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Entitled

STUDY AND SIMULATION OF LOSSES IN AN OPTICAL FIBER CONNECTION WITH APPLICATION

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Dedication

{***To those who believed in me, even when I did not believe in myself***}

My beloved parents, thank you so much for your loves, supports, prayers all the days and nights for making me able to get such success and honor, and everything that you give it to me until this moment. I will make you happy and proud of me

My sisters, my brothersand my little candies thank you for your sacrifices and make me happy all the time. I am so lucky to being your sister, thank you for everything

I want to thank my friends and my soulmate for all the memories, laughs, helps and being present when I needed you most

Finally, I dedicate this graduation to myself and my friend ASMA

For believing in our self and our friendship

For all the difficult times we have experienced with tears, for doing all this work together, for having no days off

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Dedication

{To those who believed in me, even when I did not believe in myself}

My Dear parents, thank you both for love, encouragement, prayers and support you have provided me in pursuing success and the love of knowledge

To my beloved aunt, uncle, my brothers and my grandmother

You are my biggest supporters, I want to express to you with all my love and gratitude for the encouragement you have provided

Finally, I dedicate this graduation to myself and my friend ICHRAQ

For believing in our self and our friendship

For all the difficult times we have experienced with tears, for doing all this work together, for having no days off

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List of Abbreviations

AGC: Automatic Gain Control.

APD: Avalanche photodiode.

BER: Bit error ratio.

CA: Amplifier Center.

CD: Chromatic dispersion.

DB/km: Decibels per kilometer.

DCF: Dispersion Compensating Fiber.

Dg: Group delay.

DWDM: Dense Wavelength Division Multiplexing.

EDC: Electronic Dispersion Compensation.

FBG: Fiber Bragg Grating.

FWM: Four-wave Mixing.

LD: Laser diodes.

LED: Light-emitting diodes.

LSZH: Low smoke, zero halogen jackets.

NRZ: Non-Return-to-Zero.

OTDR: Optical Time-Domain Reflectometer.

PMD: Polarization mode dispersion.

RZ: Return-to-Zero.

SBS: Stimulated Brillion Scattering.

SiO2: Silicon dioxide.

SPM: Self- Phase Modulation.

SRS: Stimulated Raman Scattering.

XPM: Cross Phase Modulation.

List of Figures

List of table

Table of Contents

Introduction

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference are required. This type of communication can transmit voice, video, and telemetry through local area networks, computer networks, or across long distances.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Researchers at ***Bell Labs*** have reached internet speeds of over ***100 Petabit per second kilometer***(equivalent to 100 million Gigabits per secondkilometer)using fiber-optic communication.

A fiber optic telecommunication link requires the following fundamental functions, respectively: signal generation (transmitter), propagation (transmission, amplification, and routing of data), and detection at the receiver.

The purpose of this study is to identify the difficulties and problems that cause signal degradation during transmission, and to explore methods for ensuring good transmission quality.

Simulation can play an important role in all phases of telecommunication systems development, from the initial design stages to the stages of implementation, testing, and deployment of the system. Thus, it is important to be able to optimize the performance of connections in terms of noise and to compare these results with those obtained experimentally.

The first chapter is dedicated to generalities about optical fibers as well as their different types and characteristics. It presents the details of all the components of an optical system, and then describes an optical fiber link with all its elements: transmitter, receiver, and transmission channel.

In the second chapter,we will discuss in detail the main problems that we face, which hinder the transmission of optical fibers.

The last chapter will be devoted to a comparative study, simulated of these connections designed by the software: OPTISYSTEM, which has impressive features, including the insertion of appropriate measuring instruments, control by BER, visual control by the eye diagram, etc. These performances will be useful for carrying out the task of studying and optimizing these optical links.

Finally, we will finish this work with a general conclusion.

Chapter I

Optical Fiber

I-1 Introduction

Transmission of information and it becomes more and more indispensable, that's where fiber The optical fiber has been in our lives for a while now. It eases the communication and the optics come in.

Fiber optic is one of the most important technologies that use light. Fiber optic cables transfer the information from one end to another. One end of the fiber connects to a LED or laser that transmits information, the other end is connected to a device designed to recognize the incoming light.

In this chapter, we will introduce everything about optical fiber starting in the first part from talking about the history of it because incorporating history enriches the content, providing depth, context, and credibility to the discussion.

The second part we will focus on the general information. In the last part of this chapter, we will explain in details the essential components in optical communication systems**[01].**

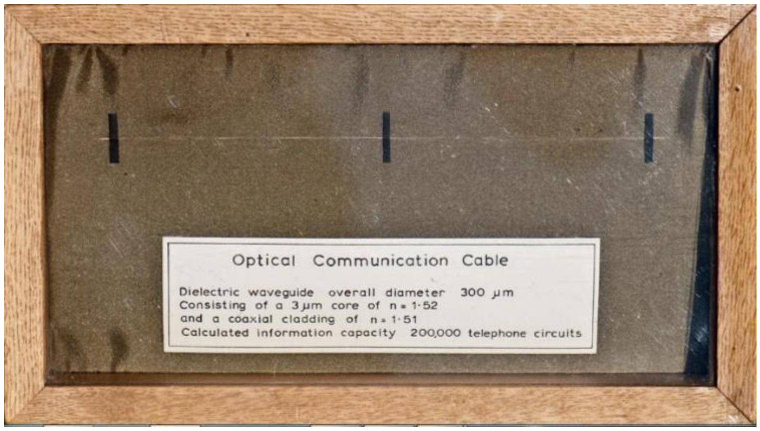
I-2 The birth of optical fiber communications

Optical Fiber annihilated the cost of communicating over global distances, and so enabled the World Wide Web.The alternative technology was Long Haul Microwave Waveguide (A big hollow pipe), which was being developed as several laboratories around the world. This would have been impractical for undersea, so would have severely limited its global application.

Optical Fiber Communication was invented in the early 1960's, at Standard Telecommunication Laboratories, in Harlow in the UK.

Charles Kuen Kao was the visionary who pioneered the use of a single mode dielectric (glass) optical fiber waveguide for long distance communications. This was at a time when the losses of the best available glasses made the idea seem impossible to almost everyone else. In recognition he was awarded the **2009 Nobel Prize in Physics**

In 1966 he and his colleague George Hockham published the paper which is now recognized as the beginning of the optical fiber revolution.**[02]**



Figure(I-1): Optical Communication Cable**[03].**

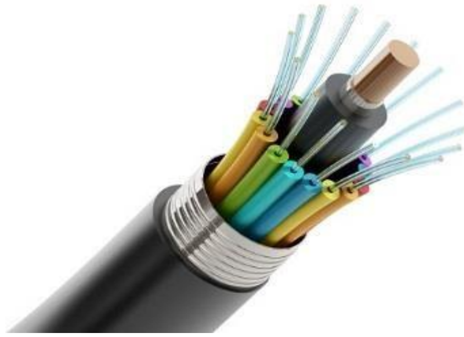
I-3Generalitieson Fiber Optics

I-3-1 Definitionof Fiber Optic

Optical fiber is the technology associated with data transmission using light pulses travelling along with a long fiber which is usually made of plastic or glass. Metal wires are preferred for transmission in optical fiber communication as signals travel with fewer damages. Optical fibers are also unaffected by electromagnetic interference. The fiber optical cable uses the application of total internal reflection of light. The fibers are designed such that they facilitate the propagation of light along with the optical fiber depending on the requirement of power and distance of transmission. Single-mode fiber is used for long-distance transmission, while multimode fiber is used for shorter distances. The outer cladding of these fibers needs better protection than metal wires **[04].**

Fiber optic cables are commonly used because of their advantages over copper cables. Some of those benefits include higher bandwidth and transmit speeds.

Fiber optics is used for long-distance and high-performance data networking. It is also commonly used in telecommunication services, such as internet, television and telephones, providing Gigabit internet speeds to users**[05].**



Figure(I-2): Optical Fiber**[06].**

I-3-2 Optical Fiber Parts

In most cases, a fiber optic cable will have five primary components: The Core, which is responsible for transporting the light signals. The Cladding, which surrounds the core with a lower refractive index and contains the light. The Coating, which serves to protect the core. The Fiber Optic Strength Member and The Cable Jacket (The Outer Jacket)**[07].**

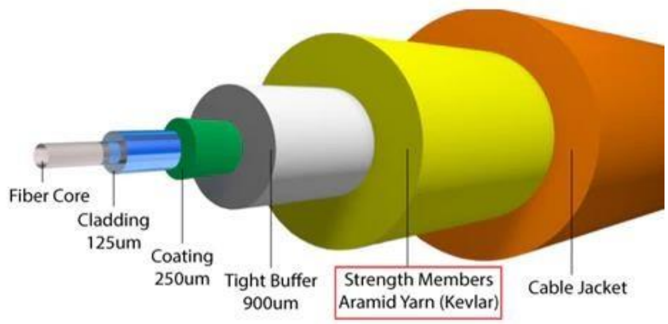


Figure (I-3):Optical fiber parts**[08].**

A) The Core

The fiber optic cable core is the glass medium that carries optical signals from a light source to a receiving device. It's the crucial component through which light travels in the optical fiber. Cores are typically made of pure silicon dioxide (SiO2), transparent enough to resemble looking through 5 miles of it like a window. Cores vary in size depending on their application, ranging from 8-10 microns for single-mode and 62.5-50 microns for multimode fibers, commonly used in telecommunications. Single-mode fibers have a smaller core diameter (8-10 microns) where light travels in a single path, while multimode fibers (50 or 62.5 microns) allow light to travel in multiple paths, bouncing between the core and cladding**[07].**

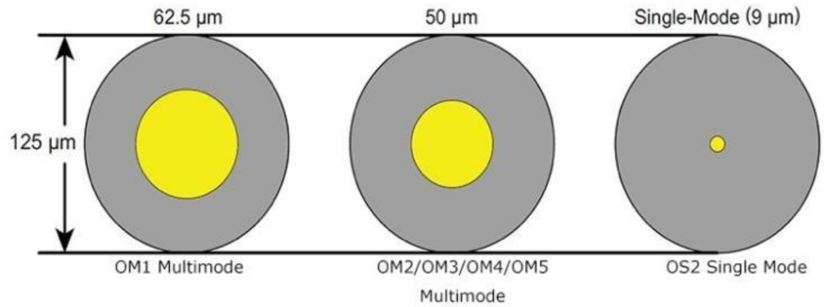


Figure (I-4): Optical fiber core diameters**[08].**

B) The cladding

The cladding is a thin layer surrounding the core of an optical fiber, with a lower refractive index than the core. It contains the light waves, allowing data transmission along the fiber.

In the manufacturing process, both the cladding and core, typically made of silicon dioxidebased material, are fused together simultaneously. Various dopants are added to maintain a refractive index difference of about 1%, ensuring efficient transmission.For example, at a wavelength of 1300nm, the core might have a refractive index of 1.49, while the cladding might be 1.47. These values vary with wavelength.

Standard cladding diameters are typically 125 micrometers or 140 micrometers. A 125um cladding usually accommodates core sizes ranging from 9m to 50m, while a 140um cladding typically pairs with a 62.5m core. **[07]**

C) The Coating

The coating is the protective layer of the optical fiber, shielding the cladding from damage such as shocks, nicks, scratches, and moisture, acting as a shock absorber. Without it, optical fibers are highly vulnerable to damage, even from slight bends that could create microscopic punctures leading to breakage. Coating is essential for all types of glass fibers, and they are not sold without it. The coating does not affect the fiber's ability to transmit light and typically has an outer diameter of 250 or 900 microns, usually colorless but may be colored for easy identification in some cases.

The choice of coating depends on specific performance requirements or environmental factors. Acrylate is a common type of coating, often applied in two layers. The primary coating is gently brushed onto the cladding, providing cushioning during bending, while the secondary coating, tougher than the first, provides additional protection.**[07]**

D) Strengthening Fibers

Aramid yarn is an essential component of fiber optic cables, providing tensile strength to prevent stretching or breaking under tension. It also offers protection against crushing, bending, and twisting. Its flame-resistant and self-extinguishing properties make it useful for fire protection.

In fiber optic cable construction, aramid yarn is combined with jacketing material to shield against moisture and environmental factors. Additionally, an outer layer of steel or aluminum provides further mechanical protection.

Beyond fiber optic cables, aramid yarn finds application in cut-resistant clothing, ballisticrated body armor, industrial and marine ropes and cables, and reinforcement for aerospace and automotive composite materials.

In fiber optic cables, aramid yarn safeguards delicate optical fibers from mechanical stress, ensuring reliable and secure operation. Its mechanical and thermal protection properties are vital for maintaining cable integrity and performance.**[07]**

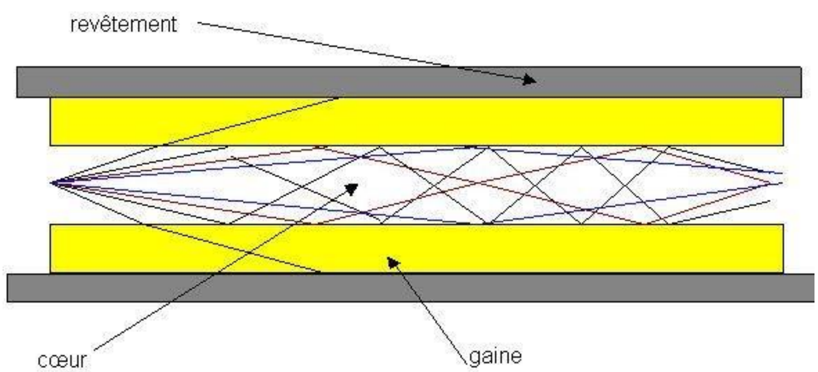
E) Cable Jacket

The protective jackets that are placed around fiber optic cables are extremely important in preventing the fragile fibers that are contained within the cable from being damaged by outside forces and elements. The following is a list of the various types of jackets that can be found in fiber optic cables:

- **Plenum:** Plenum-rated jackets are composed of a material that is resistant to fire and are used in air-handling zones like ceilings and walls.
- **Riser:** Riser-rated jackets are meant to be fire-resistant and are used in vertical cable runs between floors. These lines are referred to as risers.
- **LSZH:** Low smoke, zero halogen jackets are made of a flame-retardant material that, when burned, creates very little smoke and no harmful halogen vapors.
- **Outdoor:** Jackets that are approved for use in outdoor environments are constructed to endure severe weather conditions, and to protect against moisture and ultraviolet radiation. Outdoor applications, such as buried or aerial cable lines, are among the most prevalent places you'll find fiber optic cables installed.**[07].**

I-2-3 Guided mode

We can say that an optical fiber is capable of transmitting one mode (single-mode optical fiber) or multiple modes (multimode optical fiber). Each angle of injection of the ray into the optical fiber is called a mode (see Figure (I-5)). Whether an optical fiber is single-mode or multimode depends on the structure of the fiber and also the wavelength to be transmitted**[07].**



Figure(I- 5): Transmission of an optical fiber**[09].**

We can also talk about the numerical aperture, which is a very important parameter that informs us about the ability of a fiber to propagate optical rays. It is noted that the numerical aperture is independent of the dimensions of the fiber. The numerical aperture is denoted by (see Figure (I-6)).**[07]**

$$ON = sin\theta_{OL} = \sqrt{n_1^2 - n_2^2} \qquad \textbf{\textit{(I-1)}}$$

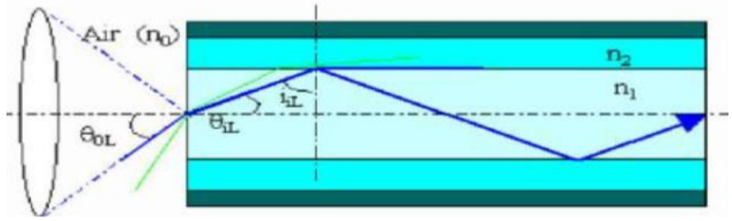


Figure (I-6): Numerical aperture**[09].**

I-3-4 Types of Optical Fibers

The types of optical fibers depend on the refractive index, materials used, and mode of propagation of light

A) Single-Mode Fiber

It is the fiber cable that is designed to carry only a single mode of light that is the transverse mode.These fibers are used for the long-distance transmission of signals. **[04]**

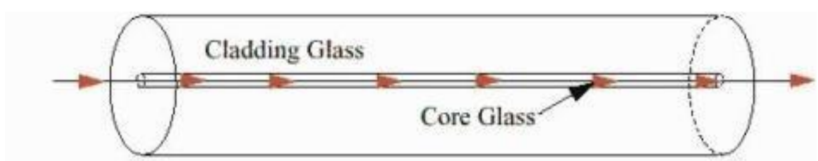


Figure (I-7):Single-mode**[10]**

B) Multi-Mode Fiber

Multimode fiber cables are the cables that transmit data via their core of larger diameters enable an average, single-mode transceiver multiple modes of light to propagate through it.However, this condition limits the maximum length of transmission links possible due to modal dispersion.**[03]**

These fibers are used for the short-distance transmission of signals.**[04]**

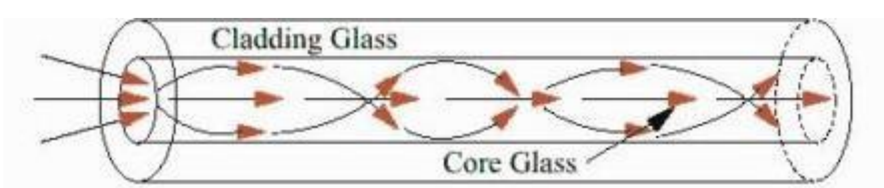


Figure (I-8): Multi-Mode.**[10]**

A. The classification based on the refractive index is as follows We have Step-Index Fiber and Graded-Index Fiber**:**

Parameter	Step-Index Fiber	Graded-Index Fiber
Definition	Step index fiber offers a constant refractive index and works with total internal reflection.	Graded index fiber offers different refractive indices at the core ad core-cladding boundary and works with folded-back reflection.
Bandwidth	Step-index fiber offers less bandwidth.	Graded index fiber offers larger bandwidth.
Effect of model dispersion	Step-index fiber has a severe effect by dispersion mode and has limitations on relay functions.	Graded index fiber has reduced or removed the dispersion mode effect and offers a larger bandwidth.
Core diameter	Step-index fiber has a 50-200 µm diameter.	Graded index fiber has nearly 55 µm diameter.
Cost	Step-index fiber has a lower cost due to the simple manufacturing	Graded index fiber has a higher cost due to the complex manufacturing
Communication distance	The step index is used for shorter distances and offers less speed.	The graded index is used for medium or longer distances and offers high speed than step index fiber.

Operation speed	Step-index fiber provides a zigzag shaped path for light transmission.	Graded index fiber has a smooth sin wave shaped path for light wave to propagate.

Table 1: The difference between Step-Index and Graded-Index Fiber.**[11]**

I-3-5Advantages of Optical Fiber

Bandwidth – One of the main benefits of using fiber-optic cable is the extremely high bandwidth that it can offer, which is far greater than any of the different categories of copper cable capabilities.

Distance – Fiber-optic cables are capable of transmitting data over very long distances with a minimal amount of power loss.

Security – Data security is a huge concern in the communications market and as fiberoptics transfer signals via light, there is no way that the data can be tapped into.

Size – Fiber-optic cable is a much smaller diameter than coaxial cable and this means there is more space in the transmission.

Weight – As fiber-optic cables are thinner and made of glass or plastic, they are much lighter and easier to install.

Future Growth – It is easy to add new equipment to an existing fiber-optic cable infrastructure to accommodate an increase in bandwidth.

Long lifespan—Optical fibers usually have a longer life cycle for over 100 years.

I-3-6Disadvantages of Optical Fiber

Fragility – As fiber-optic cables normally consist of glass they are much more fragile compared to other electrical wires.

Installation – Fiber-Optic cables are much more difficult to install and can easily get damaged during the process. If you bend a fiber-optic cable too much it will break and also they are not easy to splice.

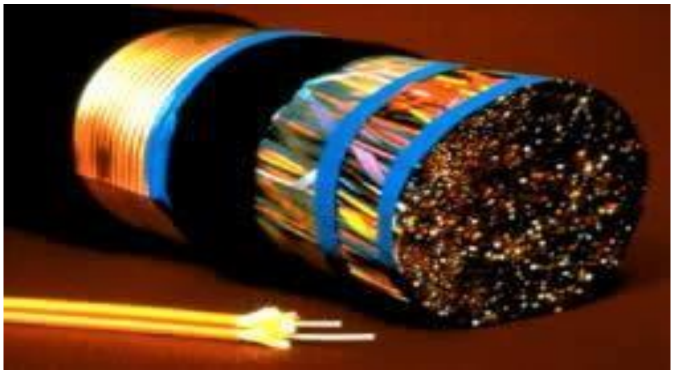
Attenuation and Dispersion – As the signal is transmitted over longer distances, the power of the light signal will be attenuated or reduced. Attenuation is a lot lower for fiber-optic cables compared to the other types of cable. Also, fiber-optics can be affected by dispersion which is when the signal is spread over time.

