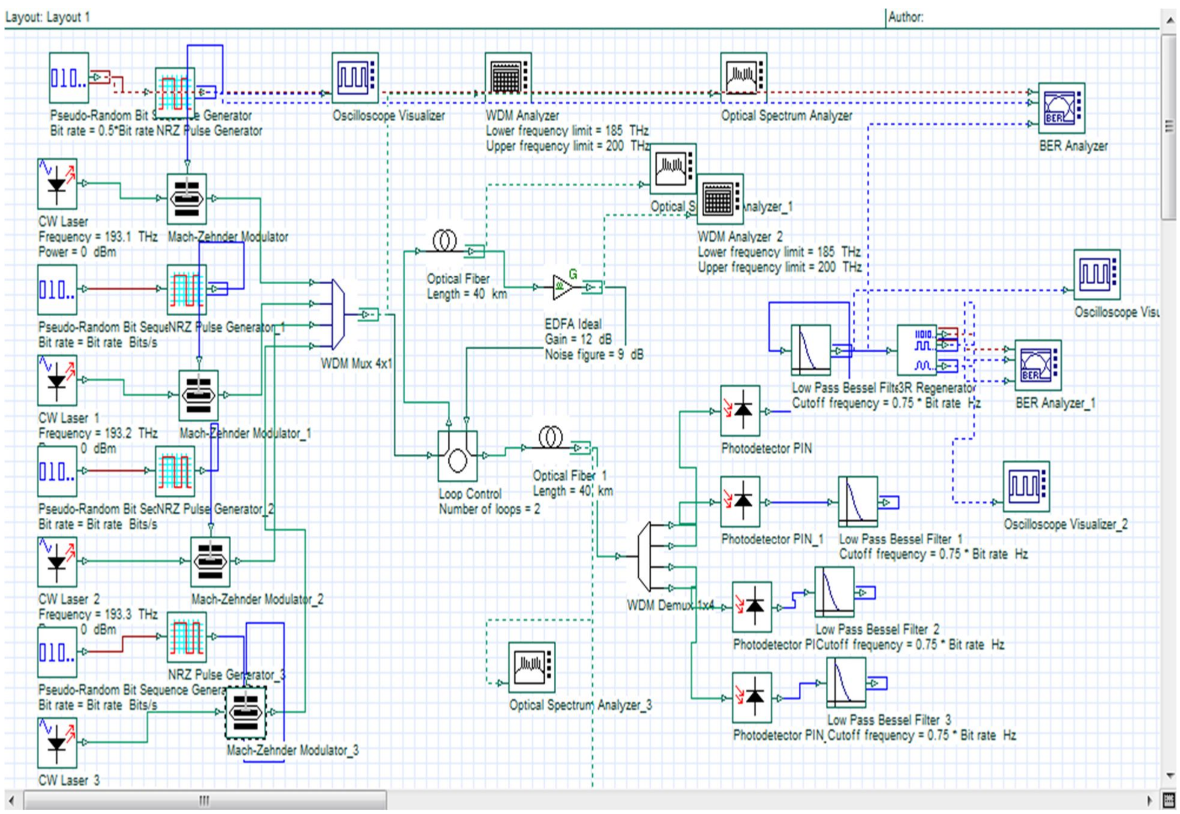


Figure 3.8: Simulation of 120km Inline Two EDFA

3.3.1 Design Pre EDFA of 120 km Length

In this cause, the two EDFAs are located at the beginning of 120 km length of optical fiber cable shows as Figure 3.9 .

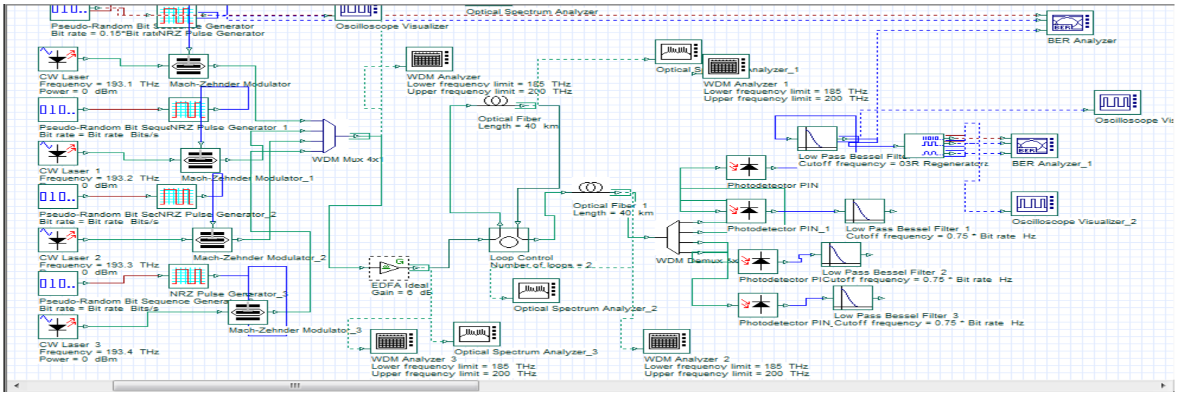


Figure 3.9: Simulation of 120km Pre Two EDFA

3.3.2 Design Post EDFA of 120 km Length

In this cause, the EDFA is located at the end of 120 km length of optical fiber cable shows as Figure 3.10 . While Figure given the setting of

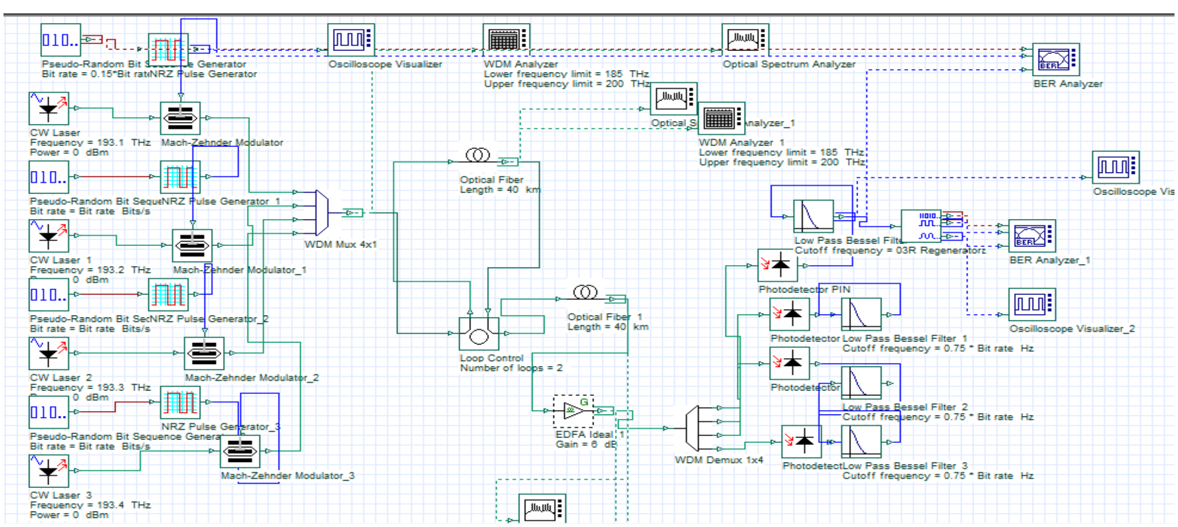


Figure 3.10: Simulation of 120km Post Two EDFA

3.4 System Power Budget

System budget: Amount of power lost or gained in each component

Power margin (3 to 10 dB) added to allows for component tolerance , system degradation , repairs, and splices .

