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Theme

Study and Simulation of an Optical Fiber Transmission Chain

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Dedication

We dedicate this humble work to the entire DJAFOUR and KAMECHE families.

And to everyone who has supported us, both near and far.

Abstract

This thesis focuses on the study and optimization of optical fiber links, which are integral to modern telecommunications due to their high transmission speeds and low transmission losses. Optical fibers are emphasized for their role in high-speed data transmission, with a particular focus on overcoming challenges such as attenuation and dispersion.

The work begins with a theoretical study of optical fibers, detailing various types and their physical characteristics. Practical experience was gained at the SONATRACH Technical Center, where transmission techniques, testing, and control methods were learned.

Two specific optical links of different topologies, including the HBK-BKH and GLA-HBK links, were studied. The Optical Time-Domain Reflectometer (OTDR) was used to acquire the specific characteristics of each link, identifying issues like breaks and poor splices, and providing continuous descriptions of bitrate and power levels.

These parameters were confirmed through simulations using the OPTISYSTEM software, which is designed to perform numerous system tests and optimize the design of optical communication systems. The primary objective of this thesis is to study and simulate the transmission systems to enhance the efficiency and reliability of two vital communication links.

Résumé

Cette thèse se concentre sur l'étude et l'optimisation des liaisons par fiber optique, qui sont essentielles aux télécommunications modernes en raison de leurs vitesses de transmission élevées et de leurs faibles pertes de transmission. Les fibers optiques sont mises en avant pour leur rôle dans la transmission de données à haute vitesse, avec une attention particulière aux défis tels que l'atténuation et la dispersion.

Le travail commence par une étude théorique des fibers optiques, détaillant les différents types et leurs caractéristiques physiques. Une expérience pratique a été acquise au Centre Technique de SONATRACH, où des techniques de transmission, des méthodes de test et de contrôle ont été apprises.

Deux liaisons optiques spécifiques de topologies différentes, y compris les liaisons HBK-BKH et GLA-HBK, ont été étudiées. Le Réflectomètre Optique dans le Domaine Temporel (OTDR) a été utilisé pour acquérir les caractéristiques spécifiques de chaque liaison, identifier des problèmes tels que les ruptures et les mauvaises épissures, et fournir des descriptions continues des débits et des niveaux de puissance.

Ces paramètres ont été confirmés par des simulations utilisant le logiciel OPTISYSTEM, conçu pour effectuer de nombreux tests de système et optimiser la conception des systèmes de communication optique. L'objectif principal de cette thèse est d'étudier et de simuler les systèmes de transmission afin d'améliorer l'efficacité et la fiabilité de ces liaisons de communication essentielles.

الملخص

تركز هذه الأطروحة على دراسة وتحسين روابط الألياف الضوئية، التي تعتبر جزءًا لا يتجزأ من الاتصالات الحديثة نظرًا لسرعات النقل العالية والخسائر المنخفضة في الإرسال. تُبرز الألياف الضوئية لدورها في نقل البيانات عالية السرعة، مع التركيز بشكل خاص على التغلب على التحديات مثل التوهين والتشتت.

يبدأ العمل بدراسة نظرية للألياف الضوئية، حيث يتم تفصيل الأنواع المختلفة وخصائصها الفيزيائية. تم اكتساب خبرة عملية في المركز التقني لشركة سوناطراك، حيث تم تعلم تقنيات الإرسال وطرق الاختبار والتحكم.

تمت دراسة ثلاث روابط بصرية محددة ذات مسافات وتضاريس مختلفة، بما في ذلك روابط حوض بركاوي المتجهة الى حوض قلالة وحوض بنكحلة.

للحصول على الخصائص المحددة لكل رابط، (OTDR) تم استخدام جهاز قياس الانعكاس البصري في النطاق الزمني . وتحديد المشاكل مثل الانقطاعات والوصلات الرديئة، وتوفير وصف مستمر لمعدل البتات ومستويات الطاقة

تم تأكيد هذه المعلمات من خلال المحاكاة باستخدام برنامج اوبتيسيستام المصمم لإجراء العديد من اختبارات النظام وتحسين تصميم أنظمة الاتصال البصرية. الهدف الرئيسي من هذه الأطروحة هو دراسة ومحاكاة أنظمة الإرسال لتحسين كفاءة وموثوقية هذه الروابط الحيوية للاتصالات .

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List of acronyms:

HBK: Haoud berkaoui

BKH: Benkahla

GLA: Guelalla

FO: Fiber Optic.

SONET-SDH: Synchronous Optical Networking – Synchronous Digital Hierarchy.

SMF: Single Mode Fiber

PMD: polarization modal dispersion.

BER: Bite error rate.

OTDR: optical time domain reflectometer.

NRZ: No return to zero.

RZ: Back to zero.

LED: light emitting diodes.

DL: Laser diode

LASER: Light Amplification by Stimulated Emission of Radiation

EDFA: Erbium-Doped Fiber Amplifier - Erbium Doped Fiber Amplifier

SAO: Semiconductor- Amplifier

WDM: Wavelength Division Multiplexing

PIN: photodiode

APD: Avalanche Photodiode

DCF: Dispersion compensation fiber.

DCM: Dispersion compensation module.

GI-FO: Gradient-Index Multimode FIBER

LC: Lucent Connector

SC: Standard connector

MTP: Multi-fiber Termination Push-on

ST(BFOC): Bayoneted optical fiber Connector

FC: fiber connector

PC: Physical Contact

APC: Angled Physical Contact

UPC: Ultra Physical Contact

IPA: isopropyl alcohol

IEC: International Electrotechnical Commission

TIA: Telecommunications Industry Associations

OTN: Optical Transport Network

PTMP: point-to-multipoint

PTP: point-to-point (PTP)

DTT: Digital terrestrial television

General introduction

The rapid growth of information technology and the increasing demand for high-speed data transmission have significantly impacted telecommunications systems worldwide. With the advent of numerous multimedia services and applications, there is a burgeoning need for substantial transmission capacities to handle the vast amounts of data exchanged daily. Optical fiber has emerged as a cornerstone of modern communication systems due to its numerous advantages, including high bandwidth, low transmission loss, and the ability to transmit data over long distances without significant degradation.

Optical fiber telecommunication links perform several essential functions: signal generation (transmitter), propagation (transmission, amplification, and routing of data), and detection at the receiving end. These links are critical for the efficient and reliable transmission of data, making them the backbone of contemporary telecommunications infrastructure.

The primary objective of this thesis is to enhance the understanding and performance of optical fiber links, ensuring they can meet the growing demands of modern telecommunications. Through a combination of theoretical study, practical application, and advanced simulation, this research aims to contribute to the development of more efficient and reliable optical communication systems.

This work is presented in four chapters, the first chapter lays the groundwork by explaining the operating principles of optical fiber and its structure. We provide an overview of the types of optical fibers, their differences, and applications. We identify attenuation and dispersion as the most significant transmission issues and explore various types of dispersion. Additionally, we delve into the optical transmission system from source to receiver and discuss multiple types of amplifiers.

In the second chapter, we delve into the concept of fiber optic testing, including procedures and tools. Starting from connectors and their types, we discuss inspection and cleaning techniques. We identify the tools used in enterprises for testing their links, such as optical power meters and Optical Time Domain Reflectometers (OTDRs), and explain how to calculate acceptable link loss. We also cover different types of splicing and examine transmission technologies like Synchronous Digital Hierarchy (SDH), Wavelength Division Multiplexing (WDM), and Optical Transport Network (OTN).

Chapter three initiates the testing phase of our links, focusing on two specific links: the BERKAOUI (HBK) – BENKAHLA (BKH) link and the BERKAOUI (HBK) – GELALA (GLA) link. This study employs an OTDR MTS 4000 device to examine multiple events and traces across different wavelengths (1310 and 1550) to determine the optimal choice for transmission of digital terrestrial television (DTT) signals to other sites relies on fiber optic support.

The final chapter aims to analyse the optical links discussed in chapter three and identify compromised parameters using Optisystem software. Understanding and optimizing these parameters are crucial for ensuring efficient and reliable communication over optical fiber networks.

Chapter I:

Optical Communication System.

I.1   Introduction

The optical fiber, a thin strand of highly transparent glass, has revolutionized telecommunications since its discovery in the 1960s due to its low attenuation, lightweight, small size, and mechanical resistance. Nowadays, optical fiber is a medium used to transmit all types of digital data, such as Ethernet packets, sound, video, and more.

Because of their properties enabling communication 100 times faster over very long distances through previously unattainable high data rates.

In 1970, three scientists from Corning Glass Works in New York, Robert Maurer, Peter Schultz, and Donald Keck, produced the first optical fiber with phase losses low enough to be used in telecommunication networks (20 decibels per kilometre, today conventional fiber exhibits losses of less than 0.25 decibels per kilometre for the 1550 nm wavelength used in telecommunications). Their optical fiber could carry 65,000 times more information than a simple copper cable, corresponding to the ratio of the wavelengths used [1].

The primary role of fibers is to propagate light with as minimal attenuation as possible from a transmitting module to a receiving module. Therefore, they involve a highly complex and sophisticated technology. In this chapter, we will first address the evolution of transmission and the various elements of an optical fiber link. Initially, we will describe an optical transmission system, its operating principle, different types, characteristics, as well as its advantages and disadvantages.

I.2   Optical Fiber

Optical fiber is an elongated cable composed of hundreds of strands of ultra-pure glass, each measuring the diameter of a human hair. These strands have the capability to transmit light signals over hundreds or even thousands of kilometers and are safeguarded by a protective sheath.

At the core of the optical fiber lies the core, the region through which light will propagate. The optical sheath surrounding the core serves to reflect and guide the light. Simultaneously, the insulating sheath acts as a protective barrier, shielding the fiber from moisture, dirt, and other environmental factors. [2]
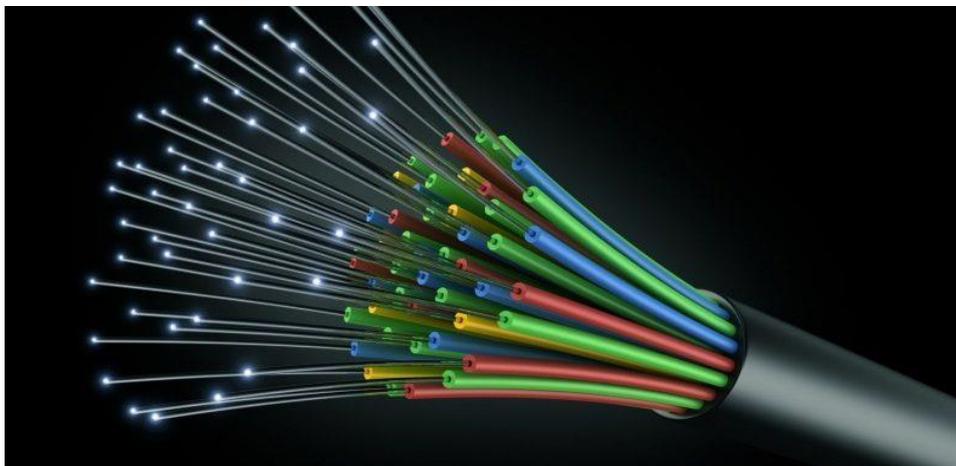
Figure I.1 Fiber Optic

I.2.1   Operating principle of optical fiber

The operating principle of an optical fiber is based on multiple total internal reflections of light at the interface between two media. [3]

If $n_2 > n_1$, the ray deviates from the normal, and if $\theta_1 > \arcsin\left(\dfrac{n_1}{n_2}\right),$ total reflection occurs.

This principle was demonstrated by Snell-Descartes, who established the following relationship: $n_1 \sin\theta = n_2 \sin\theta$
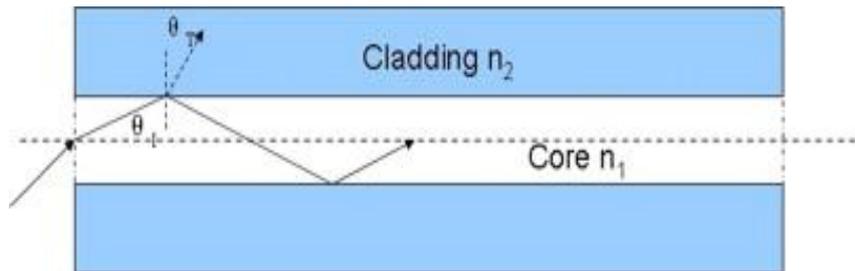
Figure I.2 Angle of incidence upon entry into an optical fiber

The maximum angle of incidence (α_{max}) at the entry of a fiber, that is the numerical aperture, is defined by the following relationship:

$$NA = \sin\alpha_{max} = n_1 \sin\left(\frac{\pi}{2} - \theta_{lim}\right) = \sqrt{n_1{}^2 + n_2{}^2}$$

I.2.2   Structure

The optical fiber comprises three main components (as illustrated in Figure 1.3): the core, the cladding, and the protective coating. [4]

- **The Core**: This is the light transmission channel, through which light travels.

- **The Cladding**: Surrounding the core, the cladding is a layer that helps maintain the losses of light rays.

- **Protective Coating**: Composed typically of plastic, the protective coating covers both the core and the cladding. Its purpose is to ensure the protection of the fibers shape and curvature [3].

4
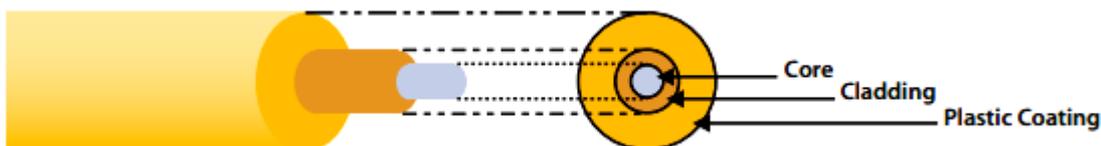
Figure I.3 The composition of Optical fiber

I.3 Types of Optical Fiber

Optical fibers can be classified into two main categories based on their diameter and wavelength: multimode and single-mode**.**
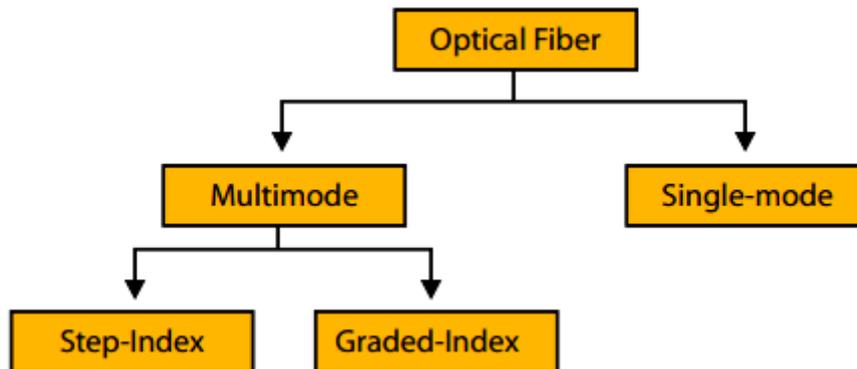
Figure I.4 Type of glass fiber

I.3.1   Single-Mode Fibers

At present, the most advanced type of existing fiber is the single-mode fiber, widely utilized in the cores of global networks. It operates with a single mode of propagation, specifically the straight-line mode, but its manufacturing costs are high.

The single-mode cable exhibits a singular type of dispersion, with only one wavelength in the core. The core is extremely thin, comparable to the diameter of a hair at 10µm. This thinness ensures no interference or overlap, and the attenuation is nearly negligible. This characteristic is a major strength, offering a significantly higher data transfer rate compared to multimode fibers. [5]
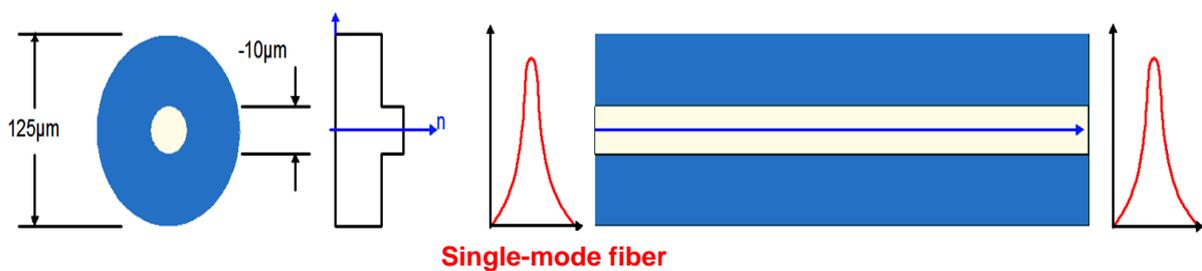
Single-mode fiber

Figure I.5: Single-mode fiber

- **OS1 and OS2 single mode fiber:**

Single mode fiber cable is categorized into **OS1** and **OS2** fiber cable. These two kinds of fiber cables have different characteristics for diverse applications. OS2 SMF cables cannot be connected with OS1 SMF cables, which may lead to poor signal performance.

The main difference between OS1 and OS2 fiber optic cables is primarily in their cable construction, not their optical fiber specifications.

OS1 type cables are typically of a tight buffered construction, where the optical fibers are surrounded by a tight-fitting buffer material, such as a plastic coating, to protect them from external damage. This construction is typically used for short-distance applications and provides a high level of protection for the fibers.

OS2 type cables are typically of a loose tube or blown cable construction, where the optical fibers are placed inside a loose-fitting tube, or are blown into a tube, rather than being tightly buffered. This construction is typically used for long-distance applications and allows the fibers to move freely inside the tube, reducing the amount of stress on the fibers. [6]

It's worth to mention that the tight buffered construction is more robust and easier to handle, while the loose tube construction is more flexible and allows the use of more fibers in the same cable.
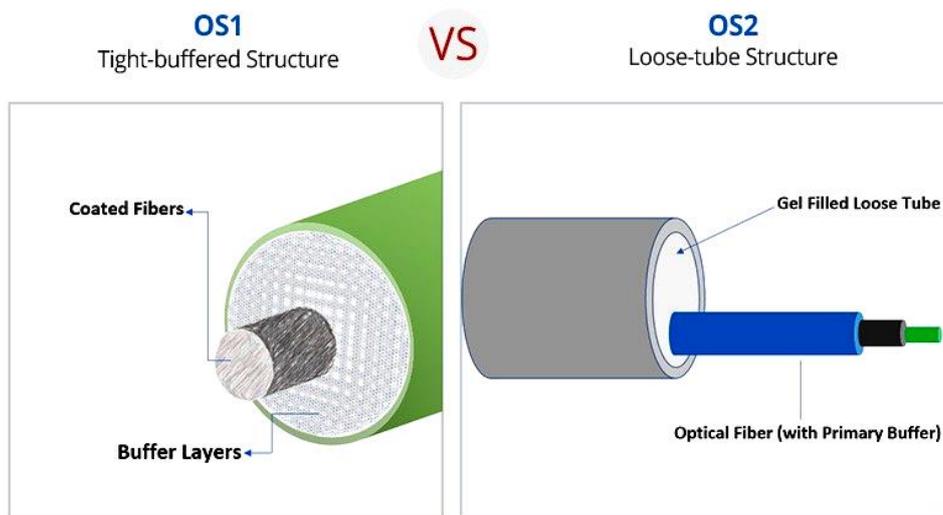
Figure I. 6 : OS1 and OS2 difference structure

The attenuation of OS2 fiber is much lower than that of OS1. In general, OS1 has a maximum attenuation of 1.0dB/km, while OS2 attenuation is only 0.4dB/km—the difference in attenuation results in different transmission distances. OS1 single mode fiber has a maximum transmission distance of 10 km, while OS2 can reach a maximum transmission distance of 200 km – far more than another. Due to this advantage, OS2 is widely used in practical fiber optic cabling.

In summary, the choice of OS1 or OS2 fiber optic cable depends on the application and the distance that the signal needs to travel, as well as the level of protection and flexibility required for the fibers. [6]

Table I.1 OS1 and OS2 difference standard

	OS1	OS2
Standards	ITU-T G.652A/B/C/D	ITU-T G.652C/G.657.A1 (part)
Cable Construction	Tight Buffer	Loose Tube
Application	Indoor	Outdoor
Attenuation	1.0db/km	0.4db/km
Max. Distance	10 km	200 km
Price	Low	High

I.3.2   Multimode Fibers

Multimode fibers offer the advantage of transmitting multiple modes (light paths). Within this category, two subcategories can be identified:

- **Step-Index Optical Fibers**

These fibers are characterized by a large core diameter and a high numerical aperture, enabling the entry of a significant amount of light into the optical fiber. They are utilized for short-distance information transfer with limited bandwidth. Step-index multimode fibers are cost-effective, making them suitable for specific applications where cost considerations play a crucial role.
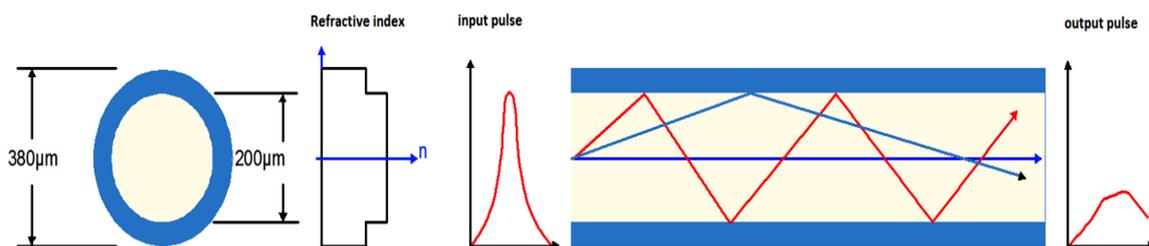
Figure I.7: step-index fiber

- **Gradient-Index Multimode Fiber (GI-FO):**

The Gradient-Index Multimode Fiber is employed in Local Area Networks (LANs). Its core consists of multiple layers of material with a slightly higher refractive index. These layers influence the direction of light propagation due to their elliptical shape.

The attenuation in this type of fiber is lower compared to step-index fibers, thanks to the intermediate size of its core. The figure below illustrates a Gradient-Index Multimode Fiber
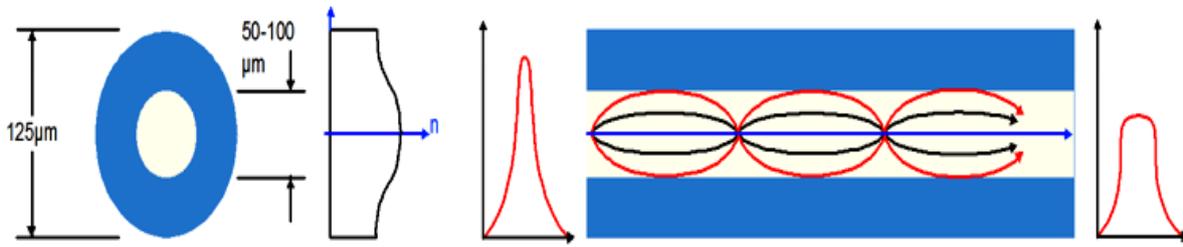
Figure I.8: gradient index fiber

I.4   Advantages and Disadvantages of Optical Fiber

Optical fiber offers numerous advantages for telecommunications:

• Transmission of digital information over long distances with very low loss, usually due to cable splicing.

• Optical fiber has a very high bandwidth that can reach up to 100 Gbit.

• Extremely high data transfer rates, 100 times higher compared to coaxial cable.

• Speeds 100 times faster than other transmission means.

• Known for its insensitivity to radio frequency disturbances and electromagnetic interference, resulting in no interruptions or interference.

• Cost-effectiveness: Optical fiber has a long lifespan, up to 20 years.

• Implementation advantages: Very small size, high flexibility, and low weight.

• Possible multiplexing of multiple signals, allowing systems to have a capacity far superior to that of conductive cables. [7]

    However, optical fiber has few drawbacks. Its main disadvantage remains its price, coupled with the manufacturing difficulty due to its highly specialized technology.

I.5   Transmission Issues:

In the realm of optical fiber communications, several transmission issues can impact the efficiency and reliability of data transmission. Two primary concerns are attenuation and dispersion, both of which can significantly degrade the performance of optical fiber links.

I.5.1   Attenuation:

Attenuation corresponds to a decrease in the power of the transmitted signal. Indeed, the power level of a signal propagating through an optical fiber weakens exponentially depending on the propagation distance. Attenuation is often expressed in decibels per kilometer and is given by the following expression:

$$\alpha = \frac{10}{L} \log\left(\frac{P_{in}}{P_{out}}\right)$$

where **P*in*** is the injected power at the input, **P*out*** is the measured power at the output, and **L** is the length of the optical fiber. The maximum distance between the transmitter and the receiver (or between the amplifiers) depends heavily on the constant A and the optical power transmitted by the transmitter. [8]
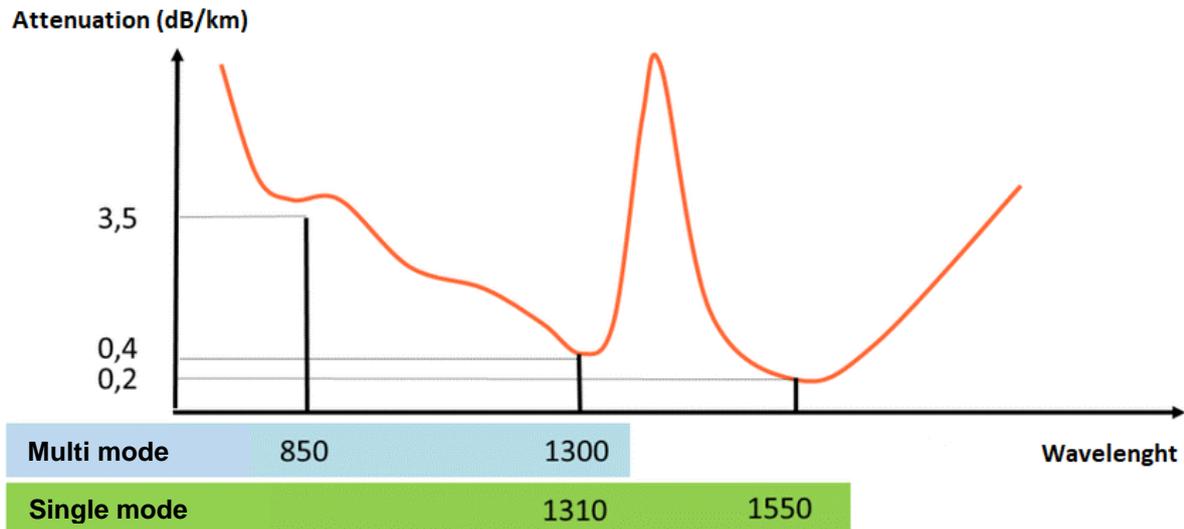
Figure I.9: Linear losses as a function of wavelength

A minimum is observed around 1550 nm. At this wavelength, fiber losses can reach values lower than 0.2 dB/km. For comparison, the attenuation of electrical cables is typically in the range of 100 to 1000 dB/km.