Distance —The distance between the transmitter and receiver should keep short or repeaters are needed to boost the signal.**[12-13]**

I-3-7Uses of Optical Fiber

a) Telecommunications

In telecommunications, optical fiber is used for the transmission of information, whether it is telephone conversations, images, or data, this is one of the fields where the use of optical fiber is most significant and has the most future potential. A copper wire can only support a few communications, compared to 300,000 for optical fiber. Optical fibers are used particularly for high-speed networks in the order of gigabits per second (transatlantic cables) with very low attenuation, and thanks to multiplexing, speeds of up to several hundred gigabits per second are achieved.**[14]**



Figure(I-9):A single pair of optical fibers carries a bandwidth that is 10 times stronger than 250 pairs of copper wires**[14]**.

b) Medicine

The first widespread use of optical fiber was in medicine, a field where it is still extensively used today. Optical fiber is used in medicine both to diagnose health problems and to treat certain diseases.

For diagnostic purposes, a cable of optical fibers carries light inside the body. This light is reflected by the internal organs and is captured by another cable of optical fibers, which then routes this light to a video imaging system. As a result, it is possible to have a high-quality view of what is happening inside the body, in real time. An example of this usage is the endoscope, particularly used in gastroenterology.

Figure (I-10): An endoscope for using in gastroenterology.**[14]**

For treatment, optical fiber is used to carry intense light from a laser inside the human body, where it will interact with tissues through thermal effects. In surgery, it is associated with a laser beam that allows for pulverizing kidney stones, cutting tumors, repairing a retina, etc.

Figure(I -11): Surgery for pulverizing kidney stones.**[14]**

So optical fiber facilitates the work of healthcare professionals and the lives of their patients. Interventions are less complex, less dangerous, and less invasive than traditional surgery. Moreover, since they often require only local anesthesia, patients can undergo the procedure and return home the same day. The application of these diagnostic and treatment techniques has therefore had a significant economic impact.**[14]**

c) Sensors (temperature, pressure, etc.)

A domain where optical fiber has found a more recent application is in measurement. Like any object, optical fiber is influenced by various parameters. It will be, among other things, slightly deformed when subjected to pressure, force, stress, or temperature variation. The deformation experienced by the optical fiber will affect the way light propagates through it. It is possible to measure these changes and convert this measurement into units of pressure, temperature, or force, depending on what is being measured. These sensors have the advantage of being very small, highly precise, and insensitive to electromagnetic disturbances.**[14]**

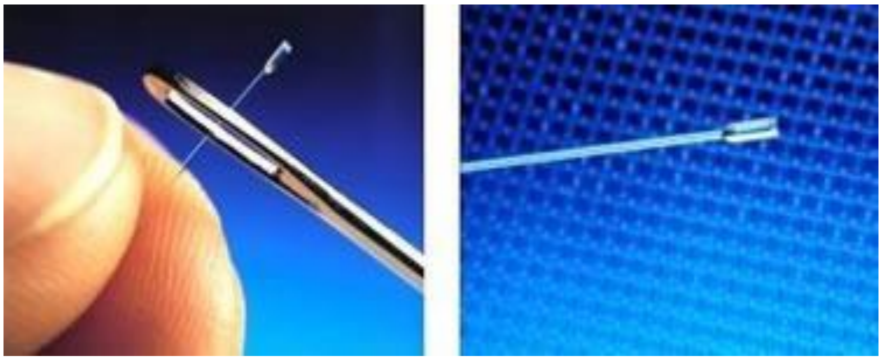


Figure (I-12): A sensor for measuring pressure in blood vessels.**[14] d)**

Lighting

In the field of lighting, optical fibers are also widely used in architecture, the design of public and domestic recreational spaces.

Furthermore, in marking, decoration, directional signage, and even in road signaling, optical fibers are commonly used tools.**[14]**

Figure (I-13): Lights Guiding Fiber Optic.**[15]**

I-4The optical link

I-4-1 Definition

The principle in optical communications consists of transporting information in the form of light from one point to another through a dielectric guide. The information to be transmitted is converted from an electrical signal to an optical signal by a transmitter, and is then injected into an optical fiber. At the receiving end, the signal undergoes the reverse treatment, namely the opticalelectrical conversion, thanks to a converter. Overall, an optical link is composed of a transmitter and a receiver connected by an optical fiber. However, for long distances, regenerators are used to maintain the signal level necessary for information retrieval. In the following, we will define each element of this link.**[16]**

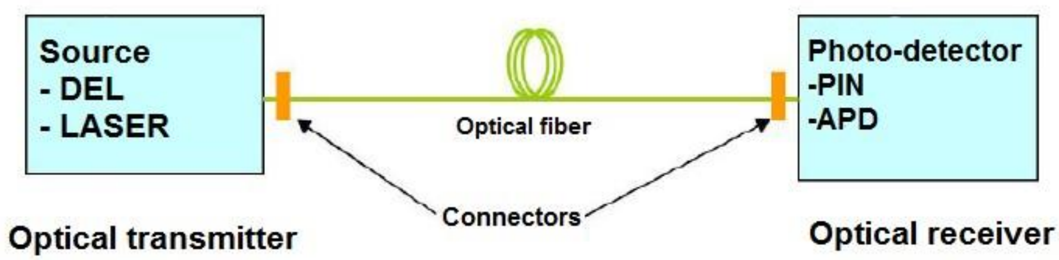


Figure (I-14): diagram of an optical transmission system.**[16]**

I-4-2 Optical transmitter

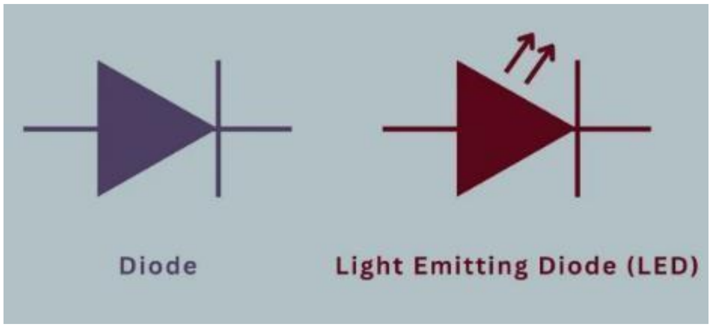
There are two types of transmitters usable for generating light signals: laser diodes (LD) and light-emitting diodes (LED). These two materials have advantages and disadvantages, and each one is adapted to a type of multiplexing. The following figure represents the symbol of the optical source.**[17]**

Figure(I-15): Symbol of the optical source.**[17]**

- ***Optical Light Source A. Light-emitting diodes LED***

LEDs, are tiny semiconductor devices that emit light when an electric current passes through them. Unlike old-fashioned light bulbs that get hot and burn out, LEDs produce light very coolly and efficiently.**[18]**

LED can be used as an optical light source in many crucial fields. Its luminous principle is electro-luminance. This phenomenon means that when electrons and holes are recombined at the junction, the forward-biased P-N junction will emit a light source.**[19]**



Figure(I-16): Diode and Light Emitting Diode Symbols.**[20]**

B. Internal Structure of Light-Emitting Diodes

The internal structure of an LED consists of:

P-type semiconductor layer – Contains excess holes with a positive charge.
N-type semiconductor substrate – Contains excess electrons with a negative charge.
Active region – The P-N junction where recombination occurs.
Anode and cathode terminals – To connect the LED to a power source.**[17]**

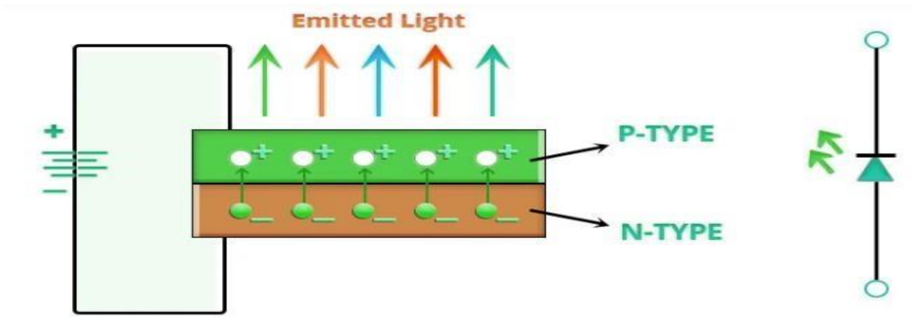


Figure 17:LED working principle.**[19]**

When a PN junction is biased in the forward direction, the electrons, which are the majority carriers in the n-type region, are injected into the p-type region where they recombine with the holes. Conversely, for the holes, the basic structure of a Light Emitting Diode (LED) is a PN junction made from semiconductors in which the recombination of excess carriers is essentially radiative. The typical structure of an LED and its operating principle are depicted in Figure (I18).**[22]**

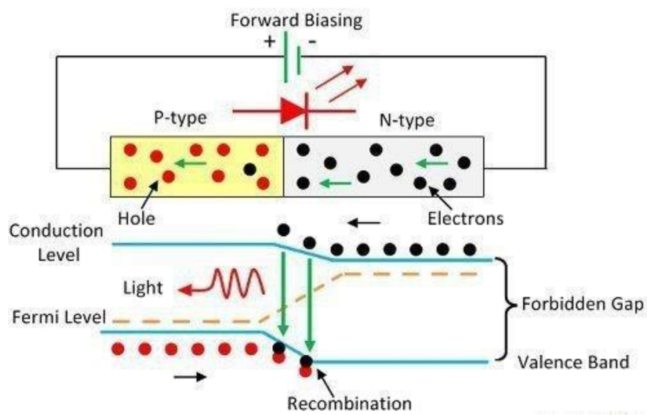


Figure (I-18): Principle of the light-emitting diode.**[17]**

A fixed forward bias voltage establishes the Fermi level separation. Recombination of excess carriers occurs in three distinct regions: the space charge region, as well as the neutral n and p regions. Within each of the latter, the emitting zone is constrained by the minority carrier diffusion length. The space charge region plays a minor role due to its narrowness resulting from the strong forward bias of the junction. Because electron mobility surpasses that of holes, the rate of electron injection into the p-type region exceeds that of hole injection into the n-type region, designating this area as the emitting face in the structure. Moreover, for emission intensity purposes, the n and p regions of the diode are heavily doped. These significant dopings cause a reduction in the bandgap, which is more pronounced in the p region than in the n region. This variation in bandgap further facilitates electron injection over hole injection. The emitted radiation's spectrum (wavelength type), hence the LED's color, primarily hinges on the bandgap of the p-type material, where the majority of radiative recombinations occur. As certain transitions involve impurity levels, the emission spectrum is also contingent on the type of dopant. Presently utilized materials allow for the coverage of nearly the entire visible spectrum.**[22]**

C. Laser Optical Light Source

A semiconductor laser that is used for signal transmission in optical fiber is the laser diode, where LASER stands for Light Amplification by Stimulated Emission of Radiation. A laser diode is like a light-emitting diode that emits a high-powered light through a glass lens to reduce signal loss.**[22]**

The laser work principle is stimulated emission radiation. Therefore, people also called it stimulated radiation optical amplification. Stimulated emission is when photons collide with atoms, they produce similar photons. **[10]**

When the electron is supplied with a lower level of electrical energy, the electron will migrate to the conduction band from the valence band and absorb the extra energy provided to it at the same time, which is called absorption.

When the electron is at a higher level, the electron will become unstable. To make it stable, it will emit some energy, possibly light energy or heat energy. When it emits light energy, it will emit in the form of photons. We call this process as spontaneous emission.

Then what is the stimulated emission? When the photons impact electrons, these electrons are endowed with high energy due to the impact of photons carrying more energy, making the electron unstable. Meanwhile, the electron will move to a lower energy state and emit another photon together with the incident photon. We called this process stimulated emission.

The process of stimulated emission is all occurs in the Laser diode, and the photons similar to incident photons converge and emit to a light beam. These emitted photons will release more photons which is similar to incident photons, so the light beams generated by laser optical light source are coherent and monochromatic.

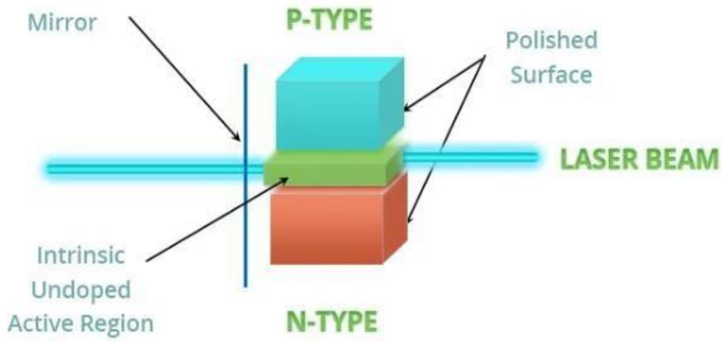


Figure (I-19): Laser working principle.**[10]**

- Construction of Laser Diode

- A laser diode is made of two semiconductor layers viz: P-type and N-type semiconductor. These semiconductors are made of Gallium arsenide and they are doped with Selenium, Aluminum, or Silicon.
- A depletion layer is between the two semiconductors because by applying a voltage to the diode, the electron-hole combination occurs.
- The front is completely polished, this surface acts as a reflecting surface or a mirror while the side view is partially polished which acts as a partially reflecting surface.
- The front face is attached with metal contacts to allow biasing in the semiconductor. Biasing means supplying power to the diode.
- Laser diodes provide a light of the same frequency.**[22]**

- Difference Between LED and Laser

The key difference between LED and laser is the light beam color, the LED can be of various colors, and the laser can only be a single color light beam. Their work principle of LED is electroluminance and the working principle of laser is that of stimulated emission. In addition to these, LED represents the standard light source, short for light-emitting diodes, while laser light source is generally used in special situations. Laser light source has faster operation speed, less optical transmission loss, and lower BER (bit error ratio). These are the benefits of laser light sources, and their price is more expensive than the LED optic light sources.**[14]**

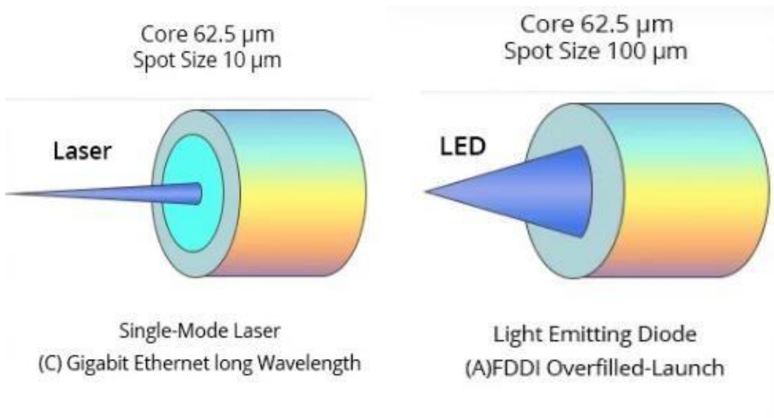


Figure (I-20):LED vs. Laser.**[25]**

I-4-3 Modulation

There are two distinct methods for modulating optical waves for communication purposes: direct modulation, in which the source itself varies its output, and external modulation, where a modulator is located in the output beam. In both cases, the required electrical power supply should be minimized as much as possible. The main formats of amplitude modulation are the RZ (Returnto-Zero) format and the NRZ (Non-Return-to-Zero) format.**[20]**

I-4-4 Optical Receiver

The basic optical receiver consists of a photodetector to convert the optical signal into a current, a low-noise preamplifier to convert and amplify the current into a voltage, an optional low pass filter to shape the received pulse or limit the basic optical receiver consists of a photodetector to convert the optical signal into a current, a low-noise preamplifier to convert and amplify the current into a voltage, an optional low pass filter to shape the received pulse or limit the bandwidth and a high-gain post amplifier (limiting amp or AGC amp) to produce a constant output voltage for a given input signal.

-The "first stage" block consists of the photodetector. It can be accompanied by a preamplifier, which aims to amplify the generated photocurrent to be sufficiently strong despite the weak optical signal received or the low sensitivity of the photodetector. Their structures were discussed in the first section.

-The "linear" block consists of a high-gain electrical amplifier and a noise-reducing filter.

-The "data recovery" block corresponds to the final stage of the receiver. It includes a decision circuit and a clock recovery circuit, also known as a synchronization circuit.**[21]**

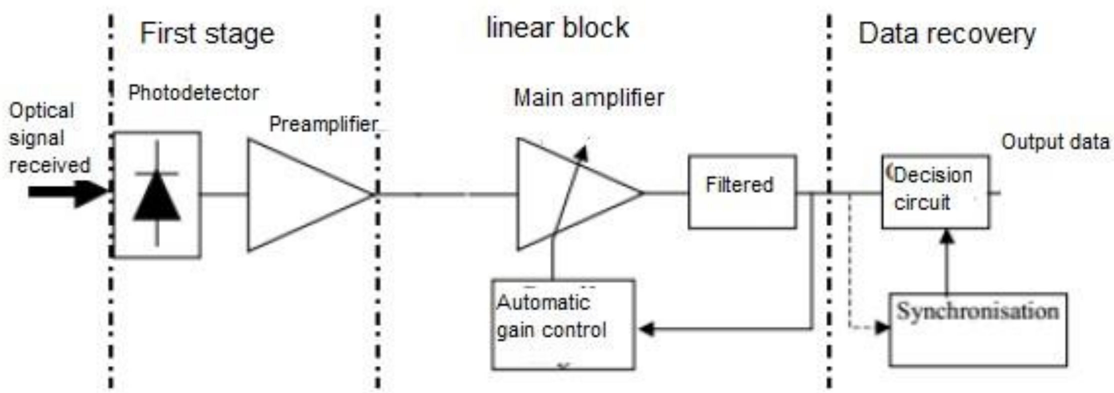


Figure (I-21): Block diagram of an optical transmission system.**[21]**

I-4-5 Photodetector

The semiconductor-based photodetector is a *p-n* junction acting as a photodiode that converts the incoming optical signal (representing stream of photons) into electrical energy representing flow of electron streams. The electron stream generating electrical current is then amplified and passed through a threshold device. The two types of photodiode are PIN photodiode and avalanche photodiode (APD)

The photodiode is basically being verse-biased *p-n* junction. Through the photoelectric effect, light incident on the junction generates electron-hole pairs in both the *“n”* and the *“p”* regions of the photo diode. The electrons released in the *“p”* region pass to the “л” region, and the holes created in the “л” region pass over to the *“p”* region providing a current flow.

In the fiber optic network, the photodiode is generally required to detect very weak signals. The detection of the weakest signal requires the photodetector, and an amplification circuit should be selected so that minimum signal-to-noise ratio (S/N) should be maintained. The S/N is written as

$$S \qquad Signal\ power\ from\ photocurrent$$

$$\frac{\;}{N} \qquad \frac{\;}{photo\ \mathrm{det}\ ectornoise+amplifier\ noise\ power} = \qquad \textbf{\textit{(I-2)}}$$

To achieve high *S/N*, the following conditions are obtained:

i. The photodetector should have a high quantum efficiency to generate large signal current.

ii. The photodetector and amplifier noises should be kept as low as possible.