If the calculated power budget the receiver power less than the specified receiver then the amplifier is required [18]. In this research using EDFA to amplification

Can be inserted

- Before regeneration
- Between regenerator

EDFA allow spacing of over 100 km between amplifier , the addition of an amplifier to any system can be a complex task

To determine amplifier spacing the first task is to determine the characteristics and expected gain

Here we define the actual system loss (LOSS actual) and the acceptable system loss

(LOSS acceptable)

The **actual system** is the loss between the transmitter and the receiver is the sum of all the losses in dB , Including fiber , connector , splices , and system power margin

The **acceptable system** loss is found by subtracting the receiver from the input power by

$$\textbf{LOSS acceptable} = P_{in} - P_{out} \quad \textbf{dBm} \qquad \textbf{(3.1)}$$

If the actual loss is greater than the acceptable loss the amplifier are necessary and the number of amplifier (N) is described by

$$\textbf{N} = \textbf{LOSS}_{actual} - \textbf{LOSS}_{acceptable} / \textbf{G}_{EDFA} \qquad \textbf{(3.2)}$$

The length between amplifier L EDFA

$$\textbf{L}_{(EDFA)} = \textbf{L} / (\textbf{N} + 1) \qquad \textbf{(3.3)}$$

Where L is the total length of fiber in system .

3.4 .1 Case 1 : Using One EDFA

Optic system simulator is used to simulate the optical fiber with amplifier EDFA. At this length 80 km transmitter data we need two amplifiers EDFAs [18], depend in the following calculation.

LOSS Actual = $P_{in} - P_{out}$

LOSS Actual = (-3.8) - (-19.01) = 15.3 dBm

LOSS acceptable = 10.3 dBm

The actual loss is greater than the acceptable loss we need the amplifier

The number of amplifier N

$$\textbf{N} = \text{LOSS}_{actual} - \textbf{LOSS}_{acceptable} / \textbf{G}_{EDFA}$$

Using Gain = 5 dBm

N = 15.3 - 10.3 / 5 = 1

At this length fiber only need one amplifier

$L = L_{total} / N + 1$

$L = 80 / 1 + 1 = 40$ km

3.4 .2 Case 2 : Using Two EDFA

Optisystem simulator is used to simulate the optical fiber with amplifier EDFA. At this length 120km transmitter data we need two amplifiers EDFAs [18], depend in the following calculation

LOSS Actual = $P_{in} - P_{out}$

LOSS Actual = (-3.8) - (-19.01) = 15.3 dBm

LOSS acceptable = 10.3 dBm

The actual loss is greater than the acceptable loss we need the amplifier

The number of amplifier N

$N = LOSS_{actual} - LOSS_{acceptable} / G_{EDFA}$

Using Gain = 3 dBm

N = 15.3 - 10.3 / 3 = 2

At this length fiber only need two amplifiers

$L = L_{total} / N + 1$ $L = 120 / 2 + 1 = 40$ k

CHAPTER FOUR

RESULTS AND DISCUSSION

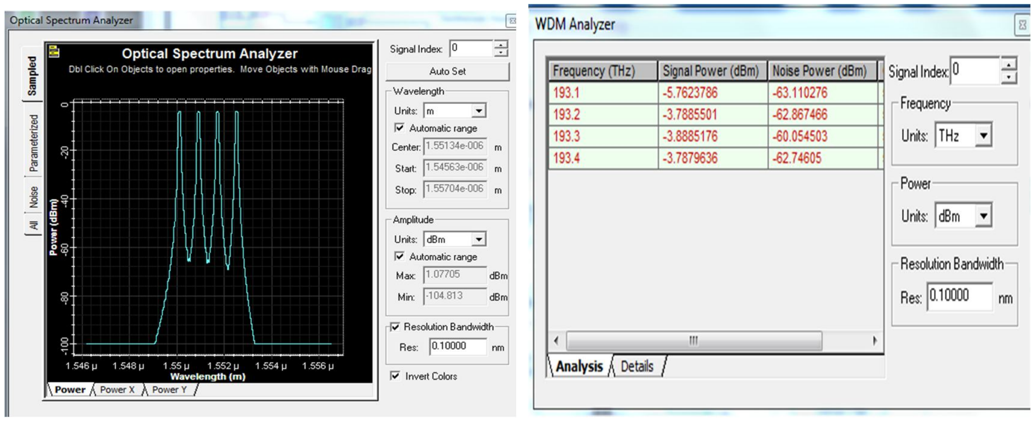
This chapter summarized the process of analyzing the results of optical networks without using amplifier show the losses of power then the results of optical networks with using amplifier (Erbium doped fiber amplifier) and the number of amplifier increase depend to increase of length cable fiber then discuss the results and compared the all values[19].

4.1 Simulation Results

In previous section, various component and parameters used in simulation are discussed. Using some of these components, the value of (BER) , Q-factor , eye height and threshold are measure in each all cases .Also by observing variation in eye diagram in all causes when transmit data through fiber in different length 80 km , 120 km with optical amplifier EDFA

4.2 Transmitted Data at 80 km Length in Optical Fiber

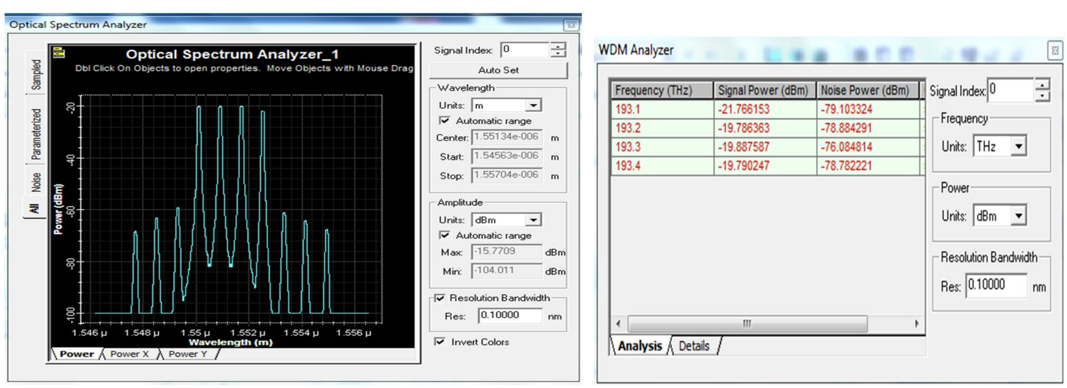
Figure 4.1 shows the input signal spectrum for four multiplexed frequencies (193.1 , 193.2 , 193.3 , 193.4 THz) as well as the analyzer information for these multiplexed signals including signal power and noise power for each frequency .In which each frequency signal has a peak signal power of – 5 dBm at beginning of 80 km fiber optic cable length .



