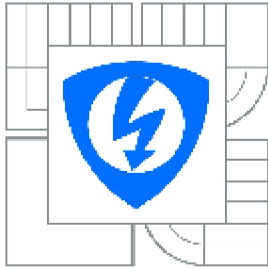




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BRNO UNIVERSITY OF TECHNOLOGY



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TECHNOLOGIÍ
ÚSTAV TELEKOMUNIKACÍ**

**FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
DEPARTMENT OF TELECOMMUNICATIONS**

THE DESIGN OF FTTH NETWORK

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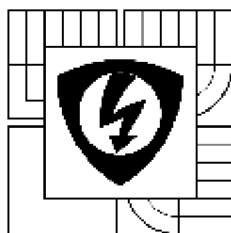
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In Brno, June 10th, 2014

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Deals with the design of FTTH Network

Draft to the connection resident housing units of 30 houses, boarding house (10 rooms) and two shops, 20 km distant from exchange. With comparing the possibilities of two options- passive and active optical network- PON system – WDM- Wave multiplex. Suggest the possibility of measuring and monitoring the created network.

Keywords: connections fiber optics-distribution-PON system-WDM-FTTH, measurements

Abstract

The aim of this thesis is to explain the problems of optical access networks with wavelength division multiplexers, main purpose is to demonstrate the difference between theoretical and real measurement. The work is divided into several thematic areas.

The introduction outlines the basic of telecommunications, fiber optics lasers, single mode, multimode, lasers fibers cables & cores, splitters division multiplexing system, there are known solutions discussed fundamental wavelength multiplexes and their possible combinations. The following chapter deals with the active elements such as AON, PON, which are essential part xWDM systems such as optical lasers, detectors and amplifiers. Another chapter focuses on passive elements, which form a key part of the wavelength multiplex. Methods of measurement of WDM/PON networks are discussed in the following part. The next section describes the topology used active and passive optical networks. The penultimate part of the work consists of architecture & technology of xWDM such as GPON and WDM-PON networks and comparing their transmission parameters. The final part of the paper presents the results of practical experimental measurements of optical access networks with wavelengths division multiplex while these results are compared with the theoretical output & methods of Optical lost test, OTDR & LSPM, with advantage & disadvantage of every methods. The second part of practical is the draft to the connection resident housing units of 30 houses, boarding-house (10 rooms) and 2 shops, 20 km distant from exchange. With comparing the possibilities of two options- passive and active optical network- PON system – WDM- Wave multiplex. Suggest the possibility of measuring and monitoring the created network.

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List of Symbols and Abbreviations

ALTOS	(Loose tube cables like Corning Cable Systems)
ANSI	(American National Standard Institute)
AON	(Active Optical Network)
APD	(Avalanche - Photodiode)
APC	(Angle Polish Connector)
APON	(ATM Passive Optical Network)
ARPU	(Average Revenues per User)
ATM	(Asynchronous Transfer Mode)
AWG	(Arrayed Waveguide Grating)
BER	(Bit Error Rate)
BPON	(Broadband PON)
BSI	(British Standard Institute)
BW	(Band Width)
CATV	(Cable Analog Television)
CD	(Chromatic Dispersion)
CIR	(Committed Information Rate)
CO	(Central Office)
CWDM	(Coarse Wavelength Division Multiplex)
DFB	(Disturbed FeedBack) - DFB laser
DHCP	(Dynamic Host Configuration Protocol)
DIN	(Germany Institute Norm)
DSL	(Digital Subscriber Line)
DWA	(Dynamic Wavelength Assignment)
DWDM	(Dense Wavelength Division Multiplex)
EDFA	(Erbium Doped Fiber Amplifier)
EIR	(Excess Information Rate)
EMI	(electro- magnetic interference)
EPON	(Ethernet PON)
FBG	(Fibre Bragg Grating)
FSR	(Free Spectral Range)
FBT	(Fused Bionic Taper)
FDDI	(Fiber Distributed Data Interface)
FTTB	(Fibre To The Building)

FTTC	(Fiber To The Crub)
FTTCab	(Fiber To The Cabinet)
FTTH	(Fiber To The Home)
FTTN	(Fiber To The Node)
FTTO	(Fiber To The Office)
GEM	(GPON Encapsulation Method)
GEPON	(Gigabit Ethernet Capable PON)
GPON	(Gigabit Capable PON)
HDTV	(High - definition television)
IEC	(International Electrotechnical Commission)
IEEE	(Institute of Electrical and Electronics Engineers)
IOR	(Index of refraction)
IPTV	(TV over Internet Protocol)
ISI	(Inter Symbol Interference)
ITU	(International Telecommunication Union)
LD	(Laser Diode)
LEDs	(light emitting diodes)
MLM	(Multi Longitudinal Mode)
MWM	(Multi Wavelength Analyser)
NENP	(No epoxy, no polish)
OAN	(Optical Access Network)
OD	(Optical Delay)
ODN	(Optical Distribution Network)
OEO	(optical-to-electrical-to-optical conversion)
OLT	(Optical Line Terminal)
OLTS	(Optical Loss Test Set)
ONU	(Optical Network Unit)
ONT	(Optical Network Terminal)
ORL	(Optical Return Loss)
ORR	(Optical Rejection Ratio)
OSA	(Optical Spectrum Analyser)
OSNR	(Optical Signal to Noise Ratio)
OTDR	(Optical Time Domain Reflect meter)
OTDV	(Optical Time Domain Visualizer)
P2MP	(Poin - To - Multipoint)
P2P	(Point – To - Point)
PDG	(Polarisation Dependent Gain)
PDL	(Polarisation Dependent Loss)

PHASARs	(Phased Arrays)
PLC	(Planar Lightwave Circuit)
PM	(Power Meter)
PMD	(Polarization Mode Dispersion)
PON	(Passive Optical Network)
QoS	(Quality of Service)
RBW	(Resolution Bandwidth)
RFI	(Radio Frequency Interference)
ROADM	(Reconfigurable Optical Add-Drop Multiplexer)
SDTV	(Standard Definition TV)
SFP	(Small Form-factor Pluggable)
SML	(Single Longitudinal Mode)
SNMP	(Simple Network Management Protocol)
SOS	(Silica On Silicon)
STP	(Spanning Tree Protocol)
TDMA	(Time Division Multiple Access)
TDL	(Tunable Diode Laser)
VLAN	(Virtual LAN)
VLSI	(Very Large Scale Integration)
VoD	(Video on Demand)
VoIP	(Voice over Internet Protocol)
FP	(Fabry- Perot)
UV	(Ultraviolet)
WDM	(Wavelength Division Multiplex)
WGRs	(Waveguide Grating Routers)
WWDM	(Wide Wavelength Division Multiplex)

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1 Introduction

Telecommunications as history has been defined as a technology concerned with communicating from a distance, and we can categorize it in various ways. Figure (1.1) shows one possible view of the different section of telecommunications [5]. It includes mechanical communication, electrical communication and optoelectronics, because telecommunications has evolved from a mechanical to an electrical form using increasingly more sophisticated electrical systems.

My main concern & goal in this Diploma work about “Fiber To The Home” which known as FTTH is Fiber Optic cable being installed from the telephone exchange to the Home and is used to deliver communications such as broadband, digital TV/Media and telephone.