The noise power determines the minimum optical power level that detected. **[23]**

- ***PIN Photodiode***

Figure **I-22**shows the PIN photodiode having *p* and *n* regions separated by a very lightly //doped intrinsic (i) region. Usually in its operation, a reverse-biased voltage is applied across the device so that the intrinsic region is fully depleted of carriers. The intrinsic *n* and *p* carrier concentrations are neglected in comparison to other impurity region concentrations. When a photon of energy greater than the bandgap energy of the semiconductor is incident, the photon can supply energy to excite the electron from valence band to conduction band. This process generates free electron-hole pairs known as photo-carriers generated in the depletion region where most incident light is absorbed. The high reverse electric fields present in the depletion region causes the carrier to be separated and collected across the junction. This gives current flow by every pair generated. This current is called as photocurrent. **[23]**

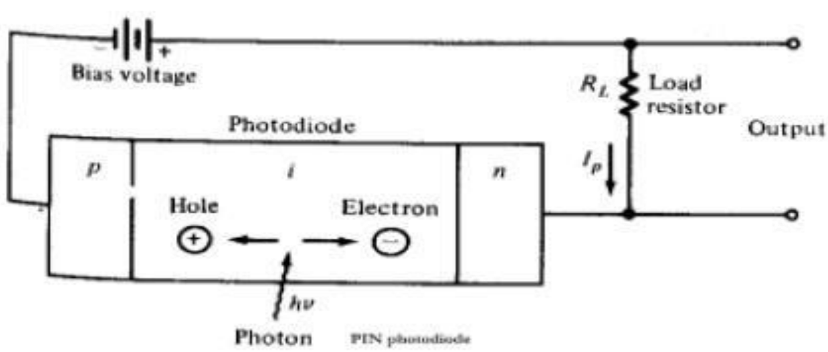


Figure (I-22): PIN diode.**[15]**

- ***Avalanche Photodiode (APD)***

APD is another photodetector in which the photo generated carriers get multiplied before it enters the input circuitry of the amplifier. For carrier multiplication, these carriers must travel through a region where a high electric field is present. In this high-field region, photo generated carriers can gain enough energy so that it ionizes the bound electrons in valence band upon colliding with them. This ionization is called impact ionization. The newly generated carriers are also accelerated by high electric field and get enough energy to cause further ionization. This is called avalanche impact ionization. While the photocurrent is enhanced by multiplication, thermal noise signal current is also multiplied. It can be avoided by reach through avalanche construction as shown in Figure**I-23**. It consists of ahigh resistivity intrinsic material deposited as an epitaxial layer on a *p+* (heavily doped) substrate. The /Mype diffusion is then made on high-resistive followed by an *n+* material layer. This makes *p+pn+* reach through construction. When a low reverse bias voltage is applied, the potential drop is obtained at a *p-n* junction. The depletion layer widens with increasing bias until a certain voltage is reached at which the peak electric field at *pn+* junction is about 5%-10% below that needed to cause an avalanche breakdown. This is called just reach through the nearly intrinsic region. When it is fully depletion mode, the light enters the device through *p+* region and is finally absorbed in the region, and then these photo generated carriers are accelerated by a high electric field. While accelerated, these carriers are multiplied through avalanche ionization. **[23]**

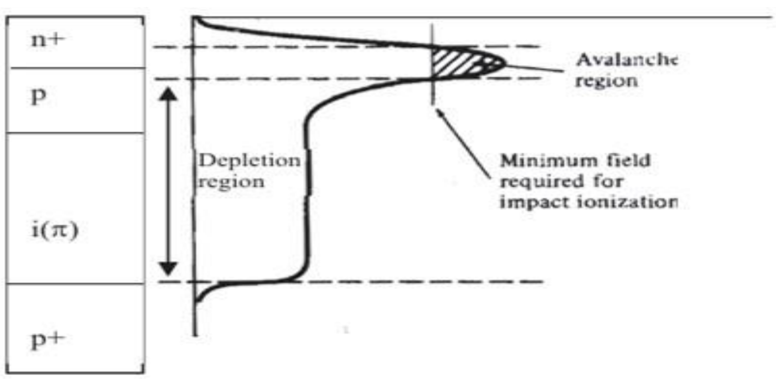


Figure (I-23): Operation of APD.**[22]**

The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal. The PIN diode comprises of three regions, namely P-region, I-region and N-region. Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts. The intrinsic region in the diode is in contrast to a PN junction diode. This region makes the PIN diode a lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.**[24]**

I.5 Conclusion

Optical fibers are a crucial component of modern telecommunications and networking systems. Their ability to transmit large amounts of data over long distances with minimal signal loss makes them invaluable for a wide range of applications, from internet connectivity to medical imaging. As technology continues to advance, optical fibers are likely to play an increasingly important role in enabling high-speed, reliable communication around the world.**[19]**

Chapter II

Critical Issues in Fiber Optic Communication transmission

II-1 Introduction

Data transfer via optical fiber has advanced more quickly in the last many years. There is an increasing demand for faster transmission across longer and longer distances. Sadly, sensitivity to propagation effects rises with speed, whether because of nonlinear effects mainly brought on by the Kerr phenomenon or linear effects such the fiber's chromatic dispersion (CD) and polarization mode dispersion (PMD).

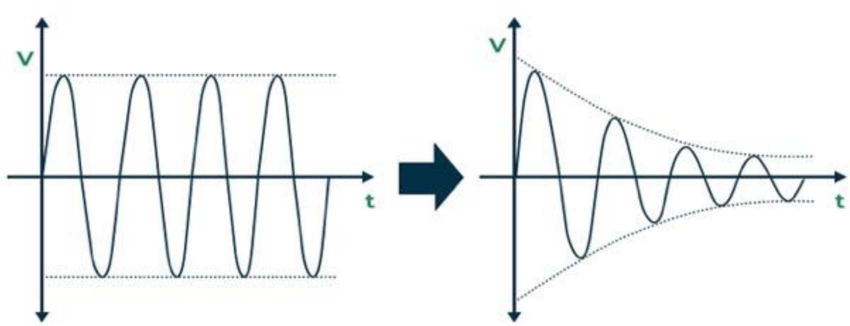
In this chapter, we will introduce the main issues that arise during light transmission and the various parameters that cause degradation in optical fiber transmission performance. Losses and dispersion effects are the major factors leading to reduced information transport capacity and data rates in fibers, increasing the probability of error during detection.

The first part focuses on the study of attenuation effects and nonlinear effects, while the second part addresses dispersion effects. In the final part of this chapter, we will present the main dispersion compensationwith three compensation techniques to better understand their impacts on transmission quality.

II-2 Linear effect

II-2-1 Attenuation of the optical signal

Attenuation, or the loss of signal intensity during the optical fiber's passage, is a crucial factor affecting the range and performance of the system. Many causes, including scattering, absorption, and intrinsic fiber defects, result in attenuation. It expresses the amount of signal power loss across a certain fiber distance in decibels per kilometer, or dB/km. The attenuation varies according to the wavelength of light; some wavelengths experience greater attenuation than others due to unique absorption properties of the fiber material.**[26]**



Figure(II-1): The effect of attenuation.**[27]**

Given a power P0 at the input of an optical fiber of length L, the power at the output Ps is given as a function of the linear attenuation coefficient by the following relation:

$$P_S = P_0 e^{\propto L} \qquad (II\text{-}1)$$

The attenuation of the fiber is expressed in decibels as:

$$\alpha(\mathrm{dB}) = 10\log \frac{P0}{PS} \qquad (II\text{-}2)$$

II-2-2 Main causes of attenuation

Attenuation represents the sum of all losses in the fiber. These losses come in various forms, intrinsic and extrinsic.

II-2-2-1 intrinsic attenuation

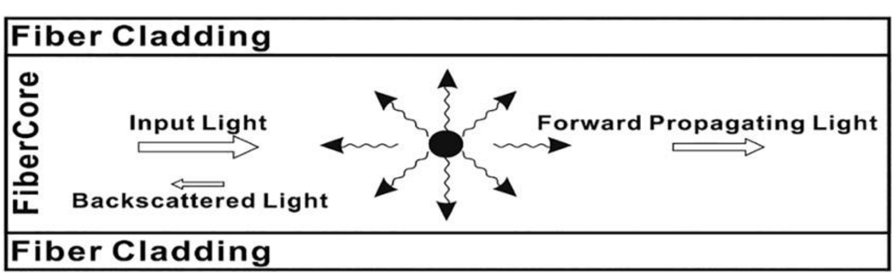
There are two main causes of intrinsic attenuation, one being light absorption and the other being scattering**.**

- ***Absorption losses***

The main source of energy loss in optical transmission is absorption, which is caused by the intrinsic characteristics of the fiber materials. The electromagnetic energy from the transmitted light signal is absorbed by these materials and is transformed into heat. Further aggravating signal energy absorption are contaminants added during fiber production, specifically metal and water ions.

- ***Losses due to Rayleigh scattering***

Rayleigh scattering is another primary cause of attenuation in the fiber. This scattering is due to microscopic variations in the refractive index of the fiber during its manufacturing. It limits performance in the short wavelength domain**. [28]**



Figure(II-2): Scattering in the core of an optical fiber**.[28]**

There is a reduction in the transmitted light energy when some of the scattered rays leave the fiber's core and scatter into the cladding. The optical fiber's non-homogeneity is caused by bubbles, tiny crystals, metallic particles, etc. These contaminants can be eliminated by applying the proper material treatment, and their effects can be reduced by carefully choosing the composition of the glass. **[29]**

II-2-2-2 Extrinsic attenuation

There is a second cause that can lead to losses. It lies in the connections that are implemented as well as the connections between two ends of the fiber. These losses are:

- ***Losses due to bends***

When navigating through terrain obstacles, it may be necessary to curve the optical fiber to facilitate passage. During bending, a portion of the guided light energy may escape the fiber, resulting in bending losses, a phenomenon particularly sensitive to longer wavelengths.

- ***Losses due to micro bends***

These occur during cable manufacturing when mechanical stresses cause microdeformations of the fiber, resulting in light losses. These losses increase rapidly as the fiber diameter decreases.

- ***Losses due to connections***

Although connecting two copper wires in electronics is straightforward, joining two optical fibers in optics is a complex and meticulous process. Minimizing losses is crucial as it is at these connection points where the signal experiences the most significant power loss. These losses stem from:

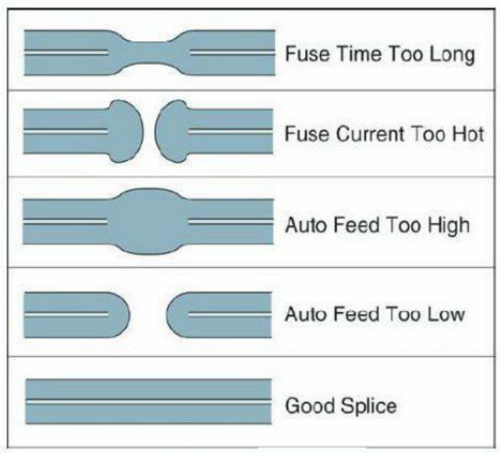
- Different core diameters
- Different numerical apertures
- Difference in refractive index (Fresnel losses).

- **Splice losses**

Fiber splicing loss is also dependent upon a host of extrinsic parameters that emerge during the process of splicing. These include :

- lateral and angular alignment.
- contamination of fiber ends.
- core deformation due to un-optimised heating and pressing.

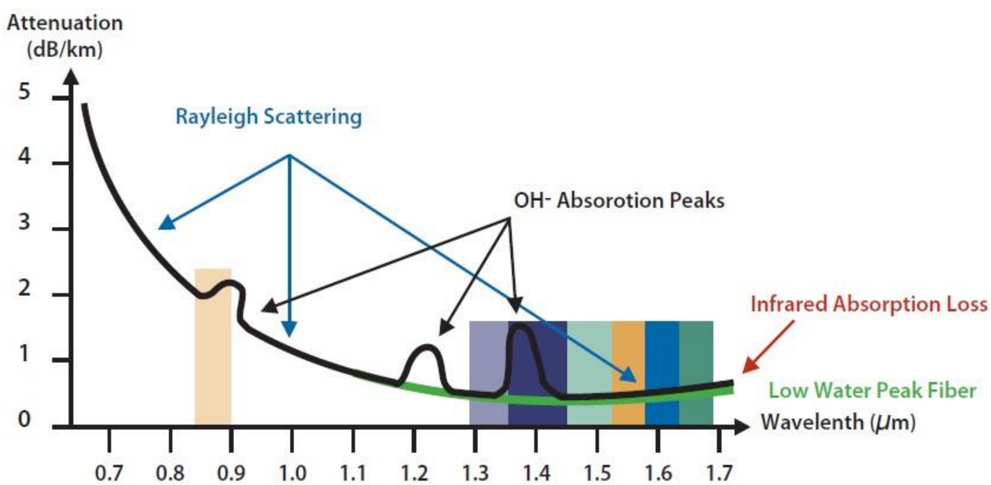
Failure to optimize splicing parameters, as illustrated in the graphic below, can result in a splice loss of up to 0.04 dB in two identical fibers. Therefore, the significance of employing proficient splicing technicians and automated machinery cannot be emphasized enough.**[30]**



Figure(II-3): Various types of losses in optical fiber.**[31]**

II-2-3 Attenuation spectrum

In optical transmission, three transmission windows are defined. Figure (II.4) shows the spectrum of losses for a silica fiber.



Figure(II-4): Intrinsic attenuation of the optical fiber**.[32]**

The band between 0.8 and 0.9 nm was historically the first selection, with an average attenuation of 2.5 dB/km. The band between 1.3 and 1.4 nm shows a reduced average attenuation of 0.7 dB/km. This feature is interesting because it provides an opportunity to counteract material dispersion, increasing transmission capacity and lengthening transmission distances. When narrow-spectrum modulated sources are available, the attenuation decreases to 0.2 dB/km (for single-mode fibers) in the 1.5–1.6 nm region, making it appropriate for long-distance applications. **[33]**

II-3 Nonlinear Effect

In optical communication, nonlinear effects arise from the interaction of propagating light with fiber optics. At low power, these effects are mild at first, but they can get stronger if the light pulse above a certain threshold, which may occur at higher power.

Moreover, these impacts also depend on the transmission distance, becoming more pronounced with increasing distance.There are two categories of Nonlinear Effects : Inelastic Scattering and Nonlinear Refractive Index (Kerr Effect). **[33]**

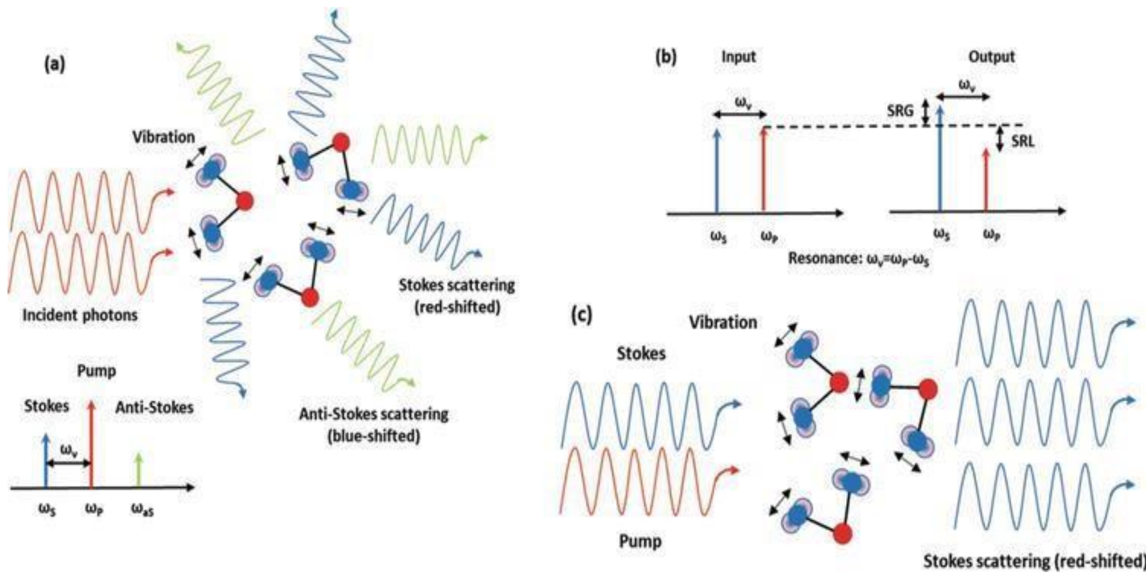
II-3-1 Inelastic Scattering

SBS (triggered Brillion Scattering) and SRS (Stimulated Raman Scattering), two phenomena related to the interaction between photons and electrons, are examples of inelastic scattering phenomena that might convince triggered effects. **[33]**

- ***Stimulated Raman Scattering***

The process of Stimulated Raman Scattering (SRS) is initiated when light interacts with the vibrational modes of molecules in a crystal's lattice vibration. When a pump photon raises a molecule to a virtual level—also referred to as an intermediate level—an inelastic phenomena known assurface tension rises.

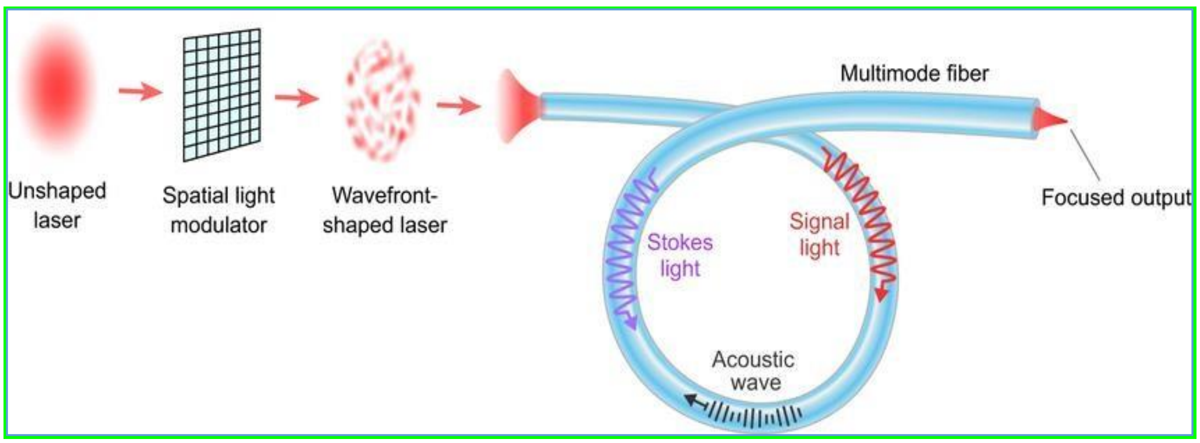
- Spontaneous: if the intensity of the incident field below threshold level, in this condition photon are scattered into random direction .
- Stimulated: when the pump power exceeds a certain threshold level. **[33]**



Figure(II-5): Stimulated Raman scattering (coherent directed radiation). **[33]**

- ***Stimulated Brillouin Scattering***

SBS occurs through the interaction between intense pump light and an acoustic wave, resulting in the generation of backward-propagating light with a frequency shift.



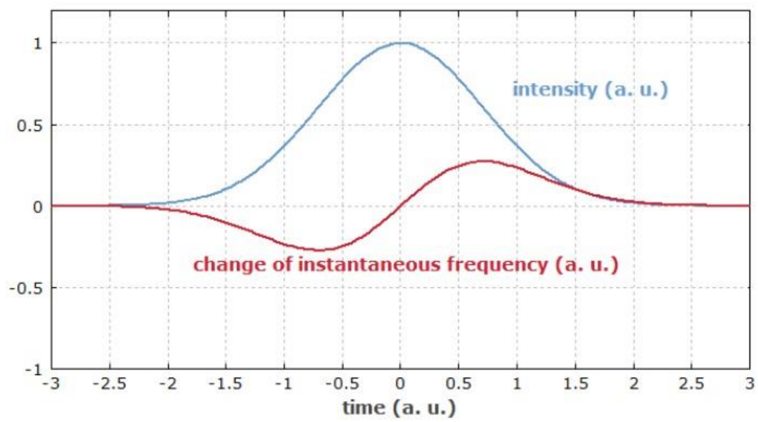
Figure(II-6): Stimulated Brillouin Scattering (SBS). **[34]**

II-3-2 Nonlinear Refractive Index (Kerr Effect)

The phenomenon of nonlinear refraction arises from the dependence of refractive index variations on power/intensity in optical fibers. These conditions give rise to effects such as SPM (Self-Phase Modulation), XPM (Cross-Phase Modulation), and FWM (Four-Wave Mixing).

II-3-2-1 Self-Phase Modulation

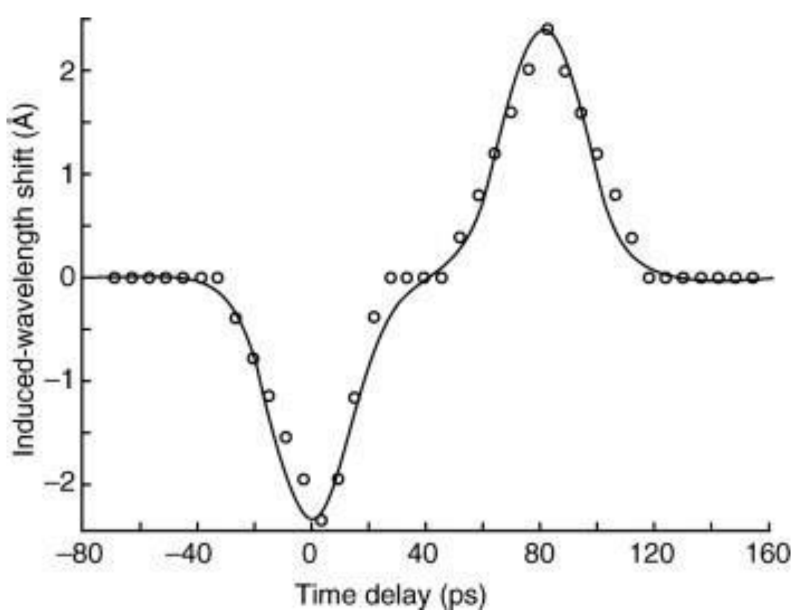
SPM is a nonlinear effect characterized by the modulation of light phase due to rapid changes in light intensity, leading to the gradual broadening of the signal spectrum. In SPM, a light beam with high optical intensity alters its phase by modifying the refractive index of the medium.