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.1: Input Signal Spectrum and Analyzer (80KM)

Figure 4.2 shows the output signal spectrum for four multiplexed frequencies (193.1 , 193.2 , 193.3 , 193.4 THz) as well as the analyzer information for these multiplexed signals including signal power and noise power for each frequency . Figure 4.2 (a) In which each frequency signal has a peak signal power of – 20 dBm reduced than input signal . As Figure 4.2 (b) shows the WDM analyzer the signal power reduce by 16 dBm and the noise power also reduce by 16 dBm for each signal .



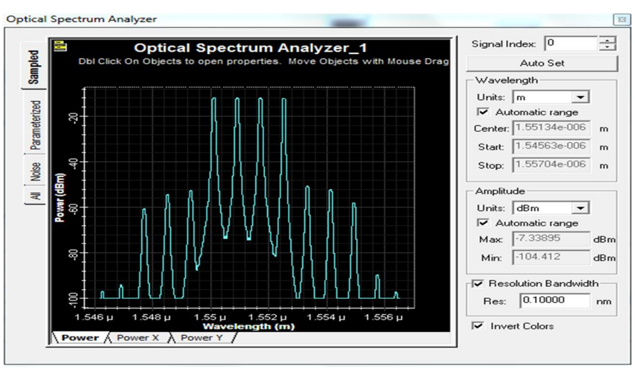
a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

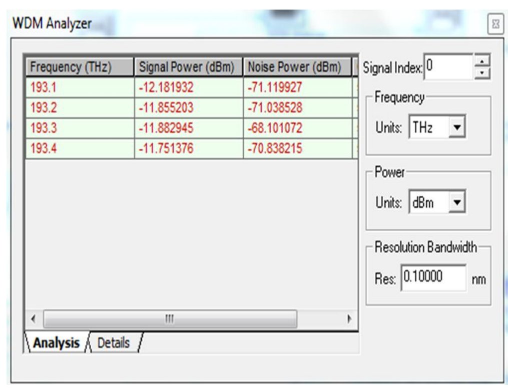
Figure 4.2: Optical Signal after 80 km

4.3 Inline EDFA of 80 km Length

Optic system simulator is used to simulate the optical fiber with EDFA amplifier. At this length we need one amplifier EDFA. Then length of 80 km fiber divided in two 40 km fiber by EDFA which has gain of 5 dBm .

As Figure 4.3 (a) In which each frequency signal has a peak signal power of – 10 dBm reduced than input. As Figure 4.3 (b) shows the WDM analyzer the signal power reduced by 7 dBm and the noise power also reduced by 8 dBm for each signal .

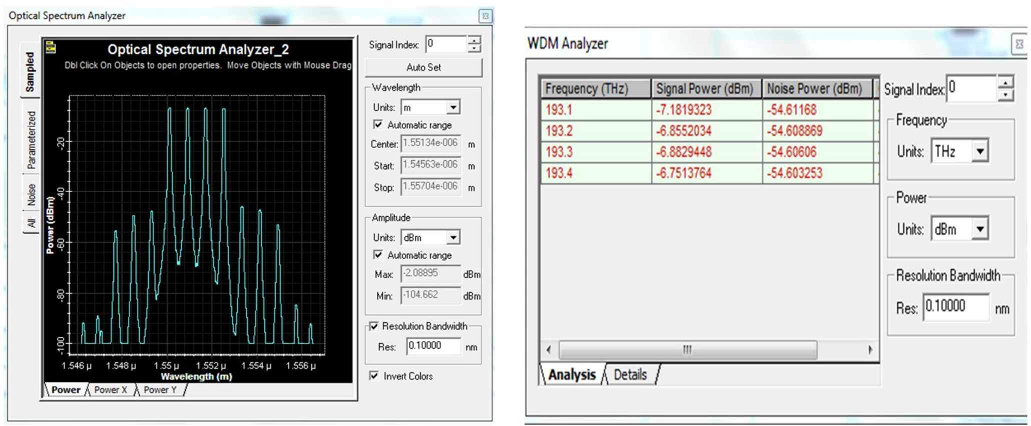




a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.3: Optical Signal before EDFA(inline)

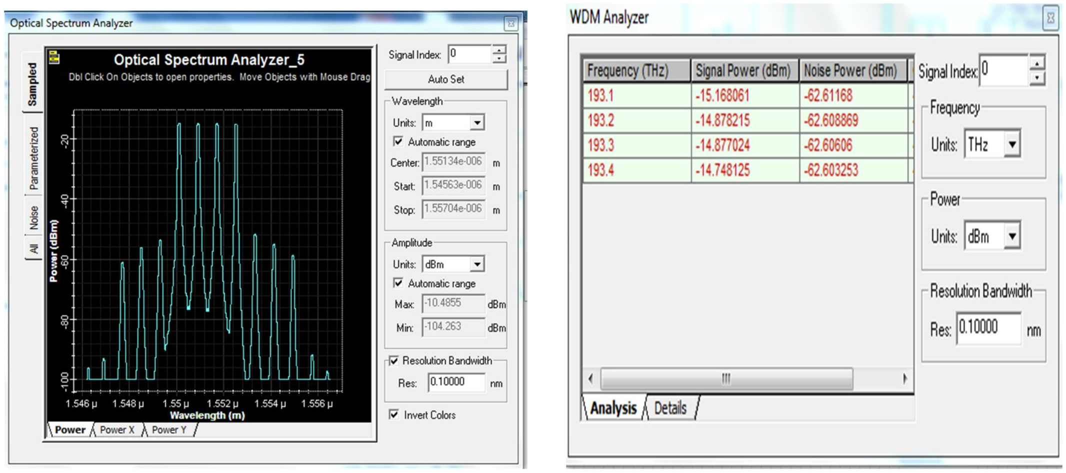
Gives as Figure 4.4 (a) In which each frequency signal has a peak signal power of – 5 dBm increased . As Figure 4.3 (b) shows the WDM analyzer the signal power increased by 5 dBm and the noise power also increased by 17 dBm for each signal .



a (Optical Spectrum Analyze **b (WDM Analyzer)**

Figure 4.4 : Optical signal after EDFA (inline)

Explain the output signal as Figure 4.5 (a) In which each frequency signal has a peak signal power of – 10 dBm reduced . As Figure 4.5(b) shows the WDM analyzer the signal power reduced by 5 dBm and the noise power also reduced by 8 dBm for each signal.



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.5: Output signal spectrum and analyzer (80km)

Through the result of simulation for post EDFA system found the following the Q-factor is very high with a value (17.171) , bit error rate is very low with a value (2.11197 e^ -066) , Eye height is very high with a value (6.46266 e^ -005) , and threshold is low with a value (5.58352 e^ -005) As shown in of table (4.1) .