The attenuation of optical fiber (made of silica) is due to several causes. On one hand, light is partially absorbed by the material in the infrared and ultraviolet regions. Additionally, a residual amount of water, incorporated as OH- ions during manufacturing, can cause an attenuation peak, clearly visible in Figure I.15 around 1.4 μm.

Furthermore, inhomogeneities in the material (silica matrix) are responsible for partial light scattering, known as Rayleigh scattering. The curve in Figure II.15 reveals favored wavelengths. Near λ=1.31 μm, there is a relative minimum in propagation losses, while near λ=1.55 μm, the losses are the lowest.

This is why optical fiber telecommunications primarily operate around the latter wavelength (1.55 μm). The attenuation is then around 0.2 dB/Km, which means light can travel 100 km before its power level is reduced by a factor of 100.

Attenuation in optical fiber has several origins; the figure below presents the various mechanical and technological constraints that can affect the losses of optical fibers.
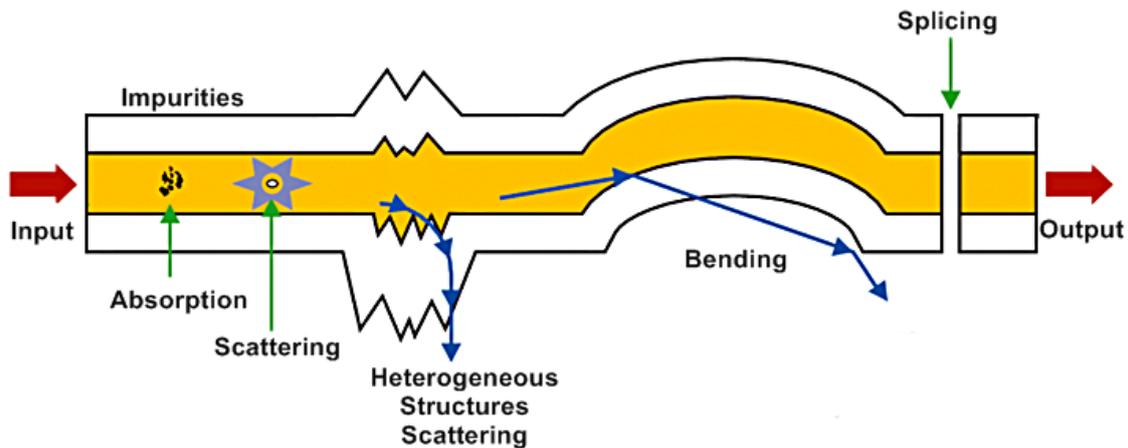
Figure I.10: Summary diagram of the different types of losses in an Optical fiber

- **Absorption**

Losses in optical fiber are the major cause of optical fiber losses during transmission. When the photon interacts with the components of the glass, an electron, or metal ions, the light power is absorbed and transferred into other forms of energy like heat, due to molecular resonance and wavelength impurities.

- **Scattering losses:**

Scattering losses in optical fiber are due to microscopic variations in the material density, compositional fluctuations, structural inhomogeneities, and manufacturing defects.

- **Bending:**

Is a common problem that can cause optical fiber losses generated by improper fiber optic handling, there are two basic types, one is micro bending, and the other one is macro bending Macro bending refers to a large bend in the fiber (with more than a 2mm radius).

- **splicing losses:**

Is another type of loss in optical fiber, by joining two optical fibers end-to-end, splicing aims to ensure that the light passing through it is almost as strong as the virgin fiber itself, but no matter how good the splicing is, the splicing loss is inevitable. Fusion splicing losses of multimode fiber are 0.1-0.5 dB, 0.3 dB being a good average value, for single mode fiber, the typical fusion splicing loss can be less than 0.05 dB.

- **Connector losses:**

When two optical fibers are connected end-to-end, point losses occur; these losses are due to longitudinal separation, radial misalignment, angular misalignment, core eccentricity, or core ellipticity, as shown in the figure below. [7]

10
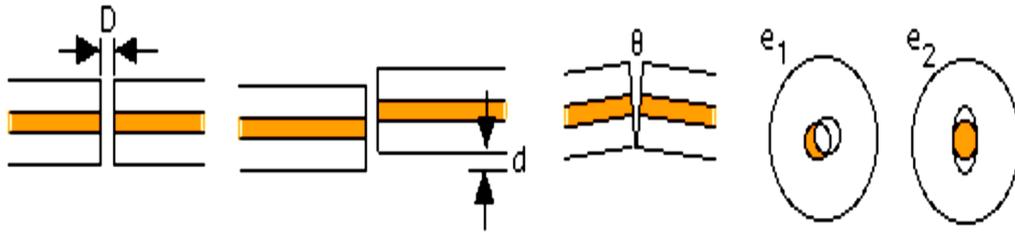
Figure I.11: Connection losses

I.5.2   Fiber Optic Dispersion

The propagation of the pulse in linear regime within a fiber optic undergoes a phenomenon of dispersion, which manifests as a temporal spreading and a reduction in the modulation amplitude of its high frequencies
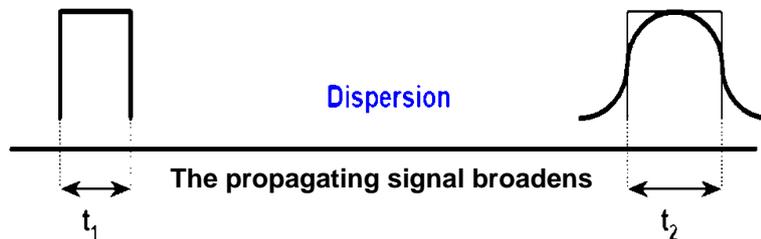
Figure I. 12: Evolution of the pulse during its propagation in the FO.

The phenomena that cause signal distortion during its propagation in the fiber are of three types: modal dispersion, chromatic dispersion, and polarization dispersion.
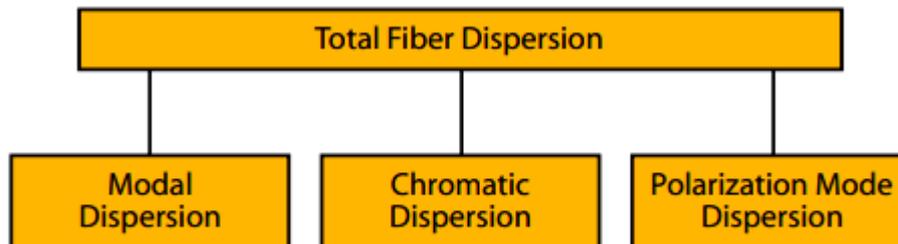
Figure I.13: The different types of dispersion

I.5.2.1   Modal dispersion

Or intermodal, typically occurs in multimode fibers; it does not exist in single-mode fibers. It arises from the difference in propagation time of light traveling through the optical fiber depending on the paths taken.

When using a multimode fiber, light can take multiple paths (modes) as it propagates through the fiber. The distance travelled by certain modes is therefore different from the distance travelled by other modes. When a pulse is sent into the fiber, it decomposes into the different modes. Some components (modes) thus arrive before others, causing the pulse to spread out. [9]

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I.5.2.2   Chromatic dispersion

Is due to the variation in the propagation velocity of different spectral components of the transmission signal. In fact, each light pulse consists of a finite number of wavelengths that propagate differently. Therefore, chromatic dispersion arises from the variation in the refractive index with the wavelength.

Chromatic dispersion results from the sum of two effects:

material dispersion: The broadening is caused by the fact that the refractive index of glass is not the same for all wavelengths. This dispersion exists in all optical fibers, whether they are single-mode or multimode, and it is very small at a wavelength of about 1300 nm.

guide dispersion: The latter stems from the evolution of the mode propagation constant, relative to the refractive index, according to the values of the optical frequency of the signal carrier.

It limits the distance over which a signal can be transmitted without electronic regeneration of the original signal. This distance, called the dispersion limit, is given by the following relationship: $L_D \approx \dfrac{1}{2 * BD\Delta\lambda}$

Where B represents the transmission rate. Therefore, chromatic dispersion also limits the rate of an optical link. [9]

I.5.2.3   Polarization mode dispersion (PMD)

Is a modal dispersion in which two orthogonal polarization modes of light at the same wavelength propagate at different speeds due to the birefringence of the fiber, also causing a broadening of light pulses. PMD results in temporal jitter, the effects of which on the receiver are more detrimental as the rate increases. [10]
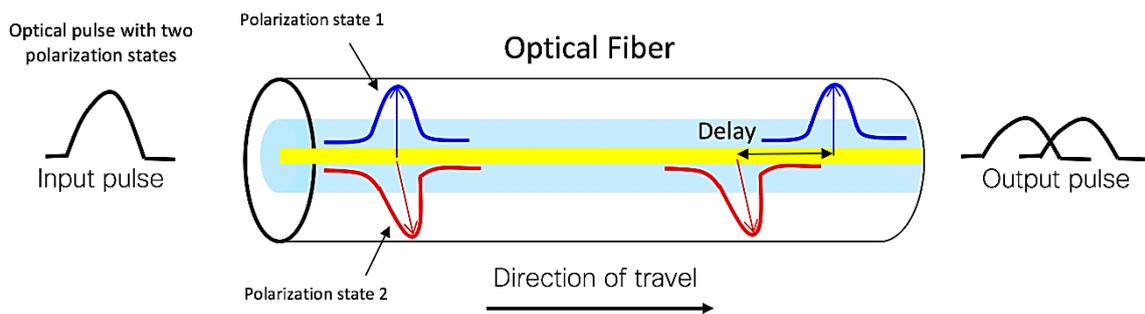
Figure I.14: Polarization dispersion

I.6   Optical Fiber Transmission System

Long-distance telecommunication systems employ ultra-fast technologies. For optical fiber transmission, there exists a transmitter and a receiver connected by an optical channel, which comprises two optical fibers: one for transmission (on the transmitter side) and the other for reception.

Information is carried over the optical channel (the fiber), with two transponders located at the ends. These transponders exchange information between them. Their function is to convert electrical impulses into optical signals along the core of the optical fiber.

Electrical signals are translated into optical impulses by a LED and then detected by a phototransistor or a photodiode.
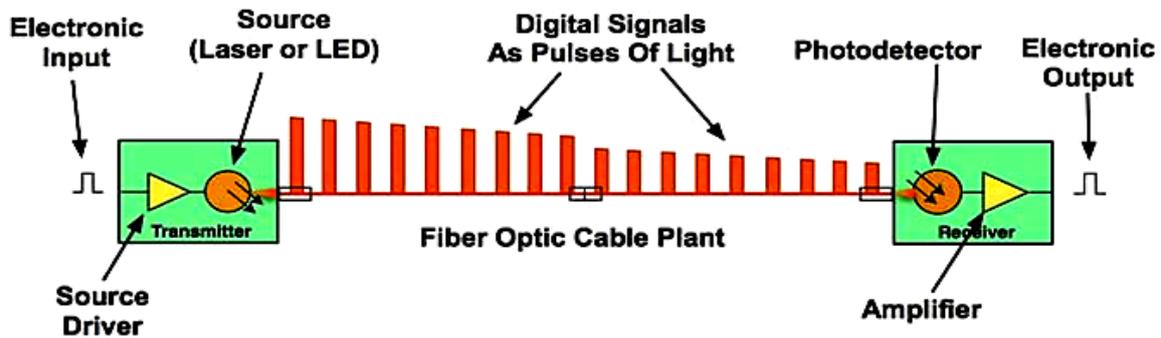
Figure I.15 Basic diagram of an optical transmission link.

I.6.1   Optical Emission:

The emission part of an optical link comprises various elements such as power supply, modulator, and an electro-luminescent light source or laser.

The role of the emission module is to deliver to the transmission channel an optical signal on which the data to be sent are encoded.
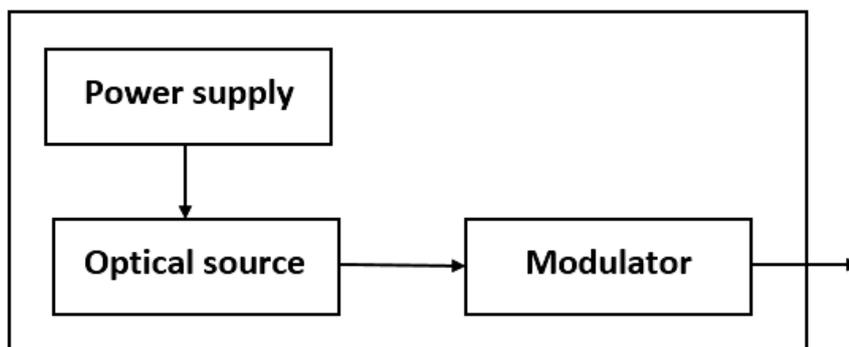
Figure I. 16 Basic diagram of an Optical emission.

There are three types of transmitters used in fiber optic transmission:

- **Light Emitting Diodes (LED)**, which operate in the near-infrared range (850 nm).
- **Lasers**, used for single-mode fiber, with wavelengths of 1310 nm or 1550 nm.
- **Infrared diodes** emitting at 1300 nm.

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The essential factor in choosing optical transmitters is semiconductors due to their small size and high transmission reliability, as well as achieving efficient coupling between the transmitter and the fiber.

In a semiconductor, an electron can transition from one energy band to another through the emission and absorption of a photon.

For high-speed fiber optic links and long distances, the most commonly used light emitter is the laser diode.

I.6.1.1   Optical sources:

Optical sources are active components in optical fiber transmission systems. Their primary function is electro-optic conversion, which means converting electrical energy into optical energy.

> ### THE LIGHT EMITTING DIODE (LED):

If we look around us, we'll find light emitting diodes everywhere. They can be found in green, yellow, or red in vehicles, computer hardware, phones, or any electronic device.

A Light Emitting Diode (LED) is the simplest emitting component. It is based on spontaneous emission, and the light produced at its output is characterized by a wide spectrum and low directionality. It is used in transmission systems that do not require very large bandwidths.

> ### THE LASER DIODE:

A laser diode is a component capable of producing radiation through stimulated emission, as indicated by the acronym, which stands for "Light Amplification by Stimulated Emission of Radiation." It is a coherent and monochromatic source, with a very wide bandwidth and a narrow spectral width. It is used in very long-distance transmission systems.

There are different types of laser diodes: Fabry Perot (FP) lasers, Distributed Feedback (DFB) lasers, and Vertical-cavity Surface Emitting Lasers (VCSELs). These laser diodes typically have a small size, good spectral quality, low energy consumption, and an adjustable wavelength compatible with the transmission windows of optical fibers. [10]

❖ The light-emitting diode (LED) is favored for the design of optical communication links over short distances, considering its low cost and ease of implementation. However, the laser diode is the most suitable source for optical telecommunications because it allows for the best optical coupling efficiency with the fiber.

I.6.1.2   The Modulators

To transmit data through an optical fiber, this data must first be encoded or modulated. There are mainly two techniques: direct (internal) modulation and external modulation. [11]

• **Direct Modulation(internal):**

In this type of modulation, it is the optical source that performs the modulation in addition to the electro-optical conversion.

Direct modulation has the advantage of being simple, easy to implement, efficient, and inexpensive. It requires low voltage and low power.

The disadvantage of this modulation is that when modulating the injection current of a laser in amplitude, it is accompanied by unwanted frequency modulation or chirp. [12]

- **External Modulation:**

It is obtained by directly modulating the light beam at the output of the laser instead of modulating the input current to the laser. It is used for very high frequencies, starting from 5 to 10 GHz. This method is faster and therefore allows higher data rates to be sent.

Two types of external modulators are commonly used in practice: The Mach-Zehnder modulator (MZM) and the electro-absorption modulator (EAM). [13]
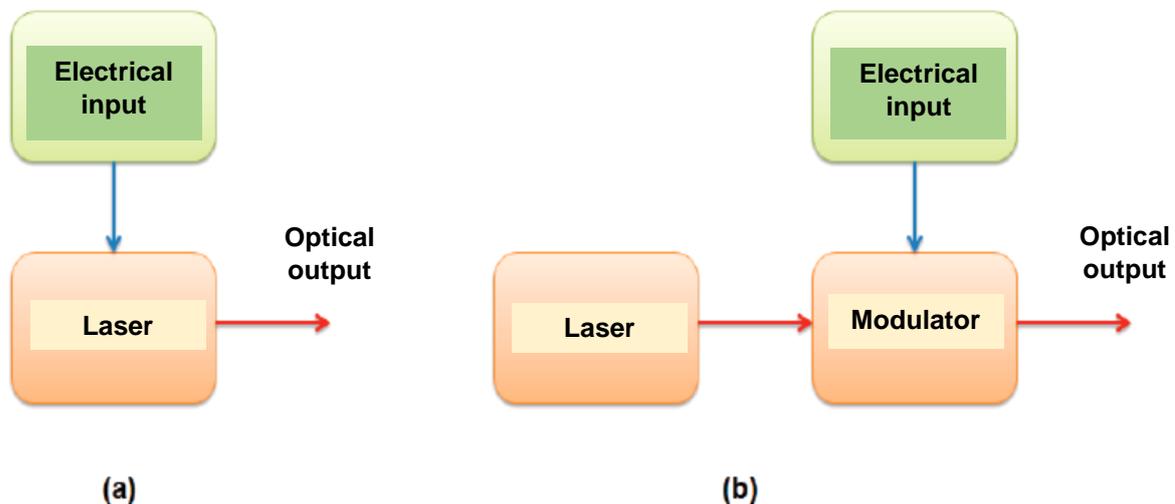
Figure I.17: Block diagram of the Optical transmitter with (a) direct modulation and (b) external modulation.

I.6.2   Optical Reception:

At the output of the modulator, the light signal enters the optical fiber and travels over a long distance to reach the receiving module. The first element encountered by the photons is the photodetectors (light detectors) or the photodiode.

- **The Photodiode**

The photodiode is an optoelectronic device that, upon absorption of photons, generates an electric current. The first required property is high sensitivity to the wavelength used. The second is speed; the photodetector must be used in systems operating at 10 Gbps or even 40 Gbps. The third property required is a minimum noise contribution. Semiconductor photodetectors meet most of these conditions.

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There are two types of photodiodes commonly used in optical telecom that meet these criteria: the **PIN photodiode** and the **avalanche photodiode (APD).**

➢ **The PIN Photodiode**: is reverse-biased and constructed from three semiconductor layers: two heavily doped P and N layers separated by a layer of high resistivity, almost intrinsic, where there are very few mobile charges. In the intrinsic region, incident photons create electron-hole pairs that are separated by the intense electric field and collected by the electrodes. In the P and N regions, photons near the intrinsic photon region create a photocurrent. PIN photodiodes are the most commonly used because they are inexpensive and simple to use, providing satisfactory performance.
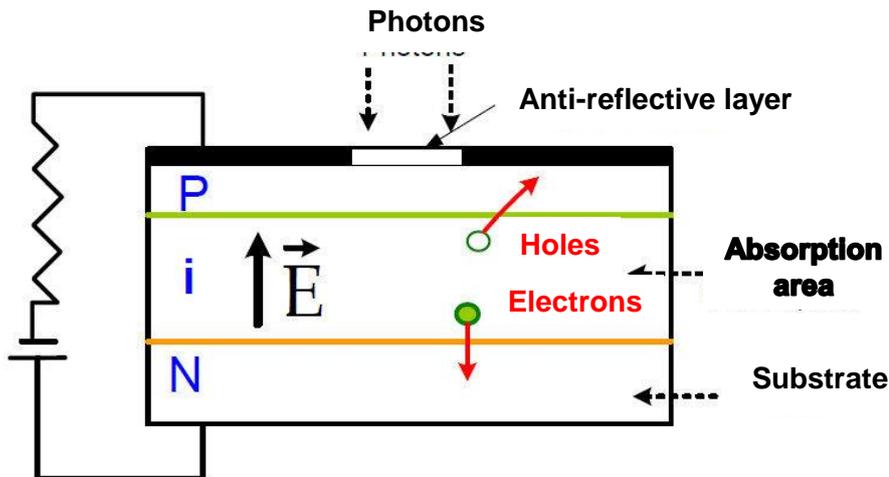
Figure I.18: The PIN photodiode.

➢ **The avalanche photodiode (APD):**

When the received optical power is very low, on the order of a few nanowatts, the detected current is higher, on the order of a few nanoamperes. This current is superimposed on the dark current, leading to a poor signal-to-noise ratio. To increase the signal-to-noise ratio, it is necessary for the detected current to be larger. This can be achieved by utilizing the multiplication effect. Essentially, when a photon is received, it produces a free electron, and through the avalanche effect, this electron generates several more electrons, resulting in increased current and thus greater sensitivity.

The PIN photodiode offers several advantages over the APD; it is more stable, requires a lower bias voltage, and is easier to implement. However, the APD, which can be seen as an enhanced version of the PIN photodiode, allows for lower incident optical powers, and its gain is 10 to 1000 times higher than   that of the PIN.

I.7   Amplifiers

In optical transmission systems, optical signals attenuate as they propagate through the fiber. Losses are due to the fiber itself and the various optical components traversed by these signals. Beyond a certain distance, losses become significant, and the signal becomes too weak to be detected. Before this happens, the signal power needs to be restored.

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Before the advent of optical amplifiers, repeaters were used to strengthen the signal. These repeaters were positioned along the transmission line to regenerate the signal (R), reshape it (2R), and resynchronize or recover its rhythm (3R).

Unlike repeaters, optical amplifiers offer higher performance because they are insensitive to the transmission speed and modulation format used by the system. Additionally, optical amplifiers benefit from a fairly wide band, and consequently, a single amplifier can amplify multiple WDM channels simultaneously, which is not possible with transmitters specified for each channel.

Amplifiers are characterized by gain, which measures the ratio between the output power of the signal and the input power. Sometimes, amplifiers are also characterized by a parameter called gain efficiency, representing the ratio between gain and pump power (in dB/mW). Only a range of optical frequencies or wavelengths called the spectral band can be amplified by a given amplifier. Every optical amplifier has a maximum output power called saturation power, beyond which increasing the input signal power will have no effect on the output power.

There are several sources of noise that affect optical amplifiers; in particular, these devices are sensitive to signal polarization variation. Polarization sensitivity refers to the gain variation of the amplifier depending on the signal polarization. [7]

The characteristics of an optical amplifier vary depending on its position in the transmission chain. There are:

- **The post-amplifier**: also called a booster amplifier, is placed just after the emission module. It amplifies the signal from the transmitter to enable transmission over a long distance. It must have a very high saturation power.
- **The in-line amplifier:** is placed on a transmission line. Its role is to amplify the signal after a certain propagation distance to enable it to cover another distance. It must have low noise figure and high gain.
- **The pre-amplifier**: is placed just before the reception module to ensure the signal has sufficient power to be detected under good conditions. It must amplify the useful signal that has accumulated a lot of noise and undergone significant attenuation. Therefore, the noise figure should be as low as possible.
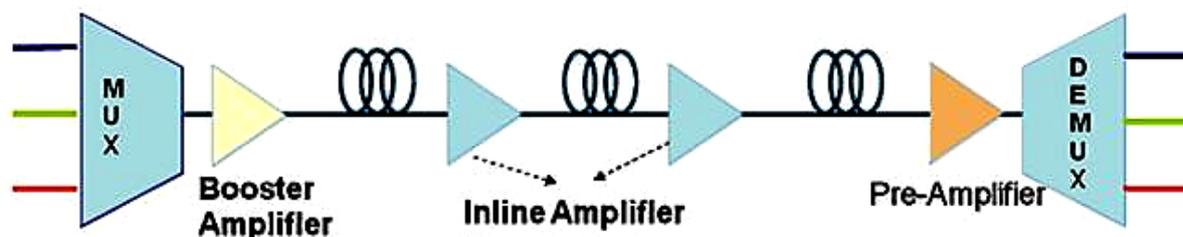
Figure I.19: Types of amplifiers according to position in the transmission chain.

Optical amplifiers operate on the same principle as lasers, based on stimulated emission. They can be classified into three main categories: semiconductor amplifier (SOA), erbium-doped fiber amplifier (EDFA) and Raman Amplifier.

I.7.1   Semiconductor Amplifier(SOA):

An optical amplifier based on a semiconductor gain medium. Light is passed through a semiconductor single-mode waveguide with transverse dimensions. The SOA is typically connected to 1310 nm transceiver outputs to amplify the signal level before entering the optical fiber. It supports all signal formats of the 1310 nm wavelength and is compatible with all data rates. Thus, SOA is mainly used for short-range optical communication systems like MANs and LANs, where it amplifies signals over shorter distances.

I.7.2   Erbium-doped fiber amplifier (EDFA):

Now the most widely used optical amplifier for long-distance fiber communications. Its optical fiber (usually a single-mode fiber) core is doped with erbium, a rare earth element, to absorb light at one frequency and emit light at another frequency. Light is pumped from laser diodes with a wavelength around 980 nm and sometimes around 1480 nm. The EDFA offers advantages of high gain, wide bandwidth, high output power, high pump efficiency, low insertion loss, and insensitivity to polarization state, making it a good solution for DWDM, CATV, and SDH applications. [14]

I.7.3   Raman Amplifier

Raman amplifiers play a significant role in long and very long-distance optical transmission systems, making them the first widely commercialized nonlinear optical devices in the telecommunications market. The Raman amplifier utilizes the transmission fiber itself as an amplification medium. The Raman amplifier is based on the principle of Raman scattering, which is a nonlinear two-photon effect where a pump photon is absorbed and a lower energy photon is emitted simultaneously with a phonon. [12]

The table below shows a comparison between the main characteristics of the SOA, Raman and the EDFA.