Figure(II-7): Change of instantaneous frequency with respect to time. **[34]**

- ***Cross Phase Modulation***

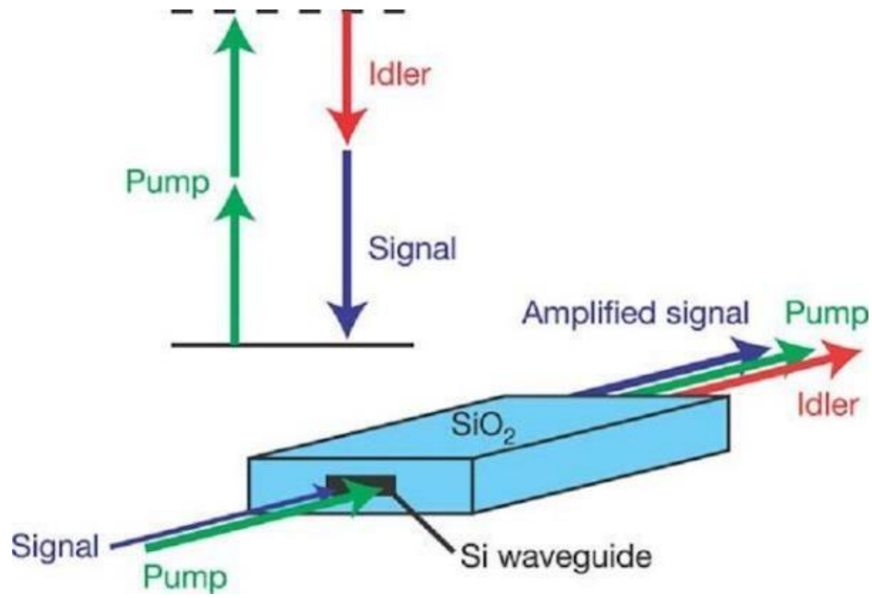
XPM manifests when the intensity of one beam impacts the phase of another beam, representing a nonlinear phenomenon where the wavelength of light influences the phase of another wavelength.



Figure(II-8): induced-wavelength shift with respect to time delay. **[34]**

- ***Four Wave Mixing***

At the receiver, different frequency harmonics of the signal are produced when many wavelengths are broadcast through a single fiber. In nonlinear optics, four-wave mixing (FWM) is an intermodulation phenomena in which interactions between two or three wavelengths produce one or two additional wavelengths. This behavior is similar to electrical systems' thirdorder intercept point.**[31]**

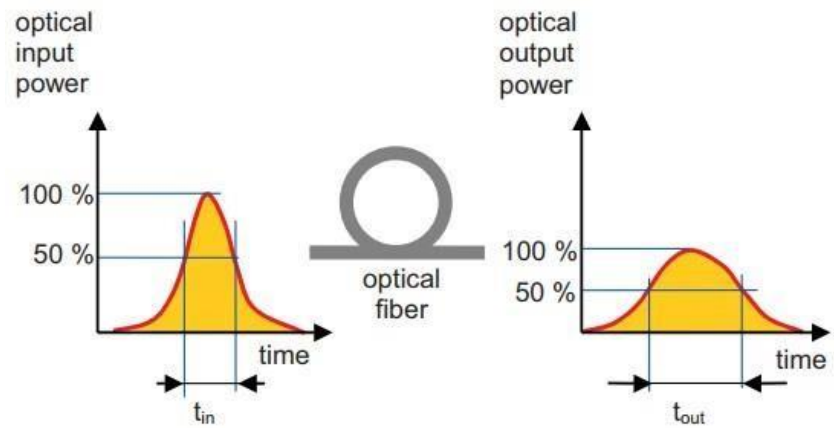


Figure(II-9): Four Wave Mixing (FWM). **[34]**

II-4 Dispersion in optical fiber

Dispersion includes all mechanisms that cause changes in the time it takes for various modes to propagate, which lowers the modulation amplitude of high frequencies and causes the pulse to spread temporally.

Two different sequential pulses at the fiber's input must continue to be distinct at the output in order for information to be transmitted accurately. Nevertheless, temporal dispersion—a spreading of the pulses within the fiber—causes two independent pulses at the input to mingle at the output. In fact, the pulse broadens in the time domain at the fiber's output when an infinitely narrow light pulse (Dirac) is fed into the optical fiber, as seen in the accompanying figure: **[35]**



Figure(II-10): The phenomenon of dispersion in an optical fiber. **[35]**

Several types of dispersion exist, all contributing to the spreading of the pulse during its propagation in the guide: Modal dispersion, polarization dispersion, and chromatic dispersion including material dispersion and guiding dispersion.

II-4-1 Modal dispersion

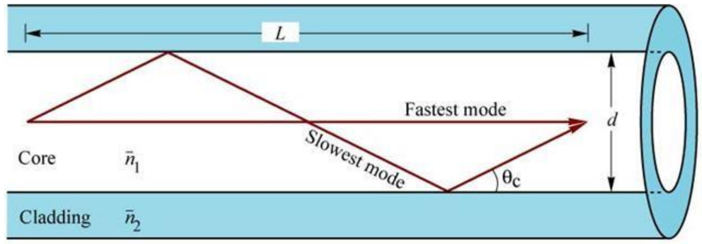
The main cause of dispersion in multimode fibers is modal dispersion, which places restrictions on data transmission speeds as well as propagation distance. It doesn't experience modal dispersion like single-mode fibers do. It results from differences in how long light takes to travel along various fiber pathways, more especially from the interval of time between the axial (fast mode) and reflected (slow mode) rays. Di, or intermodal dispersion, is defined as the maximum temporal broadening (τ) of a pulse per unit fiber length.

$$Di = \frac{t_{min} - t_{max}}{L} = \frac{\tau}{L} \qquad (\textbf{\textit{II-3}})$$

Where and are respectively the travel times of the slowest and fastest modes.**[35]**

- ***Step-Index Multimode Fiber Modal Dispersion***

Here we stress that the following analysis uses ray optics. Ray optics modal analysis is only valid when the V number is greater than 10. If the V number is lower, wave theory has to be used.



Figure(II-11): Step-Index Multimode Fiber**.[36]**

In a step-index multimode fiber, the center ray with a 0° incident angle travels fastest straight down the fiber. The ray which is incident at the critical angle travels slowest. The time delay between these two modes is given by:

$$\Delta_{\tau modal} = \frac{L(n^1-n^2)}{c}(1\text{-}\pi/v) \qquad \textit{(II-4)}$$

Where n1 is refractive index of the core, n2 is refractive index of the cladding, L is the length of the fiber, V is the V number given by:

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} = \frac{2\pi a}{\lambda} n_1\sqrt{2\Delta}. \qquad \textit{(II-5)}$$

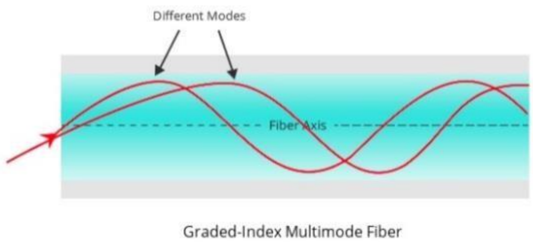
$$\Delta = \frac{n_1^2-n_2^2}{2n_1} \approx \frac{n_1-n_2}{n1}{}_2 \qquad \textit{(II-6)}$$

Here **a** is the core radius, **λ** is the light's vacuum wavelength.

- ***Graded-Index Multimode Fiber Modal Dispersion***

Modal dispersion, characterized by the value of τ mod, can be reduced by a gradual and appropriate decrease in the refractive index of the core along a radius.

Thus, the propagation velocity increases as the light ray moves away from the axis, compensating for the increased path length.



Figure(II-12): Graded-index Multimode Fiber.**[36]**

Theoretically, this dispersion is given by the following relationship:

$$d_{GI} = \frac{n_1 2}{c\,8} \qquad (II\text{-}7)$$

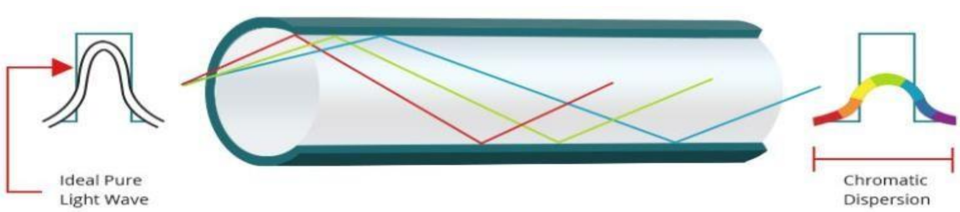
For a single-mode fiber, there is only one mode and therefore no modal dispersion.**[36]**

II-4-2 Chromatic Dispersion

The merging of material dispersion and waveguide dispersion gives rise to chromatic dispersion. These losses predominantly pertain to the spectral width of the transmitter and the selection of the appropriate wavelength.

A plot of effective refractive index versus wavelength provides a visualization of the impacts of material, chromatic, and waveguide dispersion.

Material dispersion and waveguide dispersion effects exhibit contrasting behaviors as the wavelength increases. However, at an optimal wavelength around 1300 nm, these effects nearly nullify each other, resulting in minimal chromatic dispersion. Consequently, attenuation also reaches its minimum, rendering 1300 nm a highly favorable operating wavelength.



Figure(II-13): Illustration of the temporal broadening of the light pulse envelope after propagation in an optical fiber.**[37]**

So, we can deduce quite simply the propagation time difference Δt related to the group velocity after traversing a fiber length L:

$$t = L * D(\lambda) * \lambda \qquad (II\text{-}9)$$

The parameter more commonly used in the field of optical telecommunications is the parameter D(λ) defined as:

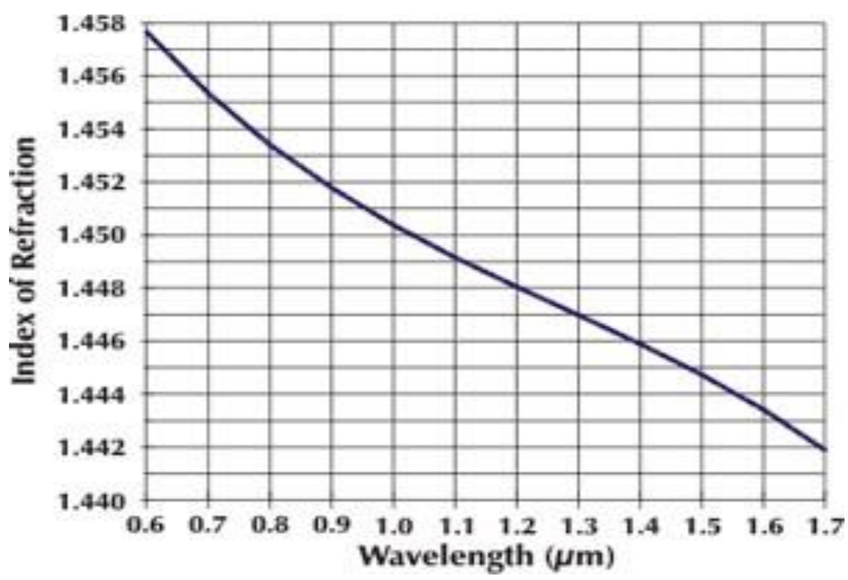
$$D(\lambda) = \frac{2\pi c}{\lambda^2}\beta 2 \qquad (II\text{-}10)$$

- c: the speed of light;
- λ: the wavelength;
- β2: the group velocity dispersion parameter (GVD for Group Velocity Dispersion).

This dispersion depends on the considered wavelength and results from the sum of two effects: material dispersion and waveguide dispersion.**[37]**

II-4-2-1 Material Dispersion

Material dispersion, also known as chromatic dispersion, arises from variations in the refractive index for different wavelengths. A light ray consists of components with various wavelengths centered around a particular wavelength, λ10. The differing time delays for these wavelength components lead to temporal dispersion of the pulse at the fiber's receiving end. Figure (II-14) depicts the refractive index as a function of optical wavelength.



Figure(II-14): Index of refraction as a function of wavelength.**[38]** The material dispersion is given by :

$\lambda d^2 n$ Ps

$D_M = -\frac{1}{2}[\text{—} \cdot Km]_{c\ d\lambda nm}$
(*II-8*)

Where, n_1 being the refractive index of the fiber core.

II-4-2-2 Waveguide Dispersion

Waveguide dispersion stems from the variance in the refractive index between the core and cladding, leading to a 'drag' effect between the core and cladding segments of the power. This dispersion is notable primarily in fibers transmitting fewer than 5-10 modes. Given that multimode optical fibers accommodate hundreds of modes, waveguide dispersion is typically not discernible in such cases.

The group delay (Dg) arising due to waveguide dispersion.

$$D_g = \Delta \text{—} \quad \text{—} \lambda n C1\, V\ d2dV(Vb2)$$
(*II-11*)

II-4-3 Chirped Gaussian Pulses

A pulse is said to be chirped if its carrier frequency changes with time. For a Gaussian spectrum having spectral width σω , the pulse broadening factor is given by:

$$= (1 + \text{—}\tfrac{2}{2})^2 + (1 + V_\omega^2)\left(\text{—}\tfrac{2}{2}\right) + (1 + C + V_\omega^2)^2(\text{—}\tfrac{2}{=})$$

πr

— $\sigma 22$ $C\beta 2\sigma 2L$ $\beta 2\sigma L0\ 2$ $4\sqrt{\beta 2L\sigma 30}$

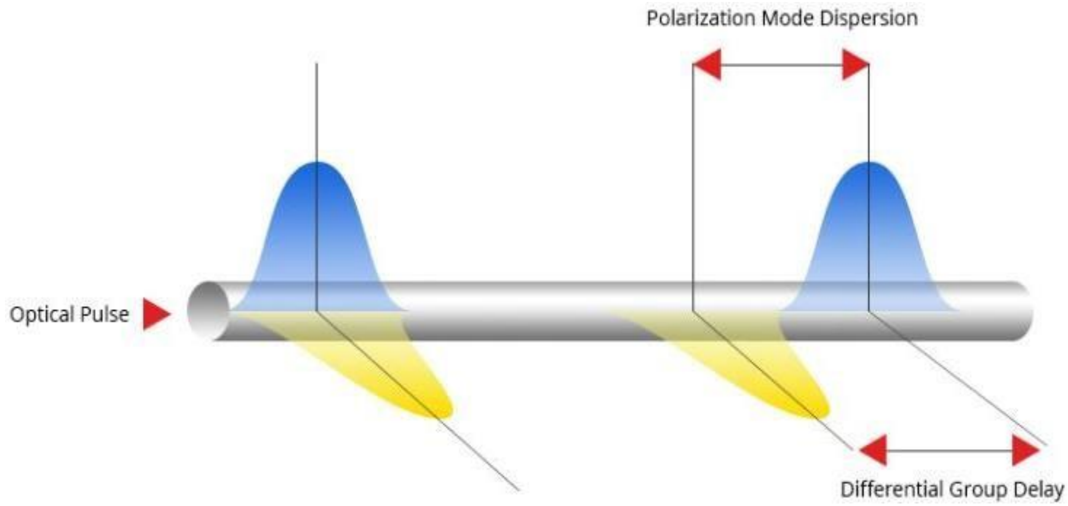
2 (*II-12*)

$\sigma 0$

where, Vω = 2σω σ0 .**[38]**

II-4-4 Polarization Mode Dispersion

Various frequency components of a pulse can adopt different polarization states, such as linear or circular polarization. This discrepancy leads to pulse broadening, a phenomenon known as polarization mode dispersion (PMD). PMD stands as a limiting factor for optical communication systems, particularly at high data rates. To mitigate the effects of PMD, compensation mechanisms must be employed. **[39]**



Figure(II-15): Polarization Mode Dispersion.**[39]**

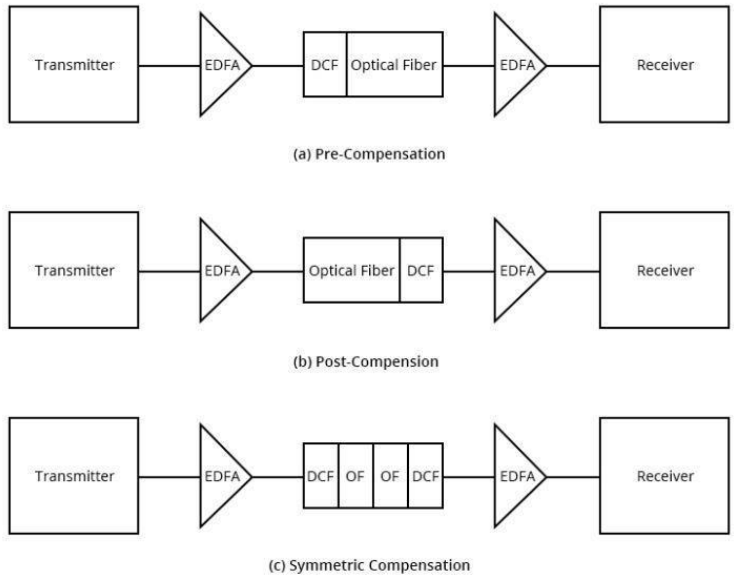
II-5 Dispersion techniques

While optical fiber dispersion does not directly attenuate the signal, it does reduce the distance the signal can travel inside the fibers and causes signal distortion. For instance, a 1nanosecond pulse at the transmitter might spread out to 10 nanoseconds at the receiver, leading to improper signal reception and decoding. Hence, reducing optical fiber dispersion or implementing dispersion compensation becomes crucial, particularly in long-haul transmission systems like
DWDM.

Here, two compensation strategies or techniques to counteract fiber dispersion will be introduced.

II-5-1 Dispersion Compensation with DCF

A normal fiber and a fiber with a large negative dispersion are used in the Dispersion Compensating Fiber (DCF) approach. The dispersion caused by the standard fiber is successfully reduced or cancelled out by the dispersion compensating fiber, which has a larger dispersionvalue of the opposite sign than the standard fiber. Dispersion compensation can be implemented using three main schemes: pre-dispersion, post-dispersion, or symmetrical dispersion. In order to adapt existing 1310nm optimized optical fiber networks for operation at 1550nm wavelengths, dispersion compensating fibers are often employed.

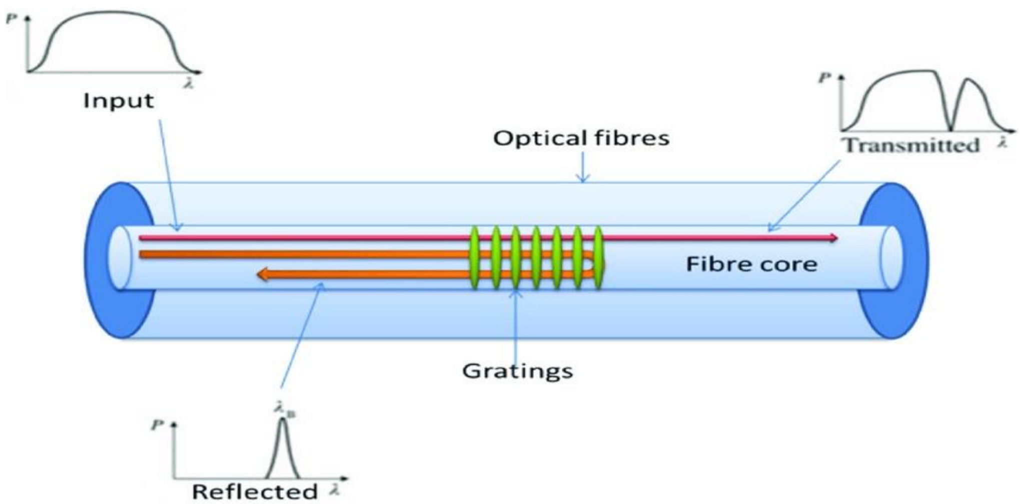


Figure(II-16): Type Dispersion Compensation with DCF**.[36]**

II-5-2 Dispersion Compensation with FBG

An optical fiber with its core refractive index modulated over a predetermined length is used to create a Fiber Bragg Grating (FBG), a reflecting device. FBGs can be used to greatly minimize dispersion effects in large transmission networks, like ones that are 100 km long. When the wavelength of the light matches the modulation frequency, these fiber gratings reflect the light as it passes through the fiber.

