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Title:

Comparative Study and Simulation of the Polymer Optical Fiber (POF) and Glass Optical Fiber(GOF) in FTTH Application

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Abstract

Polymer Optical Fiber (POF) have been developed as early as silica, also referred to plastic optical fibers, because of their significantly larger material attenuation, POFs are limited to lower data rate and shorter distance transmission applications. This choice is justified because of the strong growth in the demand for POFs in a local environment, such as in a vehicle, in a company, and in local area networks (LAN). POF (Polymer Optical Fiber) technology is well suited to these needs, particularly for reasons of low cost and ease of deployment.

The aim of this project is to study the effect of three parameters: fiber length, bit rate and power of transmission on the transmission performance of a Polymer Optical Fiber and Glass Optical Fiber in a local area network. OptiSystem software is used to simulate the overall system. The performance of the optical fiber link in terms of BER, eye diagram and quality factor for the three parameters is compared and discussed. A comparison between the POF and GOF fibers is undertaken.

Dedication

I dedicate my work to the memory of my father may his soul rest in peace.

To my beloved mother, the strong woman who through me how to be stronger than the circumstance and how to find the strength to overcome all the obstacles that life can throw in front of us. The success is ours dear mom.

To the ONE who always believed in me, the one who opened my eyes to see life in its right ways, to Yahia BOUZID may his soul rest in peace.

To my lovely sisters and her children, my brothers and friends.

To my half-sister who believed in me to complete this work together with success.

Assia

Dedication

I dedicate my humble effort to my sweet and loving father and mother for their affection, love and encouragements. To my sisters, Amel and Fatima, my brother Yacine, I am really grateful to all of you. You have been my inspiration and my soul mate. To all DAHMANI family members.

To my sweet best friends Ounissa, Houda.

A special dedication to my lovely friend and project partner ALILOUCHE Assia and her family.

To all my friends without exception.

Sylia

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I convey my sincere gratitude to our supervisor mister ZITOUNI Abd-Al-Kader, without his kind direction and proper guidance and his confidence on us and our competences to success this work. In every sentence of the project report his supervision and guidance shaped this report to be completed perfectly. Successfully, I have also taken help from different people for the preparation of this report. Now, these is a little effort to show my deep gratitude to that helpful person.

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List of Abbreviations

3D: Three Dimensions.
3R: Re-amplification, reshaping and retiming.
8k-UHDTV: 8k - Ultra High Definition Television.
APON: ATM PON Asynchronous Transfer Mode Passive Optical Network.
ASE: Amplified Spontaneous Emission.
ATM: Asynchronous Transfer Mode.
BER: Bit Error Rate.
BPON: Broadband Passive Optical Network.
BMW: Bayerische Motoren Werke.
CATV: Cable Television.
CD: Chromatic Dispersion.
CO: Central Office.
CSMA/CD: Carrier Sense Multiple Access with Collision Detect.
CW: Continuous Wave.
D2B: Domestic dual Bus.
DSI: Double Step-Index.
DSI-POF: POF fiber with Double Step-Index.
EDFA: Erbium Doped Fiber Amplifier.
EPON: Ethernet Passive Optical Network
Erfc: Error Function.
FDDI: Fiber Distributed Data Interface.
FSAN: Full Services Access Network.
FTTB: Fiber To The Building.
FTTC: Fiber To The Curb.
FTTCab: Fiber To The Cabinet.
FTTH: Fiber To The Home.
FTTO: Fiber To The Office.
FTTx: Fiber To The x
GAN: Global Area Network
GEM: GPON Encapsulation Method
GI: Gradient Index
GI-POF: Gradient Index Polymer Optical Fiber
GOF: Glass Optical Fiber
GPON: Gigabit Passive Optical Network
GPS: Global Positioning System.
GSM: Global System for Mobile communications
HD: High Definition
IDB: Intelligent transportation system Data Bus.
IEEE: Institute of Electrical and Electronics Engineers
LAN: Local Area Network.
LED: Light Emitting Diode.
MAN: Metropolitan Area Network
MC: Multi-Core
MC-POF: Multi-Core Polymer Optical Fiber
MOST: Media Orient Systems Transport

List of Abbreviations

NA: Numerical Aperture
NRZ: Non-return to Zero
OEO: Optical-Electronic-Optical
ODN: Optical Distribution Network
OLT: Optical Line Terminal
ON: Opened Numerical
ONT: Optical Network Termination
ONU: Optical Network Unit
OSA: Optical Spectrum Analyzer
PAN: Personnel Area Network
P2M: Point To Multipoint
P2P: Point To Point
PIN: Positive Intrinsic Negative photodiode
PMMA: Polymethacrylate of methyl
POF: Plastic Optical Fiber.
PON: Passive Optical Network
PRBS: Pseudo Random Binary Sequence
PDA: Personal Digital Assistant
PS: Polystyrene
Q: Quality factor
SDH: Synchronous Digital Hierarchy
Si: Silica
SI-POF: Step-Index Polymer Optical Fiber
SONET: Synchronous Optical Network
TDM: Time Division Multiplexing
TDMA: Time Division Multiple Access
TV: Television
TVHD: Television High Definition
UIT-T: International Telecommunication Union
VDSL: Very high Digital Subscriber Line
WAN: Wide Area Network
WDM: Wavelength Division Multiplexing
WDMA: Wavelength Division Multiple Access.

Introduction

Introduction

The first plastic optical fiber (POF) was manufactured by Du Pont of Nemours in the late 1950s. The concept was interesting: taking advantages of the mechanical characteristics of optical fibers and their implementation displays much larger dimensions (1000 µm) than those of silica fiber (9µm). Due to the insufficient purity of the material used at the time, Polymethyl Methacrylate (PMMA), the attenuation was been around 1000 dB / Km. during the 1980s, it was possible to reduce this attenuation to the intrinsic value of the material: 125 dB / Km for a wavelength of 650 nm. But, apart from some niche applications, plastic optical fiber had few advantages to offer.

At the same time, in Japan, the Ministry of Research anticipates a development of this technology. A consortium made up of chemists (Toray, Mitsubishi Royon and Asahi Chemical), academics (Prof. Koike's laboratory, Keio University) and potential users (such as Sony and Matsushita) then made a major contribution to industrial development and marketing of step index plastic optical fiber, generally composed of a PMMA core (980µm) and a fluoropolymer sheath, with a lower refractive index than that of PMMA.

Prof. Koike's team is thus developing the first plastic fiber with an index gradient. The introduction of the refractive index gradient profiles in the core makes it possible to considerably increase the bandwidth, compared to the step index fiber. For such profiles, the refractive index decreases continuously while following, if possible, a parabolic law from the center of the core to the cladding. Light no longer travels in a straight line, but is constantly refracted along the axis of the fiber. In theory, the mode dispersion disappears, and the bandwidth increases: the Japanese researchers obtain a record transmission performances of 1 GHz per kilometer (value obtained on 50 m of fiber).

The next step was to couple the index profile to a low attenuation material to further increase performance. In 1995, Prof. Koike and his team, who now own the main basic patents for manufacturing gradient-index POFs, and the industrialist Asahi Glass jointly developed a perfluorinated gradient index plastic optical fiber. Marketing today in Japan under the name Lucia. Its performance is impressive: 1 Gbit / s over 500 m at 850 nm, in 1998; 2.5 Gbit / s over 300 m at the three wavelengths 650, 850 and 1300 nm, in 1999; and 140 Gbit / s over 100 m at 1,300 nm, in 2000. The additional advantage of this fiber is the possibility of making links by wavelength multiplexing over a wide range (from 650 to 1,300 nm) [1].

Our final thesis aims to carry out a prospective study on Plastic Optical Fiber (POF). This choice is motivated by the strong growth in demand for POFs in local environment such as in a vehicle, in accompany, and in local area networks (LAN). POF (Polymer Optical Fiber) technology responds well to these needs. Particularly for reason of low cost and ease to employment.

Introduction

After a presentation of a state of the art of POFs in the fields of optical instrumentation, and local area network LANs, study of performances of a link approaching POFs and GOFs were studied and simulated with OptiSystem software. A comparison between them will be covered.

This work will be presented as follow:

Chapter one: Introduces some basics of Optical Access Networks and states the different Passive Optical Fiber standards.

Chapter two: Studies the characteristics and properties of Polymer Optical Fiber and states some of its applications.

Chapter three: In this chapter, we are going to simulate and discuss a POF and GOF transmission in FTTH system and compare them.

Conclusion: Summarizes the outcome of this work and gives some suggestions about future work.

Chapter One

Optical Communication System

I.1 Introduction

Due to the technological revolution, recent years have witnessed an increase in demand for bit rate and high bandwidth that can be used in multiple applications, such as high definition HD and 3D VIDEO.

Compared to other conventional media, the advantages offered by optical fiber in terms of speed result essentially from the physical properties perfectly suited to very high-speed transmissions, so the solution was to set up optical access networks of the type. FTTH (Fiber To The Home) based on passive PON architecture which can offer to high speeds to subscribe at a reduced cost.

This chapter introduces optical access networks and gives the different passive optical network standards with a comparison between them.

I.2 General Definition of a Network

A network consists of two or more computers that are linked in order to share resources (such as printers and CDs), exchange files, or allow electronic communications.

The computers on a network may be connected through cables (telephone lines, cooper cable and optic fibers) which is known as physically connection, and also they may be linked by radio waves or infrared beam which is called logical connection.

I.3 Types of Optical Networks

An optical network is a network that uses optical fibers as a transmission line, and generally an optical fiber communications network can be broken down into four categories:

1. LAN (Local Area Network)
2. PAN (Personnel Area Network)
3. MAN (Metropolitan Area Network)
4. WAN (Wide Area Network).

The figure I.1 illustrates the different categories of the optical networks:

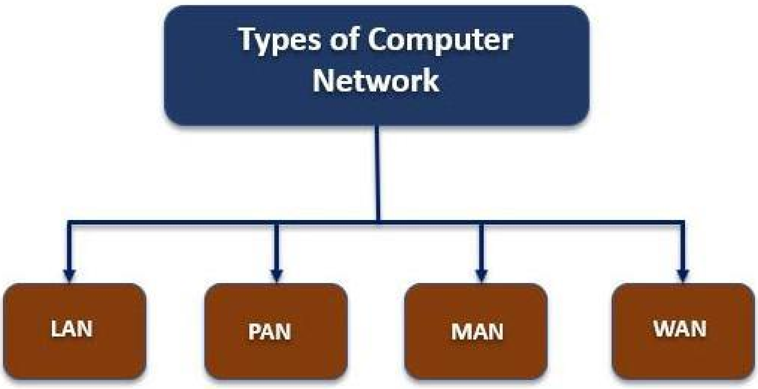


Figure I.1: Different types of computer network.

The table I.1 summarizes the characteristics of the four types of optical network:

Table I.1: Characteristics of the Optical Network's types

	LAN network	**PAN network**	**MAN network**	**WAN network**
Number of elements	A set of equipment belonging to the same company	Communication with other computers in the office	Interconnects multiple LANs	Interconnects several LANs and MANs
Geographic dispersion	A machines are located on a geographically restricted	Short range, few meters	LANs networks geographically relatives	Very large distance
Some of the protocols used	Ethernet, token ring, FDDI	Ethernet, FDDI	RS-232, ATM, IDSN	SDM, SONET, WDM

I.3.1 Long Distance Networks WAN (Wide Area Network)

They are also called WANs (Wide Area Network), which are generally networks with a mesh or a ring structure where the data transmission rates are higher than 100 Gbit / s. interconnection distances vary between 100 Km and over 1000 Km, covering geographic areas on a continental scale.

They are made up of all the major transmission, arteries around the world and therefore support international trade. They partly use ultra-high fiber links with transoceanic flow rates. As examples of the size of these arteries, one can mention the transpacific link between Japan and the United States, which reach a length of 9000 Km, or the transatlantic links between Europe and the United States over distances of 6000 Km transmission. In these applications, optical networks are ubiquitous with transmission rates ranging from 205 to 10 Gbit / s per channel, reaching a total capacity of 640,Gbits / s.

The figure I.2 gives the idea about the connection through the long distance network WAN:

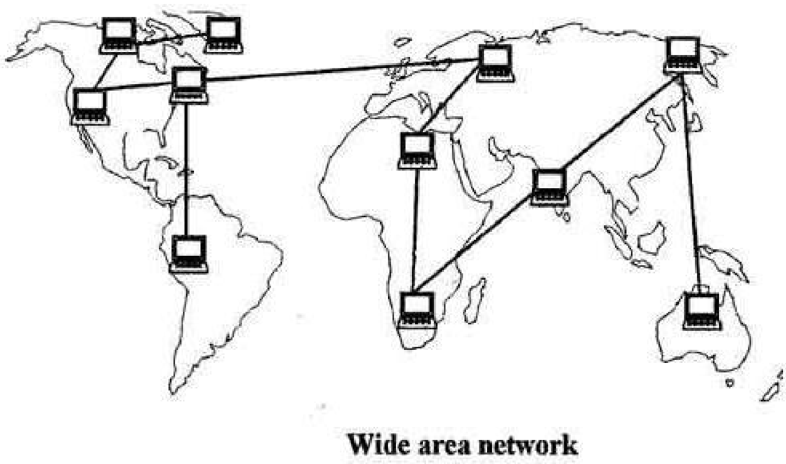


Figure I.2: Architecture diagram of a long distance WAN network.

Advantages of the Wide Area Network WAN:

The following are the advantages of the Wide Area Network:

- **Geographical area:** A Wide Area Network provides a large geographical area. Suppose if the branch of our office is in a different city then we can connect with them through WAN. The internet provides a leased line through which we can connect with another branch.
- **Centralized data:** In case of WAN network, data is centralized. Therefore, we do not need to buy the emails, files or back up servers.
- **Get updated files:** Software companies work on the live server. Therefore, the programmers get the updated files within seconds.
- **Exchange messages:** In a WAN network, messages are transmitted fast. The web application like Facebook, What's App, Skype allows you to communicate with friends.
- **Sharing of software and resources:** In WAN network, we can share the software and other resources like a hard drive, RAM.
- **Global business:** We can do the business over the internet globally.
- **High bandwidth:** If we use the leased lines for our company then this gives the high bandwidth. The high bandwidth increases the data transfer rate which in turn increases the productivity of our company [2].

Disadvantages of the Wide Area Network

The following are the disadvantages of the Wide Area Network:

- **Security issue:** A WAN network has more security issues as compared to LAN and MAN network as all the technologies are combined together that creates the security problem.
- **Needs Firewall & antivirus software:** The data is transferred on the internet which can be changed or hacked by the hackers, so the firewall needs to be used. Some people can inject the virus in our system so antivirus is needed to protect from such a virus.
- **High Setup cost:** An installation cost of the WAN network is high as it involves the purchasing of routers, switches.
- **Troubleshooting problems:** It covers a large area so fixing the problem is difficult [2].

I.3.2 Metropolitan Networks MAN (Metropolitan Area Network)

Metropolitan Area Network (MAN), or metropolitan network, is a broadband telecommunications network that connects several geographically close LANs. These are usually different branches of a company that are connected to a MAN by leased line. High performance routers and high performance fiber optic connection are used, which provides much higher data throughput than the internet.

The transmission speed between two remote nodes is comparable to that of a local network. MAN's infrastructure is provides by international network operators. As a metropolitan network, wired cities can be integrated into wide area networks (WANs) and global area networks (GANs) internationally.

We will mention several man applications, as follows:

- WAN communication with LAN performance.
- File transfer.
- Access to high performance computer.
- Common access to database (e.g. libraries of graphic elements).
- Dedicated server (e.g. compilation, link, calculation server).
- Remote access to files (e.g. broken down workstation).
- Distributed database (e.g. dependent on a work-group.
- Remote services and connection:
    - Voice transmission.
    - Video transmission.

The architecture of the MAN (Metropolitan Area Network) network is shown in the figure I.3:

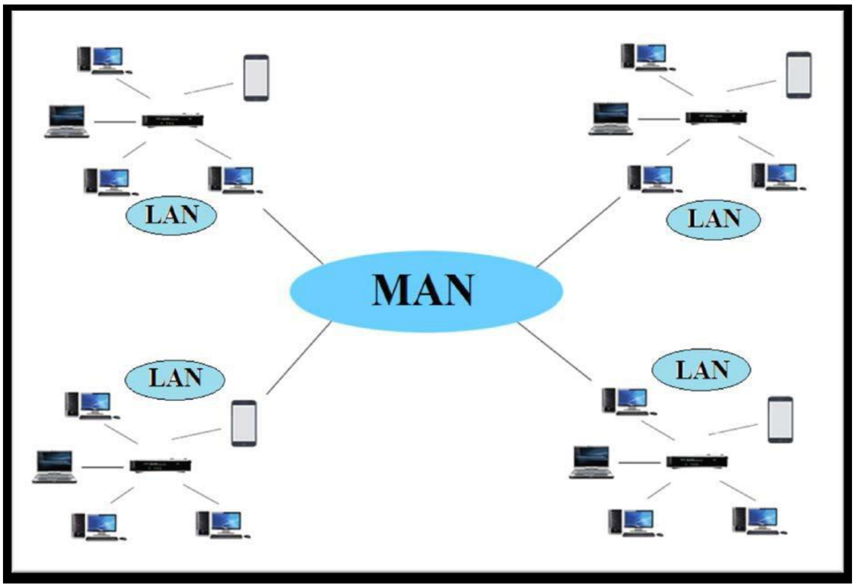


Figure I.3: Architecture Diagram of a MAN Network.

I.3.3 Interconnection of Personal Technology Device PAN (Personal Area Network)

Personal area network (PAN) offers to make connections of multiple devices or other equipment under the single user's environment within 10 meters to 360 feet.

These type of connections may be done wired or wireless. PAN network enables with few computer devices, telephones, electronic devices, laptop, PDAs, printers, smart phone, and other wearable computer devices [3].

The figureI.4 illustrates the different electronic devices that build up a personal area network (LAN):

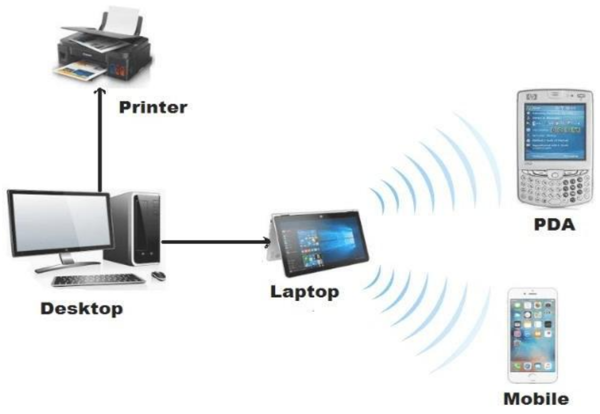


Figure I.4: Architecture Diagram of a PAN Network.

There two types of Personal Area Network such as Wired PAN and wireless PAN. In wire PAN (Personal Area Network), physical wire can be used like as USB or FireWire.

Therefore we can set up some advantages of the Personal Area Network as follow:

- **Less expensive:** in PAN network, no need any type of cable for making connection between multiple devices. So it is cost effective compare to other network systems.
- **Data protection:** PAN network is getting higher secure to other network technologies, because in this network all devices are getting permission from authorized person before transmitting data between multiple devices, so it is impossible to get any third-party interruption.
- **No need additional space:** in this network, to connect many devices you require only Bluetooth system in multiple devices, and they can share file and data between them.
- **Easy to use:** no need additional advance configuration, so can be used easily.
- **Reliable and stable:** PAN network is more reliable and stable, if it is used within 10 meters area [3].

I.3.4 Access Networks LAN (Local Area Network)

LAN stands for Local Area Network, is a group of computers located in the same room, on the same floor, or in the same building that are connected to form a single network. Local area networks (LANs) allow users to share storage devices, printers, applications, data, and other network resources. They are limited to a specific geographical area, usually less than 2 kilometers in diameter.

They might use a dedicated backbone to connect multiple sub-networks, but they do not use any telecommunication carrier circuits or leased lines except to connect with other LANs to form a wide area network (WAN).