Table 4.1 Analysis of EDFA between fiber after 3R generation (inline)

Max Q Factor	17.171
Min BER	2.11197 e^ -066
Eye Height	6.46266 e^ -005
Threshold	5.58352 e^ -005

The eye diagram is an oscilloscope display in which digital signal from receiver is repetitively sampled and applied the vertical input while the data is used to trigger the horizontal sweep. the are many measurement , that can be obtained from eye diagram such as eye opening height (18) dBm, measure additive noise in the signal , eyes width (0- 1) measure timing synchronization and eyes closure(2dBm) measure inter symbol interference additive noise .

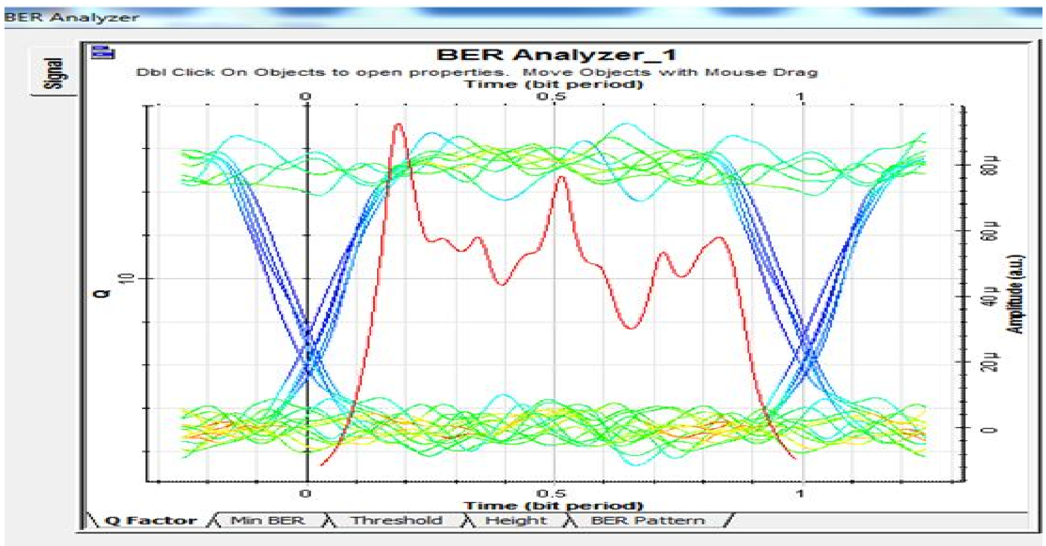
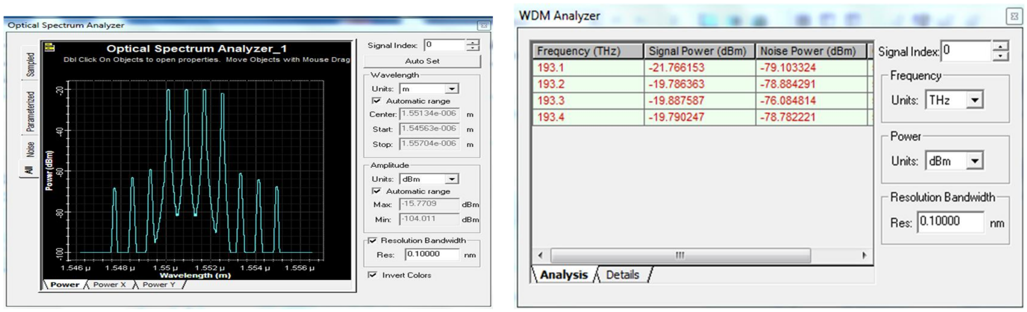


Figure 4.6: Eye diagram for One Inline EDFA

4.3.1 Post EDFA of 80 km Length

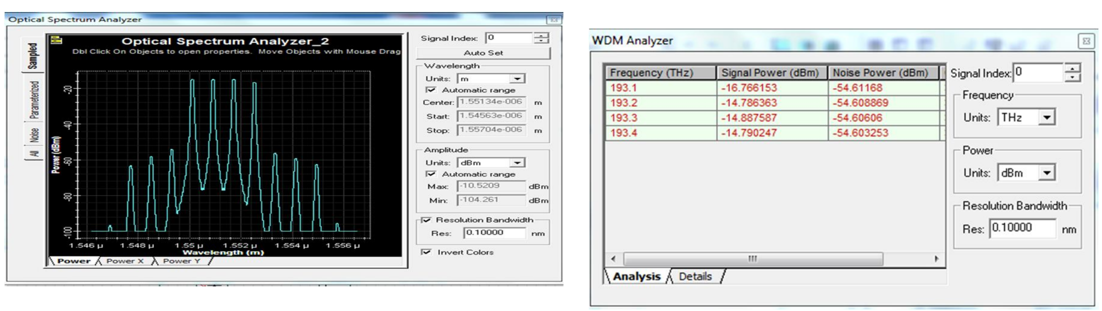
To simulate the optical fiber with EDFA amplifier. The location of amplifier in the end of optical fiber cable . As Figure 4.7 (a) In which each frequency signal has a peak signal power of – 20 dBm reduced than input. As Figure 4.7 (b) shows the WDM analyzer the signal power reduced about 16 dBm and the noise power also reduced about 16 dBm for each signal .



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.7: Optical signal before EDFA (post)

As Figure 4.8 (a) In which each frequency signal has a peak signal power of – 25 dBm reduced than input. As Figure 4.8 (b) shows the WDM analyzer the signal power increased by 5 dBm and the noise power also increased by 25 dBm for each signal .



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.8: Output optical signal after EDFA(post)

Through the result of simulation for post EDFA system found the following the Q-factor is low with a value (15.2771) , bit error rate is very high with a value (5.41425 e^ -053) , Eye height is low with a value (6.38085 e^ -005) , and threshold is very high with a value (6.23154 e^ -005) As shown in of table (4.2) .

Table 4.2   Analysis of EDFA amplifier after 3R generation (post)

Max Q Factor	15.2771
Min BER	5.41425 e^ -053
Eye Height	6.38085 e^ -005
Threshold	6.23154 e^ -005

Eye diagram it can be obtained from eye diagram such as eye opening height (16dBm) measure additive noise in the signal , eyes width(1dBm) measure timing synchronization and eyes closure(5dBm) measure inter symbol interference additive

