DEDICATION

To

My Father

Who were a great mentor and supporting and encouraging me to believe in my self

My Mother

To my soulmate, my angel, my support , to the person who believed in me , to the person that I can say am nothing without you, to my beloved mom you are my all .

My Sisters Iman & Manar and My Brothers Mehdi & Mohamed

You are my supporters, my happiness, my audience, my biggest fans my best friends.

To my second familly

All my friends who have never left my hand and they were by me side specially Hiba ,

Amina and my room mate Meleke , thank you for all.

To my person

You were so brave , what ever you passed what ever you have seen you did not give up , it was not easy but finally it is done

This is not the end actually it is the beginning of a lot of things .

Houda

I have the great pleasure to dedicate this modest work
To my Beloved Mother AMARIA ,
To my Dear Sisters SABAH and KHADRA
To all my Friends
To all my Teachers from primary school to my last year of university
And to all with whom I spent wonderful moments

And praise be to Allah, Lord of the Worlds. Also, may Allah's prayers and peace be upon Muhammad and his family and companions.

YAkhlef

Acknowledgment

Primarily, my person would like to thank God for giving me the endurance and perseverance to complete this work.

In particular, a special greeting goes to ***Mr Dr. Zitouni. A,*** *who was my supervisor, for his orientation a guidance, patience and his support on the way, until we achieved the completion of this master thesis.*

I would like to express my sincere gratitude to my supervisor for his time, support and for gracefully providing us with required files and documentations.

I wish to thank lecturers, staff and technicians, for their cooperation, indirect or direct contribution in finishing our project.

My sincere appreciation also to my special friends HIBA, AMINA and my roommate MELEKE who have involved and helped me in this project.

A special feeling of gratitude to my sisters IMEN &MANAR who always picked me up on time and encouraged me to go on every adventure, especially this one.

Last word will be destinated to the greatest person that I have in my life to the most one that believed in me even when i did not to my strong women that I have ever met to mom, thank you for being always there for me, I wish my gratitude to my father and all family members for their support, encouragement, understanding, sacrifice and love.

Abstract

One of the main factors limiting the performance of WDM systems is dispersion. The use of dispersion compensation fiber (DCF) is the most commonly used dispersion compensation method in WDM systems. In this work, the performance WDM systems at frequency of 193.1THz. with different dispersion compensation schemes using DCF (pre compensation, post compensation and symmetrical compensation techniques) are analysed in terms of BER and Q factor. As a first part of the simulation.

In the next part, 4-Channel WDM system is designed and simulated. all channels were discussed as Q factors and eye diagrams dependent on change in different parameters, such as signal input power, bite rate, and variations of both DCF and SMF length each alone. once the simulation is presented without compensation, then DCF technique is added as dispersion compensators in different configurations.

Finally, 8-Channel WDM system is designed and simulated and tested under a list of parameters signal input power, bit rate DCF and SMF lengths. The effect of all the previous parameters were studied on different channels then the obtained results are presented.

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General Introduction :

In communication system, optical fiber takes a big role that's why it is used in large applications. Optical fiber system is mainly based on three stages: transmitter block system, an optical fiber cable and a receiver. The transmitter is designed to convert the electrical signal applied to it into pulses of light which will be transmitted as an optical signal among the optical fiber cable, once light is transmitted it is then detected by the receiver which converts the light signals into electrical ones.

However whole process can be affected by factors that can degrade the optical signal during transmission such as: attenuation and dispersion. For attenuation problem as been reduced and solved with the improvement of fiber manufacturing and the invention of erbium-dopped fiber amplifier EDFA. The dispersion stays as problem that affects the system more than attenuation because it limits the potential bandwidth and transmission performance of the fiber since it increases along the fiber length.

Dispersion compensation or dispersion management is the process of designing compensators to be placed in the system in order to control performance of the fiber and reduce the dispersion, Different techniques were developed such as: Dispersion-Shifted Fiber (DSF), Dispersion Compensation Fiber (DCF), Fiber Brag Grating (FBG).

In this thesis, the work is focused on DCF technique and how it is applied a simple communication system that uses optical fiber and how it is applied to WDM systems using 4-channels and 8-channels at various data rates and input power. The simulation presented in this work have been done using OptiSystem software. This thesis contains three main chapters that are presented as follows:

- Chapter 1: Introduces the optical communication system and its main components, the transmission principle, and WDM systems.
- Chapter 2: Introduces impairments in the optical fiber communication (attenuation and dispersion) and the technologies developed to compensate different types of impairments.
- Chapter 3: Simulation and study of a simple optical fiber communication system without dispersion compensation and with DCF compensation technique at different transmission rates and for input power values. After that, this technique is applied to a different WDM systems one using 4-channel and other with 8-channel.
- Conclusion: Summarizes the outcome of this work

CHAPTER 1:

Optical Fiber Communication System

1 1. Introduction:

Optical fiber is that technology associated with the transmission using light in a discontinuous fashion "Pulses", so the pulses of light are travelling among the optical fiber which is usually made of plastic or glass, and for that reason this technology is unaffected by electromagnetic interference [1].

2.Optical fiber system main components:

Basically, an optical fiber system consists of three main components, an optical transmitter, an optical fiber channel and an optical receiver, figure 1.1 illustrates the basic components for optical fiber communication system.

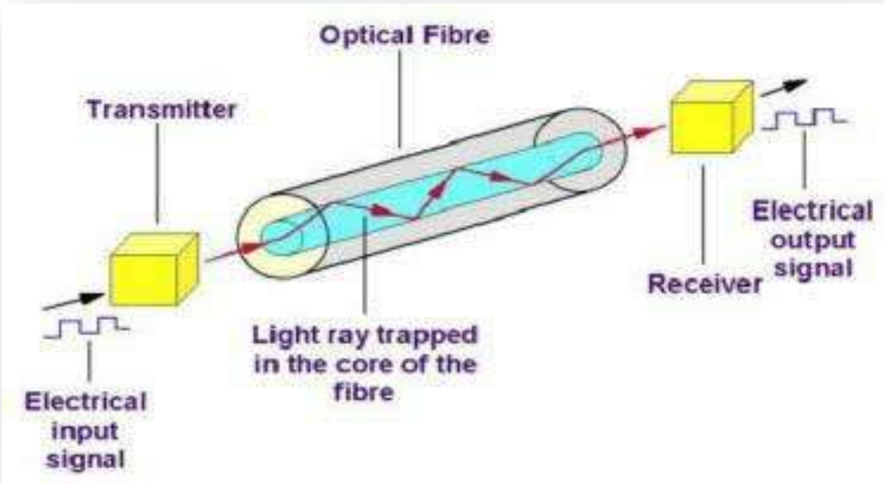


Figure 1.1 Basic optical fiber communication system [2].

2.1Optical Transmitter:

The main goal of the optical transmitter is to convert the received electrical signal into optical signal then it travels through the optical channel.

An optical transmitter system consists generally of an optical source, a device modulating optical radiation in accordance with input electrical pulses. [3]

For our simulation we will use: PRBS generator, NRZ Pulse generator, CS Laser, Mech-Zehnder modulator.

2.1.1Pseudo random binary sequence (PRBS) generator:

Pseudo random binary sequence generator is a digital device that generates the information to be transmitted represented in pseudo random bit sequence. Mainly used for simulation purpose as a source of information (audio, video, data….)

2.1.2 Non-return-to-zero (NRZ) pulse generator Non-return-to-zero (NRZ):

pulse generator receives the binary data generated by the PRBS generator in its input port and transforms it into electrical pulses without rest between any two bits. Unlike the return-to-zero coding technique.

a- Light source:

Since we are dealing with optical technology, it is important to introduce light sources, in which two types are often used: light emitting diode (LED), and light amplification by stimulated emission of radiation (LASER).

b- Light emitting diode (LED):

It is an active device with large applications. It is a forward biased P-N junction of two semiconductors that emits light when electric current passes through it (movement of holes and electrons), So the electrons and holes recombine at the junction which is a boundary that separates the P and N regions. The P region is positively charged because it contains holes, where N region is negatively charged (electrons), the movement of electrons from N region to P region releases some amount of energy, that amount of energy is determined by the Band gaps. [4]

The band gap has a direct relation with the wavelength of the emitted light, it can be expressed in coming equation:

$$\lambda = \frac{hc}{E_P} \qquad (\mathbf{1.1})$$

λ: the wavelength of the emitted light.

h: Planck’s constant. (Equal to the semiconductor band-gap energy E_g)

c: speed of light.

E_P: the energy of photons. .

2.1.3Light amplification by stimulated emission of radiation (LASER):

It is semiconductors device with P-N junction used to convert electrical energy to optical one, its principle of work based on the stimulated emission where the electrons from a high energy state moves to a lower and realise photons, as a result we get a coherent and monochromatic produced beam, compared to that of the LEDs which radiate in many directions. [5]

2.1.4Modulator (Modulation) :

For a perfect transmission process modulation is needed so a modulator is used, for direct modulation type there is no need for an external modulator. It permits the LASER to change the intensity of light according to the electrical signal input (the received electrical pulses). It is cheap and simple to implement but its most no preferred because of unwanted disadvantages very low speed of modulation. So, an external modulator is used instead, there exist two common types of external modulators

a-Electro-absorption modulator (EAM) electro-absorption modulator:

is a semiconductor device used in the purpose of modulating the output of the laser via an electric field the, it works under the Franz-Keldysh principle.

the chosen material for the EAM modulator depends on the operating wavelength.

b-Electro-optic modulator (Mach-Zehnder-Modulator (MZM)):

Mach- Zehnder Modulator is one of the most common external modulators. It works based on the change of the refractive index observed for some crystals under an external electric field. While the structure of Mach-Zehnder modulator and the interferometers inside of it, converts the induced phase modulation into intensity modulation. Figure 1.2 shows the external modulator taking place in the transmitter system components.

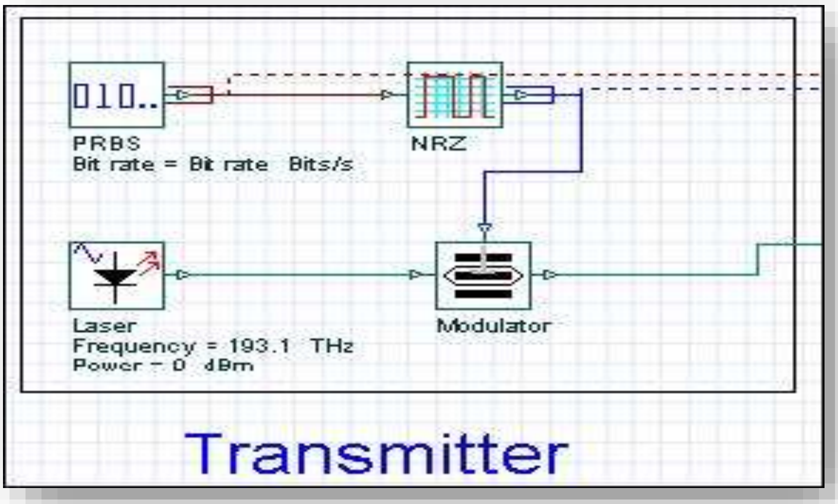


Figure 1.2 :Basic optical transmitter components.

2.2Optical Fiber:

The optical fiber is very thin cable. It is a waveguide made up of transparent dielectric materials; mainly glass or plastic; through which the light travels. It takes the place of copper cables in telecommunications because of its greater bandwidth, high speed and less losses and no heat is produced during transmission. [6]

It is composed of three main layers:

- **Core:**

it is the most important layer or element, it is the small central part made of glass or plastic through which light travels, it has verry small circular cross section with diameter that can be in the range of fractions of inch or in the size of human hair, and of course the size is chosen according to the application that is made for

- **Cladding:**

is the element which surrounds the core, according to the cladding part the total internal reflection principle can be verified also the light scattering is reduced.

- **Coating:**

refers to the element that surrounds the cladding, made for protection purposes from any physical damage. It is thicker compared to the cladding part. It is made of layers of plastic.

There are other elements that surround the coating such as: strength member and the outer jacket. Which are all presented in figure 1.3:

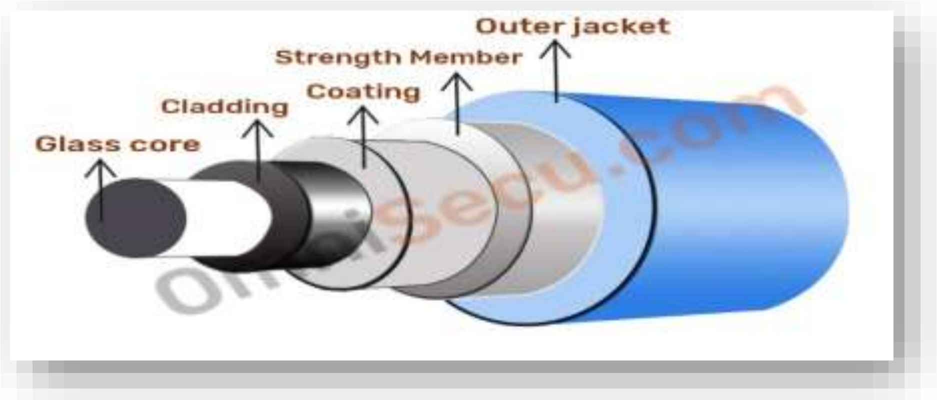


Figure 1.3 : Structure of the optical fiber[2].

2.2.1Principle of transmission:

The transmission principle is that phenomena or mechanism by which light can be guided in the optical fiber, it is based on the total internal reflection principle (TIR), but also on propagation of light and according to reflection that can happen, and for that reason we can differ two types of media: [4]

2.2.1.1Denser and rarer media:

In optics, basically we distinguish between two types of media denser or rarer.

a-The first one:

when light travels from denser to rarer media, the speed of light is less where refractive index is greater.

b-The second one:

when light travels from rarer media to denser one, the speed of light is higher and refractive index is les.

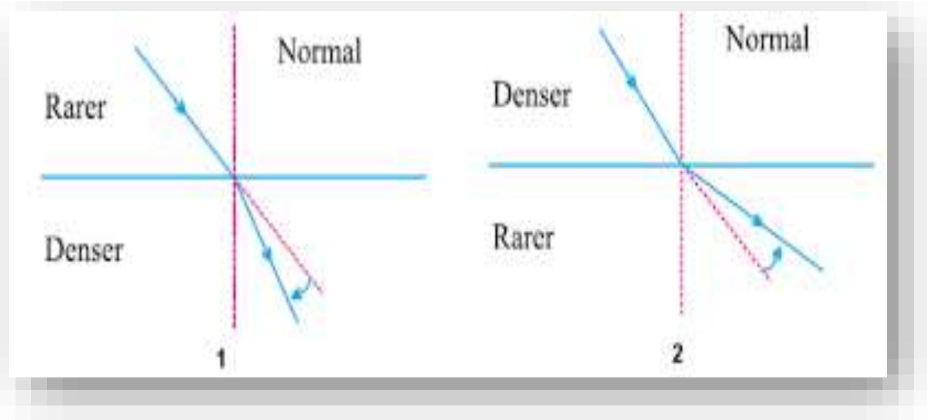


Figure 1.4 Refraction in denser and rarer media[2].

when ray travel from rarer to denser medium it bends towards normal after refraction, however when travel from denser to rarer medium it bends away from normal.

2.2.1.2Total internal reflection (TIR):

Inside the optical fiber we have a traveling beams of light which stand on the principle of TIR, but tis principle to be verified two conditions must be satisfied, which are:

- The traveling beam of light must go from the core which represents the denser medium with greater refractive index to the cladding which represents the rarer medium with smaller refractive index.
- When we have refraction obviously there will be incident angle, that incident angle must be greater than the critical one in order to have as a result a returning beam of light going back to the denser medium noticed as reflection.

Starting from **Snell’s law** we can find the critical angle.

Any incident angle that makes the beam of light refract perpendicularly to the normal is known as the critical angle.

- **Snell's law:** $n1.\sin\theta 1 = n2.\sin\theta 2$ (1.2)

n1: The refractive index of the core
n2 : The refractive index of the cladding
θ1 : The incidence angle
θ2 : The refractive angle

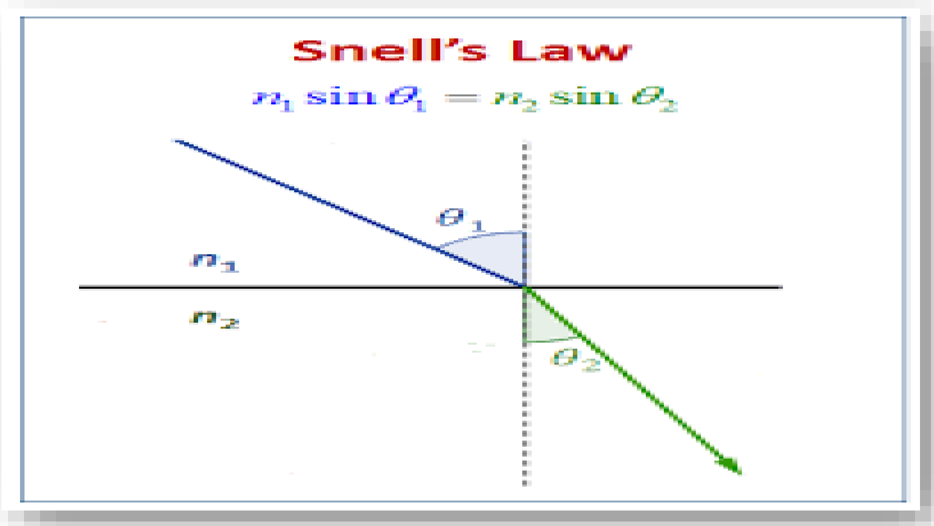


Figure 1.5 Illustration of Snell's law[2].

If: $\theta 1 = \theta c$ then: $\theta 2 = \frac{\pi}{2}$

By replacing the previous conditions in (**1. 1**), then we get :

$n1.\sin\theta c = n2.\sin\left(\frac{\pi}{2}\right)$

$n1.\sin\theta c = n2$

$$\theta c = \sin^{-1}\left(\frac{n2}{n1}\right) \quad (1.2)$$

2.2.1.3The acceptance cone:

it is known that ray transmission theory for optical fiber based on the incident angle which must be greater than the critical on.

In fact, the incident angle can be less than the critical one but, in this case we will have no transmission inside the fiber and for that reason the incident angle depends on another parameter to be controlled. [7]

- **The acceptance angle:**

it is the maximum angle of ray hitting the fiber core which allows the incident light to propagate into the fiber, it is demonstrated in figure 1.6

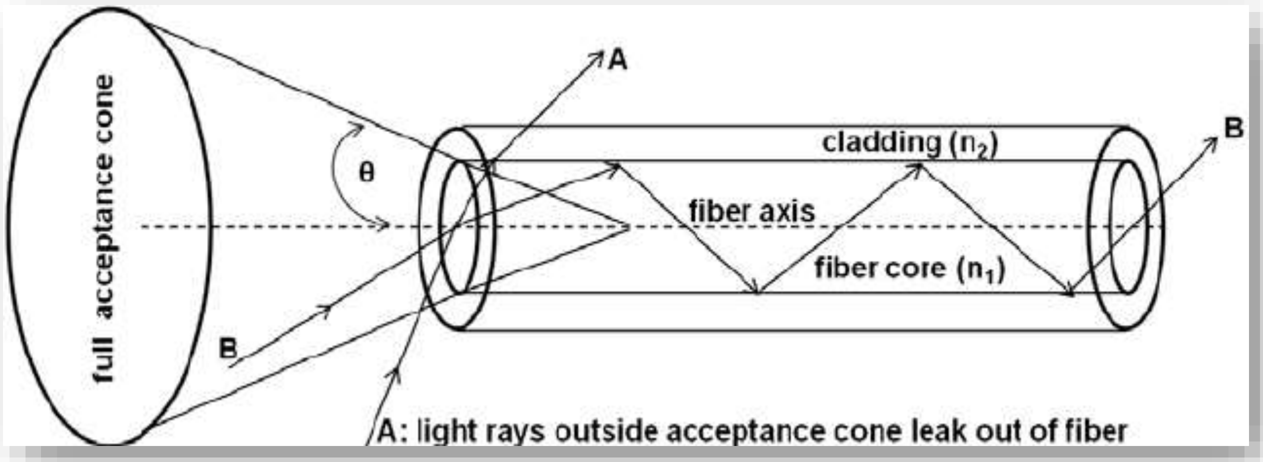


Figure 1.6 Illustration of the acceptance angle [7].

2.2.1.4Modes of propagation affecting the optical fiber:

The light inside an optical fiber propagates in two different fashions which are called modes of propagations. [8]

Actually, and based on the propagation angle an optical fiber supports a set of discrete modes, according to the mode of propagation used in the fiber we can differ two types of fibres: single mode fibres (SMF), and multimode fibres (MMF). [8]

- **Single mode fibres (SMF):**

optical fibres that are designed with verry small radius for both core and cladding, such as r=4.5 µm. for core and about r=62 µm. for cladding can support only one mode for propagation per polarization direction for given wavelength, [8]

such type has no reflections so the losses are reduced.

* **Step index Single mode fibres:** for this mode the value of the refractive index related to the core is constant, at the cladding interface the refractive index profile takes that value related to the cladding.

- **Multimode fiber:**

fibres that are constructed with a large core radius compared to that of single mode are multimode fibres (r varies from 50 µm. to hundreds of µm.), they can support more than single mode at time because of the larger radius the ray of light travels in different directions. however, the number of modes that a fiber can support are based on both the core size and the constructive interference which means that only the zigzags that are in phase can propagate through it. For multimode fibres we have two types step index multimode fiber and graded index multi-mode. [8]

***Step index multimode fibres:** it has the shape of the refractive index profile, but it's value changes to create zigzag paths.

***Graded index multimode fibres:** this type has the characterised by the changing value of the refractive index of the core in function of its radius. It is maximum at the centre and takes its minimum where getting closer to the cladding interface, then it matches with the refractive index of the cladding at its interface .it is mostly used for communications over short distances, figure 1.7 represents multi-mode both step index and graded index:

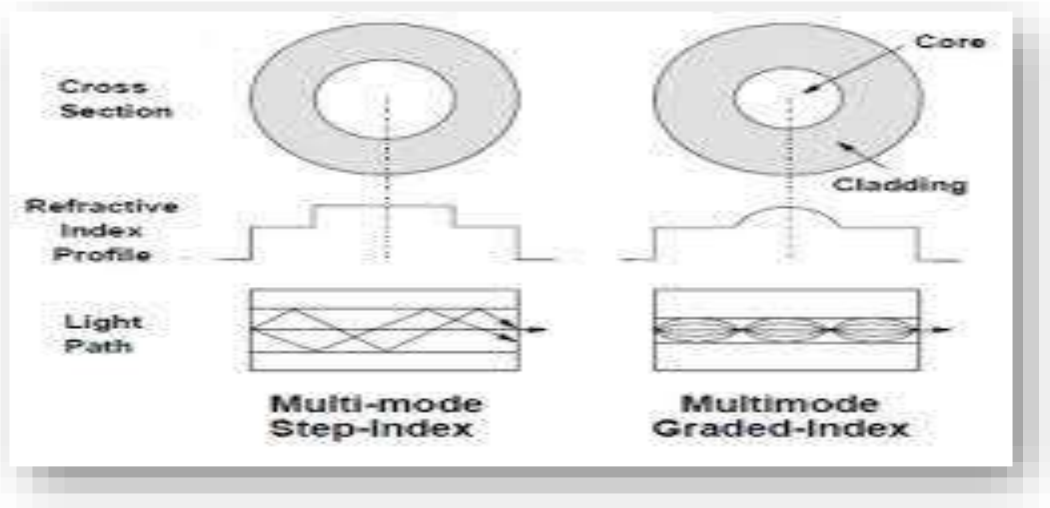


Figure 1.7 Multi modes in Optical fiber[2].

2.3 Optical Receiver:

it receives the transmitted signal through the optical fiber than it decodes the optical signal and converts it to an electrical data stream proportional to the received optical signal. the structure of an optical receiver is more complicated compared to that of the optical transmitted but basically it is composed of three main stages. It must satisfy certain system requirements such as desired level of signal-to-noise ratio (SNR) and bit error rate (BER). High sensitivity, large bandwidth and low or zero temperature sensitivity, low power consumption and polarization independence makes the optical receiver works in ideal fashion. [9]

2.3.1Optical detector:

Optical detectors are photodiodes responsible to convert the optical information (light pulses) into electrical signals. The most common types of optical receivers used in fiber optic communication systems are positive intrinsic-negative (PIN) photodiodes and avalanche photodiode (APD) receivers. Both are characterized by high sensitivity; they are semiconductor devices which convert light pulses into electrical signals.

- **Positive Intrinsic Negative (PIN) Photodiode:**

In PIN Photodiode there are two extrinsic dopped regions the first one is negative and the second is positive(as shown in figure 1.8), between them a exists a verry tick intrinsic depletion region which is a free layer of any carriers, so that no flowing current, but there will be a small flow of current because of the motion of an electron-photon pair in opposite direction when a photon strikes the intrinsic region.

PINs are the most commonly employed receivers in fiber optic communication systems due to their ease in fabrication, high reliability, low noise, low voltage and relatively high bandwidth. [7]

- **Avalanche Photodiode (APD):**

The avalanche Photodiode are similar in both structure and principle to that of PIN Photodiode It has higher gain and bandwidth than PIN because of the avalanche multiplication phenomenon with a much greater required voltage to be applied across the active region.

when a photon enters the depletion region and creates a hole-electron pair, these charge carriers will be pulled by the very high electric field away from one another with a high speed, which makes them strike the other electrons and causing other electron-hole pairs motion repeatedly, and creating a bigger electric current. [9]

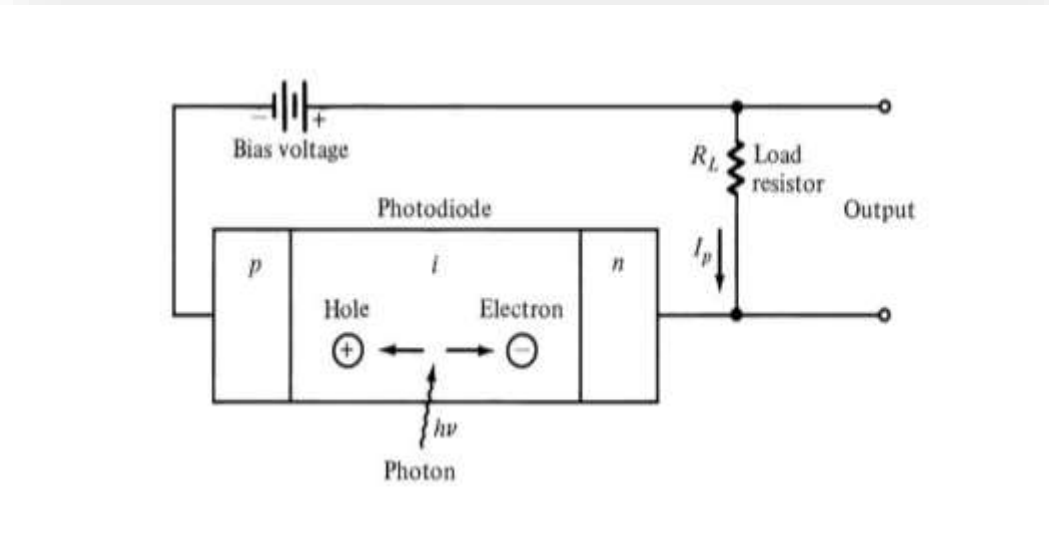


Figure 1.8: PIN Photodiode [2].