The figure I.5 shows the architecture diagram of the local area network (LAN):

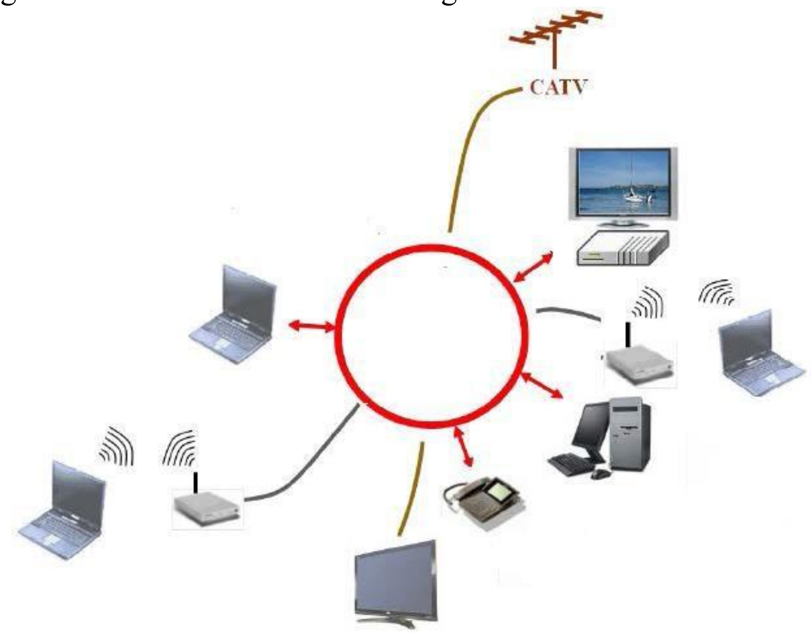


Figure I.5: Architecture Diagram of the Local Area Network (LAN).

A distinction is made between FTTx (Fiber To The x) techniques, which consist in bringing the optical fiber as close as possible to the user in order to increase the quality of service, in particular the speed. Depending on the location of the optical network termination, access to the public telephone network for voice application, as well as access to data transfer applications (voice and video) to the network using digital techniques.

I.3.4.1 FTTH (Fiber To The Home)/ (Fiber To The Office)

Fiber to the home (FTTH) or fiber to the office (FTTO) is a fiber optic communication delivery form where the fiber extends from a central office to the boundary of a home living space or business office. Once it reaches the home or business office, the signal is conveyed throughout the space using coaxial cable, wireless, optical fibers or power line communication.

I.3.4.2 FTTB (Fiber To The Building)

Fiber to the building (FTTB) is a type of fiber optic cable installation where the fiber cable goes to a point on a shared property and the other cabling provides the connection to single homes, offices and other spaces. Fiber to building may also know as fiber to the basement.

I.3.4.3 FTTC (Fiber to the Curb /fiber to the Cabinet)

Fiber to the curb refers to the installation and use of optical fiber cable directly to curbs near homes or businesses. Fiber to the curb is designed as a replacement for plain old telephone service. Coaxial cable or another medium carries signals the short distance from the curb to the home or business.

Fiber to the curb uses existing coaxial or twisted-pair infrastructures in order to provide last-mile service. As such, this system is inexpensive to employ. The basic idea of fiber to curb technology is that suitable wires can carry high-speed signals at short distances. The twisted wire pairs or coaxial cables have acceptable bandwidth loss while sending signals only a few hundred feet [4].

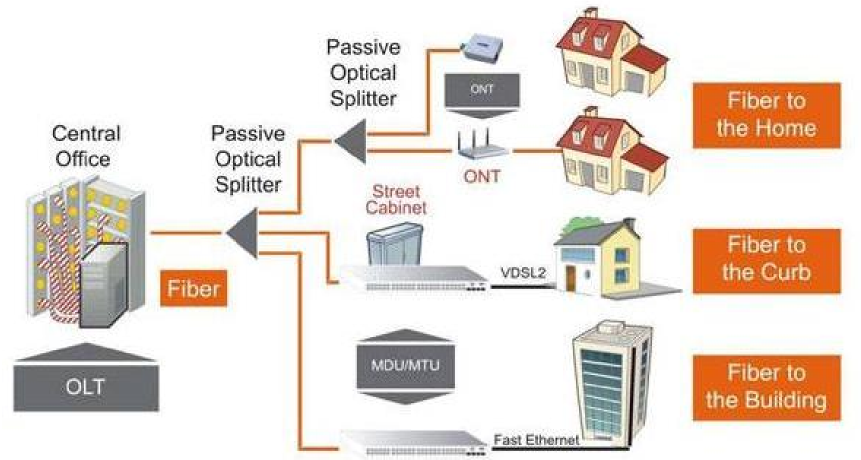


Figure I.6: Structure of a FTTH, FTTB and FTTC Networks.

I.4 Access Network Terminology

The structure of the access network consists of three parts: the exchange, the burst point and the customer as shown in the figure I.7 below:

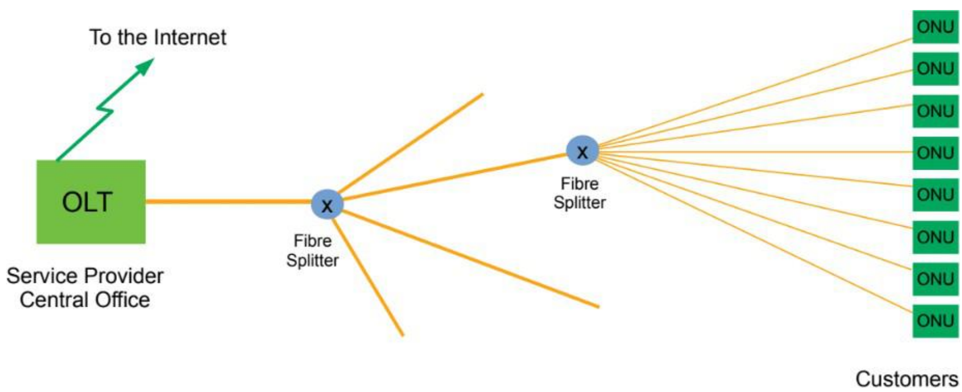


Figure I.7: Access Network Terminology.

The Central Office (CO) consists of OLT (Optical Line Termination) which is the equipment for transmitting and receiving data by users or vice versa. The burst point is the component that divide the signal in the downward direction and sums the signals in the upward direction.

The client part in the receiving part of the downlink signals and the sending of the uplink signals.

The client part ONU (Optical Network Unit) allows the connection between several client sand followed by a secondary transmission (case of FTTCab / Curb / Building) or ONT (Optical Network Termination) if it is a single FTTH client. The part between the OLT and the UN called the ODN (Optical Distribution Network). It has passive network infrastructure.

The figure I.8 terminology shows as the terminology of the network and how the distribution was done inside it:

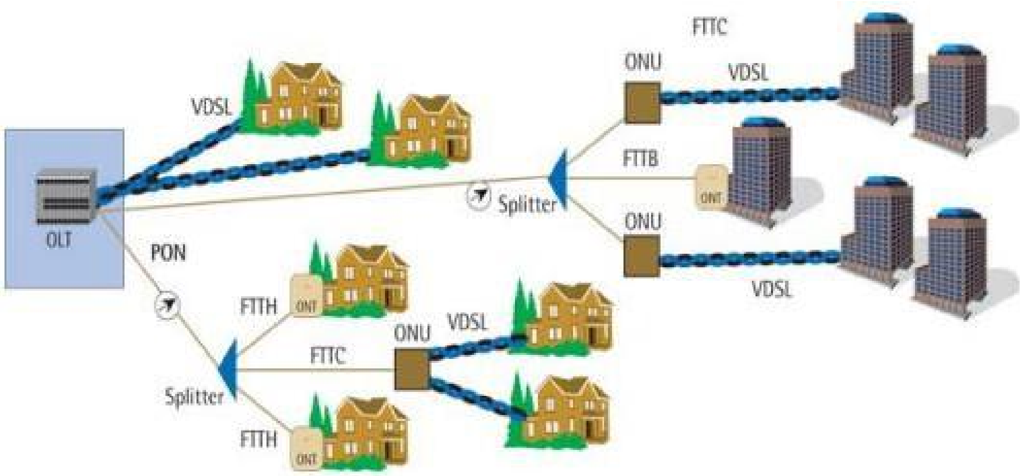


Figure I.8: Access Network Terminology with FTTx Techniques.

I.5Optical Access Network Architectures

The two architectures are commonly used for FTTH deployment are:

- The active architecture also called point to point (P2P).
- The passive architecture is commonly called PON (Passive Optical Network) or P2M (Point to Multipoint).

The choice of active or passive architecture for deployment depends on the type of services to be provided, the cost of the infrastructure and future plans migration to new technologies.

I.5.1 Point to Point Architecture (P2P)

In terms of networking, the Point-to-Point architecture is the simplest topology that connects two nodes directly together with a common link. The entire bandwidth of the common link is reserved for transmission between those two nodes.

The P2P topology contains an active element, a switch between the Optical Central and the UN customer's equipment. In this configuration, each subscriber has his own optical fiber connecting it directly to the operator's equipment as shown in the figure I.9.

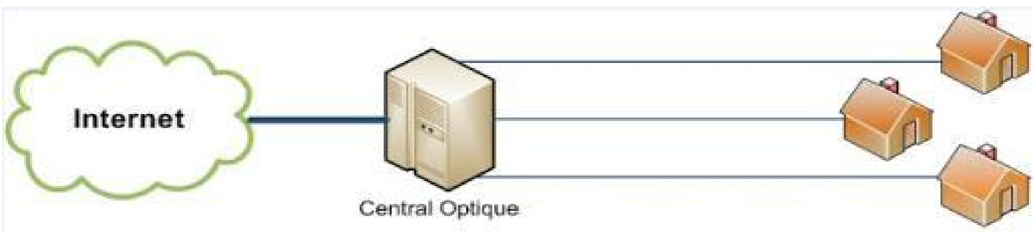


Figure I.9: Point-to-Point Architecture.

Advantages

- General solution suitable for home and business customers.
- The perfect optical financing because there is no optical element between the OLT and the ONT.
- Information security is ensured because one or two fibers are dedicated to each customer.
- Network management is greatly simplified.
- More economical in low density areas for subscribers.
- Greater flexibility of service.

Disadvantages

- Fiber management at the power plant.
- No fiber pooling.
- Congestion inside the central due to the large number of transcripts.
- No optical port or OLT sharing, lots of fibers to spread [5].

I.5.2 Passive Point to Multipoint (PON)

In terms of networking the start topology, all the computers are connected to the central located device called as hub. All the devices on the network are connected with a hub device through a communication link. Each computer requires a single wire for the connection to the hub.

Passive Optical Network represents a point to multipoint architecture network used by all the subscribers connected to the Central Optic, is characterized by a passive optical coupler from 1 to N subscribers which distributes the optical energy in several output ports.

Bandwidth is not allocated to the single subscriber, but each user is allocated to the total capacity of the system

The figure I.10 illustrates the architecture of the passive point to multipoint which has a shape of a star.

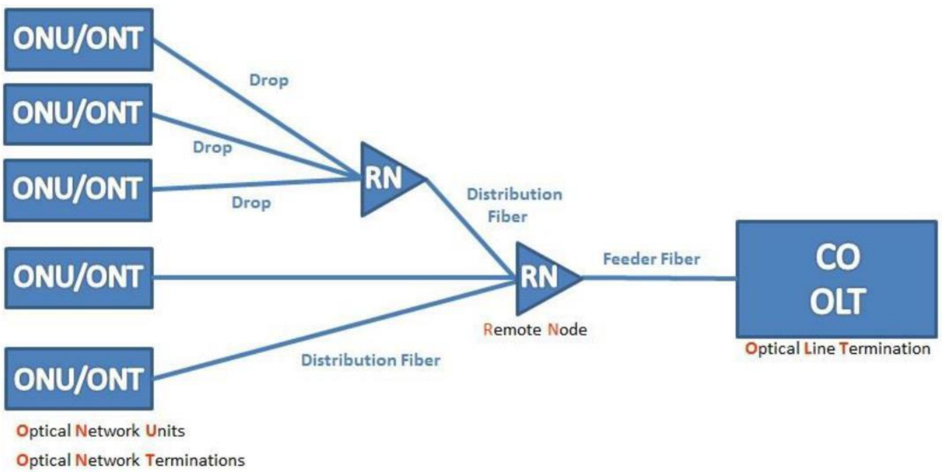


Figure I.10: The Architecture of the Passive Point to Multipoint.

Therefore, the star architecture possess a numerous advantages hence it is most widely used topology in today's local-area-networks (LANs).

I.5.2.1 Study of a Passive Optical Network Elements

Optical power splitter is the central component in a power-splitting passive optical network where its primary function is to split the optical power at the common port equally among all its output port.

The architecture of a passive optical PON network is basically based on three essential elements: OLT optical line terminal, the ONU (Optical Network Unit), and the passive element which is the coupler or splitter, shown schematically in the figure I.11.

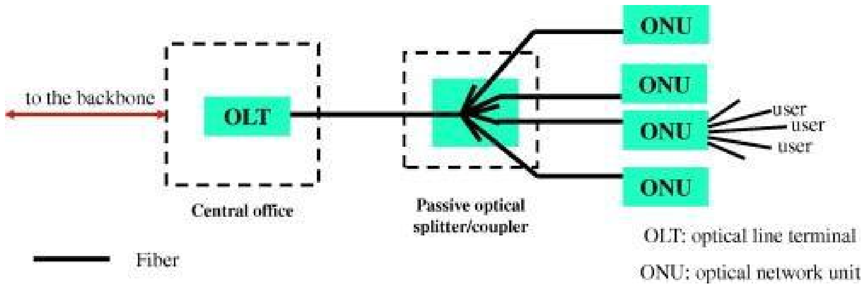


Figure I.11: The Architecture of a Passive Optical Network PON.

I.5.2.2 Advantages and the Disadvantages of Passive Optical Network (PON)

Many of the PON properties are given by the use of fiber, and of course, of the passive elements that compose the network, which added to the specific configuration of a star or tree give it certain advantages over other topologies. It has also some disadvantages.

Advantages

- Cost savings in implementation.
- The capacity and bandwidth of passive optical networks.
- Allows for longer distances between central offices and customer premises (up to 5.5 Km).
- Avoiding the mix of signals to each other.
- Facilitating diffusion from the OLT to the different ONTs.
- High scalability to PON transmission system, given the variety of wavelengths.
- Flexibility in the allocation of bandwidth.
- Architecture favorable to dissemination.

Disadvantages

- No operation with other network
- Command and limited bandwidth
- Information security required.
- Limited coverage area: maximum 20 Km depending on the number of the divisions (more divisions=b less distance) [5].

I.5.2.3 Comparison between the Two Architectures P2P and PON

The table below give the comparison of the two; point to point and point to multipoint architectures [5]:

Table I.2: Comparison between the two architectures P2P and PON.

Parameters	Point to point P2P	Point to multipoint P2M or PON
Encryption management	not necessary	required
Band-pass management	Bandwidth not shared on the access network.	Dynamic band allocation based on user needs
Service area	The dispersed habitat and for specialized lines	Residential and for high density areas.
Distance (km)	15	20
fiber	1 fiber per end-to-end subscriber	1 fiber per subscriber in part distribution and connection, 1 fiber for n.
Energy	2 watt/ subscriber dissipated	0.6 watt / subscriber dissipated
Guaranteed flow	100Mbit/s or 1Gbit/s symmetrical depending on connection	Up to 78Mbit/s downstream in split of 32
Maximum flow	100Mbit / s or 1Gbit/s symmetrical depending on connection	Up to 2.5 Gbit /s downstream and 1 Gbit /s upstream
Occupied place	1U for 24 to 48 subscribers	4U for 512 to 2304 subscribers

I.6 The Different Standard of a Network PON

At the time when the growth of the internet traffic and high-speed multimedia applications are increasing exponentially, such as HDTV, 3D TV, 8k-UHDTV digital cinema format or even medical TV services. The Passive Optical Network (PON) technology, which is the basis of FTTH, is one of the powerful access networks capable of delivering gigabit class bandwidth to subscribers [6].

The evolution of the different Passive Optical Network are shown clearly in the figure below:

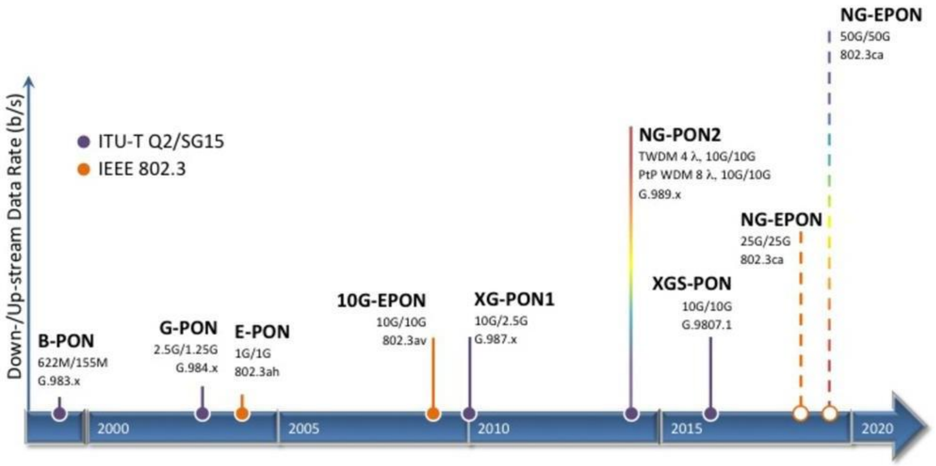


Figure I.12: Evolution of Passive Optical Network PON.

The PON network is based on several standards, the best known are classified as follows:

I.6.1 Standard APON

The A-PON was designed to provide an economical ads universal access network by FSAN (full services access network), a group of multinational operators and suppliers, which is today one of the largest telecommunications companies in the world [7].

It is a simply a Point-to-Multipoint fiber optic system that uses ATM as the transmission protocol.

These standards are define by the ITU-T (the international telecommunication unit). With APON, high-speed data, voice and video can be delivered to subscribers over a single optical fiber. An APON system can connect up to 32 subscribers to the PON and provide them with a flexible access system and high throughput (622 Mbit / s or 155 Mbit / s downstream, 155 Mbit / s upstream).

In the downstream direction, multiplexing of ATM cells is used, while a TDMA protocol controls the uplink access of network subscribers [5].

I.6.2 Standard BPON

BPON (Broad PON) is the extension of the APON standard for the provision of other services, such as Ethernet broadcast and video (Video broadcast). It is a broadband fiber optic distribution network. Indeed, recent enhancements to APON include a higher speed, Wavelength Division Multiplexing (WDM), for better data security. For this development, the ITU-T officially changes the name of the system to broadband PON or BPON. BPON is currently used in one of the three down/up operating modes:

- 155 Mbits / s /155 Mbits / s.
- 622 Mbits /s /155 Mbits / s.
- 622 Mbits /s /622 Mbits /s.

The other characteristics of the BPON are:

- Uses TDMA multiplexing for the upstream direction
- Uses WDMA multiplexing for the downstream direction.
- OLT-ONU distance does not exceed 20 km.
- A BPON can connect up to 32 subscribers to the PON network.
- Voice and data use 1490 nm and 1310 nm for downstream and upstream respectively.
- For the transport and digital video in the downstream direction, the wavelength 1550 nm can be used.
- BPON is the extension of APON with the integration of other services such as Ethernet and video streaming.

I.6.3 Standard EPON

The EPON standard was developed in November 2000; the IEEE 802.3 drafted the standard in June 2004. It uses the protocol "Multipoint Control and Protocol Ethernet", which is a local area network technology based on the principle that all the users of an Ethernet network are connected to the same transmission line and the communication done using a protocol called CSMA/CD (Carrier Sense Multiple Access With Collision Detect) which means that it is a multiple access protocol with carrier monitoring and collision detection. The data is transmitted from the OLY to the UN by packets of 1518 bytes at 1.25 Gbit / s, each ONU takes into account only the packet with concern it.

The advantages of Ethernet PON can be summarized as follow:

- The EPON connection can be easily upgraded from 1 Mbit / s to 155 Mbit /s.
- EPON uses optical components in point to multipoint architecture which are simpler and cheaper than electronics.
- The EPON standard allows up to 64 ONUs to be connected to the exchange by OLT on a single optical fiber for a high overall speed.
- ATM protocols are no longer necessary, resulting in significant savings in hardware [8].

I.6.4 Standard GPON

Advances in technology, the need for greater bandwidth, in addition to the insufficiency of ATM, have prompted to revise the APON standard and to think about another solution called GPON (Gigabit PON) which has been standardized by the ITU in 2003. GPON is based on a point to multipoint architecture based on time division multiplexing. It has a passive optical architecture based on a coupler of the type shown schematically bellow, the coupler is achromatic to allow transmission of the wavelengths 1.3, 1.49 and 1.55 µm.