Table I.2: Comparison between SOA and EDFA and RAMAN

Property	EDFA	Raman	SOA
Gain (dB)	> 40	> 25	>30
Wavelength (nm)	1530-1560	1280-1650	1280-1650
Bandwidth (3dB)	30-60	Pump dependent	60
Max. Saturation (dBm)	22	$0.75 \times$ pump	18
Polarization Sensitivity	No	No	Yes
Noise Figure (dB)	5	5	8
Pump Power	25 dBm	>30 dBm	< 400 mA
Time Constant	10^{-2} s	10^{-15} s	2×10^{-9}
Size	Rack mounted	Bulk module	Compact
Switchable	No	No	Yes
Cost Factor	Medium	High	Low

The comparison of performance between SOA, RAMAN and erbium-doped fiber amplifiers (EDFAs) currently favors EDFA amplifiers. The advantage lies in their ease of use. Indeed, it is easier to connect a fiber amplifier to an optical fiber because the same type of waveguide is retained. Insertion losses will be minimized if a good connector is used. In contrast, in the case of a semiconductor amplifier, adapting the signal from the fiber to the amplifier, and from the amplifier to the fiber requires adjustment, leading to greater losses.

Conclusion

The principle of all data transmission is to circulate information between a sender and a receiver while minimizing the risks of signal distortion, thus ensuring maximum reliability of information transfer. The demand for high data rates has already reached the limit of current wired solutions (such as power lines and coaxial cables), and optical fiber has already surpassed these transmission mediums.

In this chapter, we began by providing general information about optical fiber, including its types such as single-mode and multimode fibers, step-index fibers, and graded-index fibers. Then, we studied attenuation and dispersion in optical fibers, while not forgetting the advantages of optical fibers and the disadvantages that arise in their use, as well as the components that constitute an optical fiber-based connection.

Chapter II:
Fiber optic enterprise Testing, analysis and transmission.

II.1   Introduction

The concept of fiber optic testing encompasses all procedures, tools, and standards used to test optical components, fiber optic links, and already deployed optical networks. This includes optical and mechanical testing of each distinct element, as well as overall transmission tests to verify the integrity of complete optical network installations.

Fiber optics has emerged as the primary medium for global communications due to three distinct advantages over copper infrastructures: reduced operational costs (power and maintenance), reliability (fiber optic cables are immune to electromagnetic and radio frequency interference), and high bandwidth/transmission speeds. The growing diversity of fiber optic applications and point-to-point (PTP) and point-to-multipoint (PTMP) architectures has underscored the need to train technicians and provide versatile and user-friendly testing solutions.

II.2   Principle of testing enterprise networks

Over the years, industry standards for optical fiber have developed to certify components and installations of optical networks before they are put into service. Due to the proliferation of deployments, compliance with national and international standards has become necessary to maintain consistency, interoperability, and performance. The deployment of homogeneous optical fiber testing based on standards offers enormous benefits for network operators and their customers, ensuring optimal network operation throughout its lifecycle, from fiber construction to customer service activation, including assurance monitoring, network maintenance, and upgrades.

The performance standards of the market, service level agreements, and warranty requirements make testing optical networks inevitable, but there are many other good reasons to test and monitor the performance of these networks. Currently, the aim of testing is to maximize the performance of optical network assets in terms of bandwidth, reliability, and return on investment. [15]

II.3   Fiber optic connector types

Fiber optic connector that comes in various configurations and types is considered as an important component for the fiber optic cable. Generally speaking, different fiber cable connector types can be categorized according to different standards like the utilization, fiber count, fiber mode, transmission method, the transmission media, the boot length, the polishing type and the termination way, etc.

The following fiber connector types, such as **LC-SC-MTP-ST-FC** fiber optic connectors, require an adapter panel when connecting. Fiber cables with these optical connector types are usually used in data centers, telecom rooms, enterprise networks and so on. [16]

Figure II.1: Optical fiber connector types

II.3.1   PC vs UPC vs APC Connector

According to the polishing type, optical fiber cable connectors can be divided into three types: **PC, UPC**, and **APC** connectors. The color code provides a convenient method to identify these three types of connectors: PC's color code is black, the color code for the APC fiber connector is green, and the UPC's connector is blue. The structure and the performance of the three fiber optic connectors also vary, which reflects on the values of insertion loss and return loss.
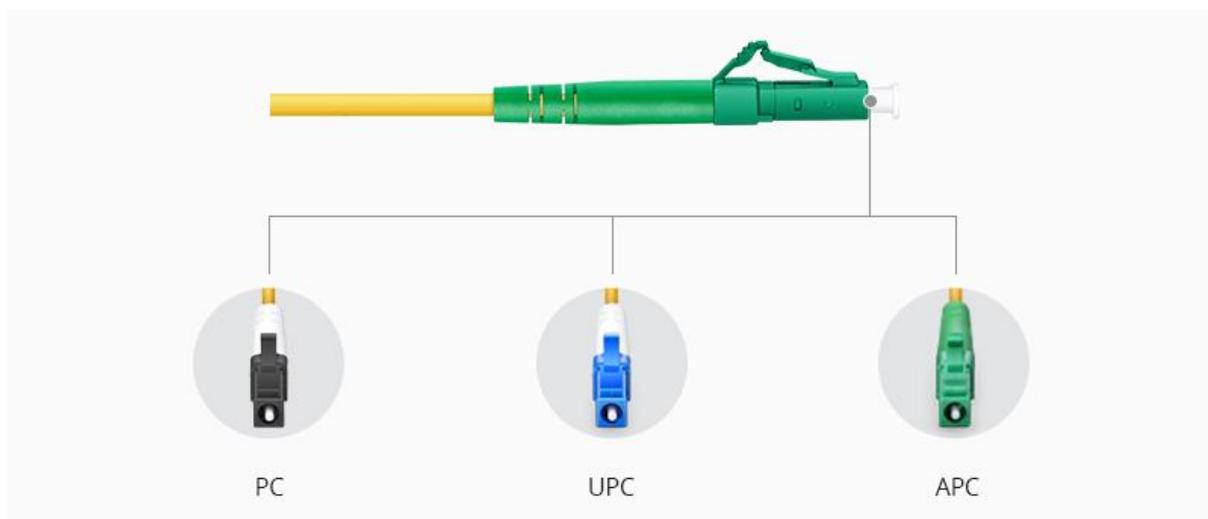
Figure II.2: Optical fiber connector types

PC, UPC, and APC refer to the polish styles of the ferrules inside the fiber optic connectors, just as the following figure shows. The ferrule is the housing for the exposed end of a fiber, designed to be connected to another fiber, or into a transmitter or receiver. When connectors are installed on the end of a fiber, light is reflected back up the fiber towards the source, disrupting the signal. To increase the efficiency of fiber, engineers began to upgrade the surface of the critical point of attachment, and that's how ferrule polish technologies are introduced. [16]

Physical Contact Connector

Ultra Physical Contact Connector

Angled Physical Contact Connector
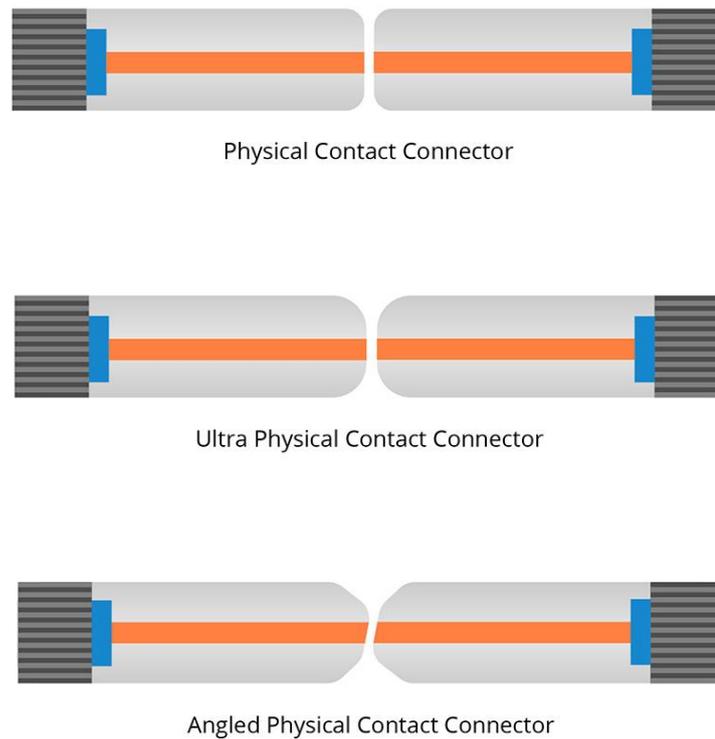
Figure II.3: PC vs UPC vs APC fiber optic

II.3.2   Inspection and cleaning of connectors

Connectors are key components that connect all elements of the network. It is for this reason that it is essential to maintain them properly to ensure optimal operation of these elements and to avoid irreversible failures. Since connectors can damage elements invisible to the naked eye, it is essential not to neglect the inspection phase.
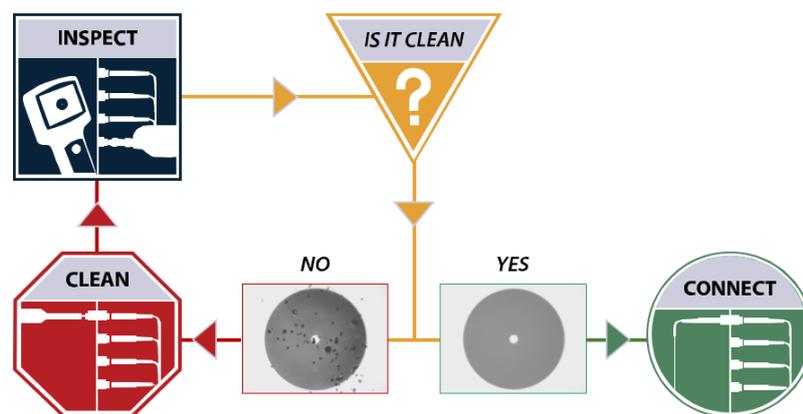
Figure II.4: connectors cleaning procedure

The cleanliness of fiber optic connectors and testing equipment connectors is crucial. An optical fiber inspection microscope can be used as a fiber optic tester to check the cleanliness of the core and connector ferrules. Automated inspection tools can be used for common simplex fiber optic interfaces (FC, SC, LC, etc.). It is recommended to use specialized cleaning products to clean fiber optic connections. The cleanliness of reference cables and test equipment connectors is equally important.

Figure II.5: Types of fiber optic microscope

II.3.3   The Cleaning Procedure

Figure 9 below illustrates the detailed inspection and cleaning procedure to be strictly followed before connecting the fiber to another optical component. This simple procedure can help limit costs associated with network downtime caused by failures. [17]
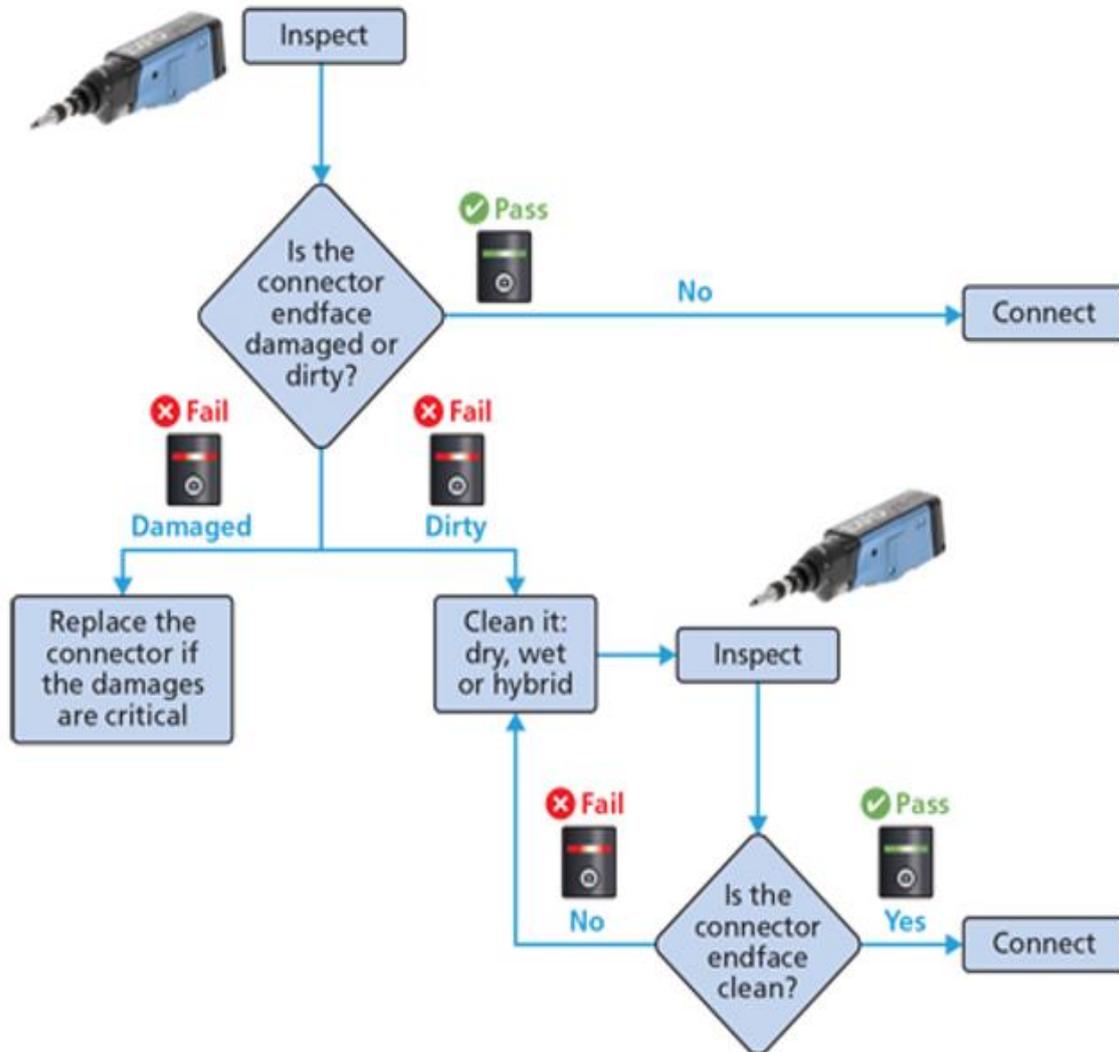
Figure II.6: Connector Inspection and Cleaning Procedure

II.3.3.1   Dry Cleaning

Dry cleaning effectively removes contaminants such as light dust particles or body oil. This technique is often considered the most efficient in controlled manufacturing environments where speed and ease of use are paramount. This cleaning method is also widely used in outdoor environments. However, it does not completely eliminate all types of contaminants potentially present in this complex environment. [17]

Figure II.7: Fiber Optic Dry Cleaning Product

II.3.3.2   wet cleaning

The primary objective of wet cleaning is to lift dust and contaminants from the connector end face to prevent scratching. The most commonly used solvent in the industry is 99.9% isopropyl alcohol (IPA). While effective for removing the majority of contaminants, some, such as index gel and most lubricants, can resist it and may leave residue. [17]

Figure II.8: wet cleaning.

II.4   calculate acceptable link loss

In the installation of optical fiber cables, precise measurement and calculation of attenuation in the optical fiber are crucial steps to verify the integrity of the network and ensure network performance. Optical fiber will cause obvious signal loss (optical fiber loss) due to optical absorption and scattering, which will impact the reliability of the optical transmission network.

If you want to verify whether the optical fiber link can function normally, you need to calculate the optical fiber loss, power budget, and power margin.

 The calculation method is as follows:

❖ **Total Link Loss (LL) = Optical Cable Attenuation + Connector Attenuation + splice Attenuation**

✓ **Optical Cable Attenuation (dB) = Maximum Attenuation Coefficient of Optical Fiber (dB/km) × Length (km)**

✓ **Connector Attenuation (dB) = Number of Connectors × Connector Loss (dB)**

✓ **splice Attenuation (dB) = Number of Fusion Splices × Fusion Splice Loss (dB).**

II.4.1   Link loss limits

Before beginning the calculation of your optical fiber link loss limits, you need to know the acceptable minimum loss values. These can be found in the ANSI/TIA/EIA-568-C.3 and ISO/IEC 11801:2002 standards. [18]

Table II.1: Maximum cable attenuation

Maximum cable attenuation dB/km							
	OM1, OM2, OM3 and OM4 Multimode		OS1 Monomode		OS2 Monomode		
Wavelength	850 nm	1300 nm	1310 nm	1550 nm	1310nm	1383 nm	1550 nm
Attenuation	3.5dB	1.5dB	1.0 dB	1.0dB	0.4dB	0.4dB	0.4dB

Table II.2: Attenuation criteria for splices.

Type of optical fiber	Loss of splices (in dB)
Multimode 62,5 µm (OM1)	0,3
Multimode 50 µm (OM2, OM3, OM4)	0,3
Monomode	0,3

Table II.3: Attenuation criteria for Connectors

Type of optical fiber	Loss of connector (in dB)
Multimode 62,5 µm (OM1)	0,75
Multimode 50 µm (OM2, OM3, OM4)	0,75
Monomode	0,75

II.5   Power test (Optical Power Meter):

The Optical Power Meter (insertion loss measurement) is a type of electronic testing device is used to inject light radiation into a fiber and determine the amount of light coming out of the fiber. The difference between the initially injected value and the transmitted value gives an attenuation expressed in dB.

  An Optical Power Meter (OPM) used to measure the output power of an optical fiber equipment or the power or loss of an optical signal transmitted through an optical fiber cable

An Optical Power Meter utilizes a photodiode to generate an electric current proportional to the optical power. It is thereby capable of determining the average optical output power of an optical source. Optical power meters are calibrated to accurately measure optical output levels at defined wavelengths. Commonly used wavelength parameters include measurements at 850 nm and 1,300 nm for multimode optical fiber, or at 1,310 nm and 1,550 nm for single-mode optical fiber. During testing, wavelength parameters are chosen to correspond to the actual service transmission wavelength. [19]

Figure II.9: Optical power meters

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An optical power meter displays two essential test parameters that allow for the evaluation of optical fiber design specifications, such as attenuation or low loss. The first is the wavelength parameter, measured in nanometers (nm), and the second is power level, measured in decibels (dB or dBm). Optical loss is measured in dB, a dimensionless unit, which represents a ratio between the measured value and a reference value. Power measurements can be displayed using dBm as a measurement unit with specific resolution. The dBm unit quantifies the power level based on a reference value of 1 milliwatt for 0 dBm.

The versatility of the optical power meter allows it to be used for other basic functions of optical fiber testing, including continuity testing. Establishing the presence of a signal within an optical fiber is important for quick verification of the optical fiber link in the field while minimizing equipment changes. When the optical power meter is deployed within an optical loss test kit, its measurements can also conveniently determine the length and send/receive polarity of an optical fiber.
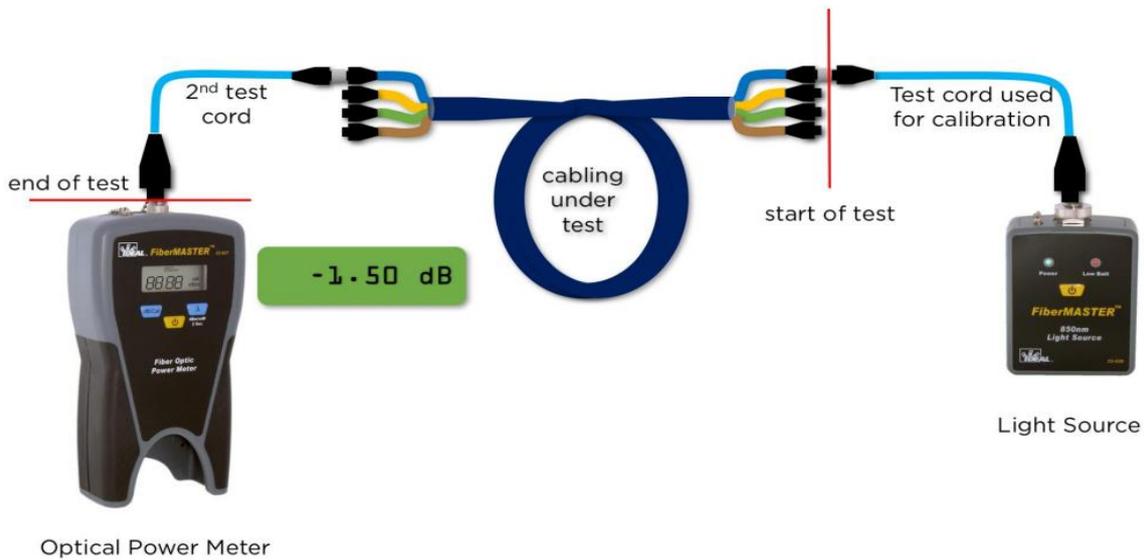
Figure II.10: Optical power meters' test method

II.6   Reflectometer Test (OTDR)

An Optical Time Domain Reflectometer (OTDR) is an instrument used to measure an optical fiber cable route and create a virtual representation.

The measurement data can provide information about the condition and performance of optical fibers and passive optical components such as connectors, splices, couplers, and multiplexers present throughout the cable.

 Once this data is captured, analyzed, and stored, it can be revisited at any time to evaluate the same cable over time.

Figure II.11: Optical Time Domain Reflectometer (OTDR)

II.6.1   Principle of operation of the OTDR

The optical reflectometer sends a pulse of light energy (optical power), generated by a laser diode, into one end of the relevant optical fiber. A photodiode measures the return of light energy or optical power (reflected and backscattered) over time and converts it into a measurement value, which is then displayed graphically (or as a trace) on a screen.

The location of each event and the total length of the cable are calculated based on the propagation time of the light pulse diffused in the core of the optical fiber and considering the light reflected/backscattered towards the OTDR detector. Attenuation is calculated based on the proportional amplitude change of the reflected/backscattered light. [20]
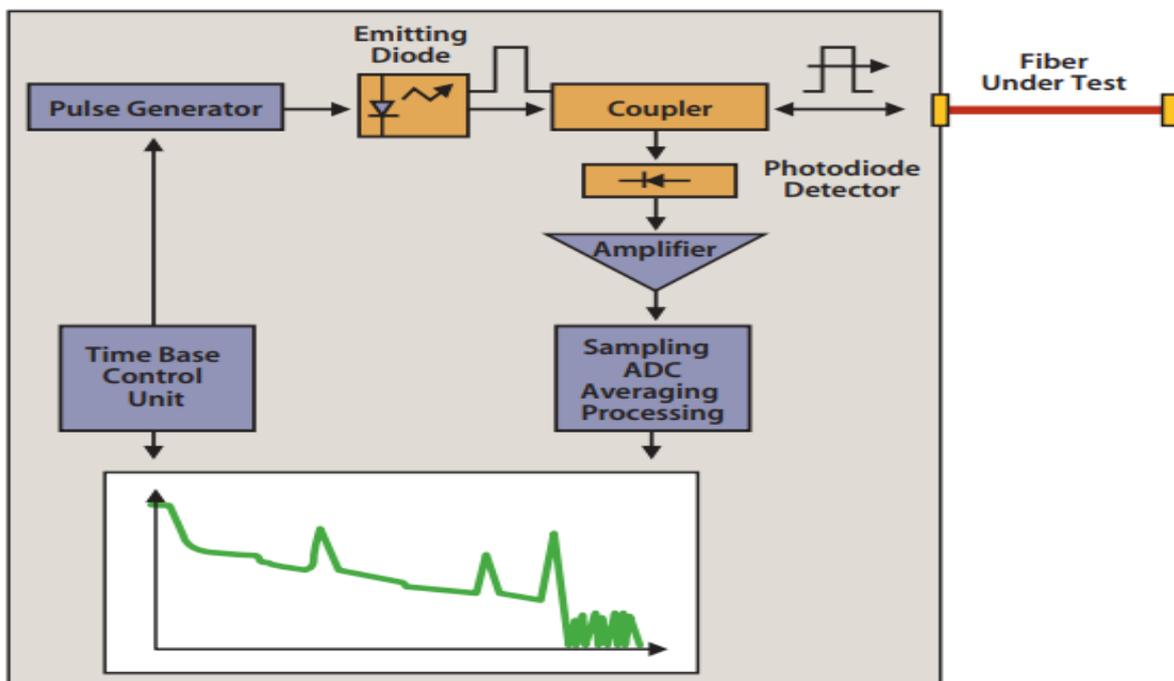
Figure II.12: OTDR principal operation

II.6.2   OTDR Testing Process

Performing an OTDR test requires following basic processes of configuration, programming, test execution, and report generation. [21]

- Turn on the OTDR and ensure the battery is charged and the test screen is functioning.

- Clean and inspect the ends of all optical fibers to be tested, launch cables, connectors, and adapters.

- Gently connect the launch cable to the OTDR test port at one end and the optical fiber to be tested at the other end.

- Select a pre-programmed test configuration based on the network type and test conditions, or configure/adjust test parameters appropriately.

     Manual OTDR test parameters typically include:

   ✓ **Wavelength**: will depend on the nature of the Optical Fiber to be measured (850nm and 1300nm for multimode fibers, 1310nm and 1550nm for single-mode fibers.)

   ✓ **Range**: adjusts the appropriate range (distance) based on the overall length of the optical fiber.

   ✓ **Pulse width**: adjusts the duration of each emitted laser pulse.

   ✓ **Acquisition time**: sets a duration to calculate an average of reflected light measurements.

   ✓ **Refractive index**: corresponds to the index of the material of the tested cable.

- Start the OTDR acquisition to obtain test results and a graphical "trace."

- Store and/or upload test results as needed.

- Carefully disconnect all cables, connectors, and adapters.