2.3.2Signal amplification :

at the end of the optical detector the output current is too small, so an amplification is needed to be processed, after the pulses ere are distorted, so the signal passes through a law pass filter in order to reduce the noise in the signal and minimize inter symbol interference (ISI) so that the distorted pulses are reshaped. [4]

2.3.3Decision circuit:

once the distorted pulses are reshaped a comparison between the output of the linear channel to that of the threshold level in order to decide if the received pulse is zero or one.

2.3.4Optical amplifier:

Optical amplifiers are important devices in optical communication, they have the ability to amplify the optical signal (incident light) without converting it to electrical signal. the same mechanism is used here as in lasers, so that they are the same as lasers but without feedback.

There are several types of optical amplifiers. The Erbium Doped Fiber Amplifier (EDFA) is one of the most widely used one. they operate no to the wavelength region 1.55mm when fiber loses reaches minimum values. According to referance11 amplifier gains can range from 30dB to 40dB with only a few milliwatts of pump power when EDFAs are pumped by using 0.98-mm or 1.48-mm semiconductor lasers. [10]

The proposed block diagram for EDFA is presented in figure 1.9

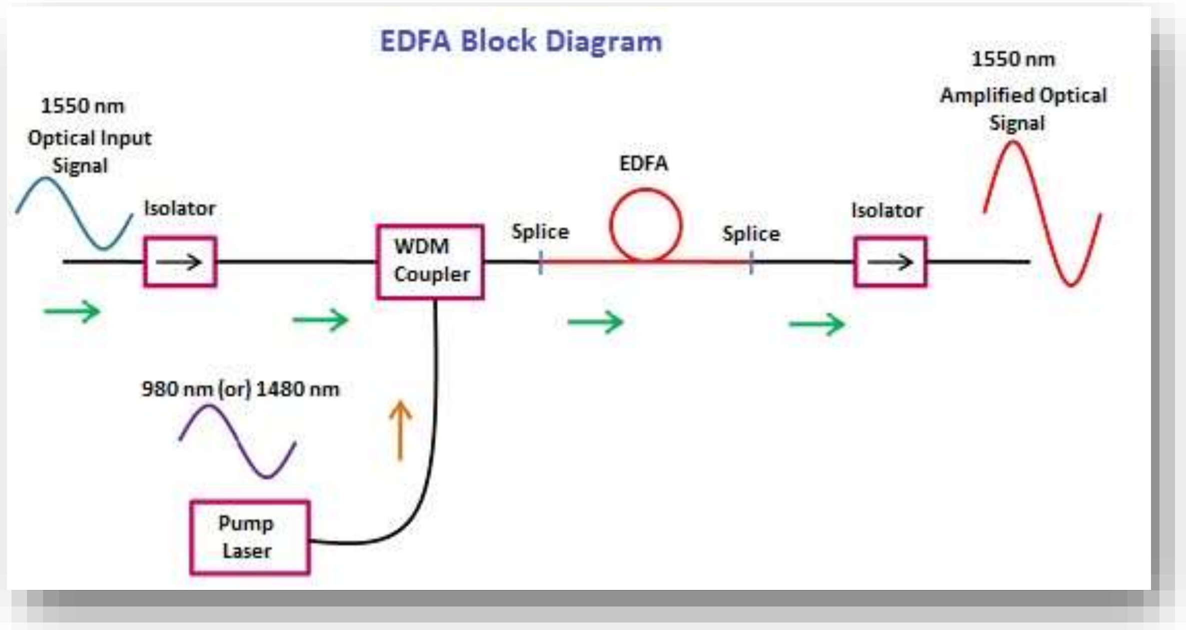


Figure 1.9: EDFA block diagram [2].

3.Wavelength division multiplexing systems (WDM):

Before the existence of wavelength division multiplexing systems, the optical fiber were able to support only one channel so increasing the transmission capacity of a link required multiplying transmission lines. WDM technology changed that radically so single optical fiber is enough to transmit multiple signals of different colours or channels at the same time as light waves of different lengths do not interfere with each other. [11]

wavelength division multiplexing system consists basically of multiplexer and demultiplexer, so optical signals from terminals of fiber optic are converted into controlled wavelengths and passe trough the multiplexer so that they are multiplexed, then transmitted into a single fiber, the output signals of the fiber passe trough the demultiplexer so that they are demultiplexed and delivered as individual signals to the receiver. [11]

Once this technology became developed over and over, it allows hundreds of channels to be multiplexed and transmitted through the same optical fiber so that the data transmission bandwidth capacity increases but the losses needed know to be compensated.

3.1 Advantages of WDM: [14] [15] [16]

Wavelength division multiplexing several advantages, these are some of them: [9]

- Optical components are similar and more reliable, instead of switching to a new technology a new channel can easily be added to the existing channels .
- It provides higher bandwidth.
- Easier to reconfigure , so if customers need additional capacity that will no take long time.so this technology could be the best approach.
- It is transparent which means doesn’t depend on the protocol that has to be transmitted .
- Works with low-speed equipment

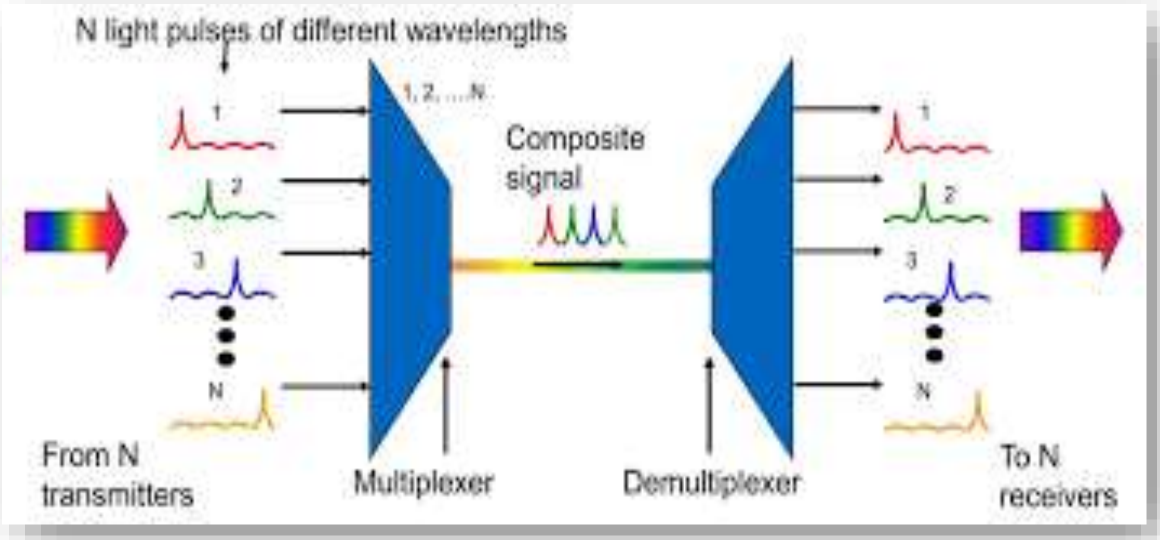


Figure 1.10: Wavelength division multiplexing (WDM) [12].

4.Parameters affecting the optical system:

In optical communications systems such as fiber optic systems, losses that can affect the system are too many , so there are some parameters that must be taken in consideration to improve the quality of the transmitted data within the optical fiber received back in good quality and to ensure that the losses do not affect the information and data transmitted ,these parameters are optical signal to noise ratio (OSNR), Q factor and bit error rate (BER).

4.1Optical signal to noise ratio (OSNR):

It is important to study the noise affecting the signal in communication system, and in optical communication we deal with optical signal to noise which is the ratio of the optical signal power (S) to the system noise power (N) in decibels expressed in dB,

$$OSNR = 10Log\left(\frac{S}{N}\right) \quad (1.3)$$

OSNR affects both parameters in the system Q factor and BER, and in order to distinguish the signal that holds the information from the noise signal so it must be greater than a threshold value of about 15dB to 18 dB at the receiver. [13]

4.2 Q factor: measures the quality of the received signal and how noisy is our signal in terms of optical signal to noise ratio (OSNR). The Q factor is expressed in decibels, by the expression:

$$Qdb = 20\sqrt{OSNR}\sqrt{\frac{\mathrm{Bo}}{\mathrm{Bc}}} \quad (1.4)$$

Bo: is the optical bandwidth of the photodetector (receiver device).

Bc : is the electrical bandwidth of the receiver filter.

4.3 Bit error rate (BER): when transmitting data from one point to another point obviously there will be amount of errors at the end point ,the BER or Bit error rate permits the user to know how much is this amount of error , BER is a unitless performance measure, often expressed a percentage it is expressed as follows :

$$\text{BER} = \frac{n}{N} \tag{1.5}$$

Where: **N** is the total numbers of transmitted bits and

n: is the number of bit errors received.

BER it is related to the Q factor so it can be can be determined in terms of it.

$$BER = (\frac{1}{2}) erfc\ (\frac{Q}{\sqrt{2}}) \tag{1.6}$$

Q: the quality factor

Where erfc function is the complementary error function defined as:

$erfc(x) = 1 - erf(x)$, while erf function is the error function, defined as:

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^X e^{-t2} dt \tag{1.7}$$

The relation between the Q factor and BER can be expressed or presented in a graph Q versus BER as shown in figure 1.11.

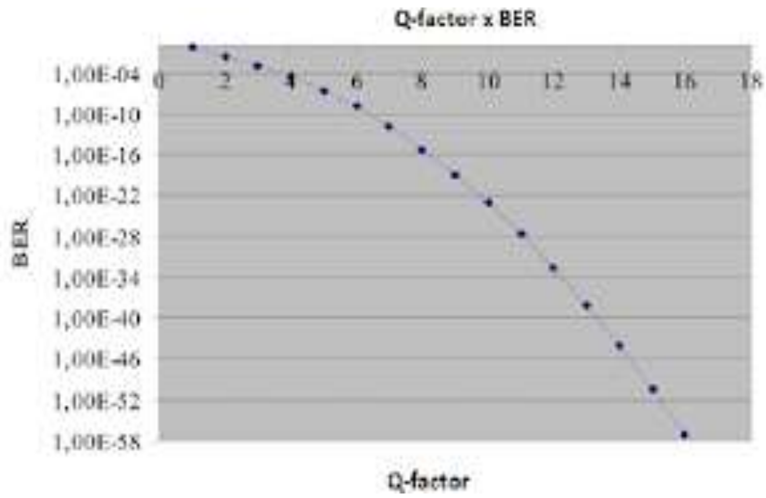


Figure 1.11: Q factor versus BER parameter [2].

3.Conclusion:

In this chapter, an introduction to the optical fiber technology were presented, so that a description for the hole optical fiber components wit deferent stages were Donne. Till now, optical fiber is preferred in optical communication but actually a lot of losses can affect the system, and that will be discussed in the second chapter.

Chapter 02:

TRANSMISSION IMPAIRMENT MANAGEMENT

2.1 Introduction:

The rapid growth in demand for high-capacity telecommunication links and efficient utilization of fiber bandwidth has resulted in an extraordinary increase in the use of Wavelength Division Multiplexing (WDM) in advanced lightwave networks. WDM is a method of transmitting data from different sources over the same fiber optic link at the same time whereby each data channel is carried on its own unique wavelength. The optimal design and application of optical fiber are very important for the transmission quality of optical fiber transmission system. And the main goal of communication systems is to provide data transmission with high quality at a longer distance. Loss and dispersion are the major factor that affect WDM network

2.2 Dispersion in optical fiber:

Dispersion is the spreading out of a light pulse in time as it propagates down the fiber. And loss of information due to the broadening of the pulses in the signal as they travel along the channel , which can cause inter symbol interference (ISI). This limits the maximum possible bandwidth and so the information carrying capacity of the optical cable such that the digital bit rate is related to the broadened pulse duration by: $B_R \leq \frac{1}{2\tau}$.[12]

B_R and τ , are the bit rate and the pulse duration respectively

2.2.1 Chromatic Dispersion:

Chromatic dispersion is a phenomenon of signal spreading over time resulting from the different speeds of light rays. The chromatic dispersion is the combination of the material and waveguide dispersion effects.

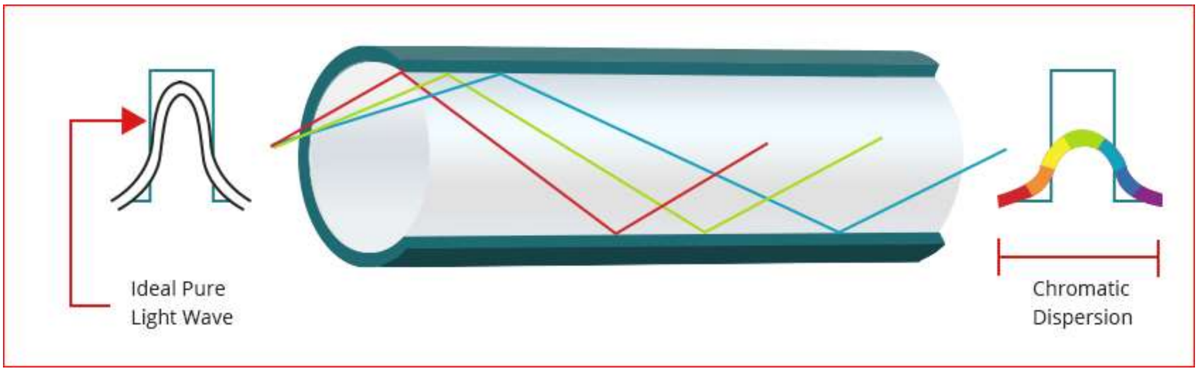


Figure 2.1 Chromatic dispersion.

2.2.1.1 MATERIAL DISPERSION:

Material dispersion is the result of the finite linewidth of the light source and the dependence of refractive index of the material on wavelength.

Material dispersion is a type of chromatic dispersion. Chromatic dispersion is the pulse spreading that arises because the velocity of light through a fiber depends on its wavelength.

The following picture shows the refractive index versus wavelength for a typical fused silica glass.

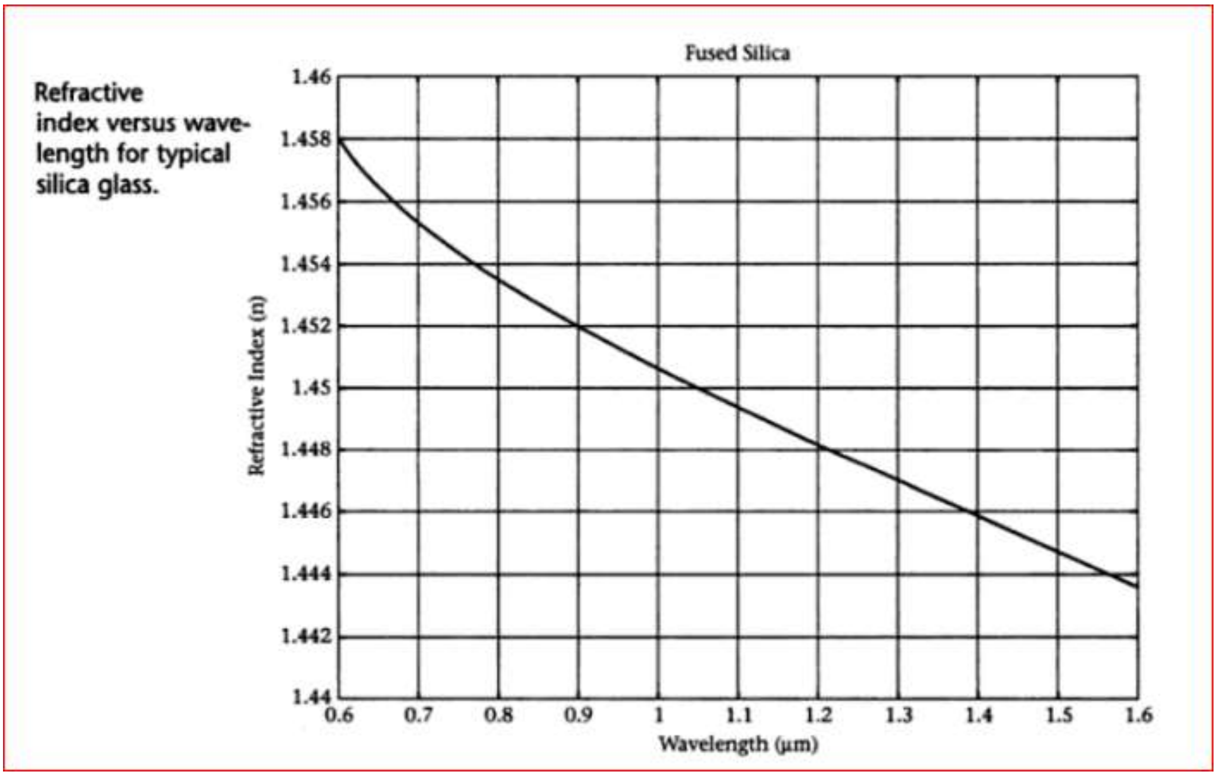


Figure 2.2 the refractive index versus wavelength for a typical fused silica glass.

2.2.1.2WAVEGUIDE DISPERSION:

Waveguide dispersion is only important in single mode fibers. It is caused by the fact that some light travels in the fiber cladding compared to most light travels in the fiber core.

Since fiber cladding has lower refractive index than fiber core, light ray that travels in the cladding travels faster than that in the core. Waveguide dispersion is also a type of chromatic dispersion. It is a function of fiber core size, V-number, wavelength and light source linewidth.

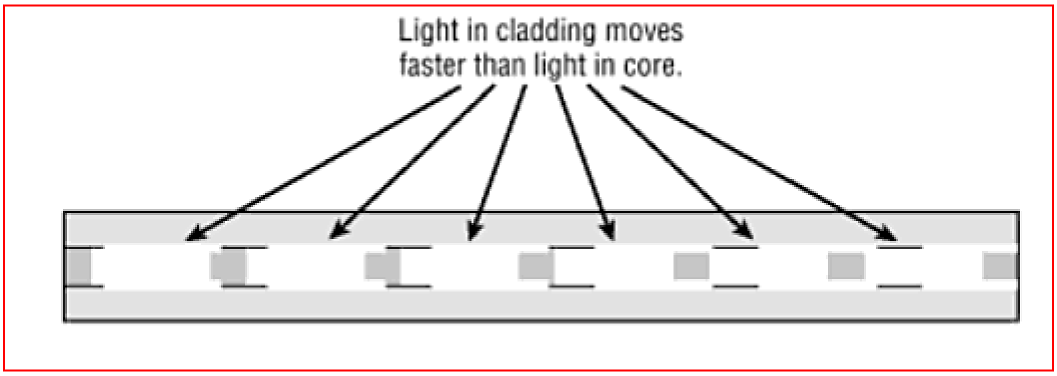


Figure 2.3 Waveguide Dispersion.

While the difference in refractive indices of single mode fiber core and cladding are minuscule, they can still become a factor over greater distances. It can also combine with material dispersion to create a nightmare in single mode chromatic dispersion.

Various tweaks in the design of single mode fiber can be used to overcome waveguide dispersion, and manufacturers are constantly refining their processes to reduce its effects.

2.2.2 Modal dispersion:

Multimode fibers can guide many different light modes since they have much larger core size. Each mode enters the fiber at a different angle and thus travels at different paths in the fiber.

Since each mode ray travels a different distance as it propagates, the ray arrive at different times at the fiber output. So the light pulse spreads out in time which can cause signal overlapping so seriously that you cannot distinguish them any more.

Model dispersion is not a problem in single mode fibers since there is only one mode that can travel in the fiber.

2.2.3 Polarization Mode Dispersion:

Polarization mode dispersion (PMD) represents the polarization dependence of the propagation characteristics of light waves in optical fibers. In optical fibers, there is usually some slight difference in the propagation characteristics of light waves with different polarization states. When the light is defined as an energy wave or energy region, it possesses 2 mutually perpendicular axes, namely the electromotive force and magnetomotive force. The moment the energy inside these two axes transfers at different speeds in a fiber, PMD occurs.

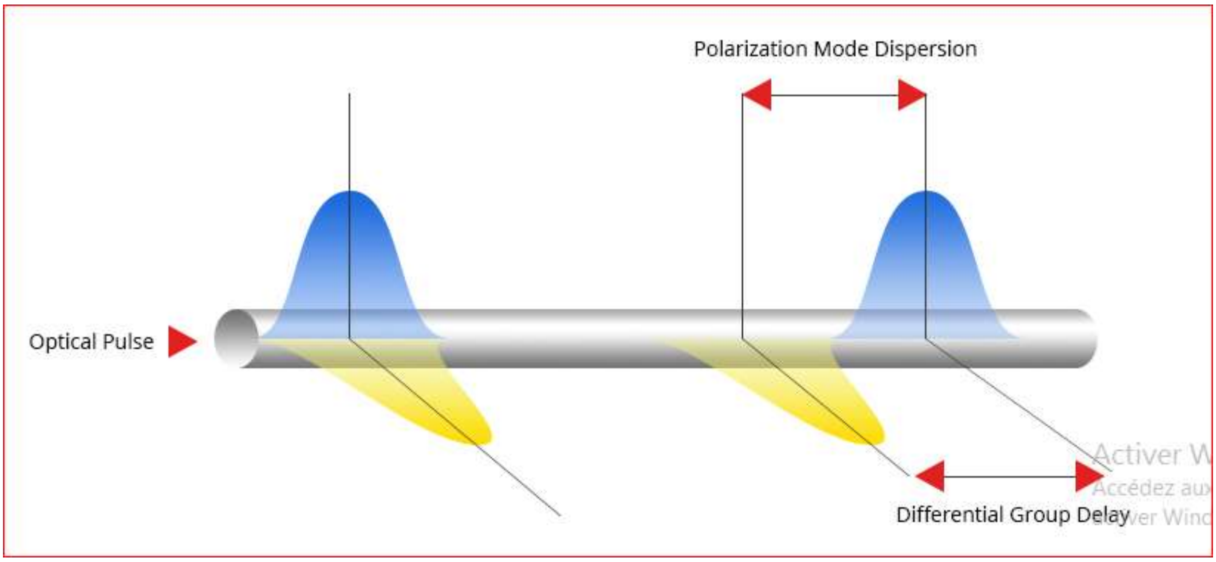


Figure 2.4 Polarization Mode Dispersion (PMD).

PMD has small effects for networks whose link speeds are lower than 2.5 Gbps even if the transmission distance is longer than 1000 km. However, as speeds increase, it becomes a more important parameter especially when the speeds are over 10 Gbps. In addition to the major inherent PMD caused by the glass manufacturing process, the PMD can be affected or caused by the fiber cabling, installation and the operating environment of the cable as well.

2.3 Dispersion Compensation techniques:

The transmission of the optical signal through the optical cable gets effected by several kinds of losses which can be mitigated or compensated by several techniques.

2.3.1 Dispersion compensation techniques:

The different types of dispersion can be compensated by different techniques that depends on the type of dispersion and on the technology used for compensation.

2.3.1.1 Polarization mode dispersion compensation techniques:

PMD is a kind of modal dispersion usually associated with single mode fibers. The PMD is measured in picoseconds per square root of kilometer (ps/√km) as it is proportional to the square root of the length of the fiber. The typical values of PMD range from 0.05 to 1.0 ps/√km. Polarization Mode Dispersion is one of the most serious impairments which limit the data rate in long distance transmission and high speed transmission systems. Increase in PMD causes pulse broadening and severely degrades the system performance. In low data rate systems (100 Mb/s) PMD is negligible but in high data rate systems it affects the bandwidth distance product severely. It normally increases the bit error rate in long distance communication, since it is time varying. Thus compensation of PMD is required to avoid such problems.

- **Delay method:**

This technique is based on a delay line between the two components of the electromagnetic wave along the two axes at its initial state called principle state of polarization (PSP). The polarization controller and the beam splitter separate the signal into two along the PSP. The component having the highest speed is delayed by using variable delay in its branch. Finally, polarization combiner is added to combine the two components together.

- **Phase shift method:**

Phase shift technique is based on polarization rotator, which is a device that rotates the state of polarization (SOP) of the signal from the fiber with different angles. The variation in the angle causes an adjustable delay. Hence, the polarization distortion can be compensated.

2.3.1.2Chromatic dispersion compensation techniques:

- **Dispersion Compensation With DCF**

In DCF (Dispersion Compensating Fiber) technique, one can use a fiber having large negative dispersion alongside a typical fiber. The number of light distributed by a traditional fiber is reduced or maybe nullified by using a dispersion compensating fiber having a really giant value of dispersion of opposite sign as compared to that of normal fiber. There are primarily 3 schemes (fiber-pre, post or symmetrical) which will be used for dispersion compensation. And the dispersion compensating fibers are used extensively for upgrading the installed 1310nm optimized optical fiber links for operation at 1550nm. [17]

DCF is the most common dispersion compensation technique, used for long distance communication, it is a loop of fiber relatively short in length comparing to the length of the transmission fiber. It has high values of negative dispersion -70 to -90 ps/nm.km related to the dispersion of the transmitting fiber by the following equation:

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \qquad (2.1)$$

D_{SMF} : Dispersion of single mode transmission fiber

L_{SMF} : Length of single mode transmission fiber DDCF : Dispersion of DCF

L_{DCF} : Length of DCF

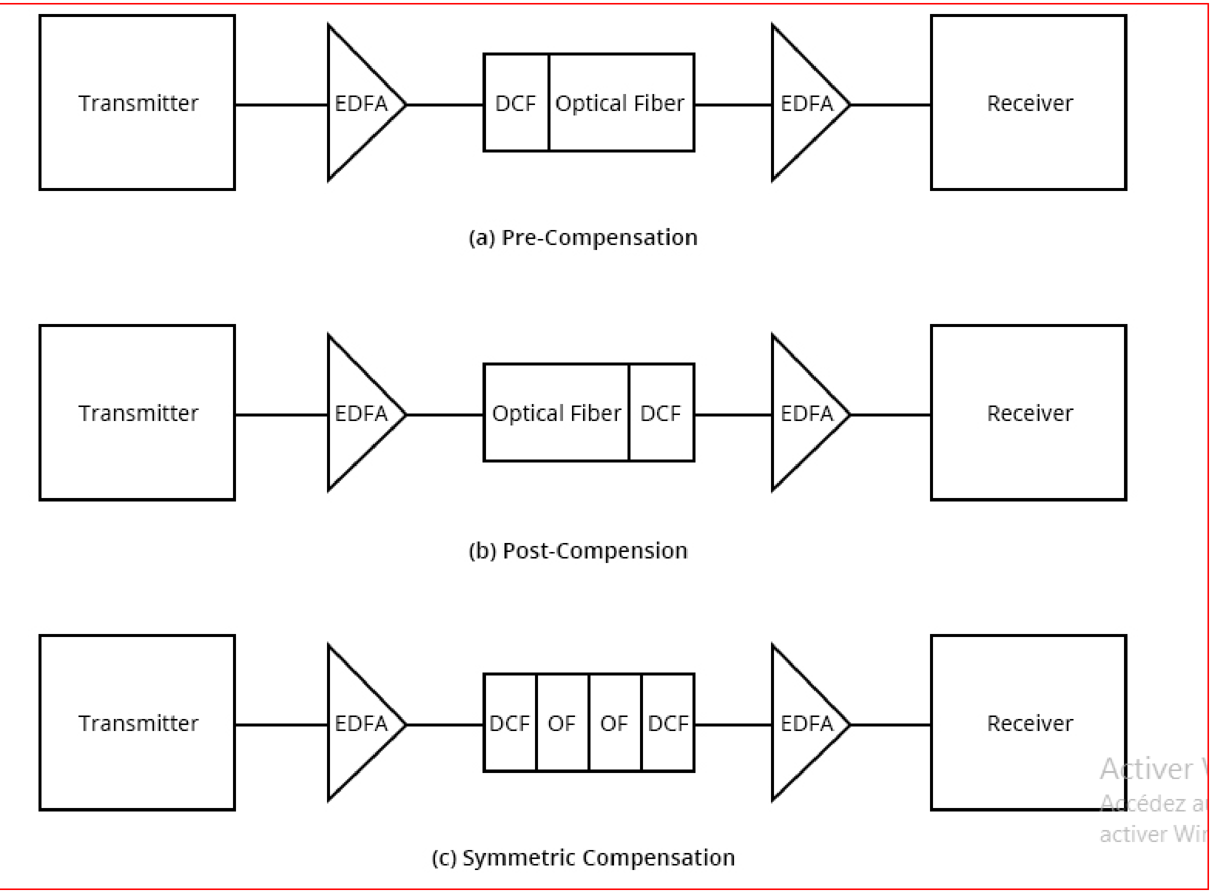


Figure2.5 Dispersion Compensating Fiber.