Time division multiplexing allocates packets in a time frame for each client. The synchronization is carried out continuously. The operating distance of 20 Km is fixed between the exchange and the most distant customer. The throughput is up to 2.5 Gbps downstream and 1.24 Gbps upstream [9].

The figure below presents the working principle of the GPON network with the upstream and downstream wavelengths:

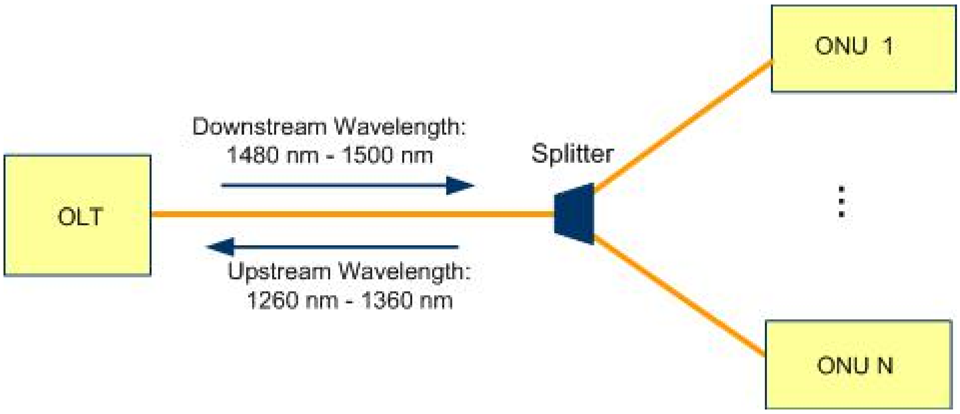


Figure I.13: The Working Principle of GPON Network.

In the down direction (from OLT to ONT), each customers receives all the information but is only authorized to receive the data intended for him. The distribution of debits between clients can be fixed or variable. Upstream direction (from ONT to OLT), the sharing of resources in the upstream direction is carried out by TDMA (time division multiple access). Each client has a specific time interval to transmit so as not to interfere with another client. This GPON technology has advantages and disadvantages.

Advantages of GPON:

- The structure is passive because it is dependent on optical couplers.
- The civil engineering has been improved and the cost is low.
- The participation of infrastructure by telecommunications operators.
- The architecture is conductive to dissemination.
- The OLT is shared (one duplexer at the central office for 32 clients) [9].

Disadvantages of GPON:

- The optical cost is limited by coupler, which is proportional to its losses with the number of outputs.
- As the flow is common, it is therefore limited.
- Synchronization is difficult for the upward direction.

The security of incoming data is not ideal because all users receive the entire stream transmitted by the control panel [9].

I.7 Comparison of Network Standards PON

The following table presents the characteristics of the different standards defined previously:

Table I.3: Comparison of network standards PON.

standard	APON	BPON	EPON	GPON
Recommendation standard	ITU-T G.982	ITU-T G.982	IEEE 802.3 ah IEEE 802.av	G.983 (FSAN)
Protocols	ATM	ATM	Ethernet with CSMA/CD access	GEM (ATM, Ethernet, TDM)
Wavelength descending	1490 nm 1310 nm	1490 nm 1310 nm	1490 nm 1310 nm	1490 nm 1310 nm
Down flow	155 Mbit / s 622 Mbit / s	155 Mbit / s 622 Mbit / s	2.5 Gbit / s 10 Gbit / s	2.5 Gbit / s
Amount Bit Rate	155 Mbit / s	155 Mbit / s 622 Mbit / s	2.5Gbit/s 1Gbit/s 10Gbit/s	1.25 Gbit / s
Distance OLT/ONT	10 or 20 Km	10 or 20 Km	20 Km	20 Km

I.8 Conclusion

This chapter has been devoted to optical networks, first giving the general definition and detailing the types of optical networks. The different topologies used for the deployment of access networks were presented: point to point and point to multipoint.

Then we defined the passive optical network (PON), its different standards and we concluded with a comparison between these different standards.

In the next chapter, we will present the characteristics and properties of plastic optical fibers (POF).

Chapter Two

General Presentation of Plastic Optical Fiber (POF) Characteristics

II.1 Introduction

In recent years, there have been a strong growth in demand for optical fibers in local environment, such as in a vehicle, home and in local area networks (LAN). The plastic optical fiber technology POF (Polymer Optical Fiber) responds well to these needs particularly for reasons of low cost and ease of handling.

In this chapter we will study the main characteristics and properties of plastic optical fiber, as well as their advantages, and finally some essential concepts concerning their use in short distance optical communications.

II.2 Optical Fibers

Transparent fiber made of glass (silica) or plastic (polymer) to a diameter slightly thicker than that of human hair. Is it the method of transmitting data, voice and images from one place to another by setting pulses of light though an optical fiber.

II.3 Optical Fiber Structure

Optical fiber consists of three parts; the core, the cladding and the protective coating.

- **The core:** is the light transmission channel.
- **The cladding:** the layer that surround the core, it helps the preserve the losses of the light rays.
- **Protective coating:** layer generally made of plastic which covers the core and the cladding. It ensures the protection of the shape and the curvature of the fiber.

The figure II.1 shows the structure of the optical fiber:

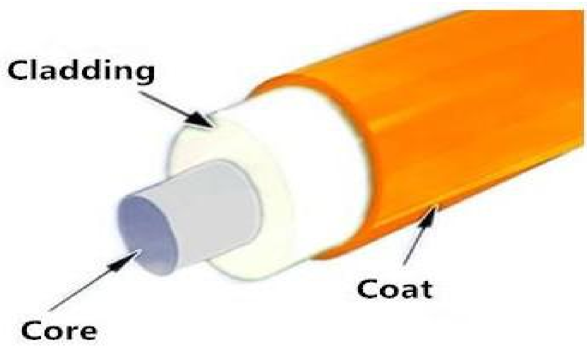


Figure II.1: Optical Fiber Structure.

II.4 Light Propagation in Optical Fiber Cables

The light in Fiber-Optics travels through the core by constantly bouncing from the cladding, a principle called total internal reflection. Because the cladding does not absorbs any light from the core. The wave can travel great distance; figure II.2.

Space light propagates with velocity which $C = 2.999 \times 10^8$ m/s is the speed of the light in the free space.

The speed of light is affected by the factor n. the refractive index of the medium:

$$n = \frac{\text{speed of light in the free space}}{\text{speed of light in the medium}} \qquad \text{(II.1)}$$

When the light ray encounters the interface of the medium the light ray is refracted and its direction of propagation changes according to Snell's low of refraction.

$$n_1 \sin \emptyset_1 = n_2 \sin \emptyset_2 \qquad \text{(II.2)}$$

Where: n_1, n_2 and $\emptyset_1, \emptyset_2$ are the refractive indexes and propagation angles of medium 1 and medium 2 respectively.

If $n_1 > n_2$, at a certain angle of incidence, the refracted wave propagates in parallel to the interface and the angle of the refraction reaches 90°, and the corresponding angles of incidence called critical angle $\emptyset_c$.

For an angles of incidences greater than the critical angle, the rays are totally reflected, means that the total reflection occurs.

Optical fibers are cylindrical waveguides made of two concentric layers of very pure class. The core with refractive index n_1 serves as the medium for light propagation, while the cladding has a lower refractive index n_2 where $n_1 > n_2$ assuring the light rays are reflected to the core.

Based on the principle of the total internal reflection, only rays with incident angles greater than the critical angle, at the cladding-core interface, can be transmitted.

The cone of the acceptance of light into the core is defined by the acceptance angle $\emptyset_a$ of the fiber, whose maximum value can be calculated directly by:

$$\sin \emptyset_a \leq \sin \emptyset_{amax} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \text{(II.3)}$$

Assuming that the refractive index of the medium outside the fiber is 1 (air), the result above can be expressed as:

(Refractive index outside the fiber) $n_0 = 1$yields

$$\sin \emptyset_{amax} = \sqrt{n_1^2 - n_2^2} \qquad \text{(II.4)}$$

The numerical aperture NA measures the light gathering capacity of a fiber and the sine of the maximum acceptance angle:

$$NA = \sin \emptyset_{amax} \tag{II.5}$$

Another parameter is the normalized refractive index difference, Δ

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \tag{II.6}$$

Whose relation with the numerical aperture is:

$$NA = n_1\sqrt{2\Delta} \tag{II.7}$$

The figure II.2 demonstrates how the light is propagating inside the fiber [10].

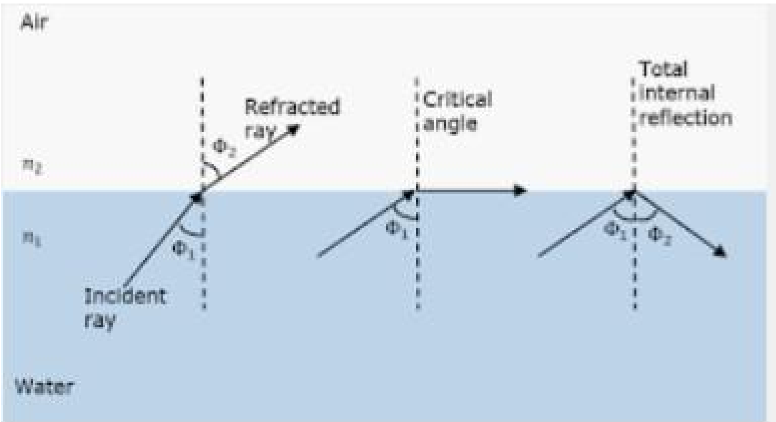


Figure II.2: Light propagation in the Optical Fiber.

II.5 Mode Couplings

Mode is the path for light rays through an optical fiber. An optic fiber support only one mode, it is called single mode fiber. Multimode fiber supports more than one mode. The electric field distribution of various modes yields similar distributions of light intensity within the fiber core.

These patterns are called mode pattern which gives idea of different mode propagating in the fiber. Propagation characteristics of a fiber are very sensitive to derivation of the fiber axis from straightness, variation in the core diameter, irregularities in the core-cladding interface and instinctive index variations.

Individual modes do not normally propagate throughout the length of the fiber. This result in the mode conversion which is known as mode coupling. Coupled mode equation obtained from Maxwell's equations can be used for the analysis of mode coupling. Mode coupling affects the transmission properties of the fiber which is a serious cause for concern when used for long distance communication. Mode coupling leads to intra-modal (chromatic) dispersion like material dispersion and waveguide dispersion and also intermodal dispersion [11].

II.6 Coupling Losses

Coupling losses in the fiber optics refers to the power loss that occurs when coupling light from one optical device or medium to another.

Coupling losses can results from a number of factors. In electronics, impedance mismatch between coupled components result in reflection of a portion of energy at the interface. Likewise, in optical systems, where there is a change in index of refraction (most commonly at a fiber/air interface), a portion of energy is reflected back into the source component.

When a fiber is integrated into a device, it is associated with other components. To evoke the junction between these components and the fiber we speak about coupling. At these junctions, we can cite various defects such as poor alignment, a difference in diameter, a difference in numerical aperture or even a poor surface condition of the fiber input (or output) face, can causes losses as shown in figureII.3:

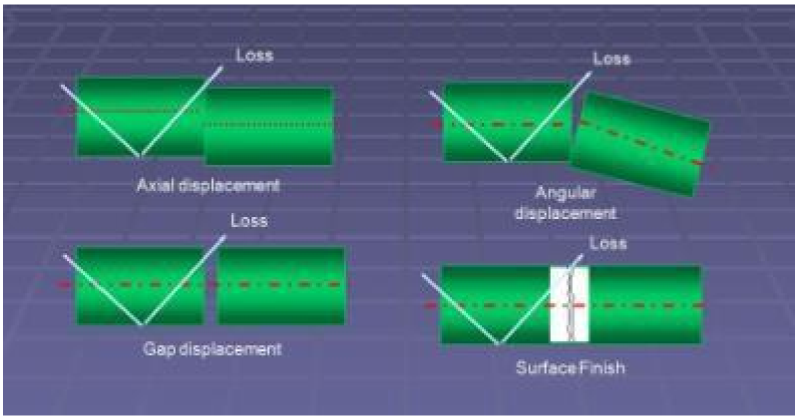


Figure II.3: Different Type of Coupling Losses.

II.7 The Different Type of Polymer Optical Fibers (POF)

II.7.1 Step-Index Polymer Optical Fiber (SI-POF)

As was the case with silica glass fibers, the first polymer optical fibers were pure step index profile fibers (SI-POF). This means that a simple optical cladding surrounds a homogeneous core. For this reason, a protective material is always included in the cable. Figure II.4 schematically represents the refractive index curve. As already shown above, the refractive index step determines the numerical aperture (NA) and thus the acceptance angle. The refractive index of the core was always taken as 1.5, whereas the cladding has a correspondingly smaller refractive index. The last line is valid for wave guiding against air (n = 1). Here an acceptance angle of 90° is valid since the NA exceeds the value of one [12].

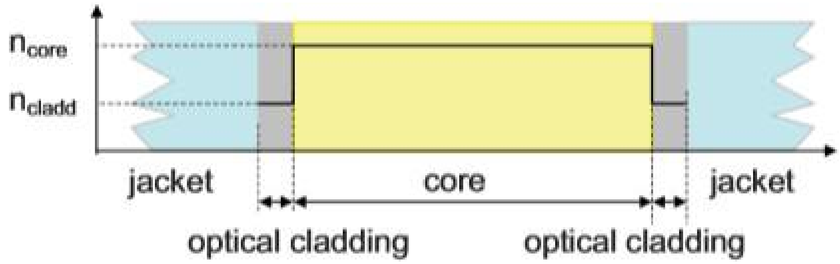


Figure II.4: Structure of a Step Index Profile Fiber.

II.7.2 Graded Index Polymer Optical Fiber (GI-POF)

Gradient index refers to the fact that the refractive index of the core gradually decreases farther from the center. The increased refraction in the center of the core slows the speed of some light rays, allowing all the rays to reach the receiving end at approximately the same time, thus reducing dispersion.

The figure II.5 shows the principle of multimode graded-index fiber, the cores central refractive index, n_a, is grater then the outer cores refractive index, n_b. As discussed earlier, the cores discussed earlier, the cores refractive index is parabolic, being higher at the center [13].

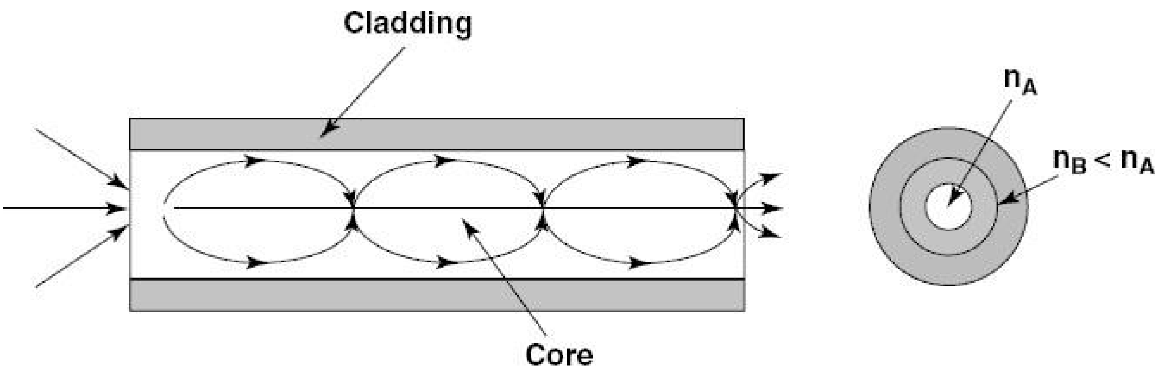


Figure II.5: Multimode Graded-Index Fiber.

II.7.3 Multi-Core Polymer Optical Fiber with Step-Index (MC-POF)

In the MC-POF, too, an increase in bandwidth was achieved by reducing the index difference. Due to the smaller core diameters it was still possible to avoid an increase in bending sensitivity. Even better values were achieved with individual cores having a two-step optical cladding such as illustrated in Figure II .6. The principle is the same as in the double-step index POF with an individual core. In this case a bundle with single cladding is completely surrounded by a second cladding material [12].

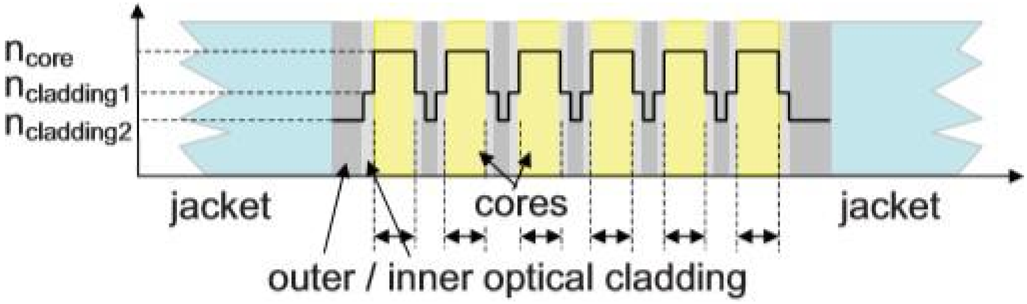


Figure II.6: Structure of a Double Step Index Profile Multi-Core POF.

II.7.4 Step-Index Polymer Optical Fiber with Low Noise Numerical Aperture (Low- NA POF)

However, when it became necessary to replace copper cables with polymer optical fiber to accomplish the transmission of ATM data rates of 155 Mbit / s (ATM: asynchronous transfer mode) over a distance of 50 m, a higher bandwidth was required for the POF. In the mid-nineties all three important manufacturers developed the so-called low-NA POF. POF with a reduced numerical aperture (low-NA POF) feature a bandwidth increased to approximately 100 MHz · 100 m because the NA has been reduced to approximately 0.30. Mitsubishi presented the first low-NA POF in 1995. Rayon ([Koi98]).

Figure II.7 shows that the fiber construction corresponds to the standard POF, the distinction being that the refractive index difference is smaller (approximately 2%). Usually the same core material is used, but the cladding material has a modified composition [12].

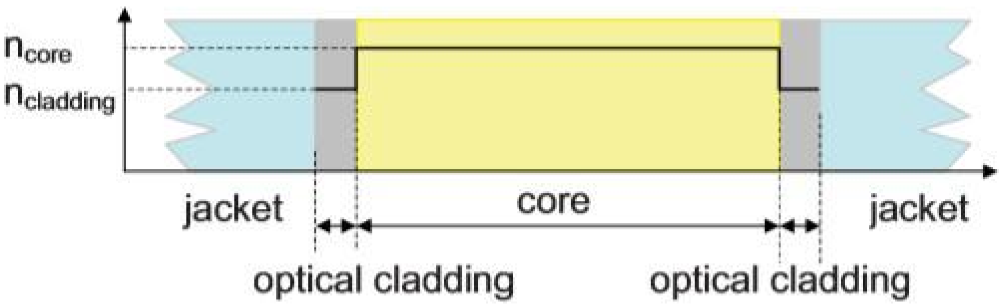


Figure II.7: Structure of a Low-NA Step Index Profile Fiber.

II.7.5 POF Fiber with Double Step-Index (DSI-POF)

The double-step index POF features two claddings around the core, each with a decreasing refractive index see the figure II.8. In the case of straight installed links, light guiding is achieved essentially through the total reflection at the interface surface between the core and the inner cladding. This index difference results in an NA of around 0.30, similar to the value of the original low-NA POF.

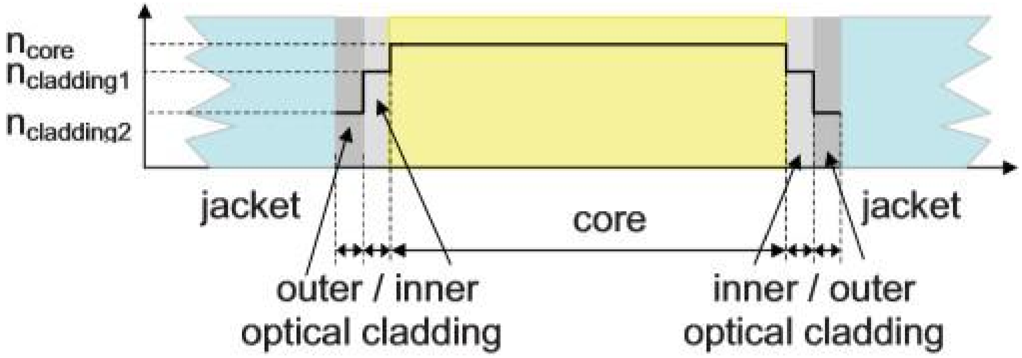


Figure II.8: Structure of a Double Step Index Profile Fiber.