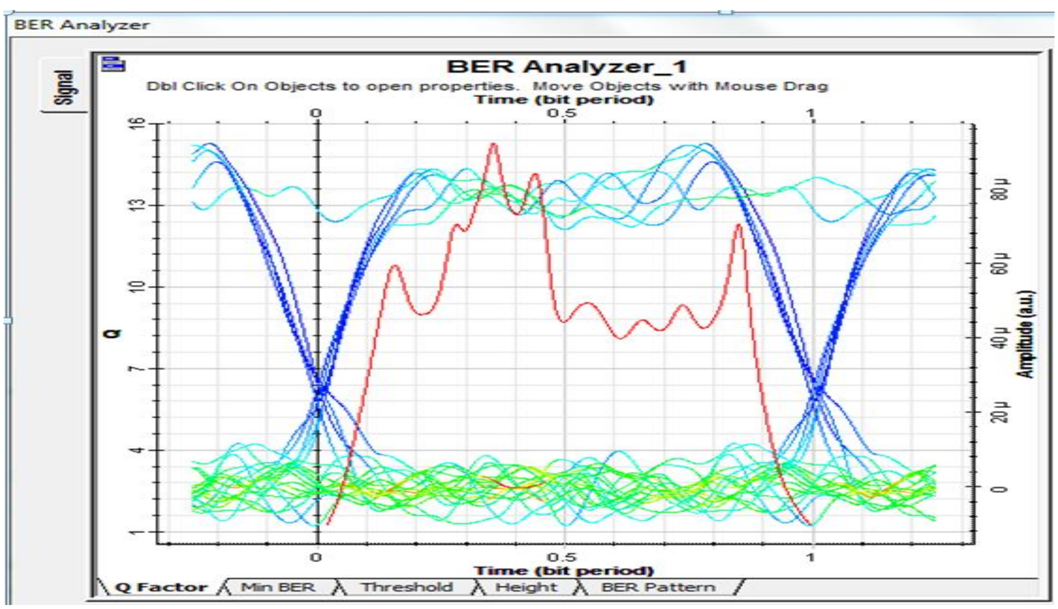
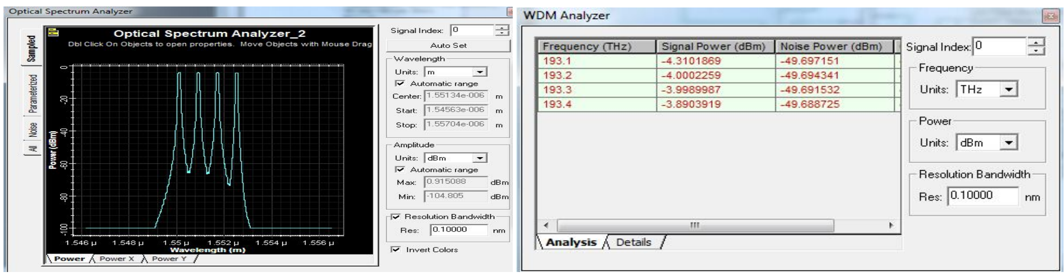


Figure 4.9: Eye diagram for post EDFA

4.3.2 Pre EDFA of 80 km Length

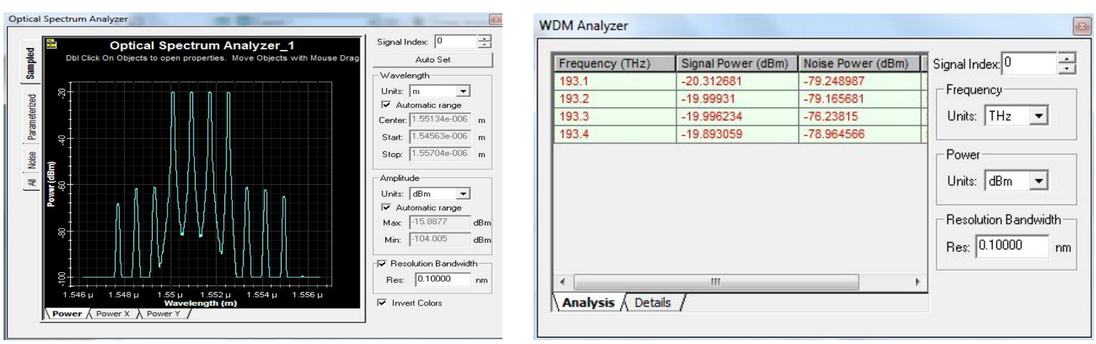
Optic system simulator is used to simulate the optical fiber with EDFA amplifier .The location of amplifier in the beginning of optical fiber cable (pre EDFA) . As Figure 4.10 (a) In which each frequency signal has a peak signal power of – 5 dBm . As Figure 4.10 (b) shows the WDM analyzer indicate the signal power increased by 1 dBm and the noise power increased by 14dBm for each signal.



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.10: optical signal after EDFA (pre)

As Figure 4.10 (a) given in which each frequency signal has a peak signal power of – 20 dBm . As Figure 4.10 (b) shows the WDM analyzer indicate the signal power reduced by 16 dBm and the noise power reduced by 30 dBm for each signal



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.11: Output Optical Signal (pre)

Through the result of simulation for post EDFA system found the followin g the Q-factor is very low with a value (4.76969) , bit error rate is very high with a value (4.19649 e^ -007) , Eye height is very low with a value (8.93668 e^ -006) , and threshold is low with a value (1.58414 e^ -005) As shown in of table (4.3) .

Table 4.3 Analysis of pre EDFA after 3R generation (pre)

Max Q Factor	4.76969
Min BER	4.19649 e^ -007
Eye Height	8.93668 e^ -006
Threshold	1.58414 e^ -005

Eye diagram it can be obtained from eye diagram such as eye opening height (5 dBm) measure additive noise in the signal , eyes width (0.8 dBm) measure timing synchronization and and eyes closure(2.9dBm) measure inter symbole interference additive noise .

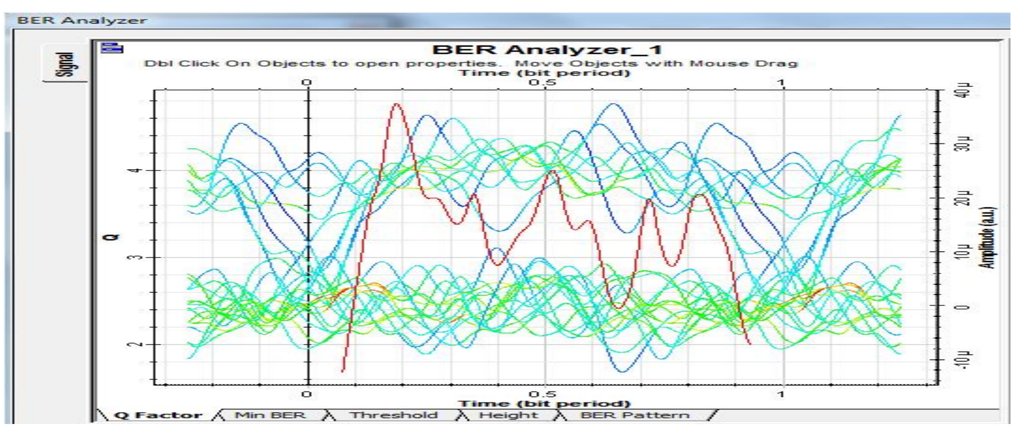
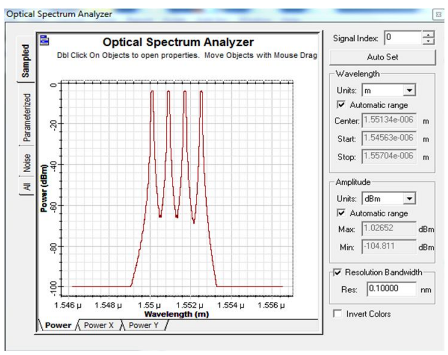
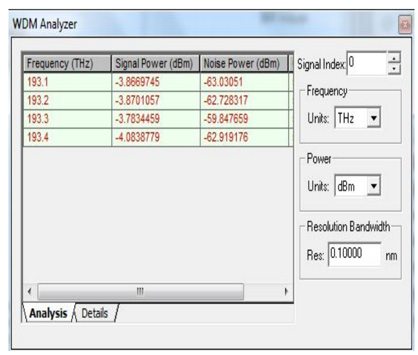