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OTDR Trace Information
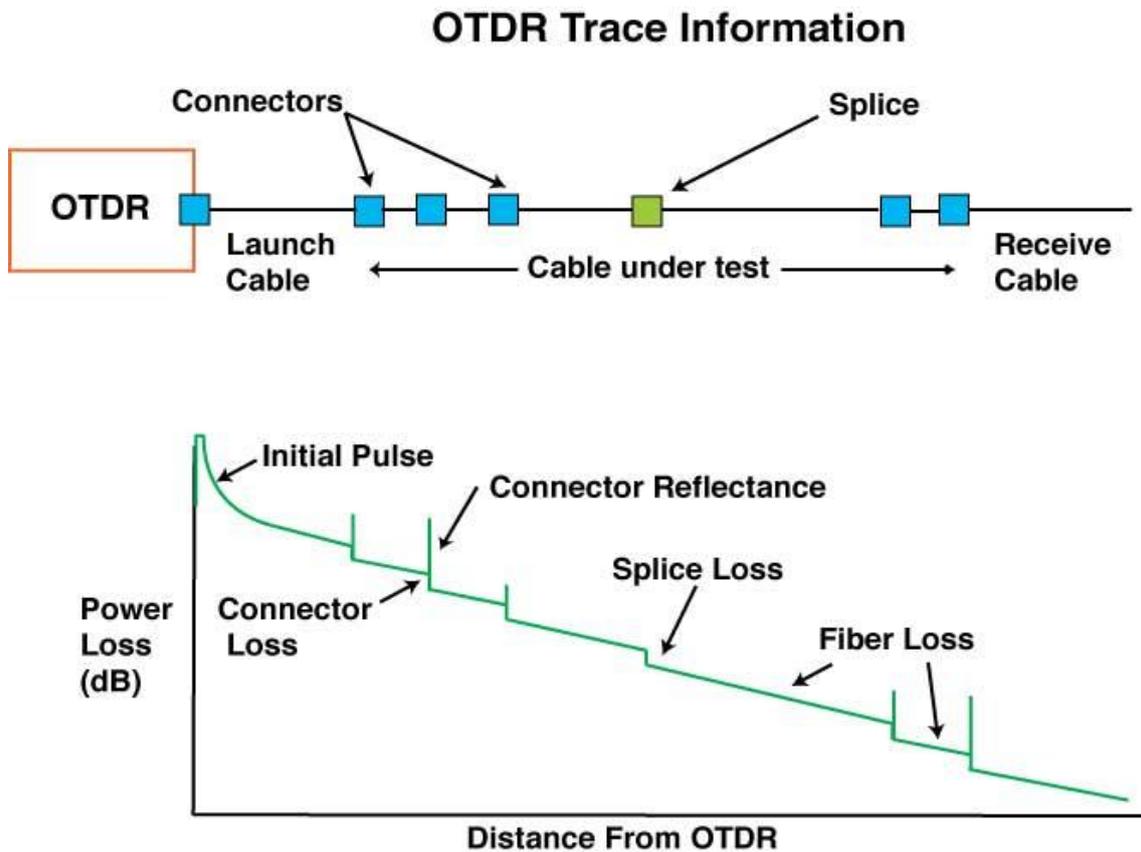
Figure II.13: OTDR trace information

II.6.3   Launch/Dead Zone Reels

Launch reels Used with OTDRs to cover the dead zone, in order to detect events within the first meter of the installation. Also, to identify issues with the first connector / optical fiber splice.

The dead zone of OTDR is the distance (or time) where the OTDR cannot detect or precisely localize any event or artifact on the fiber link, caused by high return level of reflection and affected by the pulse width, might extend hundred meters from the OTDR. Full length of optical fiber is suggested to use before the optical fiber under test. Thus, the receiver of the OTDR can have enough time to settle. OTDR launch box, which is actually a long spool of optical fiber inserted between the fiber under test and OTDR, can ensure that the OTDR dead zone happens in the OTDR launch box. Then, the fiber optic link under test won't be largely affected by the OTDR dead zone. [22]
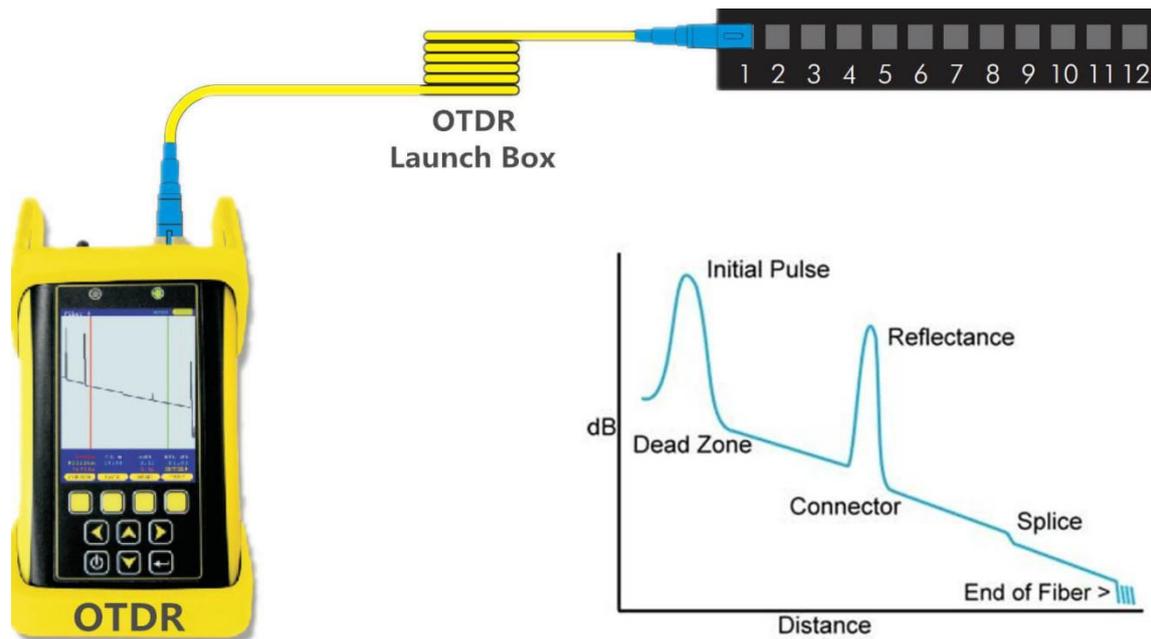
Figure II.14: OTDR launch box

The choice of reels depends on:

- ✓ Connector types
- ✓ Type of optical fiber
- ✓ Cable length

Reel lengths:

- 500m for multimode fiber,
- 1km for short networks (<10km) in single mode
- 2km (>10km) for longer single-mode fiber networks.

Figure II.15: OTDR launch boxes

II.7   Fiber optic Splicing:

Fiber splicing is a fiber-to-fiber connection, meaning joining the ends of two fiber strands together.

There are numerous use cases for fiber optic splicing. Through splicing, fiber optic technicians can extend the length of the fiber to make it long enough for use in a required cable run. As fiber optic cables are generally only produced in lengths up to around 5km, so when lengthier connections are needed, splicing two cables together becomes necessary.

So when the cable runs are too long for a single length of the fiber, or if there's a need to join two different types of fibers, such as a 48-fiber cable to four 12-fiber cables, splicing is the answer. Splicing is also used to repair severed fiber optic cables that are buried underground or to re-join fiber optic cables when inadvertently broken.

II.7.1   The Methods of Fiber Optic Splicing:

fiber optic splicing can be carried out using one of two methods**: fusion splicing** and **mechanical splicing**.[23]

II.7.1.1   Mechanical Splicing

This fiber optic splicing technique involves the precise alignment of two fiber optic cables, held in place by a self-contained assembly rather than a permanent bond. A mechanical splice

is designed to hold two fiber cables in a way that allows light to pass through seamlessly, with a typical loss of around 0.3 dB or 10%.

In this process, the technician must use an alignment device along with an index matching gel. The gel must have a similar refractive index to enhance the light transmission across the joint, with minimal back reflection.
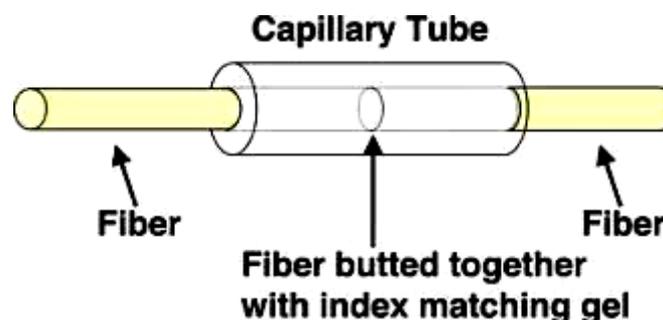

Figure II.16: fiber optic mechanical splicing.

Mechanical splicing is usually used when splices need to be made quickly and easily, for instance, to temporarily connect cables during installation. That's because mechanical splicing can be easily disconnected if the need arises and you don't require costly apparatus to perform the splice.

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II.7.1.2   Fusion Splicing

The other method to join two fiber optic cables together and this time we're talking a permanent connection is fusion splicing.

In this technique, a machine or an electric arc is used to produce heat and fuse/weld glass ends that are precisely aligned together for continuous transmission of light. This translates to a much lower attenuation of around 0.1 db.
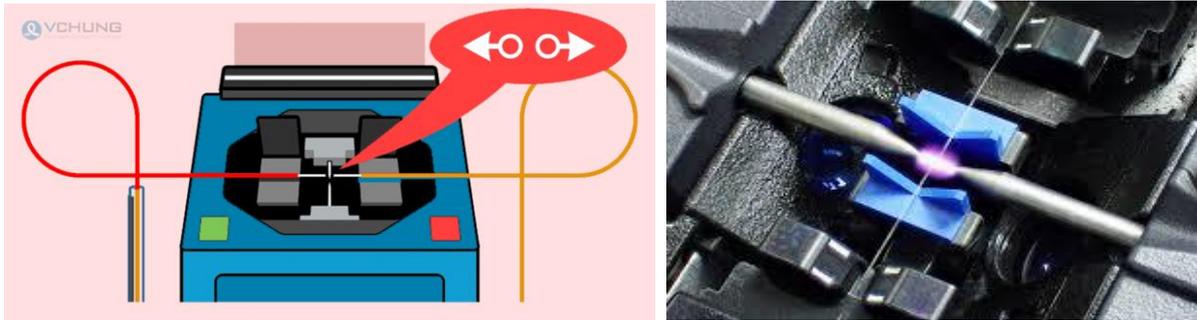
Figure II.17: fiber optic fusion splicing.

Fusion splicing produces a reliable joint with low insertion loss and nearly zero back reflection when done correctly, and thus, is more widely used than mechanical splicing. For example, it's used in long high data rate connection lines that, once installed, are unlikely to be modified.

II.8   Transmission system technology

Currently, optical devices are integral to broadband transmissions, telecommunications networks, and both underwater and terrestrial communications. This widespread use is attributed to the substantial transmission capacity offered by optical fibers. However, the increasing demand for data traffic has driven the search for technologies that can further enhance the transmission capacity of optical networks such a SDH.WDM and OTN technology's.

II.8.1   SDH technology

Synchronous Digital Hierarchy (SDH) represents an international standard for high-speed telecommunications in optical transmission networks. This technology enables the transport of digital signals transmitted at variable bit rates. Based on Time Division Multiplexing (TDM) technique, which is to divide a standard duration (1 second) into several small time segments (8000), and each small time segment (1/8000=125us) transmits one signal.

SDH is designed to manage end-to-end circuit-mode communications and is used to transport IP/MPLS, ATM, DSL, Ethernet, PDH, etc. flows.

The SDH technology can be deployed in various levels of transport networks:

access networks which represent an entry point for user traffic, **metropolitan networks** which interconnect access networks and ensure the transport of traffic on a regional scale, and

core networks which handle the aggregation and routing of data on a large scale. Most of these SDH transport networks (access, metropolitan, and core) are primarily based on optical fiber infrastructure, allowing for significant transmission capacities on the order of tens of Gaps. [24]
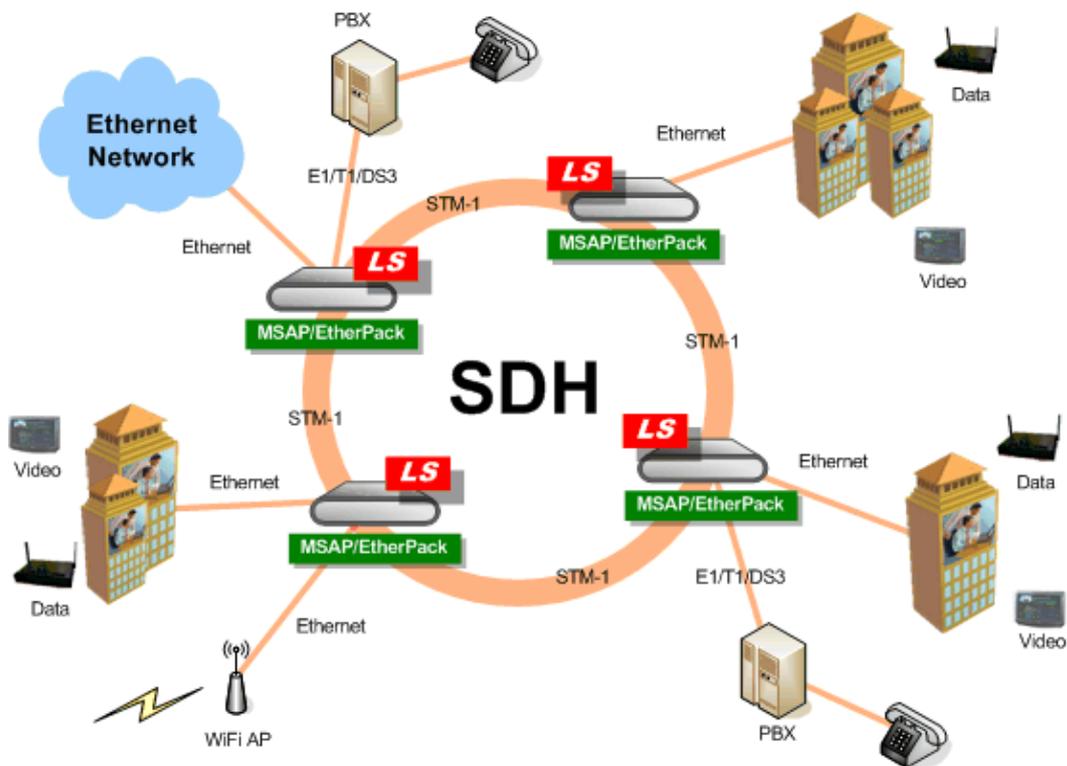
Figure II.18: SDH technology.

The basic transport frame of an SDH network, operating at a minimum of 155Mbps (STM-1). The payload of an STM-1 frame can vary, supporting potentially 63 E1 trunks, a combination of E1 to E3 bearers, a single E4 trunk or alternatively IP data. The STM-1 frame is comprised of Overhead blocks, Payload blocks (Virtual Containers) and Pointers, the ratio of each depending on the initial payload to be transported.

STM-1 can be multiplexed to create higher order STM, for example an STM-4 would be 4 x STM-1 and an STM-16 would be 4 x STM-4.

SDH uses the following STM (Synchronous Transport Modules) and rates: STM-1 (155Mbps), STM-4 (622Mbps), STM-16 (2.5Gbps), and STM-64 (10Gbps).

The STM-1 MUX multiplexes 63 E1 signals into a STM-1 stream
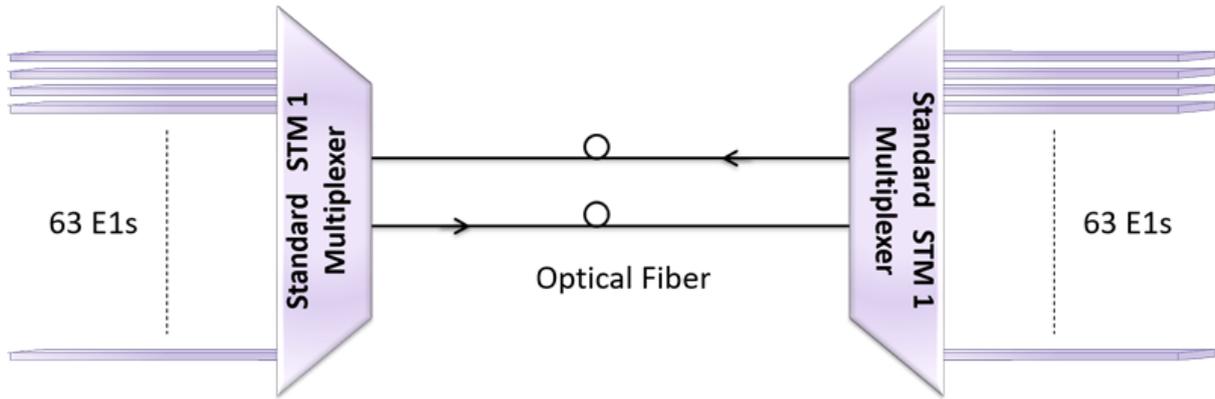
Figure II.19: SDH principal working.

II.8.2   WDM technology

Optical transport networks consist of interconnected nodes through optical fibers. These nodes perform the functionalities of multiplexing/demultiplexing, transmission, reception, and traffic switching. Optical fibers allow the transport of traffic flows between interconnection nodes in the form of an optical signal. SDH networks send only a single optical channel, carrying the STM-N frame, over each fiber. This sometimes necessitates multiplying fibers between two nodes to obtain the capacity needed to transport new demands.

Technological progress has led to the emergence of wavelength division multiplexing (WDM) technique, which combines multiple channels on the same optical signal, with each channel using a different wavelength. The available bandwidth in a fiber can then be significantly expanded, each wavelength allows for a throughput of several Gbps, and dozens of wavelengths can be used. This evolution enables the exploitation of a wider bandwidth of optical fiber than that used by a single optical transmitter in the case of SDH.

WDM involves overlaying multiple signals of different wavelengths on the same optical fiber. To implement this technique, a WDM system utilizes two interconnected terminals via an optical link. The first terminal is a multiplexer, and the second terminal is a demultiplexer.
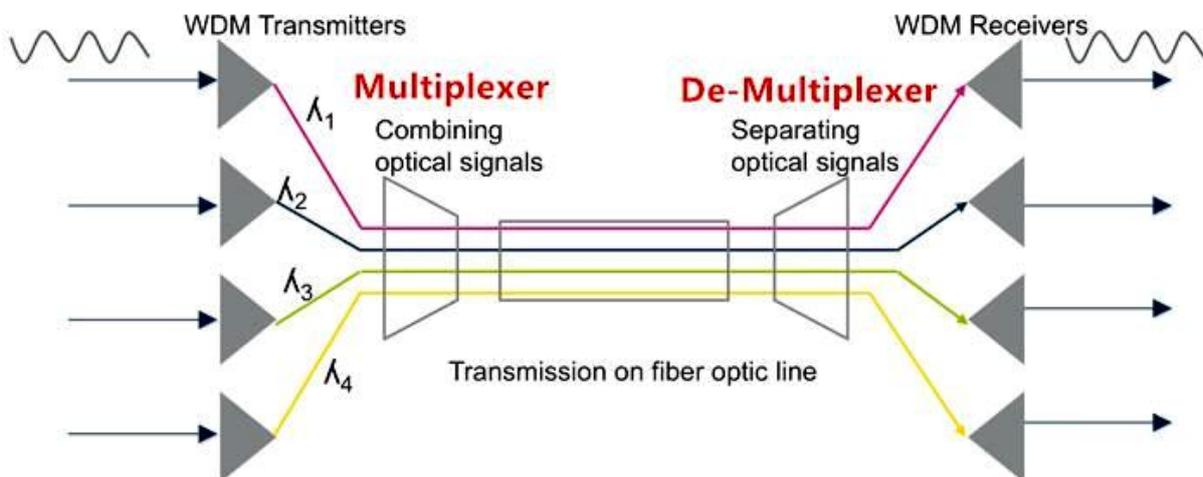
Figure II.20: WDM technology

There are several WDM systems, all based on the same principle but differing only in the number of channels (wavelengths) usable in a fiber. WDM multiplexing is characterized by the minimum interval between two accessible wavelengths. This interval is expressed in nanometres (nm) or gigahertz (GHz). If this interval is less than or equal to 0.8 nm (or 100 GHz), we refer to it as **Dense WDM (DWDM)** multiplexing.

Experimentations have even been conducted with intervals of 0.4 and 0.2 nm where 160 channels can be usable in a fiber. In this case, we refer to it as **Ultra Dense WDM (UDWDM)** multiplexing.

There exists another form of WDM, known as **Coarse WDM (CWDM).** Up to eighteen channels can be used, but in practice, equipment typically operates on four, eight, or sixteen channels. [25]

Table II.4: CWDM vs DWDM.

	CWDM	DWDM
Channel width	13nm	1nm
Channel spacing	20nm	0.8nm
Number of channels	4 to 18	Up to 160
Optical amplifiers	Not used	Used
Range	Up to 120km	Up to 500 km
Power /wave length	1.6w	5w
Wavelength drift	-+6.5nm	-+0.16nm

Importance of traditional WDM: (resolution of capacity and distance problems)

Addressing the issue of insufficient capacity in the SDH network. The maximum bandwidth of metro WDM can support $80 \times 10G$, while the maximum bandwidth of the SDH network is 10G.

Figure II.21: TDM vs WDM

II.8.3   OTN technology

Traditional WDM has limitations in providing broadband services. Issues include inflexible service planning, poor networking capacity, imperfect pro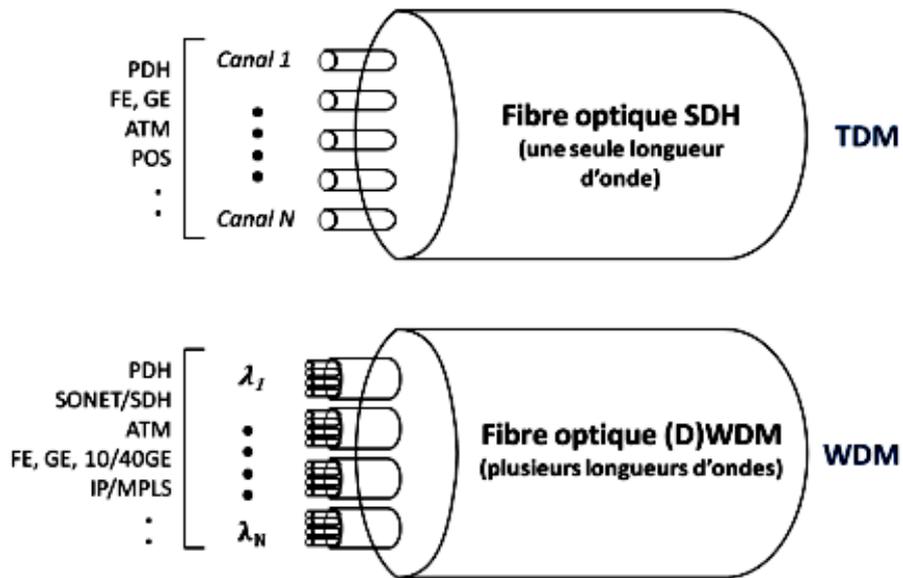tection mechanisms, simple OSC (Optical Supervisory Channel), and inability to accurately manage channels... SDH boasts powerful and flexible interconnection planning capabilities, a variety of perfect protection mechanisms, standardized mapping and multiplexing, multi-level embedded overload, rich operational and manageable experience, etc. These advantages can compensate for the shortcomings of WDM.

The limitations of traditional WDM in protection, management, and programming make it unable to adapt to the transmission requirements of broadband services with large particles. The transmission capacity of WDM is combined with the SDH's electrical layer processing mechanism, and the OTN (Optical Transport Network) is born.

OTN was designed to provide higher throughput (currently 800G in 2024) than its predecessor SONET/SDH, which stops at 40 Gbit/s, per channel.

The aim of OTN is to combine the benefits of SONET/SDH technology with the bandwidth expandability of DWDM. In short, OTNs will apply the operations, administration, maintenance, and provisioning (OAM&P) functionality of SONET/SDH to DWDM optical networks. So simply we can say **OTN=WDM+SDH**.

OTN is composed of a set of Optical Network Elements connected by optical fiber links, able to provide functionality of **transport, multiplexing, routing, management, supervision and survivability of client signals**, [26]
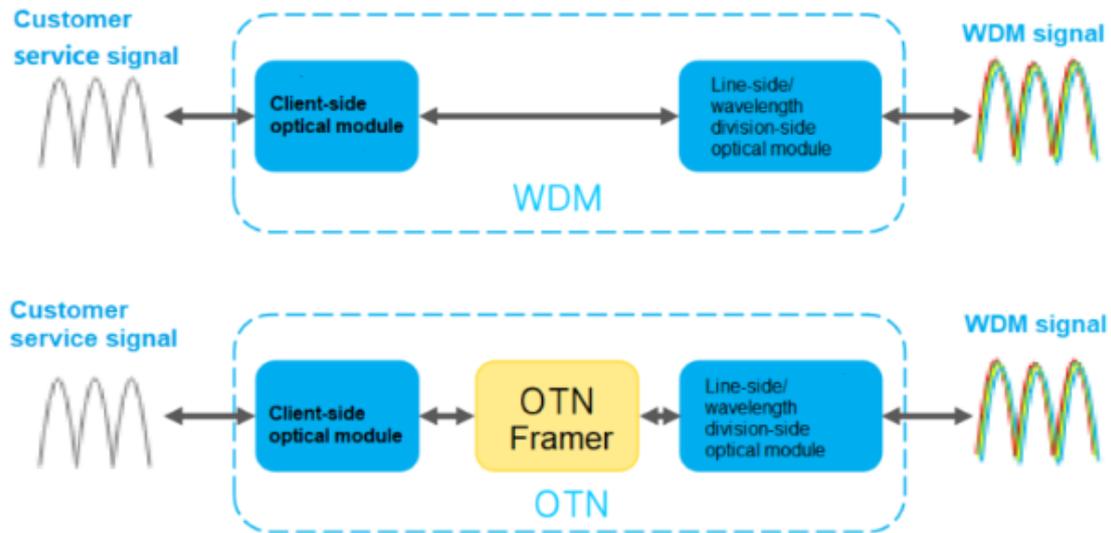
Figure II.22: The comparison diagram of WDM and OTN system

According to the simplified comparison diagram of WDM and OTN systems above, we can see that:

In the WDM system, services without wavelength information entering the WDM system are simply converted into services with wavelength information and placed in the system for transmission. In other words, the WDM system lacks any monitoring mechanism for transmitted services and only ensures that services can be transmitted to the receiving end.

In the OTN system, a set of rules for placing services into the OTN system is provided, known as frame structure requirements. Services entering the OTN system will be grouped according to the OTN frame structure requirements, by adding monitoring, management, operation, and maintenance information. Then, the services are converted into services with wavelength information and sent to the OTN system for transmission.

Figure II.23: XTRAM OTN Equipment

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In summary, OTN is an optimization of WDM, which further enhances the operational and maintenance capabilities, as well as the flexible resource planning capabilities of WDM systems.

In essence, WDM/OTN technology now serves as a high-capacity data network transport system. It continuously transmits these "data assets" with greater reliability, increased flexibility in resource planning, and higher resource utilization rates.

Conclusion

Fiber optic testing is a crucial aspect of maintaining and evaluating optical fiber links to ensure optimal performance and reliability in communication systems. This comprehensive exploration delves into essential procedures, tools, and techniques involved in the testing and maintenance of fiber optic networks.

Chapter III
-Practical part-
Optical fiber links
measurements.

III.1   Introduction

In this chapter, we will explain the principles of power, attenuation, and loss measurements and the acceptable link loss of an optical fiber link, by studying two optical links using an OTDR, we can observe losses, defects, and the distances between events. Additionally, we will simulate the equivalent assemblies of two links using Optisystem software, connecting three oil fields in the Haoud Berkaoui petroleum region.