When fibers are bent, part of the light will no longer be guided by this inner interface. However, it is possible to reflect back part of the decoupled light in the direction of the core at the second interface between the inner and the outer cladding. At further bends, this light can again be redirected so that it enters the acceptance range of the inner cladding. The inner cladding has a significantly higher attenuation than the core.

Light propagating over long distances within the inner cladding will be attenuated so strongly that it will no longer contribute to pulse propagation. Over shorter links, the light can propagate through the inner cladding without resulting in too large a dispersion [12].

II.8 Attenuation in POF Fibers

The most important process encountered by light as it passes through a fiber is attenuation. When passing through an optical fiber of the length L, the power of the light decreases as shown figure II.9.

The following equation applies to the optical power:

$$P_L = P_0 . e^{-\alpha' L} \quad \text{(II.8)}$$

Where P_l and P_0 are the power of the light after passage through a fiber of length L in km and at the front end of the fiber, respectively; α' is the value of the attenuation coefficient in Km^{-1} [12].

Figure II.9: Definition of Attenuation.

To make it easier to work with the numbers involved here, it is usual to express attenuation logarithmically. Thus, the attenuation coefficient is expressed as α in dB/km [12].

$$\alpha = \frac{10}{L}.log\frac{P_0}{P_L} = 4.343.\alpha' \quad \text{(II .9)}$$

Attenuation value a is the non-dimensional variable (given as a number or in dB) obtained from the product α·L. Figure II.10 illustrates the relationship between the attenuation value and the change in power as a percentage [12].

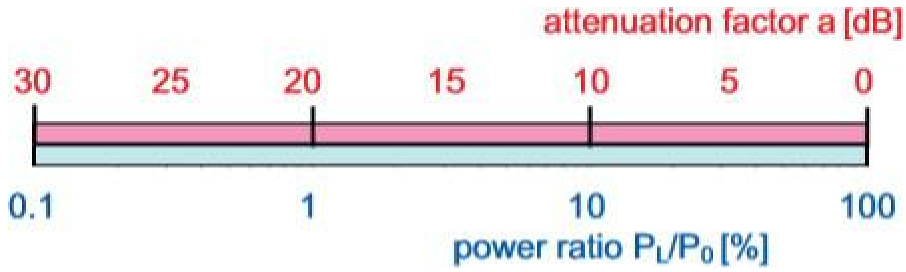


Figure II.10: Conversion of the Power Ratio PL/P0 in % into the dB Value.

Very often there is not a clear differentiation in the technical literature between attenuation per unit length α and attenuation factor a. One often speaks simply of the attenuation of the fiber. The addition "spectral" refers to the wavelength dependence. A mistake is avoided, however, when the unit is indicated. We still have to mention that attenuation and attenuation per unit length are practically always indicated as positive numbers [12].

Table II.1: Attenuation per unit length.

Quantity	Symbol	Unit	Formula
Attenuation coefficient, lin.	α'	Km^{-1}.	{ln (P_0/P_L)}/L
Attenuation coefficient, log.	α	dB/Km	{10.log(P_0/P_L)}/L
attenuation	a	dB	10log(P_0/P_L)

Especially in the area of optical short-range communication, indicating the fiber attenuations in dB is much more practical than, for example, representing the absolute transmission. POFs are being used more and more in the near infrared range for quite short transmission lengths. Finally, PMMA can also be used for waveguide structures in the mm range. Figure II.11 shows the attenuation curve of a PMMA-POF [12].

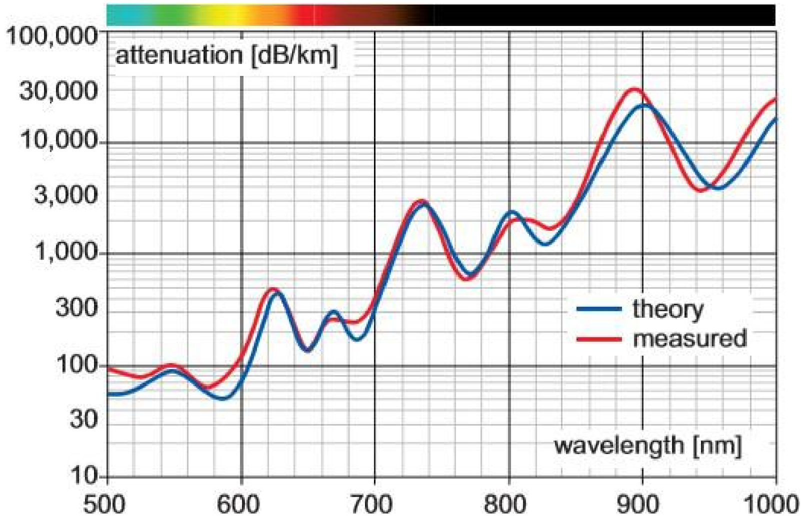


Figure II.11: Attenuation Spectrum of the PMMA-POF.

Nevertheless, the representation comprises approximately 3 decades, i.e. a factor of 1,000 which cannot be overlooked on a linear scale [12].

II.9 Dispersion in POF Fibers

Dispersion refers initially to all processes that result in a difference in the transit times of various modes. One mode is thereby always a propagation condition of the light that is uniquely defined by the wavelength, polarization, and propagation path. Differential delays between the various light components lead to a reduction in the modulation amplitude of higher frequencies. This makes the fiber a low-pass filter [12].

II.9.1 Intermodal (or Modal) Dispersion

In multimode fibers, different modes travel down the fiber at different speeds and so pulses launched into multimode fibers will broaden (or even potentially break up into separate parts). This is called intermodal dispersion and leads to a pulse spread [12].

II.9.2 Chromatic Dispersion

Chromatic dispersion describes the influence of the spectral width of a transmitter on a temporal broadening of the input pulse. This includes the material-dispersion and waveguide dispersion types of dispersion. Both effects also occur in single mode fibers. Waveguide dispersion is caused by the fact that light waves penetrate into the fiber cladding to various depths, depending on the wavelength of the light wave. Thus, the different speeds of the core and cladding parts result in pulse broadening. Since only a small portion of the light wave in higher modes of large diameter fibers spreads into the cladding, this effect is only considered for single mode fibers [12].

II.9.3 Waveguide Dispersion

For single mode fibers, it is due to the fact that part of the light enters the cladding with different angles and depth. It is caused by the difference in relative index which also depends on the wavelength. In multimode fibers, only a small portion of the light modes enter the cladding. Therefore, the effect of the dispersion of the waveguides is negligible there and is not considered in multimode with step-index [10].

II.9.4 Material Dispersion

A light pulse from an optical source is composed of several wavelengths, the refractive index of the fibers is different according to the wavelength propagates in the fiber at a specific speed.

The material dispersion therefore varies according to the wavelength of use. It is weak and often negligible compared to the modal dispersion [10].

II.10 Bandwidth in POF Fibers

The term bandwidth describes the frequency range of a system within which the transmission of signals can be achieved with reasonable attenuation. In POF systems, the limiting factor is usually the bandwidth of the fiber itself, which is created by modal dispersion. We can describe the SI-POF as being very close to a Gaussian low-pass filter, and we will use the following definition of bandwidth. The frequency at which the amplitude of a sinus modulated monochromatic signal has been reduced to ½ of the optical level [12].

Figure II.12 schematically illustrates this definition.

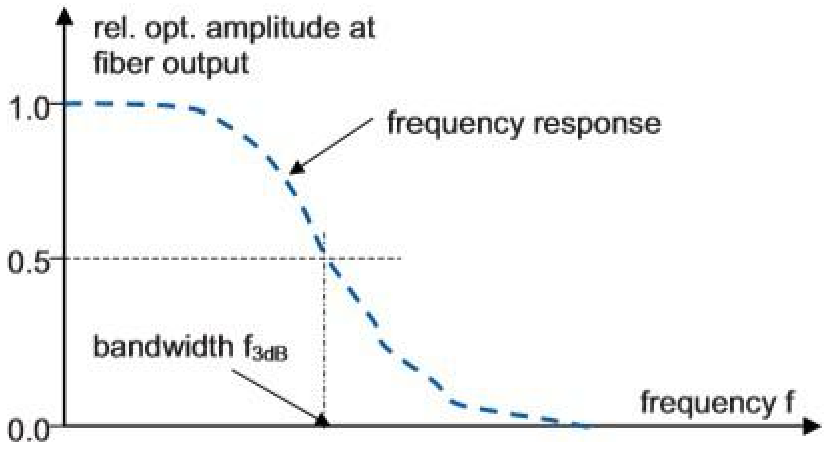


Figure II.12: Definition of the POF Bandwidth.

Nonetheless, knowledge of the bandwidth alone is not adequate for estimating what the actual capacity of the complete link will be. In order to determine this parameter, it is further necessary to know the actual transmission procedure as well as the complete transmission function. For example, it is possible to transmit signals of significantly broader bandwidth if an electrical compensation of the frequency response takes place, as illustrated schematically in the figure II.13.

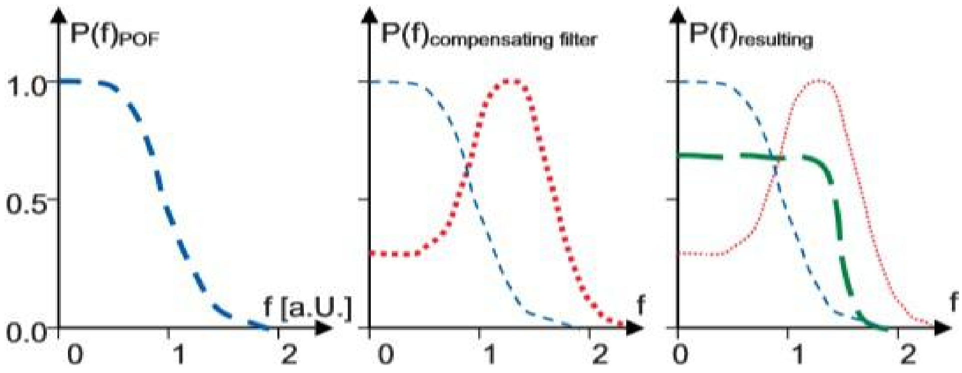


Figure II.13: Compensation of the POF Low Pass Characteristic.

A high pass filter is used for compensation. In the case of low frequencies, the signal is attenuated - in the case of higher frequencies the signal is passed through without attenuation. The resulting function has a significantly higher bandwidth; however, due to the overall existing level of attenuation, a higher level of signal is necessary [12].

II.11 Advantages and Disadvantages of Polymer Optical Fibers

Advantages

We can cite some advantages of POF as following:

- Plastic fiber has a lower cost than silica 0.1-1/meter.
- Transmitters and receivers require less energy compared to copper transceiver.
- System installation uses simple and less expensive requirement.
- Easy to connect and handle (the plastic fiber diameter is 1 mm while the fiber glass is 8 to 100 micrometer).
- POF are lighter.
- Greater flexibility, resistance to bending and vibration.
- Immunity to electromagnetic interference.
- Insensitive to parasites [14].

Disadvantage

- High losses during transmission.
- POF supplied are limited worldwide.
- Absence of standard and lack of certification on the part of the installation.
- Lack of fibers at high temperature (125°C).
- Difficulties in connecting both between two fibers and between a fiber and the transmission or receiving module. In the laboratory, connections can be made for which the losses are less than 0.2Db. in the field, it is necessary to use removable connectors which require a precise adjustment and cause losses greater than 1dB.
- The lifespan of a fiber is around 20 years [14].

II.12 Plastic versus Glass Characteristics

It is interesting to compare the characteristics of POF with those of silica fibers. The table II.2 below provides a comparison of essential characteristics of these two type of optical fibers [10].

Table II.2: Polymer versus Glass Optical Fiber Characteristics.

Characteristics	Polymer Optical Fiber(POF)	Glass Optical Fiber (GOF)
Numerical aperture	Strong 0.4	Weak[0.1-0.2]
Material	Plastic : PMMA	Glass
Core diameter	1 mm	0.062 mm
Attenuation	200 dB/Km (to 650 nm)	2.9 dB/Km (to 850 nm)
Fiber length at 100 Mbps	100 meters	1 Km
Bandwidth	About 10MHz*Km	200 MHz*Km
Operating wavelength	Visible band	Infrared band
Flexibility	Flexible	Brittle
Connectivity	Easy to connect, requires little training and tools	Takes more time, requires special training and tools
Cost of components and test equipment	Low	expensive

II.13 Polymer Optical Fiber Applications

Since the polymer optical fiber doesn't support the longue distances therefore the most field of applications are local area networks such as vehicles and homes.

II.13.1 In Multimedia and Telecom Field

Even the polymer optical fiber is difficult to adapt to the needs of the multimedia communication network, but it has light and soft, flexural, impact strength, cheap, anti-radiation, easy to process and can make a series of advantages, so favored.

In addition, the light passes through the central portion of the plastic optical diameter of about l m, about 10 times larger than the glass fiber, and the connection between the fiber connection and personnel computer terminal apparatus is very easy. Plastic optical fiber installation costs low, very simple installation can align the connectors plug, this plug can be used existing technology to procedure.

II.13.2 Automotive Applications

The first time that plastic fiber took its place in automotive industry, was in 1998 for luxury vehicles such as Mercedes-Benz then Jugar and Peugeot via the D2B network. In 2001, most dealers a adopted this technology, mainly in high-end vehicles such as MOTOROLA, which began equipping the BMWs. The automotive industry installed the first MOST 25 network with speed of 25Mb/second, then the MOST 50 network with a speed of 50 Mb/second at the same time the IDB-1394 which in the 1394 standard of the American association IEEE. This standard has several amendments since 2008 with the version"1394-2008-IEEE standard for a High performance Serial Bus" and the industry is always looking for evolution in this field [15].

II.13.3 In Local Networks

The use of less expensive and reliable products in local networks has been the dream of engineers for years. But optical integration has not progressed as quickly as electronic integration due to several factors [16].

II.14 Summary of Various Applications

Silica fibers are very suited for simultaneous transmission and over long distances. Thanks to wavelength multiplexing, the transmission speed is amplified. Silica-based optical fibers are much lighter and less bulky than copper wires. They have the advantage of having very low attenuation over long distances.

As for Plastic Optical Fiber (POF), their applications are limited to transmissions over short distances, to lighting, and to their role as sensors in many fields. In the automotive industry, multiplexed signals from radiotelephones (GSM), positioning systems (GPS), CD and DVD players, etc. are transmitted by plastic optical fibers. Medicine has also taken advantage of technological advances in optical fibers to use them as a medical tool (prevention and care of laser surgery). POF-bade interferometry is still a vast field of study and research for measurements speed by Doppler effects, polarization, birefringence, etc.

II.15 Conclusion

This chapter made it possible to present characteristics of plastic optical fibers in general. Then we studied plastic optical fibers with its performance, advantages and disadvantages as well as its applications on short distances.

In the next chapter, we will discuss the simulation of a POF and GOF transmission in an FTTH system and the interpretation results.

Chapter Three

Study of POF Transmission in an FTTH System (Fiber To The Home)

III.1. Introduction

The growth of fiber optic telecommunications has multiplied network architectures, coding techniques and available components. The influence of several parameters penalizing performance of the link, and the complexity of designing the associated systems, pushed the researchers to use simulation tools because they constitute an effective assistance to find solutions, both at the component level and at the system level.

In this chapter, we will study an optical transmission channel using short distance Multimode fiber, that is to say the FTTH type with direct laser modulation using the Optisystem simulation software. Plastic optical fiber does not exist in the Optisystem software component library and that is why we modified a multimode fiber to get a plastic fiber.

III.2. Overview on Optisystem

Optisystem is an optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks, it is a system level simulator based on the realistic modeling of fiber-optic communication systems [17].

Applications

Optisystem has a wide range of applications that include:

- Optical communication system design from component to system level at the physical layer.
- TDM/WDM network design.
- Radio over fiber (ROF) systems.
- SONET/SDH ring design.
- Transmitter, channel, amplifier, and receiver design.
- Dispersion map design [17].

III.3. General Description of the Architecture:

The figure III.1 introduces the general architecture of our channel simulated by Optisystem. It is composed of: transmitter part, channel of propagation and a receiver part.

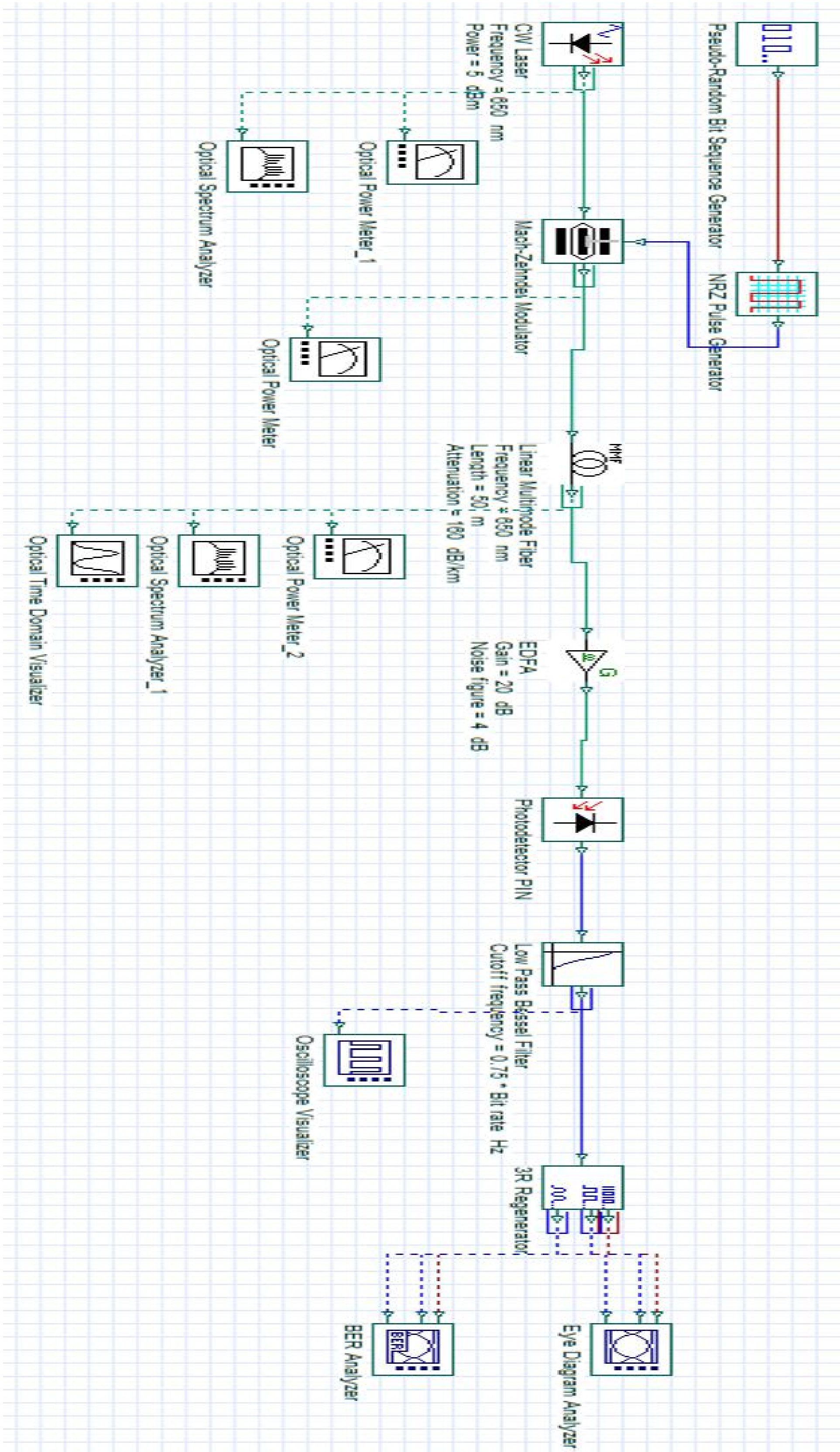


Figure III.1: General Architecture of our Channel.

III.3.1.Transmitter Part:

The principle function of this part is to generate light signals. The figureIII.2 represents the components of the transmitter part.