Because of their low insertion losses, affordability, and compatibility with passive optical elements, FBGs are a promising option for dispersion compensation. In addition to being dispersion compensation filters, FBGs are also used as sensors, pump laser wavelength stabilizers, and narrow-band WDM add-drop filters.



Figure(II-17): Fiber Bragg Grating.**[40]**

II-6 Conclusion

High-speed optical fiber transmission systems are often the most widely used for various transmissions due to their numerous advantages. Optical fiber possesses many qualities for transmitting a large amount of information over long distances. The study of point-to-point optical links requires an examination of each fiber parameter influencing signal quality. Both linear and nonlinear effects degrade signal quality, with each acting to diminish the transmitted signal quality. Therefore, devices and methods are developed to mitigate these detrimental effects.

Chapter III

Results and Discussions

III-1 Introduction

The main objective of this chapter is to study, through simulation, four optical fiber links in terms of losses and attenuations using the Optisystem software. The latter allows for the design of various optical links and facilitates testing on multiple types of links, boasting a very rich simulation environment. And finally, to study a practical case, which is the optical link in C.A. Msila, with C.T Hammam Dalaa, C.T BBA, C.T.Boussaada and C.T Oulled Derredj.

III-2Presentation of OptiSystem software

III-2-1Working interface

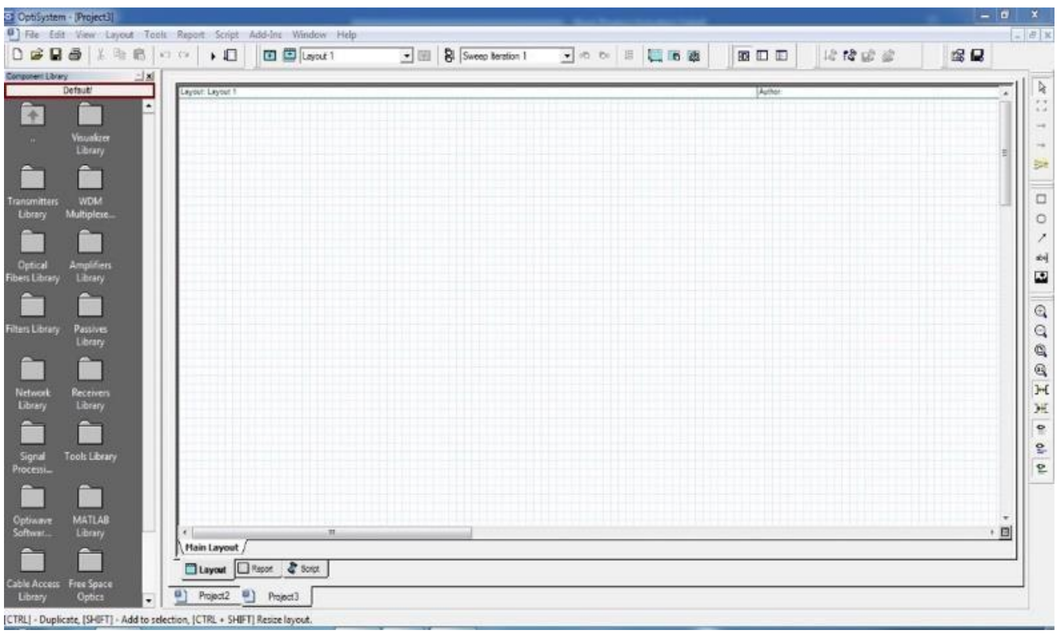
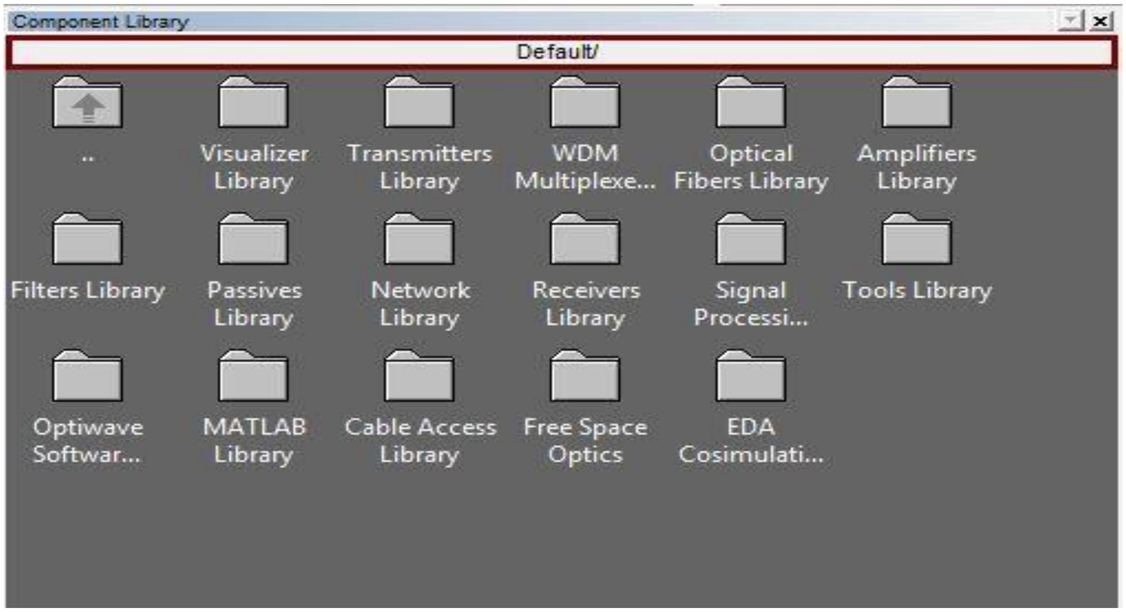


Figure (III-1): The working interface on OptiSystem.

III-2-2Library

It contains all types of models that allow the realization of different block diagrams: inputs, regenerators, encoders, modulators, filters,

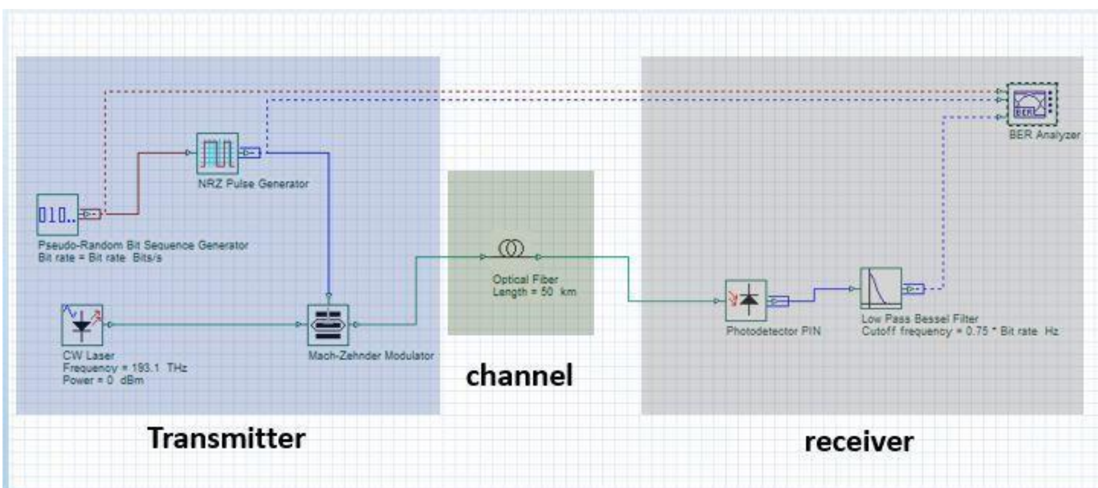


Figure(III-2): The Optisystem software library.

III-3Components of the optical communication system

An optical communication system consists of:

- Transmitter
- The transmission channel
- Receiver



Figure(III-3): Components of the optical communication system.

III-3-1Optical transmitter

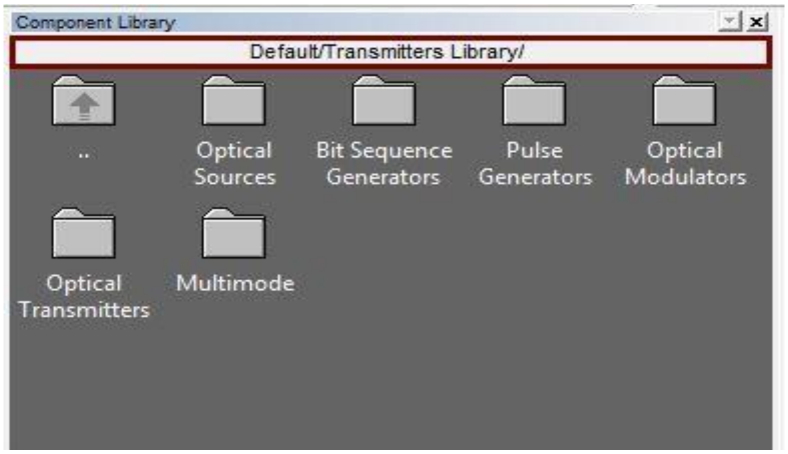
The tasks of the optical transmitter are:

- Convert the electrical signal into an optical signal.
- Inject the resulting optical signal into the optical fiber.
- An optical transmitter is modeled by:

  Optical source.

  Electrical pulse generator.

  Optical modulator.

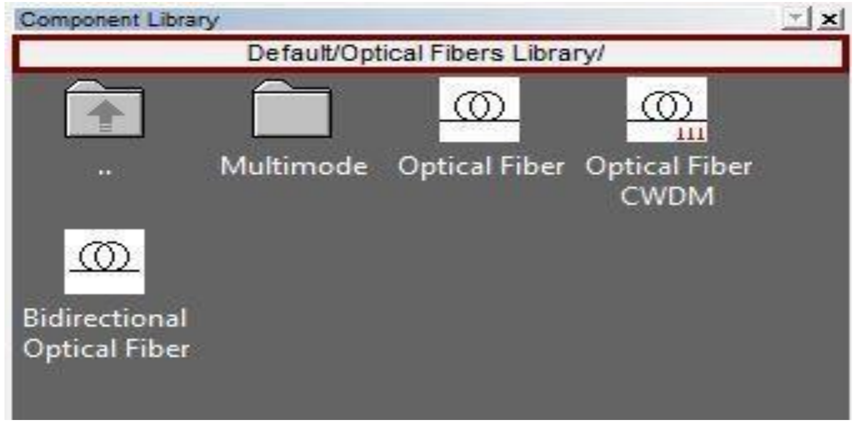


Figure(III-4): The library of optical transmitters.

The launch power is an important parameter during the design of a transmission chain, typically expressed in dBm.

III-3-2Transmission channel

The optical transmission channel used is the optical fiber, its role is to transport an optical signal from the transmitter to the receiver. In a transmission chain, several losses can be encountered such as attenuation and dispersion. By adjusting the length of the fiber, we can observe signal degradation at the receiver as well as pulse broadening inside the fiber.

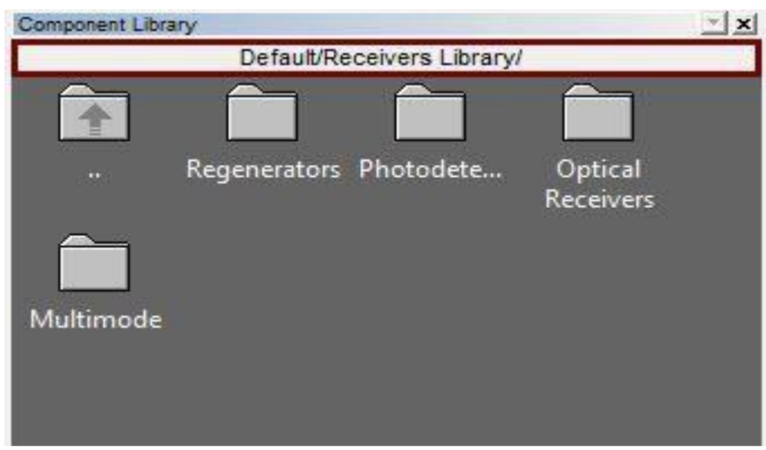


Figure(III-5): The library of optical fibers Links.

III-3-3Optical Receivers

An optical receiver converts the optical signal received at the output of the fiber into an electrical signal. The receiver consists of the following components:

- Photodetector.
- Filter.



Figure(III-6): Library of optical receiver.

Often, the received signal is in the form of optical pulses represented by a 0 or 1. The performance of a digital communication system is evaluated by its bit error rate (BER), where BER is defined as the probability of erroneous bits over the total number of transmitted bits. Generally, the BER of an optical system is set to a rate of 10^{-9}.

III-4 Design of optical link

The optical link design essentially involves the placement of various optical components, so that information can be transmitted satisfactorily. The satisfactoriness of the transmission can be defined in terms of some characteristic parameters. The goal is to successfully design an optical link that allows us to make variations either in the distance traveled by the light beam or in components (modulator, optical amplifier, ...) and to apply our theoretical knowledge to the optical link C.A.Msila with C.T Hammam dalai, C.T BBA, C.T Boussaada and C.T Oulled Derredj.

III-4-1LinkStudying (C.A M'sila /C.T Hammam Dallaa)

The table below defines the actual parameters for Tow links (The test parameters):

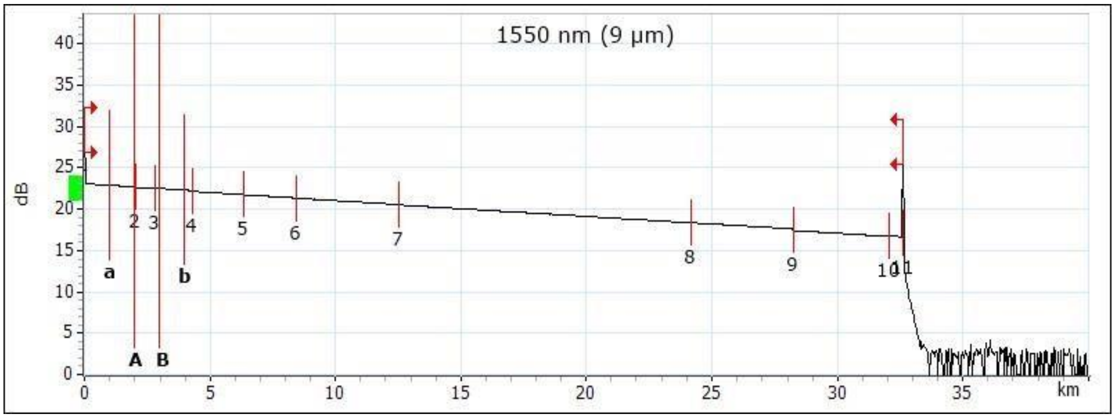
Wavelength	**1550nm**	**1310nm**
Range	40km	40km
Pulse	50ns	50ns
Acquisition time	10s	10s
Section length	32,6090 km	32,6090 km
Section loss	***6,436 dB***	***11,157 dB***
Average loss	***0,197 dB/km***	***0,342 dB/km***
Rayleigh scattering	-81,87db	-81,87db

Table 2: Optical link parameters C.A M'sila _C.T Hammam Dallaa.

III-4-1-1Optical link test configuration C.A M'sila /C.T Hammam Dallaa

- ***Viewing the link on OTDR for λ = 1550 nm***

In automatic mode, the OTDR displays the trace directly as shown in the following figure:



Figure(III-7): OTDR trace of the link C.A M'sila /C.T Hammam Dallaa **-Verification of the analysis OTDR trace of the link C.A M'sila _C.T Hammam Dallaa**

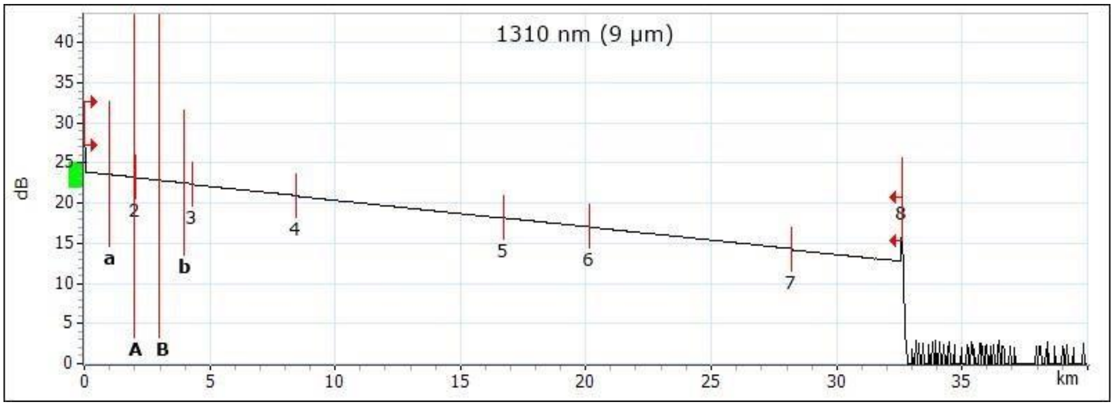
Type	Nº	Pos./Long.	Loss (dB)	Reflectance	Attenuation (dB/km)	Cumulative (dB)
first connector	1	0,0000	- --	-32,4		0,000
Section		2,0596	0,410	/	0,199	0,410
non-reflective	2	2,0596	0,052	/		0,462
Section		0,7797	0,141	/	0,180	0,603
positive	3	2,8393	-0,033	/		0,570
Section		1,4611	0,271	/	0,185	0,840
non-reflective	4	4,3004	0,108	/		0,948
Section		2,0258	0,381	/	0,188	1,330
non-reflective	5	6,3262	0,022	/		1,352
Section		2,1317	0,402	/	0,188	1,754

non-reflective	6	8,4579	0,019	/		1,773
Section		4,0886	0,766	/	0,187	2,539
non-reflective	7	12,5464	0,052	/		2,591
Section		11,6328	2,166	/	0,186	4,758
positive	8	24,1792	-0,026	/		4,732
Section		4,0490	0,760	/	0,188	5,492
non-reflective	9	28,2282	0,191	/		5,684
Section		3,8206	0,706	/	0,185	6,389
positive	10	32,0488	-0,061	/		6,328
Section		0,5602	0,109	/	0,194	6,436
reflective	11	32,6090	- --	/	/	6,436

Table 3: Digital data of the OTDR trace.

- ***Viewing the link on OTDR for λ = 1310 nm***

In automatic mode, the OTDR displays the trace directly as shown in the following figure:



Figure(III-8): OTDR trace of the link C.A M'sila _C.T Hammam Dallaa

-Verification of the analysis of the OTDR trace of the link C.A M'sila / CT Hammam Dallaa.

Type	Nº	Pos./Long.	Loss (dB)	Reflectance	Attenuation (dB/km)	Cumulative (dB)
first connector	1	0,0000	---	-31,7		0,000
Section		2,0554	0,676		0,329	0,676
non-reflective	2	2,0554	0,070			0,746
Section		2,2443	0,736		0,328	1,482
Positif	3	4,2997	0,118			1,600
Section		4,1541	1,351		0,325	2,951
non-reflective	4	8,4538	0,089			3,040
Section		8,2559	2,740		0,332	5,780
non-reflective	5	16,7097	-0,041			5,739

Section		3,4201	1,121		0,328	6,861
non-reflective	6	20,1298	0,038			6,898
Section		8,0957	2,686		0,332	9,584
non-reflective	7	28,2255	0,163			9,747
Section		4,3910	1,410		0,321	11,157
Positif	8	32,6165	---	-13,4		11,157

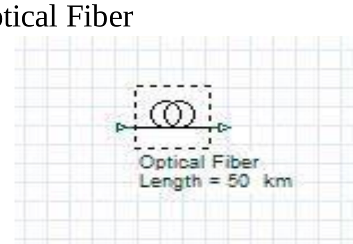
Table 4: Digital data of the OTDR trace.

III-4-1-2Simulation

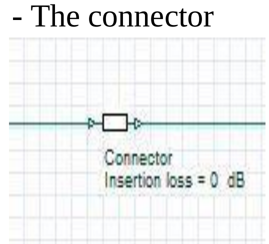
In this section, we will conduct a simulation using the Optisystem software to model the equivalent setups of the CA M'sila_ C. T Hammam Dallaa links.

The implementation of links within the Optisystem interface is based on the data from Table (III3). During the implementation process, we replaced each segment with a length of fiber that separates the events. These events are replaced by connectors, as represented in Figure (III-7). The parameters of distance, attenuation, and dispersion are indicated in Table (III-1). The purpose of this simulation is to replicate the various losses encountered in the tested links and to establish a comparison between the simulated and experimental results.