- **Dispersion Compensation With FBG:**

Fiber Bragg Grating (FBG) is a reflective device composed of an optical fiber that contains a modulation of its core refractive index over a definite length. By applying FBGs, the dispersion effects can be dramatically decreased in long transmission systems like 100 km. The fiber grating reflects light-weight propagating through the fiber once its wavelength corresponds to the modulation regularity. Using FBGs for dispersion compensation may be a promising approach since FBGs are passive optical element fiber compatible, having low insertion losses and prices. The FBGs can not only be used as filters for dispersion compensation, but also be used as sensors, wavelength stabilizers for pump lasers, in narrow band WDM add drop filters.

2.3.2 Optical amplifiers

An optical fiber amplifier is a fiber optic device used to amplify optical signals directly without conversion into electrical signals. Optical fiber transmission has revolutionized networking and communication systems. Multiple communication devices, like optical transmitters and receivers, are used in optical fiber transmission systems.

An optical fiber amplifier is used in transmitting data in fiber optic communication systems.

Amplifiers are inserted at specific places to boost optical signals in a system where the signals are weak. This boost allows the signals to be successfully transmitted through the remaining cable length. In large networks, a long series of optical fiber amplifiers are placed in a sequence along the entire network link.

The first optical fiber amplifier, called an erbium-doped fiber amplifier (EDFA), was invented in the late 1980s. An optical fiber amplifier consists of a low single mode fiber made of silica glass. A coupling pump light generates length gain at both fiber ends or in between locations.

Optical fiber amplifiers are categorized, based upon different physical mechanisms, as follows:

- Doped fiber amplifiers (DFA): Use a doped optical fiber medium for boosting signals in a similar manner to fiber lasers. The signal requiring amplification, along with a pump laser, is multiplexed in a doped fiber medium and intersects with doping ions. Amplified spontaneous emission is the major reason behind the DFA noise. An ideal noise level for DFA is around 3 decibels. Practically, the noise figure is calculated at around 6 to 8 decibels.
- Semiconductor optical amplifiers: Use semiconductors to produce the gain medium in the laser. The analogous structure is made of laser diodes. The recent design of semiconductor optical amplifiers has added antireflective coatings and window regions to minimize the end face reflection.

- Raman amplifiers: Employ Raman amplification techniques to boost optical signals. The two types of Raman amplifiers are distributed, where the transmission fiber is used by multiplexing the pump wavelength along with the signal wavelength as the gain medium, and lumped, where short length and dedicated fibers are used for amplification. Nonlinear fiber is used to increase the intersection between the pump wavelength and the signal to reduce the fiber to the required length.
- Optical parametric amplifiers: Permit the amplification of weak signal impulses to a nonlinear optic medium. They use non-collinear interaction geometry for broader bandwidth amplifications.

2.4 OPTICAL FIBER LOSS AND ATTENUATION:

2.4.1 Attenuation in optical fiber:

Attenuation is the reduction in power of the light signal as it is transmitted. Attenuation is caused by passive media components, such as cables, cable splices, and connectors.
The attenuation of an optical fiber measures the amount of light lost between input and output. Total attenuation is the sum of all losses.

Optical losses of a fiber are usually expressed in **decibels per kilometer (dB/km)**. The expression is called the **fiber's attenuation coefficientα** and the expression is

$$\alpha = -\frac{10}{z[Km]}\log\left(\frac{P(z)}{P(z)}\right) \qquad \textbf{(2.1)}$$

where P(z) is the optical power at a position z from the origin,

P(0) is the power at the origin.

For a given fiber, these losses are wavelength-dependent which is shown in the figure below. The value of the attenuation factor depends greatly on the fiber material and the manufacturing tolerances, but the figure below shows a typical optical fiber's attenuation spectral distribution**.**

2.5 Optical Fiber Loss Mechanisms:

2.5.1 Absorption:

Absorption is uniform. The same amount of the same material always absorbs the same fraction of light at the same wavelength. If you have three blocks of the same type of glass, each 1-centimeter thick, all three will absorb the same fraction of the light passing through them.

Absorption also is cumulative, so it depends on the total amount of material the light passes through. If the absorption is 1% per centimeter, it absorbs 1% of the light in the first centimeter, and 1% of the *remaining* light the next centimeter, and so on.

2.5.1.1 Intrinsic Material Absorption:

Intrinsic absorption is caused by interaction of the propagating lightwave with one more more major components of glass that constitute the fiber's material composition. These looses represent a fundamental minimum to the attainable loss and can be overcome only by changing the fiber material.

An example of such an interaction is the **infrared absorption band** of SiO_2 shown in the above figure. However, in the wavelength regions of interest to optical communication (0.8-0.9um and 1.2-1.5um), infrared absorption tails make negligible contributions.

2.5.1.2 Extrinsic Impurity Ions Absorption

Extrinsic impurity ions absorption is caused by the presence of minute quantity of metallic ions (such as Fe^{2+}, Cu^{2+}, Cr^{3+}) and the OH^{-} ion from water dissolved in glass. The attenuation from these impurity ions is shown in the following table.

Table 2.1 ***The attenuation from these impurity .***

Impurity Ion	Loss due to 1ppm of impurity (dB/km)	Absorption Peak Wavelength (um)
Fe^{2+}	0.68	1.1
Fe^{2+}	0.15	0.4
Cu^{2+}	1.1	0.85
Cr^{3+}	1.6	0.625
V^{4+}	2.7	0.725
OH^{-}	1.0	0.95
OH^{-}	2.0	1.24
OH^{-}	4.0	1.38

From the table above, we can see that 1 part per million (ppm) of Fe^{2+} would lead to a loss of 0.68 dB/km at 1.1um. This shows the necessity of ultrapure fibers. Luckily, losses due to the metallic ions can be reduced to very low by refining the glass mixture to an impurity level below 1 par per billion (ppb).

The OH^{-} ion from water vapor in the glass leads to absorption peaks at 0.72um, 0.88um, 0.95um, 1.13um, 1.24um and 1.38um. The broad peaks at 1.24um and 1.38um in the first figure cure are due to OH^{-} ion. The good news is OH^{-} ion absorption band is narrow enough that ultrapure fibers can achieve losses less than 0.2 dB/km at 1.55um.

With new manufacturing techniques, we can reduce the OH^{-} ion content to below 1 part per billion (ppb). The results are ultra-low-loss fibers which have a wider low-loss window in silica glass fibers shown in the following figure. This improvement enables the use of WDM technology in fiber optic networks, which dramatically increased the capacity of fiber optic systems.

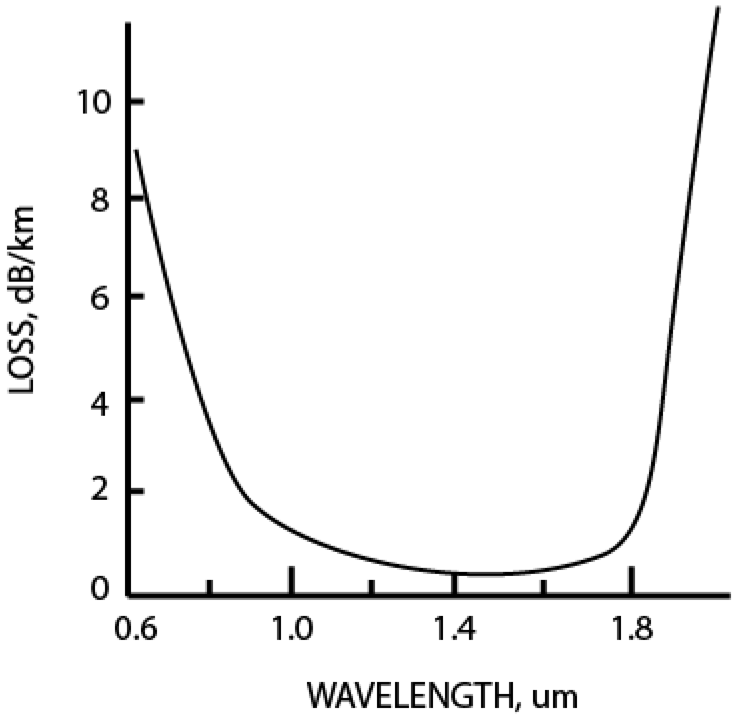


Figure 2.6 loss versus wavelength .

2.5.1.3 Hydrogen Effects:

When fused silica glass fiber is exposed to hydrogen gas, attenuation of the fiber also increases. The hydrogen can interact with the glass to produce hydroxyl ions and their losses. Hydrogen can also infiltrate the fiber and produce its own losses near 1.2um and 1.6um.
The fibers can come into contact with hydrogen which is produced by corrosion of steel-cable strength members or by certain bacteria. The way to solve this problem is to add a coating to the fiber that is impermeable to hydrogen.

2.5.2 Scattering:

Scattering losses occur when a wave interacts with a particle in a way that removes energy in the directional propagating wave and transfers it to other directions. The light isn't absorbed, just sent in another direction. However, the distinction between scattering and absorption doesn't matter much because the light is lost from the fiber in either case.

There are two main types of scattering: **linear scattering** and **nonlinear scattering**.

2.5.2.1 linear scattering:

is the amount of light power that is transferred from a wave is proportional to the power in the wave. It is characterized by having no change in frequency in the scattered wave.

- **Mie Scattering :**

Mie scattering is named after German physicist Gustav Mie. This theory describes scattering of electromagnetic radiation by particles that are comparable in size to a wavelength (larger than 10% of wavelength).
For particles much larger, and much smaller than the wavelength of scattered light there are simple and excellent approximations that suffice.
For glass fibers, Mie scattering occurs in inhomogeneities such as core-cladding refractive index variations over the length of the fiber, impurities at the core-cladding interface, strains or bubbles in the fiber, or diameter fluctuations.
Mie scattering can be reduced by carefully removing imperfections from the glass material, carefully controlling the quality and cleanliness of the manufacturing process.
In commercial fibers, the effects of Mie scattering are insignificant. Optical fibers are manufactured with very few large defects. (larger than 10% of wavelength)

- **Rayleigh Scattering :**

Rayleigh scattering (named after the British physicist Lord Rayleigh) is the main type of linear scattering. It is caused by small-scale (small compared with the wavelength of the light wave) inhomogeneities that are produced in the fiber fabrication process. Examples of inhomogeneities are glass composition fluctuations (which results in minute refractive index change) and density fluctuations (fundamental and not improvable). Rayleigh scattering accounts for about 96% of attenuation in optical fiber.

2.5.2.2 Nonlinear Scattering:

is accompanied by a frequency shift of the scattered light. Nonlinear scattering is caused by high values of electric field within the fiber (modest to high amount of optical power). Nonlinear scattering causes significant power to be scattered in the forward, backward, or sideways directions.

- **Stimulated Raman Scattering :**

Stimulated Raman scattering is a nonlinear response of glass fibers to the optical intensity of light. This is caused by vibrations of the crystal (or glass) lattice. Stimulated Raman scattering produces a high-frequency optical phonon, as compared to Brillouin scattering, which produces a low-frequency acoustical phonon, and a scattered photon.
When two laser beams with different wavelengths (and normally with the same polarization direction) propagate together through a Raman-active medium, the longer wavelength beam can experience optical amplification at the expense of the shorter wavelength beam. This phenomenon has been used for Raman amplifiers and Raman lasers.

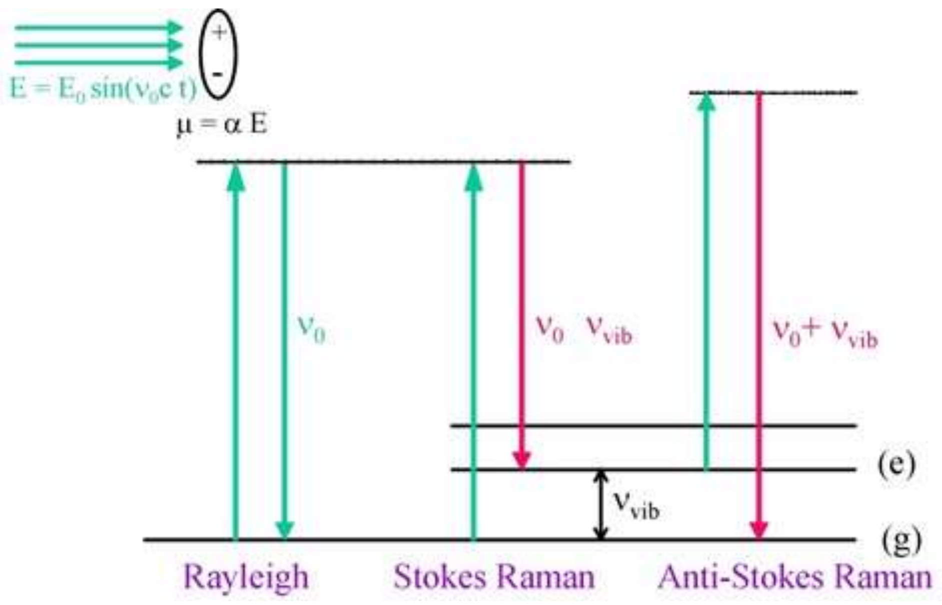


Figure 2.7 Stimulated Raman scattering.

In Stimulated Raman scattering, the scattering is predominately in the forward direction, hence the power is not lost to the receiver.

Stimulated Raman Scattering also requires optical power to be higher than a threshold to happen. The formula below gives the threshold

$$P_R = (23.6\times10^{-2})\ a'^2\lambda'\alpha \qquad (2.2)$$

where

P_R = Stimulated Raman Scattering Optical Power Level Threshold (watts)

a' = Fiber radius (um)

λ' = Light source wavelength (um)

α = Fiber loss (dB/km)

- **Stimulated Brillouin scattering (SBS):**

It may be regarded as the modulation of light through thermal molecular vibrations within the fiber. It is based on frequency shift such as the scattered light appears as upper and lower sidebands which are separated from the incident light by the modulation frequency. The incident photon in the scattering process produces an acoustic phonon (mode of vibrational energy) of low frequency (sound frequency) as well as a scattered photon producing an optical frequency shift which varies with the scattering angle. The frequency shift is maximum in the backward direction and reduced to zero in the forward one. Brillouin threshold power is given by:

$$PB = 4.4 \times 10^{-3} d^2\lambda^2\alpha_{dB}\upsilon\ (watt) \qquad (2.3)$$

Such that :

d: is the fiber core diameter

λ: is the operating wavelength

α_{dB}: is the fiber attenuation in decibels per kilometer
υ: is the source bandwidth in gigahertz

2.5.3Macrobending Loss:
Macrobending happens when the fiber is bent into a large radius of curvature relative to the fiber diameter (large bends). These bends become a great source of power loss when the radius of curvature is less than several centimeters.

Macrobend may be found in a splice tray or a fiber cable that has been bent. Macrobend won't cause significant radiation loss if it has large enough radius.

However, when fibers are bent below a certain radius, radiation causes big light power loss as shown in the figure below.

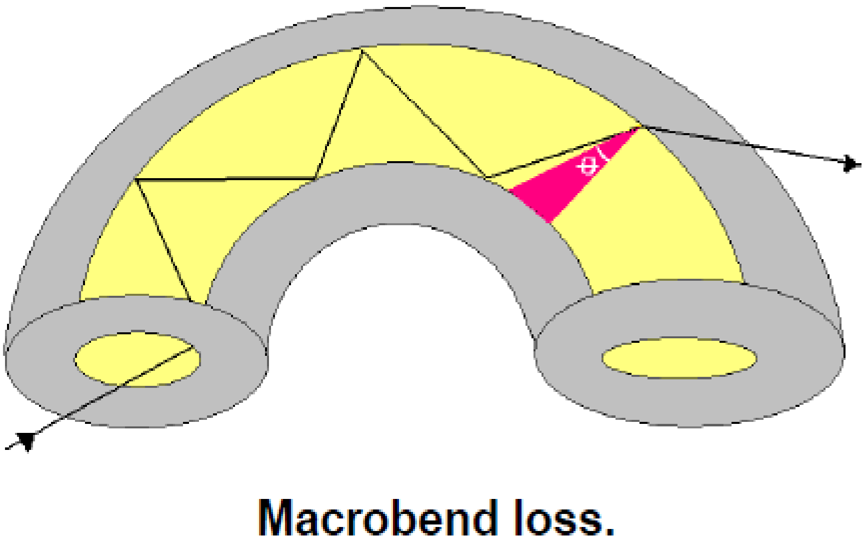


Figure 2.8 Macrobend loss.

Corning SMF-28e single mode fibers should not be bent below a radius of 3 inches. 50um graded-index multimode fibers, such as Corning Infinicor 600, should not be bent below a radius of 1.5 inches. 62.5um graded-index multimode fibers, such as Corning Infinicor 300, should be be bend below a radius of 1 inch.

2.5.4 Microbending Loss:

Microbendings are the small-scale bends in the core-cladding interface. These are localized bends can develop during deployment of the fiber, or can be due to local mechanical stresses placed on the fiber, such as stresses induced by cabling the fiber or wrapping the fiber on a spool or bobbin.

Microbending can also happen in the fiber manufacturing process. It is sharp but microscopic curvatures that create local axial displacement of a few microns (um) and spatial wavelength displacement of a few millimeters.

Microbends can cause 1 to 2 dB/km losses in fiber cabling process.

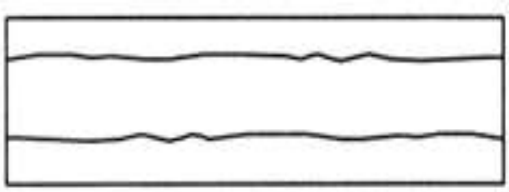


Figure 2.9 Microbends.

The following figure shows the impact of a single microbend, at which, analogous to a splice, power can be coupled from the fundamental mode into higher order leaky modes.

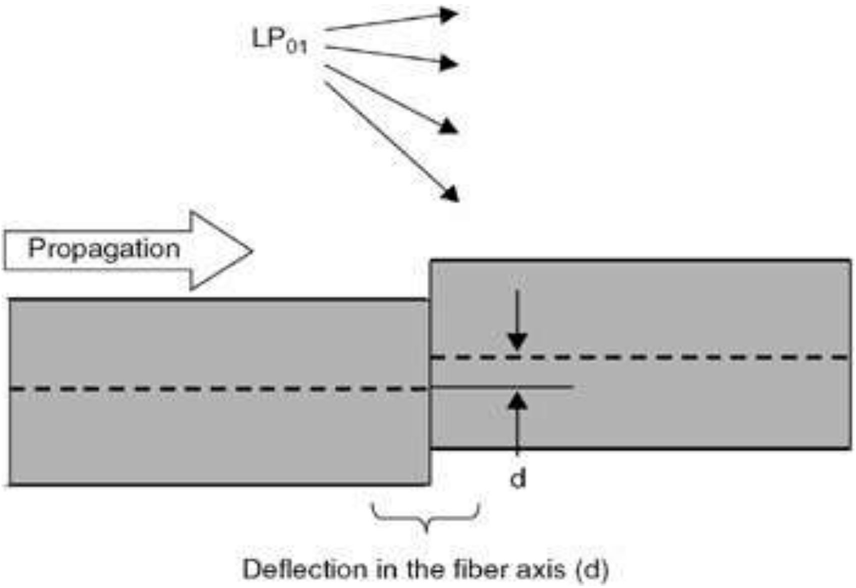


Figure 2.10 the impact of a single microbend.

Because external forces are transmitted to the glass fiber through the polymer coating material, the coating material properties and dimensions, as well as external factors, such as temperature and humidity, affect the microbending sensitivity of a fiber.

Microbending sensitivity is also affected by coating irregularities such as variations in coating dimensions, the presence of particles such as those in the pigments of color coatings, and inhomogeneities in the properties of the coating materials that vary along the fiber axis.

2.6Conclusion:

In this chapter, technologies for attenuation and dispersion compensation have been explained, so that the quality of transmission is enhanced.

Chapter 3:

Simulation and results

3.1 Introduction:

In this chapter, multiple configurations of the dispersion compensation using DCF technique were designed and simulated, starting with the **Pre** configuration passing to **Post** configuration, then **Symmetric** configuration. each configuration is discussed alone. then a small comparison between the three configurations is presented taking in account their bit error rates (BERs) and the quality factors (Q factors) for different bit rates, we have used optical amplifiers after each fiber to compensate for the span loss. The dispersion parameter of SMF is 120 km long and 16 ps/nm-km. Therefore, total accumulated dispersion is 16x120 = 1920 ps/nm. This much dispersion can be compensated by using a 24 km long DCF with - 80 ps/km-nm dispersion. Total transmission distance is 120x2 =240 km for each case. After that we process simulations for WDM systems using the previous configurations using different number of channels (4 and 8 channels).

All the simulation steps performed before are done by the aid of Opti System software.

3.2 Optisystem software description:

Optisystem is an optical communication system simulation package Based on the purposes of designing, optimizing, and testing any type or category of optical link in the physical layer of the broad spectrum for optical networks, from Long-Haul Networks, Metropolitan Area Networks (**MANs**) and Local Area Networks (**LANs**).It is full of operators that can be joined together to design experiments and simulate many applications, such as **CATV** or **WDM/TDM** or networks, It is a system level simulator based on the realistic modelling of fiber-optic communication systems. OptiSystem possesses a powerful simulation environment and a truly hierarchical definition of components and systems.

Optisystem software is the mirror of the optical link in the physical layer of the broad spectrum for optical networks that's why in addition to **CATV** or **WDM/TDM** or network

Designs it has many applications, such as:

- **SONET /SDH** ring design.
- Transmitter, channel, amplifier and receiver design.
- Dispersion map design.
- Free space optic (**FSO**) systems
- Radio over fiber (**ROF**).
- Estimation of **BER** and system penalties with many models of receivers.
- Amplified system **BER** and link budget calculations.

The OptiSystem main window is represented in **Figure 1**.

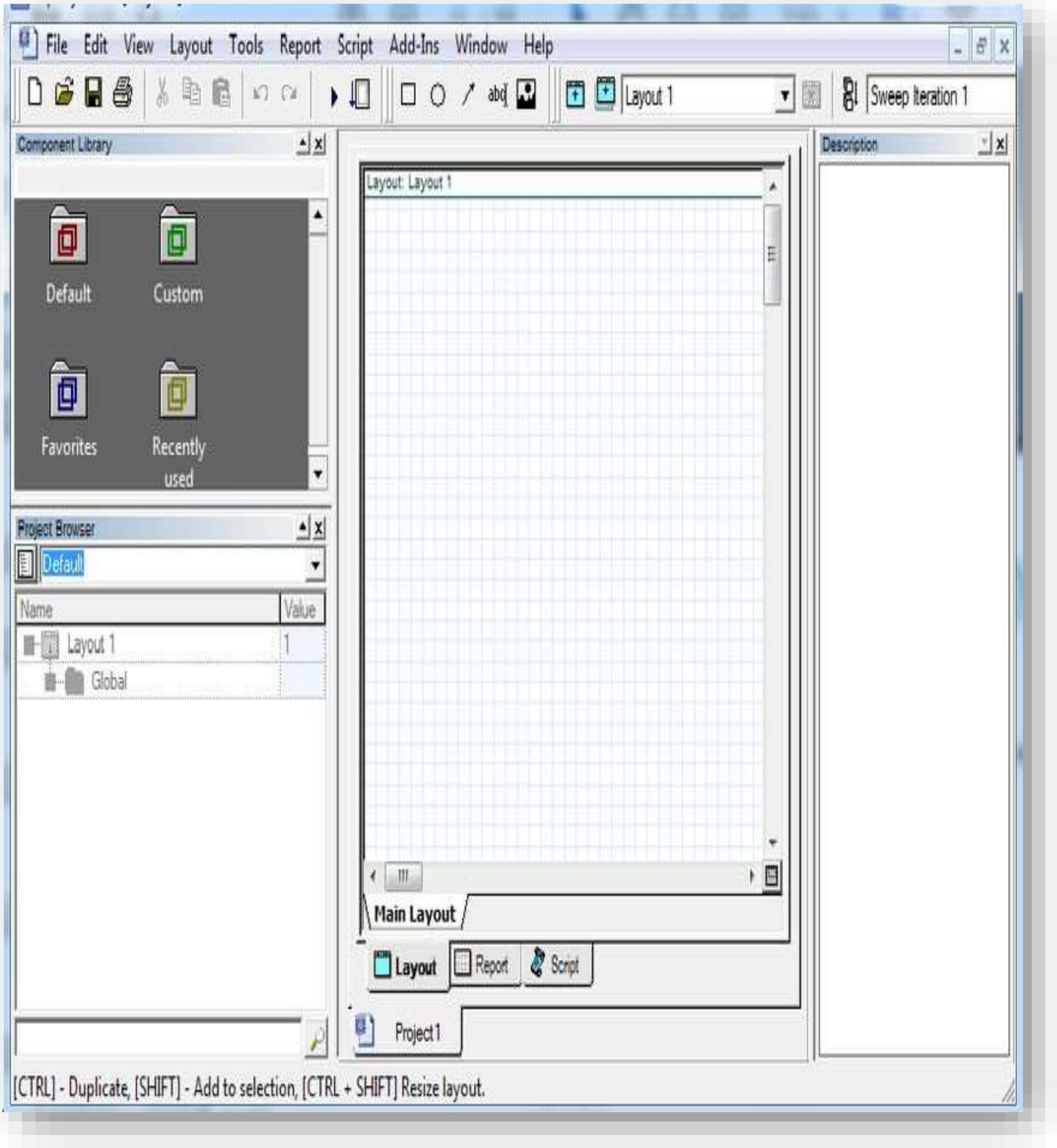


Figure 3.1 : The OptiSystem main window [2].

3.3 Simulation setup:

This section describes the simulation setup in the OptiSystem software, and focusses on the parameters used for different configurations. Our work will be divided into three steps:

- First step, we will test the three different configurations of dispersion compensation.
- Second step, we will design 4ckannel **WDM,** then discussion of the obtained result will be presented.
- Third step, we will design 8 channel **WDM** system, after that we discuss the obtained results then comparing theme with the obtained ones using 4 channel **WDM** system.

3.3.1 First step:

In this section, we will show how the performance of the system could be affected by the different dispersion compensation schemes. The inter symbol interference (**ISI**) is caused by the pulse broadening effect of chromatic dispersion when the signals in the adjacent bit periods overlap. Broadening is a function of distance as well as dispersion parameter **D**. The dispersion parameter **D** is given in ps/nm/km and changes from fiber to fiber.it is usually about **17 ps/nm/km** in the **1.55 µm** wavelength range for a standard single mode fiber (**SMF**). It is at a maximum of **3.3 ps/nm/km** in the same window for a dispersion-shifted fiber (**DSF**).