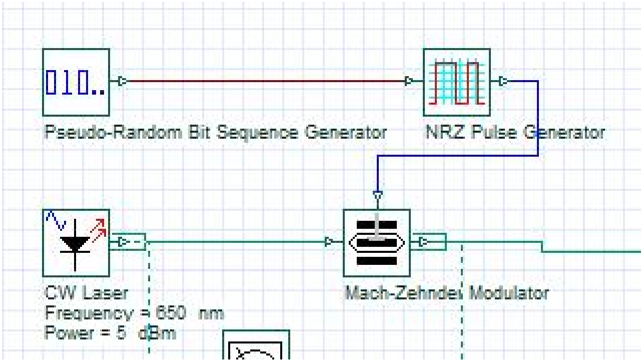


Figure III.2: Components of Transmitter Part.

III.3.1.1 Pseudo Random Binary Generator (Binary Sequence)

The output from a pseudo random binary sequence generator is a bit stream of binary pulses; i.e., a sequence of 1`s (HI) or 0`s (LO), of a known and reproducible pattern. The bit rate, or number of bits per second, is determined by the frequency of an external clock, which is used to drive the generator. For each clock period a single bit is emitted from the generator; either at the '1' or '0' level, and of a width equal to the clock period. For this reason the external clock is referred to as a bit clock. For a long sequence the 1`s and 0`s are distributed in a (pseudo) random manner. The sequence pattern repeats after a defined number of clock periods [18].

III.3.1.2 Non-Return-Zero Format

The modulation used in this link is NRZ (Non-return to zero), in an NRZ generator the bit "1" is associated with an optical pulse and the bit "0" corresponds to the absence of the signal but in practice the total absence of signal does not exist since the extinction rate is never infinite. The NRZ format is used for bit rates less than 10 Gbit /s and the bandwidth in an NRZ format is equal to 1/2 of the bit rate because on-off transitions occur fewer times.
Figure (III.3) shows the encoding of data (101101) in NRZ format.

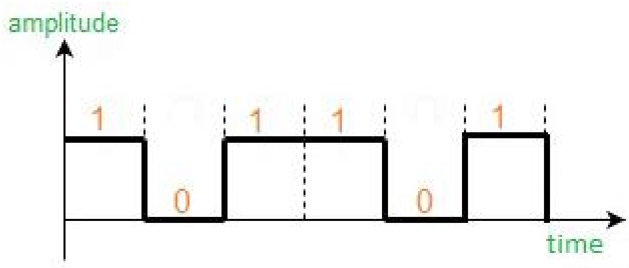


Figure III.3: Encoding of Data (101101) in NRZ Format.

III.3.1.3 CW Laser (Continuous Wave Laser)

The source chosen in the simulation is a continuous source. It emits at a wavelength of 650 nm with a varying power of 5 dBm to 10 dBm. Figure III.4 shows the power spectrum of the optical source used in the simulation. The spectrum is centered at 650 nm.

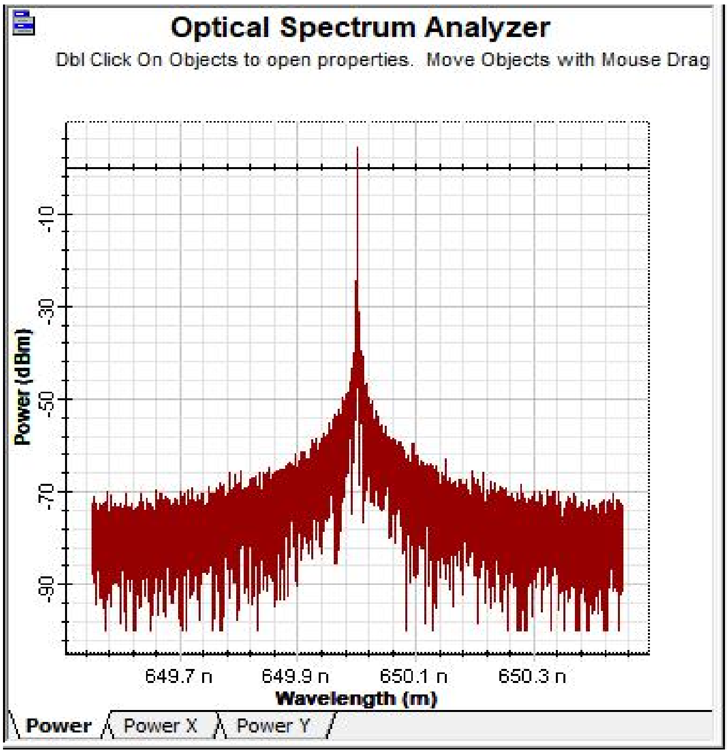


Figure III.4: The Power Spectrum of the Optical Source.

III.3.1.4 Mach-Zehnder Modulator

A Mach-Zehnder modulator is an integrated optical device; it is used for controlling the amplitude of an optical wave. The input waveguide is split up into two waveguide interferometer arms; a voltage V applied to an electrode causes a change in the phase of the optical signal in the arm of the interferometer. FigureIII.5 shows the schematic of a Mach-Zehnder modulator [19].

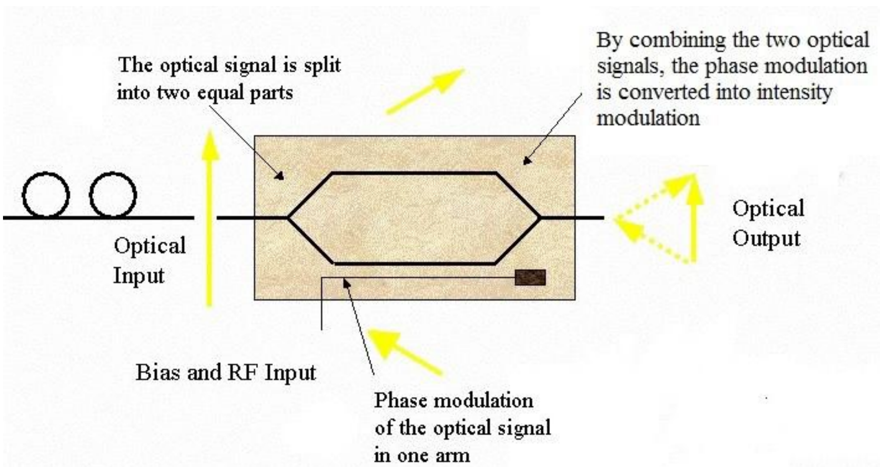


Figure III.5: The Schematic of a Mach-Zehnder Modulator.

There are two types of Mach-Zehnder modulators, Semiconductor and Lithium-Niobate, the latter is the most common used one, and it has two different configurations:

• **Single-drive configuration**: modulating voltage is applied to one arm of the Interferometer causing a phase change of π in the arm.

• **Dual-drive configuration:** modulating voltages are applied to both arms of the interferometer causing a phase changes of $\pm \pi/2$ in the arms [19].

III.3.2.Transmission Channel: Optical Fiber

The characteristics of the used multimode fiber are shown in following table:

Table III.1: Characteristics of the used Multimode Fiber.

Length	From 10m to 100m
Attenuation	150dB/Km
Reference wavelength	650nm

For a fiber length of 20m we have attenuation of 3dB {0.02Km*150dB/Km} see figure III.6:

Figure III.6: Optical Power after Transmission.

III.3.3.Receiver Part:

The following figure represents the components that build up the part of the reception.

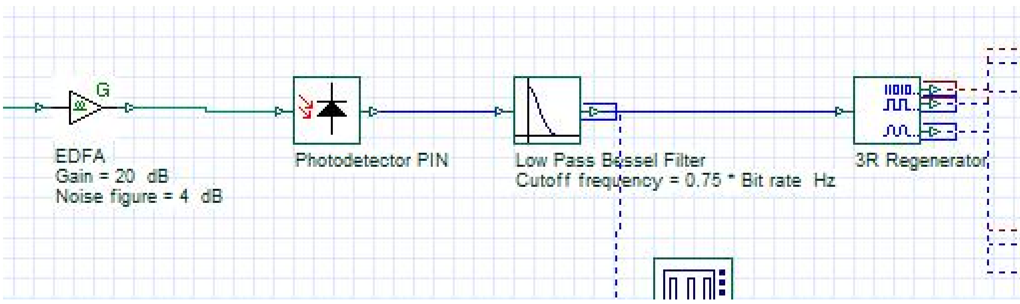


Figure III.7: Components of Receiver Part.

III.3.3.1 Erbium-Doped Fiber Amplifier (EDFA)

Erbium-Doped fiber amplifier is the most widely used fiber-optic amplifiers, it amplify optical signal directly without electric and electric optical transformation EDFA optical amplifiers are made of short lengths (a few meters) of optical fiber doped with the element Erbium. A pumping laser excites Erbium ions in the fiber, which can then give their energy to the optical signals passing through. The pump wavelengths are *980 nm* and/or *1480 nm* [19].

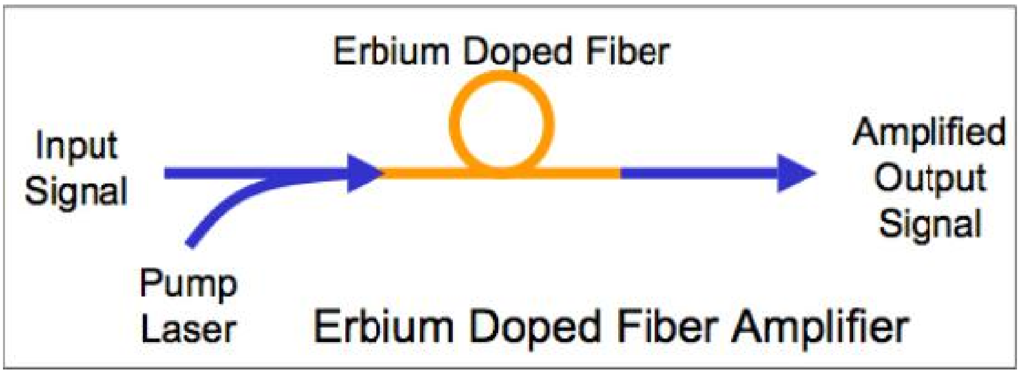


Figure III.8: The working principles of EDFA.

Advantages & Disadvantages of EDFA

Advantages

- EDFA has high pump power utilization (>50%).
- Directly and simultaneously amplify a wide wavelength band (>80nm) in the 1550nm region, with a relatively flat gain.
- Flatness can be improved by gain-flattening optical filters.
- Gain in excess of 50 dB.
- Low noise figure suitable for long haul applications.

Disadvantages

- Size of EDFA is not small.
- It cannot be integrated with other semiconductor devices [20].

III.3.3.2 Photodiode PIN

A photodiode is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode.
The photodiode used is a PIN photodiode. Its role is to convert the optical signal into an electrical signal with the minimum of distortions. The performances required for a photodiode are speed of detection, good sensitivity, and with good signal to noise ratio.

III.3.3.3 Bessel filter:

The Bessel filter, also known as the Thompson filter, is a polynomial ("all pole") filter whose main characteristic is to provide a constant delay in pass-band. Concretely, this means that all the pure frequencies, in band, cross it in a strictly equal time. The Bessel filter therefore makes it possible to minimize the distortion that a complex signal undergoes during a filtering operation [21].

III.3.3.4 3R Regenerator:

An optical communications repeater is used in a fiber-optic communications system to regenerate an optical signal. Such repeaters are used to extend the reach of optical communications links by overcoming loss due to attenuation of the optical fiber. Some repeaters also correct for distortion of the optical signal by converting it to an electrical signal, processing that electrical signal and then re-transmitting an optical signal. Such repeaters are known as optical-electrical-optical (OEO) due to the conversion of the signal. These repeaters are also called re-generators for the same reason. In addition to re-amplification and reshaping, re-timing of data pulse is done by the 3R Re-generator [22].

III.4. Evaluation Methods

III.4.1. Bit Error Rate (BER)

During the transmission of data through an optical channel, the receiver should be able to receive individual bits without errors. Errors occur when a receiver fails to detect an incoming bit correctly. The bit error rate (BER) is a ratio of error bits to total transmitted bits.

$$BER = \frac{error\ bits}{total\ transmitted\ bits} \tag{III.1}$$

For most practical WDM networks, this requirement of BER is 10^{-12} (~ 10^{-9} to 10^{-12}), which means that a maximum one out of every 1012 bits can be corrupted during transmission. Therefore, BER is considered an important figure of merit for WDM networks; all designs are based to adhere to that quality [17].

III.4.2. Quality Factor

The Q-factor is a measure of how noisy a pulse is for diagnostic purposes. It provides a qualitative description of the receiver performance because it is a function of the signal to noise ratio (optical) and suggests the minimum SNR required to obtain a specific BER for a given signal.

The relationship of Q-factor to BER is shown in both equation (III.2) and FigureIII.9.

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{III.2}$$

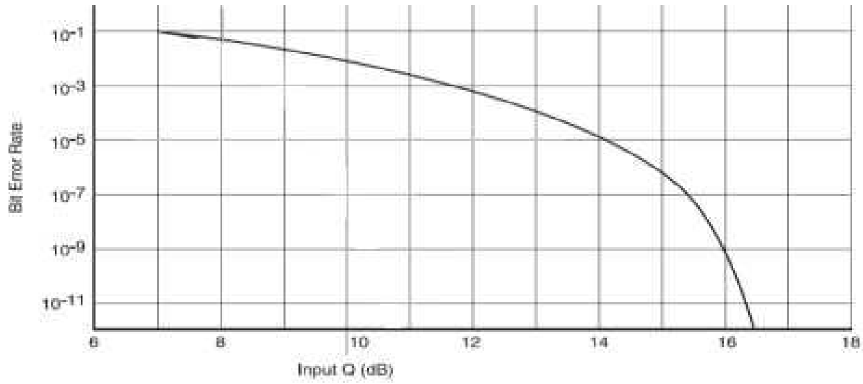


Figure III.9: The Relationship of Q-factor to BER.

As we can see, the higher the value of Q - factor the better the BER [17].

III.5. Results:

In this part we will evaluate the performances of a POF and GOF transmissions in an FTTH system by analyzing the influence of each parameter on the quality of transmission, so that we can get the best parameter for a higher quality factor.

III.5.1. Performances of Polymer Optical Fiber

III.5.1.1 Effect of Varying Fiber Length

The length of the optical fiber affects the transmission quality because of the attenuation. To look into this we can vary, for example the length of the fiber from 10m to 90 m (fiber length for local networks) by setting the bit rate to 1.5 Gbit / s, the transmission power to 10 dBm, and the attenuation at 150 dB / km at a wavelength of 650 nm. We take down each time the BER and the quality factor.

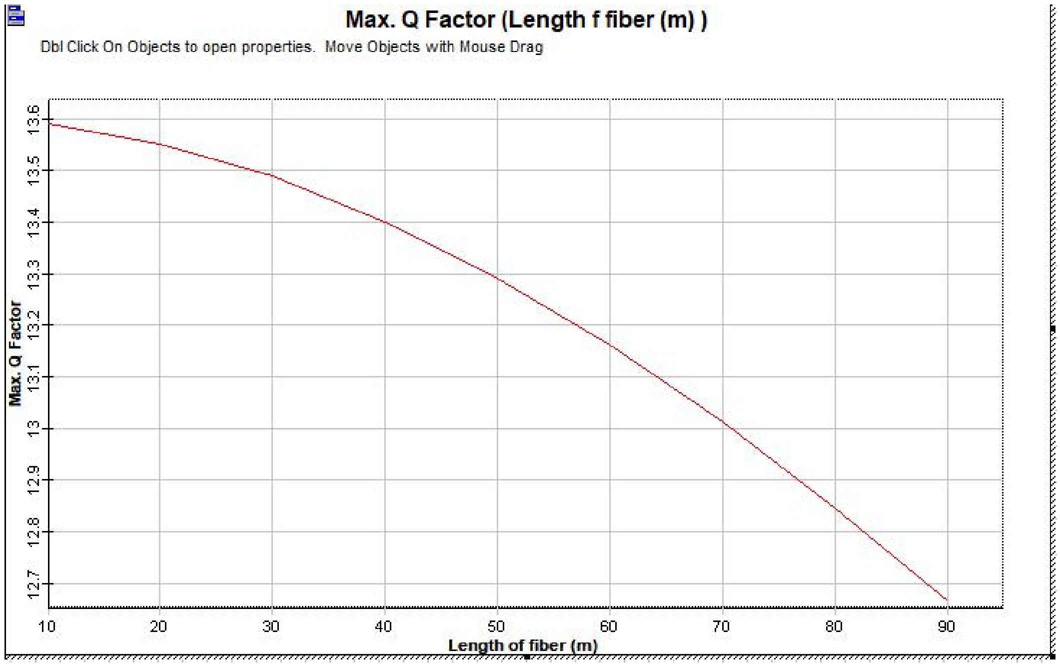
The table below records the simulation results for different fiber lengths:

Table III.2: Effect of Fiber Length on BER and Quality Factor for POF.

Fiber length(m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Quality factor Q	13.591	13.552	13.488	13.401	13.292	13.161	13.0117	12.8456	12.6651
BER	2.2764 1e-42	3.8614 e-42	9.1561 2e-42	2.9760 2e-41	1.2948 9e-40	7.3303 8e-40	5.22384 e-39	4.51999 e-38	4.57332 e-37

Figure III.10 shows the variation of the quality factor and BER versus the length of the fiber.

Variation of Quality Factor versus Length of Fiber for POF.



Variation of BER versus Length of the Fiber for POF.

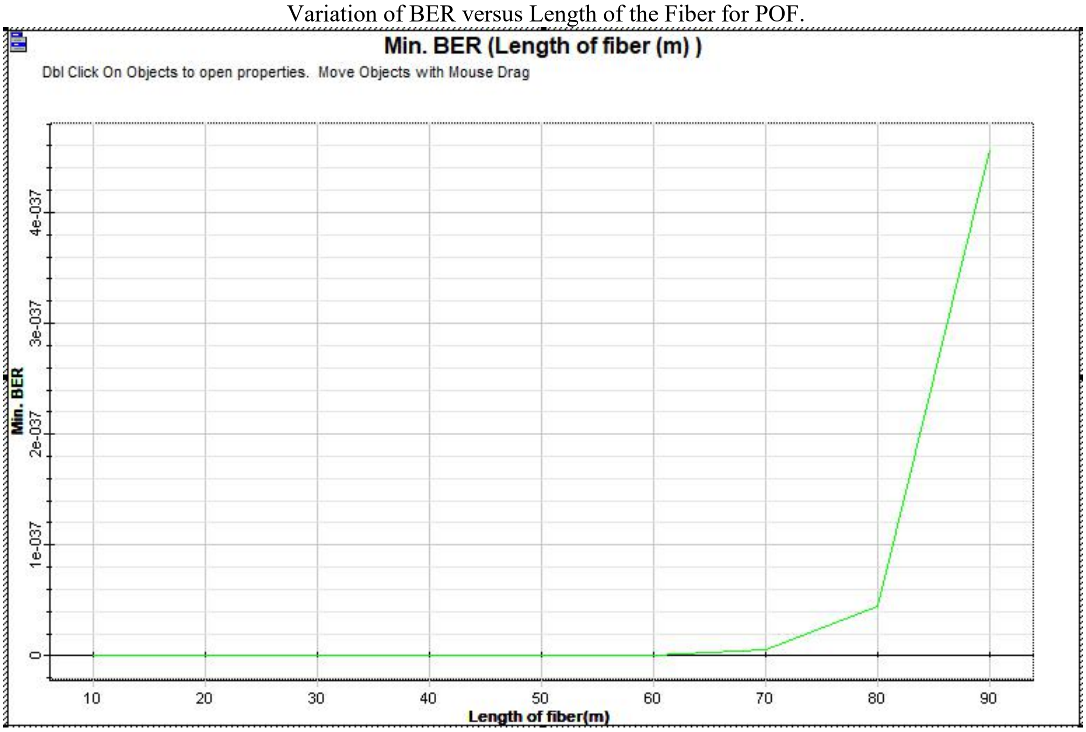
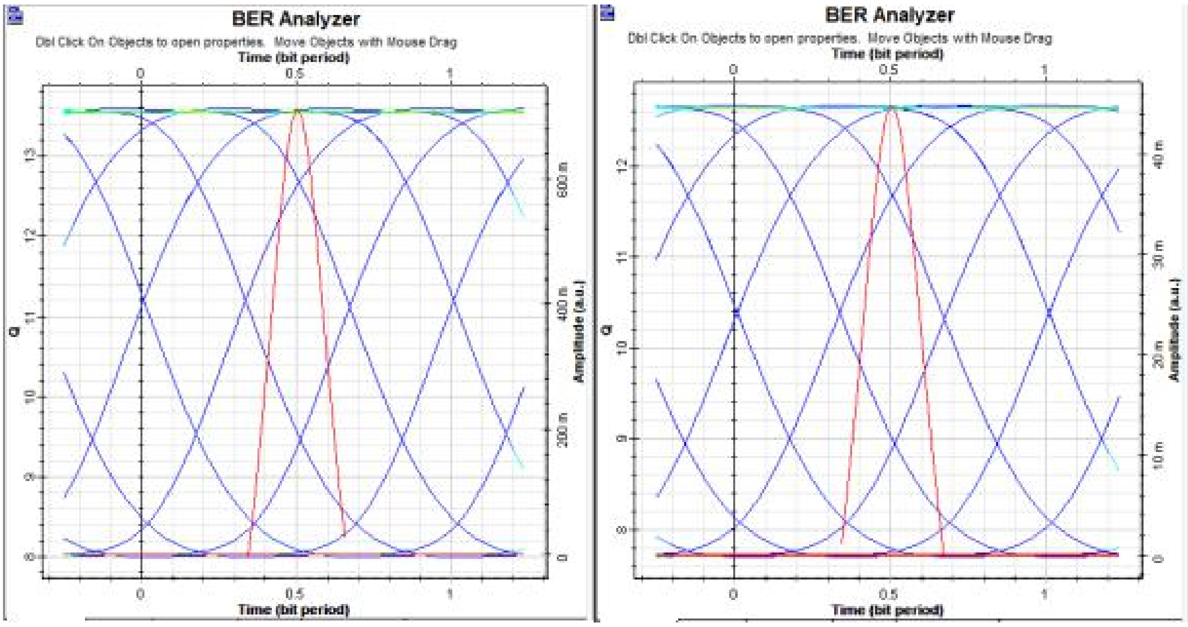


Figure III.10: Variation of Q-Factor and BER versus Length of the Fiber for POF.