Growing the demand for high speed internet is the primary driver for the new access technologies which enable experiencing true broadband. Today, there is an increasing demand for high bandwidth services in market around the world. However, traditional technologies, like Digital Subscriber Line (DSL) and cable modem technologies, commonly used for ‘broadband access, which have access speed to the order of a megabit & gigabit per second, with actual rates strongly dependent on distance from the exchange (central office) and quality of the copper infrastructure, cannot fulfil today’s customer demand for bandwidth hungry applications such as high-definition TV, 3-D TV, high-speed internet access, video on demand, IPTV, online gaming, distance learning... etc.

Amongst various technologies, the access methods based on the optical fiber has been given extra emphasis keeping into long term perspective of the country. It has many advantages over other competing access technologies of which ‘Being Future Proof’ and providing ‘True Converged Network’ for high quality multi-play are the salient ones. The stable and long term growth of Broadband is, therefore, going to be dependent on robust growth of fiber in the last mile. FTTH is a true multi service communications access which simultaneously handles several phone calls, TV/Video streams and Internet users in the home/office.

2 Telecommunications in fibers optic

2.1 Standardization authorities

National standardization authorities approve official national standards. Many international standards include alternatives and options from which a national authority selects those suitable for their own national standards. These options are included in cases for which a common global understanding could not be agreed on. Sometimes some aspects are left open and they require a national standard. For example, national authorities determine the details of their national telephone numbering plan, for which international standards give only guidelines. Another example is frequency allocation. International standards define usage of frequency bands, whereas the national authority defines detailed usage of frequencies inside the country. Some examples of national authorities are shown in the (Figure 2.1). They take care of all areas of standardization, and they set up specialized organizations or working groups to work with the standardization of each specific technical area, such as telecommunications and information technology. These example organizations are shown in (Figure 2.1): the British Standards Institute (BSI; United Kingdom), (DIN; Germany), American National Standards Institute (ANSI; United States) & The Institute of Electrical and Electronics Engineers (IEEE), ITU-T standardization union [5].

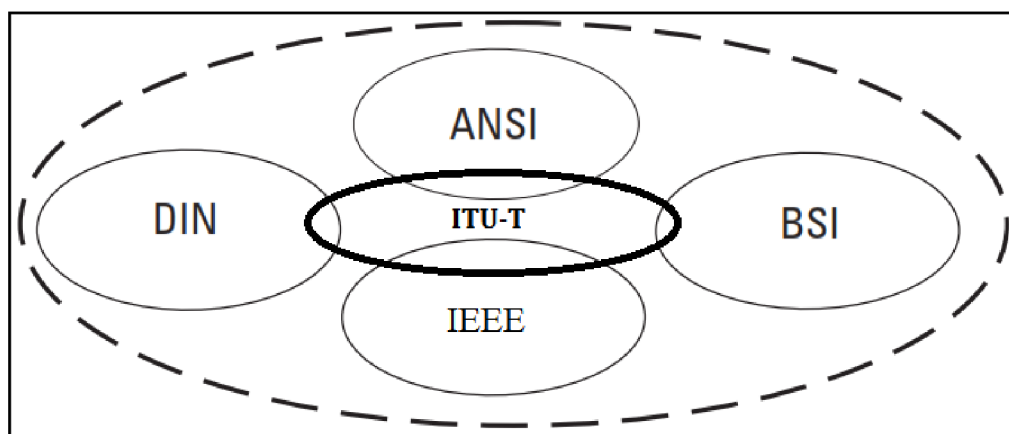


Fig. (2.1) some examples of national standardization authorities [2], [5].

2.2 Principles of transmission in optical fibers

Transmission of information and telecommunications through optical fiber is made possible by light ray. The peculiarities of information transmission by light result from differences between electrical and optical light signals [2]. In simplest terms, fiber optics is technology of using ‘waveguides, to transport information from one point to another in the form of light. Unlike the copper form of transmission, fiber optics is not electrical in nature. A basic fiber optic system consists of a transmitting device, which generates the light signal; an optical fiber cable, which carries the light; and a receiver, which accepts the light signal transmitted. The fiber itself is passive and does not contain any active, generative properties [6].

As depicted in Figure (2.2), information (voice, data, or video) is encoded into electrical signals. At the light source, these electrical signals are converted into light signals. It is important to note that fiber has the capability to carry either analogue or digital signals. Many people believe that fiber can transmit only digital signals due to the on/off binary characteristic of the light source. The intensity of the light and the frequency at which the intensity changes can be used for (AM and FM) analogue transmission.

Once the signals are converted to light, they travel down the fiber until they reach a detector, which changes the light signals back into electrical signals. (This is called OEO, or optical-to-electrical-to-optical conversion.). The area from light source to detector constitutes the passive transmission subsystem; i.e. that part of the system manufactured and sold by Corning Cable Systems. Finally, the electrical signals are decoded into information in the form of voice, data or video [6].

Inside of each of the electronics (switches, routers, etc.) resides a receiver/photo detector to accept the incoming information and a transmitter to send the information back out on the network. Typical switches in a local area network use an OEO conversion. The data comes into the switch as an optical signal, is converted into an electrical signal and switched/routed as needed. The signal is then converted back to an optical signal and sent out the port. OEO is not protocol transparent like a true optical switch, but does allow for the 3Rs (re-amplification, re-shape and re-time) of digital signals.

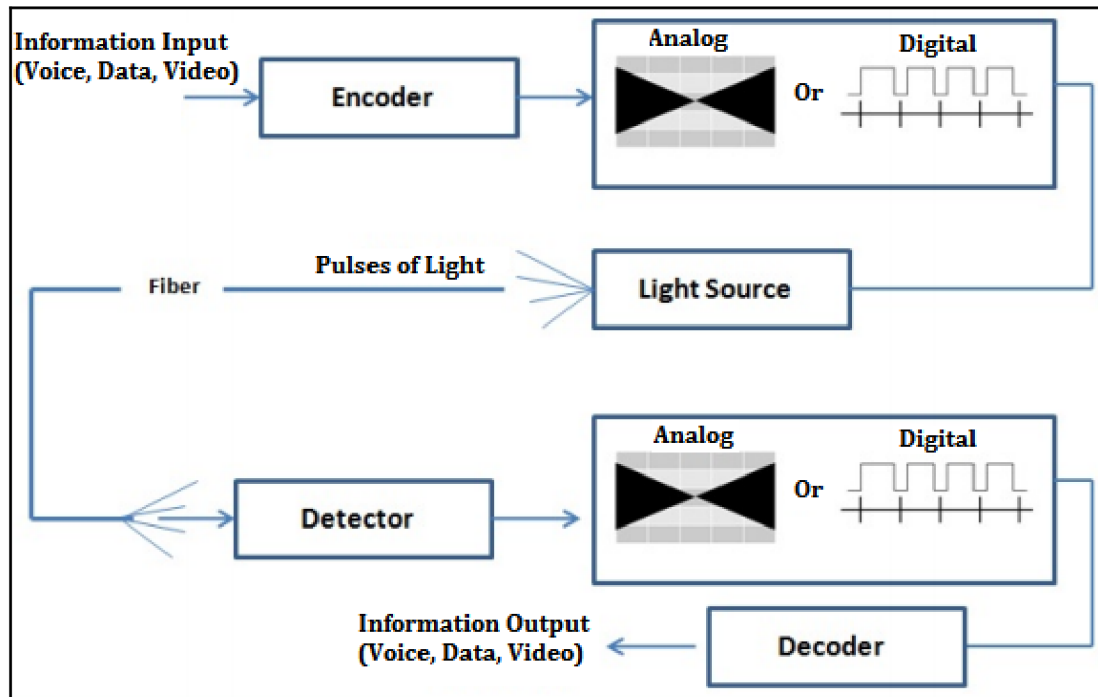


Fig. (2.2) Information Transmission Sequence [9].