The figure 2 represents different configurations for dispersion compensation using **DCF**

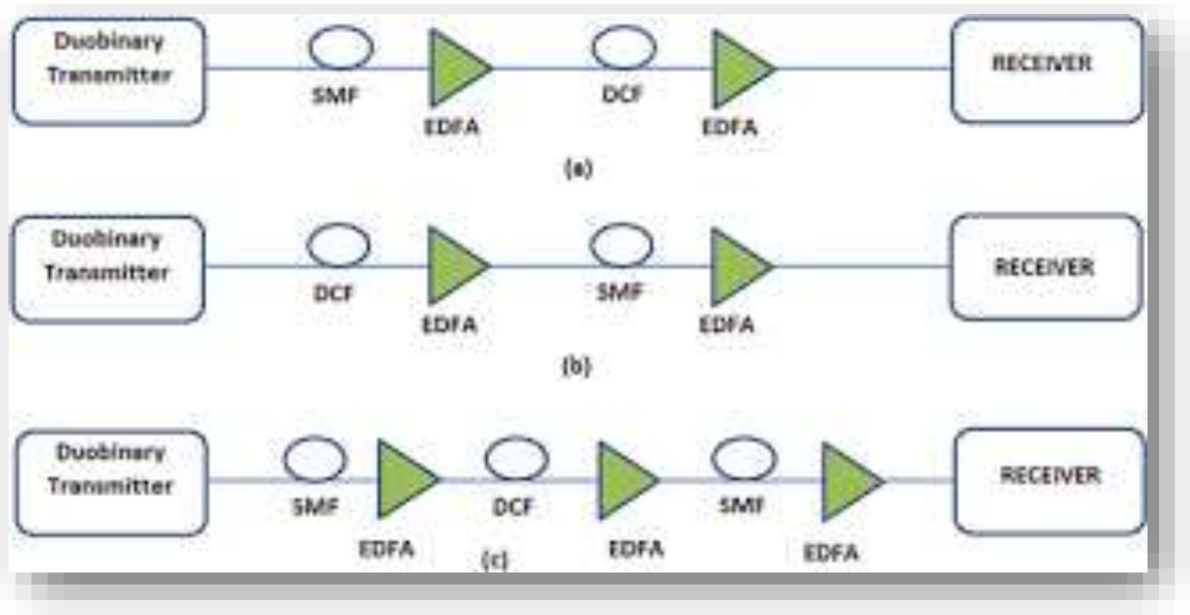


Figure 3.2 : Transmission line model : a-pre-compensation, b-post-compensation, c-symmetrical compensation.

3.3.1.1 First configuration is Dispersion Pre-compensation

It is defined as the condition when **DCF** is placed at the first point of optical link before **SMF**, this process of simulation contains 3 sections, which are transmitter section, medium for transmission and receiver section.

- For the transmitter section, we have pseudo random bit sequence generator, **NRZ** pulse generator used for line coding, **CW** laser and Mach-Zehnder modulator. The pseudo random bit sequence generator has a bit rate of 10 Gbps for generation of pulses. CW laser having different values for power starting from 5dBm that frequency will be used at frequency **193.1THz.**
- For the transmission medium we have **DCF,** two optical amplifiers
- (**Ideal EDFA**) to amplify the signal and also to overcome the attenuation whenever required. Connected to the loop control.
- For the transmitter section, we have a Photodetector, a Low Pass Bessel Filter, and a **BER** Analyzer to evaluate the system **Q** factor and obtain the eye diagram.

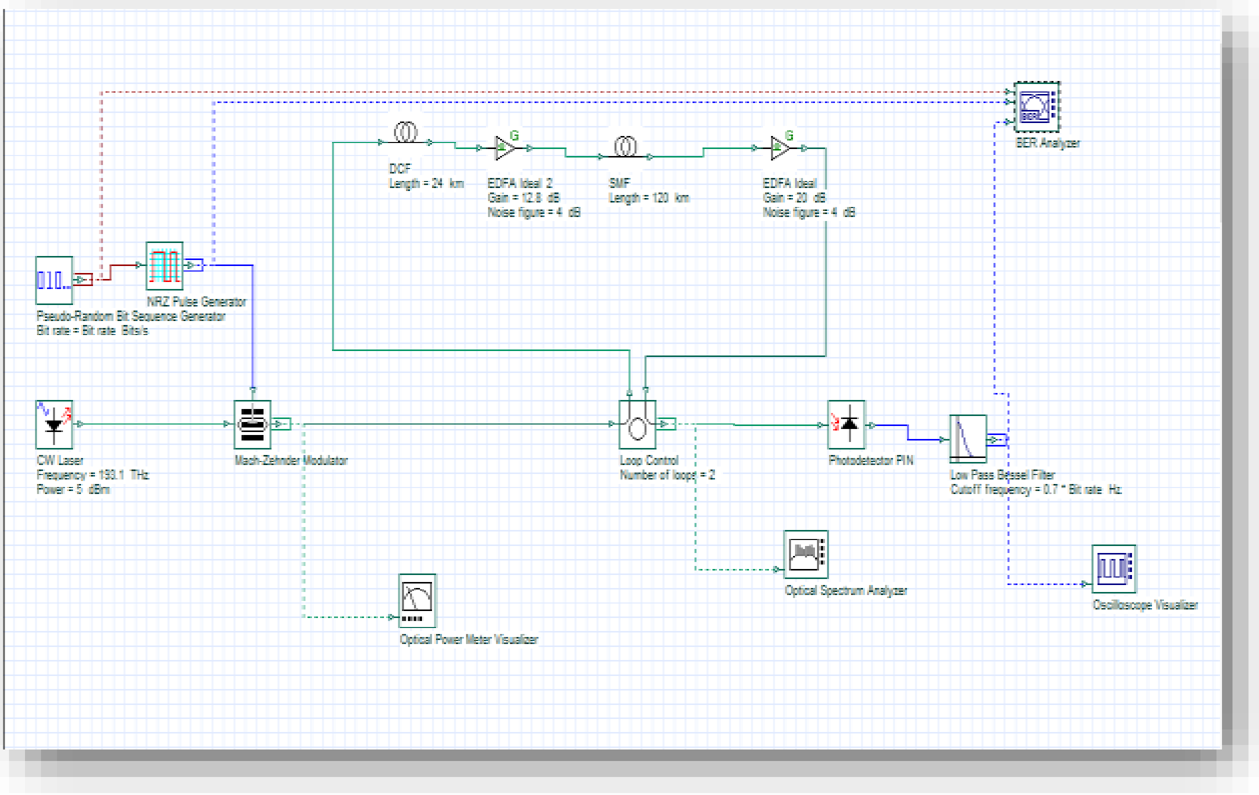


Figure3.3*: *Transmission Line model for Pre-compensation.

The system simulated in the above figure has the following parameters represented in table 1:

Table 3.1 : The parameters of our System.

System parameters:	Values:
Bit rate (Gbps)	2.5 5 8 10 12 14
Laser power (dBm)	-15 -10 -5 0 5 8 10
Length of SMF(Km)	120
Length of DCF(Km)	24
EDFA 1	Gain=12.8dB Noise figure =4dB
EDFA 2	Gain=20dB Noise figure =4dB

The Dispersion length is dependent on the group velocity dispersion (**GVD**) parameter **ß**, but For externally modulated sources, transmission distance limited by chromatic dispersion:

$$L \leq \frac{2\pi c}{16|D|\lambda^2 ß^2} \qquad (3.1)$$

When D=16 ps/(km-nm) and at 2.5 Gbps, L=500 km, whereas it drops to 30 km at 10 Gbps bit rate.

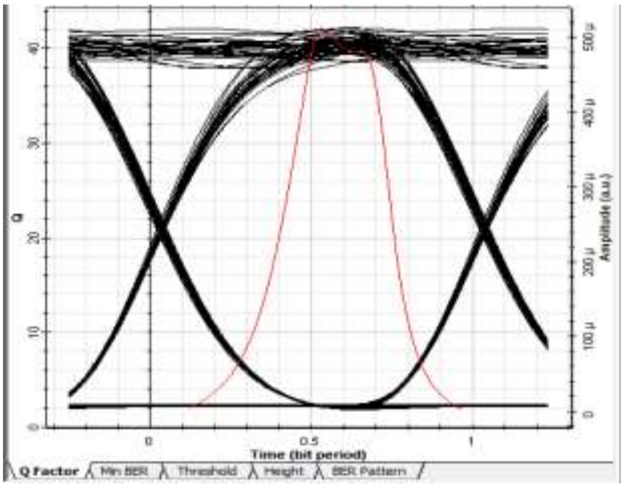
The dispersion parameter of **SMF** is **120 km** long and **16 ps/nm-km.** Therefore, total accumulated dispersion is **16x120 = 1920 ps/nm**. This much dispersion can be compensated by using a **24 km** long **DCF** with **- 80 ps/km-nm** dispersion. Total transmission distance is **120x2 =240 km** for each cases.

First, we simulate for the different values of bit rate but for the laser power we keep it 8dBm, we will get the results summarized in table.2

Table3.2 :The different values of bit rates with their corresponding Q factor and BER for the Pre-compensation configuration.

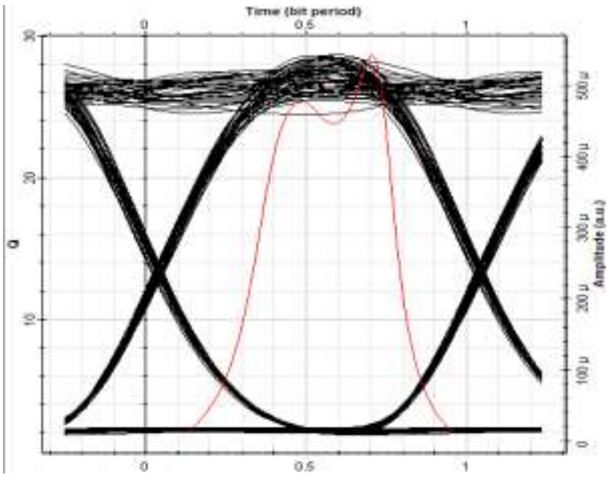
Bit rate (Gbps):	BER:	Q factor:
2.5	0	42.223
5	$4.6477e^{-181}$	28.6615
8	$9.87304e^{-82}$	19.0943
10	$7.0833e^{-57}$	15.8266
12	$1.49711e^{-91}$	20.244
14	$1.24744e^{-35}$	12.3768

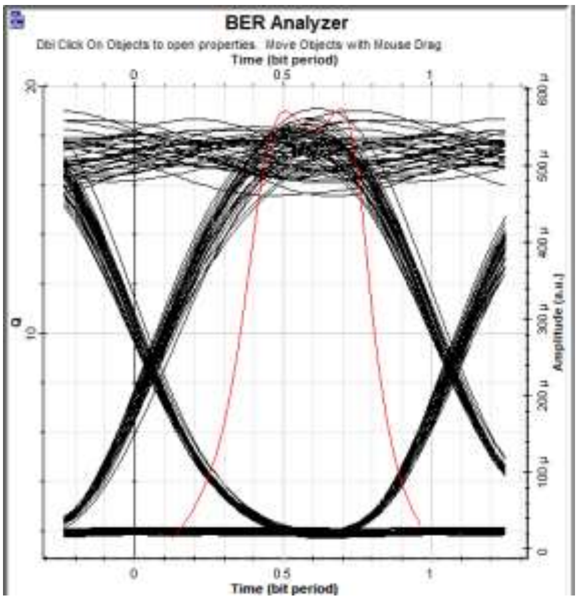
In addition to the Q factor and the BER parameter, the eye diagram is an interesting parameter in our simulation, so here are the corresponding eye diagrams for each bit rate.



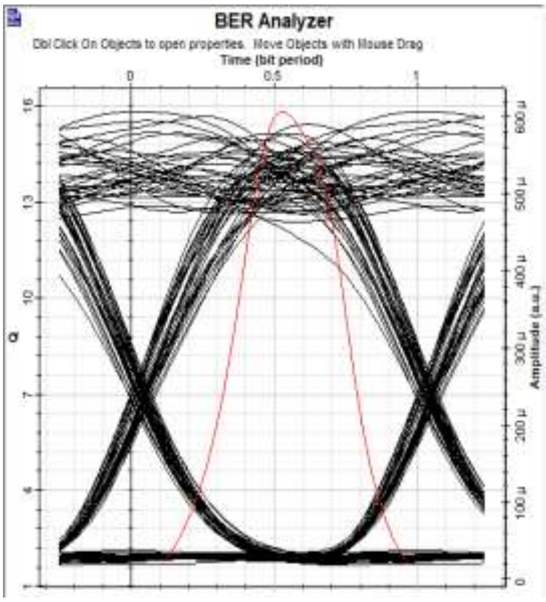
Aye diagram at bit rate 2.5 Gbps

Aye diagram at bit rate 5 Gbps



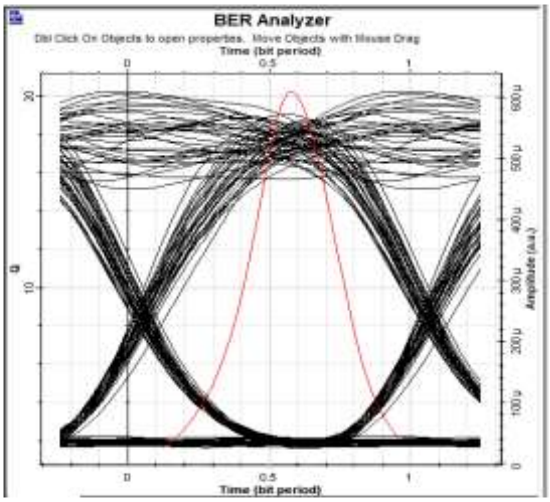


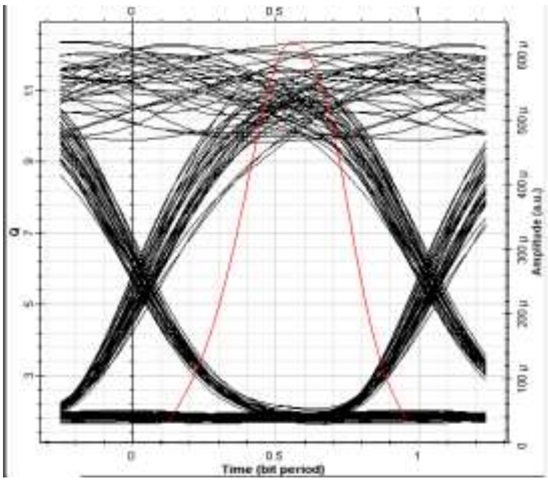
Eye diagram at bit rate 8 Gbps



Eye diagram at bit rate 10 Gbps

Eye diagram at bit rate 12Gbps





Eye diagram at bit rate 14 Gbps

3.3.1.2 Second configuration is Dispersion Post-compensation

It is defined as the condition when **DCF** is placed at the last point of optical link before **SMF,** this process of simulation contains **3 sections,** which are transmitter section, medium for transmission and receiver section.

- For the transmitter section we have pseudo random bit sequence generator, **NRZ** pulse generator used for line coding, **CW laser** and Mach-Zehnder modulator. The pseudo random bit sequence generator has a bit rate of **10 Gbps** for generation of pulses. CW laser having different values for power starting from 5dBm that frequency will be used at frequency **193.1THz.**
- For the transmission medium we have **DCF**, two optical amplifiers
- **(Ideal EDFA)** to amplify the signal and also to overcome the attenuation whenever required. Connected to the loop control.
- For the transmitter section we have a Photodetector, a Low Pass Bessel Filter, a **BER** Analyzer to evaluate the system **Q** factor and obtain the eye diagram.

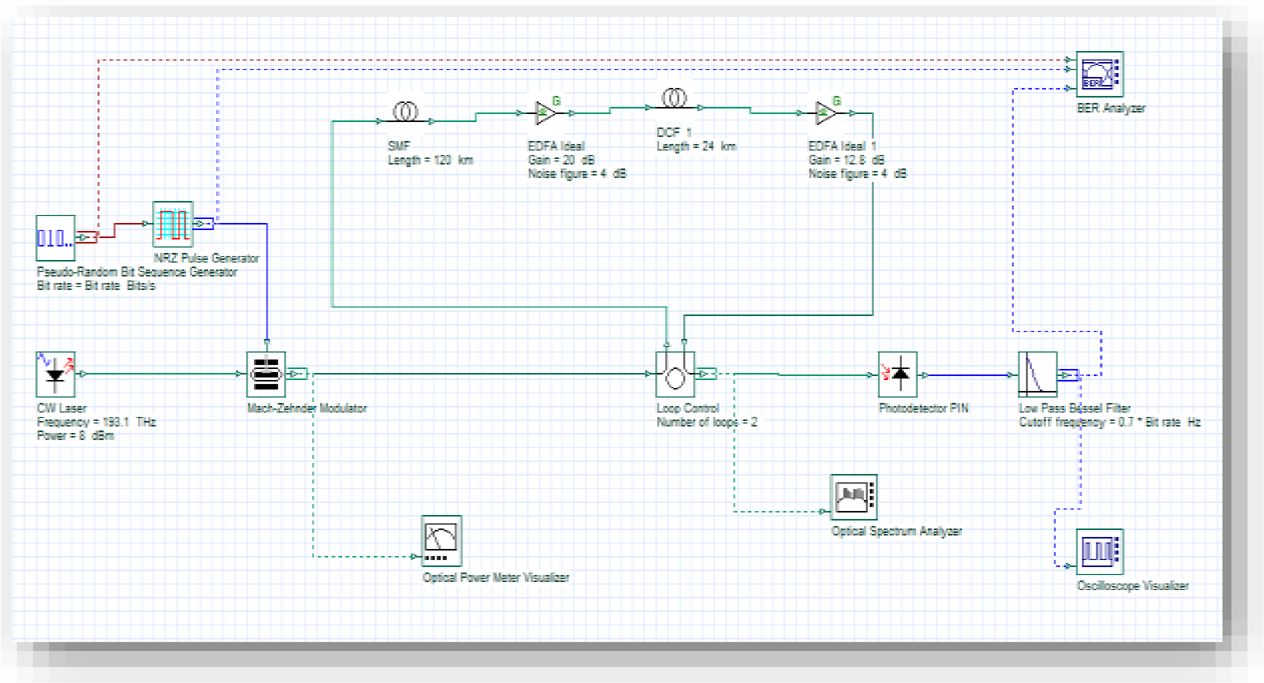


Figure3.4: transmission line model: post-compensation

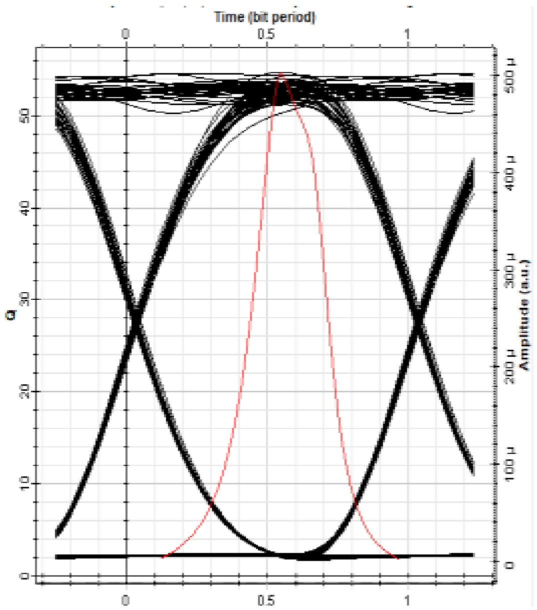
The system simulated in the above figure has the same parameters represented in table 1.

First, we simulate for the different values of bit rate but for the laser power we keep it **8dBm**, we will get the results summarized in table 3

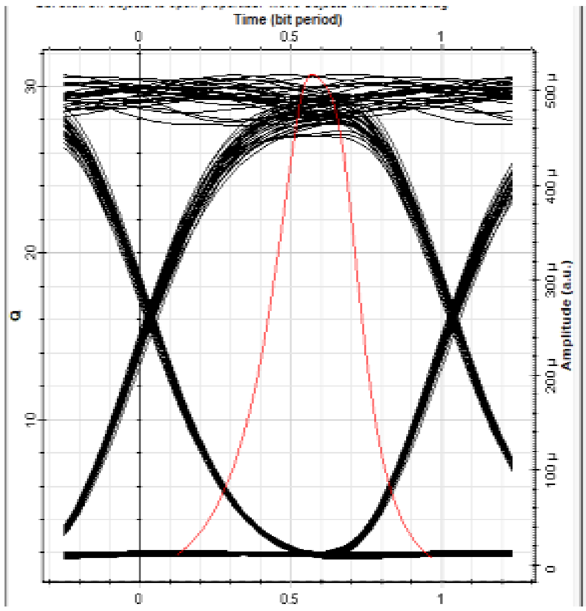
Table3.3 : the diffrent values of bit rates with their corresponding Q factor and BER for the post-comensation configuration.

Bit rate (Gbps):	BER:	Q factor:
2.5	0	54.68
5	$1.391e^{-207}$	30.71
8	$1.09e^{-111}$	22.41
10	$5.53e^{-96}$	20.74
12	$7.08e^{-131}$	24.30
14	$1.04e^{-67}$	17.33

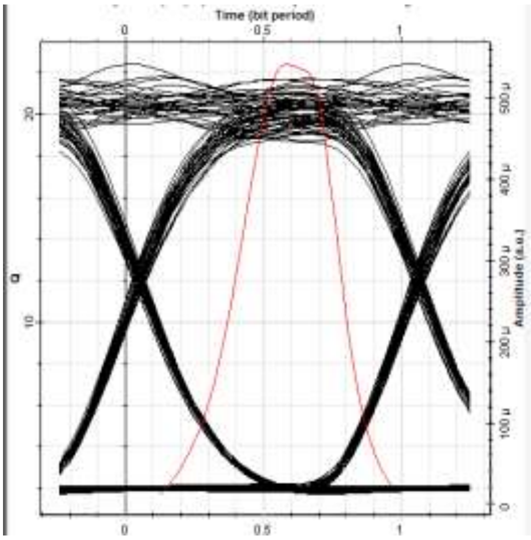
The corresponding eye diagrams for each bit rate when using post-compensation configuration are as follows:



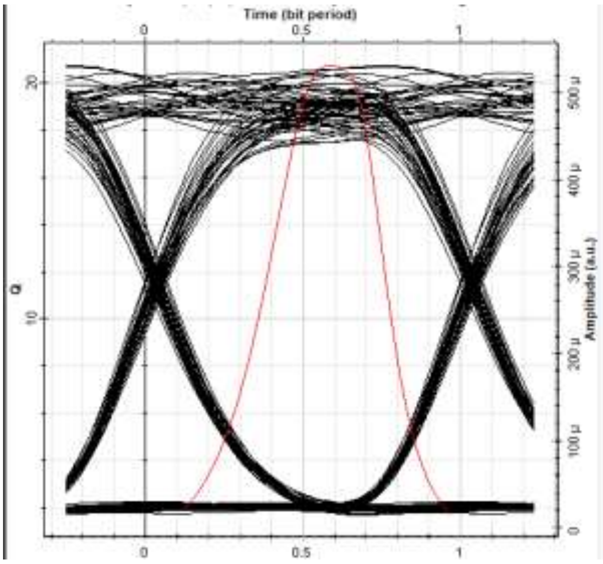
Eye diagram at bit rate 2.5 Gbps



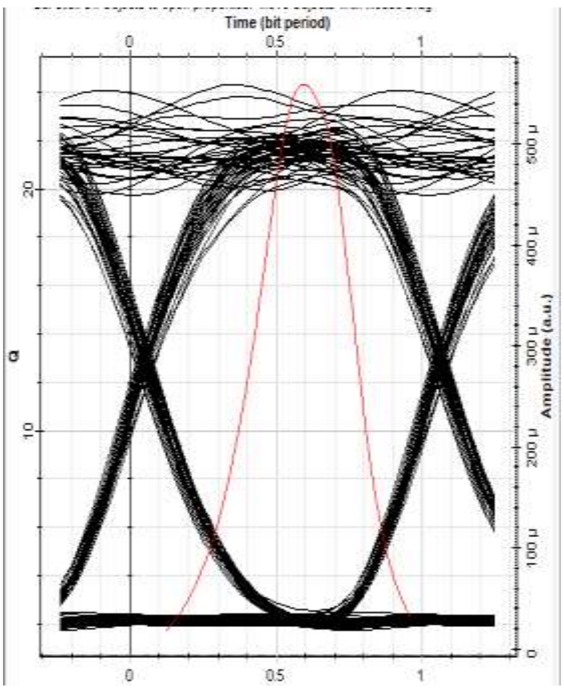
Eye diagram at bit rate 5 Gbps



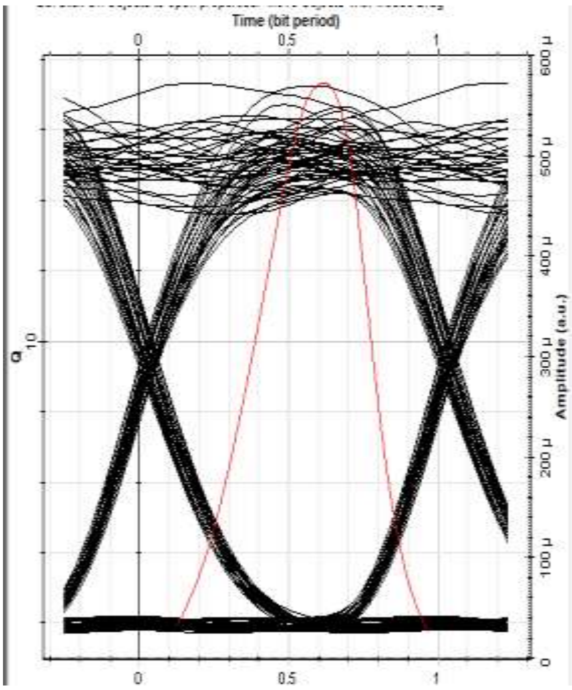
Eye diagram at bit rate 8 Gbps



Eye diagram at bit rate 10 Gbps



Eye diagram at bit rate 12Gbps



Eye diagram at bit rate 14 Gbps

3.3.1.3 Third configuration is Dispersion Symmetrical-compensation:

It is defined as the condition when two **DCFs** are placed at both the transmitter end also the receiver end point of where the **SMF** is placed between theme, this process of simulation contains 3 sections, which are transmitter section, medium for transmission and receiver section.

- For the transmitter section we have pseudo random bit sequence generator, **NRZ** pulse generator used for line coding, **CW** laser and Mach-Zehnder modulator. The pseudo random bit sequence generator has a bit rate of **10 Gbps** for generation of pulses. **CW** laser having different values for power starting from **5dBm** that frequency will be used at frequency **193.1THz**.
- For the transmission medium we have **2 DCFs**, two **SMFs** and four optical amplifiers
- (**Ideal EDFA**) to amplify the signal and also to overcome the attenuation whenever required. Connected to the loop control.
- For the transmitter section we have a Photodetector, a Low Pass Bessel Filter, a **BER** Analyzer to evaluate the system **Q** factor and obtain the eye diagram.