The results show that the quality factor decreases with respect to length of optical fiber, while the BER increases.

Figure III.11 represents the eye diagram for fiber length of 10 m and 90 m respectively.



(a) **(b)**

Figure III.11: Eye Diagram; (a):10m (b):90m

We notice that there is a little difference between the two diagrams, but we still have a good quality of transmission.

III.5.1.2. Effect of Varying Power of Transmission

Now, we vary the transmitting power from 5 dBm to 10 dBm with fixing the distance of the fiber 50 m, setting the bit rate to 1.5 Gbit / s, and the attenuation at 150dB / km at a wavelength of 650 nm. We note each time the BER and the quality factor.

TableIII.3 below shows the simulation results for different transmission power:

Table III.3: Effect of Transmission Power on Quality Factor and BER.

Transmission power in dBm	**5**	**6**	**7**	**8**	**9**	**10**
Quality factor	13.2895	13.29	13.2904	13.2908	13.2912	13.2915
BER	1.32953 e-40	1.32078 e-40	1.31306 e-40	1.30625 e-40	1.30022 e-40	1.29489 e-40

Figure III.12 illustrates the variation of the quality factor and BER versus the power of transmission.

Variation of BER versus Power of Transmission for POF.

Variation of Quality Factor versus Power of Transmission for POF.

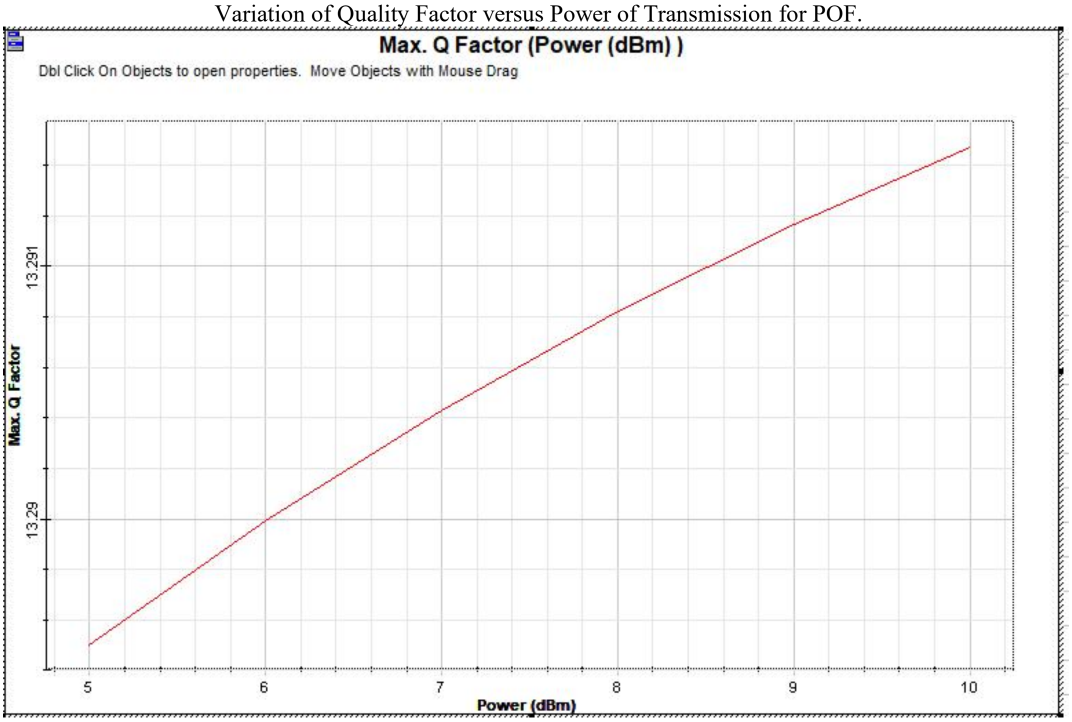
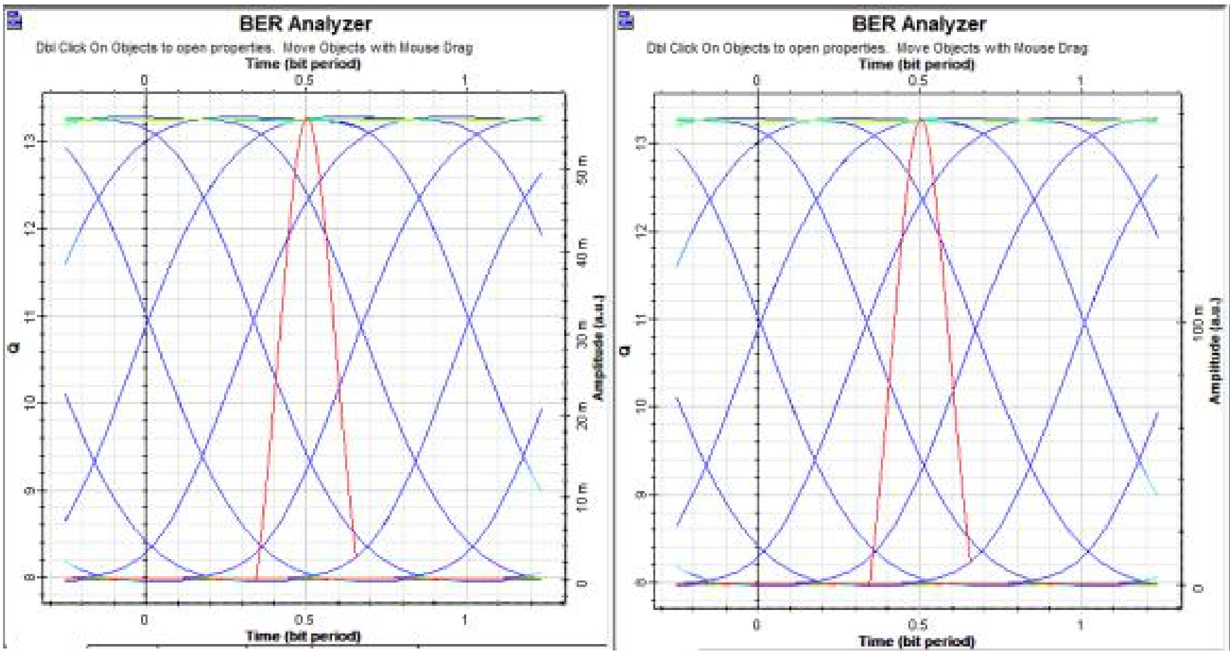


Figure III.12: Variation of BER and Quality Factor versus Power of Transmission for POF.

By analyzing the figures, we notice that the quality of the transmission still good, even by changing the power of the transmission, so it does not cause a big effect.

Figure III.13 represents the eye diagram for power of transmission 5 dBm and 10dBm respectively.



(a) **(b)**

Figure III.13: The Eye Diagram; (a): 5dBm (b):10dBm.

From the above diagrams, we see that the quality of the transmission is good for both values.

III.5.1.3 Effect of Varying the Bit Rate:

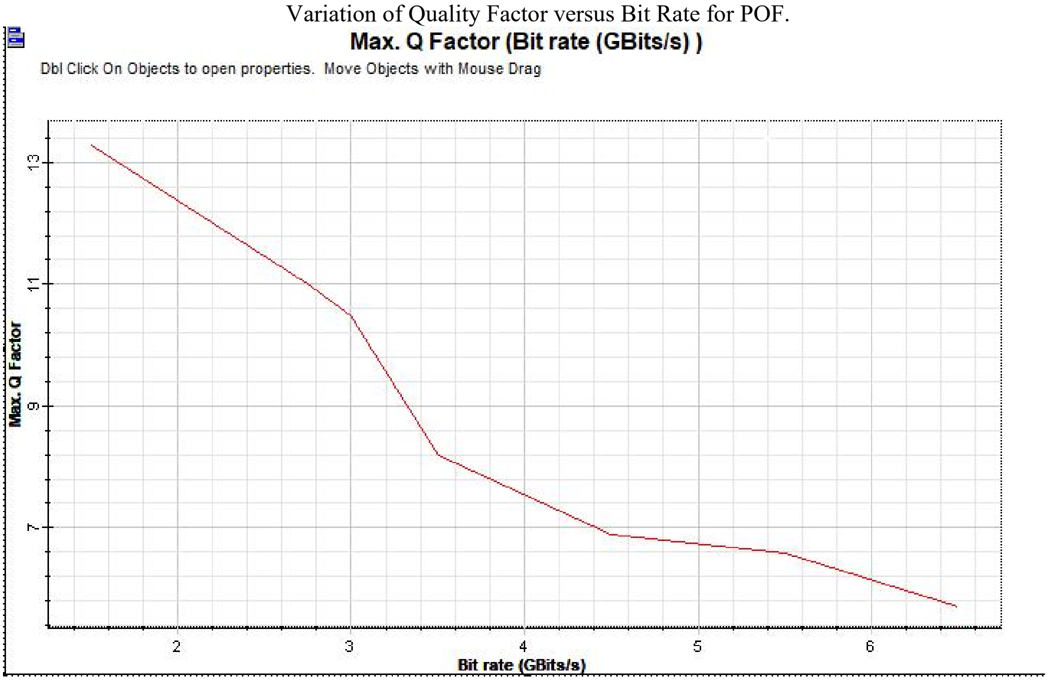
Now, we will proceed to the variation of the bit rate. The latter is essential for the good transmission of the signal because it is always necessary to adjust the bit rate with various parameters such as the power and the transmission medium. We will vary the bit rate from 0.5 Gbit / s up to 6.5 Gbit / s by setting the wavelength at 650nm, the optical fiber length at 50m, the transmission power at 10 dBm and the attenuation at 150 dB / km. The results are collated in the table III.4 below:

Table III.4: Effect of Bit Rate on Quality Factor and BER for POF.

Bit Rate (Gbit/s)	**1.5**	**2.75**	**3**	**3.5**	**4.5**	**5.5**	**6.5**
Quality factor Q	13.2915	11.0087	10.4787	8.19545	6.90144	6.58487	5.71919
BER	1.29489 e-40	1.31086 e-28	5.4107 e-26	6.23862 e-17	2.44243 e-12	2.24903 e-11	5.07108 e-9

Figure III.14 shows the variation of the quality factor and BER versus the bit rate.

Variation of Quality Factor versus Bit Rate for POF.



Variation of BER versus Bit Rate for POF.

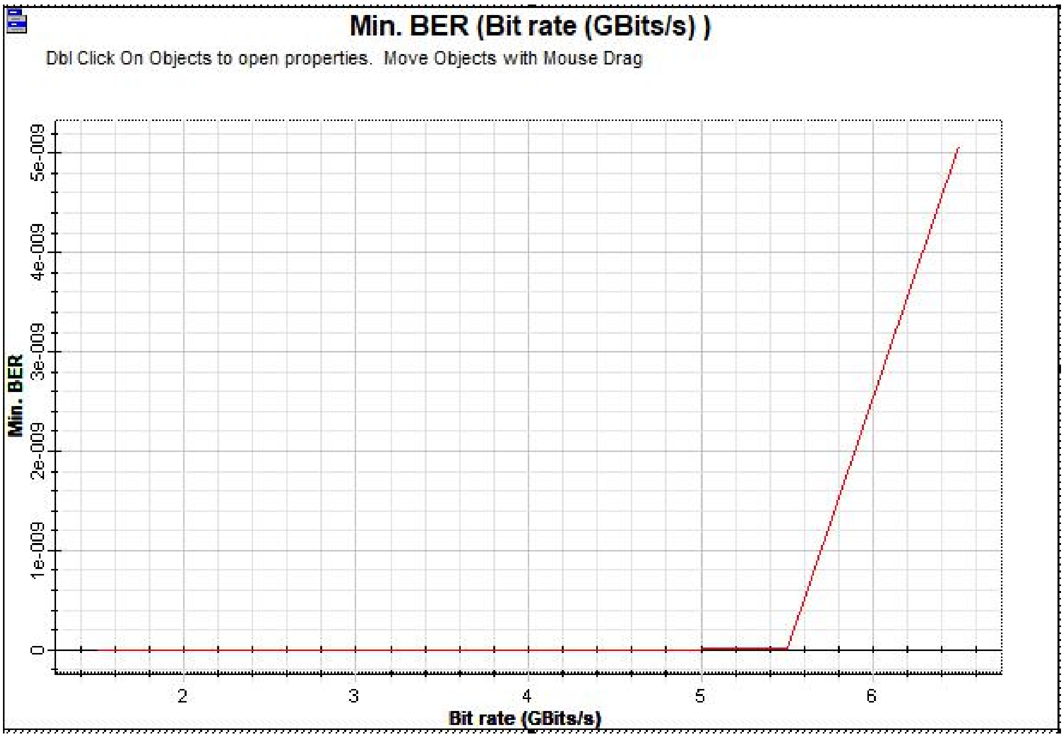
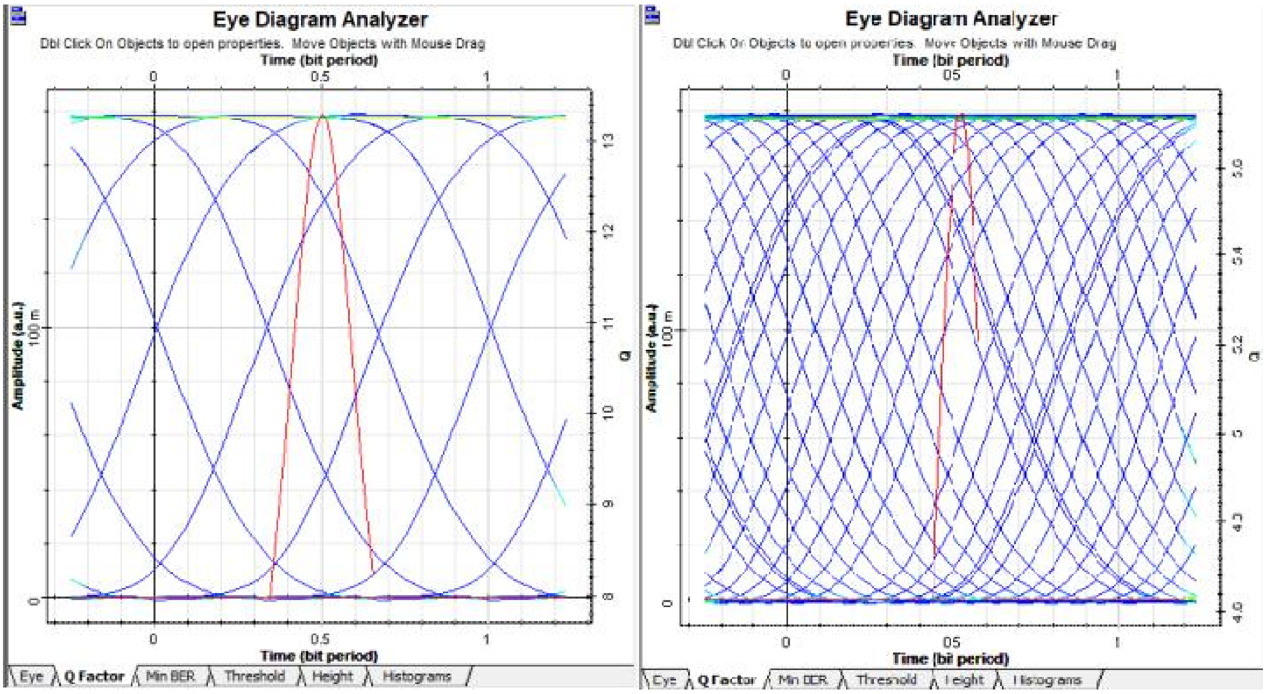


Figure III.14: Variation of Quality Factor and BER versus Bit Rate for POF.

From the above results, we can see that as we increase the bit rate, the quality factor decreases. The highest quality was at the lowest bit rate.

Figure III.15 represents the eye diagram for the bit rate of 1.5 Gbit / s and 6.5 Gbit /s respectively.



(a) **(b)**

Figure III.15: The Eye Diagram; (a): 1.5Gbit/s (b): 6.5Gbit/s.

III.5.2. Performances of Glass Optical Fiber

In this section, we will repeat the same previous steps, but changing the parameters of the multimode fiber from the one of polymer fiber to Glass fiber parameters.

Table III.5: Parameters of a Multimode GOF.

length	From 10m to 100m
attenuation	2.1dB/Km
Reference wavelength	850nm

III.5.2.1 Effect of Varying Fiber Length

We will vary the length of the fiber from 10 m to 90 m with keeping the ordinary parameters. We note each time the BER and the quality factor.

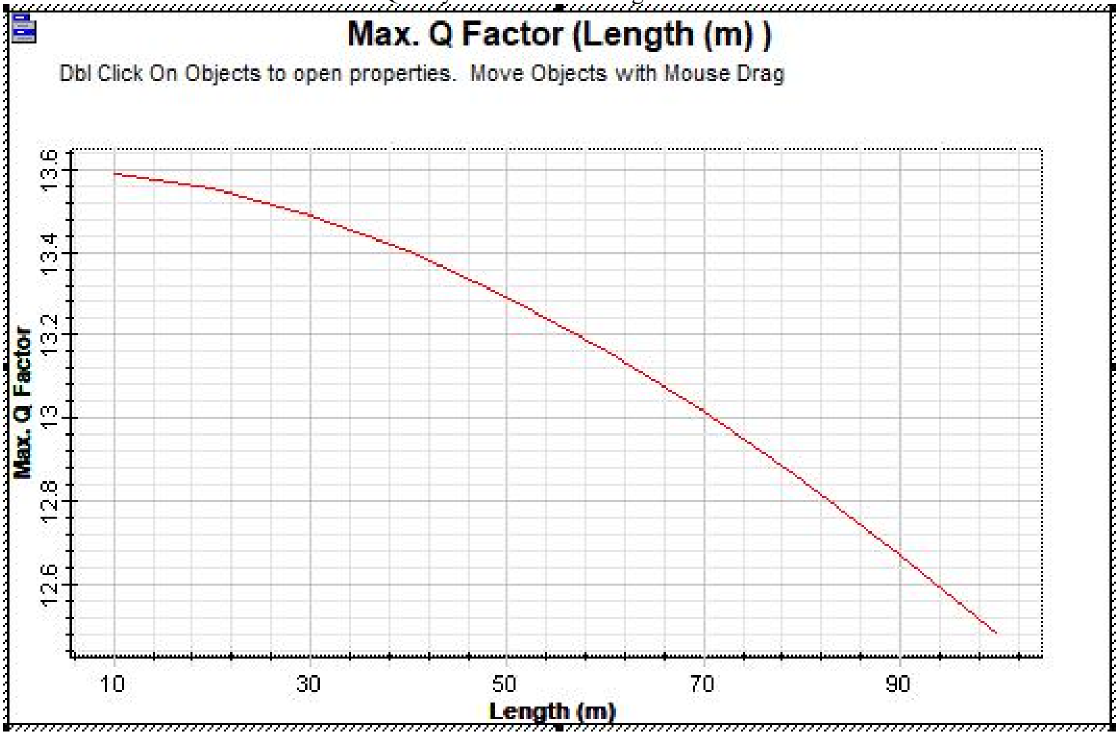
The table below demonstrates the simulation results for different fiber lengths:

Table III.6: Effect of Fiber Length on BER and Quality Factor for GOF.