2.2.1 Advantage of fiber optics

Optical fiber systems have many advantages over metallic based communication systems. These advantages include [1], [2], and [6].

a) Large bandwidth, light weight and small diameter

The amount of information carried in two strands of optical fiber would require a copper cable four inches in diameter. While today's applications require an ever-increasing amount of bandwidth, it is important to consider the space constraints of many end-users. The relatively small diameter and light weight of optical cables make such installations in existing duct systems easy and practical, and saves valuable conduit space in these environments [2],[6].

b) Easy installation and upgrades

Optical fiber cables can be installed with the same equipment that is used to install copper and coaxial cables, with some modifications due to the small size and limited pull tension and bend radius of optical cables. System designers typically plan optical systems

that will meet growth needs for a 15- to 20-year span. Although sometimes difficult to predict, growth can be accommodated by installing spare fibers for future requirements. Installation of spare fibers today is more economical than installing additional cables later [2], [6].

c) Designed for future applications needs

Fiber optics is affordable today, as the price of electronics fall and optical cable pricing remains low. In many cases, fiber solutions are less costly than copper. As bandwidth demands increase rapidly with technological advances, fiber will continue to play a vital role in the long-term success of telecommunications [2], [6].

d) Long distance signal transmission

The low signal loss and superior signal integrity found in optical systems allow much longer intervals of signal transmission without active or passive processing than metallic-based systems [2],[6].

e) Security

Unlike metallic-based systems, the dielectric (non-conducting) nature of optical fiber makes it impossible to remotely detect the signal being transmitted within the cable. The only way to do so is by actually accessing the optical fiber itself. Accessing the fiber requires intervention that is easily detectable by security surveillance. These circumstances make fiber extremely attractive for security applications [2], [6].

f) Non-conductivity

Optical fibers, because they are dielectric, can be installed in areas with electro- magnetic interference (EMI), including radio frequency interference (RFI). Areas with high EMI include utility lines, power-carrying lines and railroad tracks. All-dielectric cables are also ideal for areas of high-lightning-strike incidence [1], [2], [6].

2.2.2 Optical fiber structure

Optical fiber for telecommunications consists of three components:

- Core
- Cladding
- Coating

The core is the central region of an optical fiber through which light is trans-

mitted. In general, telecommunications uses sizes from 8.3 micrometres (μm) to 62.5 μm . The standard telecommunications core sizes in use today are 8.3 μm (single-mode), 50 μm (multimode) and 62.5 μm (multimode). (Single-mode and multimode will be discussed shortly.) The diameter of the cladding surrounding each of these cores is 125 μm . Core sizes of 85 μm and 100 μm have been used in early applications, but are not typically used today. To put these sizes into perspective, compare them to a human hair, which is approximately 70 μm or 0.003 inch. The core and cladding are manufactured together as a single piece of silica glass with slightly different compositions and cannot be separated from one another. Contrary to myth, this glass does not have a hole in the core, but is completely solid throughout. The third section of an optical fiber is the outer protective coating which has a diameter of 250 μm . This coating is typically an ultraviolet (UV) light-cured acrylate applied during the manufacturing process to provide physical and environmental protection for the fiber. During the installation process, this coating is stripped away from the cladding to allow proper termination to an optical transmission system [1], [2], [6].

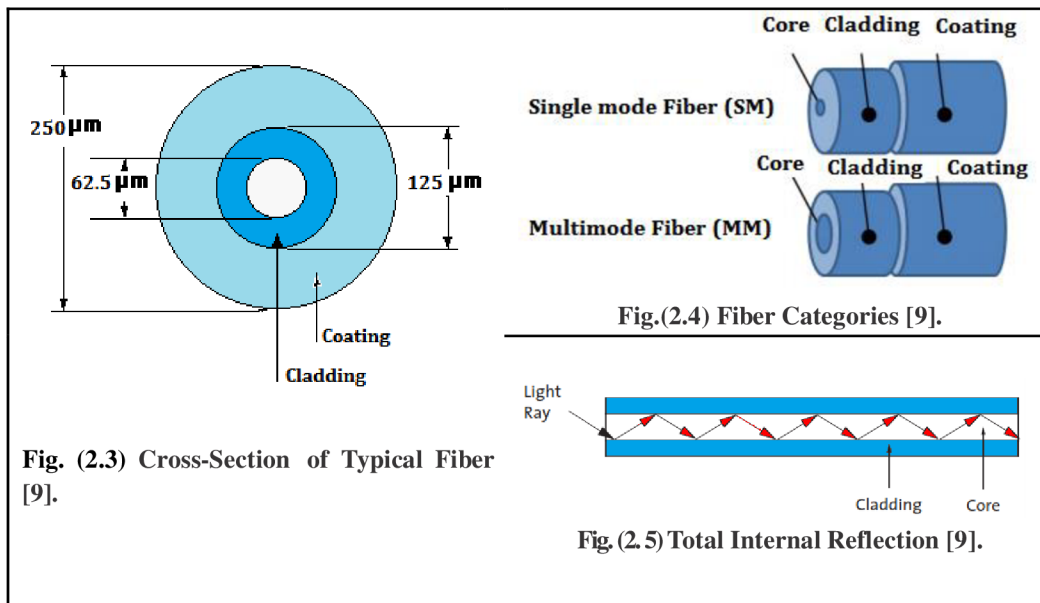
2.2.3 Types of fiber

Once light enters an optical fiber, it travels in a stable state called a mode. There can be from one to hundreds of modes depending on the type of fiber. Each mode carries a portion of the light from the input signal. Generally speaking, the number of modes in a fiber is a function of the relationship between core diameter, numerical aperture and wavelength, which will be discussed later.

Every optical fiber falls into one of two categories:

- a) Single-mode
- b) Multimode

It is impossible to distinguish between single-mode and multi-mode fiber with the naked eye. There is no difference in outward appearances. Only the core size is different. Both fiber types act as a transmission medium for light, but they operate in different ways, have different characteristics and serve different applications [2], [6].



a) Single-mode fiber allows for only one pathway, or mode, of light to travel within the fiber. The core size is $8.3 \mu\text{m}$. Single-mode fibers are used in applications where low-signal-loss and high-data-rates are required, such as on long spans where repeater/amplifier spacing needs to be maximized.

b) Multimode fiber allows more than one mode of light. Common multimode core sizes are $50 \mu\text{m}$ and $62.5 \mu\text{m}$. Of the two, $50 \mu\text{m}$ fibers, particularly $50 \mu\text{m}$ fibers optimized for laser transmission offers the highest bandwidth. Multimode fiber is better suited for shorter distance applications. Where costly electronics are heavily concentrated, the primary cost of the system does not lie with the cable. In such a case, multimode fiber is more economical because it can be used with low-cost transmitters for high bandwidth [1], [2], [6].

2.2.4 Inside an optical Fiber

Index of refraction (IOR)

The index of refraction (IOR) is a way of measuring the speed of light in a material. The index of refraction is calculated by dividing the speed of light in a vacuum (the fastest possible speed of light) by the speed of light in some other medium. The larger the index of refraction, the more slowly that light travels in that medium [1], [2], [6].

Total internal reflection

When a light ray traveling in one material hits a different material and reflects back into

the original material without any loss of light, total internal reflection occurs. Since the core and cladding are constructed from different compositions of glass, theoretically, light entering the core is confined to the boundaries of the core because it reflects back whenever it hits the cladding. For total internal reflection to occur, the index of refraction of the core must be higher than that of the cladding. In simpler terms, there is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate, or travel, in the core of the fiber. The sine of this maximum angle is the numerical aperture (NA) of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA. Single-mode fiber has a smaller NA than multimode fiber. [2], [6], [7].