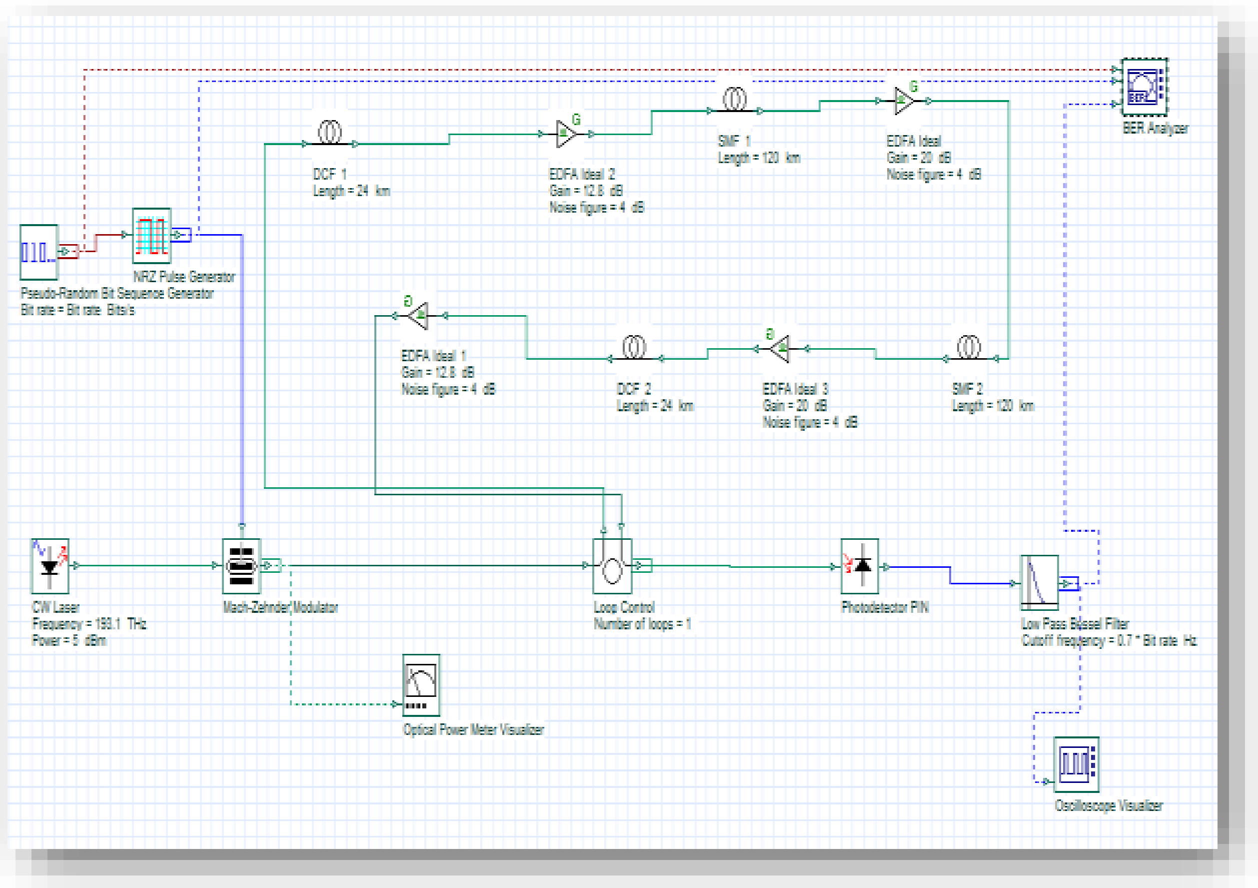


Figure 3.5 : transmission line model for symmetrical-compensation.

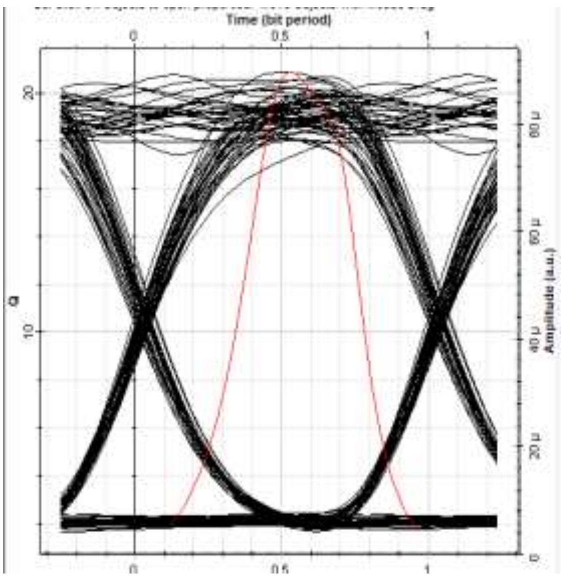
The system simulated in the above figure has the same parameters represented in table.2, except that we have two **DCFs DCF1** and **DCF2** both with length **24km,** two **SMFs** both with length **120km,**

First, we simulate for the different values of bit rate but for the laser power we keep it **8dBm**, we will get the results summarized in table.4

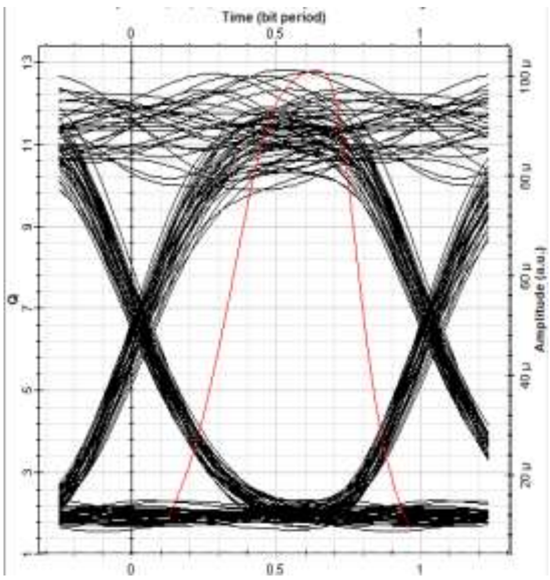
Table 3.4 : the different values of bit rates with their corresponding Q factor and BER for the Symmetrical-compensation configuration.

Bit rate (Gbps):	BER:	Q factor:
2.5	$3.91\ e^{-97}$	20.87
5	$6.17e^{-38}$	12.81
8	$1.89e^{-25}$	10.35
10	$4.50e^{-18}$	8.58
12	$9.50e^{-16}$	7.94
14	$1.63e^{-9}$	5.89

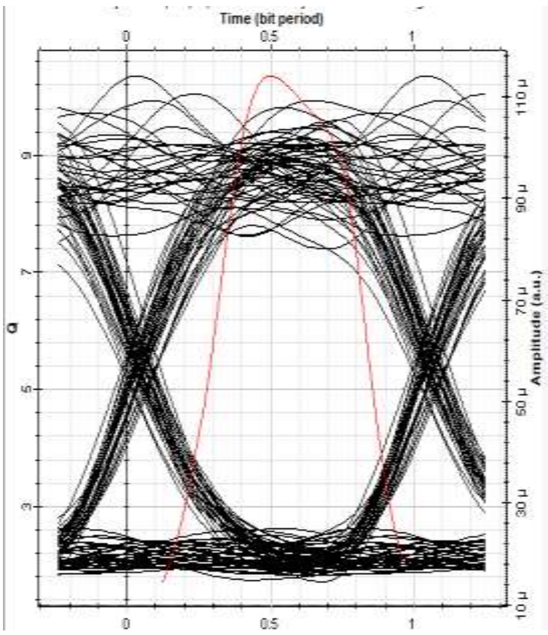
The corresponding eye diagrams for each bit rate when using symmetrical-compensation configuration are as follows:



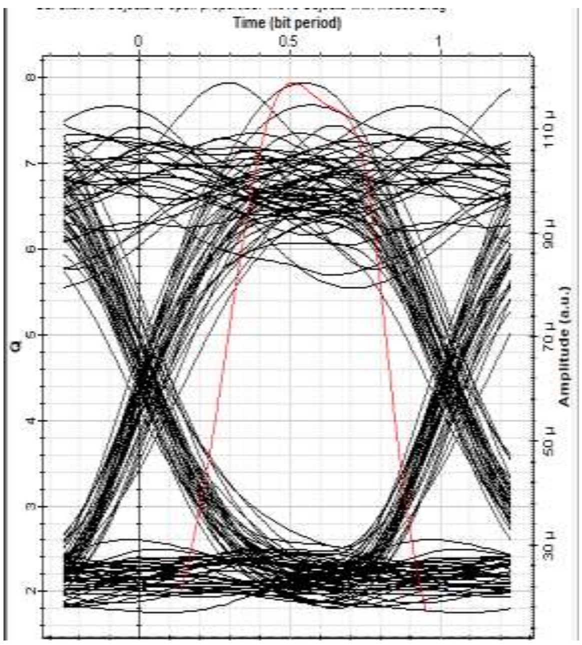
Eye diagram at bit rate 2.5Gbps



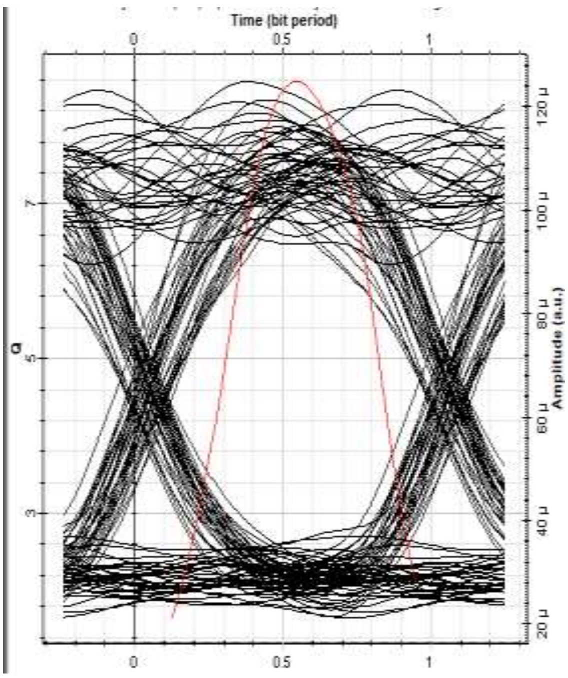
Eye diagram at bit rate 5 Gbps



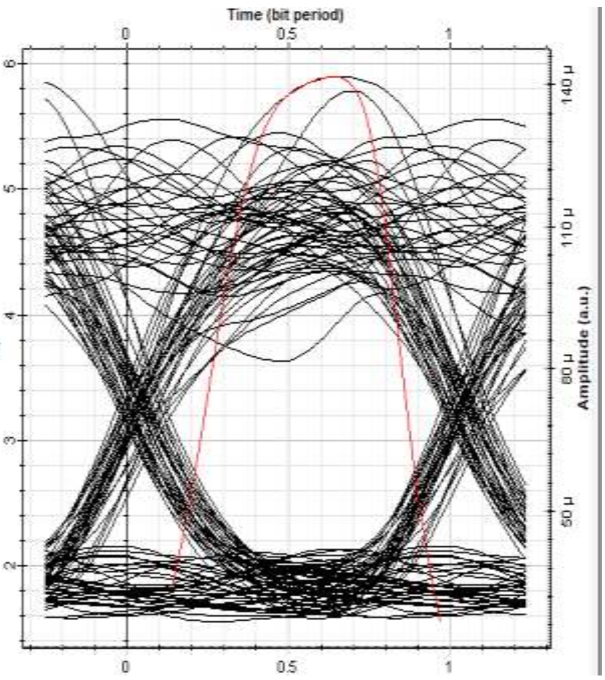
Eye diagram at bit rate 8Gbps



Eye diagram at bit rate 10 Gbps



Eye diagram at bit rate 12Gbps



Eye diagram at bit rate 14 Gbps

3.3.2 Second step:

In this section we will design **4ckannel WDM**, using the same software as before, the simulation setup consists of three sections: the transmitter section, the transmission medium section and the receiver section.

- The first section, the transiter section in a **WDM** system is a bloc consists of pseudo random bit sequence generator works at different bit rates (**in the range of Gbps**), **NRZ** pulse generator used for coding**, CW** laser powered with **8dBm** and frequency **193.1THz**, and Mach-Zehnder modulator, the block will be connected to a **MUX** through which the signal passes, it has **4*1** channel shown in **figure 6**

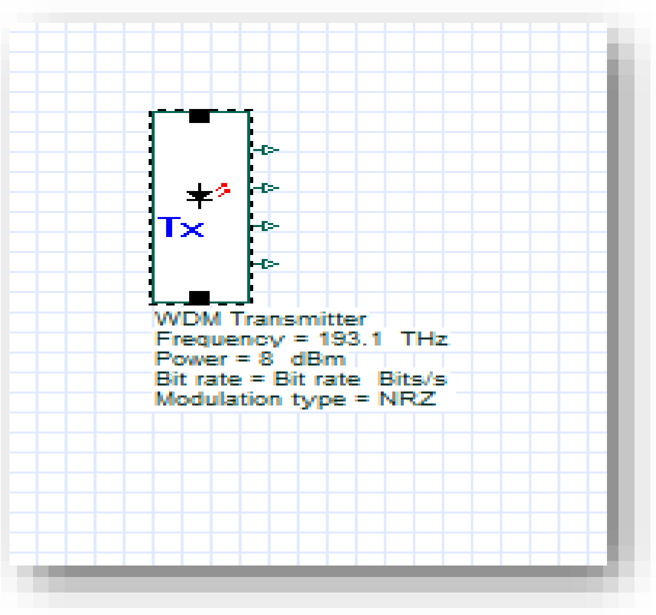


Figure3.6 : transmitter model.

- The second section, the transmission line or the transmission medium consists of two optical amplifiers (**EDFA**), an optical fiber (**SMF**), tis section will connected at the first point to a **4*1** channel **MUX** and ended by a **1*4 WDM** Demux.

- The third section, the receiver structure based on a **PIN** Photodetector, a Low Pass Bessel Filter, connected to a **3R** Regenerator and a **BER** Analyzer to evaluate the system **Q factor**, **BER** and show the eye diagram.

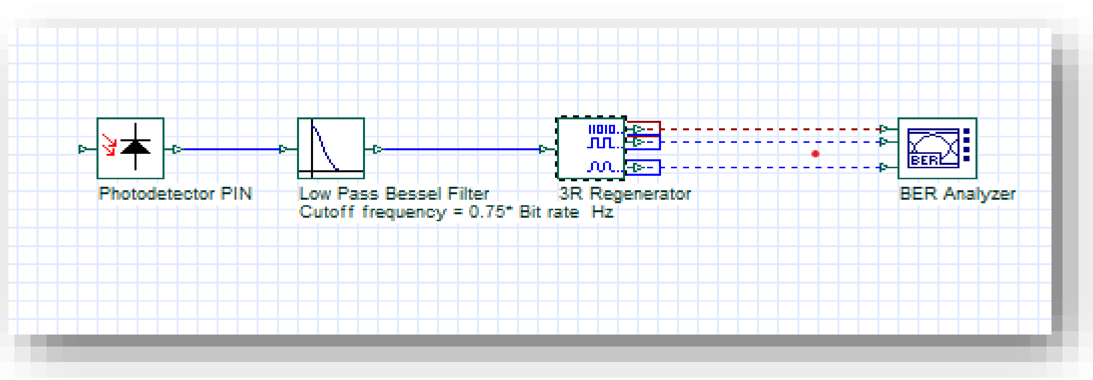


Figure3.7 : the receiver model.

The receiver structure will be connected at each channel of a **1*4 WDM Demux** as shown in figure 3.8:

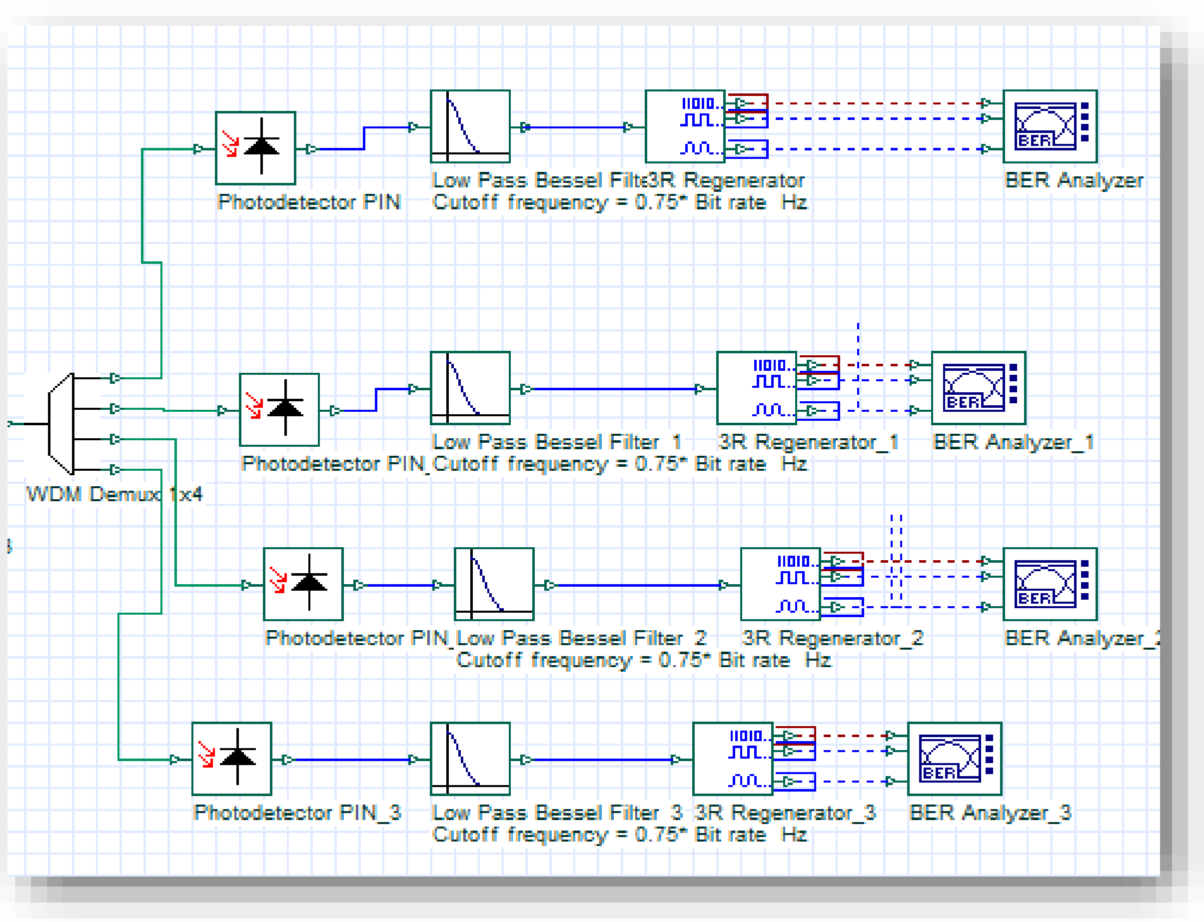


*Figure 3.8 :the receiver model connected to a 1*4WDM Demux.*

The system that will be simulated has the following system parameters, presented in table.5

Table 3.5 : The system parameters.

Parameter :	Value :
Bite rate (Gbps)	2.5 3 5 8 10 12
Laser power (dbm)	-10 0 5 8 10 12 15
Length of SMF (km)	30 45 60 75 90 100 120
Length of DCF (km)	5 10 15 20 24 30
Dispersion coefficient of SMF (ps/nm/km)	16
Dispersion coefficient of DCF (ps/nm/km)	-83.75
EDFA gain(dB)	6
SMF attenuation (dB/km)	0.25
DCF attenuation(dB/km)	0.265
Dispersion slope of SMF (ps/nm2 /km)	0.075
Dispersion slope of DCF (ps/nm2 /km)	-0.075

For the system parameters summarized in table 5, we will simulate the system with, without compensation, and for different **SMF** length in order to see the role of compensation

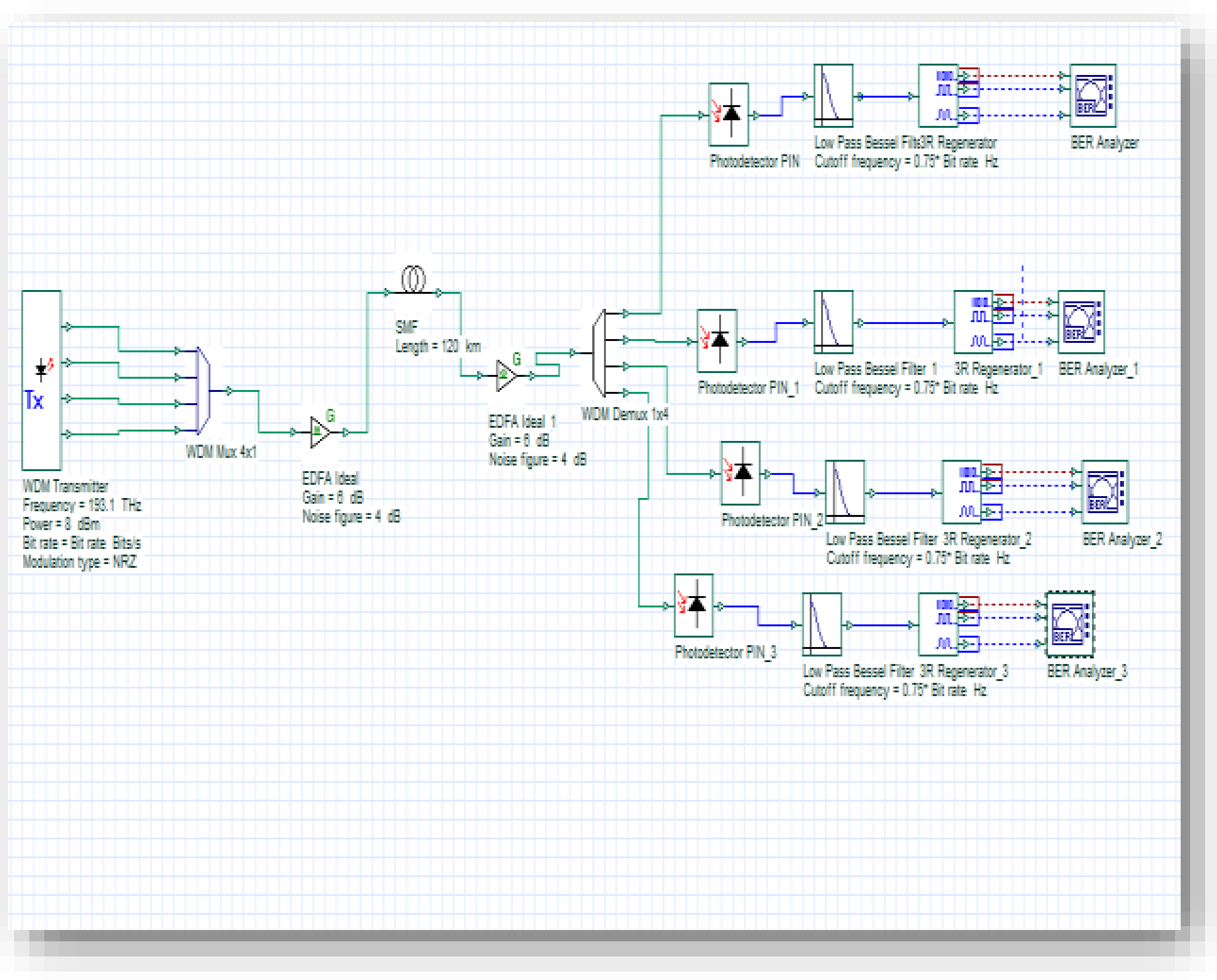


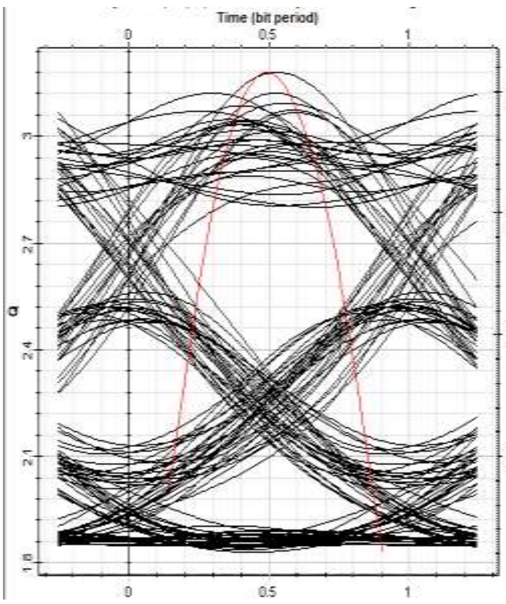
Figure 3.9 : 4-Channel WDM system of 120Km optical fiber length.

The obtained results (**BER, Q factor**) will be presented in table 6:

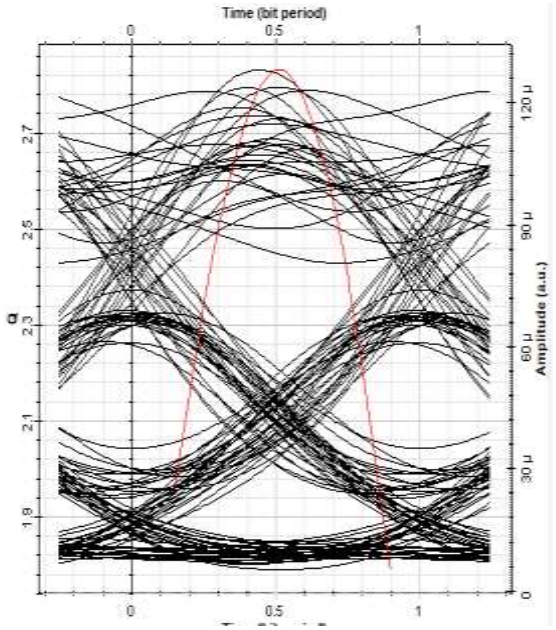
Table 3.6 : the obtained results (BER , Q factor) for the system simulated in figure 9.