Fiber length(m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Quality factor Q	13.591	13.552	13.489	13.4021	13.293	13.163	13.014	12.8486	12.6687
BER	2.2701 e-42	3.8383 e-42	9.0670 e-42	2.9342 e-41	1.2703 e-40	7.1510 e-40	5.0639 e-39	4.35094 e-38	4.36819 e-37

Figure III.16 shows the variation of the quality factor and BER versus the length of the glass fiber.

Variation of Quality Factor versus Length of Fiber for GOF.



Variation of BER versus Length of the Fiber for GOF.

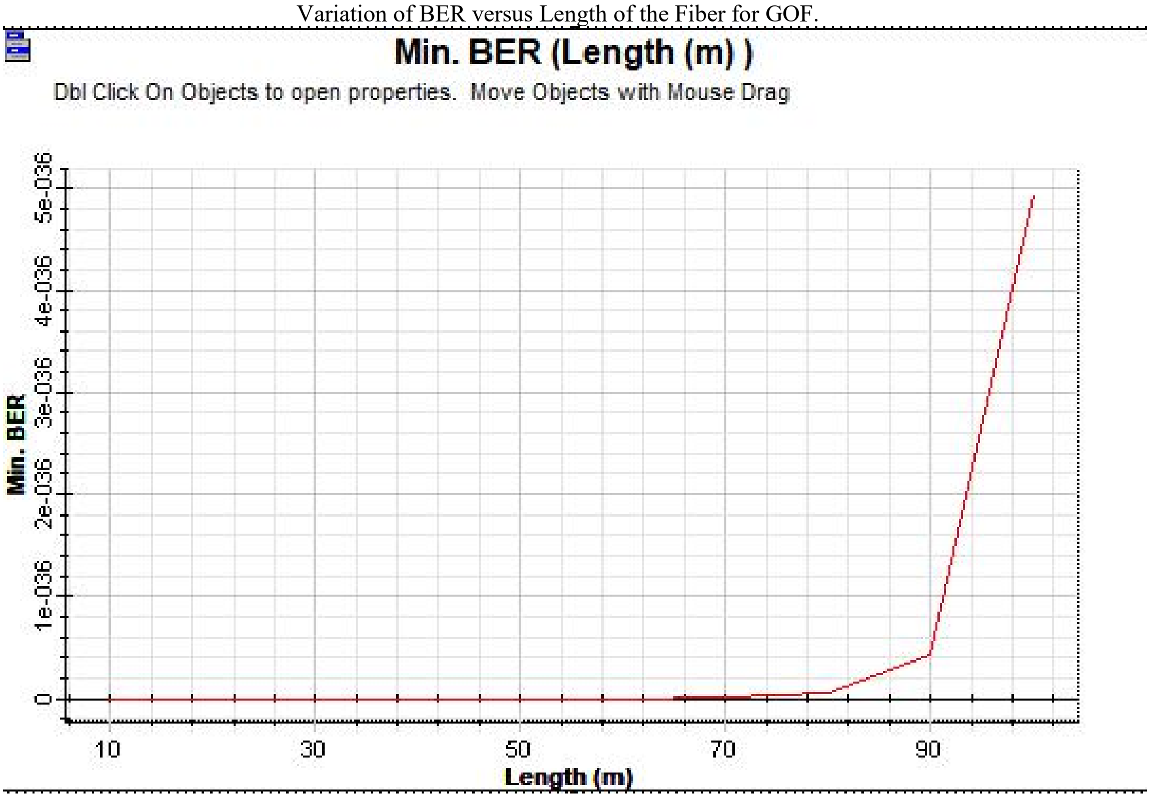
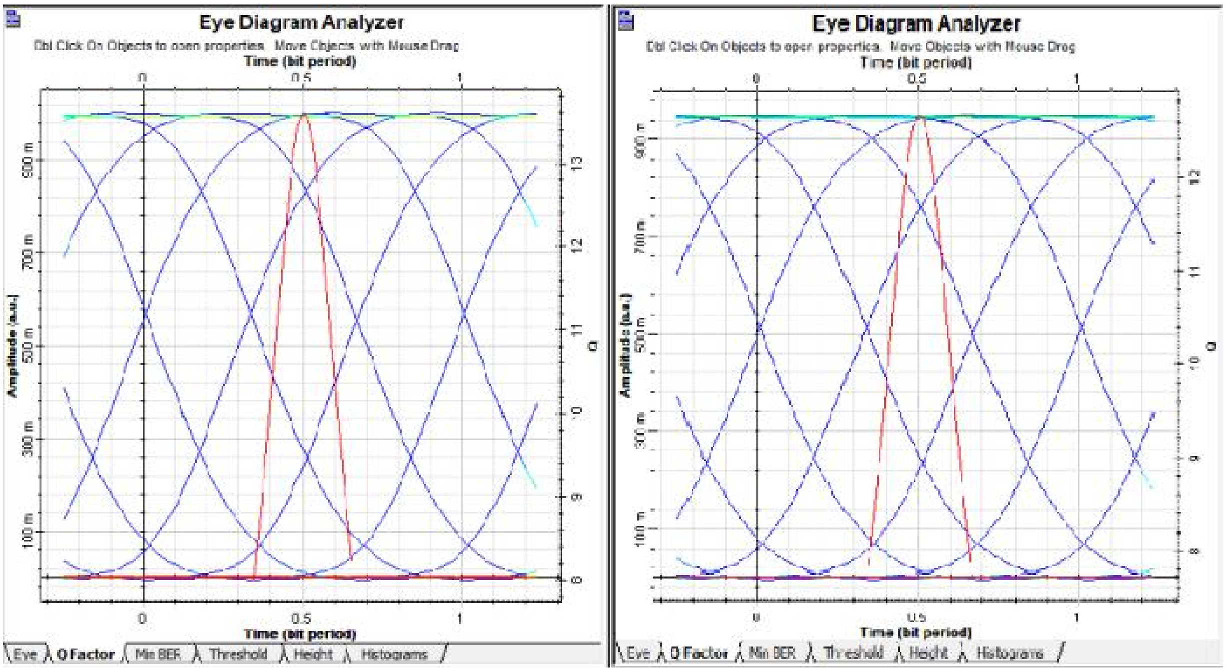


Figure III.16: Variation of Quality Factor and BER versus Length of the Fiber for GOF.

As we can see by increasing the distance of the fiber the quality factor decreases and the BER increases, but we still have a good quality of transmission.



(a) (b)

Figure III.17: Eye Diagram; (a):10 m (b):90 m.

Figure III.17 presents the eye diagram for fiber length of 10 m and 90 m respectively. Quality of transmission is good for both lengths.

III.5.2.2 Effect of Varying Power of Emission

We vary the transmission power from 5 dBm to 10 dBm with fixing the length of the fiber to 50 m, setting the bit rate to 1.5 Gbit / s, and the attenuation at 2.1 dB / km at a wavelength of 850 nm. We note each time the BER and the quality factor.

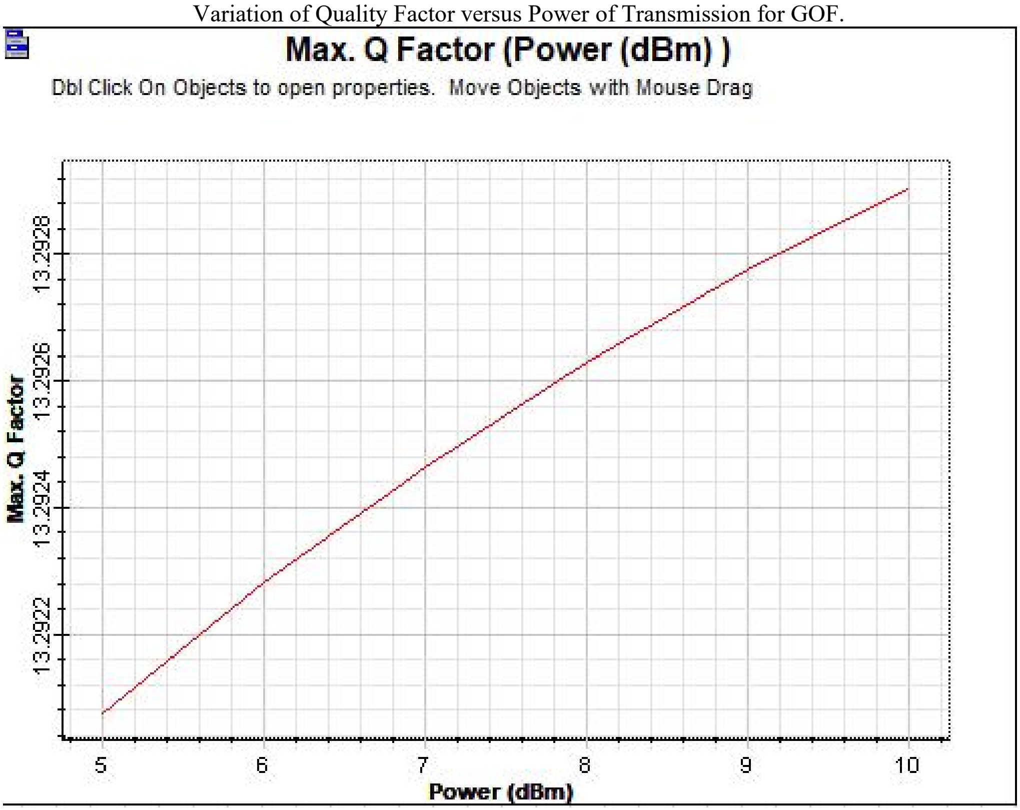
TableIII.7 below illustrates the simulation results for different transmission power:

Table III.7: Effect of Transmission Power on Quality Factor and BER for GOF.

Transmission power in dBm	**5**	**6**	**7**	**8**	**9**	**10**
Quality factor	13.2921	13.2923	13.2925	13.2926	13.2928	13.2929
BER	1.28455 e-40	1.281 e-40	1.27785 e-40	1.27505 e-40	1.27256 e-40	1.27035 e-40

Figure III.18 displays the variation of the quality factor and the BER versus the power of transmission for the GOF.

Variation of Quality Factor versus Power of Transmission for GOF.



Variation of BER versus Power of Transmission for GOF.

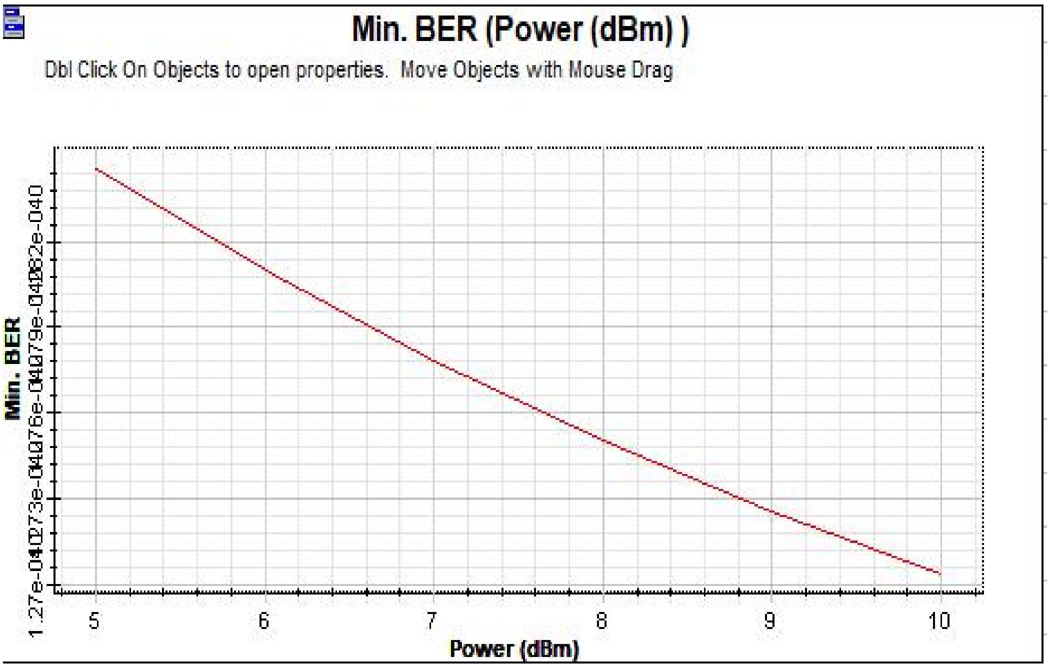
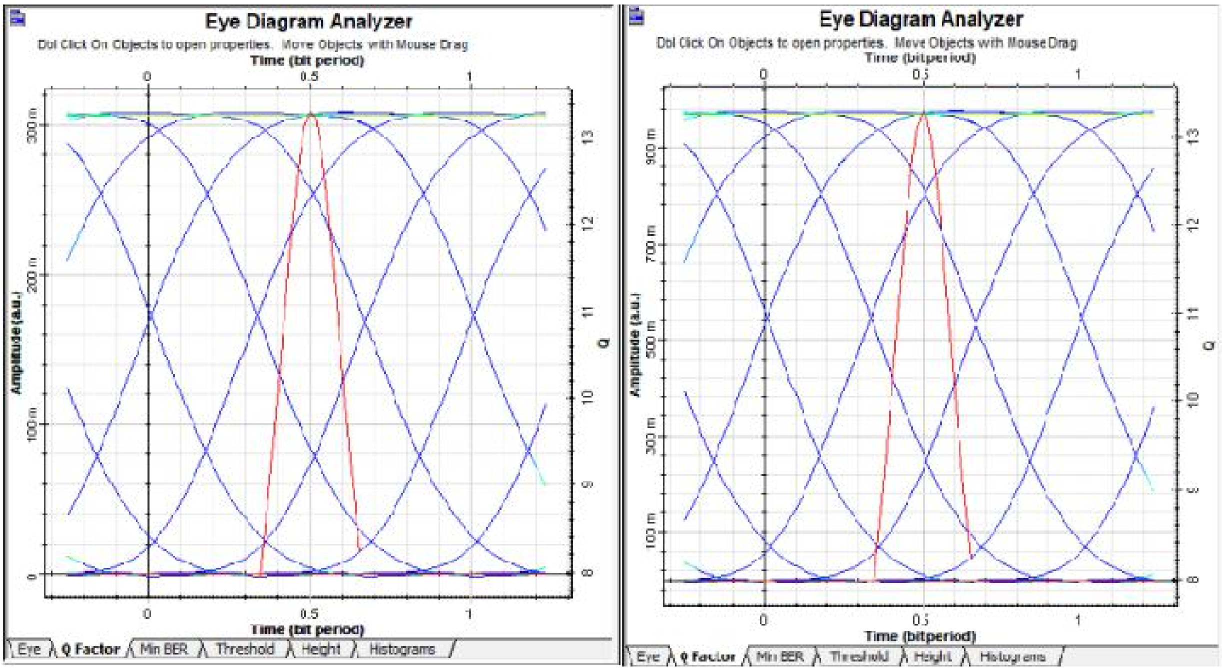


Figure III.18: Variation of Q-Factor and BER versus Power of Transmission for GOF.

From the above graphs, by increasing the power of transmission the quality factor increases a little bit and is good for all values.

Figure III.19 represents the eye diagram for power of transmission 5 dBm and 10dBm respectively.



(a) **(b)**

Figure III.19: The Eye Diagram; (a): 5dBm (b):10dBm.

Both eye diagrams are good which means we have a good quality of transmission.

III.5.2.3 Effect of Varying the Bit Rate:

We will vary the bit rate from 1.5 Gbit / s up to 6.5 Gbit / s by fixing the wavelength at 850 nm, the optical fiber length at 50 m, the transmission power at 10dBm and the attenuation at 2.1 dB / km.

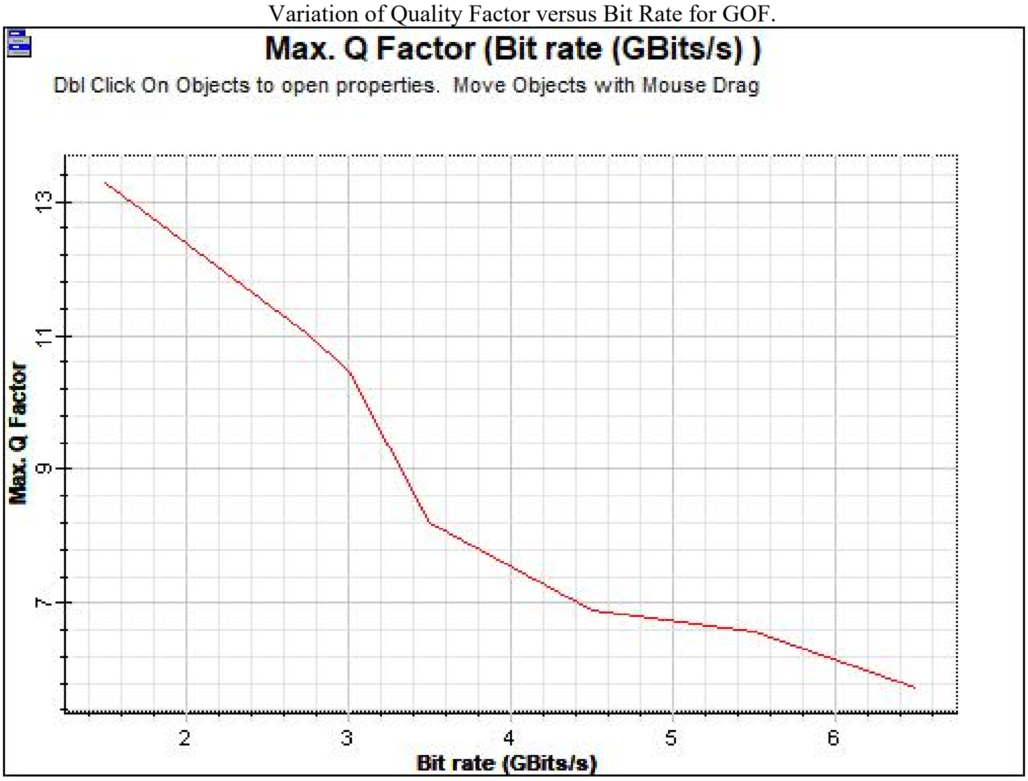
The results are collated in the table III.8 below:

Table III.9: Effect of Bit Rate on Quality Factor and BER for GOF.

Bit Rate (Gbit/s)	**1.5**	**2.75**	**3**	**3.5**	**4.5**	**5.5**	**6.5**
Quality factor Q	13.2929	11.0085	10.4783	8.19515	6.9009	6.58455	5.71931
BER	1.27035 e-40	1.31402 e-28	5.43218 e-26	6.2541 e-17	2.44243 e-12	2.25527 e-11	5.06752 e-9

Figure III.20 exposes the variation of the quality factor and the BER versus the bit rate.

Variation of Quality Factor versus Bit Rate for GOF.



Variation of BER versus Bit Rate for GOF.