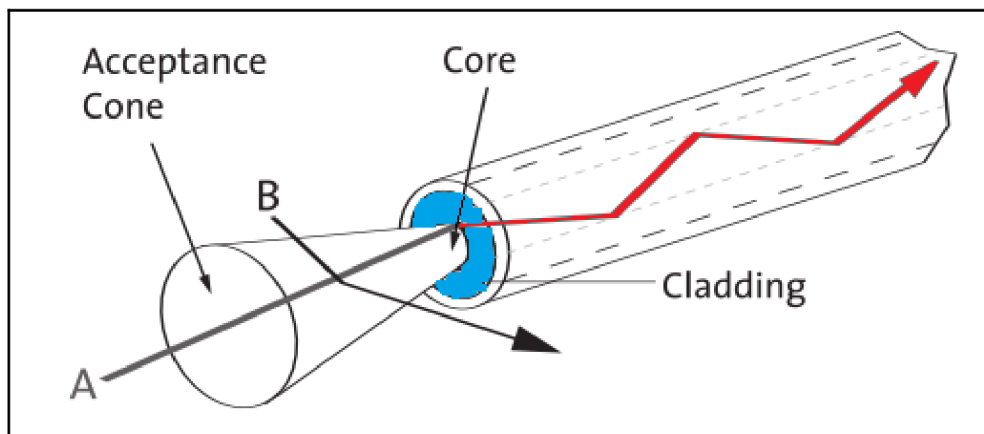


Fig. (2.6) Acceptance Cone Light ray A: entered acceptance cone; transmitted through the core by total internal reflection (TIR). Light ray B: did not enter acceptance cone; signal lost [7].

2.2.5 Optical fiber parameters

As with any type of transmission system, certain parameters affect the system's operation. I will show the optical fiber parameters as following:

a) Wavelengths

Light that can be seen by the unaided human eye is said to be in the visible spectrum. In the visible spectrum, wavelength can be described as the color of light. To put this into perspective, at Fig. (2.7), notice that the colors of the rainbow – red, orange, yellow, green, blue, (indigo, not shown) and violet – fall within the visible spectrum. Optical

fiber transmission uses longer wavelengths which are invisible to the unaided eye. (Longer wavelengths have higher readings; for example, red light has a longer wavelength than blue light.) Typical optical transmission wavelengths are 850 nanometers (nm), 1300 nm and 1550 nm [2], [6]. Both lasers and light emitting diodes (LEDs) are used to transmit light through optical fiber. (More information on lasers and LEDs is available later in the text.). Lasers typically transmit at 850, 1310 and 1550 nm, making them ideal for laser-optimized multimode fibers (850 nm) and single-mode fiber (1310 and 1550 nm). LEDs are used at 850 or 1300 nm, making them useful for standard multimode fiber [2], [6], [7].

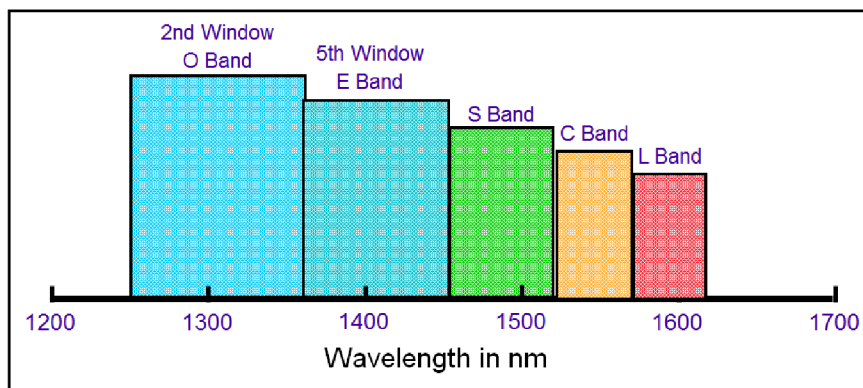


Fig. (2.7) Optical Spectral Bands [7].

b) Window

There are operational ranges of wavelengths at which the fiber best operates. Each range is known as an operating window. Each window is centred on the typical operational wavelength.

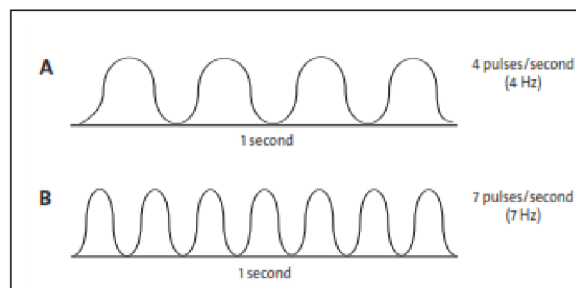
Table (2.1) Operational wavelength, these wavelengths were chosen because they best match the transmission properties of available light sources with the transmission qualities of optical fiber [7].

Window	Operating
800-900	850 nm
1250-1350	1310 nm
1500-1600	1490 and 1550 nm

c) Frequency

The frequency of a system is the speed of modulation of the digital or analogue output of

the light source; in other words, the number of pulses per second emitted from the light source (see Figure 2.8). Frequency is measured in units of hertz (Hz), where 1 Hertz is equal to 1 pulse or cycle per second. A more practical measurement for optical communications is megahertz (MHz) or millions of pulses per second [6], [7].



"B" represents a higher frequency than "A"

Fig. (2.8) Frequency Measurement [7].

d) Increasing frequency

Figure (2.9), shows the relations between the visible spectrum of light & the light, which use in multimode respectively in single mode. In the same figure, also I show the wavelengths which are used as visible spectrum (400 nm up to 800 nm) & the laser wavelengths which are used in fiber optics such as multimode and single mode systems (850-1300-1550 nm).

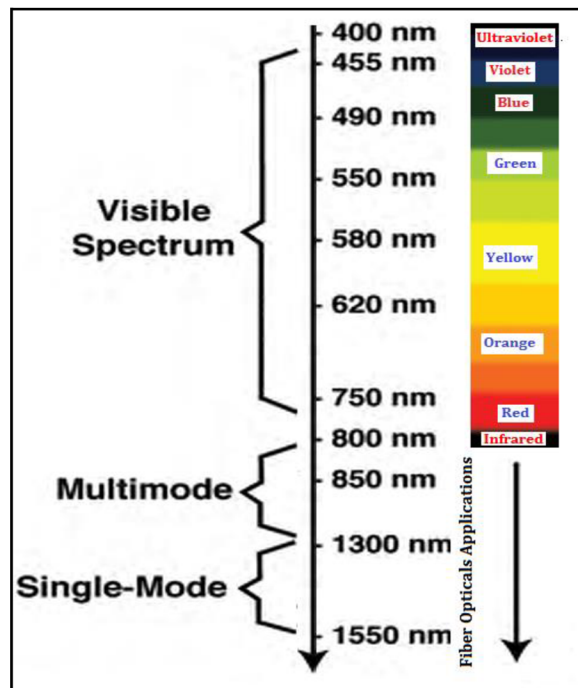


Fig. (2.9) Visible Spectrum of Light [6].

e) Intrinsic attenuation

Attenuation is the loss of optical power as light travels down a fiber. It is measured in decibels (dB). Over a set distance, a fiber with a lower attenuation will allow more power to reach its receiver than a fiber with higher attenuation. Attenuation can be caused by several factors, but is generally placed in one of two categories: intrinsic or extrinsic. Intrinsic attenuation occurs due to something inside or inherent to the fiber. It is caused by impurities in the glass during the manufacturing process. As precise as manufacturing is, there is no way to eliminate all impurities, though technological advances have caused attenuation to decrease dramatically since 1970.