	Channel 1	Channel 2	Channel 3	Channel 4
BER	7.28322 e^{-4}	2.19 e^{-4}	3.68 e^{-3}	1.18 e^{-3}
Q	3.18005	2.83079	2.65478	3.03258

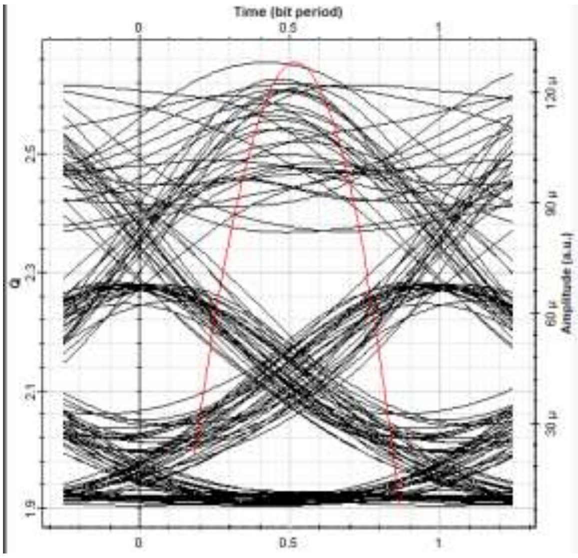
- For the corresponding eye diagrams:



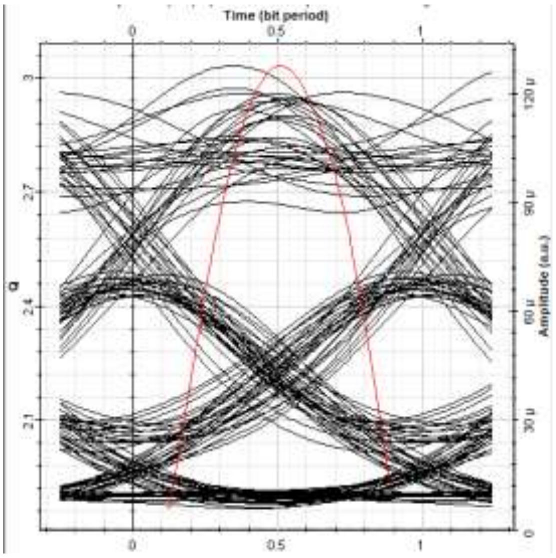
Eye diagram for channel 1



Eye diagram for channel 2



Eye diagram for channel 3



Eye diagram for channel 4

- From the presented figures and table 6, it is noticed that the uncompensated system kas a low **Q** factor, a high **BER** and unclear eye diagrams. Which are all unlikely results.
- Simulation of the system with compensation, where the three configurations will be used (**Pre, Post and Symmetrical**) but our results and discussion focus on channel 1

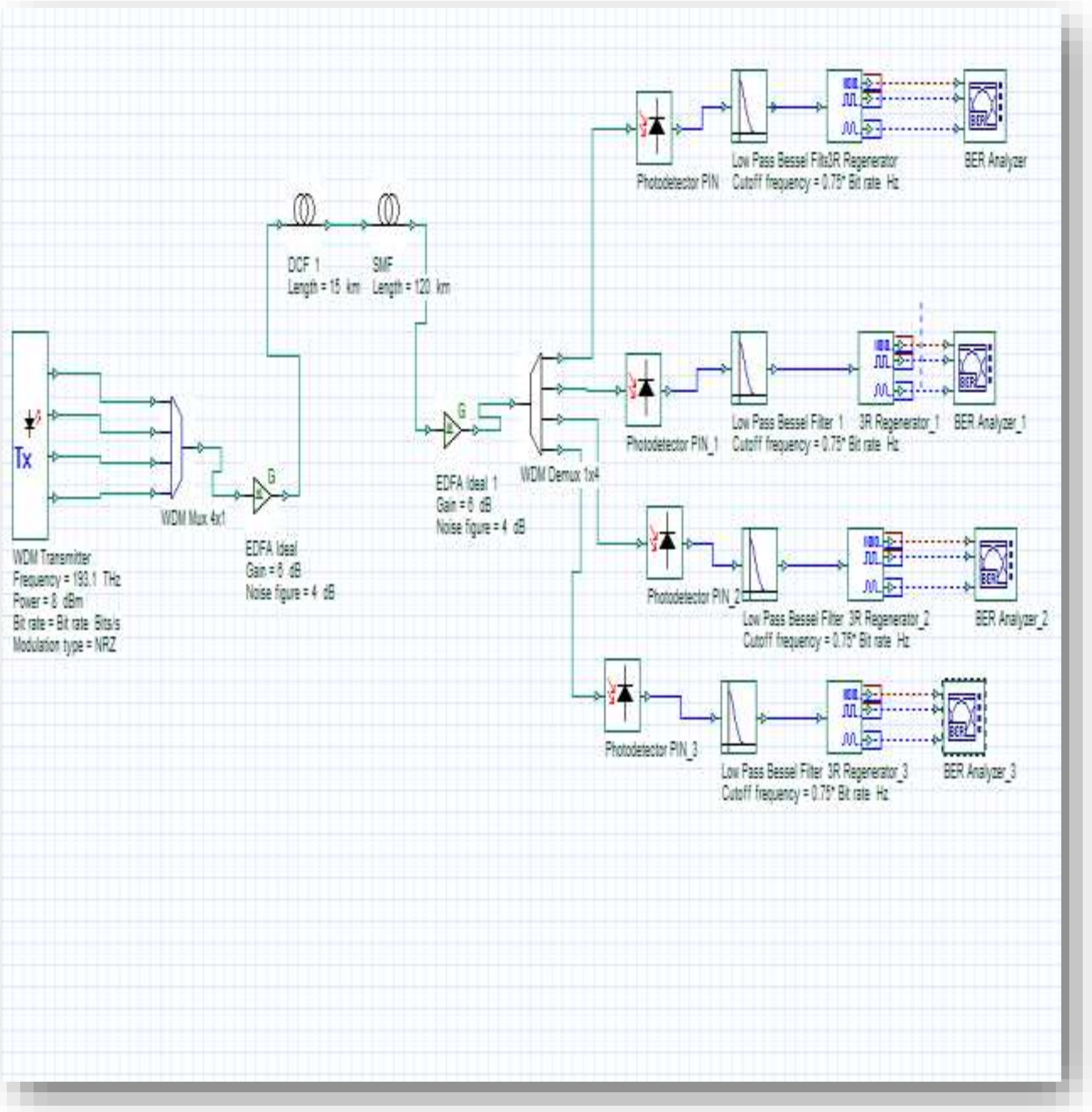


Figure 3.10 : 4-channel WDM system of 120 Km optical fiber length using Pre-compensation.

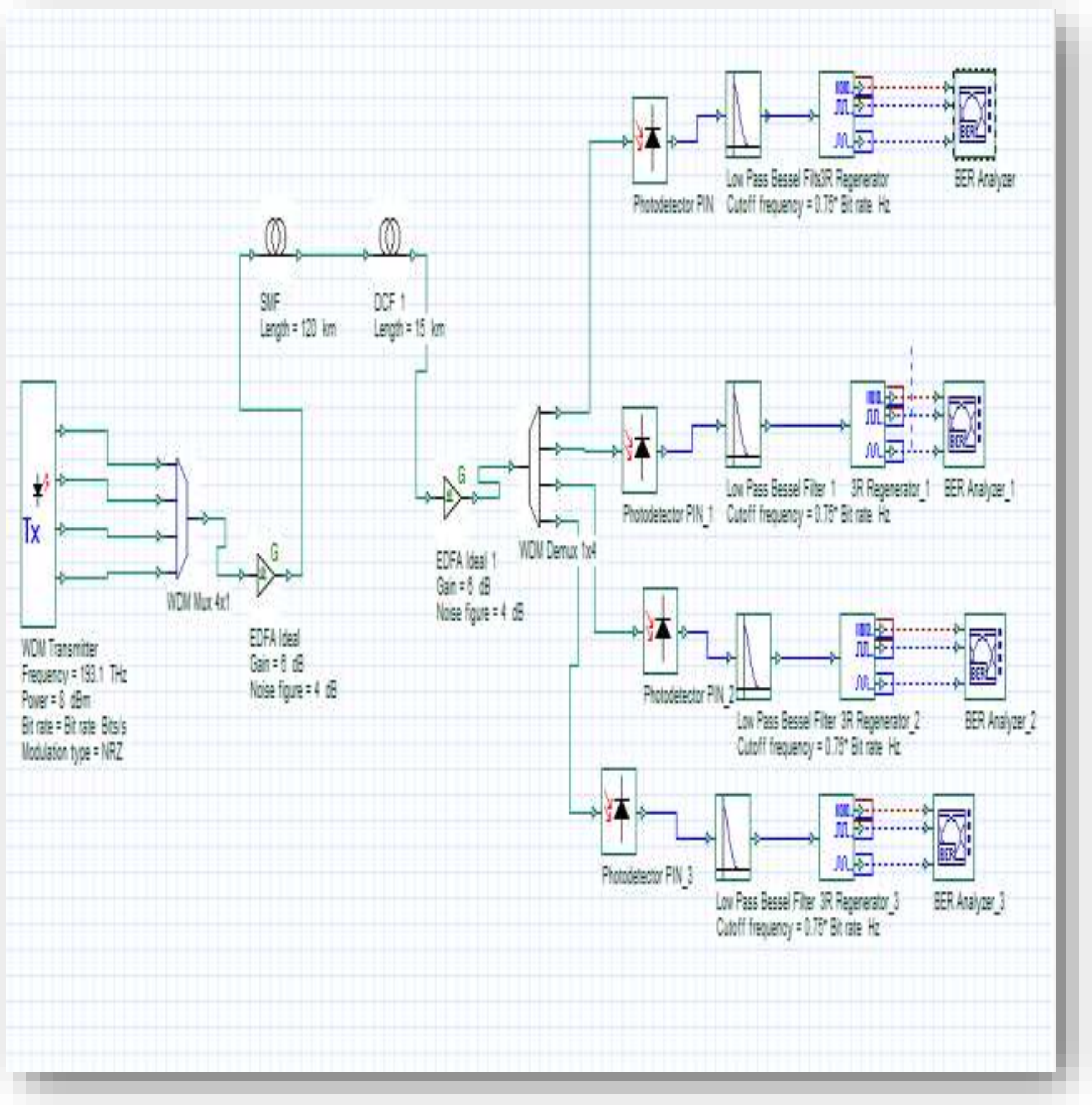


Figure 3.11 : 4-Channel WDM system of 120 Km optical fiber length using Post-compensation.

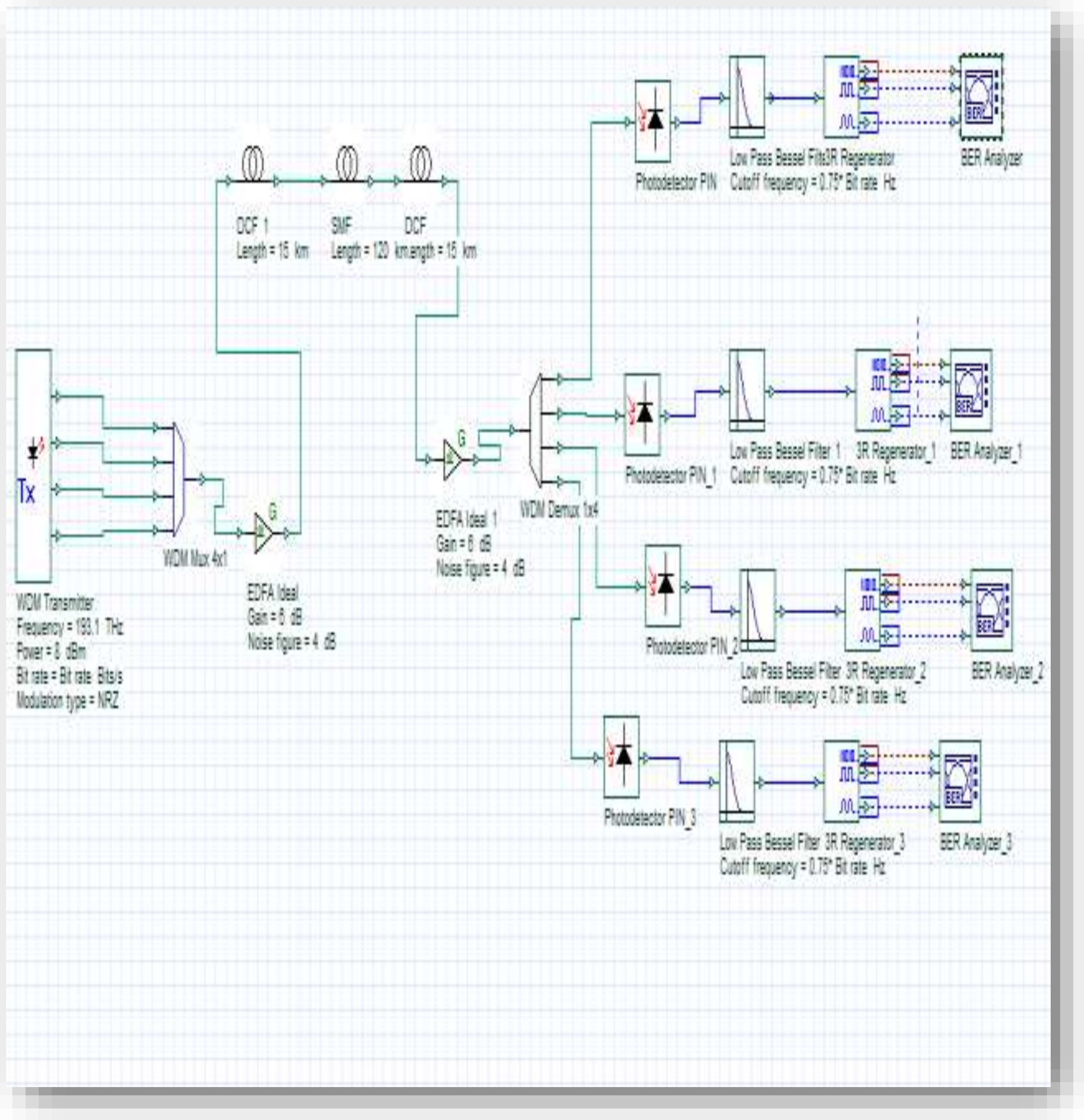
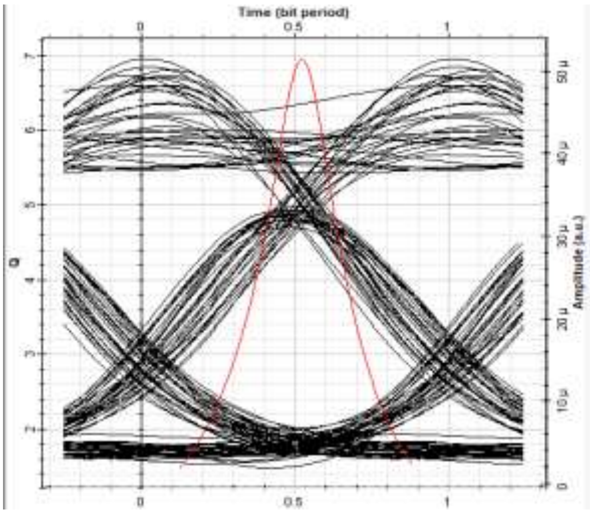


Figure 3.12: 4-Channel WDM system of 120 Km optical fiber length using Symmetrical –compensation.

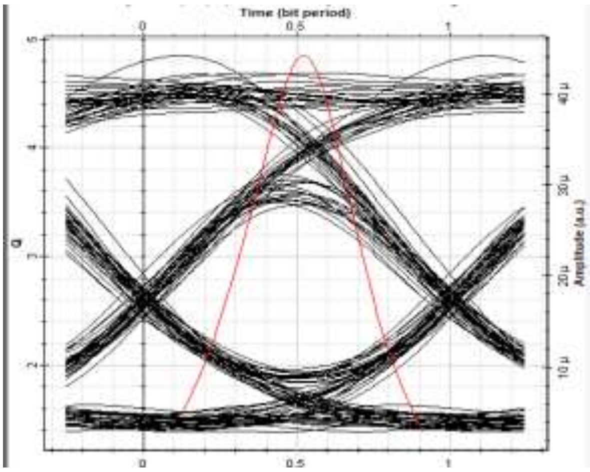
- The obtained results of channel one for te three configurations are resumed in table.7

Table 3.7 : The obtained results of channel one for three diferent configurations.

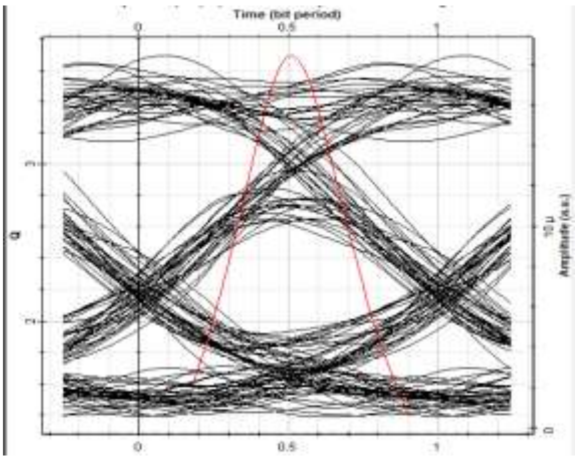
Pre compensation		Post compensation		Symmetrical compensation	
Q	BER	Q	BER	Q	BER
6.95	1.482 e^{-12}	4.84	5.82 e^{-7}	3.69	1.05 e^{-4}



Eye diagram for channel 1 using pre-compensation



Eye diagram for channel 1 using post-compensation



Eye diagram for channel 1 using symmetrical-compensation

- From the previous results, the once obtained whit Pre- compensation are preferred, for that reason we will use this configuration to study other parameters effects on the system.
- Now, we will show the effect of different parameters on the **Q** factor and **BER,** such as: power, bit rate, length of **DCF** and **SMF** length.

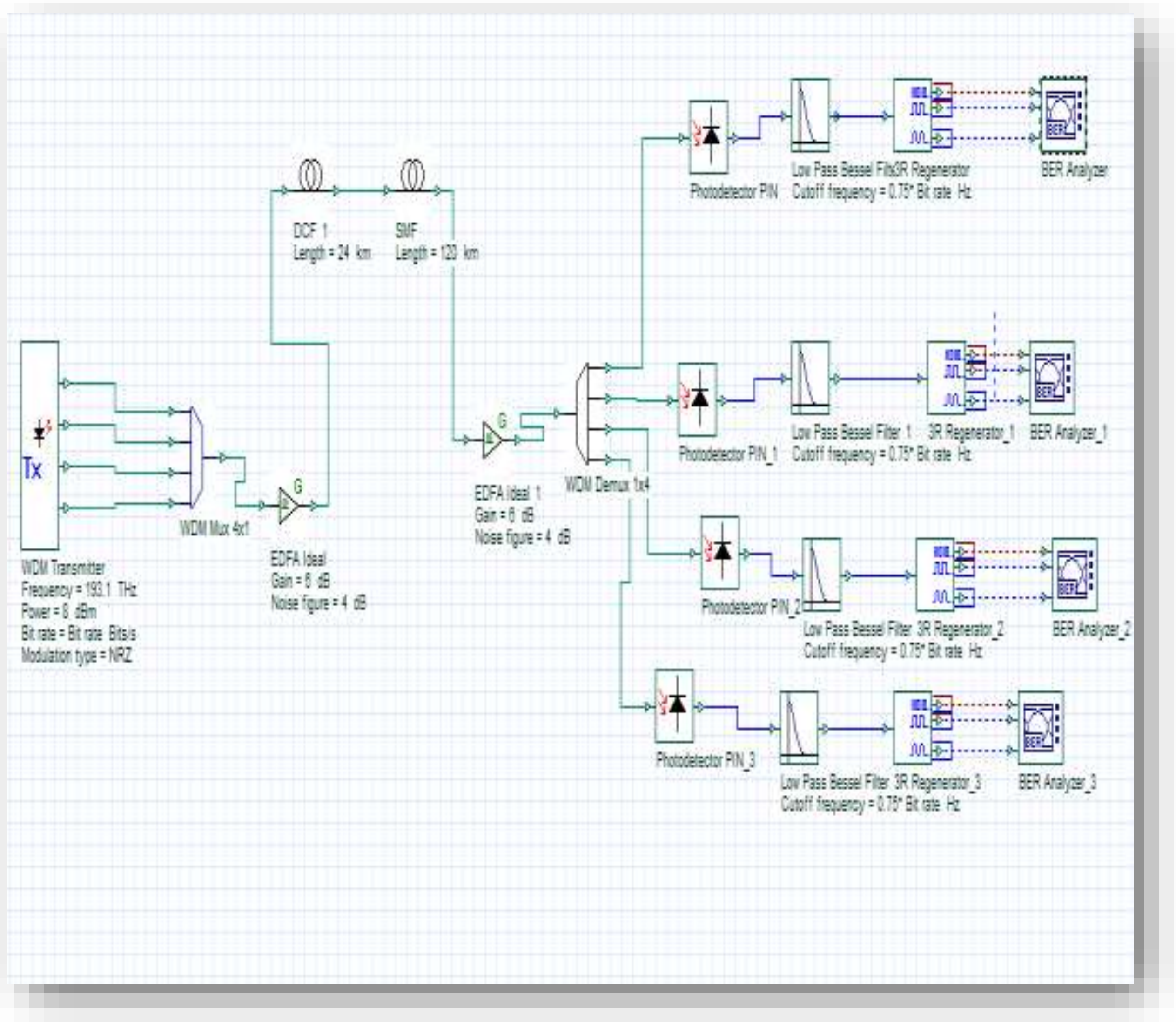


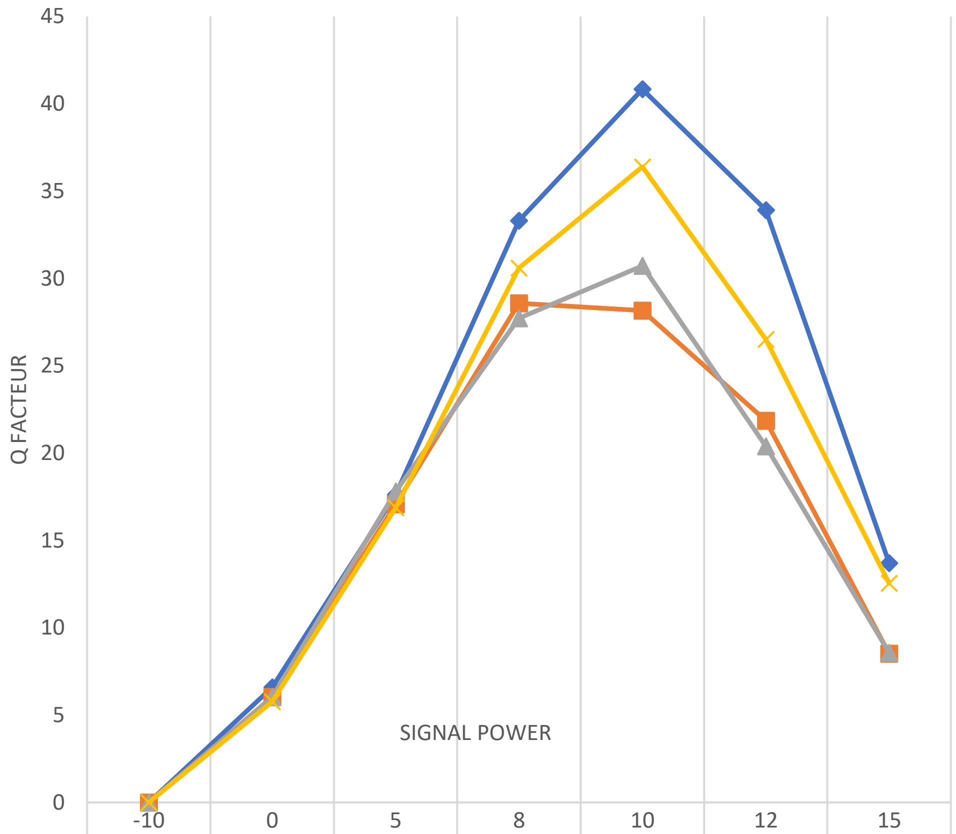
Figure 3.13 : 4-Channel WDM system of 120 Km optical fiber length and DCF 24 Km length using Pre-compensation.

- In order to study the effect of the signal power on the **Q** factor and **BER**, we simulate the circuit presented in **figure 13,** we get the following results:

Table 3.8 : the obtained results of circuit simulated in figure 13 for different values of signal power.

Signal power dBm	Channel 1	Channel 2	Channel 3	Channel 4
-10	Q=0 BER=1	Q=0 BER=1	Q=0 BER=1	Q=0 BER=1
0	Q=6.06 BER=6.87 e^{-10}	Q=6.05 BER=7.80 e^{-10}	Q=6.02 BER=8.49e^{-10}	Q=5.77 BER=3.95 e^{-9}
5	Q=17.62 BER=8.38 e^{-70}	Q=17.08 BER=1.01 e^{-65}	Q=17.80 BER=3.39 e^{-71}	Q=16.88 BER=3.12 e^{-64}
8	Q=33.31 BER=1.19 e^{-243}	Q=28.58 BER=5.13 e^{-180}	Q=27.72 BER=2.12 e^{-169}	Q=30.60 BER=5.05 e^{-206}
10	Q=40.83 BER=0	Q=28.16 BER=6.72 e^{-175}	Q=30.72 BER=1.34 e^{-207}	Q=36.39 BER=2.09 e^{-290}
12	Q=33.91 BER=2.12 e^{-252}	Q=21.86 BER=2.39 e^{-106}	Q=20.39 BER=7.45 e^{-93}	Q=26.51 BER=3.49 e^{-155}
15	Q=13.71 BER=3.20 e^{-43}	Q=8.52 BER=5.23 e^{-18}	Q=8.57 BER=3.88 e^{-18}	Q=12.54 BER=1.67 e^{-36}

The results presented in table 7 can be expressed in graph as follows:



	-10	0	5	8	10	12	15
Chanel 1	0	6,6	17,62	33,31	40,83	33,91	13,71
Chanel 2	0	6,05	17,08	28,58	28,16	21,86	8,52
Chanel 3	0	6,02	17,8	27,72	30,72	20,39	8,57
Chanel 4	0	5,77	16,88	30,6	36,39	26,51	12,54

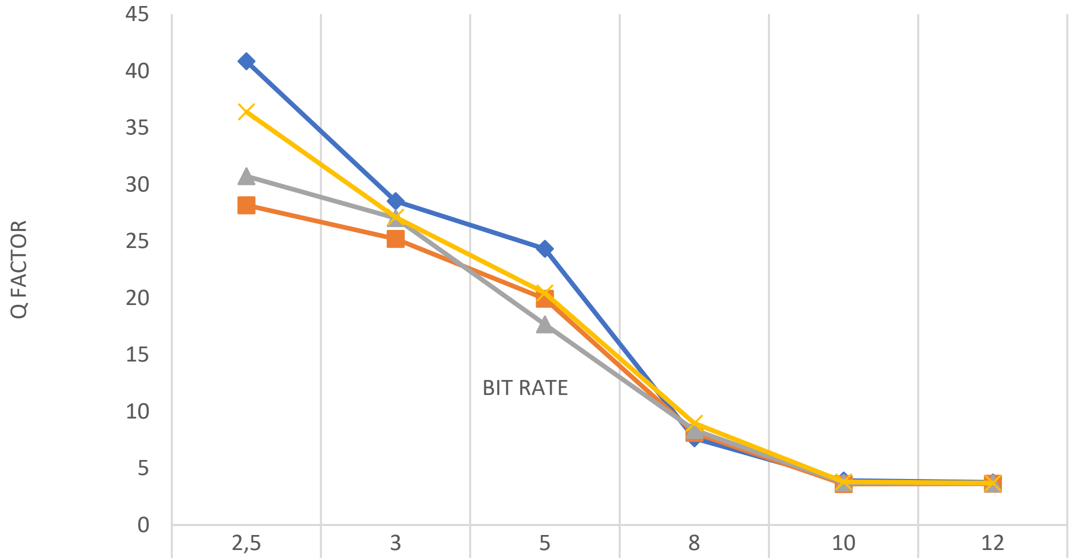
Figure 3.14 : Signal power versus Q factor at 2.5 Gbps bite rates for 4-Channel WDM system using Pre-compensation

- In order to study the effect of the bit rates on the **Q factor** and **BER,** we simulate the circuit presented in **figure 13,** with **10dBm** power, we get the following results:

Table 3.9 : The obtained results of circuits simulated in figure 13 for different values for bit rate.