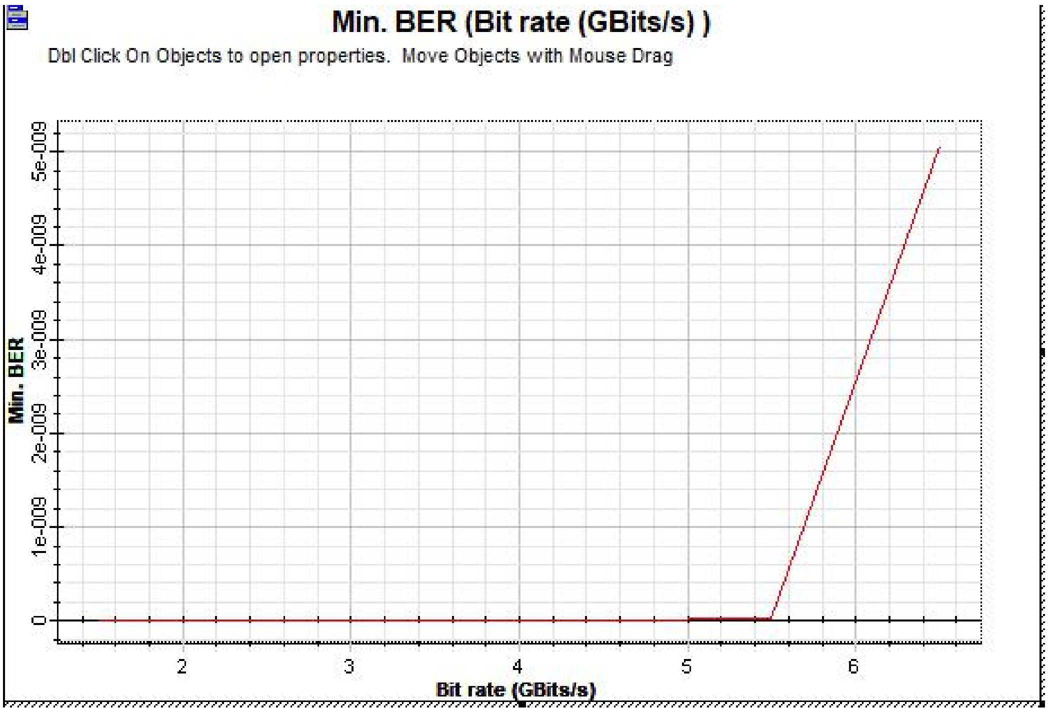
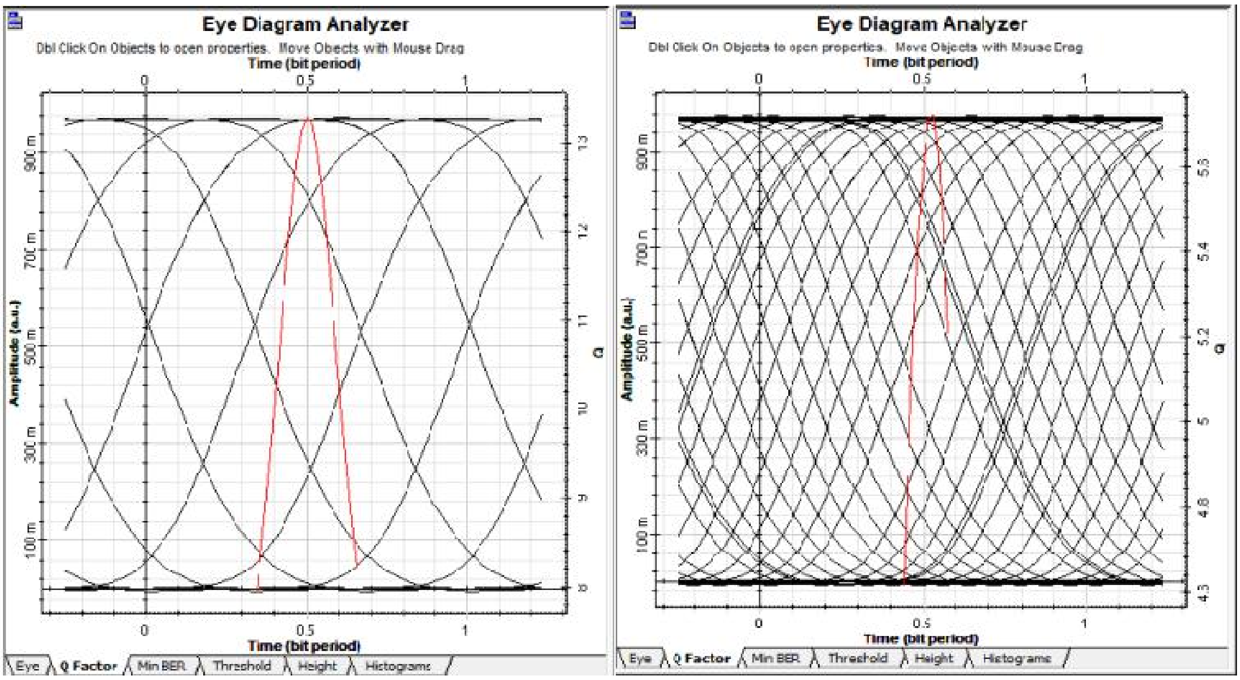


Figure III.20: Variation of Q-Factor and BER versus Bit Rate for GOF.

The above figure illustrates that changing the bit rate has a big effect on the quality factor, since the graph is decreasing from 13.29 at 1.5 GBit / s to 5.71 at 6.5 Gbit / s.

Figure III.21 represents the eye diagram for the bit rate of 1.5 Gbit /s and 6.5 Gbit / s respectively.



(a) **(b)**

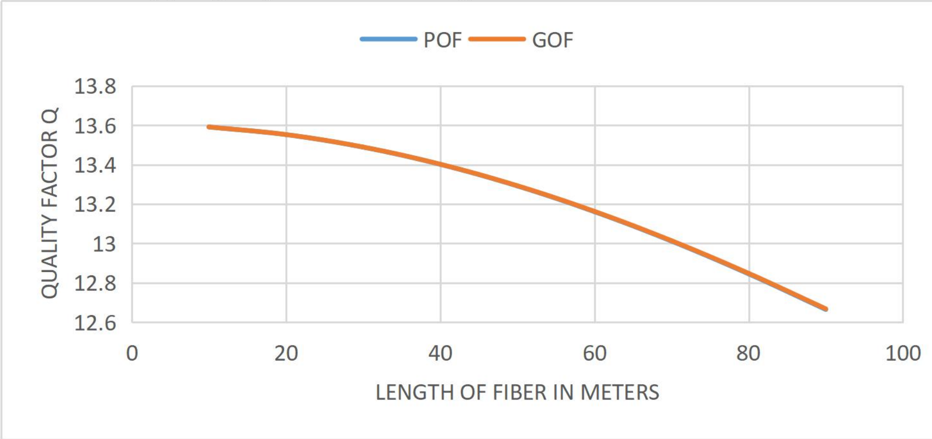
Figure III.21: The Eye Diagram; (a): 1.5Gb/s (b):6.5Gb/s.

III.6. Comparison between Results of the POF and the GOF

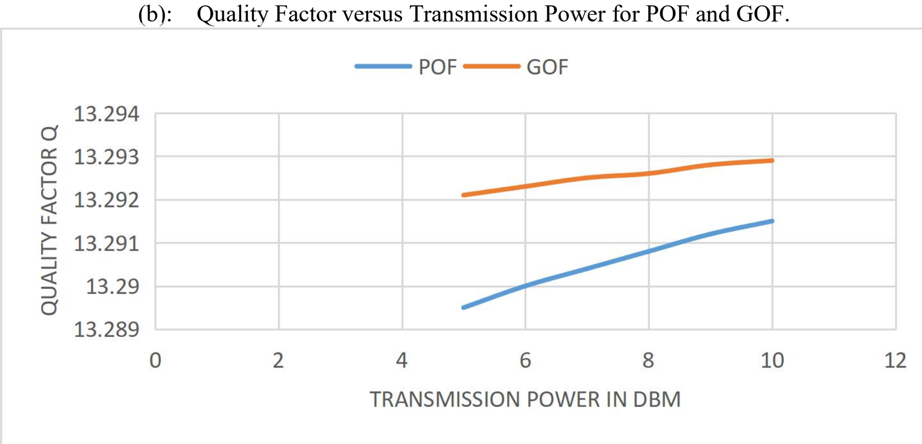
In this part, we will compare the results obtained from the previous sections of the Polymer Optical Fiber and the Glass Optical Fiber.

The figure III.22 represents the quality factor versus: the length of the fiber, the power of transmission and the bit rate; for both POF and GOF respectively.

(a): Quality Factor versus Length of the Fiber for POF and GOF.



(b): Quality Factor versus Transmission Power for POF and GOF.



(c): Quality Factor versus Bit Rate for POF and GOF.

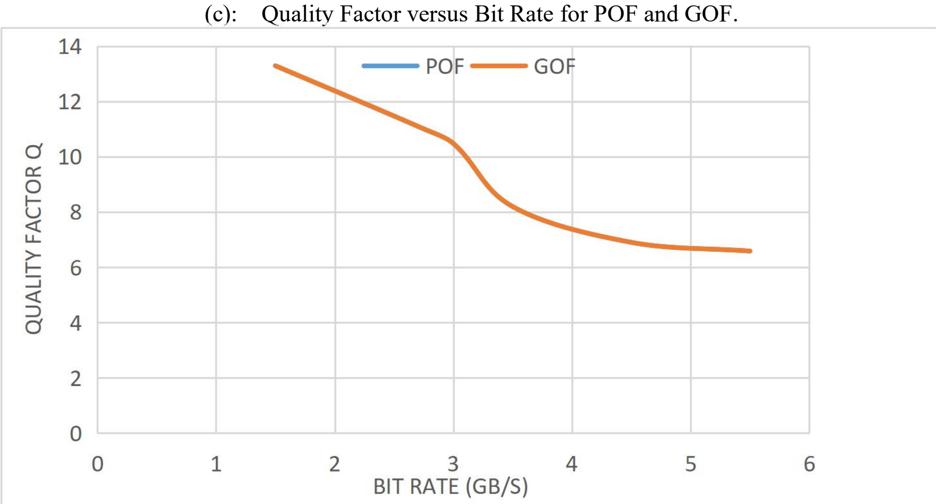
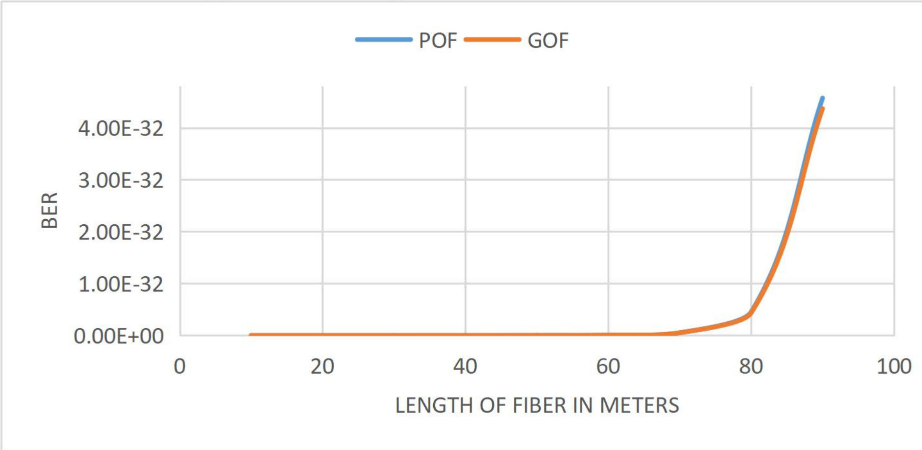


Figure III.22: The Quality Factor for POF and GOF versus
(a):Length of the fiber
(b): Power of Transmission
(c): Bit Rate.

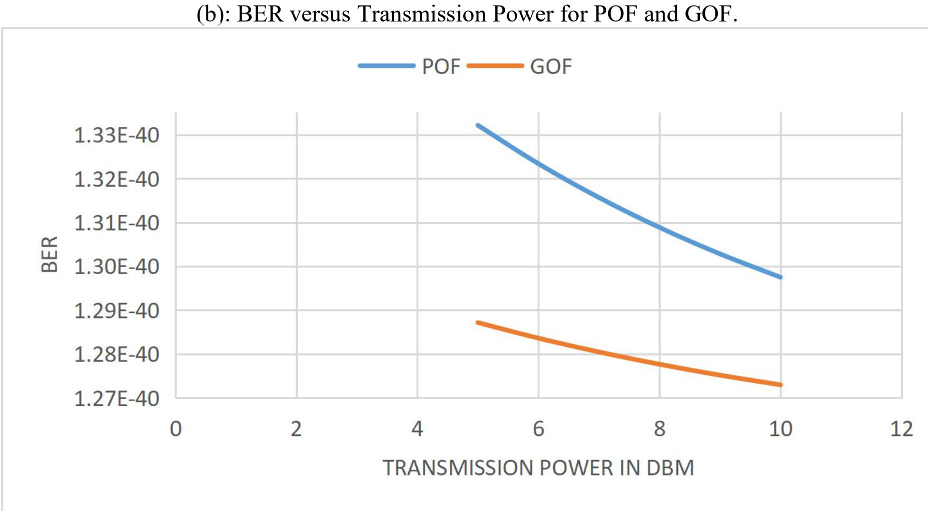
From the above graphs, we can notice that there is no difference between the polymer fiber and the glass fiber, the obtained results are approximately the same for quality factor. The quality factor is a little bit better for the glass fiber, but also the POF has good results and there is no big difference between them.

The figure III.23 displays the BER versus: the length of the fiber, the power of transmission and the bit rate for both POF and GOF respectively.

(a):BER versus Length of the Fiber for POF and GOF.



(b): BER versus Transmission Power for POF and GOF.



(c): BER versus Bit Rate for POF and GOF.

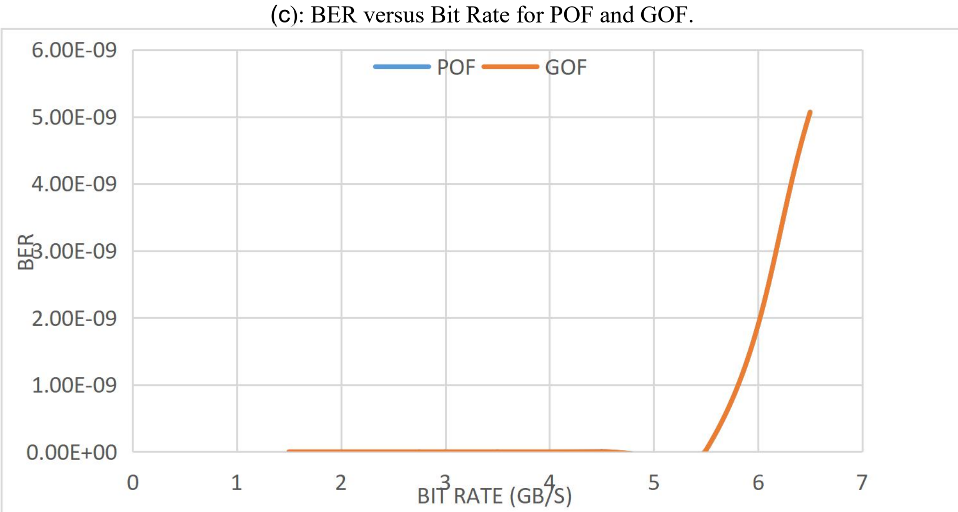


Figure III.23: The BER for POF and GOF versus
(a):Length of the fiber.
(b): Power of Transmission.
(c): Bit Rate.

Discussion:

In the practical domain, there are many factors that affect the optical transmission like the quality of the fiber, the length of the fiber, the operating bit rate, the power of the transmission and other sources of dispersion.

These results can be explained by the fact that different degradation occurs mainly due to:

Modal dispersion, since we used a multimode fiber the rays travel along multiple paths and have multiple path lengths. Since the rays do not travel the same distance, different rays will arrive at the end of the fiber at different times.

Chromatic dispersion, even if all the rays in a pulse travel the same path length, rays with different wavelengths arrive at the output of the fiber at different times.

In a FTTH network it is preferable to use a Polymer fiber since the quality of transmission stills good as the one of glass fiber.

The simulation predicts that in short distances polymer fiber is better because of its advantages over the glass fiber since it is a low-cost, flexible, solid and easy to deploy.

But for long distances, the glass fiber is better, because the signal attenuation and dispersion of POF are typically very high and POF cannot withstand the extreme temperature as glass optical fiber does.

On the other hand, OptiSystem is a powerful software design tool that enables simulation of optical link with advanced and highly parameterized optical fiber models.

III.7. Conclusion

This last chapter was devoted to study the transmission via POF and GOF in short distances as Fiber To The Home application.

In order to study their performances, we have analyzed the influence of some parameters such as the length of the fiber, the transmission power and the bit rate. The analyses were performed using the Bit Error Rate and the Quality Factor.

Finally, the comparison between the two types of fiber was covered.

Conclusion

Conclusion

High bandwidth networking has become an important trend in telecommunication systems. As a transmission medium widely used for telecommunication and computer networking, optical fiber has the unique advantage of high-speed data transmission over long distances. For FTTH networks, plastic fibers are one of the solutions to achieve a high bandwidth transmission.

The first part of this work was devoted to the study of the optical telecommunication system as well as to the description of FTTx fiber networks; in particular PON passive Optical network, their advantages and disadvantages, and the various standards with their characteristics and comparing them.

The second part was dedicated to the study of Plastic Optical Fibers POF by specifying the types of plastic fibers, their characteristics and their applications. A comparison between the glass fiber and the polymer fiber was presented.

In the last part; two studies in terms of transmission quality of multimode fiber link were implemented. One approaching the characteristics of POF in an FTTH system and the other one using a multimode glass fiber in FTTH networks. The simulation was performed using OptiSystem software. A comparison between them was undertaken.

Obtained results are very encouraging. POF remains a very good solution for local networks because of the high speed, the transmission quality and low cost of this transmission medium.

Future Work

Future engineering students in the field of communication should consider the degradation of transmission rate caused by the increase in modal dispersion arising from the increase in core diameter and investigate solutions by improving the transmission method.

Appendix

Eye Diagram Interpretation

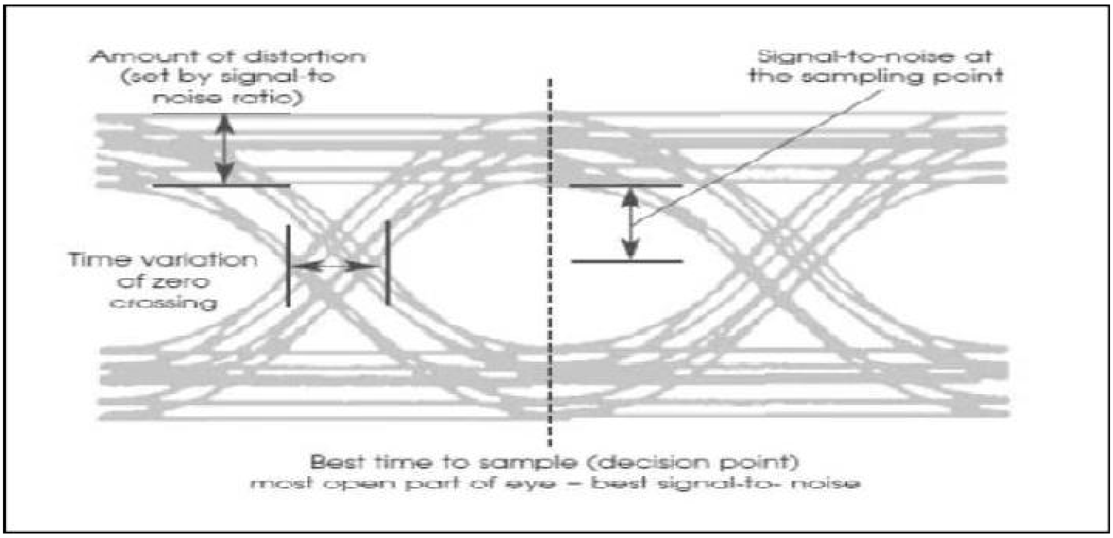


Fig: Sample of an Eye Diagram.

The eye diagram is a useful tool for the qualitative analysis of signals used in digital transmission. It provides at-a-glance, an evaluation of system performance and can offer insight into the nature of channel imperfection. The eye diagram is an oscilloscope display of a digital signal, repetitively sampled to get a good representation of its behavior. The eye diagram can also be used to examine signal integrity in a pure digital system, such as fiber optic transmission, network cables or on a circuit board.

The eye diagram is created by taking the time domain signal and overlapping the traces for a certain number of symbols. If we are sampling a signal at a rate of 10 samples per second and we want to take a look at two symbols, then we would cut the signal every 20 samples and overlap these. The overlapped signals show us a lot useful information and this is called the eye diagram.

The open part of the signal represents the time that we can safely sample the signal with fidelity. That said, it is then obvious that we want an open looking eye and the larger the opening (the white space in the middle), the better.

The horizontal band represents the amount of signal variation at the time it is sampled. This variation is seen in the scatter diagram and is directly related to the SNR of the signal. A small band means a large SNR.

The slope of the eye determines how sensitive the signal is to timing errors. A small slope allows eye to be opened more and hence less sensitivity to timing errors.

The width of the crossover represents the amount of jitter present in the signal. Small is obviously better.

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