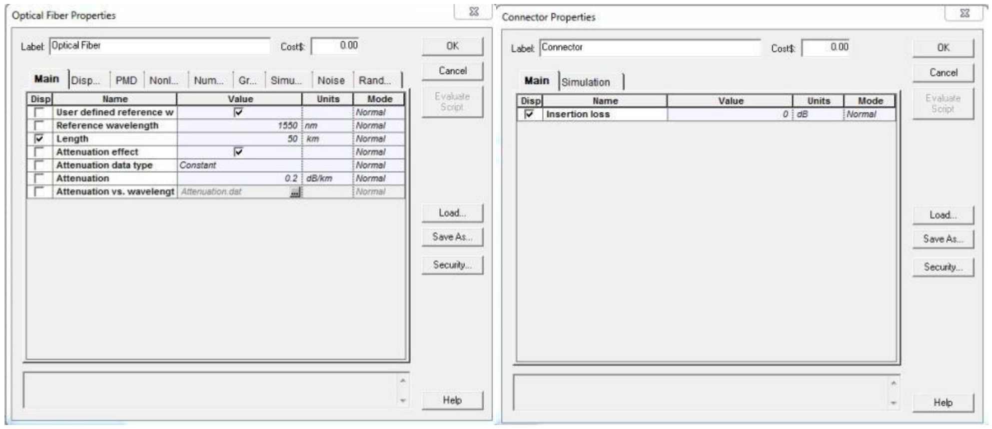
- Optical Fiber



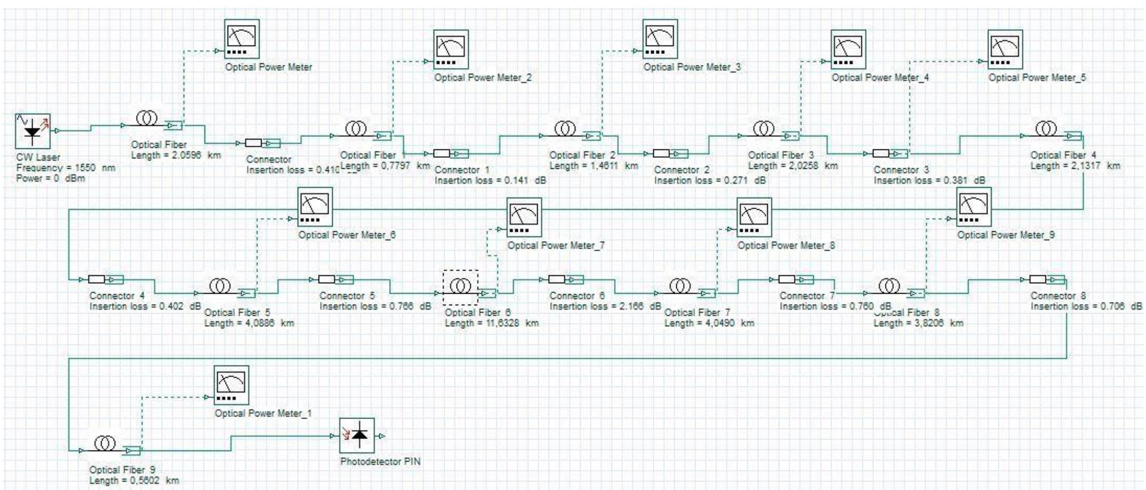
- The connector



- Parameter Modification Tables:



III-4-1-3Equivalent setups of the tested links (C.A MSILA /C.T HAMMAM DALLAA)



Figure(III-9): Equivalent setup of the link (C.A M'sila_CT Hammam Dallaa)

The results obtained by the equivalent setup of link C.A M'sila /CT Hammam Dallaa:

the segment	The total power of each segment simulation	OTDR (dbm)
1		0.410 dBm

Table 5: Total power at first segment of the link C.A M'sila/CT Hammam Dallaa. -Comparative table of simulation results and OTDR measurements of total power losses:

Wavelength	simulation	OTDR

<table>
<tr><td>1550 nm</td><td>
</td><td>7.650dBm</td></tr>
<tr><td>1310 nm</td><td>
</td><td>29.948dBm</td></tr>
</table>

Table 6: Comparative table of simulation results and OTDR power measurements.

In this simulation, we observe that the results obtained from the simulation are identical to the results provided by the OTDR.

III-4-2Link Studying C.A M'sila/C.T Ouled Derradj

The table below defines the actual parameters for Tow links (The test parameters):

Wavelength	**1550nm**	**1310nm**
Range	40km	40km
Pulse	50ns	50ns
Acquisition time	15s	15s
Section length	23,6688 km	23,6688 km
Section loss	***6,502 dB***	***9,549 dB***
Average loss	***0,275 dB/km***	***0,403 dB/km***
Rayleigh scattering	-81,87db	-81,87db

Table 7: Optical link parameters C.A M'sila/C.T Ouled Derradj.

III-4-2-1Optical link test configuration C.A M'sila _ C.T Ouled Derradj

- ***Viewing the link on OTDR for λ = 1550 nm***

In automatic mode, the OTDR displays the trace directly as shown in the following figure:

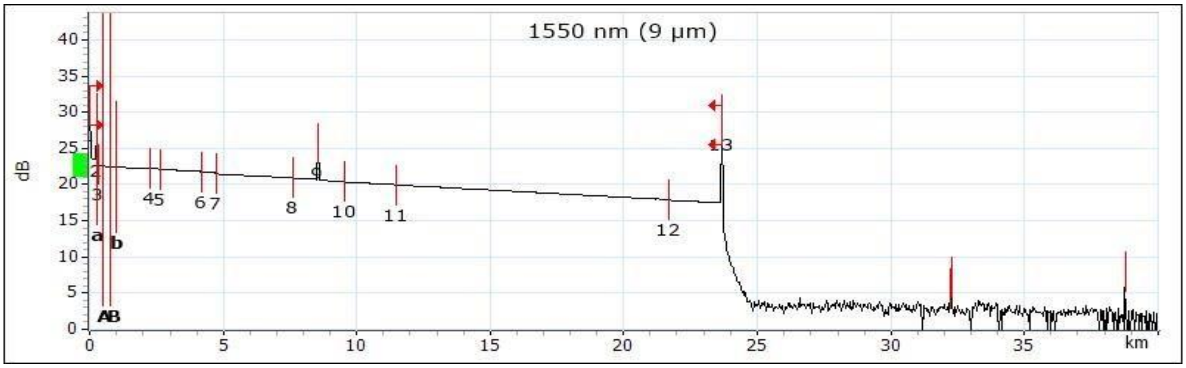


Figure (III-10):OTDR trace of the link C.A M'sila/ CT Ouled Derradj

- ***Viewing the link on OTDR for λ = 1310 nm***

In automatic mode, the OTDR displays the trace directly as shown in the following figure:

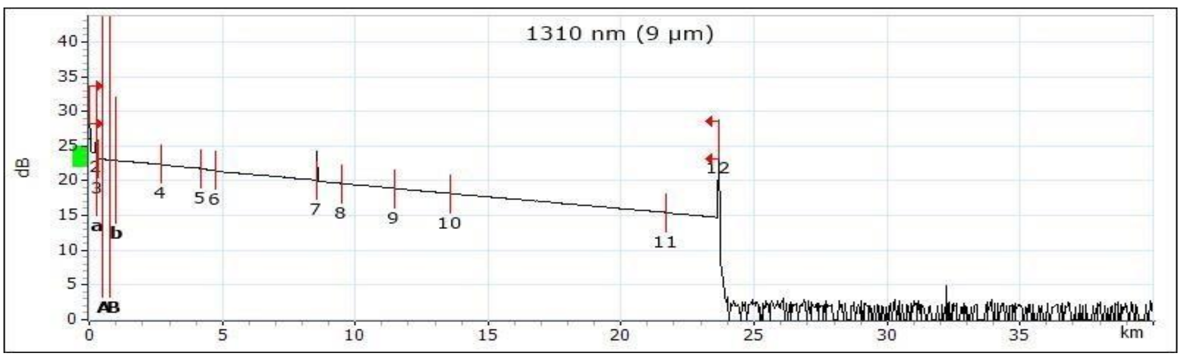
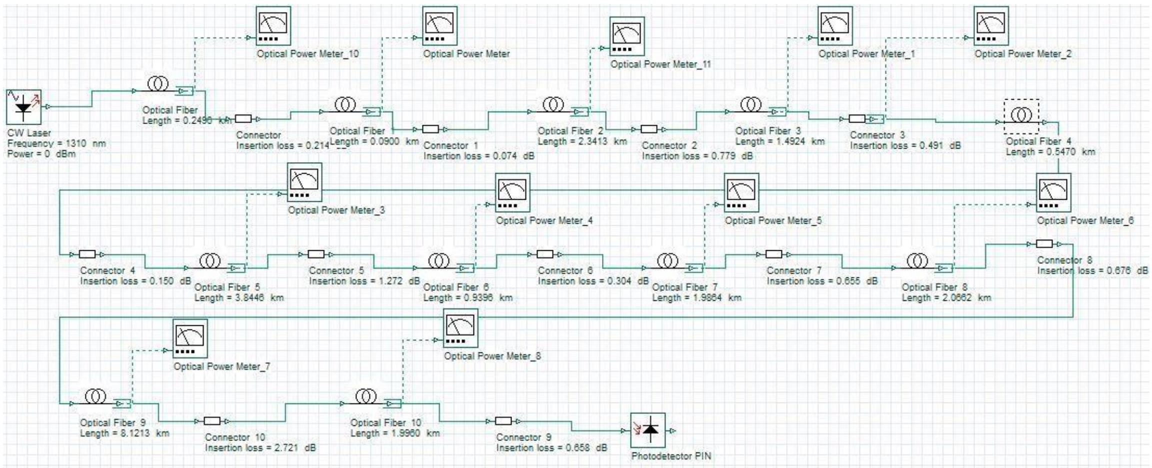


Figure (III-11): OTDR trace of the link C.A M'sila / CT Ouled Derradj

III-4-2-2Simulation

- ***The equivalent setups of the tested links***

The equivalent setup of the link (C.A M'sila / CT OULLED DERRADJ)



Figure(III-12): Equivalent setup of the link (C.A M'sila / C.T Ouled Derradj)

-The results obtained by the equivalent setup of link C.A M'sila _C. T Oulled Derradj:

Wavelength	simulation	OTDR
1550 nm		9.340dBm
1310 nm		12.071dBm

Table 8: Comparative table of simulation results and OTDR power measurements.

III-4-3Link Studying C.A M'sila / Boussada

The table below defines the actual parameters for Tow links (The test parameters):

Wavelength	**1550nm**	**1310nm**
Range	160 km	40km
Pulse	10µs	50ns
Acquisition time	15s	15s
Section length	77,0192 km	77,0192 km
Section loss	**14,862 dB**	**9,549 dB**
Average loss	**0,193 dB/km**	**0,403 dB/km**

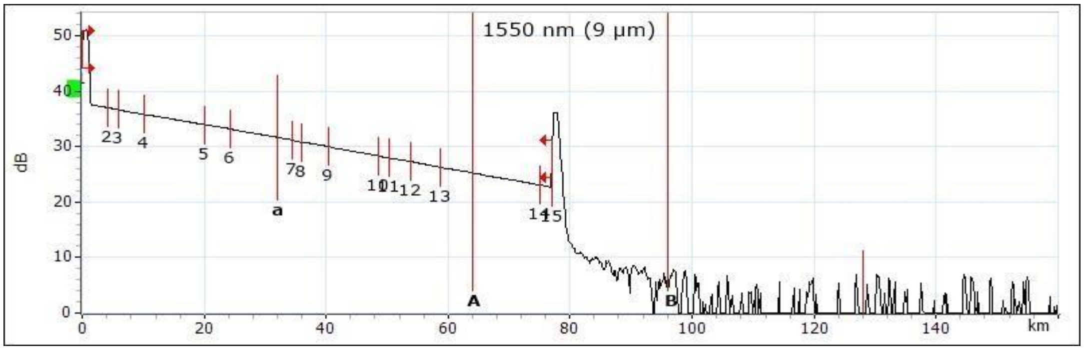
Rayleigh scattering	-81,87db	-81,87db

Table 9: Optical link parameters C.A M'sila/ Boussada.

III-4-3-1Optical link test configuration C.A M'sila_CT Boussaada

- ***Viewing the link on OTDR for λ = 1550 nm:***

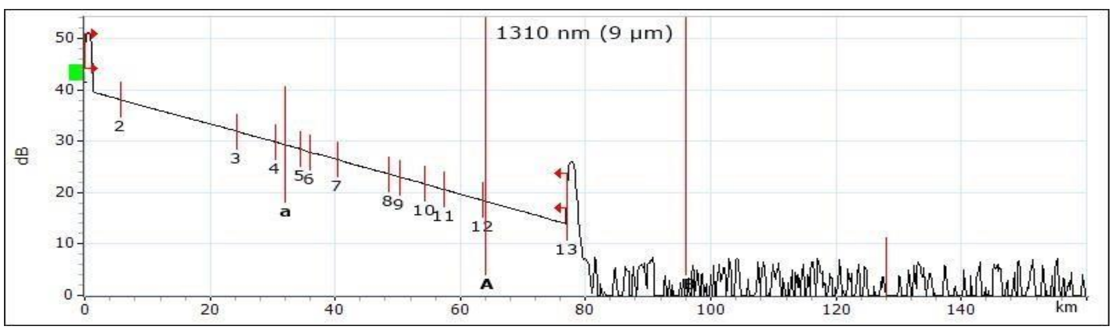
In automatic mode, the OTDR displays the trace directly as shown in the following figure:



Figure(III-13): OTDR trace of the link C.A M'sila/ CT Boussaada

- ***Viewing the link on OTDR for λ = 1310 nm***

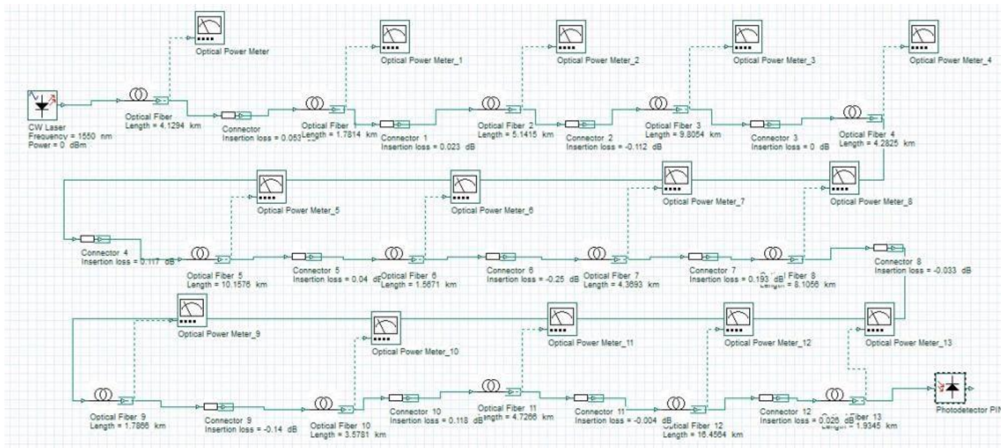
In automatic mode, the OTDR displays the trace directly as shown in the following figure:



Figure(III-14): OTDR trace of the link C.A M'sila_CT Boussaada.

III-4-3-2Simulation

- ***The equivalent setups of the tested links***



Figure(III-15): The equivalent setup of the link (C.A M'sila/ CT Boussaada)

-The results obtained by the equivalent setup of link C.A M'sila / CT Boussaada

Wavelength	simulation	OTDR
1550 nm		15.595dBm
1310 nm		15.348dBm

Table 10: Comparative table of simulation results and OTDR power measurements.

III-4-4Link Studying C.A M'sila_CT Borj Boueririj

The table below defines the actual parameters for Tow links (***The test parameters***):

Wavelength	**1550nm**	**1310nm**
Range	80km	80km
Pulse	5 µs	5µs
Acquisition time	5s	5s
Section length	61,1498 km	61,1498km
Section loss	***12,595 dB***	***21,069 dB***
Average loss	***0,206 dB/km***	***0,345 dB/km***

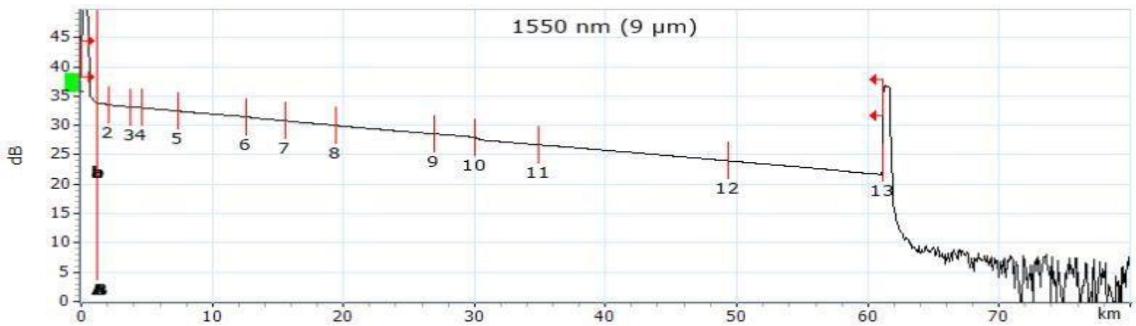
Rayleigh scattering	-81,87db	-79,45db

Table 11: Optical link parameters C.A M'sila_CT Borj Boueririj.

III-4-4-1Optical link test configuration C.A M'sila _ CT Borj Boueririj

- ***Viewing the link on OTDR for λ = 1550 nm***

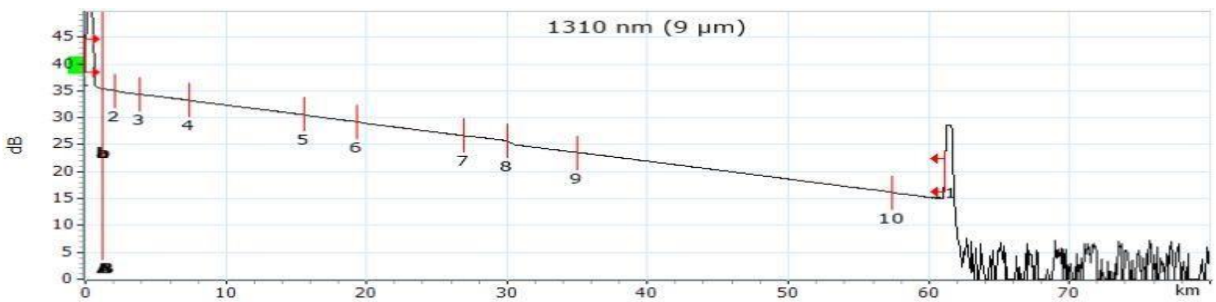
In automatic mode, the OTDR displays the trace directly as shown in the following figure:



Figure(III-16): OTDR trace of the link C.A M'sila _ CT BBA.

- ***Viewing the link on OTDR for λ = 1310 nm:***

In automatic mode, the OTDR displays the trace directly as shown in the following figure:

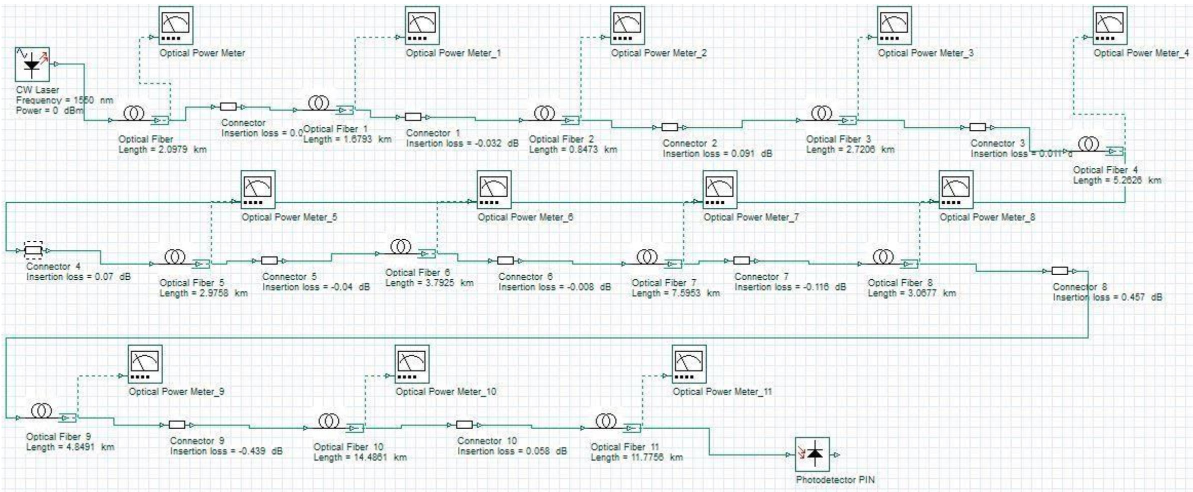


Figure(III-17): OTDR trace of the link C.A M'sila _ CT BBA.