When a light signal hits an impurity in the fiber, one of two things will occur: it will scatter or it will be absorbed [1], [2], and [6].

f) Scattering

Rayleigh scattering accounts for the majority (about 96 per- cent) of attenuation in optical fiber. Light travels in the core and interacts with the atoms in the glass. The light waves elastically collide with the atoms, and light is scattered as a result. Some scattered light is reflected back toward the light source (input end). This is a property that is used in an

optical time domain reflect-meter (OTDR) to test fibers. This same principle applies to analyzing loss associated with localized events in the fiber, such as splices.

g) Absorption

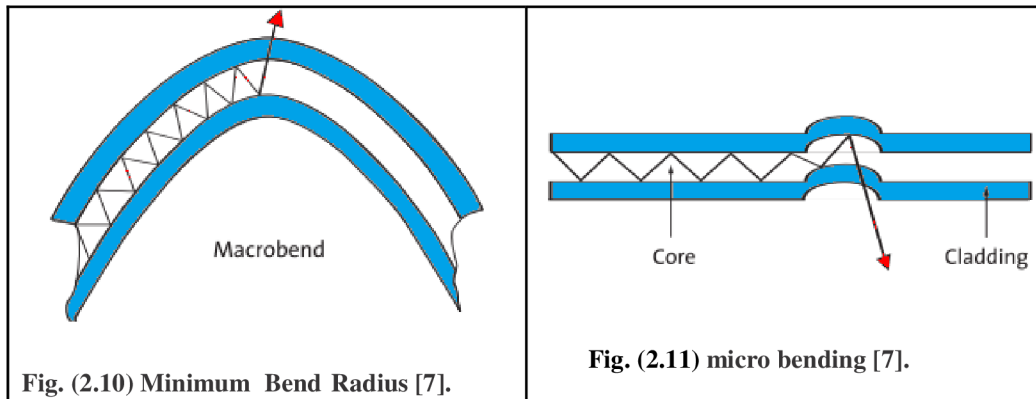
The second type of intrinsic attenuation in fiber is absorption. Absorption accounts for 3-5 percent of fiber attenuation. This phenomenon causes a light signal to be absorbed by natural impurities in the glass. Unlike scattering, absorption can be limited by controlling the amount of impurities during the manufacturing process

h) Extrinsic attenuation

The second category of attenuation is extrinsic attenuation. Extrinsic attenuation can be caused by two external mechanisms: macro-bending or micro-bending. Both cause a reduction of optical power:

- **Macro bending** if a bend is imposed on an optical fiber, strain is placed on the fiber along the region that is bent. The bending strain will affect the refractive index and the critical angle of the light ray in that specific area. As a result, light traveling in the core can refract out, and loss occurs. A macro bend is a large-scale bend that is visible; for example, a fiber wrapped around a person's finger. This loss is generally reversible once bends are corrected. To prevent macro bends, all optical fiber (and optical fiber cable) has a minimum bend radius specification that should not be exceeded. This is a restriction on how much bend a fiber can withstand before experiencing problems in optical performance or mechanical reliability [1], [2], [6].

- **Micro bending** the second extrinsic cause of attenuation is a micro bend. This is a small-scale distortion, generally indicative of pressure on the fiber. Micro bending may be related to temperature, tensile stress, or crushing force. Like macro bending, micro bending will cause a reduction of optical power in the glass. Micro bending is much localized, and the bend may not be clearly visible upon inspection. With bare fiber, micro bending may be reversible; in the cabling process, it may not. Micro bending attenuation affects all optical wavelengths



i) Dispersion

Dispersion is the “spreading” of a light pulse as it travels down a fiber. As the pulses spread, or broaden, they tend to overlap and are no longer distinguishable by the receiver as 0s and 1s. Light pulses launched close together (high data rates) that spread too much (high dispersion) result in errors and loss of information [2], [6].

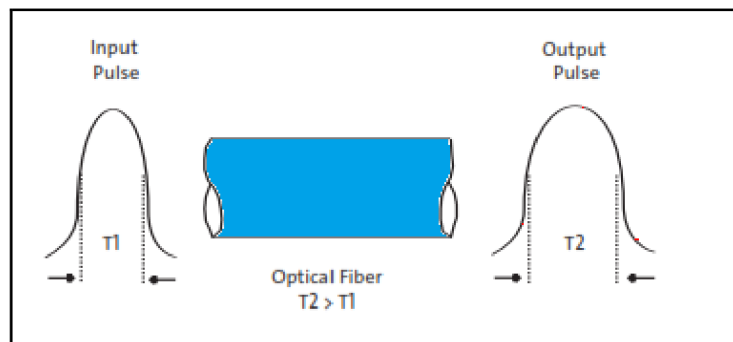


Fig. (2.12) Dispersion [7].

- **Chromatic dispersion** occurs as a result of the range of wavelengths in the light source. Light from lasers and LEDs consists of a range of wavelengths. Each of these wavelengths travels at a slightly different speed. Over distance, the varying wavelength speeds cause the light pulse to spread in time. This is of most importance in single-mode applications. The index of refraction of a material is dependent on the wave-length, so each frequency component actually travels at a slightly different speed. As the distance increases, the pulse becomes broader as a result. Material dispersion is a significant source of dispersion in single-mode fiber only [1], [2], [6], [7].

- **Modal dispersion** affects multimode fibers only and is a result of the modes of

light traveling down the fiber arriving at the receiver at different times, causing a spreading effect. Graded index profiles, only used in multimode fibers, are used to mitigate the effects of modal dispersion.

j) Bandwidth

In simplest terms, bandwidth is the amount of information a fiber can carry so that every pulse is distinguished by the receiver at the end. As discussed in the previous section, dispersion causes light pulses to spread. The spreading of these light pulses causes them to merge together. At a certain distance and frequency, the pulses become unreadable by the receiver. The multiple pathways of a multimode fiber cause this overlap to be much greater than for single-mode fiber. These different paths have different lengths, which cause each mode of light to arrive at a different time. System bandwidth is measured in megahertz (MHz) at one km. In general, when a system's bandwidth is 20 MHz•km, it means that 20 million pulses of light per second will travel down 1 km (1000 m) of fiber, and each pulse will be distinguishable by the receiver [1],[2],[6],[7].

2.2.6 Fiber optic cabling basics

2.2.6.1 Cable environments

In general, fiber optic cable can be categorized by its deployment environment. As outdoor and indoor as these:

- **Outdoor:** Outside plant (OSP) cables must withstand a variety of environmental and mechanical extremes. The cable must offer excellent attenuation performance over a wide range of temperatures, resist water ingress, sustain years of ultraviolet radiation from direct sunlight and tolerate a wide range of mechanical forces.
- **Indoor:** Inside plant cables generally experience a more controlled, stable environment. Therefore, performance requirements are based on other factors. The cables must meet the requirements of the National Electrical Code (NEC) and local building codes based upon their installed location. These cables should also be easy to terminate.
- **Indoor and outdoor:** Corning Cable Systems led the development of flame-retardant indoor/outdoor cables. These cables use specialty materials to meet the flame-retardant requirements of the indoor environment. They also provide

reliable water-blocking and robust construction critical for OSP use [1], [2], [6], [7].