We will focus on the first link between the Haoud Berkaoui Fields (HBK) and the Geullala Fields (GLA), and the second link between the Haoud Berkaoui Fields (HBK) and the Benkahla Fields (BKH). The measurements obtained earlier will allow us to set up both links within the Optisystem interface in the next chapter.

III.2   Introduction to Sontrach company:

SONATRACH, being an oil and gas state company, operates across various locations situated in the vast Algerian desert. The efficient communication and transmission of data between these dispersed sites are crucial for the seamless functioning of the business operations.

The telecoms department within SONATRACH plays a pivotal role in ensuring effective communication between the different locations of the company. By utilizing advanced technologies such as fiber optic networks, satellite communication systems like VSAT, and secure data encryption protocols, the telecoms engineers within SONATRACH ensures seamless connectivity and reliable communication channels. These technologies enable high-speed data transmission, real-time monitoring of operations, and efficient collaboration among employees across various sites.

 the department stays abreast of emerging technologies to continually enhance communication infrastructure, thereby supporting the company's mission of maximizing operational efficiency and productivity.
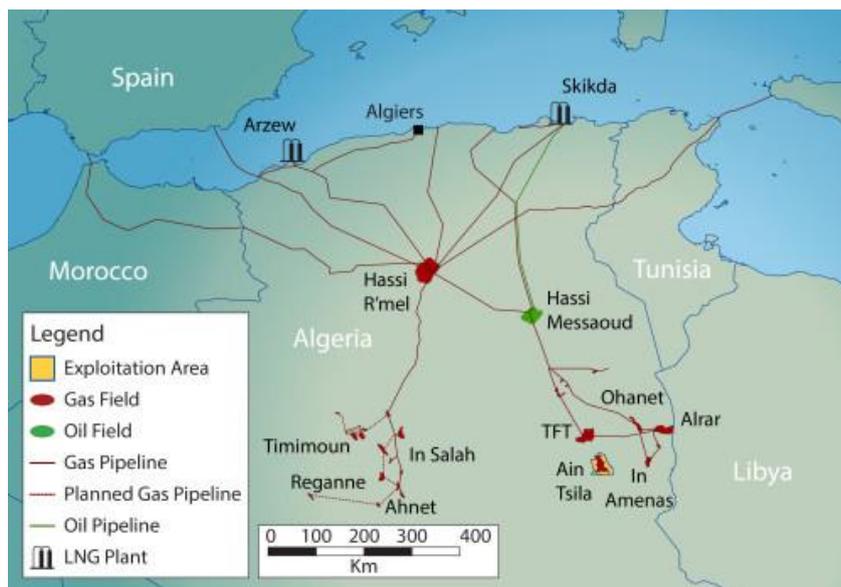

Figure III.1: Sonatrach company fields

III.2.1   Sonatrach TV system broadcasting:

Sonatrach currently operates a low-quality analog broadcasting TV system, the engineers are planning a project to launch a high-quality digital terrestrial broadcasting system. The IT and telecommunications unit of Sonatrach, the national hydrocarbon company, aims to install digital terrestrial television (DTT) in the living quarters. To achieve this, Sonatrach engineers plan to broadcast the TV signal using fiber optic cables as the transmission medium. They are currently facing a challenge with signal distance, as it does not reach its intended destination. In this chapter, we will test the links to determine their ability to transmit the signal with minimal loss and identify the most suitable wavelength for transmission.

III.2.2   DTT Transmission System:

At the regional directorate of Haoud Berkaoui, digital terrestrial television (DTT) will definitively replace analog broadcasting in the living quarters. The architecture of the television broadcasting networks is centred around a main DTT station. The transmission of DTT signals to other sites will relies on fiber optic support.
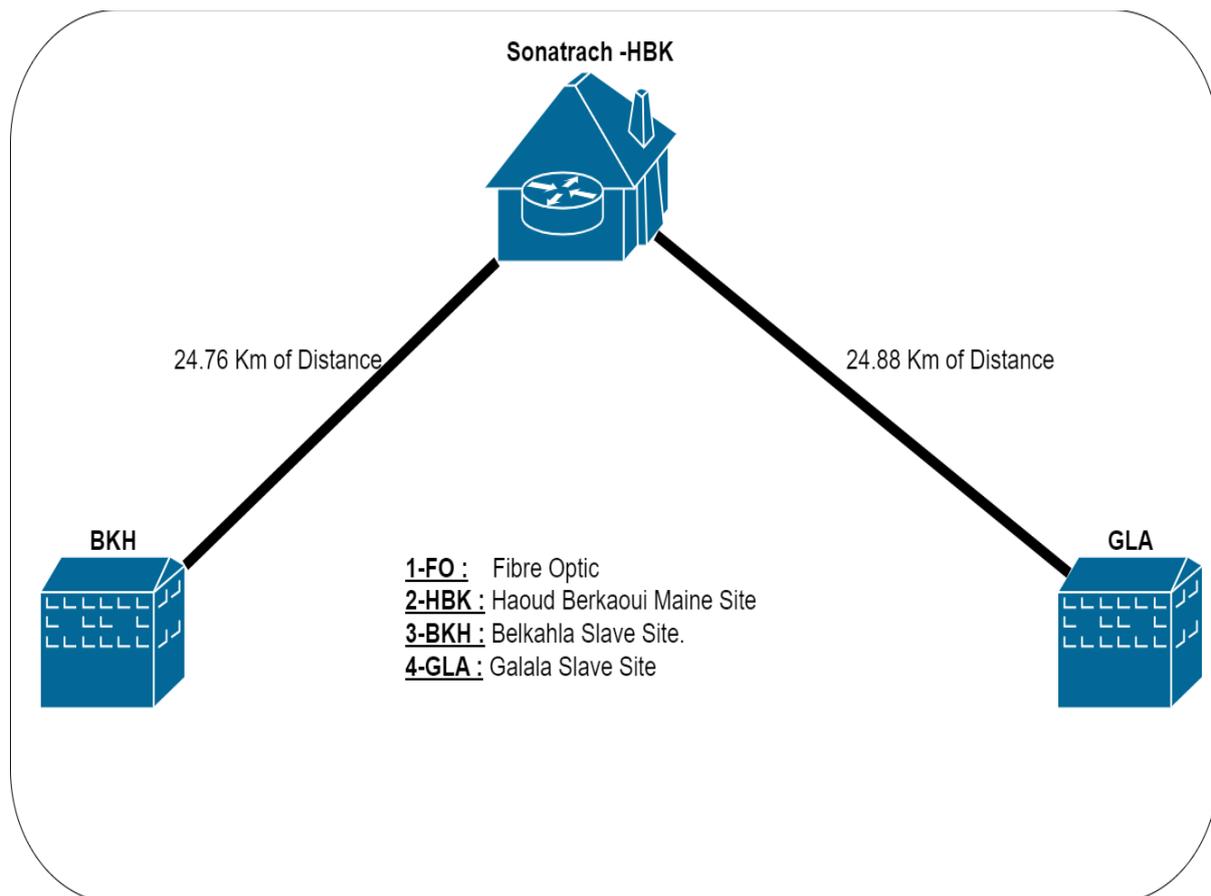
FO Sites Interconections Diagrame
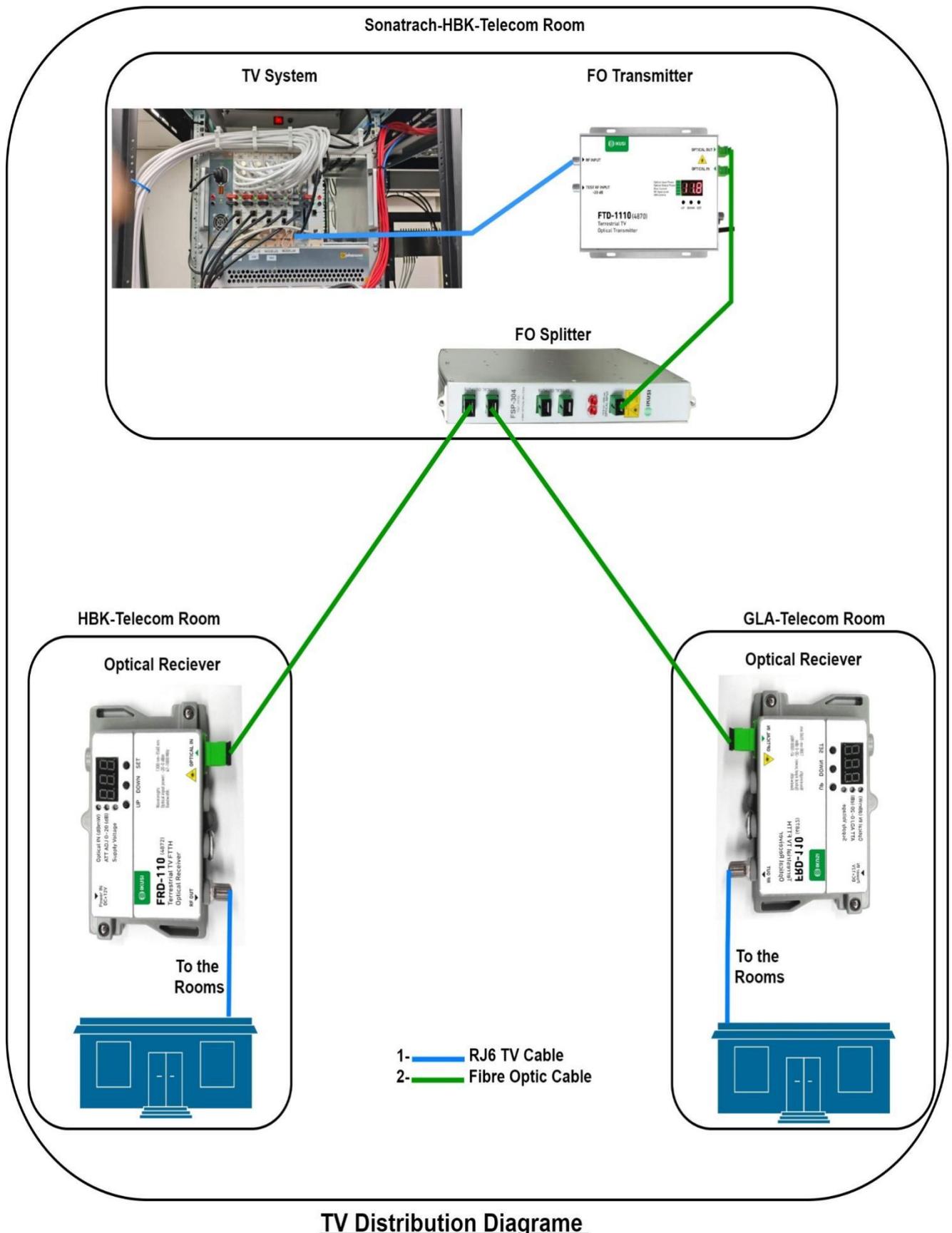
Figure III.2: DTT system distribution

Before distributing the DTT signal via optical fiber, it must be converted into an optical signal. Similarly, before sending it to users, the signal needs to be converted back into an electrical signal. Therefore, each type of optical converter is available in either a Transmitter (electrical to optical) or Receiver (optical to electrical) version.

The conversion from electrical signal to optical signal is performed by an optical transmitter of the IKUSI FTD 1110 brand.

The IKUSI FTD 1110 is the solution for the distribution of terrestrial analog and digital TV signals in large collective installations and residential areas.

Figure III.3: Optical Transmitter IKUSI FTD 1110

And the conversion from optical signal to electrical signal is performed by an optical receiver of the IKUSI FRD 110 brand.

Figure III.4: Optical Receiver IKUSI FTD 110

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III.3   Measurements made on the optical links:

To study the optical links deployed by Sonatrach, we examined two specific links in this section: the BERKAOUI (HBK) – BENKAHLA (BKH) link and the BERKAOUI (HBK) – GELALA (GLA) link. This study was conducted using an OTDR MTS 4000 device.

III.3.1   Event symbol array on MTS 4000 OTDR:

Before displaying the results in our links, it is important to understand the meaning of each event symbol and traces that will appear in the OTDR. The table below outlines the key event symbols that we will encounter during our testing.
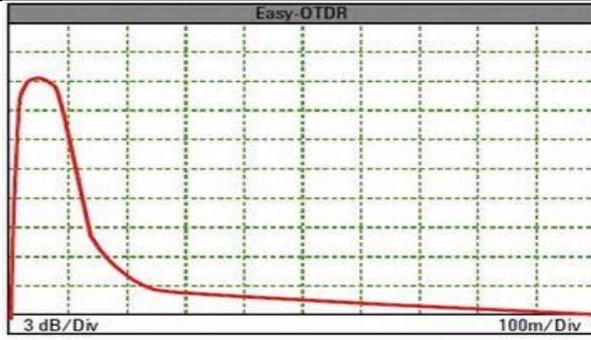
Table III.1: Event Symbols description

Symbol	Event type	Description
	Fiber Start	Indicates the beginning of the fiber.
	Reflective Event	Represents a reflective event such as a connector or mechanical splice.
	Non-reflective Event	Indicates a non-reflective event, typically a splice or bend.
	Fiber End	Marks the end of the fiber or the end of the measurable distance.

III.3.2   Event trace of fiber on OTDR:

Any issue that causes a fiber to lose or reflect light, beyond the normal diffusion of the material itself, is considered an event. This includes all types of connections and various forms of damage, such as twists, cracks, or breaks. The trace of an OTDR (Optical Time-Domain Reflectometer) represents the result of a measurement in graphical form on the screen. The vertical axis corresponds to power, while the horizontal axis corresponds to distance. In this section, we will present traces corresponding to most of the common events encountered in fiber optics.

Table III.2: Events trace description

Fiber Beginning		If you are using a normal straight connector, the beginning of a fiber always has a strong reflection at the front connector
Connector		Connectors inserted into a link cause reflection and loss
Bending		Overall Bend loss depends on how the FOC is bend, if there is too much bend then that point will show too much bend loss. Bend loss 0.5 to 0.75dB can be considered.
Patch Cords		Patch cords are used to connect the OTDR to the fiber being tested. The initial reflection does not cover the beginning of the fiber. This allows for a better inspection of the first connector.
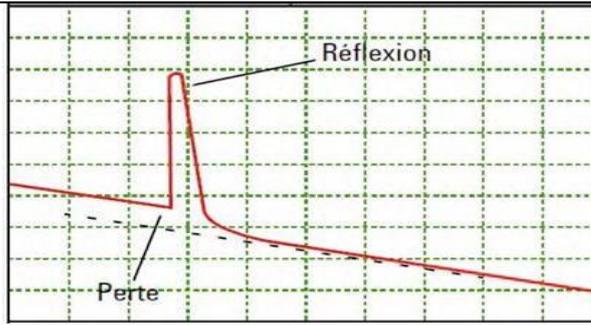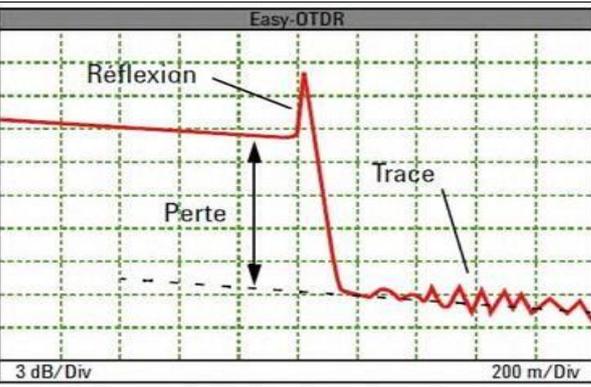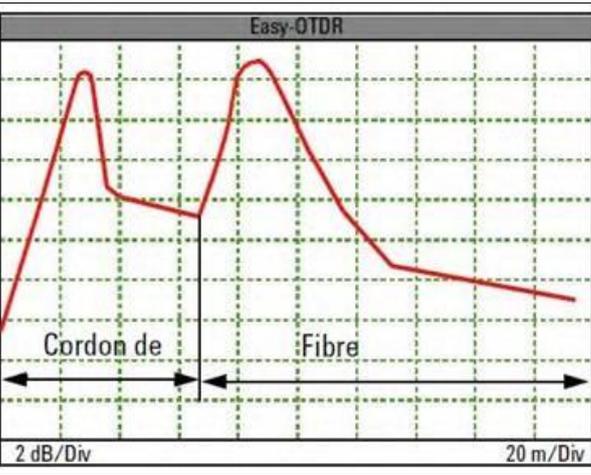
fusion splice		A fusion splice is a non-reflective event. Only the loss can be detected. Modern fusion splices are so perfect that they are virtually invisible
End of Fiber		In most cases, you'll see a strong reflection at the end of the fiber before the trace drops back to the noise level
Fiber Break		The interruption or breakage of a fiber is called a break. Ruptures are non-reflective events. The trace falls to the level of noise
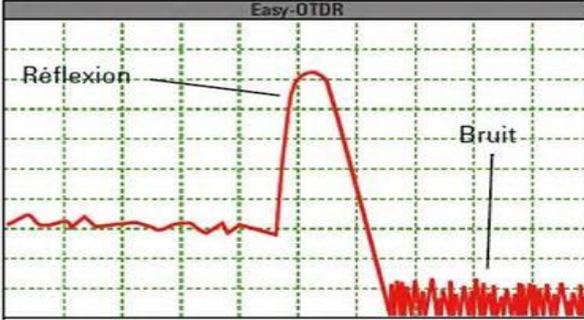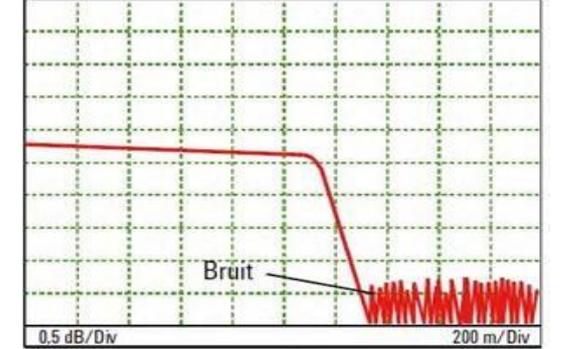
III.3.3   Cable type:

In this study, the cable being tested is an optical fiber of the type SINGLE MODE G652D. The table below presents the optical characteristics that will be utilized later to calculate the acceptable link loss.

Table III.3: fiber G652D characteristics

OPTICAL FIBER. SINGLE MODE. G652D

OPTICAL CHARACTERISTICS

PARAMETER	VALUE	UNITS	TEST METHOD
Typ./Max. Individual fibre Attenuation at 1310 nm (*)	0,32 / 0,35	dB/km	UNE-EN 188000-303 IEC 60793-1-40
Typ./Max. Individual fibre Attenuation at 1383 nm (*)	0,28 / 0,31	dB/km	
Typ./Max. Individual fibre Attenuation at 1550 nm (*)	0,19 / 0,21	dB/km	
Typ./Max. Individual fibre Attenuation at 1625 nm (*)	0,20 / 0,24	dB/km	
Att. Uniformity (Point discontinuities at 1310 or 1550 nm)	< 0,05	dB	

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III.4   Optical Link Testing Between HBK and BKH/GLA:

After providing an overview of the links to be studied and highlighting the key trace and events we will encounter in our tests, we will now proceed with the tests. The first test will use a **1310 nm** wavelength for the optical link between the Haoud Berkaoui Fields (HBK) and the Benkahla Fields (BKH),

as well as for the link between HBK and the Geullala Fields (GLA). Following this, we will conduct the same test using a **1550 nm** wavelength.

For each test, we will detail the parameters utilized, present the OTDR trace for the link, and provide a table of event symbols. The results from these tests will help us enhance the link and provide the best possible service.

III.4.1   The parameters of the HBK-BKH (λ=1310) optical link:

Below is a table detailing the parameters configured on the Optical Time-Domain Reflectometer (OTDR) for the analysis of the HBK-BKH link.

These parameters are crucial for conducting a thorough analysis of the HBK-BKH link using the OTDR. They dictate the characteristics of the optical signal sent along the link and the parameters used by the OTDR to measure various properties such as attenuation, reflectivity, and distance to faults.

Table III.4: Parameters of the HBK BKH optical link (λ=1310)

Wavelength (nm)	1310	Measurement time(mn)	1 min
Distance range(km)	40 Km	Pulse width (ns)	100ns
Slope(dB km)	>0.33	Connector Loss(dB)	>1.50
Refractive index	1.46750	splice loss	0.10dB
Reflectance (dB)	>-36 dB	Events number	12
Total Loss (dB)	9.459 dB	**Total Distance**	24.760

III.4.1.1   The OTDR trace:

Upon analysing the OTDR trace for the HBK-BKH link, we have identified various events that provide insights into the condition and characteristics of the optical fiber We have identified the first event as a connector peak, followed by nine fiber splice and strand placement events at sleeves. Events 1 and 11 are connector events, and event 12 is a connector peak accompanied by fiber end noise.
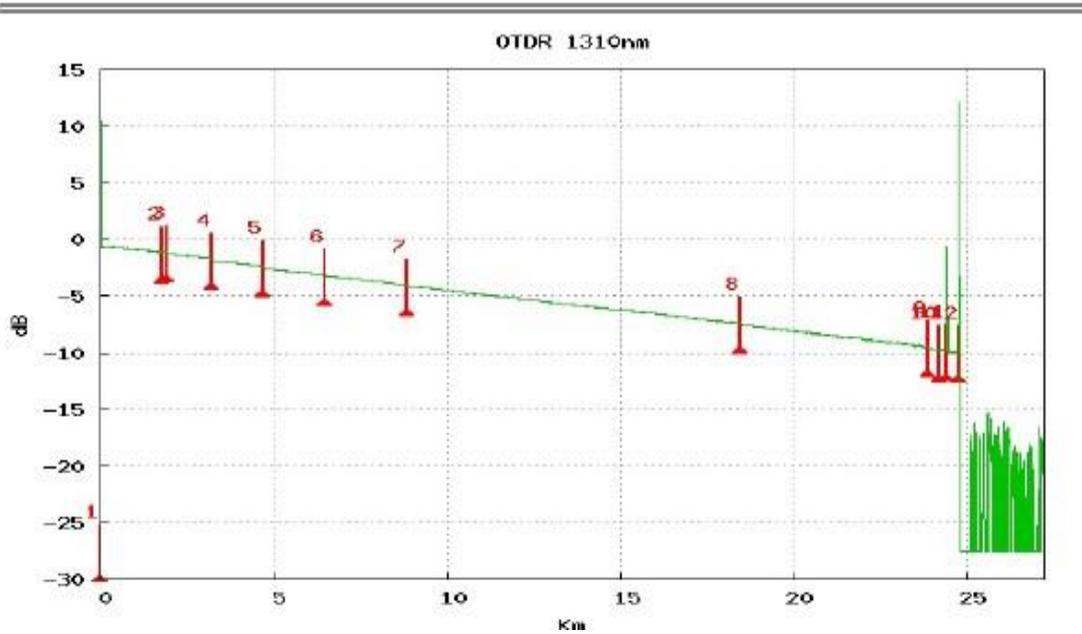

Figure III.5: The trace of the HBK-BKH optical link (λ=1310)

III.4.1.2   The event parameter table:

The OTDR provides a comprehensive table of parameters for all events detected along the HBK-BKH link. Below is the detailed event parameter table:

Event		Distance	Loss	Reflect.	Slope	Section	T. Loss
		Km	dB	dB	dB/km	Km	dB
1	⬦	0.000	0.570	-28.59		0.000	0.000
2	▬	1.785	-0.122		0.320	1.785	0.572
3	▬	1.933	0.204		0.299	0.148	0.494
4	▬	3.241	0.195		0.329	1.307	1.127
5	▬	4.714	0.198		0.323	1.473	1.798
6	▬	6.481	0.057		0.331	1.767	2.581
7	▬	8.818	0.091		0.349	2.337	3.456
8	▬	18.450	0.119		0.300	9.632	6.838
9	▬	23.863	0.122		0.361	5.414	8.907
10	▬	24.206	-0.104		0.657	0.342	9.254
11	⬚	24.412	0.021	-39.73	0.703	0.207	9.295
12	⬦	24.760		-14.01	0.413	0.347	9.459

Figure III.6: The events of the HBK-BKH optical link (λ=1310)

This table provides crucial information about each detected event, including its type, distance from the origin (HBK), loss encountered, reflectance, and location along the link. By analysing

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these parameters, we gain insights into the characteristics of the optical fiber, such as splice points, connector locations, and potential signal attenuation or reflections.

III.4.2   The parameters of the table HBK GLA optical link (λ=1310):

For the HBK-GLA optical link analysis at a wavelength of 1310nm, we will conduct a similar test as performed for the HBK-BKH link.