Figure 4.12 : Eye diagram pre EDFA

4.4 Inline EDFA of 120 km Length

Optic system simulator is used to simulate the optical fiber with amplifier EDFA. At this length transmitter data we need two amplifiers EDFAs. length of 120 km fiber divided in to three 40 km fiber by two EDFA which has gain of 3 dBm .Figure 4.13 (a) the input wavelength consists of four frequencies (193.1,193.2 ,193.3,193.4) THz with transition power -5 dBm .Figure 4.13(b) shows the WDM analyzer indicate the signal power and the noise figure for each signal .



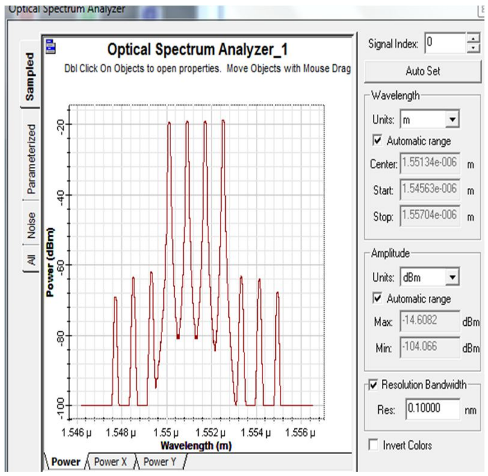


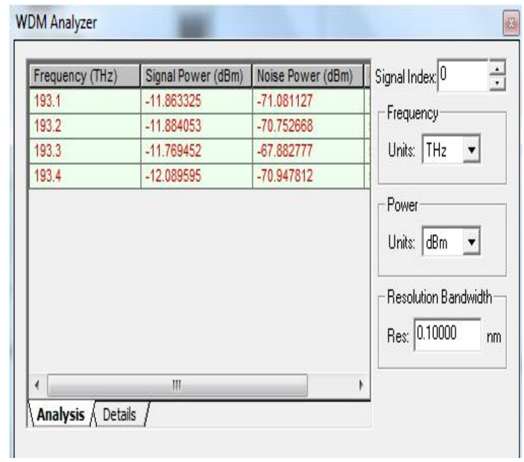
a

(Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.13: Input Optical Signal Spectrum and Analyzer (120km)

Figure 4. 14(a) shows the spectrum of input frequencies after 120 km , which indicate the power -20 dBm .Figure 4.14 (b) shows the WDM analyzer indicate .the input frequency , the signal power reduced by 8 dBm and the noise figure reduced by 8 dBm for each signal .

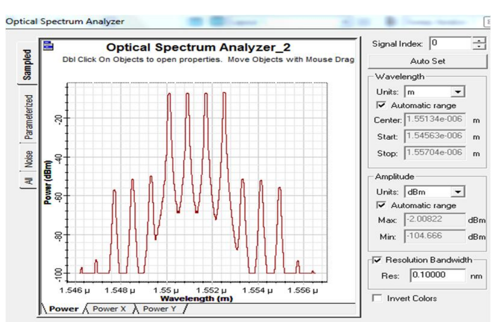


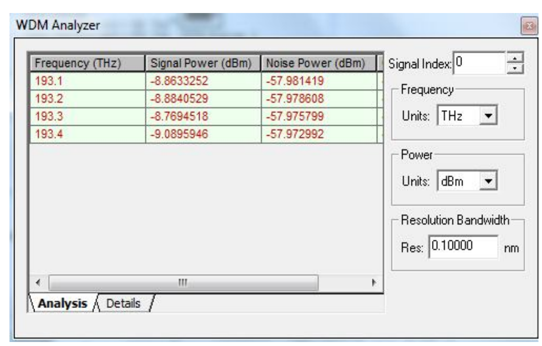


a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.14 : Optical signal before two EDFAs

Figure 4.15(a) shows the spectrum of input frequencies after 120 km , which indicate the power -5 dBm .Figure 4.7 (b) shows the WDM analyzer indicate .the input frequency , the signal power increased about 3 dBm and the noise figure increased about 14 dBm for each signal .

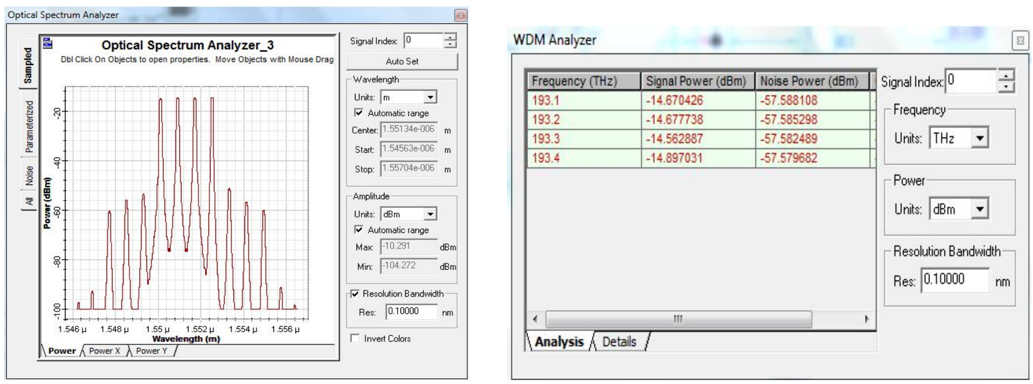




a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.15 : Optical signal after two EDFAs

Figure 4.16 (a) shows the spectrum of input frequencies after 120 km , which indicate the power -10 dBm .Figure 4.16 (b) shows the WDM analyzer indicate , the signal power reduced by 6 dBm and the noise figure reduced for each signal .



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.16: Output optical signal (two EDFAs)

Through the result of simulation for post EDFA system found the following the Q-factor very high with a value (19.7032) , bit error rate very low with a value (1.00775 e^ -086) , Eye height very high with a value (7.19673 e^ -005) , and threshold low with value (4.08877 e^ -005) As shown in of table (4.4) .

Table 4.4 Analysis of two EDFAs between fiber after 3R generation

Max Q Factor	19.7032
Min BER	1.00775 e^ -086
Eye Height	7.19673 e^ -005
Threshold	4.08877 e^ -005

Eye diagram it can be obtained from eye diagram such as eye opening height (20dBm) measure additive noise in the signal , eyes width (0-1 dBm) measure timing synchronization and and eyes closure(2.9dBm) measure inter symbole interference additive noise .