III-4-4-2Simulation

- ***The equivalent setups of the tested links***

The link (C.A MSILA / CT BBA)



Figure(III-18): Equivalent setup of the link (C.A M'sila_ CT Borj Boueririj).

The results obtained by the equivalent setup of link C.A MSILA_ CT BBA:

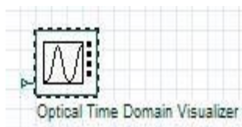
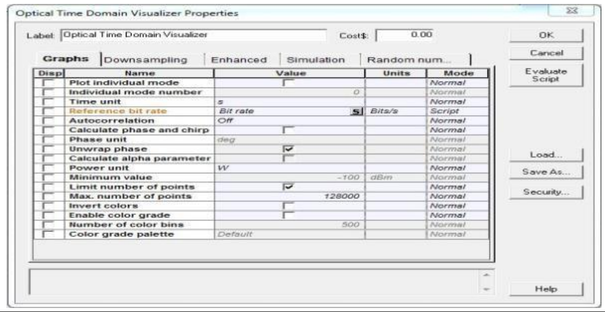
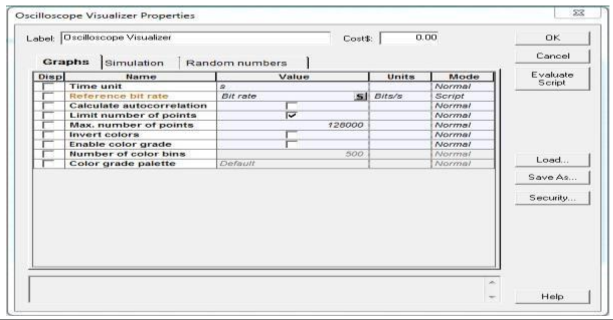
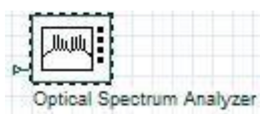
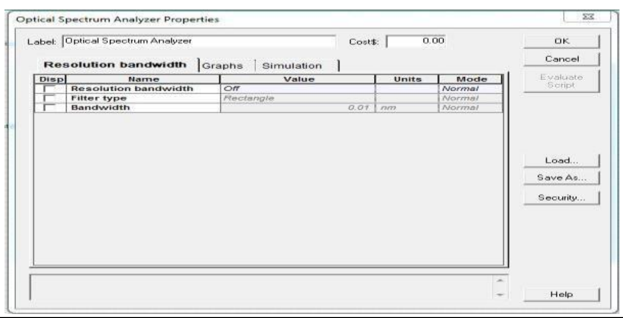
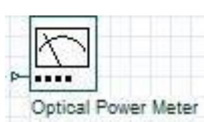
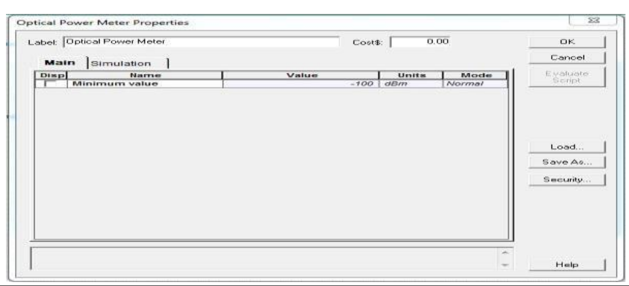
Comparative table of simulation results and OTDR measurements of total power losses:

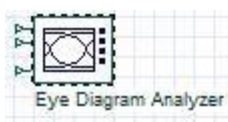
Wavelength	simulation	OTDR
1550 nm	Optical Power Meter: 57.917 E-6 W; -12.372 dBm; Signal Index: 0; Total Power	12.372dBm
1310 nm	Optical Power Meter: 4.192 E-6 W; -23.775 dBm; Signal Index: 0; Total Power	23.775dBm

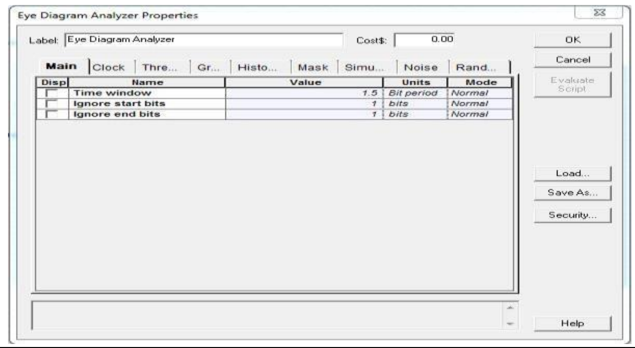
Table 12: Comparative table of simulation results and OTDR power measurements.

III-5 Analysis of the Link Performance

In this section, we will first present all the devices for optical and electrical signals along with their configurations given in the table below. Then, we modeled the link using OptiSystem to evaluate its performance.

Visualization device	Visualization parameters
	
	
	
	





III-5-1 Visualization blocks

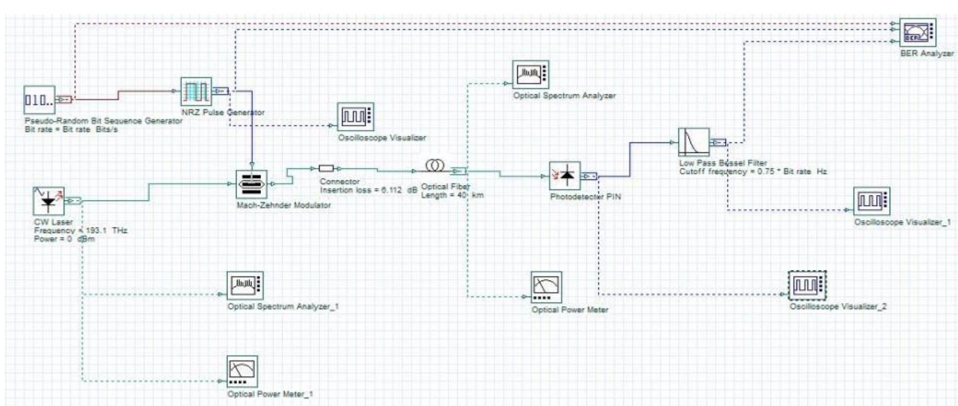
In this section, we will evaluate the three links using Optisystem by studying the input signals, output signals, and noise, as well as the output signal after filtering.

III-5-1-1 Simulated link parameters

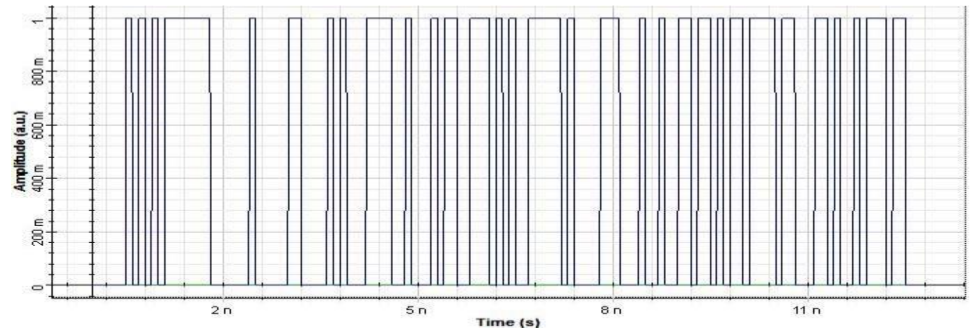
settings	**M'sila _ HD**	**M'sila_ O D**	**M'sila-BOU**	**M'sila -BBA**
distance (km)	40Km	40Km	160Km	80km
Average Loss	0,197 dB/km	0,275 dB/km	0,193 dB/km	0,206 dB/km
The total losses (dB)	6.112dB	4.986dB	0.031dB	0.142dB

Table 13: Link Parameters.

III-5-1-2 The simulation setup of the link



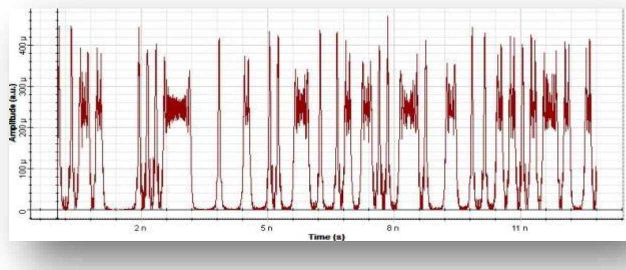
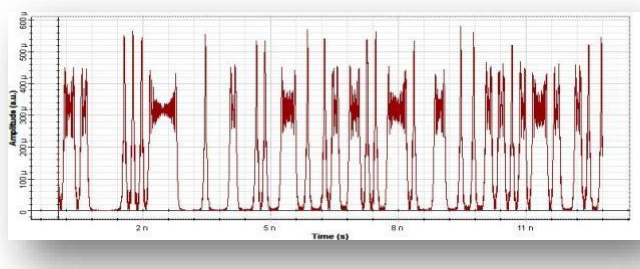
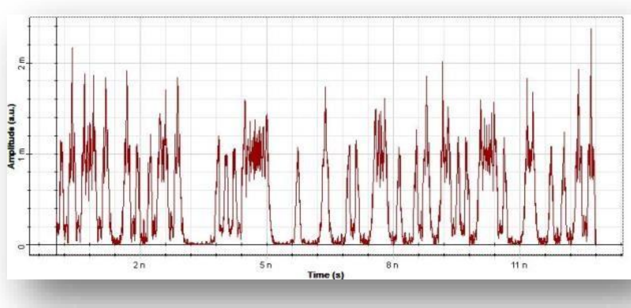
Figure(III-19): The equivalent setup of the transmission chain with measuring devices.

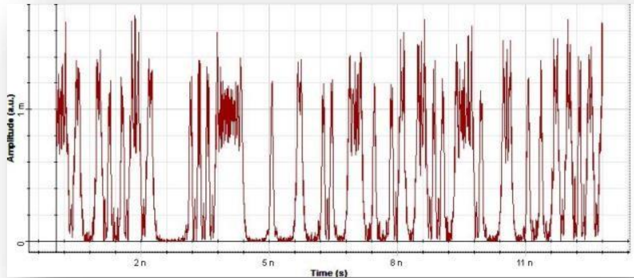


Figure(III-20): The input signal at 10 Gbits/s.µ.

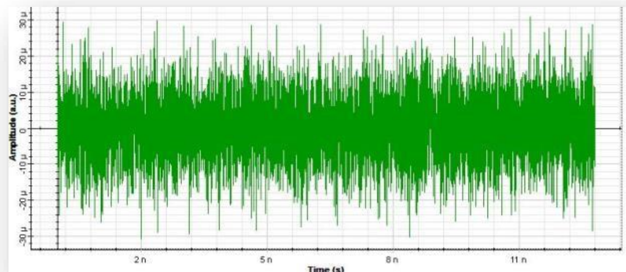
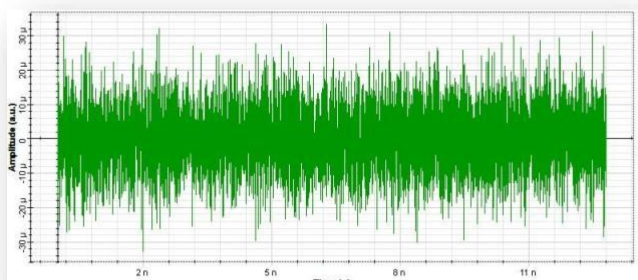
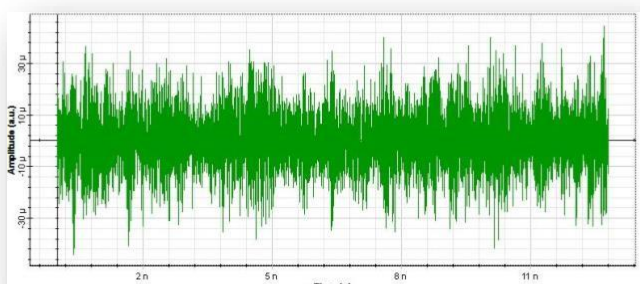
III-5-1-3 Visualization in the time domain

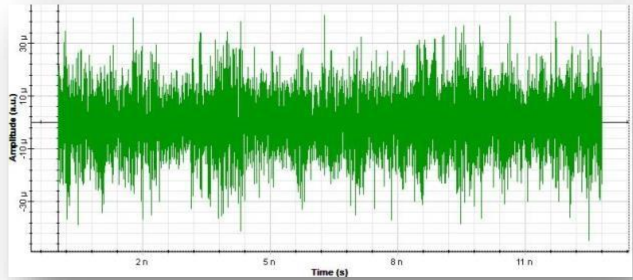
The visualization in the time domain of different signals.

HD	
Oulled Derradj	
Boussaada	

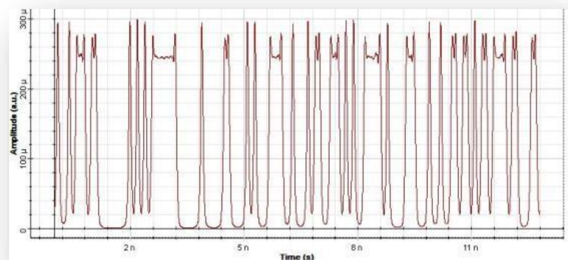
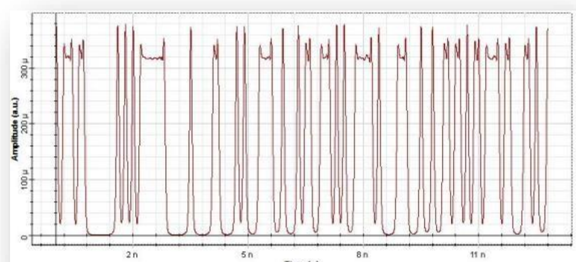
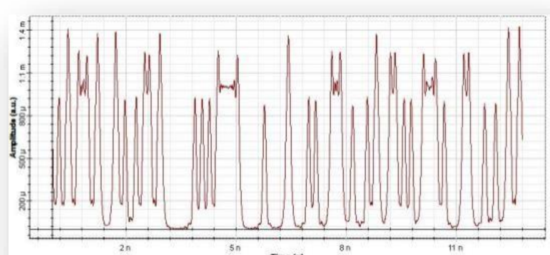
BBA	

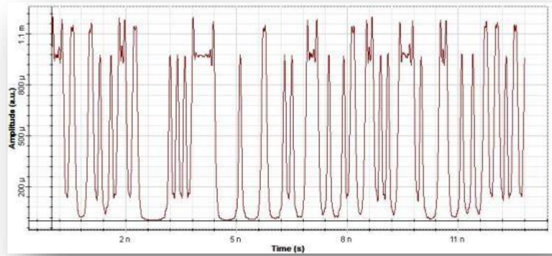
a- Output signal.

HD	
Oulled Derradj	
Boussaada	

BBA	

b- Noise signal

M'sila– HD	
Oulled Derradj	
Boussaada	

BBA	

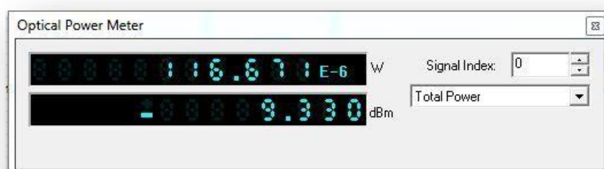
c- After filtering.

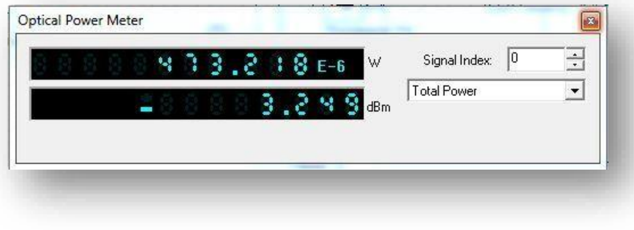
A binary signal of 10 GB/s is injected at the input of this link. After propagation, we receive at the output a signal with amplitude distortion (attenuation) and pulse broadening (dispersion).For this link, we represent the input signal, the output signal, the noise signal, and the output signal after filtering.

Comparing the output signals after filtering, the first observation noted is that the signal amplitude has reduced, especially for M'sila-BBA link. Its reduction was significant with high noise, causing pulse degradation.

III-5-1-4 The optical power at the output of each link

Through simulation, we deduced the total powers of the Four links, as illustrated in Table (III-5) below. MSILA-HD link has maintained a very high power due to its short distance compared to the other links, and also thanks to the good quality of the fiber used (recent link).

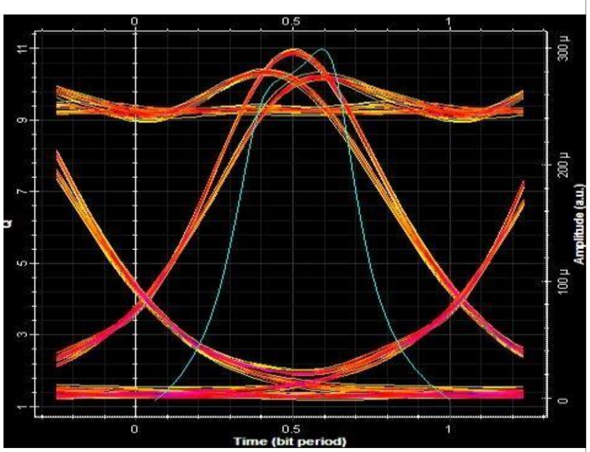
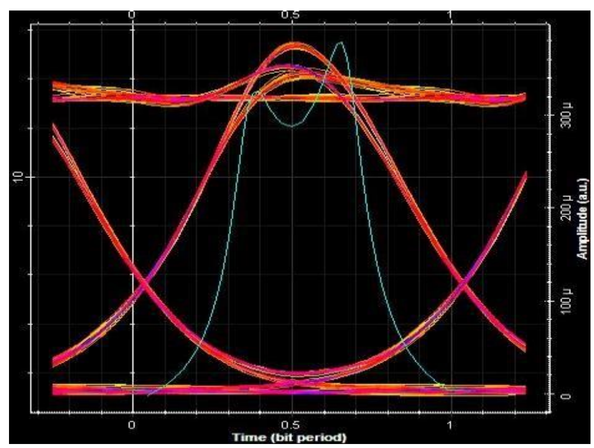
M'sila–HD	
M'sila -Oulled Derradj	

M'sila-Boussaada	
M'sila -BBA	

III-5-1-5 Visualization in the frequency domain

The eye diagram is a visual method for assessing signal quality, for which it has been determined for the three connections and evaluate them differently.

- ***The eye diagram of the four optical connections***

M'sila -HD	M'sila -Oulled Derradj
	

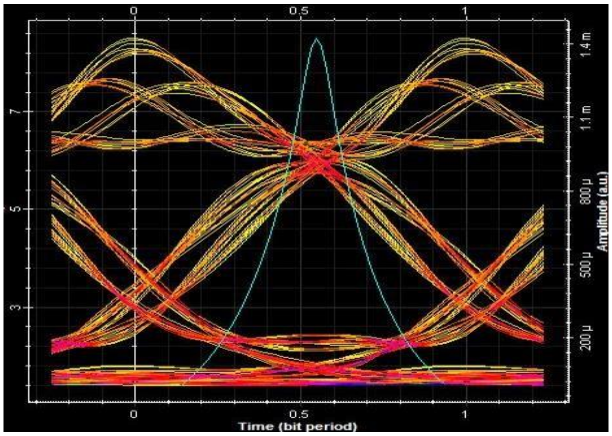
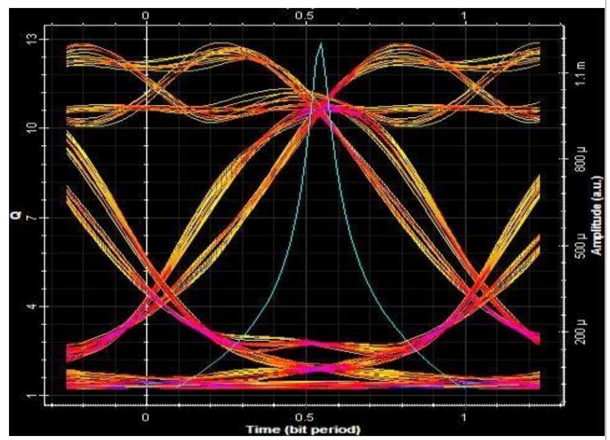
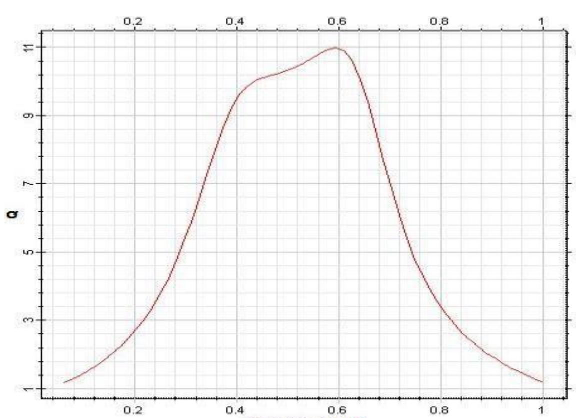
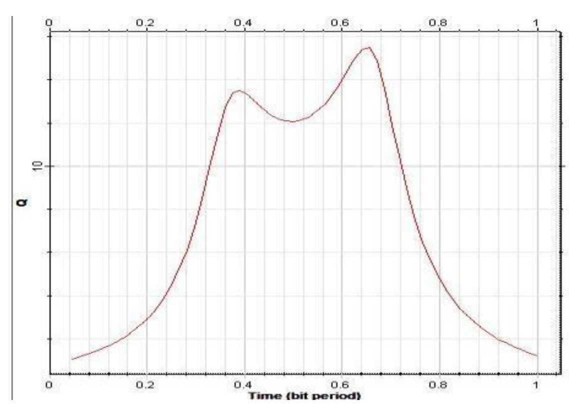
M'sila-Boussaada	M'sila -*BBA*
	

Table 14:The eye diagram of the four optical connections.