Table III.5 Parameters of the HBK GLA optical link (λ=1310)

Wavelength (nm)	1310	Measurement time(mn)	1 min
Distance range(km)	40 Km	Pulse width (ns)	100ns
Slope(dB :km)	>0.33	Connector Loss(dB)	>1.50
Refractive index	1.46750	splice loss	0.10dB
Reflectance (dB)	>-36 dB	Events number	12
Total Loss (dB)	**8.202dB**	**Total Distance**	**24.887**

III.4.2.1   The OTDR trace:

The events displayed on the OTDR trace indicate anomalies and attenuation at the second, third, and fifth splices. Specifically, there is attenuation at a distance of 12.911 km and at 18.687 km, with an attenuation of 0.339 dB.
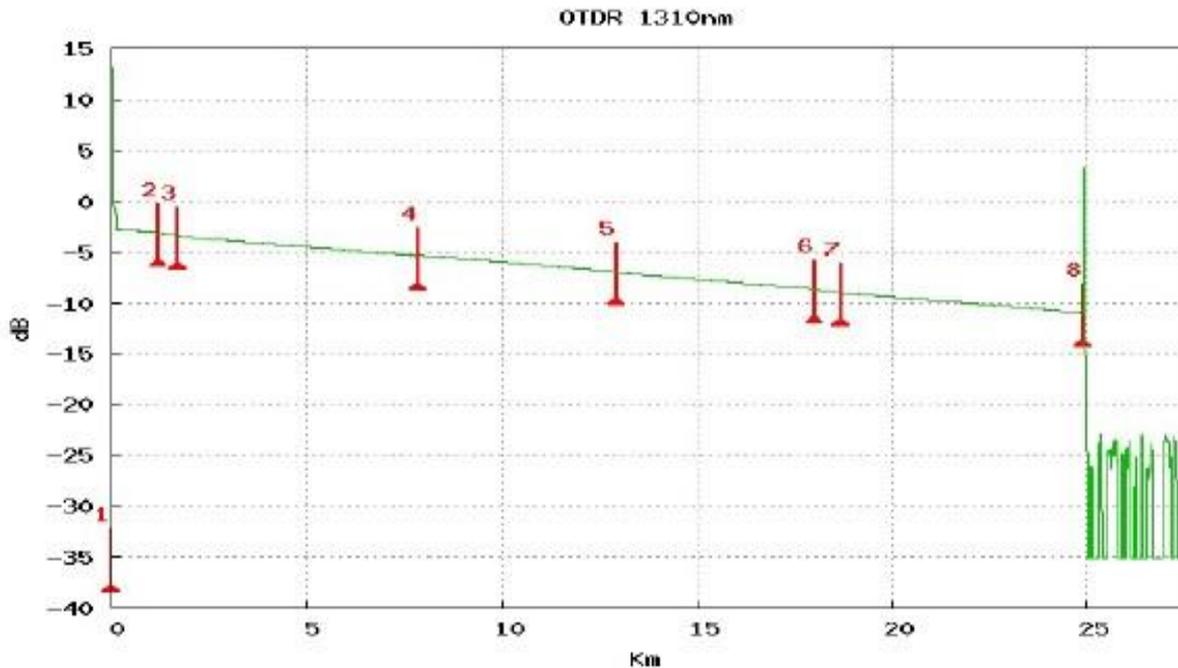
Figure III.7: The trace of the HBK-GLA optical link (λ = 1310)

III.4.2.2   The event parameter table:

Upon analysing the OTDR trace for the HBK-GLA optical link, we have observed anomalies and attenuation at specific points along the fiber. Notably, anomalies and attenuation are detected at the second, third, and fifth splices. The following details summarize the findings:

Anomalies at Splices: Anomalies indicating potential irregularities or disruptions are noted at the second, third, and fifth splices along the optical fiber link.

Attenuation Locations: Attenuation is observed at a distance of 12.911 km and at 18.687 km along the optical fiber. The attenuation measured at these locations is 0.339 dB.

Event		Distance	Loss	Reflect.	Slope	Section	T. Loss
		Km	dB	dB	dB/km	Km	dB
1		0.000	2.778	-27.96		0.000	0.000
2		1.195	0.122		0.274	1.195	0.325
3		1.726	0.128		0.301	0.531	0.607
4		7.891	-0.066		0.228	6.164	2.643
5		12.911	0.106		0.318	5.020	4.174
6		18.028	0.079		0.316	5.117	5.900
7		18.687	0.059		0.339	0.659	6.203
8		24.887		-25.83	0.313	6.200	8.202

Figure III.8: The events of the HBK-GLA optical link (λ = 1310)

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III.4.3   The parameters of the HBK-BKH (λ=1550) optical link:

Now we will change the wavelength to 1550 nm for the two link under test.

Table III.6: Parameters of the HBK-BKH Optical Link (λ=1550)

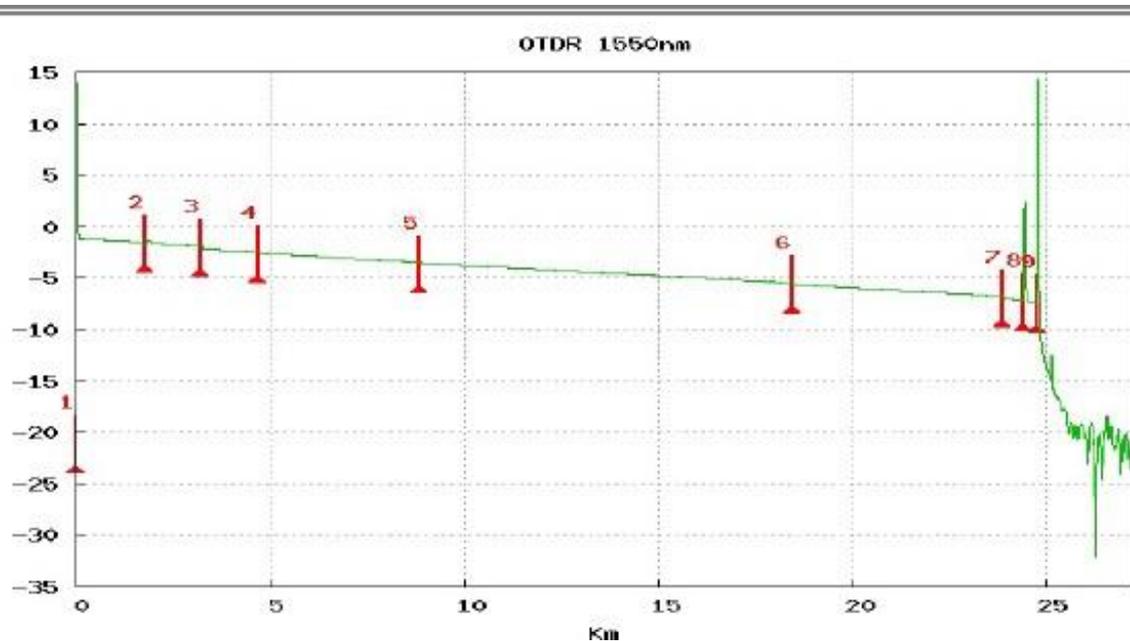| Wavelength (nm)	1550	Measurement time(mn)	1 min
Distance range(km)	40 Km	Pulse width	300ns
Slope(dB :km)	0.22 dB/km	Connector Loss(dB)	1.5 dB
Refractive index	1.46750	splice loss	0.10 dB
Reflectance (dB)	**>-34 dB**	Events number	09
Total Loss(dB)	**6.112**	**Total Distance**	**24.756**

III.4.3.1   The OTDR trace:

Figure III.9: The trace of the HBK-BKH optical bond (λ = 1550)

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III.4.3.2   The event parameter table:

As we transition to a higher wavelength, such as 1550nm, it's notable that the number of events displayed on the OTDR decreases. This phenomenon occurs because certain events, particularly those associated with lower wavelengths like 1310nm, become less pronounced or even invisible due to changes in attenuation and scattering properties of the optical fiber.

Event		Distance	Loss	Reflect.	Slope	Section	T. Loss
		Km	dB	dB	dB/km	Km	dB
1	⌖	0.000	1.211	-28.21		0.000	0.000
2	⊡	1.792	0.081	-68.31	0.194	1.792	0.304
3	▬	3.242	0.323		0.198	1.450	0.672
4	▬	4.717	0.144		0.194	1.475	1.282
5	▬	8.822	0.066		0.206	4.105	2.284
6	▬	18.446	0.154		0.198	9.624	4.269
7	▬	23.883	0.257		0.238	5.437	5.609
8	⊡	24.414	0.072	-37.15	0.238	0.531	5.993
9	⌖	24.756		-12.98	0.138	0.342	6.112

Figure III.10: The events of the HBK-BKH optical link (λ = 1550)

III.4.4   The event parameter table HBK-GLA (λ=1550) optical link:

Table III.7: Parameters of the HBK-GLA optical link (λ=1550)

Wavelength (nm)	1550	Measurement time(mn)	1 min
Distance range(km)	40 Km	Pulse width	300ns
Slope(dB :km)	0.22 dB/km	Connector Loss(dB)	1.5 dB
Refractive index	1.46750	splice loss	0.10 dB
Reflectance (dB)	>-36 dB	Events number	08
Total Loss(dB)	5.299 dB	**Total Distance**	24.889

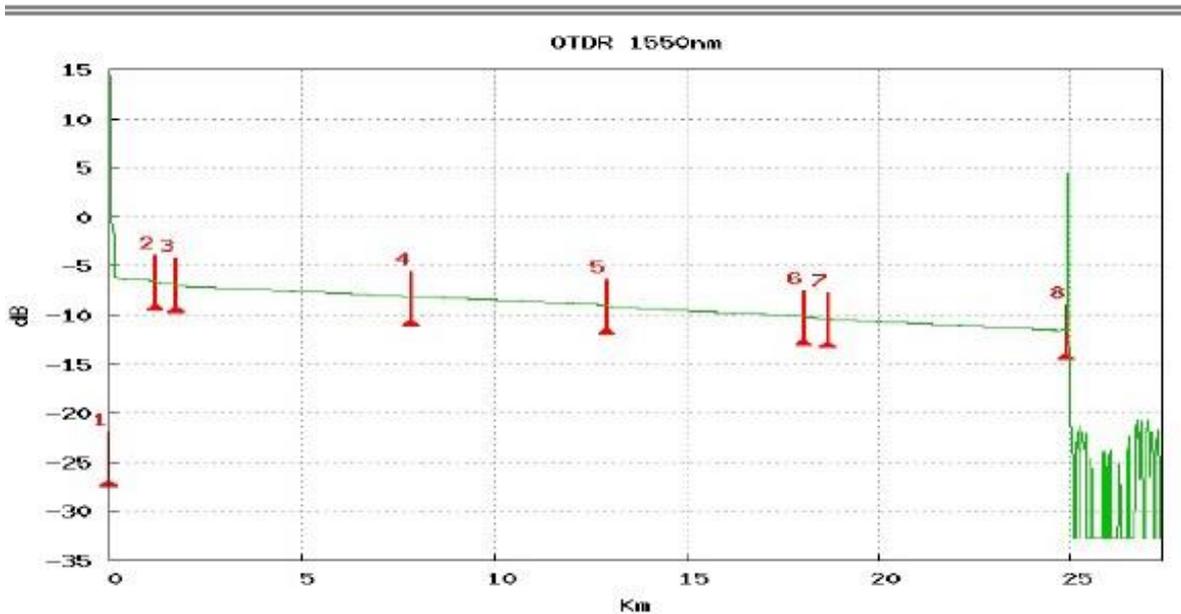### III.4.4.1   The OTDR trace:

Figure III.11: The trace of the HBK-GLA optical link (λ = 1550)

III.4.4.2   The event parameter table:

Event		Distance	Loss	Reflect.	Slope	Section	T. Loss
		Km	dB	dB	dB/km	Km	dB
1	⊙	0.000	6.279	-27.39		0.000	0.000
2	▬	1.195	**0.209**		0.205	1.195	0.245
3	▬	1.736	**0.212**		0.185	0.541	0.554
4	▬	7.873	-0.073		0.180	6.137	1.870
5	▬	12.907	**0.168**		0.184	5.034	2.724
6	▬	18.078	0.097		0.202	5.172	3.879
7	▬	18.681	0.062		0.173	0.602	4.080
8	◁	24.889		-24.05	0.187	6.208	5.299

Figure III.12: The events of the HBK-GLA optical link (λ = 1550)

III.5   Comparable Linking Table:

After completing all the tests on our links, the table below provides a comparison of the results. This will help us determine which link performs best and will aid in identifying the most suitable wavelength for optimal performance and minimal transmission losses.

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Table III.8: Comparable Linking Table

Link	Wavelength (nm)	Total loss (dB)	Fiber length (Km)
HBK-BKH	1310	9.459	24.760
HBK-BKH	1550	6.112	24.756
HBK-GLA	1310	8.202	24.887
HBK-GLA	1550	5.299	24.889

After concluding our assessments of the optical links connecting the Haoud Berkaoui Fields (HBK) to both the Benkahla Fields (BKH) and the Geullala Fields (GLA), a clear preference emerged for the 1550 nm wavelength over the 1310 nm counterpart. The tests consistently revealed that the 1550 nm wavelength boasted superior performance characteristics.

Notably, the 1550 nm wavelength demonstrated lower levels of attenuation and overall losses compared to its 1310 nm counterpart. This translated to more efficient and reliable transmission across the optical links. Furthermore, the 1550 nm wavelength exhibited a

reduced number of significant events indicating potential issues such as splices, bends, and faults along the fiber.

Given these findings, it is recommended that the 1550 nm wavelength be adopted for optimal performance in our TV broadcasting system and to minimize transmission losses across our optical links. This wavelength choice promises enhanced reliability and efficiency, ensuring seamless communication between the HBK and both the BKH and GLA fields.

III.6   Calculation of Acceptable Link Loss:

By performing these calculations and comparing them with the actual OTDR measurements, we can confirm the integrity and performance of the fiber optic links, ensuring that they meet the necessary standards and operate reliably within the designed parameters.

 To calculate the acceptable loss for our links, we will use the method described in Chapter II. The formula for Total Link Loss (LL) is as follows:

- ❖ **Total Link Loss (LL) = Optical Cable Attenuation + Connector Attenuation + splice Attenuation**

- ✓ **Optical Cable Attenuation (dB) = Maximum Attenuation Coefficient of Optical Fiber (dB/km) × Length (km)**

- ✓ **Connector Attenuation (dB) = Number of Connectors × Connector Loss (dB)**

- ✓ **splice Attenuation (dB) = Number of Fusion Splices × Fusion Splice Loss (dB).**

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Considering the characteristics of our links and the events obtained from the OTDR trace, the results are as follows:

> **HBK-BKH link total loss (λ =1310 nm):**

Optical Cable Attenuation = 24.760 km×0.32 dB/km=7.9232 dB

Connector Attenuation=1×0.75 dB=0.75 dB

Splice Attenuation=9×0.3 dB=2.7 dB

Total Link Loss = 7.9232+0.75+2.7=11.3732 dB ≈ 11.37 dB

> **HBK-GLA link total loss (λ =1310 nm):**

Optical Cable Attenuation=24.887 km×0.32 dB/km=7.964 dB

Connector Attenuation=1×0.75 dB=0.75 dB

Splice Attenuation=9×0.3 dB=2.7 dB

Total Link Loss=7.964+0.75+2.7=11.414 dB ≈ 11.41 dB

> **HBK-BKH link total loss (λ =1550 nm):**

Optical Cable Attenuation=24.756 km×0.19 dB/km=4.70364 dB

Connector Attenuation=1×0.75 dB=0.75 dB

Splice Attenuation=5×0.3 dB=1.5 dB

Total Link Loss=4.70364+0.75+1.5=6.95364 dB ≈ 6.95 dB

> **HBK-GLA link total loss (λ =1550 nm):**

Optical Cable Attenuation=24.889 km×0.19 dB/km=4.72991 dB

Connector Attenuation=1×0.75 dB=0.75 dB

Splice Attenuation=6×0.3 dB=1.8 dB

Total Link Loss=4.72991+0.75+1.8=7.27991 dB ≈ 7.27 dB

III.6.1   Comparison OTDR result to the acceptable link loss

After performing the OTDR tests and comparing the results with our calculated acceptable link loss, we noted that the calculated link loss results are higher than the results obtained from the OTDR measurements of our actual links. This indicates that the actual link loss is within acceptable limits, and thus, the link is in good condition.

Since our calculated losses are higher than the OTDR measurements, the actual link losses are lower, confirming that the links are performing better than the worst-case scenarios accounted for in our calculations. This verification ensures the quality and reliability of the links.

Table III.9: Comparison OTDR result to the acceptable loss

Link	OTDR (dB)	Acceptable link loss(dB)
HBK-BKH (λ =1310)	9.459	11.37
HBK- GLA (λ =1310)	8.202	11.41
HBK- BKH (λ =1550)	6.112	6.95
HBK-GLA (λ =1550)	5.299	7.27

Conclusion

thorough analysis and testing conducted on the optical links between the Haoud Berkaoui Fields (HBK) and both the Benkahla Fields (BKH) and the Geullala Fields (GLA) have yielded positive results.

By comparing the calculated acceptable link losses with the actual losses obtained from OTDR measurements, we have confirmed that the links are in good condition and operating within acceptable limits. Interestingly, the calculated losses were found to be higher than the measured losses, indicating that the links are performing even better than anticipated.

This outcome is a testament to the quality and reliability of the optical infrastructure supporting our systems, ensuring seamless communication and transmission of data between the HBK and both the BKH and GLA fields.

Moving forward, we aim to enhance the links by implementing strategies such as selecting optical fibers with lower attenuation coefficients, ensuring high-quality connectors and splices, and optimizing the route of the optical cables to minimize signal loss. Additionally, the integration of optical signal amplification and advanced testing techniques will further contribute to reducing losses and optimizing link performance.

Chapter IV: Optical Link Simulation.

IV.1   Introduction

Our objective in this part is to study the optical links discussed in the chapter III and to determine the compromised parameters for these optical links by using Optisystem software. Understanding and optimizing these parameters is crucial for ensuring good communication over optical fiber networks.

By the end of this chapter, we expect to have a comprehensive understanding of the optical links under study. We will identify the key compromised parameters and propose strategies to mitigate their impact. This will lead to enhanced performance of the optical fiber communication systems.

In the following sections, we will delve into the detailed analysis of the OptiSystem simulations, explore the event symbols and their significance, and discuss the optimization techniques for the identified compromised parameters.

IV.2   Optisystem software overview:

OptiSystem is a software designed for the design, testing, and optimization of nearly any type of optical link. It features a robust simulation environment, and its capabilities can be easily extended by adding user components and integrating seamlessly with a variety of widely used tools. [27]

IV.2.1   Component Library:

The OptiSystem Component Library includes hundreds of components, all of which have been carefully validated to provide results that are comparable with real-world applications.

The process to follow is divided into two steps:

- Building the block diagram,

- Analysing the diagram.

Optisystem Interface: The Optisystem interface consists of a main window divided into several parts.

- Library: a database of various existing components.

- Layout Editor: allows editing and configuring the current design diagram.

- Current Project: displays various files and components corresponding to the current project.
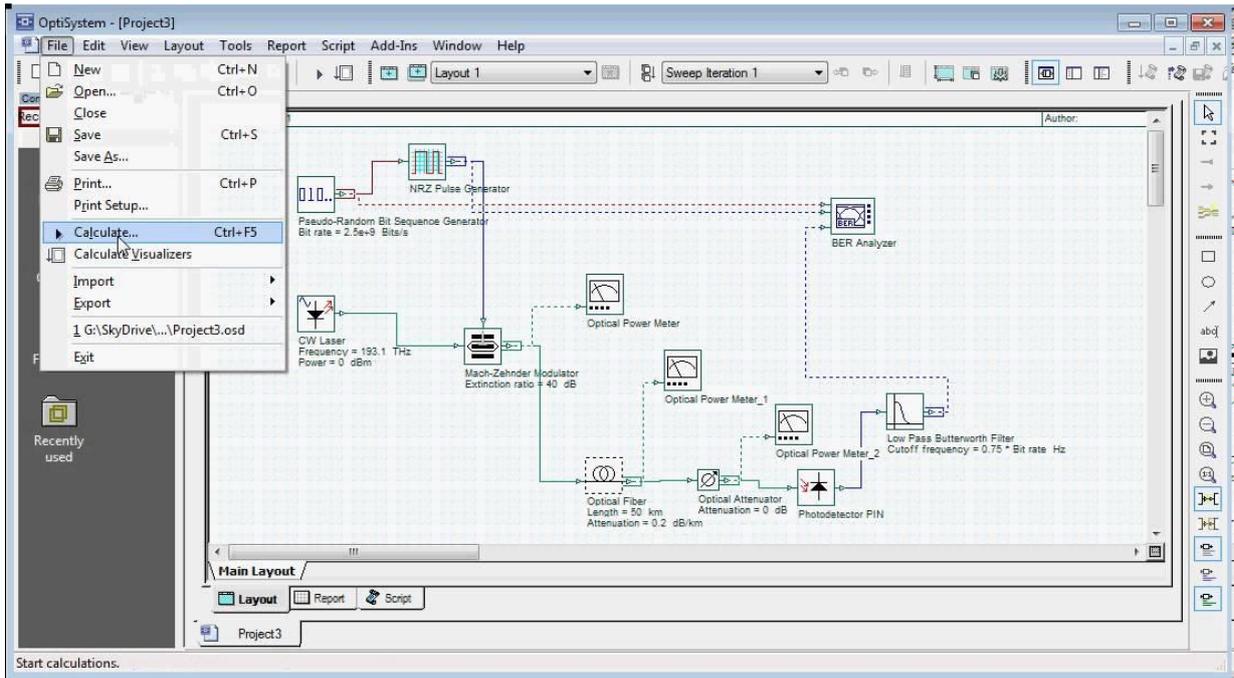
Figure IV.1 Optisystem software interface

IV.2.2   Software Advantages:

Among the advantages of this software are:

- Providing an overview of performance for the global optical fiber system.

- Evaluating parameter sensitivities to aid in design tolerance specifications.

- Visually presenting design options to potential clients.

- Providing direct access to comprehensive system characterization datasets.

- Offering automatic parameter scanning and optimization.

Optisystem enables the automation and design of practically any optical link in the physical layer and analyses a wide range of optical networks. Optisystem allows users to plan, test, and simulate:

- WDM/TDM or CATV network design (Cable Television).

- SONET/SDH ring design.

- Dispersion map design.

- Estimation of BER penalties for systems with different receiver models.

IV.2.3   User-defined components:

The OptiSystem component library boasts a diverse array of components, rigorously validated to ensure results align with real-world scenarios.

- **Pseudo-Random Bit Generator**: Generates random binary sequences.

- **NRZ Pulse Generator**: Produces NRZ (non-zero return) pulses.

- **CW Laser**: Emulates a laser-based optical transmitter.

- **Mach-Zehnder Modulator**: Modulates optical signals.

- **PIN Photodetector**: Converts light into electric current, featuring a PIN design.

- **Low Pass Bessel Filter**: Filters out high-frequency components as a low-pass filter.

- **BER Analyser**: Analyses bit error rate (BER) and Q factor.

- **DCF (Dispersion Compensation Fiber**): Supports transmission.

- **Ideal EDFA (Erbium-Doped Fiber Amplifier**): Boosts signals.

- **Loop Control**: Regulates signal propagation between input and output ports, facilitating system performance analysis based on parameters like the number of EDFA fibers and spans.

- **Optical Power Meter**: Measures and displays optical energy.

- **Oscilloscope**: Displays output signals.

IV.3   The simulation:

In this phase, we utilized Optisystem to simulate the optical links between the Haoud Berkaoui Fields (HBK) and the Benkahla Fields (BKH), as well as between HBK and the Geullala Fields (GLA), as studied in the previous chapters. Through these simulations, we aimed to replicate real-world conditions and assess the performance of the optical links under various scenarios. By employing Optisystem's powerful simulation capabilities, we were able to analyse factors such as signal attenuation, dispersion, and noise, providing valuable insights into the behaviour of the optical links. These simulations serve as a crucial step in understanding and optimizing the performance of the optical communication network between HBK, BKH, and GLA, ultimately ensuring reliable and efficient data transmission.

IV.3.1   The link between HBK and BKH-GLA:

In the following diagram, we present the equivalent arrangement of the links from Haoud Berkaoui (HBK) to the Benkahla (BKH) field and the Glala (GLA) field, respectively. These two links will be thoroughly tested in the next section.
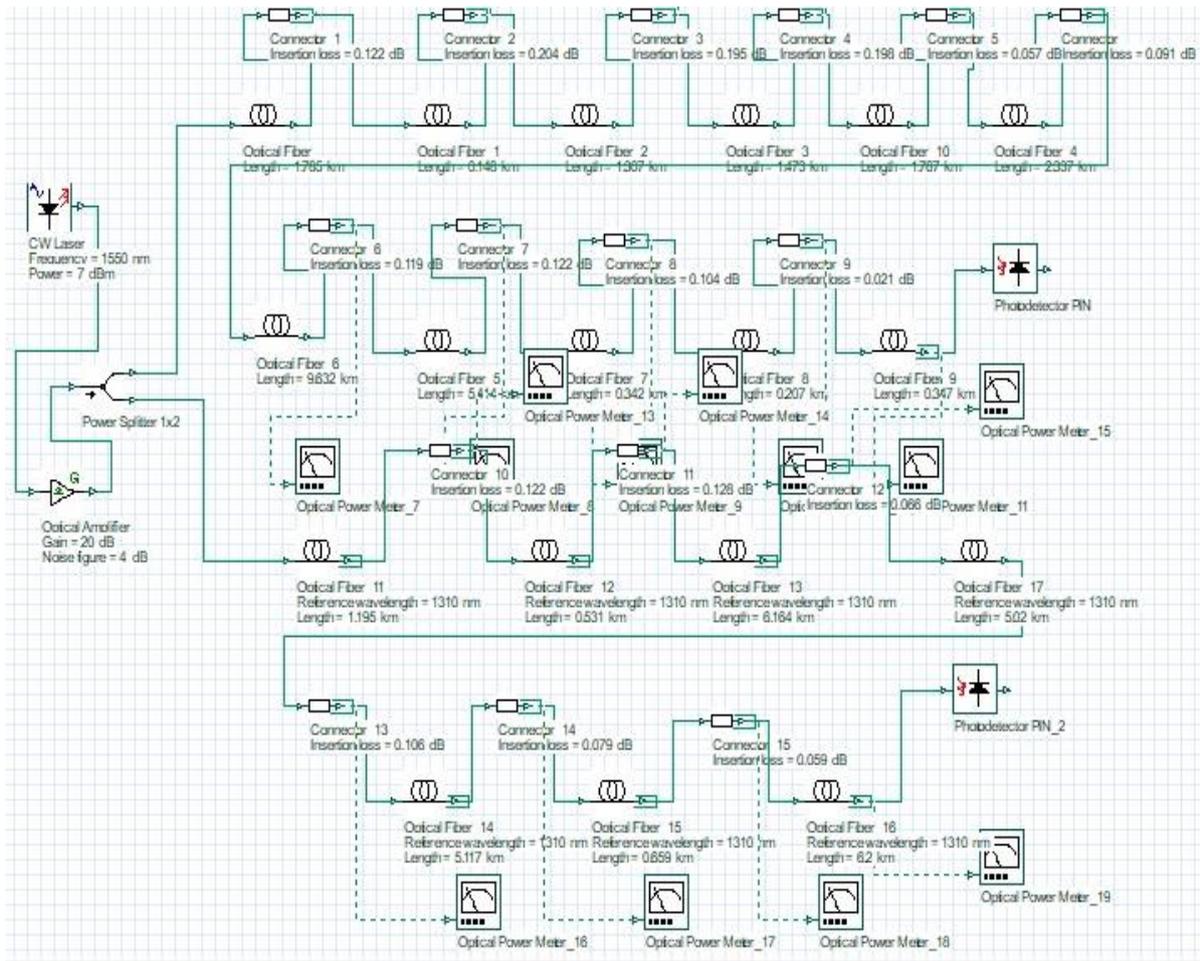
Figure IV.2: The equivalent arrangement of the HBK – BKH-GLA link:

The diagram illustrates the connection setup, highlighting the infrastructure and key components identified by the Optical Time-Domain Reflectometer (OTDR) in the previous chapter. These components are crucial in establishing communication between HBK and the respective fields BKH and GLA. By analysing this arrangement, we aim to identify and address any potential issues, ensuring optimal performance and reliability in the network links.