2.2.6.2 Cable ratings

Article 770 of the National Electrical Code (NEC) requires indoor fiber cables to meet different requirements based on where they are placed in the environment requirement: Listed most to least stringent, they are plenum, riser and general purpose areas [1], [2], [6], [7].

- **Plenum area:** A compartment or chamber that forms part of the air distribution system and to which one or more air ducts are connected. Any space with a primary function of air handling is also considered a plenum space. These cables must be listed OFNP or OFCP in accordance with the NEC.
- **Riser:** An opening or shaft through which cable may pass vertically from floor to floor in a building. These cables must be listed OFNR or OFCR in accordance with the NEC.
- **General purpose:** All other indoor areas that are not plenum or risers. These cables must be listed OFN or OFC in accordance with the NEC.

2.2.7 Typical cable types

a) Loose tube cables: Loose tube cables like Corning Cable Systems ALTOS cable are designed primarily for OSP environments and campus backbone applications. One to 12 fibers are placed in individual, water blocked buffer tubes to isolate them from external forces and are typically stranded around a fiberglass central strength member to provide additional strength and resistance. A loose tube cable typically will hold up to 288 fibers in total within these tubes. With more than 25 years of successful operation in the field, the loose tube cable design has been used more extensively than any other in the industry. It provides stable and highly reliable optical transmission characteristics over a wide temperature range. Corning Cable Systems offers stranded loose tube cables for outdoor as well as indoor and indoor/outdoor riser applications.

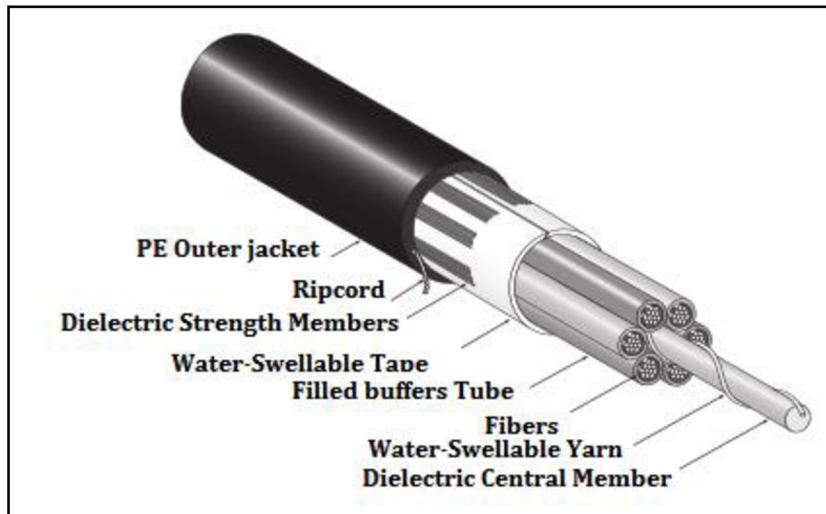


Fig. (2.13) tube cable [7].

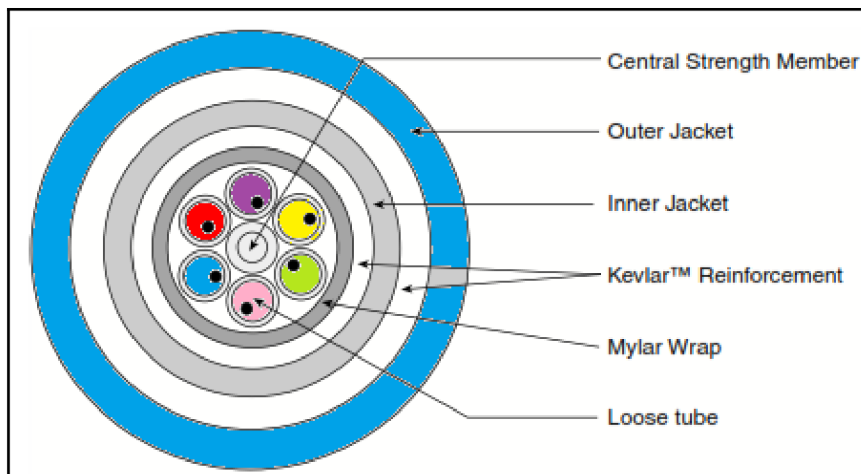


Fig. (2.14) Loose Tube Cable [2], [6], [7].

b) Tight-buffered cables: Tight-buffered cables are designed for use in building and data center backbones, horizontal applications and patch cords and equipment cables. This proven design is the most widely deployed cable type for indoor applications. Tight-buffered cables contain 250 μm optical fibers that are directly coated with a thermoplastic buffer to a diameter of 900 μm . Tight-buffered cables are desirable for intra-building applications because of their ability to meet building fire code requirements as well as their increased physical flexibility, smaller bend radius and easier handling characteristics. These cables, however, are more sensitive to temperature extremes and mechanical disturbances than loose tube or ribbon cables and, with the exception of

Corning Cable Systems FREEDM Fan-Out and FREEDM One Cables, do not have waterblocking materials[2],[6].

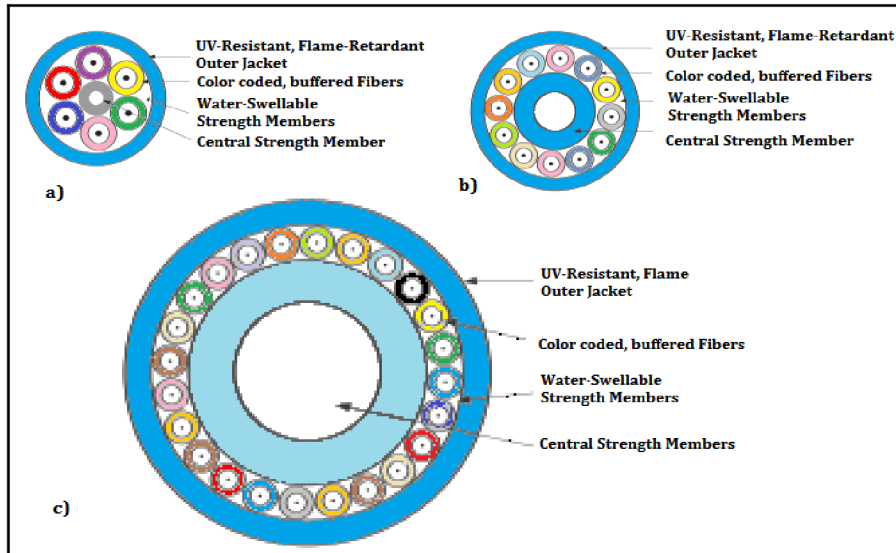


Fig. (2.15) FREEDM One a) 6-, b) 12- and c) 24-Fiber Cable [2], [6], [7].

Corning Cable Systems FREEDM Fan-Out Cables utilize flame-retardant, 900 μm TBII buffered, fiber subunits surrounded by water-resistant, dielectric strength members and protected by a flexible, flame-retardant outer jacket. These OFNR and FT-4 rated cables eliminate the need for a transition splice entering the building and have 2.9 mm subunits to enable easy field termination. These environmentally robust, small diameter cables are ideal for routing inside/outside buildings into riser spaces to security, surveillance or monitoring cameras, and within telecommunications rooms and workstations. FREEDM one Cable offers select attributes of both indoor and OSP cables. Selecting a FREEDM One Cable is often more cost effective than making a splice transition from OSP to indoor cabling. FREEDM One Cable is available with riser and plenum ratings.