Bit rates Gbps	Channel 1	Channel 2	Channel 3	Channel 4
2.5	Q=40.84 BER=0	Q=28.17 BER=6.72 e^{-175}	Q=30.72 BER=1.34 e^{-207}	Q=36.39 BER=2.09 e^{-290}
3	Q=28.53 BER=2.31 e^{-179}	Q=25.19 BER=2.19 e^{-140}	Q=27.04 BER=2.53 e^{-161}	Q=27.12 BER=2.35 e^{-162}
5	Q=24.33 BER=3.92 e^{-131}	Q=19.94 BER=8.44 e^{-89}	Q=17.68 BER=2.38 e^{-70}	Q=20.44 BER=3.41 e^{-93}
8	Q=7.63 BER=9.18 e^{-15}	Q=8.12 BER=1.92 e^{-16}	Q=8.37 BER=2.51 e^{-17}	Q=8.95 BER=1.54 e^{-19}
10	Q=3.91 BER=4.46 e^{-5}	Q=3.61 BER=1.39 e^{-4}	Q=3.73 BER=8.94e^{-5}	Q=3.80 BER=7.02 e^{-5}
12	Q=3.76 BER=8.26 e^{-5}	Q=3.63 BER=1.40e^{-4}	Q=3.65 BER=1.28 e^{-4}	Q=3.70 BER=1.09 e^{-4}

- The results presented in table 9 can be expressed in graph as follows:



	2,5	3	5	8	10	12
Chanel 1	40,84	28,53	24,33	7,63	3,91	3,76
Chanel 2	28,17	25,19	19,94	8,12	3,61	3,63
Chanel 3	30,72	27,04	17,68	8,37	3,73	3,65
Chanel 4	36,39	27,12	20,44	8,95	3,8	3,7

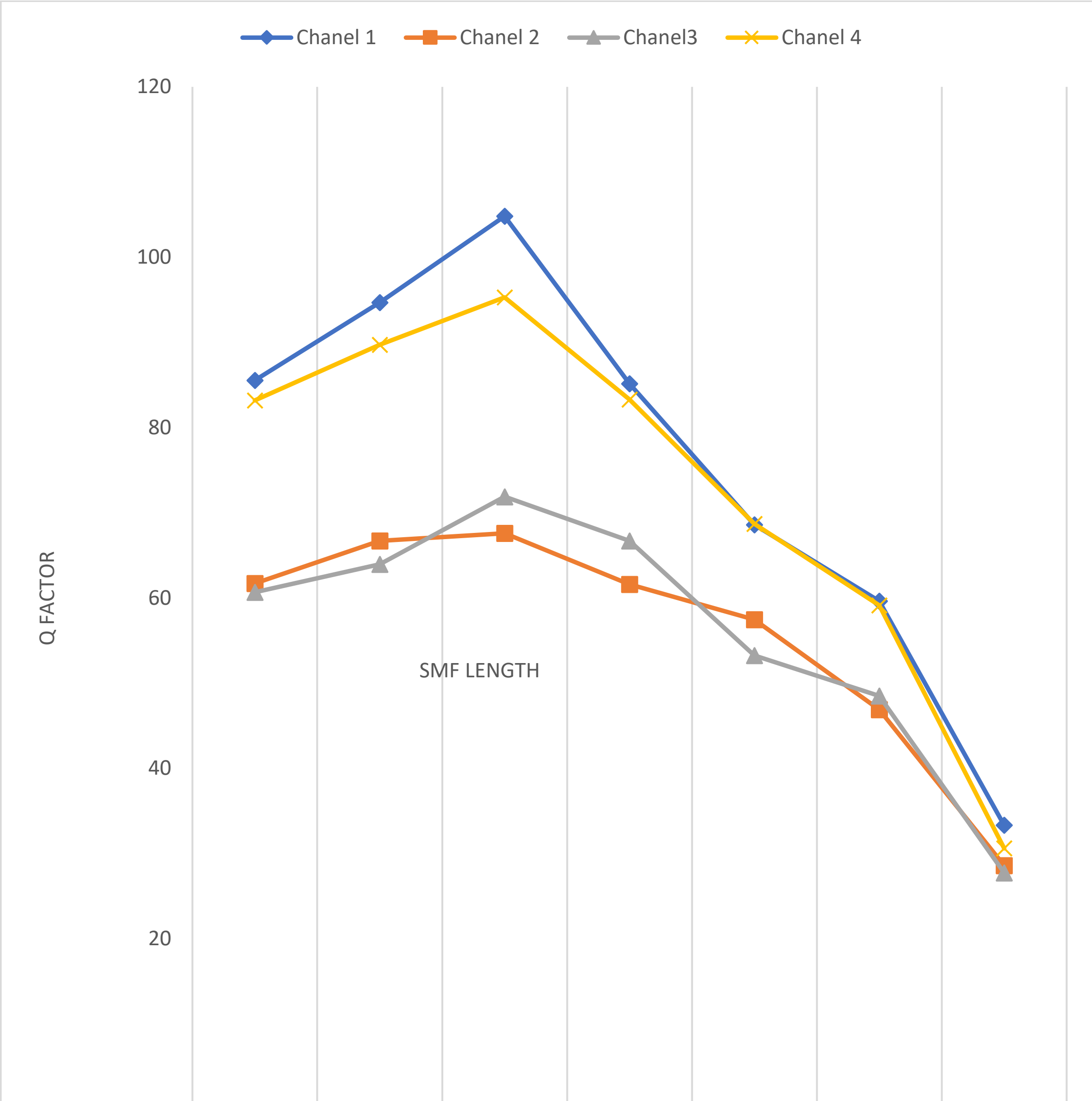
Figure 3.15 : Bit rate versus Q factor for 4-channel WDM system using Pre-compensation.

- In order to study the effect of **SMF** length on the **Q factor** and **BER,** we simulate the circuit presented in **figure 13,** we get the following results:

Table 3.10 :The obtained results of circuit simulated in figure 13, with 8dBm power 2.5Gbps bit rate 24Km DCF length for different values for SMF lengths.

SMF length(km)	Channel 1	Channel 2	Channel 3	Channel 4
30 km	Q=85.54 BER=0	Q=61.71 BER=0	Q=60.68 BER=0	Q=83.19 BER=0
45km	Q=94.69 BER=0	Q=66.71 BER=0	Q=63.96 BER=0	Q=89.71 BER=0
60 km	Q=104.81 BER=0	Q=67.59 BER=0	Q=71.89 BER=0	Q=95.29 BER=0
75 km	Q=85.17 BER=0	Q=61.58 BER=0	Q=66.70 BER=0	Q=83.30 BER=0
90 km	Q=68.60 BER=0	Q=57.44 BER=0	Q=53.23 BER=0	Q=68.71 BER=0
100 km	Q=59.62 BER=0	Q=46.90 BER=0	Q=48.50 BER=0	Q=59.12 BER=0
120 km	Q=33.31 BER=1.19 e^{-243}	Q=28.58 BER=5.13e^{-180}	Q=27.72 BER=2.12e^{-169}	Q=30.60 BER=5.05e^{-206}

- The results presented in table 3.9 can be expressed in graph as follows:



	30	45	60	75	90	100	120
Chanel 1	85,54	94,69	104,81	85,17	68,6	59,62	33,31
Chanel 2	61,71	66,71	67,59	61,58	57,44	46,9	28,58
Chanel3	60,68	63,96	71,89	66,7	53,23	48,5	27,72
Chanel 4	83,19	89,71	95,29	83,3	68,71	59,12	30,6

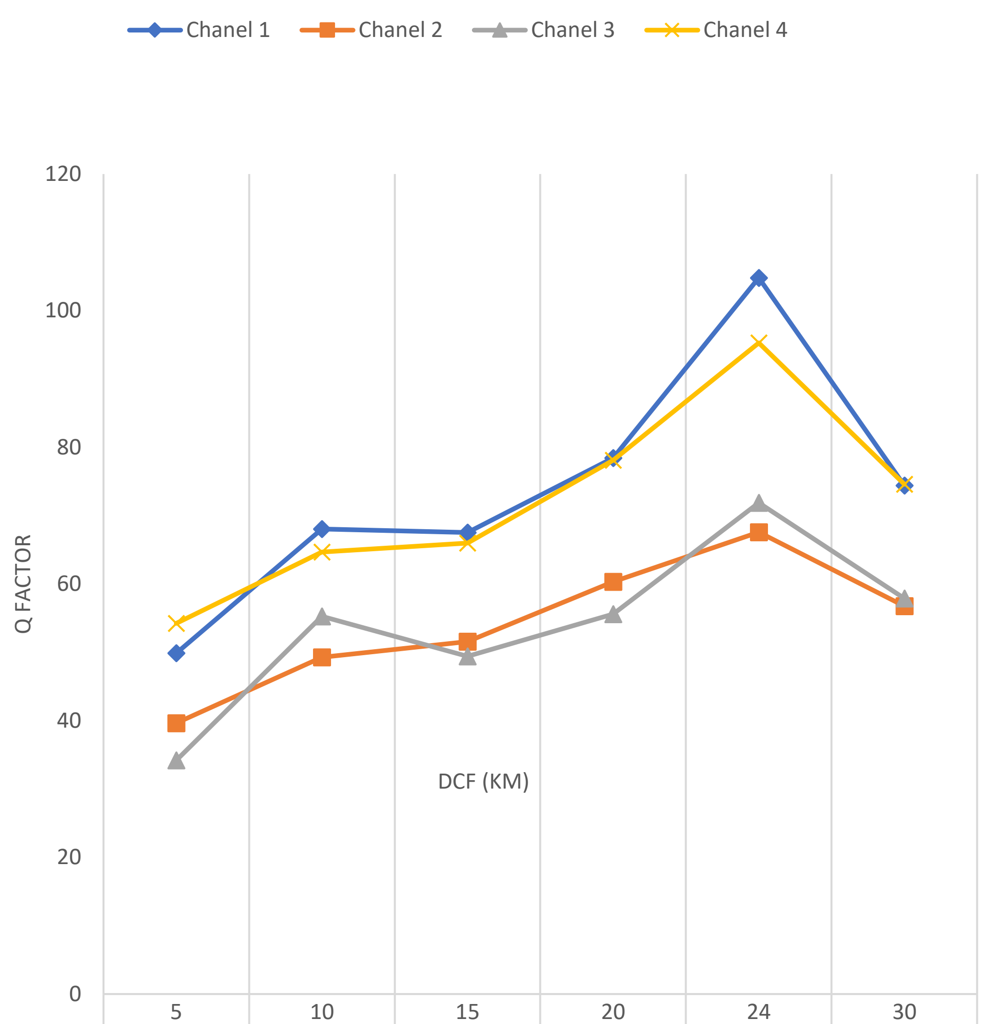
Figure 3.16: SMF length versus Q factor at 2.5 Gbps bite rates for 4-Channel WDM system using Pre-compensation.

- In order to study the effect of DCF length on the Q factor and BER, we simulate the circuit presented in figure 3.13, we get the following results:

Table 3.11: The obtained results of circuit simulated in figure 3.13 , with 8 dBm power, 2.5 Gbps bit rate, 60 km SMF length for different values for DCF lengths.

DCF length(km)	Channel 1	Channel 2	Channel 3	Channel 4
5 km	Q=49.88 BER=0	Q=39.65 BER=0	Q=34.24 BER=0	Q=54.25 BER=0
10 km	Q=68.04 BER=0	Q=49.26 BER=0	Q=55.27 BER=0	Q=64.67 BER=0
15 km	Q=67.55 BER=0	Q=51.60 BER=0	Q=49.41 BER=0	Q=65.99 BER=0
20 km	Q=78.47 BER=0	Q=60.34 BER=0	Q=55.62 BER=0	Q=78.10 BER=0
24 km	Q=104.81 BER=0	Q=67.59 BER=0	Q=71.89 BER=0	Q=95.29 BER=0
30 km	Q=74.42 BER=0	Q=56.75 BER=0	Q=57.89 BER=0	Q=74.62 BER=0

- The results presented in table 3.9 can be expressed in graph as follows:



	5	10	15	20	24	30
Chanel 1	49,88	68,04	67,55	78,47	104,81	74,42
Chanel 2	39,65	49,26	51,6	60,34	67,59	56,75
Chanel 3	34,2	55,27	49,41	55,62	71,89	57,89
Chanel 4	54,25	64,67	65,99	78,1	95,29	74,62

Figure 3.17: DCF length versus Q factor at 2.5 Gbps bit, 8 dBm power, 60km SMF length for 4-Channel WDM system using Pre-compensation.

3.3.3Third step: In this section we will design 8channel WDM, using Optisystem software as before, the simulation setup consists of three sections: the transmitter section, the transmission medium section and the receiver section.

- The first section, the transiter section in a WDM system is a bloc consists of pseudo random bit sequence generator works at different bit rates (in the range of Gbps), NRZ pulse generator used for coding, CW laser powered with 8dBm and frequency 193.1THz, and Mach-Zehnder modulator, the block will be connected to a MUX through which the signal passes, it has 8*1 channel.
- The second section, the transmission line or the transmission medium consists of two optical amplifiers (EDFA), an optical fiber (SMF), tis section will connected at the first point to an 8*1 channel MUX and ended by a 1*8 WDM Demux.
- The third section, the receiver structure based on a PIN Photodetector, a Low Pass Bessel Filter, connected to a 3R Regenerator and a BER Analyzer to evaluate the system Q factor, BER and show the eye diagram.
- But before the design of 8channel WDM we will simulate the three different configurations for depression compensation using DCF as used before but with a quite change in the system parameters. The different parameters of the system are listed in Table 3.12

Table 3.12 : The system parameters.

Parameter :	**Value :**
Laser Power (dBm)	-10, 0, 5, 8, 10,12,15
Length of SMF (km)	30, 45, 60,90,120,150,180
Length of DCF (km)	6,9,15,24,40
Dispersion coefficient of SMF (ps/nm/km)	16.75
Dispersion coefficient of DCF (ps/nm/km)	-83.75
Gain of EDFA Ideal 1 (dB)	20
Gain of EDFA Ideal 2(dB)	12.8
Noise Figure of EDFA Ideal 1 and EDFA Ideal 2 (dB)	4
Frequency (Thz)	193.1

- For the system parameters summarized in table 3.12, we will simulate the system without and with compensation and for different SMF length in order to see the role of compensation.

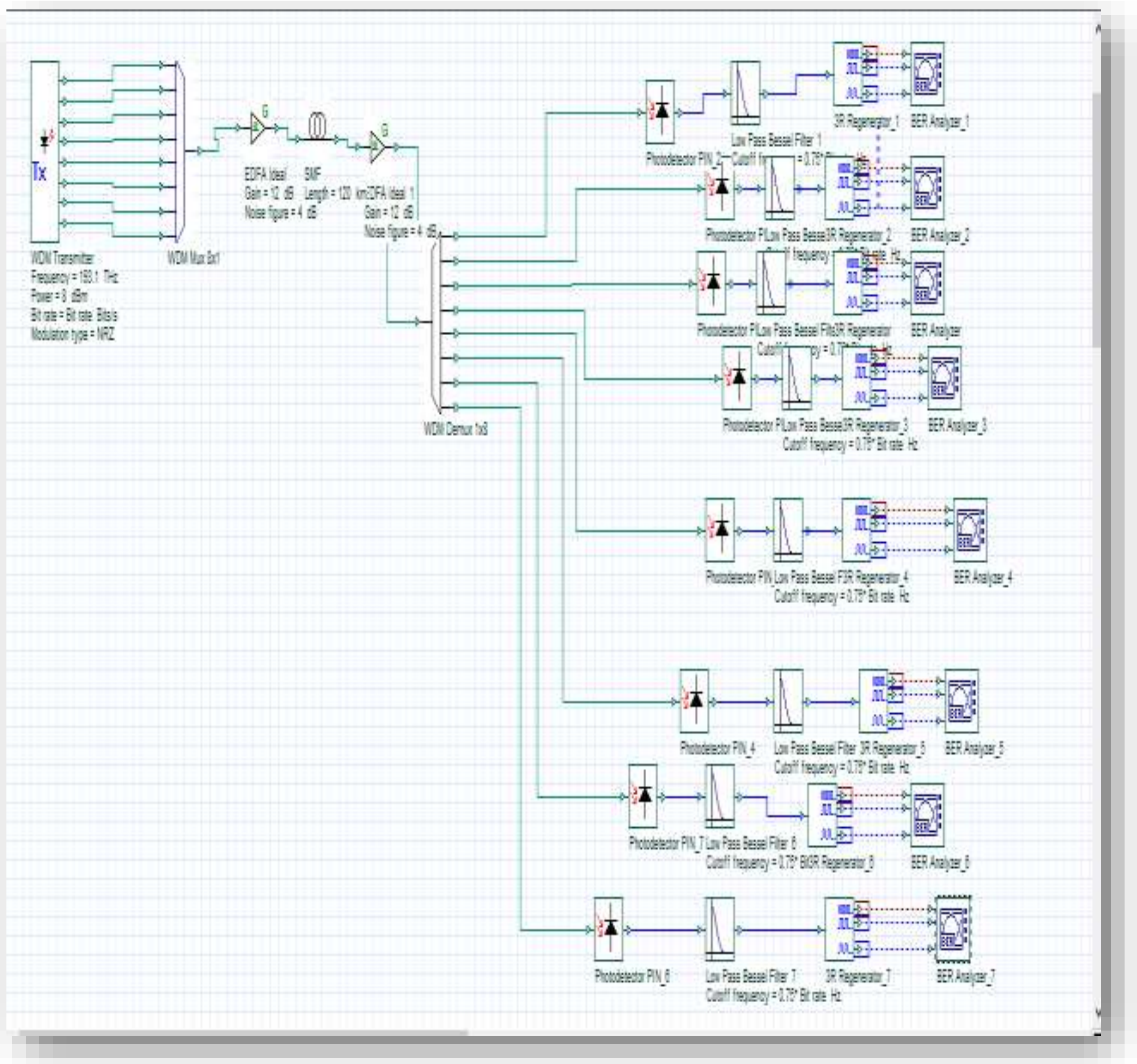


Figure 3.18: 8-Channel WDM system of 120Km optical fiber length. without compensation.

3.3.3.1.The simulation of 8-channel WDM system without compensations: this section the system presented in figure 3.18 is simulated using optisystem software, then we present the results that we get in table 3.13:

Table 3.13: The obtained results of circuit simulated in figure 3.18 .

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Q	10.87	7.62	6.19	6.57	7.40	7.58	7.44	12.40
BER	$5.12e^{-28}$	$8.49e^{-15}$	$1.91e^{-10}$	$1.69e^{-11}$	$4.95\ e^{-14}$	$1.20\ e^{-14}$	$3.29\ e^{-14}$	$8.81\ e^{-36}$

- After that, we use compensation with DCF technique.
- First configuration using DCF compensation is Pre-compensation as follows in figure 3.19:

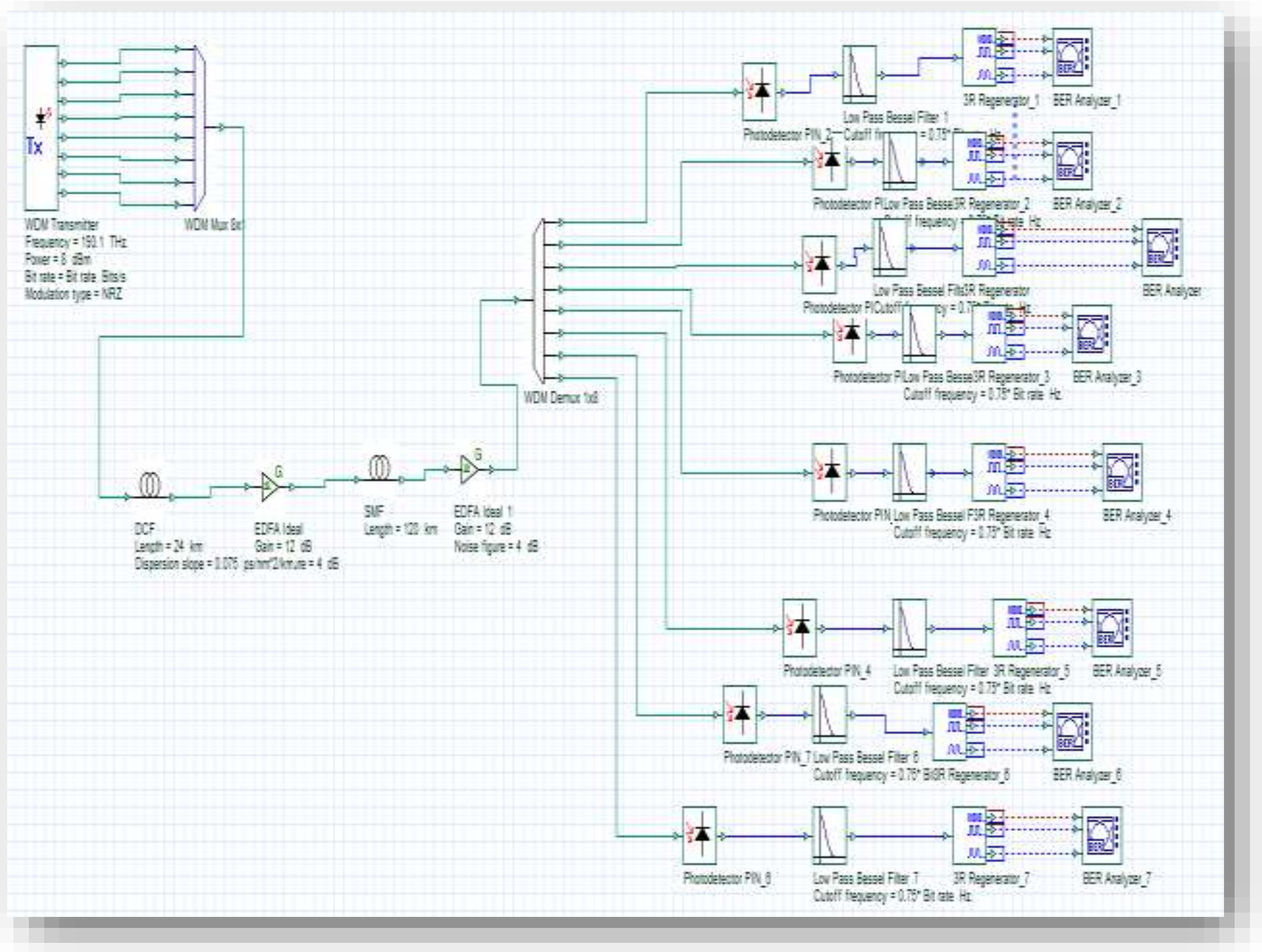


Figure 3.19: 8-Channel WDM system of 120Km optical fiber length using pre-compensation.

➢ The results obtained after simulating the system presented in figure 3.19 are summarized in table 3.14, as follows:

Table 3.14: The obtained results of circuit simulated in figure 3.19 .

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Q	34.81	38.25	33.06	27.04	25.47	37.11	35.98	35.10
BER	6.54 e^{-266}	1.66e^{320}	3.5e^{-240}	1.7e^{-161}	1.4 e^{-143}	7.4 e^{-302}	5.2e^{-284}	2.3 e^{-270}

➢ Second configuration using DCF compensation technique is post-compensation as follows in figure 3.20:

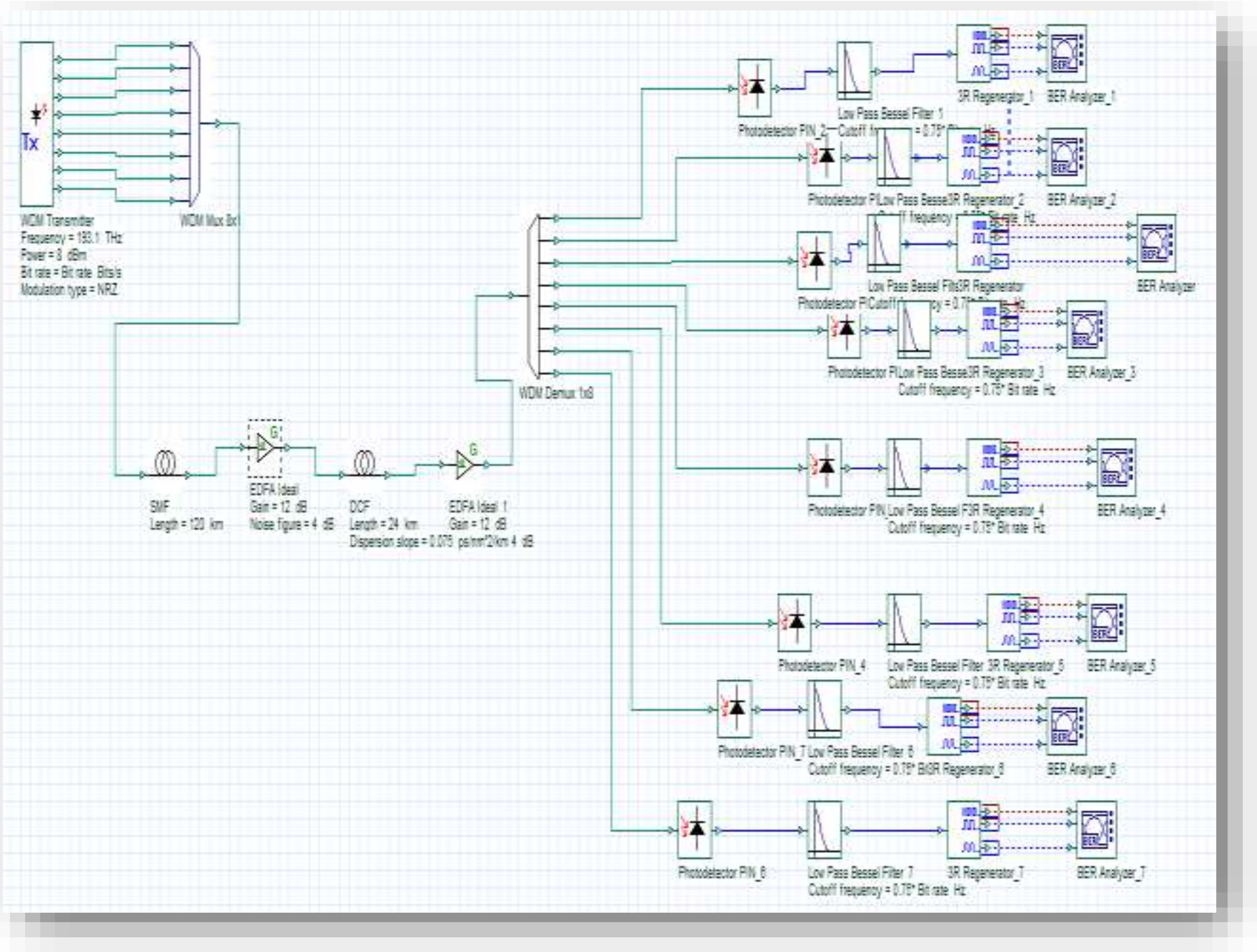


Figure 3.20: 8-Channel WDM system of 120Km optical fiber length using post-compensation.