IV.4   The HBK-BKH Link*:*
IV.4.1 Equivalent arrangement of the HBK-BKH link (λ = 1310nm):

We begin our analysis with the HBK-BKH link, specifically examining the equivalent arrangement at a wavelength of 1310nm.
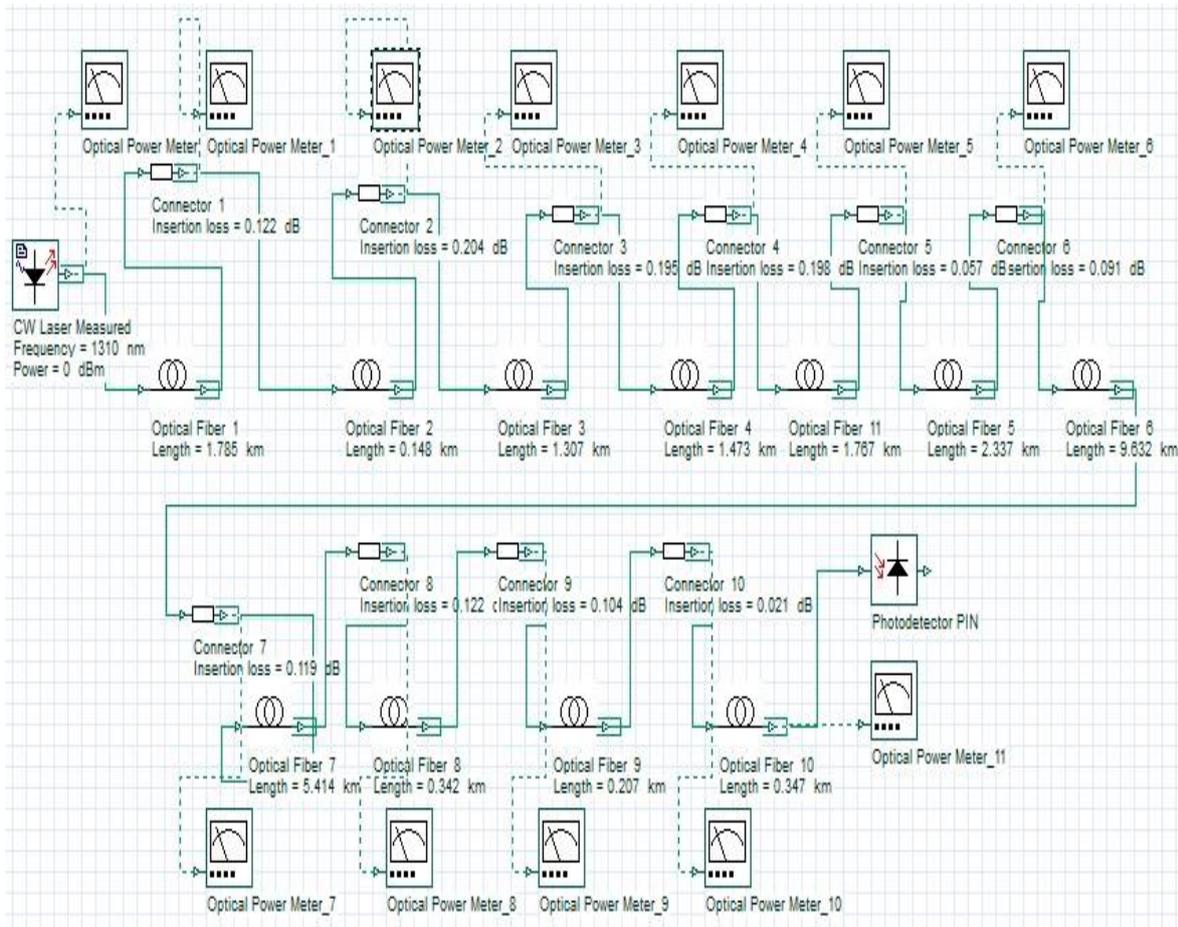
Figure IV.3: The equivalent arrangement of the HBK–BKH link (λ = 1310nm)

IV.4.2   Power Measurements for the Equivalent Connection:

The powers obtained by the equivalent connection assembly are given in the following table:

Table IV.1: The powers at each connector of the HBK-BKH link (λ = 1310)

segment	Power
1	
2	

3	Optical Power Meter ☒ 8 8 8 8 8 **8 0 5 . 0 8 2** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **0 . 9 4 2** dBm Total Power ▼
4	Optical Power Meter ☒ 8 8 8 8 8 8 **6 9 7 . 1 7 2** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **1 . 5 6 7** dBm Total Power ▼
5	Optical Power Meter ☒ 8 8 8 8 8 **5 9 6 . 9 8 3** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **2 . 2 4 0** dBm Total Power ▼
6	Optical Power Meter ☒ 8 8 8 8 8 **5 1 4 . 9 6 1** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **2 . 8 8 2** dBm Total Power ▼
7	Optical Power Meter ☒ 8 8 8 8 8 **4 1 7 . 9 3 9** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **3 . 7 8 9** dBm Total Power ▼
8	Optical Power Meter ☒ 8 8 8 8 8 **2 0 9 . 0 5 1** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **6 . 7 9 7** dBm Total Power ▼
9	Optical Power Meter ☒ 8 8 8 8 **1 2 9 . 6 0 1** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **8 . 8 7 4** dBm Total Power ▼
10	Optical Power Meter ☒ 8 8 8 8 **1 2 0 . 1 5 4** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **9 . 2 0 3** dBm Total Power ▼
11	Optical Power Meter ☒ 8 8 8 8 8 **1 1 5 . 6 3 4** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **9 . 3 6 9** dBm Total Power ▼
12	Optical Power Meter ☒ 8 8 8 8 8 **1 1 1 . 0 8 0** E-6 W Signal Index: 0 ⬍ _ 8 8 8 8 **9 . 5 1 2** dBm Total Power ▼

IV.5   The HBK-GLA link
IV.5.1   Equivalent arrangement of the HBK-GLA link: (λ = 1310):
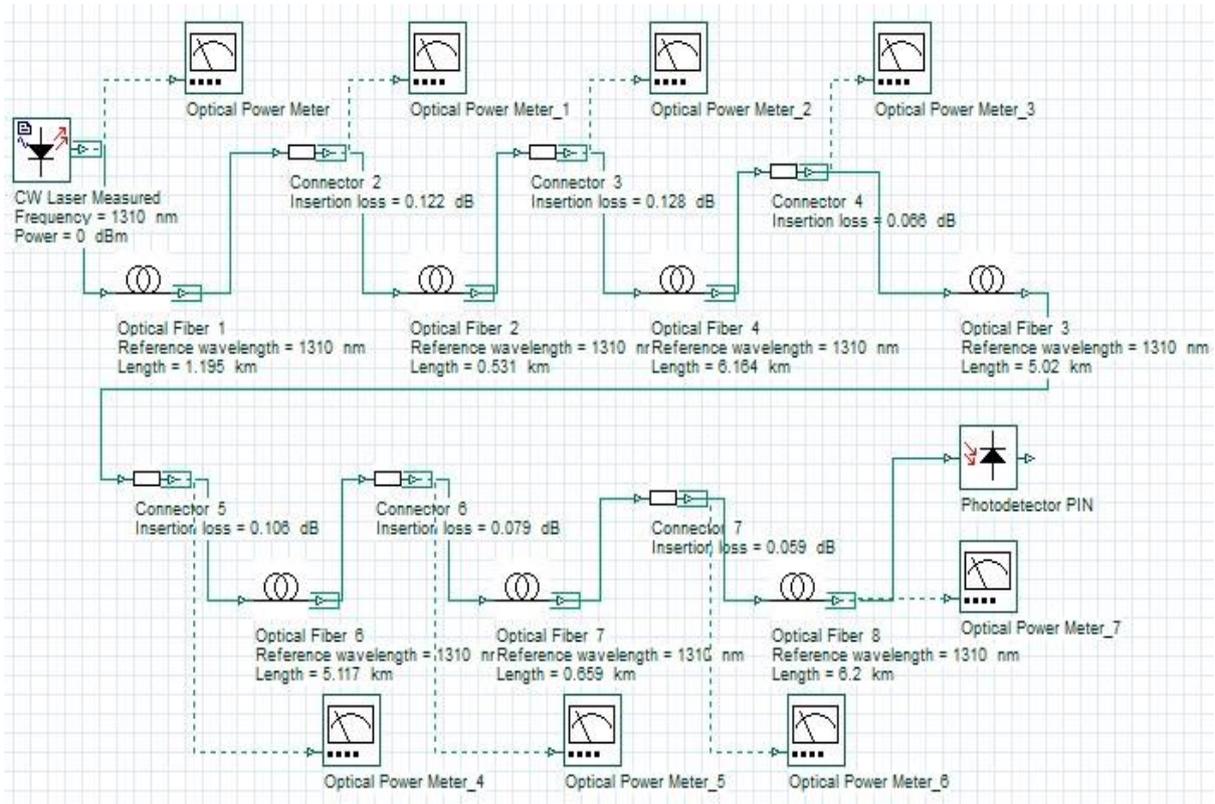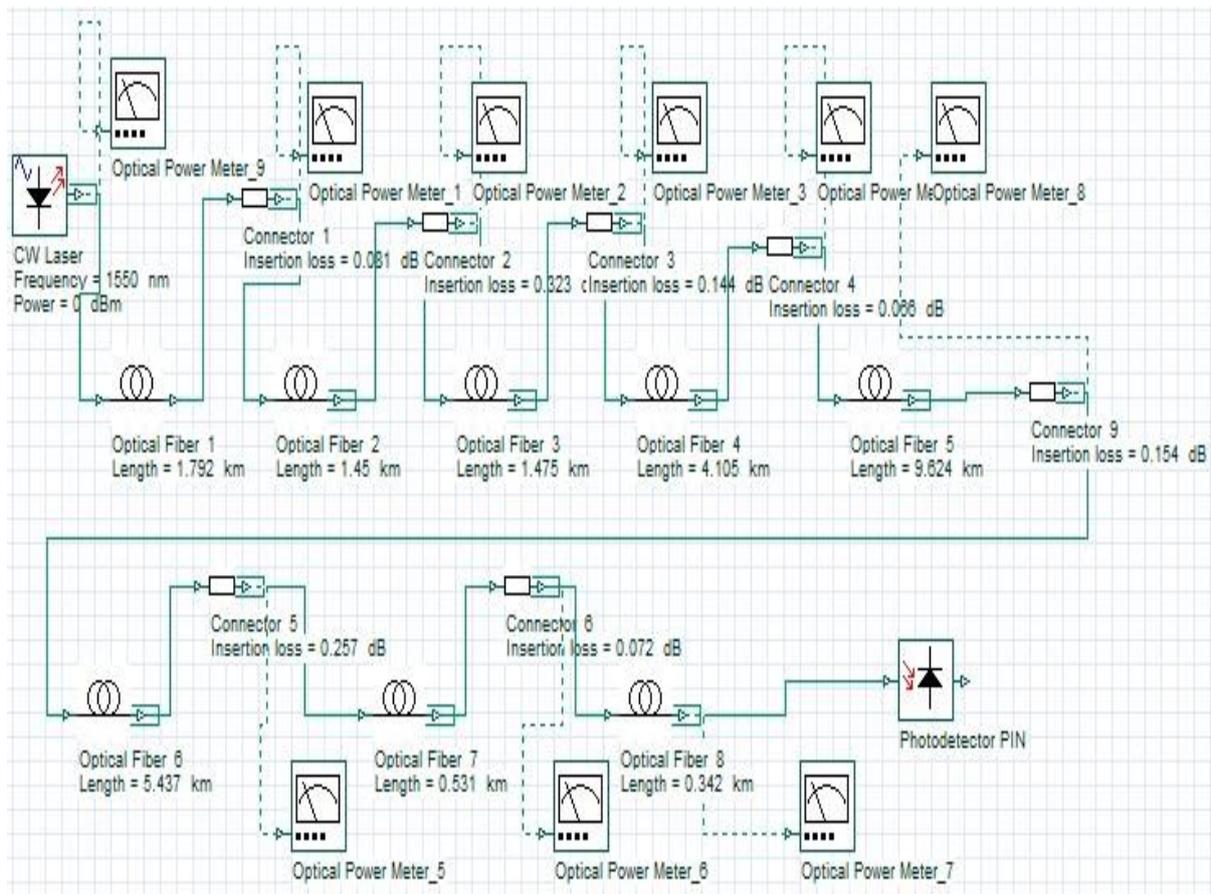

Figure IV.4: The equivalent arrangement of the HBK–GLA link (λ = 1310)

IV.5.2   Power Measurements for the Equivalent Connection HBK-GLA

The power levels obtained from the equivalent connection assembly for the optical link between Haoud Berkaoui Fields (HBK) and Geullala Fields (GLA) are presented in the table below:

Table IV.2: The powers at each connector of the HBK – GLA link (λ = 1310)

segment	Power
1	
2	

3	Optical Power Meter [×] 8 8 8 8 8 8 4 3 . 8 6 7 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 0 . 0 3 7 dBm Total Power [▼]
4	Optical Power Meter [×] 8 8 8 8 8 6 0 1 . 3 6 0 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 2 . 2 0 9 dBm Total Power [▼]
5	Optical Power Meter [×] 8 8 8 8 8 4 0 6 . 3 4 8 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 3 . 9 1 1 dBm Total Power [▼]
6	Optical Power Meter [×] 8 8 8 8 8 2 7 4 . 9 8 0 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 5 . 6 0 7 dBm Total Power [▼]
7	Optical Power Meter [×] 8 8 8 8 8 2 5 7 . 6 6 8 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 5 . 8 8 9 dBm Total Power [▼]
8	Optical Power Meter [×] 8 8 8 8 8 1 6 4 . 8 1 7 E-6 W Signal Index: 0 [▲▼] ⊥ 8 8 8 8 7 . 8 3 0 dBm Total Power [▼]

IV.6   The HBK-BKH link: (λ = 1550)

now we will present the equivalent arrangement and configuration of the optical link between Haoud Berkaoui Fields (HBK) and Benkahla Fields (BKH) using a 1550 nm wavelength.

IV.6.1   Equivalent arrangement of the HBK-BKH link (λ = 1550):

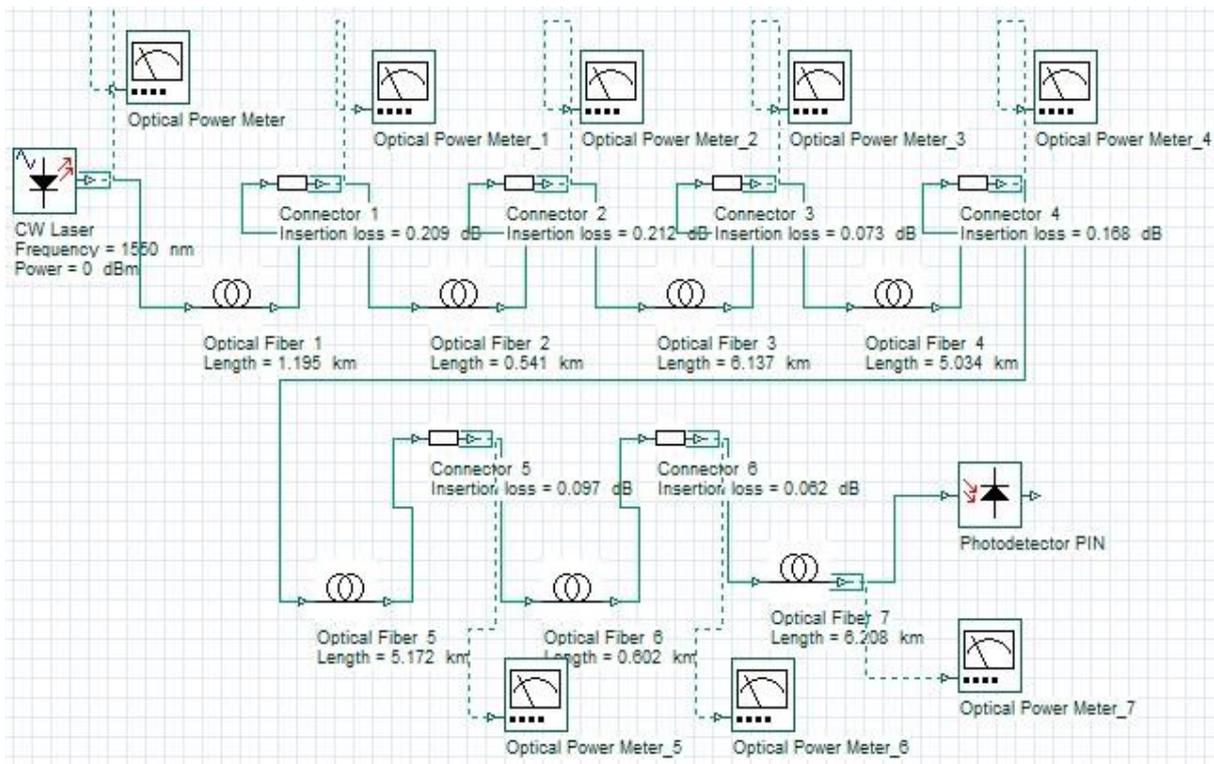*Figure IV.5: The equivalent arrangement of the HBK-BKH Link (λ = 1550)*

IV.6.2   Power Measurements for the Equivalent Connection HBK-BKH

The powers obtained by the equivalent connection assembly are given in the following table:

Table IV.3 The powers at each connector of the HBK – BKH link (λ = 1550 nm)

segment	Power
1	
2	
3	

4	
5	
6	
7	
8	
9	

IV.7   The HBK-GLA link: (λ = 1550 nm)
 IV.7.1 Equivalent arrangement of the HBK-GLA link (λ = 1550 nm):

Figure IV.6: The equivalent arrangement of the HBK GLA Link (λ = 1550 nm)

IV.7.2   Power Measurements for the Equivalent Connection HBK-GLA

The powers obtained by the equivalent connection assembly are given in the following table:

Table IV.4: The powers at each connector of the HBK – GLA link (λ = 1550)

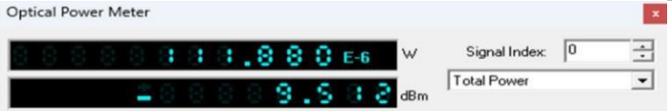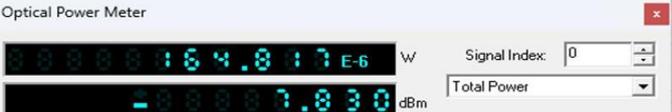| Segment	Power
1	
2	
3	
4	

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5	
6	
7	
8	

IV.8   Literature Comparing Simulation Results and OTDR Power Measurements:

Below is a table comparing the simulation results obtained from Optisystem with the power measurements gathered using Optical Time Domain Reflectometer (OTDR) for the optical links between Haoud Berkaoui Fields (HBK) and Benkahla Fields (BKH), as well as between HBK and Geullala Fields (GLA):

Table IV.5: Comparison of simulation and OTDR results

Link	OTDR (dB)	Simulation
HBK-BKH (λ =1310)	**9.459**	
HBK- GLA (λ =1310)	**8.202**	
HBK- BKH (λ =1550)	**6.112**	
HBK-GLA (λ =1550)	**5.299**	

 From the previous table, it can be observed that the power measurements obtained through simulation are nearly identical to the results given by the OTDR Furthermore, the 1550 nm

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wavelength consistently shows superior performance in both links, suggesting its suitability for ensuring best data transmission in our optical network. By focusing on reducing losses in the HBK-BKH link and leveraging the advantages of the 1550 nm wavelength, we can enhance the overall performance of our optical communication to ensure best TV broadcasting service to the living quarters.

IV.9   Evaluation of the quality of optical links
IV.9.1   Measurement setup: HBK-(GLA-BKH) (λ = 1550)

In this section, we detail the measurement setup used to evaluate the quality of the optical links between Haoud Berkaoui Fields (HBK) and both Geullala Fields (GLA) and Benkahla Fields (BKH) using a 1550 nm wavelength. This setup is designed to ensure accurate and reliable measurements, providing a clear understanding of the link performance.
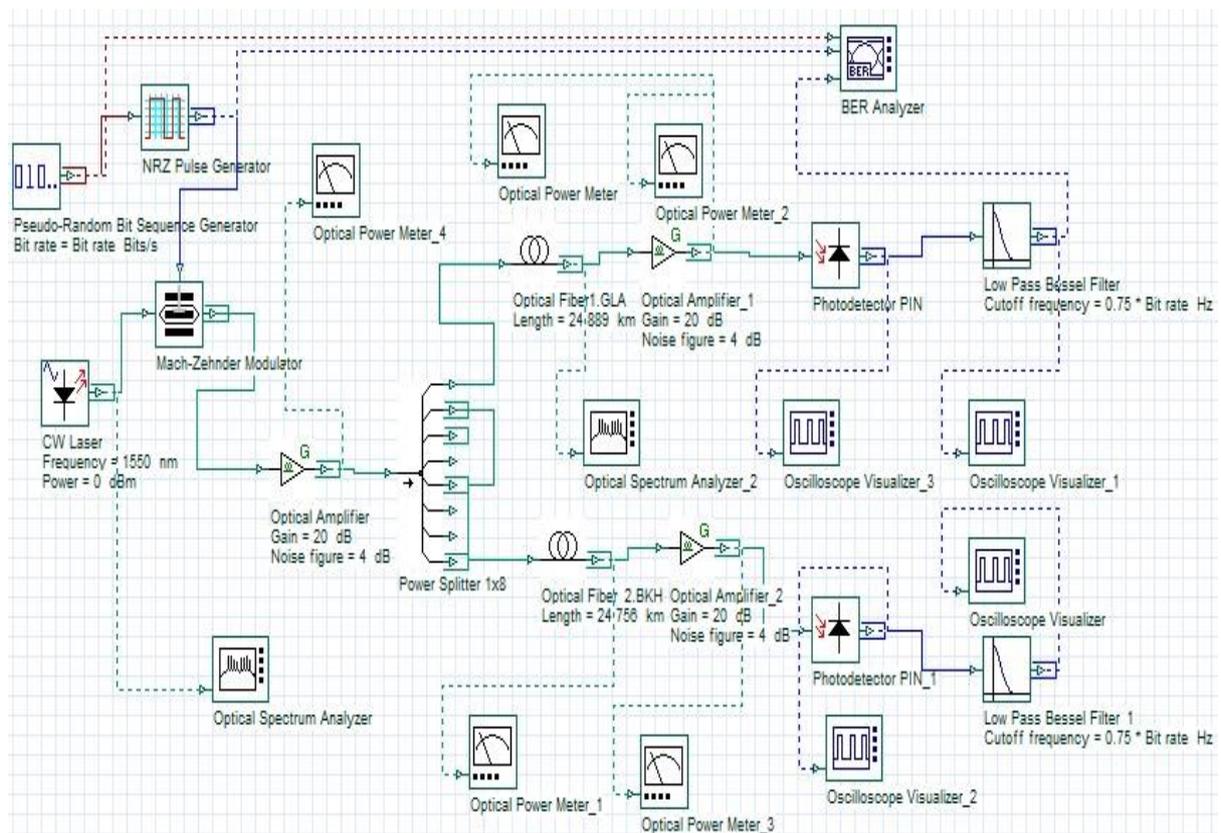

Figure IV.7: The equivalent assembly of the transmission chain with measuring devices.

IV.9.2   Visualization of signals in the time domain:

In this part, we will evaluate the two links with Optisystem by studying the input, output and noise signals as well as the output signal after filtering and also see the signal before and after the amplifier.