Corning Cable Systems MIC cables, available in 2-144 fibers, are constructed by stranding the desired number of color-coded tight-buffered optical fibers around a dielectric central member, applying a layer of strength member yarns and extruding a flame-retardant jacket over the cable core. Corning Cable Systems' unique TBII buffered, fiber buffering method allows for easy, one-pass stripping and a slick jacket on 2-24 fiber tight buffered cables for easier pulling during cable installation.

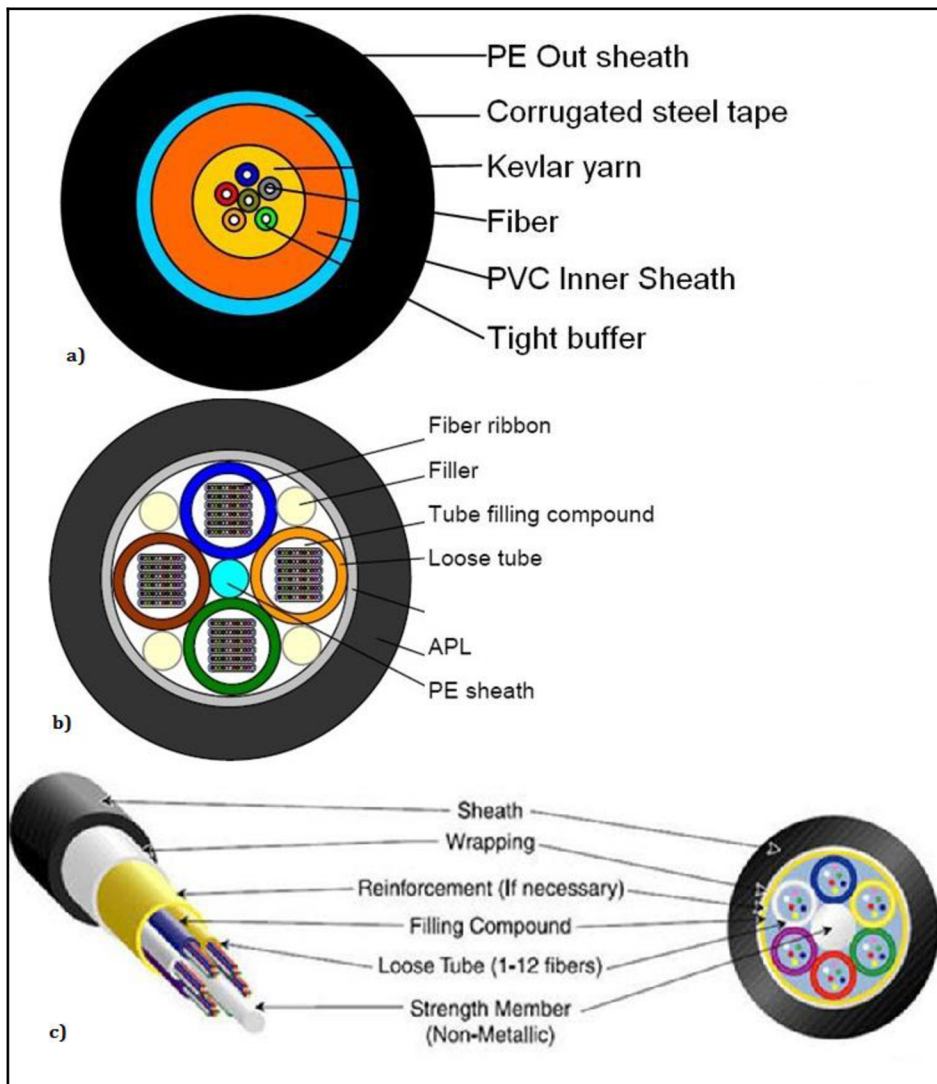


Fig. (2.16) a) tight buffered fiber optic cable, b) ribbon fiber optic cable
c) loose-tube fiber optic [7], [12].

c) Ribbon cables: Ribbon cables like Corning Cable Systems LANscape solutions Ribbon Riser and Plenum Cables are designed primarily for indoor use, though outside and inside/outside versions are also available. The cable ribbonizing process takes 12 individual fibers, positions them into a horizontal array, and extrudes an acrylate coating onto and around them. These 12-fiber ribbons can then be stacked via a cable buffering process inside a central tube. Dielectric strength members are typically stranded around the tube for additional durability. Ribbon cables offer high fiber density in a small diameter package – a 96-fiber ribbon cable may only be half an inch in diameter. They

are also ideal for mass fusion splicing or for quick termination with MTP, 12- fiber connectors.

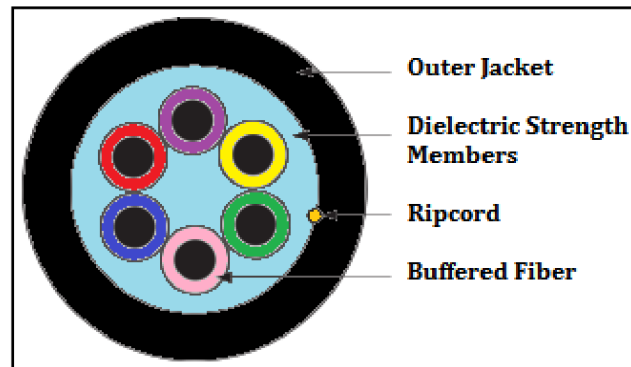


Fig. (2.17) 6-Fiber OFNP MIC Cable [12].

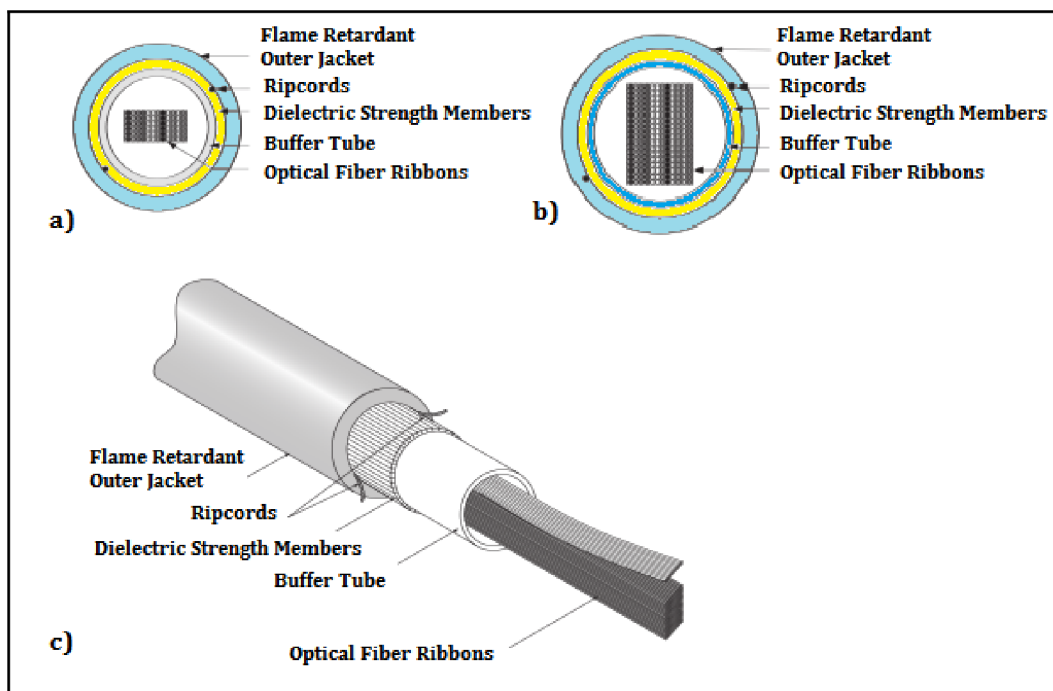


Fig. (2.18) Ribbon Riser cables [7], [12].