- The results obtained after simulating the system presented in figure 3.20are summarized in table 3.15, as follows:

Table 3.15: The obtained results of circuit simulated in figure 3.20.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Q	47.60	53.68	47.48	42.85	40.29	48.25	47.50	43.68
BER	0	0	0	0	0	0	0	0

- **Third configuration using DCF compensation technique is symmetrical-compensation as follows in figure 3.21:**

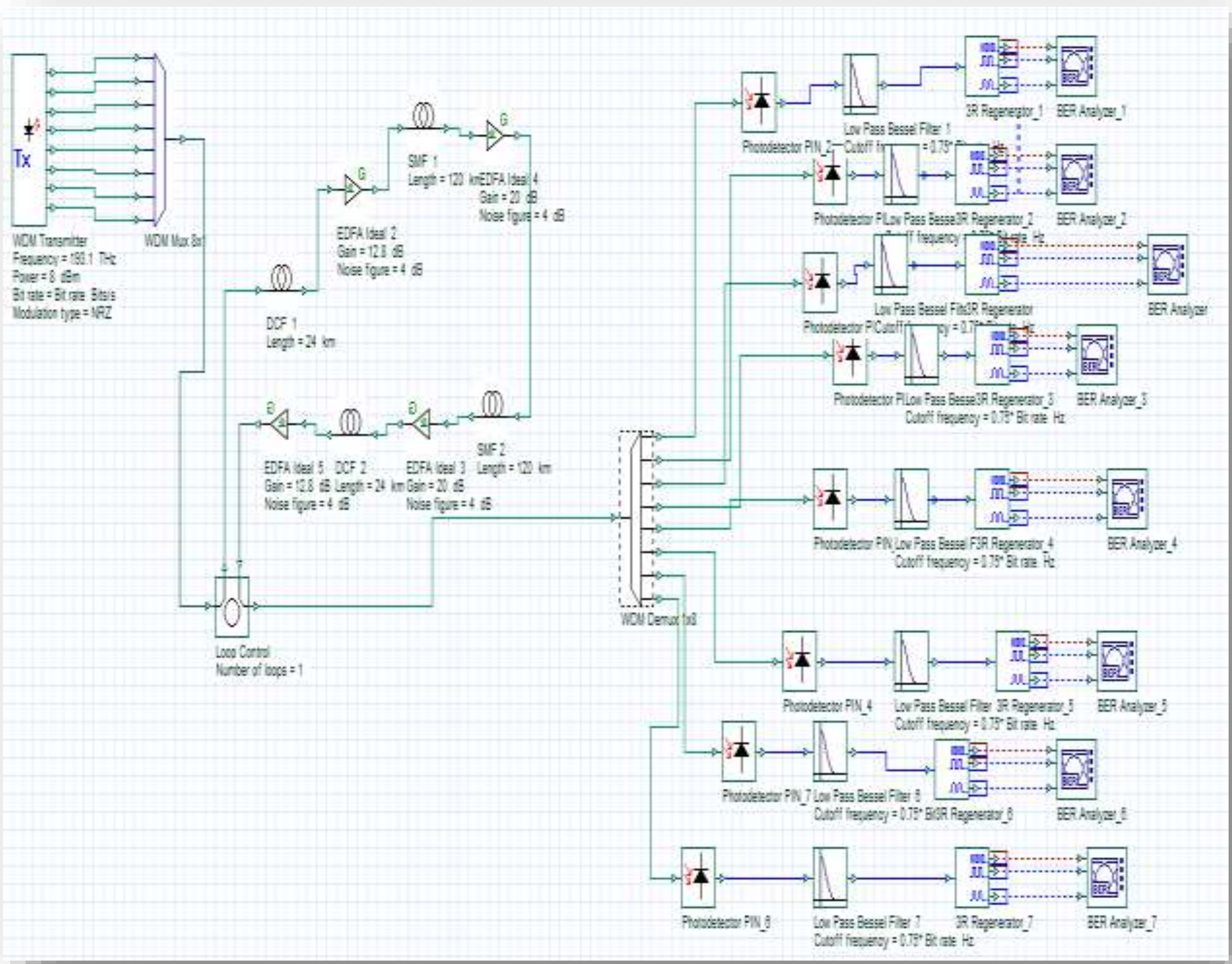


Figure 3.21: 8-Channel WDM system of 120Km optical fiber length using symmetrical-compensation.

- The results obtained after simulating the system presented in figure 3.21 are summarized in table 3.16, as follows:

Table 3.16: The obtained results of circuit simulated in figure 3.21.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Q	28.1	26.9	25.6	22.8	22.2	25.3	28.3	28.1
BER	9.7 e^{-174}	5.5 e^{-160}	2.1 e^{-145}	5.4 e^{-116}	1.4 e^{-109}	7.1 e^{-142}	2.5 e^{-177}	2.2 e^{-174}

- After simulating the three configurations we notice the results obtained with the post-compensation are the preferred ones, so we will adopt the symmetrical compensation
  In order to study the effect of multiple parameters such as input power, DCF and SMF lengths on Q factor and BER.

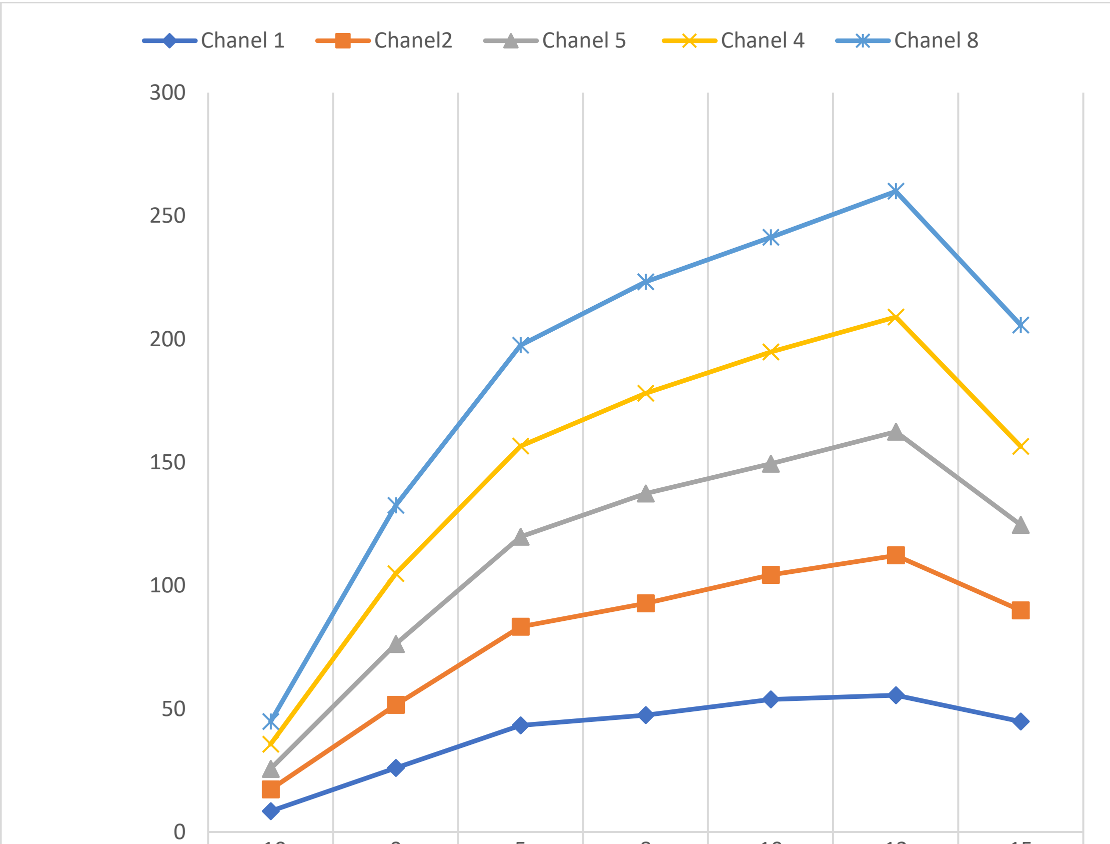
3.3.3.2Effect of input power variation on Q factor:

In order to study the effect of the signal power on the Q factor and BER, we simulate the circuit presented in figure 3.21with a 2.5 Gbps bit rate, many times, each time we change the value of the input power, the obtained results are summarized in table 3.13, as follows (we select some channels not all of theme):

Table 3.17: The obtained results of circuit simulated in figure 3.21 for different values of signal power.

Signal power dBm	Channel 1	Channel 2	Channel 4	Channel 5	Channel 8
-10	Q=8.46 BER=1.1 e^{-17}	Q=8.82 BER=4.6 e^{-19}	Q=9.98 BER=8.0e^{-24}	Q=8.36 BER=2.60 e^{-17}	Q=9.14 BER=2.6 e^{20}
0	Q=26.04 BER=6.5e^{-150}	Q=25.5435 BER=2.7 e^{-144}	Q=28.6315 BER=1.2e^{-180}	Q=24.70 BER=3.9e^{-135}	Q=27.59 BER=5.5e^{168}
5	Q=43.29 BER=0	Q=39.96 BER=0	Q=36.85 BER=9.3e^{-298}	Q=36.49 BER=6.7e^{-292}	Q=40.93 BER=0
8	Q=47.42 BER=0	Q=45.33 BER=0	Q=40.71 BER=0	Q=44.58 BER=0	Q=45.22 BER=0
10	Q=60.51 BER=0	Q=56.71 BER=0	Q=46.55 BER=0	Q=50.21 BER=0	Q=50.97 BER=0
12	Q=52.73 BER=0	Q=57.16 BER=0	Q=38.60 BER=0	Q=50.10 BER=0	Q=59.88 BER=0
15	Q=44.78 BER=0	Q=45.18 BER=0	Q=31.91 BER=1.0e^{-268}	Q=34.59 BER=6.8e^{-224}	Q=49.25 BER=0

The results presented in table 3.13 can be expressed in graph as follows:



	-10	0	5	8	10	12	15
Chanel 8	9,14	27,59	40,93	45,22	46,58	50,97	49,25
Chanel 4	9,98	28,63	36,85	40,71	45,35	46,55	31,91
Chanel 5	8,36	24,7	36,49	44,58	45,01	50,21	34,59
Chanel2	8,82	25,54	39,96	45,33	50,59	56,71	45,18
Chanel 1	8,46	26,04	43,29	47,42	53,78	55,5	44,78

Figure3.22: Signal power versus Q factor at 2.5 Gbps bite rates for 8-Channel WDM system using post-compensation

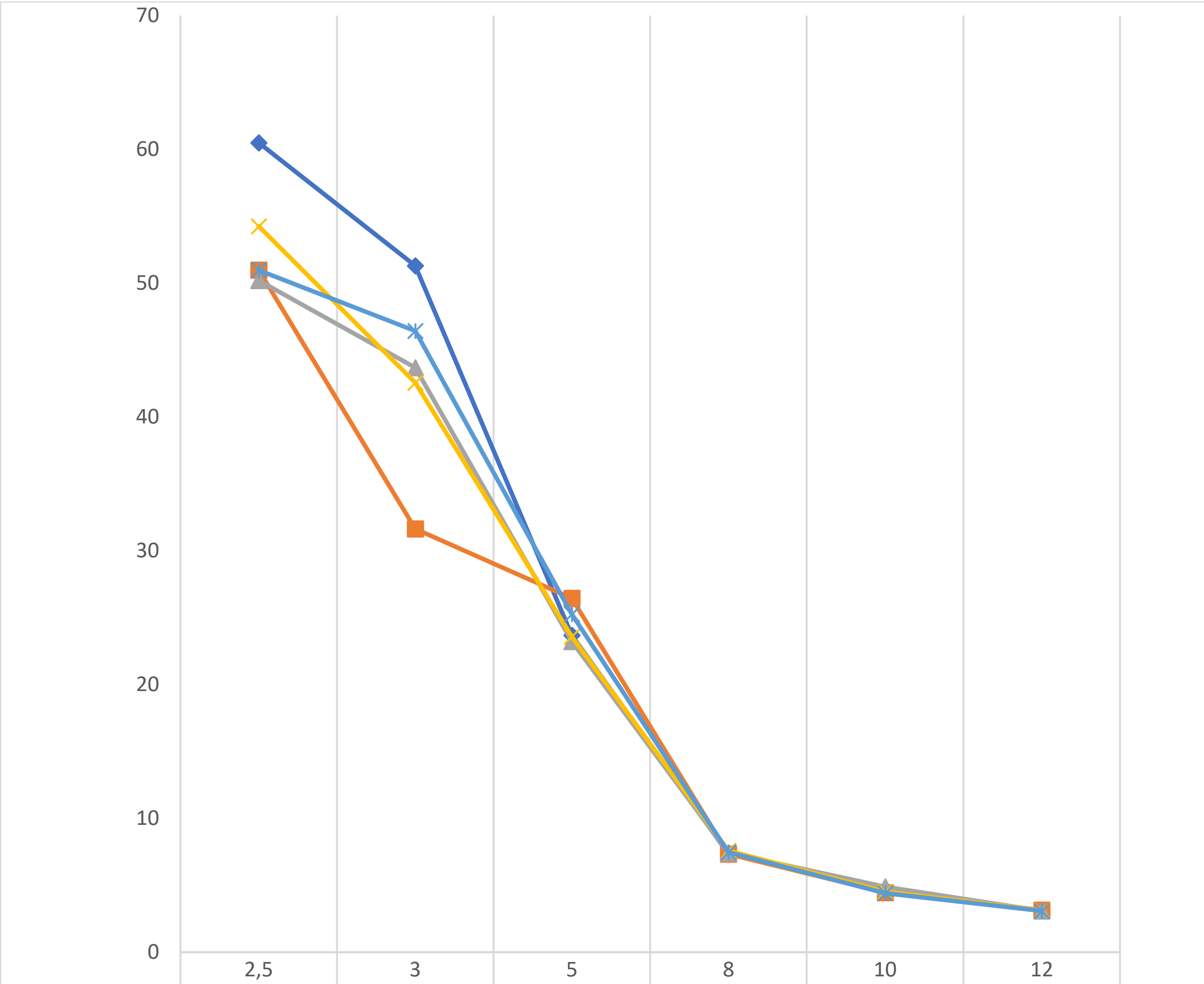
3.3.3.3Effect of the bit rate variation on Q factor and BER:

In order to study the effect of the bit rate on the Q factor and BER, we simulate the circuit presented in figure 3.21with a 10 dBm power, many times, each time we change the value of the bit rate, the obtained results are summarized in table 3.14, as follows (we are interested in channels 1,3,5,6 and 8):

Table 3.18: The obtained results of circuit simulated in figure 3.21 for different values of bit rate.

Bit rates Gbps	Channel 1	Channel 3	Channel 5	Channel 6	Channel 8
2.5	Q=60.5 BER=0	Q=50.99 BER=0	Q=50.22 BER=0	Q=54.26 BER=0	Q=50.97 BER=0
3	Q=51.29 BER=0	Q=31.65 BER=$3e^{-220}$	Q=43.69 BER=0	Q=42.57 BER=0	Q=46.43 BER=0
5	Q=23.68 BER=$2.3\ e^{124}$	Q=26.46 BER=$1.1e^{-154}$	Q=31.65 BER=$1.0e^{-119}$	Q=23.60 BER=$1.5e^{-123}$	Q=25.26 BER=$3.4e^{-141}$
8	Q=7.36 BER=$7.91e^{14}$	Q=7.35 BER=$8.79e^{-14}$	Q=7.44679 BER=$4.3e^{-14}$	Q=7.59382 BER=$1.4e^{-14}$	Q=7.47 BER=$3.6e^{-14}$
10	Q=4.49 BER=$3.3e^{-6}$	Q=4.45 BER=$3.9e^{-6}$	Q=4.30 BER=$7.5e^{-6}$	Q=4.53 BER=$2.6e^{-6}$	Q=4.42 BER=$4.6e^{-6}$
12	Q=3.14 BER=$7.8e^{-4}$	Q=3.16 BER=$7.3e^{-4}$	Q=3.09 BER=$9.2e^{-4}$	Q=3.13 BER=$8.1e^{-4}$	Q=3.09 BER=$9.2e^{-4}$

The results presented in table 3.14 can be expressed in graph as follows:



	2,5	3	5	8	10	12
Chanel1	60,5	51,29	23,68	7,36	4,49	3,13
Chanel 3	50,99	31,65	26,46	7,35	4,45	3,16
Chanel 5	50,21	43,69	23,22	7,44	4,9	3,09
Chanel 6	54,26	42,57	23,6	7,59	4,53	3,13
Chanel 8	50,97	46,43	25,26	7,47	4,41	3,09

Figure3.23 : Bit rate versus Q factor for 8-channel WDM system using Post-compensation

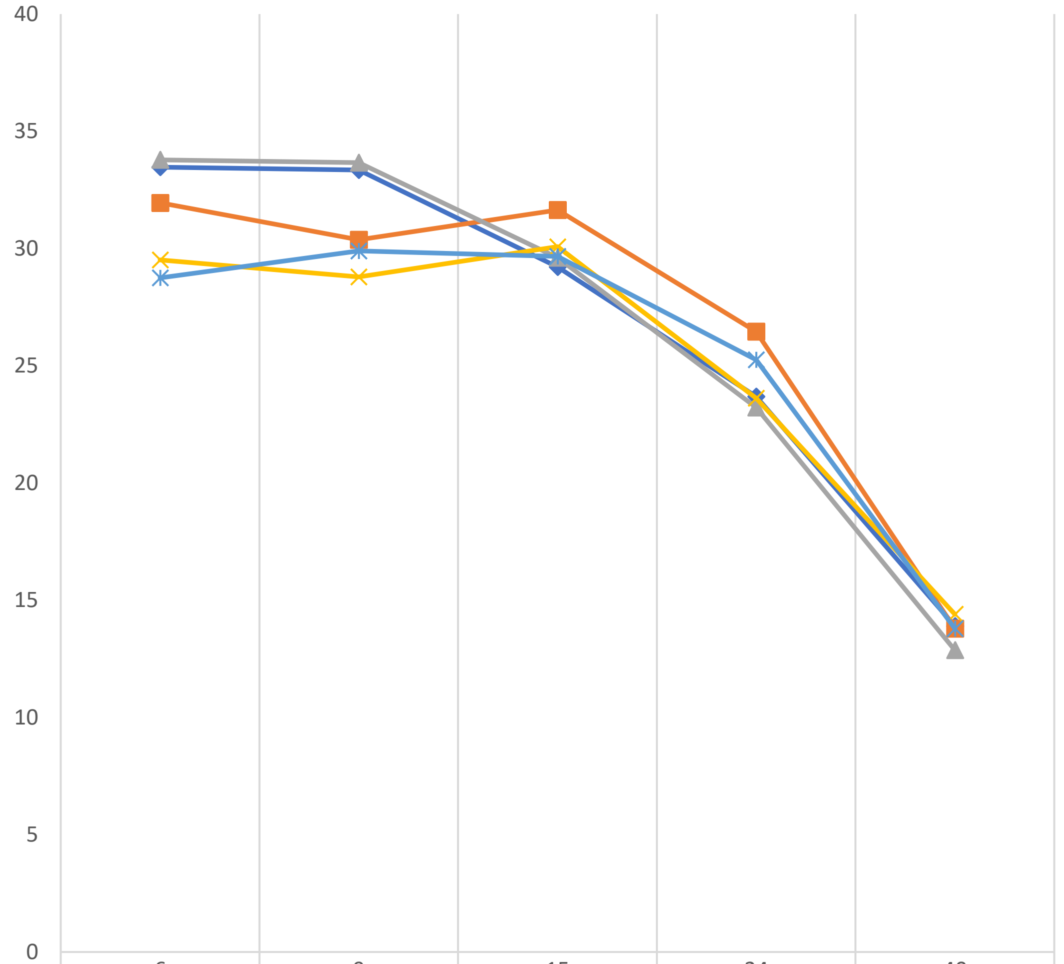
3.3.4Effect of the DCF length variation on Q factor and BER:

In order to study the effect of the DCF length on the Q factor and BER, we simulate the circuit presented in figure 3.21with a 10 dBm power and 5 Gbps bit rate, many times, each time we change the value of the DCF length, the obtained results are summarized in table 3.15, as follows (we are interested in channels 1,3,5,6 and 8) :

Table 3.19: The obtained results of circuit simulated in figure 3.21 for different values of DCF length.

DCF length(km)	Channel 1	Channel 3	Channel 5	Channel 6	Channel 8
6	Q=33.47 BER=$6.3e^{-246}$	Q=31.95 BER=$2.1e^{-224}$	Q=33.78 BER=$1.5e^{-250}$	Q=29.51 BER=$7.9e^{-192}$	Q=28.75 BER=$3.3e^{-182}$
9	Q=33.35 BER=$2.7e^{-244}$	Q=30.37 BER=$5.1e^{-203}$	Q=33.66 BER=$8.4e^{-249}$	Q=28.79 BER=$1.1e^{-182}$	Q=29.90 BER=$7.0e^{-197}$
15	Q=29.22 BER=$4.0e^{-188}$	Q=31.65 BER=$2.6e^{-220}$	Q=29.61 BER=$3.9e^{-193}$	Q=30.08 BER=$2.9e^{-199}$	Q=29.66 BER=$8.7e^{-194}$
24	Q=23.68 BER=$2.2e^{-124}$	Q=26.46 BER=$1.1e^{-154}$	Q=23.22 BER=$1.0e^{-119}$	Q=23.62 BER=$1.5e^{-123}$	Q=25.26 BER=$3.4e^{-141}$
40	Q=13.90 BER=$2.8e^{-44}$	Q=13.79 BER=$1.2e^{-43}$	Q=12.87 BER=$2.7e^{-38}$	Q=14.40 BER=$2.2e^{-47}$	Q=13.79 BER=$2.2e^{-43}$

The results presented in table 3.15 can be expressed in graph as follows:



	6	9	15	24	40
Chanel 1	33,47	33,35	29,22	23,68	13,9
Chanel 3	31,95	30,37	31,65	26,46	13,79
Chanel 5	33,78	33,66	29,61	23,22	12,87
Chanel 6	29,51	28,79	30,08	23,62	14,4
Chanel 8	28,75	29,9	29,66	25,26	13,79

Figure 3.24: DCF length versus Q factor at 2.5 Gbps bit, 10 dBm power, 120km SMF length for 8-Channel WDM system using Post-compensation.

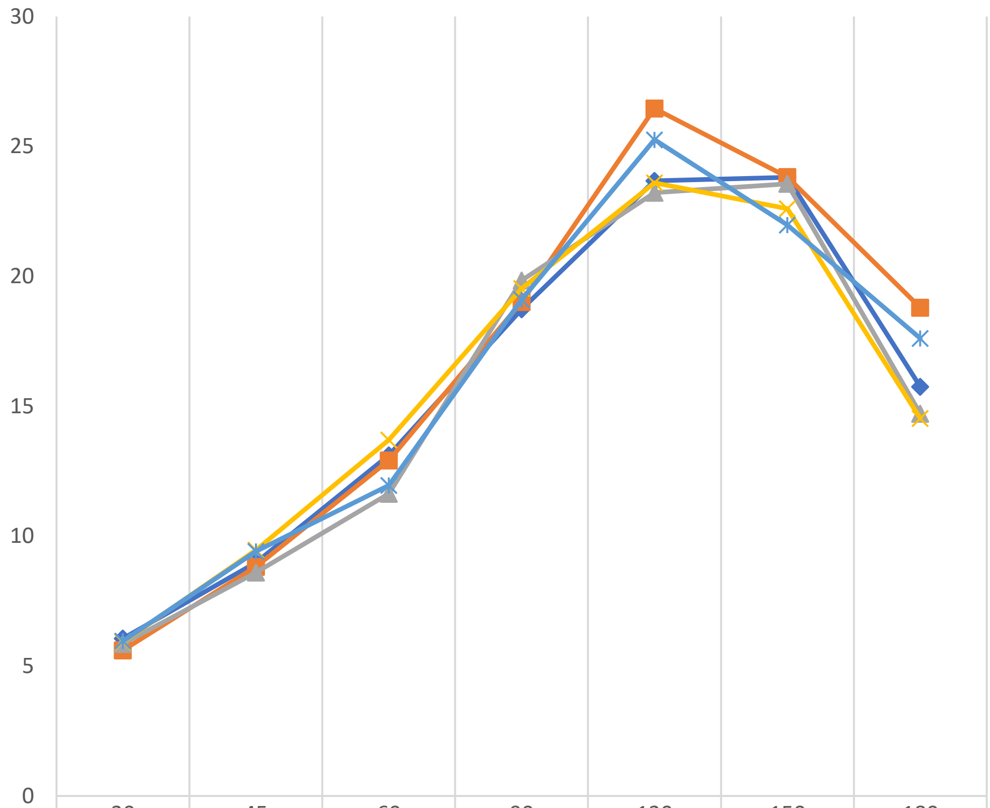
3.3.5Effect of the SMF length variation on Q factor and BER:

In order to study the effect of the SMF length on the Q factor and BER, we simulate the circuit presented in figure 3.21with a 10 dBm power ,5 Gbps bit rate and 24 km DCF length, many times, each time we change the value of the SMF length, the obtained results are summarized in table 3.16, as follows (we are interested in channels 1,3,5,6 and 8):

Table 3.20: The obtained results of circuit simulated in figure 3.21 for different values of SMF length.

DCF length(km)	Channel 1	Channel 3	Channel 5	Channel 6	Channel 8
30	Q=6.06 BER=6.1e^{-10}	Q=5.61 BER=8.99e^{-9}	Q=5.86 BER=2.1e^{-9}	Q=5.93 BER=1.3e^{-9}	Q=5.96 BER=1.1e^{-9}
45	Q=8.98 BER=1.1e^{-19}	Q=8.82 BER=4.7e^{-19}	Q=8.6 BER=3.5e^{-18}	Q=9.46 BER=1.3e^{-21}	Q=9.41 BER=2.1e^{-21}
60	Q=13.11 BER=1.2e^{-39}	Q=12.92 BER=1.54e^{-38}	Q=11.64 BER=1.0e^{-31}	Q=13.70 BER=4.1e^{-43}	Q=11.96 BER=2.3e^{-33}
90	Q=18.73 BER=1.1e^{-78}	Q=19.02 BER=4.8e^{-81}	Q=19.84 BER=4.7e^{-88}	Q=19.54 BER=1.9e^{-85}	Q=19.10 BER=1.4e^{-82}
120	Q=23.68 BER=2.2e^{-124}	Q=26.46 BER=1.1e^{-154}	Q=23.22 BER=1.0e^{-119}	Q=23.60 BER=1.5e^{-123}	Q=25.26 BER=3.4e^{-141}
150	Q=23.81 BER=1.0e^{-125}	Q=23.82 BER=6.9e^{-126}	Q=23.56 BER=3.6e^{-123}	Q=22.61 BER=1.4e^{-113}	Q=21.97 BER=2.1e^{-107}
180	Q=15.75 BER=2.7e^{-56}	Q=18.79 BER=4.1e^{-79}	Q=14.71 BER=2.3e^{-49}	Q=14.53 BER=3.1e^{-48}	Q=17.61 BER=7.5e^{-70}

The results presented in table 3.16 can be expressed in graph as follows:



	30	45	60	90	120	150	180
Chanel 1	6,06	8,98	13,11	18,73	23,68	23,81	15,75
Chanel 3	5,61	8,82	12,92	19,02	26,46	23,82	18,79
Chanel 5	5,86	8,6	11,64	19,84	23,22	23,56	14,71
Chanel 6	5,93	9,46	13,7	19,54	23,6	22,61	14,53
chanel 8	5,96	9,41	11,96	19,1	25,26	21,97	17,61

Figure 3.25: DCF length versus Q factor at 2.5 Gbps bit, 10 dBm power, 120km SMF length for 8-Channel WDM system using Pre-compensation.

3.4 Discussion:

- the DCF compensation technique is affecting the system.
- DCF pre-compensation and symmetrical compensation techniques are the best techniques to improve system performance.
- Although post-compensation techniques will not produce any enhancements to 4-channel or 8-channel WDM system.
- We select our preferred WDM system if it is 4-channel or 8-channel system according to the parameters of the system that we have.

3.5 Conclusion: This chapter, focusses on the depression compensation using DCF technique, the study of various parameters that can affect the system performance as bit rate, input power, the DCF and SMF lengths, so the managing depression that we did were based on different parameters.

General Conclusion:

In optical fiber communication systems transmission faces problems which eliminate the performances. These main problems are attenuation and dispersion, the first problem was solved by the development of the materials used in transmission. For that moment the dispersion becomes so interesting to study. Studies were focused on the theme of dispersion management came up with many techniques that are used to compensate dispersion and enhance the system performance. For this thesis we are interested to focus on the dispersion compensating fiber (DCF) technique which is the most used one, in addition to that there exist other techniques such as: fiber Bragg grating (FBG), electronic dispersion compensation (EDC).

In this project, DCF technique with different configurations (pre, post and symmetrical configurations) have been applied to a simple optical fiber communication system, then to different WDM systems (4-channels and 8-channels) in order to minimize the dispersion and compensate the system.

Performance analysis have been made during this work to evaluate the importance of DCF technique with its different configurations, on the WDM system. So that the simulation was first done without dispersion compensation then with dispersion compensation.

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Ministry of Higher Education and Scientific Research

University M'HAMED BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering

Department of Electronics

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MASTER

In **Telecommunication**

Option: **Telecommunications**

Title:

Dispersion compensation schemes- a system perspective.

Presented by:

- **DERIAS NOUR EL HOUDA**
- **DJELLOUL BEN CHERIF ikhlef**

Supervisor:

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Registration Number: ………../2021