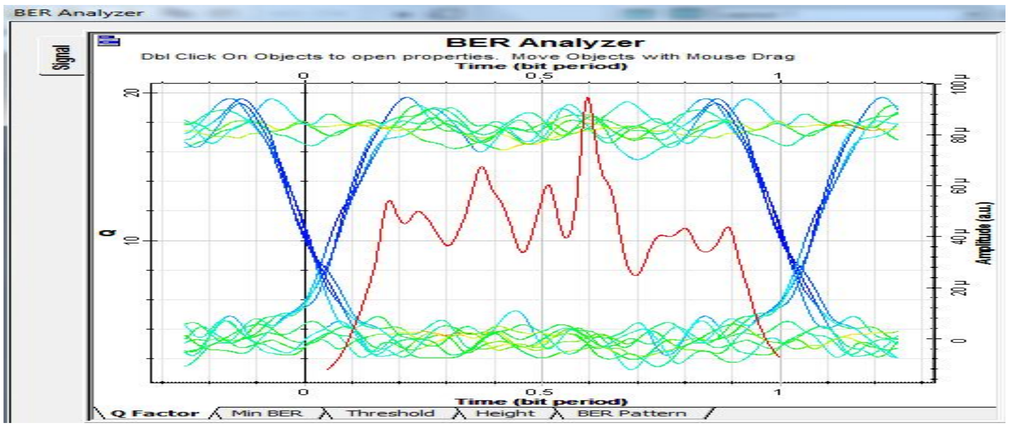
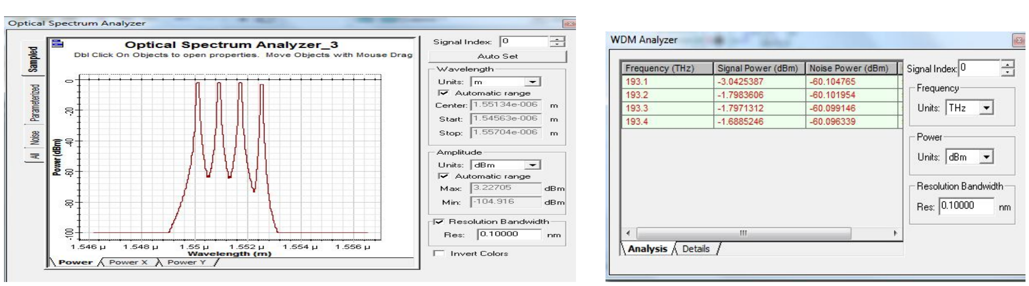


Figure 4.17: Eye Inline two EDFA

4.4.1 Pre EDFA of 120 km Length

Optic system simulator is used to simulate the optical fiber with amplifier EDFA. The location of amplifier beginning of optical fiber (pre EDFA).

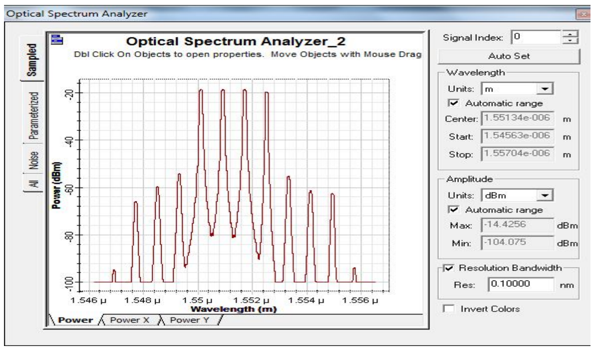
Figure 4.18 (a) shows the spectrum of input frequencies after 120 km , which indicate the power -5 dBm .Figure 4.18 (b) shows the WDM analyzer indicate , the signal power increased by 0.4 dBm and the noise figure increased by 3 dBm for each signal.

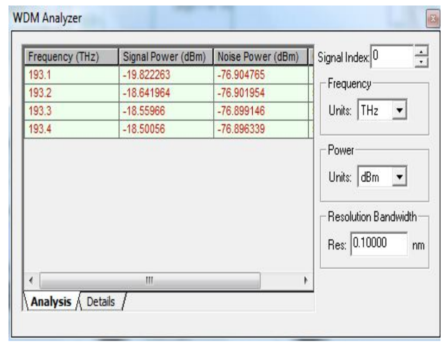


a b

Figure 4.18 : optical Signal after two EDFAs

Figure 4.19 (a) shows the spectrum of input frequencies after 120 km , which indicate the power -20 dBm .Figure 4.19 (b) shows the WDM analyzer indicate , the signal power reduced by 16 dBm and the noise figure reduced by 16 dBm for each signal.





a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.19: Output optical Signal (two EDFAs)

Through the result of simulation for post EDFA system found the following the Q-factor very low with a value (7.52047) , bit error rate very high with a value (2.53308 e^ -014) , Eye height very low with a value (2.00799 e^ -005) , and threshold low with a value (1.73066 e^ -005) As shown in of table (4.5) .

Table 4.5 Analysis of pre EDFAs amplifier after 3R generation

Max Q Factor	7.52047
Min BER	2.53308 e^ -014
Eye Height	2.00799 e^ -005
Threshold	1.73066 e^ -005

Eye diagram it can be obtained from eye diagram such as eye opening height (8 dBm) measure additive noise in the signal , eyes width (0-1 dBm) measure timing synchronization and eyes closure(3.4dBm) measure inter symbol interference additive noise

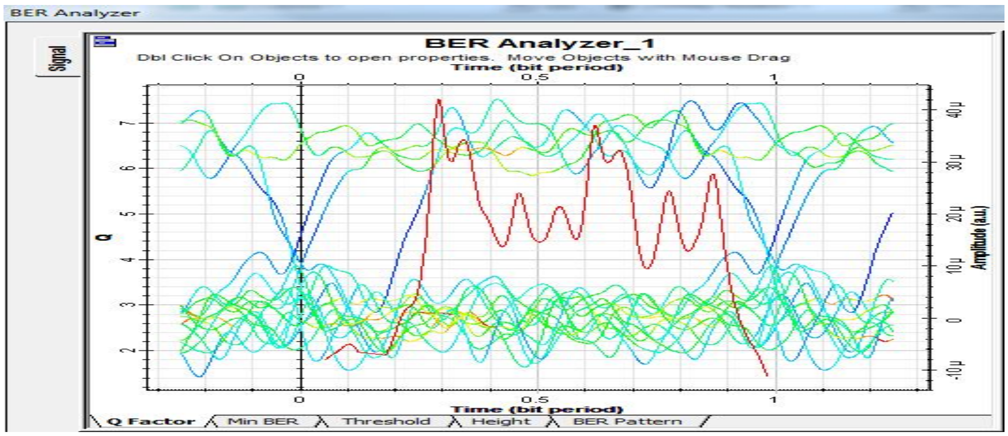
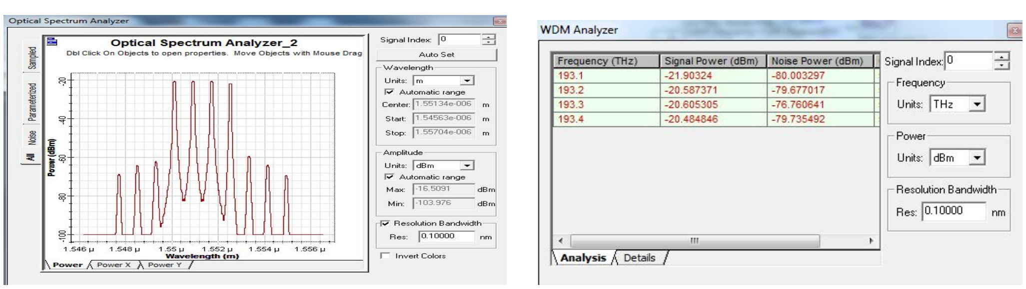