The eye diagram represents the synchronous superposition of all binary symbols of the transmitted sequence, with greater coherence and synchronicity indicating better transmission quality and less concentrated noise at the center. The MSILA-BBAlink is the poorest, as indicated by Table (III12).Noticeable noise and significant attenuation compared to other links are observed. ○ ***Quality Factor Q***

It is defined as the ratio of the frequency to the bandwidth of the system.

M'sila -HD	M'sila -Oulled Derradj
	

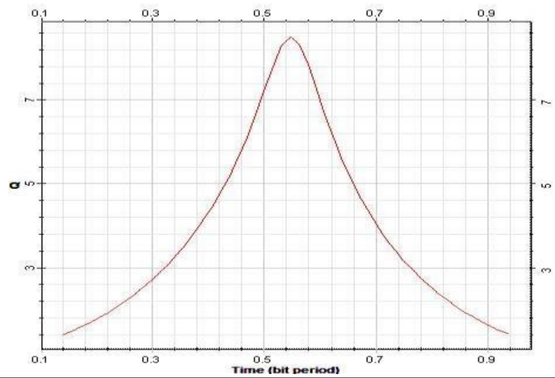
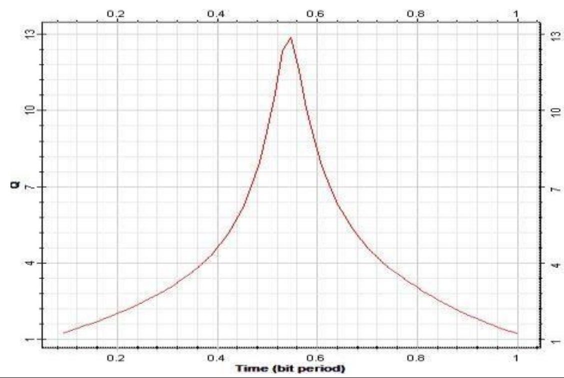
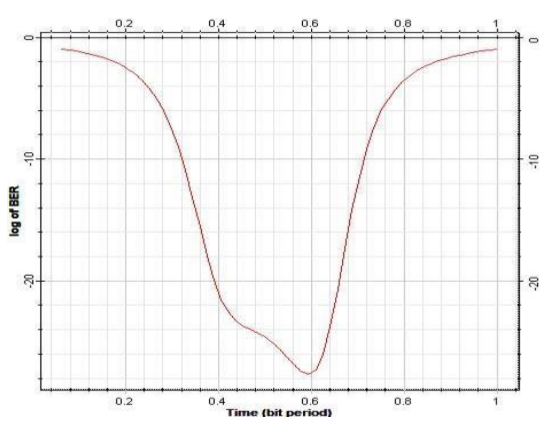
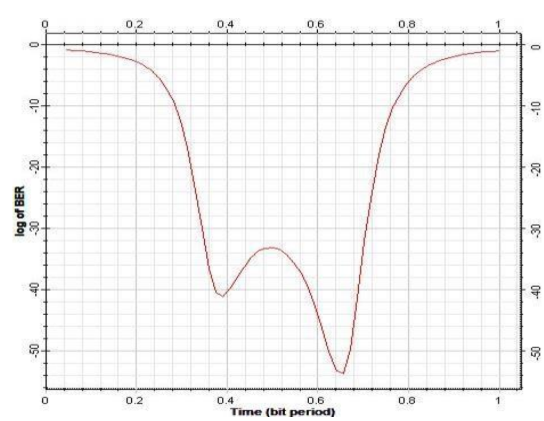
M'sila-Boussaada	M'sila -BBA
	

Table 15: Quality factor curve for each link.

Still, the optical link from M'sila-BBA provides poor replication, with the quality factor reaching only 13. In contrast, M'sila -HD link achieved a value of 11, and the M'sila-Oulled Derradj link reached a value of 16.

- ***The binary error rate (BER)***

Is defined as the number of erroneous bits over the total number of transmitted bits during the measurement period.

	
M'sila -HD	M'sila -Oulled Derradj

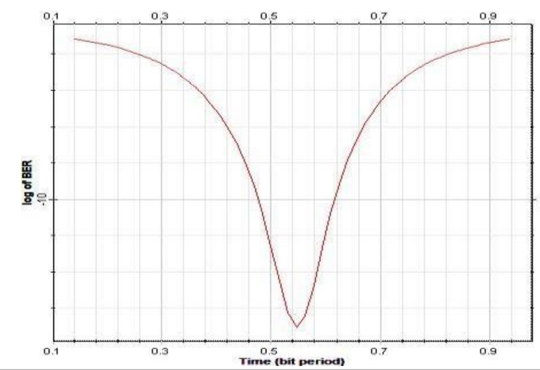
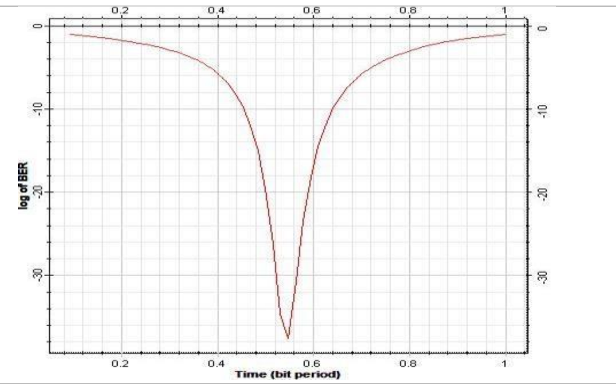
M'sila- Boussaada	M'sila -BBA
	

Table 16: Binary error rate trace of each link.

It is evident that M'sila -BBA link exhibits poor transmission quality due to its long distance, installation issues, road maintenance work, and the use of outdated optical fiber with crude quality.

M'sila -HD	M'sila -Oulled Derradj	M'sila–BBA	M'sila - Boussaada
Max. Q Factor 10.9856 Min. BER 2.11951e-028 Eye Height 0.000186183 Threshold 0.000100572 Decision Inst. 0.59375	Max. Q Factor 15.4905 Min. BER 2.0111e-054 Eye Height 0.000257773 Threshold 0.000171007 Decision Inst. 0.65625	Max. Q Factor 8.50499 Min. BER 8.8137e-018 Eye Height 0.00054523 Threshold 0.000617315 Decision Inst. 0.546875	Max. Q Factor 12.8786 Min. BER 2.63092e-038 Eye Height 0.000689028 Threshold 0.000754863 Decision Inst. 0.546875

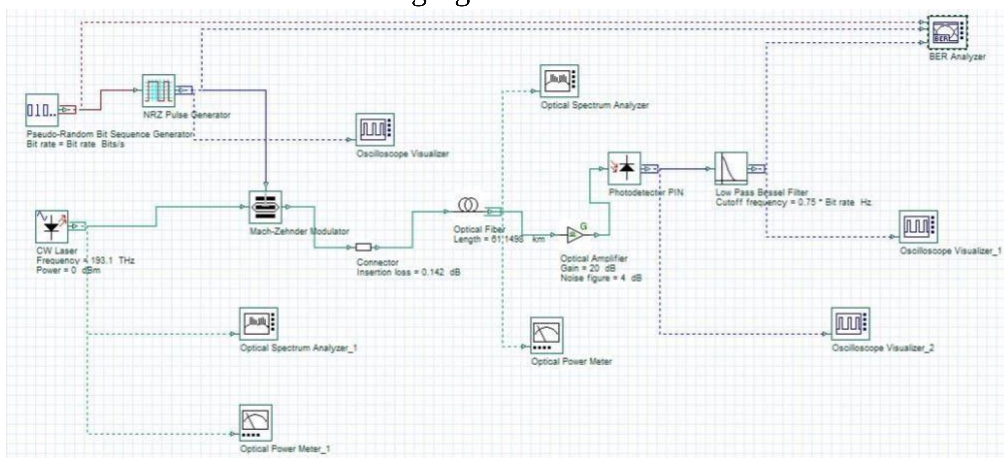
Table 17: Numeric values of the studied parameters.

III-5-2 The proposed optimization for problem solving

III-5-2-1 Attenuation Compensation

To improve the quality of optical links, amplification is used to compensate for attenuation. An optical amplifier (EDFA) is employed. The simulation of inserting an EDFA optical amplifier with a 20 dB gain and 4 dB connection losses in

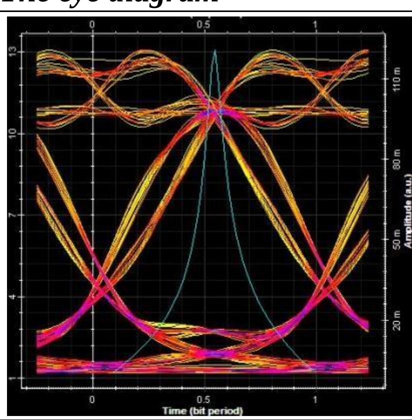
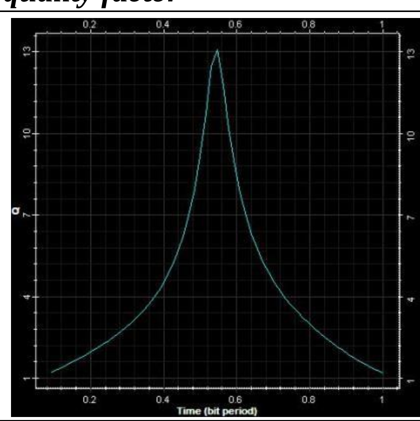
M'sila -BBA link is illustrated in the following figure:



Figure(III-22): The M'sila -BBA link with an EDFA optical amplifier.

- ***The eye diagram and quality factor of the M'sila-BBA link after amplification:***

The insertion of the amplifier in the optical link resulted in an improved quality factor when comparing the values in Table (III-18)with those in Table (III-17)The eye diagram confirms this clearly; there's a noticeable reduction of noise in the center of the diagram and a significant amplification.

The eye diagram	*quality factor*	*The different parameters*
		

Max. Q Factor	13.079
Min. BER	1.92574e-039
Eye Height	0.0690793
Threshold	0.0748658
Decision Inst.	0.546875

Table 18: The different characteristics after amplification of M'sila-BBA link.

III-5-2-2 Dispersion Compensation

These are fibers designed to have high negative dispersions through modifications to their geometric parameters. By adjusting the refractive index profile of the fiber, it is possible to control the dispersion and achieve a fiber with negative dispersion (up to -200 ps / (nm.km)), serving as a Dispersion Compensating Fiber (DCF). This technique is considered the best solution for minimizing penalties introduced by chromatic dispersion over a wide range of wavelengths. Let's start by calculating the length of the compensation fiber:

$$-L_{DCF} \times C_{DCF} = L_{DSF} \times C_{DSF} \quad \textbf{(III-1)}$$

Where;

LDCF: is the length of the dispersion compensating fiber.

CDCF: is the chromatic dispersion of the compensating fiber.

CDSF: is the positive chromatic dispersion of the transmission fiber.

LDSF: is the length of the transmission fiber.

LDSF = 61,1498 km CDSF

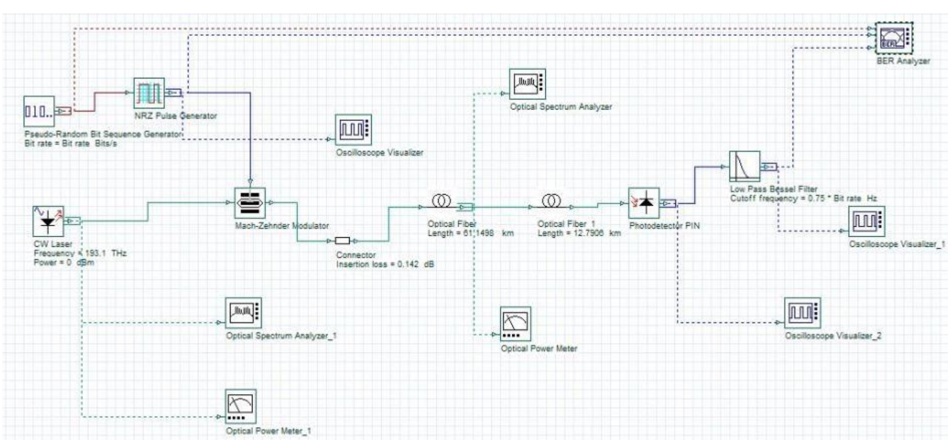
= 16.75 ps/nm*km.

CDCF = -80 ps/nm*km.

LDCF = 12.7906km.

Thus, to compensate for this amount of dispersion, we must add a compensating fiber at the end of the previous link, with a length of 12.7906km and a dispersion of -80 ps/nm.km, along with an attenuation of 0.6 dB/km.

- ***The measurement setup***



Figure(III-23): Measurement setup for the optical link with compensation.

- ***The eye diagram and quality factor of the M'sila-BBA link withcompensation***

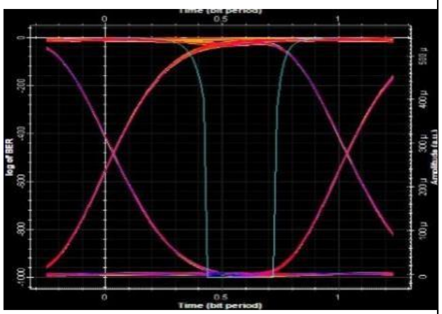
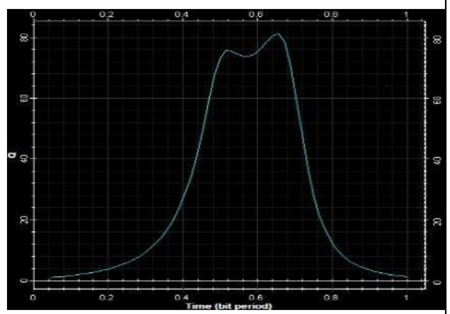
The eye diagram	***quality factor***	***The different parameters***
		Max. Q Factor: 81.2045 Min. BER: 0 Eye Height: 0.000512725 Threshold: 0.00018397 Decision Inst.: 0.4375

Table 19: The different characteristics with compensation of M'sila-BBA link.

After inserting the amplifier and the DCF compensating fiber, and based on the eye diagram and the quality factor, a considerable improvement in signal quality is observed.

III-6 Conclusion

The study of the four optical links with varying distances and topological conditions has led us to conclude that these parameters are inversely related to the quality of transmission rate. An excessive number of connectors implies splice losses, signal attenuation, and dispersion. These issues can be mitigated by:

- Minimizing the impact of difficult geographical conditions as much as possible.
- Adhering to standards when connecting optical fibers, generators, receivers, etc.
- Choosing routes away from road maintenance and pipeline work to avoid damage during maintenance activities.
- Using newer fibers with good physical quality.

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Conclusion

The advancements in the field of telecommunications are so significant and rapid that the solution for high-speed transmissions relies on the use of optical fiber transmission systems.

In our work, we conducted a practical study on optical links between **C.A. M'sila** and **C.T Hammam Dalaa, C.TBoussaada, C.T Oulled Derredj,** and **C.T BBA,** with distances of 23.6688 km, 77.0192 km, 61.1498 km, 32.6090 km and 77.0192 km respectively.

To do this, we used an Optical Time Domain Reflectometer (OTDR) to detect and locate various anomalies that could disrupt transmission.

The optical link stimulation in our study was performed using Optisystem software.
After establishing real optical connections simulation between four links and measuring the losses, we compared the results with those obtained from the OTDR.

- We checked the similarity between the simulation results and the those obtained from the OTDR
- DCF is considered the best solution for minimizing losses introduced by chromatic dispersion over a wide range of wavelengths
- Choosing routes away from road maintenance and pipeline work to avoid damage during maintenance activities
- Using newer fibers with good physical quality
- Adhering to standards when connecting optical fibers, generators, receivers, etc
- This study demonstrated improved performance of the C.A. M'sila/ C.T Oulled Derradj link.

ملخـــــص :

سلك الألياف البصرية هو خيط رفيع جِدًا مصنوع من الزجاج أو البلاستيك يتميز بخاصية كونه موص لاً للضوء ويستخدم في نقل البيانات والضوء. يوفر معدل نقل المعلومات بشكل كبير مقارنة بالكابلات المتعامدة ويمكن أن يكون متوسطًا لشبكة "النطاق العريض" التي تمر من خلالها التلفزيون والهاتف والفيديو المؤتمري وبيانات الكمبيوتر.

بدأ عملنا بإنشاء اتصالات بصرية حقيقية بينM'sila.A.C و C.T Hamam DalaaC.T BBA,C.T. C.T Oulled Derredj ,Boussaada , ثم قمنا بقياس الخسائر التي تكبدناها عن طريق مقارنتها مع النتائج التي تم الحصول عليها من جهاز قياس الضوء البصري التصاعدي) OTDR(. كشفت هذه الدراسة عن تشابه بين نتائجنا وتلك التي تم الحصول عليها من OTDR.

تعُتبر ألياف التعويض للتشتت)DCF(الحل الأمثل لتقليل العقوبات التي تفرضها التشتت الطيفي عبر مجموعة واسعة من الطول الموجي. من المهم بشكل خاص في هذا السياق تحديد المصادر الرئيسية للتخفيض والتشتت في النظام وكذلك تعزيز أدائه من خلال تقليل هذه المصادر من الضوضاء من أجل تحقيق جودة الناتج المرغوبة مع الحفاظ على نسبة "الجودة/ الناتج" عن بعُد طويل.

Abstract

An optical fiber is an extremely thin strand made of glass or plastic that possesses the property of being a conductor of light and is used in the transmission of data and light. It provides a significantly higher information transfer rate compared to coaxial cables and can serve as a medium for a "broadband" network through which television, telephone, video conferencing, and computer data can all be transmitted.

Our work initially involved establishing real optical connections between***C.A. M'sila*** and ***C.T Hammam Dalaa, C.T BBA, C.T. Boussaada, C.T Oulled Derredj,*** and then measuring the losses incurred by comparing them with the results obtained using the OTDR. This study revealed a great similarity between our results and those obtained by the OTDR.

Dispersion compensation fiber (DCF) is considered the best solution for minimizing penalties introduced by chromatic dispersion over a wide range of wavelengths. It is particularly important for this approach to identify the main sources of attenuation and dispersion in the system and also to enhance its performance by reducing these sources of noise in order to achieve the desired throughput quality while maintaining the "Quality Throughput / Long Distance" ratio.

Résumé

Une fibre optique est un fil en verre ou en plastique très fin qui a la propriété d'être un conducteur de la lumière et sert dans la transmission de données et de lumière. Elle offre un débit d'information nettement supérieur à celui des câbles coaxiaux et peuvent servir de support à un réseau « large bande » par lequel transitent aussi bien la télévision, le téléphone, la visioconférence ou les données informatique.

Notre travail a tout d'abord consisté à développer des liaisons optiques réelles entre***C.A. M'sila*** *et* ***C.T Hammam, Dalaa, C.T BBA, C.T. Boussaada, C.T Oulled Derredj,*** et puis de relever les pertes enregistrées en les comparant avec les résultats de l'OTDR. Cette étude a permis d'observer une similitude entre nos résultats et ceux de l'OTDR.

La fibre de compensation de dispersion (DCF) est considérée comme la meilleure solution pour minimiser les pénalités introduites par la dispersion chromatique sur une large gamme de longueurs d'onde. Il est important en particulier que cette approche puisse déterminer les principales sources d'atténuation et de dispersion, dans le système et aussi d'améliorer ses performances en réduisant ces sources de bruit afin d'obtenir la qualité de débit souhaitée toute en gardant le rapport « Qualité Débit / Large Distance ».