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IV.9.2.1   The HBK-GLA link with and without noise filter:

we will evaluate the HBK- optical link by examining the input and output signals, both before and after applying a noise filter. This analysis will help us understand the impact of noise on the signal quality and the effectiveness of the noise filter in improving the signal.
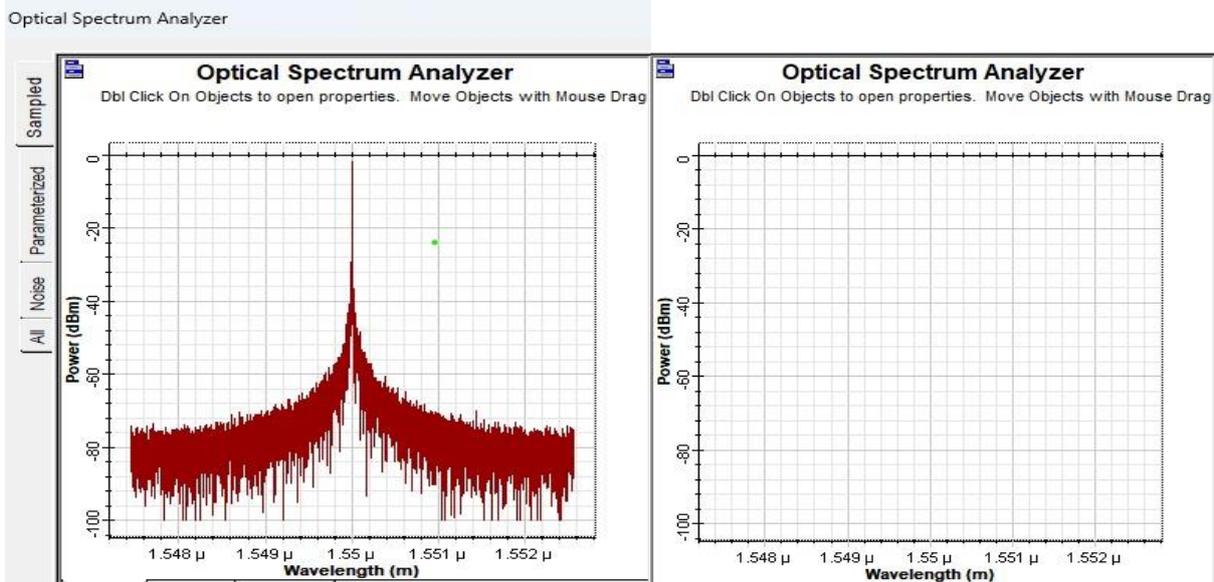
a) The input signal without noise:

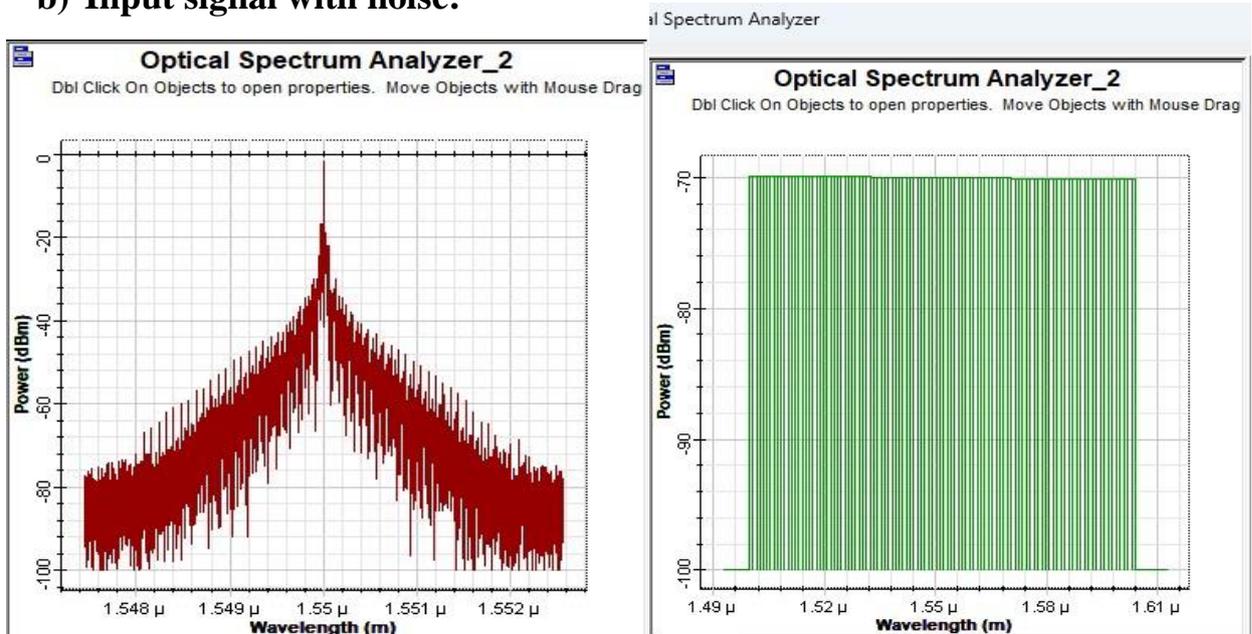*Figure IV.8: The entry signal*

b) Input signal with noise:

Figure IV.9: The exit Signal
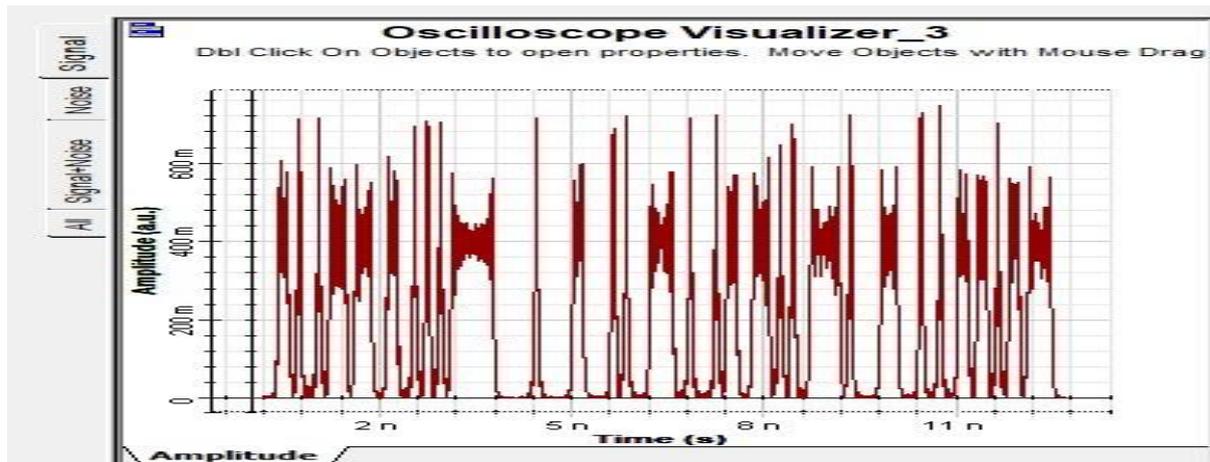
c) **Flags it before filtering:**

Figure IV.10: The Signal Before Filtering

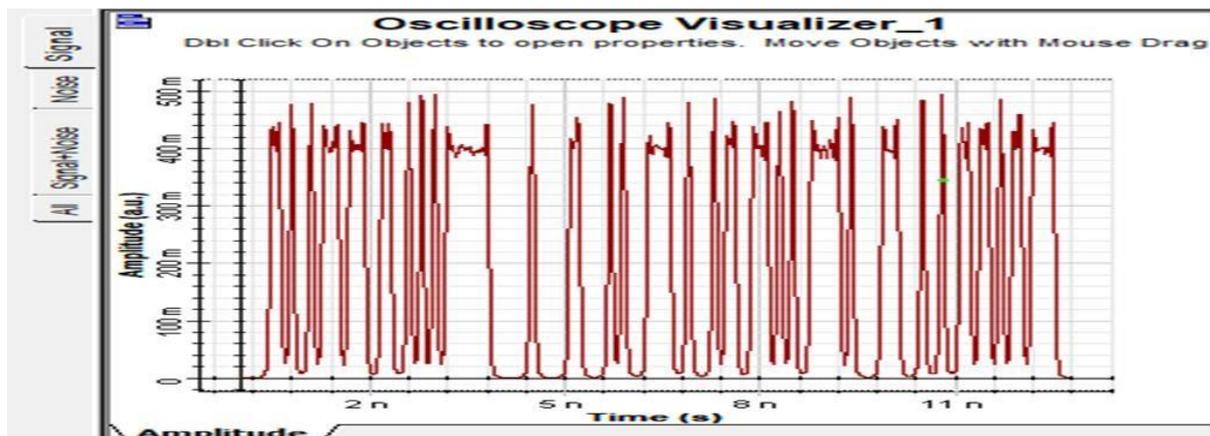### d) **Indicates it after filtering:**

Figure IV.11: The Signal after Filtering
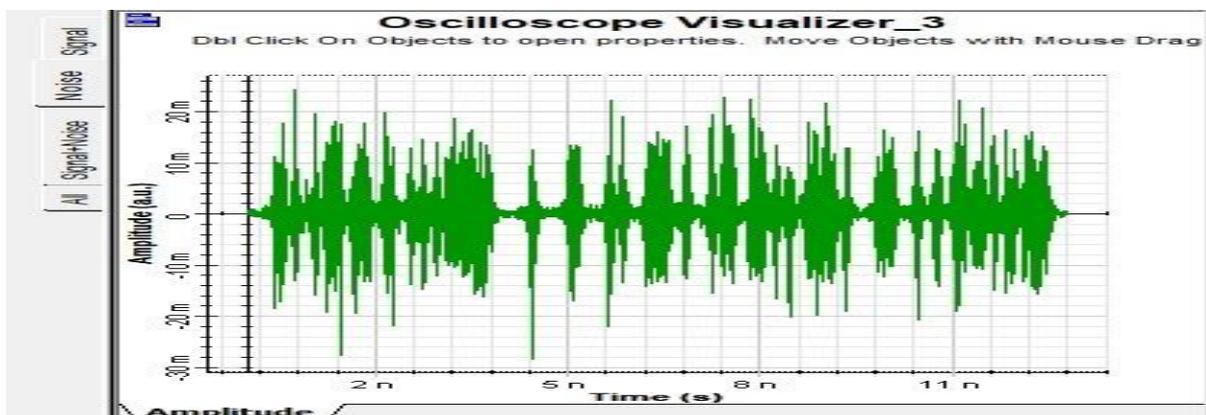
e) **Noise before filtering**

Figure IV.12: Noise Before Filtering
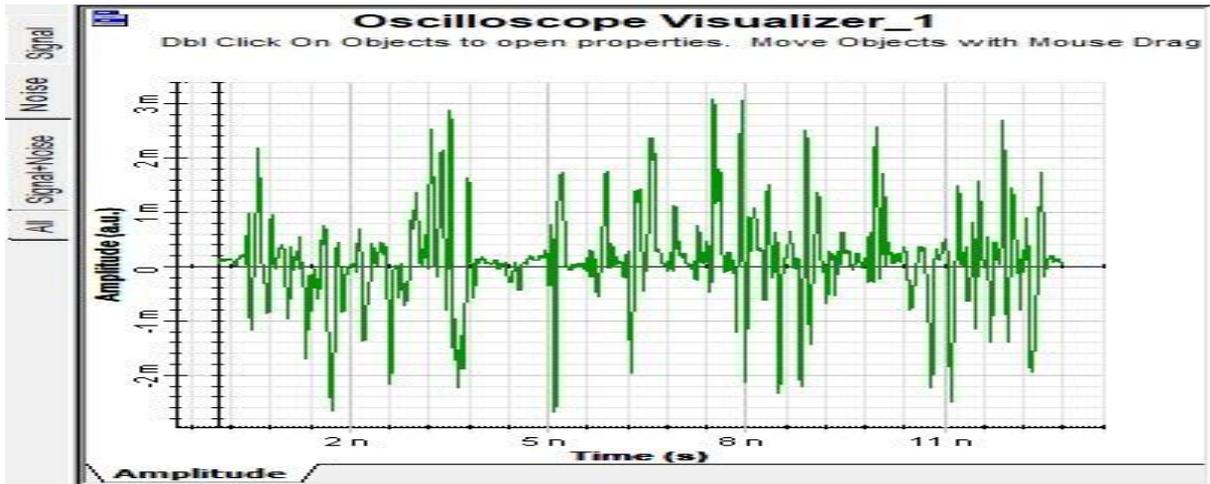
f) Noise after filtering

Figure IV.13: Noise after filtering

IV.9.2.2   Measurement assembly with and without amplifier

Amplifiers are crucial in optical communication links for boosting signal strength, especially over long distances, they can also introduce noise and other distortions. The following analysis compares the signal characteristics before and after amplification.
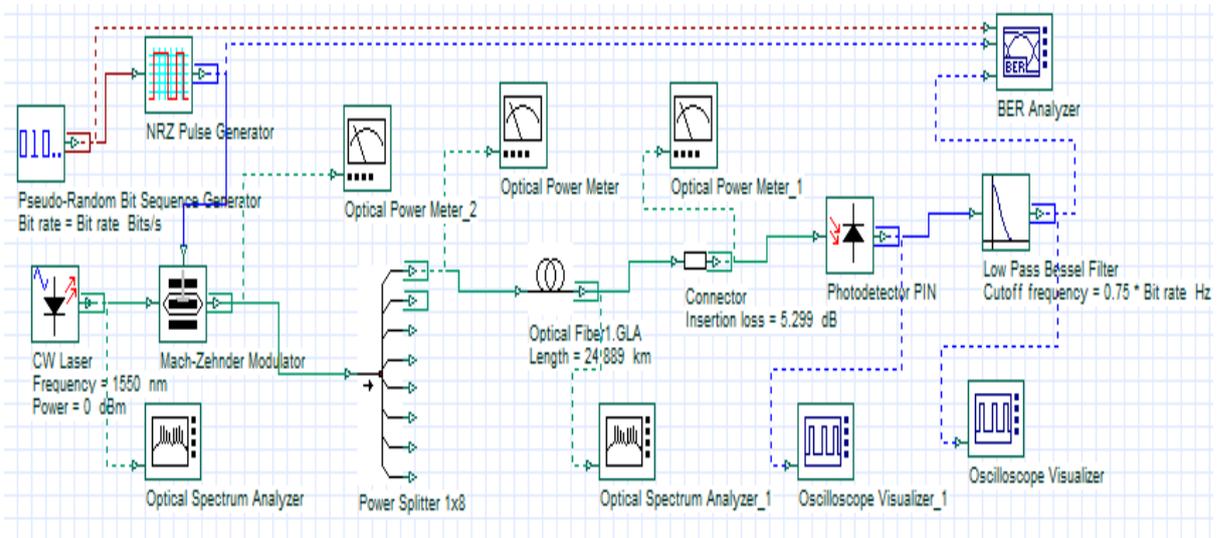
1) without amplifier

Figure IV.14: The equivalent diagram without amplifier

a) Quality factor Q
The Q factor is the signal-to-noise ratio at the input of the receiver's decision circuit.
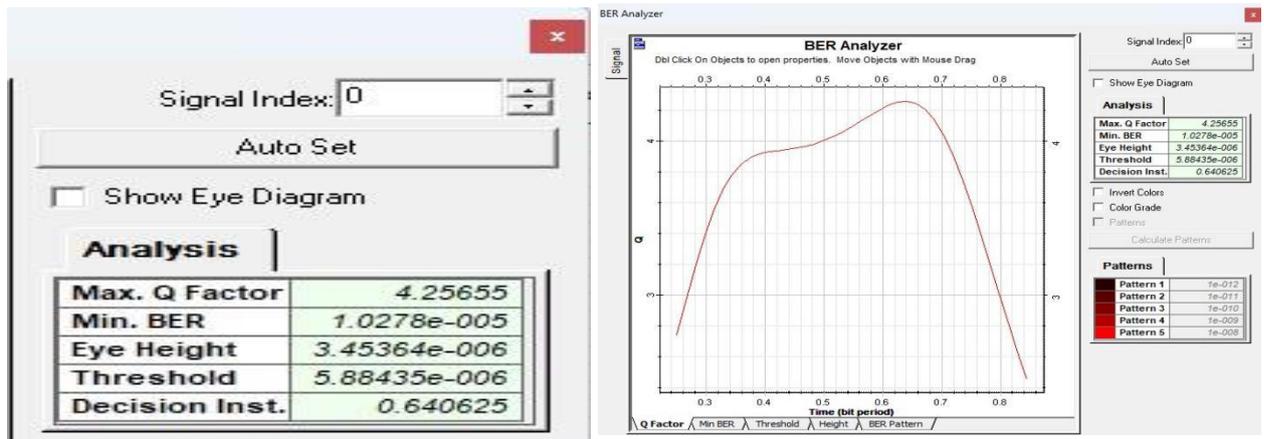
Figure IV.15: Bit Error Rate

The quantitative method to evaluate the performance of a system involves comparing the sent bits with the received bits. The bit error rate (BER) is defined as the ratio of the number of erroneous bits to the number of transmitted bits.

b) The eye diagram

The eye diagram is an oscilloscope display of a digital signal, sampled repeatedly to obtain a good representation of its behaviour. The eye diagram can also be used to examine signal integrity in a purely digital system, such as fiber optic transmission.
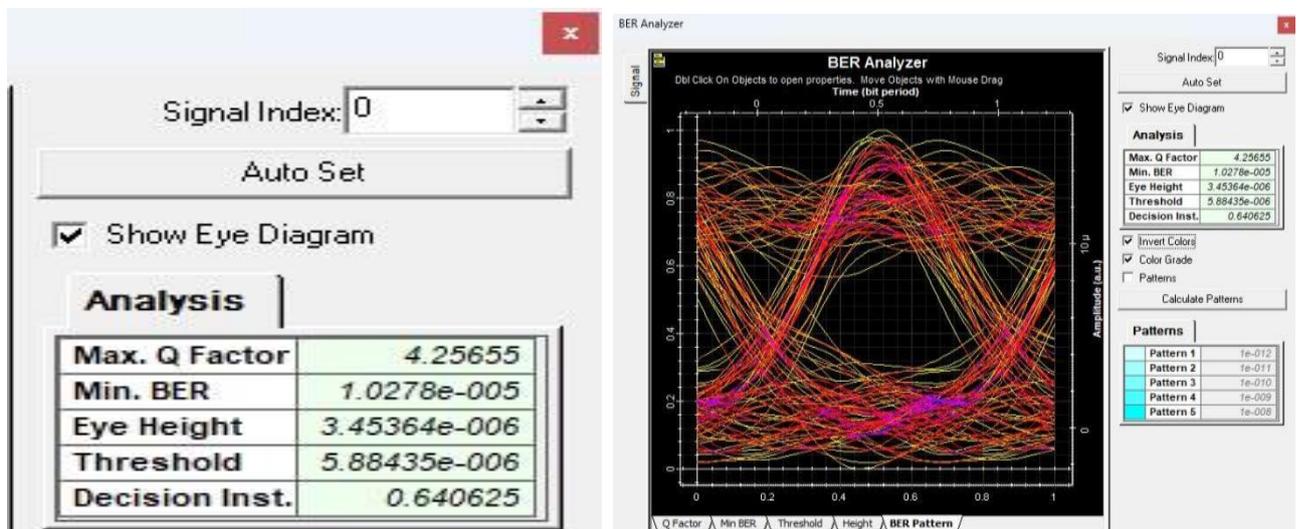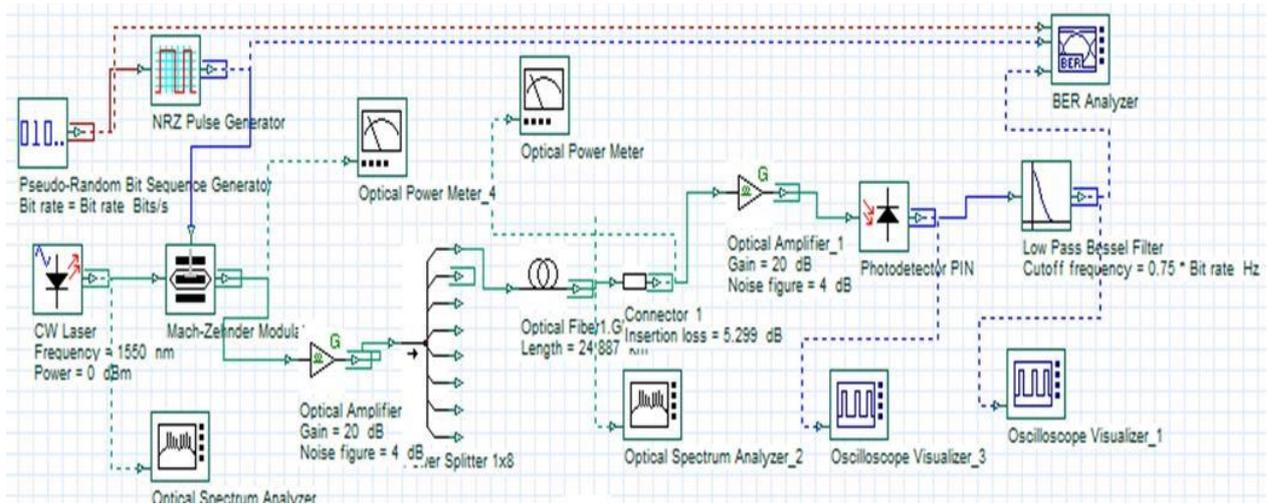

Figure IV.16: The eye diagram

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Figure IV.17: The equivalent diagram with amplifier

2) With amplifier
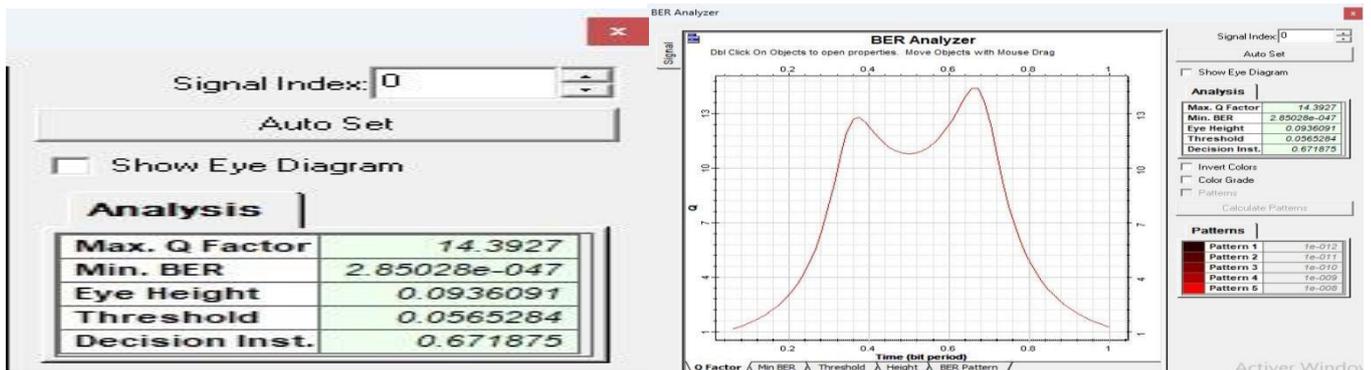### a) Quality factor Q

Figure IV.18: Bit Error Rate
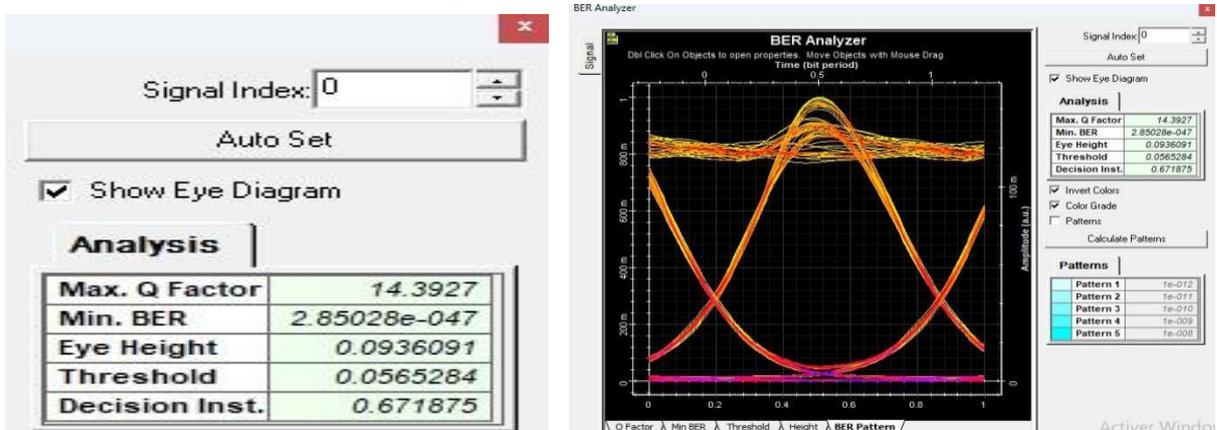
b) The eye diagram

Figure IV.19: The eye diagram

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The implementation of filters and amplifiers in our links has led to notable improvements in signal quality. By strategically using filters, we effectively reduced noise interference, resulting in clearer and more reliable signal transmission.

The use of amplifiers increased signal strength, mitigating attenuation effects and ensuring consistent power levels across the entire links. This also improved the Q factor and the eye diagram.

IV.9.3   The optical power at the output of the link

These measurements provide valuable insights into the optical power levels at the output of the links connecting Haoud Berkaoui Fields (HBK) to both Benkahla Fields (BKH) and Geullala Fields (GLA). Analysing these values allows us to assess the effectiveness of signal transmission and ensure that the optical power levels meet the required specifications for reliable communication within the optical links.

Table IV.6: Optical link powers.

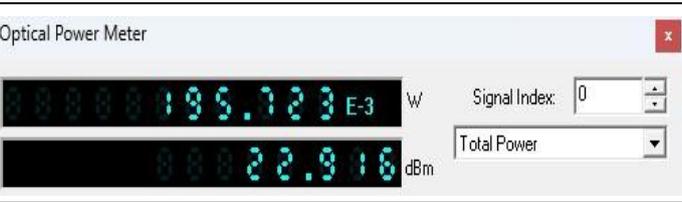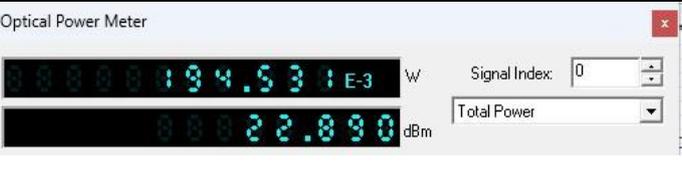| HBK to (GLA-BKH) (fiber input)	Optical Power Meter 48.853 E-3 W Signal Index: 0 16.889 dBm Total Power
HBK-GLA (fiber output)	Optical Power Meter 195.723 E-3 W Signal Index: 0 22.916 dBm Total Power
HBK-BKH (fiber output)	Optical Power Meter 194.531 E-3 W Signal Index: 0 22.890 dBm Total Power

Conclusion

The implementation of filters and amplifiers in our links has led to notable improvements in signal quality. By strategically using filters, we effectively reduced noise interference, resulting in clearer and more reliable signal transmission.

the use of amplifiers increased signal strength, mitigating attenuation effects and ensuring consistent power levels across the entire links.

These improvements have collectively contributed to a significant improvement in overall signal performance. With cleaner signals and stronger amplitudes, our network is now better equipped to provide high-quality data transmission, ensuring optimal service delivery for applications such as TV broadcasting to the residential areas.

In the future, the continued optimization and refinement of these filtering and amplification techniques will be essential to maintaining the reliability and efficiency of our optical communications network.

General Conclusion

This thesis is dedicated to studying optical links, which are the backbone of today's telecommunications, and optimizing work methods to overcome issues that reduce their efficiency, such as attenuation and dispersion. We began this work with a theoretical study of optical fiber, in which we described the different types of optical fibers and their physical characteristics, and learned the testing and control methods used by technicians to evaluate their optical links.

After that we moved on to our application, dedicated to a study conducted on two links with different topologies: the HBK-BKH and HBK-GLA links, which are still in existence today. The specific characteristics of each link were obtained using the OTDR optical reflectometer. This instrument scans the optical link and displays a curve that identifies various events along the link, such as breaks, poor splices, etc. The parameters obtained were confirmed by simulating the two links using the OPTISYSTEM software in pa Chapter IV.

Transmission quality is generally affected by several factors: the significant number of joints causing attenuation, connection losses, splice losses, road and pipeline maintenance work that sometimes damages these optical links, and the physical properties of the fiber itself. To optimize transmission quality, one must master the setup of optical links and ensure good interconnection quality by adhering to standards.

Technically, our simulation confirmed that using the optical amplifier and the filters yielded good results and significantly boosted the signal amplitude, so it is recommended for less profitable links.

By adhering to the guidelines for compliance with standards, careful path selection, utilization of high-quality fibers, and strategic use of optical amplifiers, we can enhance the efficiency and reliability of optical links. This ensures the robustness of our telecommunications infrastructure, enabling superior service delivery for various applications, including TV broadcasting and data transmission.

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