Figure 4.20: Eye diagram of pre two EDFA

4.4.2 Post EDFA of 120 km Length

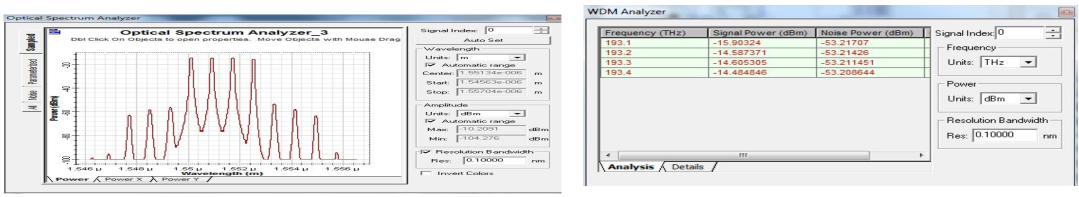
Optic system simulator is used to simulate the optical fiber with amplifier EDFA. The position of amplifier after optical fiber (post EDFA) . Figure 4.21 (a) shows the spectrum of input frequencies after 120 km , which indicate the power -20 dBm .Figure 4.21 (b) shows the WDM analyzer indicate , the signal power reduced by 18 dBm and the noise figure reduced by 6 dBm for each signal.



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.21: Optical Signal before two EDFAs

Figure 4.22 (a) shows the spectrum of input frequencies after 120 km , which indicate the power -15 dBm .Figure 4.19 (b) shows the WDM analyzer indicate , the signal power increased by 6 dBm and the noise figure increased by 16 dBm for each signal.



a (Optical Spectrum Analyzer) **b (WDM Analyzer)**

Figure 4.22: Output optical Signal after two EDFAs

Through the result of simulation for post EDFA system found the following the Q-factor high with a value (19.4911) , bit error rate very high with a value (6.37576 e^ -085) , Eye height high with a value (6.63183 e^ -005) , and threshold very high with a value (5.37677 e^ -005) As shown in of table (4.6) .

Table 4.6 Analysis of post EDFAs after 3R generation

Max Q Factor	19.4911
Min BER	6.37576 e^ -085
Eye Height	6.63183 e^ -005
Threshold	5.37677 e^ -005

Eye diagram it can be obtained from eye diagram such as eye opening height (18dBm) measure additive noise in the signal , eyes width (0.9 dBm) measure timing synchronization and and eyes closure(2.5dBm) measure inter symbole interference additive noise .

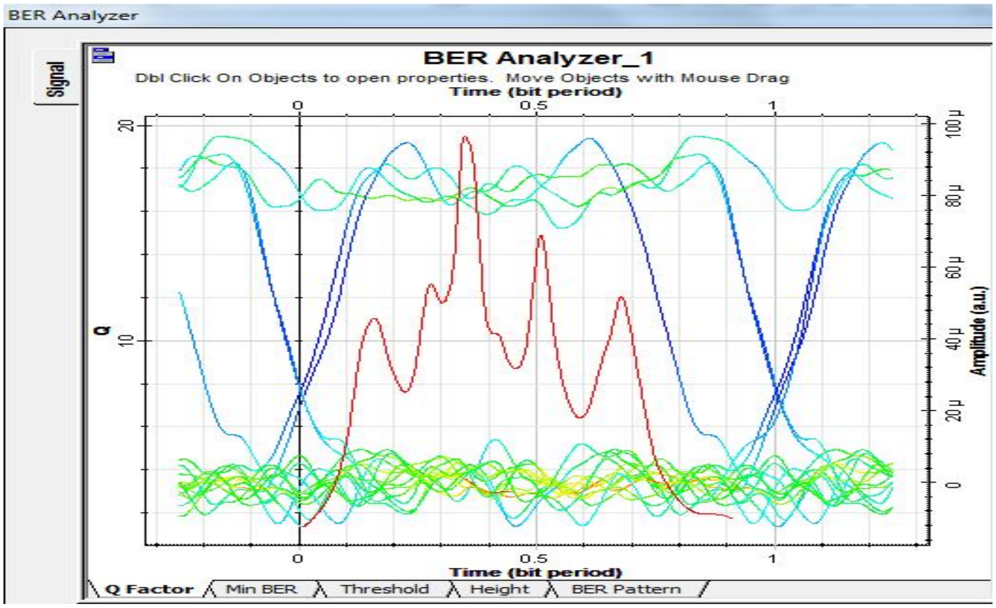


Figure 4.23 : Eye diagram of post two EDFAs

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Implementation of optical fiber network with and without optical amplifier (EDFA) to reduce the losses of data, used optic system to simulated optical networks then after the evaluation analysis for using EDFA with different position pre, post , and inline the fiber cable was implemented . All of these networks were tested standard length of optical fiber which is (80, 120 kilometers). Result and performance evaluation of optical network was obtained and it shows that the number of optical amplifier (EDFA) increase as the fiber length increase. Also the result shows the optical networks using the eye diagram such as Q-factor, bit error rate , eye height , and threshold . When has one EDFA the position of EDFA inline the fiber cable the result of simulation the Q-factor is very high) , bit error rate is very low, Eye height is very high , and threshold is low .The position before fiber (pre EDFA) shows the Q-factor is very low , bit error rate is very high , Eye height is very low , and threshold is low .The position after fiber (post EDFA) shows the Q-factor is low, bit error rate is very high, Eye height is low, and threshold is very high . When has two EDFA the position EDFA inline the length fiber cable the result of simulation the Q-factor very high w , bit error rate very low , Eye height very high , and threshold low .

The position before fiber (pre EDFA) shows the Q-factor very low, bit error rate very high , Eye height very low , and threshold low .

The position after fiber (post EDFA) shows the Q-factor high , bit error rate very high , Eye height high , and threshold very high , from result it conclude that position of inline EDFA fiber cable is the best of position than pre and post because it gave high Q-factor , very small bit error rate , eye height , and threshold .

5.2 Recommendations

There are many types of optical amplifier can be used to compensate the attenuations and it required to evaluate their performance. In this thesis Erbium Doped Fiber Amplifier is evaluated , there for its recommended to consider other types such as Raman optical amplifier and Semiconductor optical amplifiers in the future research .

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