2.2.8 Fiber Optic Connectivity

One of the most important steps in the installation of fiber optic systems is the termination of the individual fibers. There are several widely used termination methods. Field installing the connector is commonly done using either an epoxy/polish connector or the

labour-saving no-epoxy, no polish connector. Fusion splicing of pig-tails is a common practice in single-mode applications. Finally, a fast growing approach to termination is to purchase factory terminated assemblies in the form of complete pre-terminated solutions [2], [6].

2.2.9 Field installable connectors

No epoxy, no polish (NENP) connectors have become a widely deployed connector termination technology. As its name suggests, this connector type eliminates the most laborious tasks associated with traditional connectors: the epoxy and polish of the fibers. These connectors utilize mechanical splicing, an optical junction where two or more fibers are aligned and held in place by a self-contained assembly. In an NENP connector, the fiber to be terminated is inserted into the connector body and mechanically spliced to an existing pre-polished, factory-installed fiber stub. Corning Cable Systems' UniCam Connectors, which are NENP connectors, consistently exhibit excellent end-face geometry characteristics, as the polishing and epoxy insertion and adhesion are precisely measured and controlled in the factory.



Fig. (2.19) the most commonly use connector types [2]; [6], [14].

3 Optoelectronic and telecommunication systems

In the previously chapter (2), I have defined the basic of the telecommunications network, principles of transmission in optical fibers, the advantage of optoelectronics used in telecommunications and optical fiber deconstructed, types of fiber and optical fiber Parameters & cable Basics, with characters of each of these process.

In this chapter I will define the applications of these components in telecommunication systems such as transmitter & receiver & components between them such as multiplexer & de multiplexer.

The main advantage of optical fiber is that it can transport more information

longer distances in less time than any other communications medium. In addition, it is unaffected by the interference of electromagnetic radiation, making it possible to transmit information and data with less noise and less error. There are also many other applications for optical fiber that are simply not possible with metallic conductors. These include sensors/scientific applications, medical/surgical applications, industrial applications, subject illumination, and image transport. Most optical fibers are made of glass, although some are made of plastic. For mechanical protection, optical fiber is housed inside cables. There are many types and configurations of cables, each for a specific application: indoor, outdoor, in the ground, underwater, Deep Ocean, overhead, and others. An optical fiber data link is made up of three elements (Figure 3.1) [1], [2], [6], and [7].

1. A light source at one end (laser or light-emitting diode [LED]), including a connector or other alignment mechanism to connect to the fiber. The light source will receive its signal from the support electronics to convert the electrical information to optical information.
2. The fiber (and its cable, connectors, or splices) from point to point. The fiber transports this light to its destination.
3. The light detector on the other end with a connector interface to the fiber. The detector converts the incoming light back to an electrical signal, producing a copy of the original electrical input. The support electronics will process that signal to perform its intended communications function [1], [2], [6], [7].

The source and detector with their necessary support electronics are called the transmitter and receiver, respectively.

In long-distance systems (Figure 3.2) the use of intermediate amplifiers may be necessary to compensate for the signal loss over the long run of the fiber. Therefore, long-distance networks will be comprised of a number of identical links connected together.

Each repeater consists of a receiver, transmitter, and support electronics [1], [2], [5], [6], and [7].

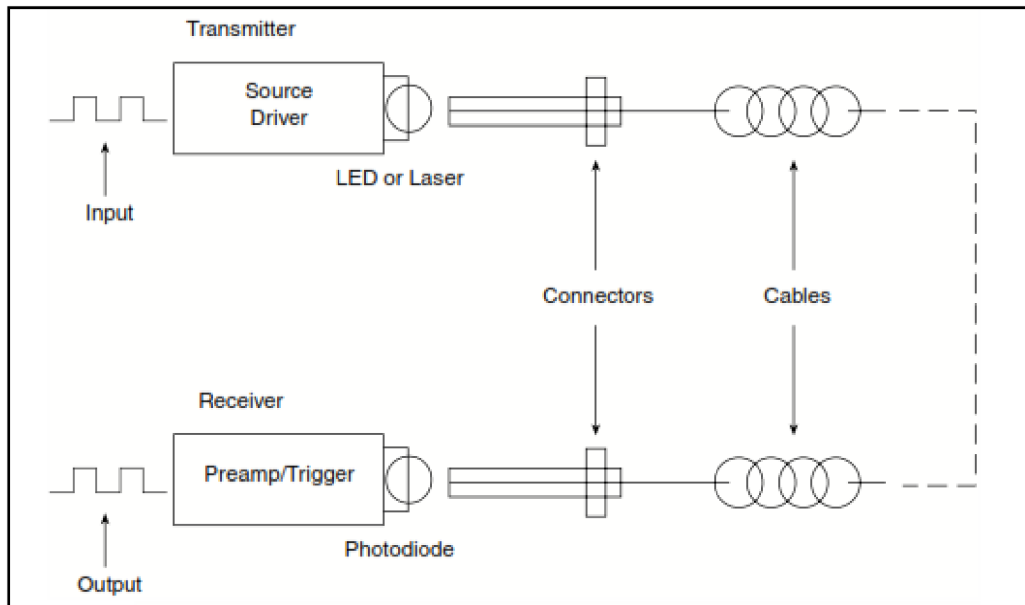


Fig. (3.1) A typical fiber optic data link [6],[7].

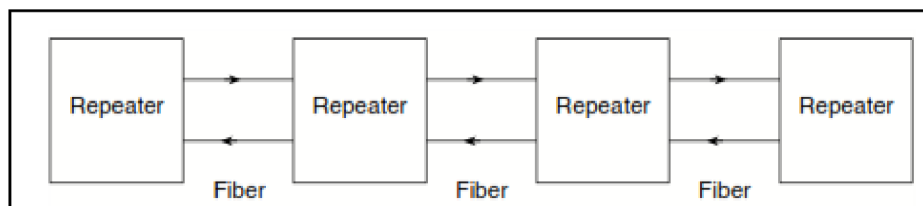


Fig. (3.2) loose-tube cable shown in cross-section [6],[7].

3.1 Active elements

The basic sources of optical radiation, its types of optical radiation sources used for optoelectronic transmissions generally are LED diodes and laser diodes LD. The main difference between the LED and LD is the LD has a significantly higher optical power and the spectral purity (Coherence) is several orders of magnitude higher. Laser diodes which have a range of up to 1000 times narrower than the spectrum of the LED, to allow placing the work area substantially more channels [19], [20]. While semiconductor lasers are sources of coherent radiation, but are not completely perfect. Each semiconductor laser emits radiation which is ideally spectrally "clean", always has some finite width of the spectrum. To transmit the signal downstream (space) is used thermo - electrical cooled DFB (Disturbed FeedBack) lasers. For the opposite direction is used in most cases reversibly modulated uncooled Fabry - Perot laser. Figure 3.3 shows the spectrum of DFB and Fabry - Perot laser. DFB lasers are longitudinal SML

(Single Longitudinal Mode) lasers with narrow spectral line. Therefore, they are used in DWDM, where this property is necessary. They operate typically in the range of 1530-1565 nm [20], [21]. Fabry - Perot lasers require temperature stabilization or frequency, are also significantly cheaper. They MLM (Multi Longitudinal Mode) lasers, the spectrum consists of periodic waves.

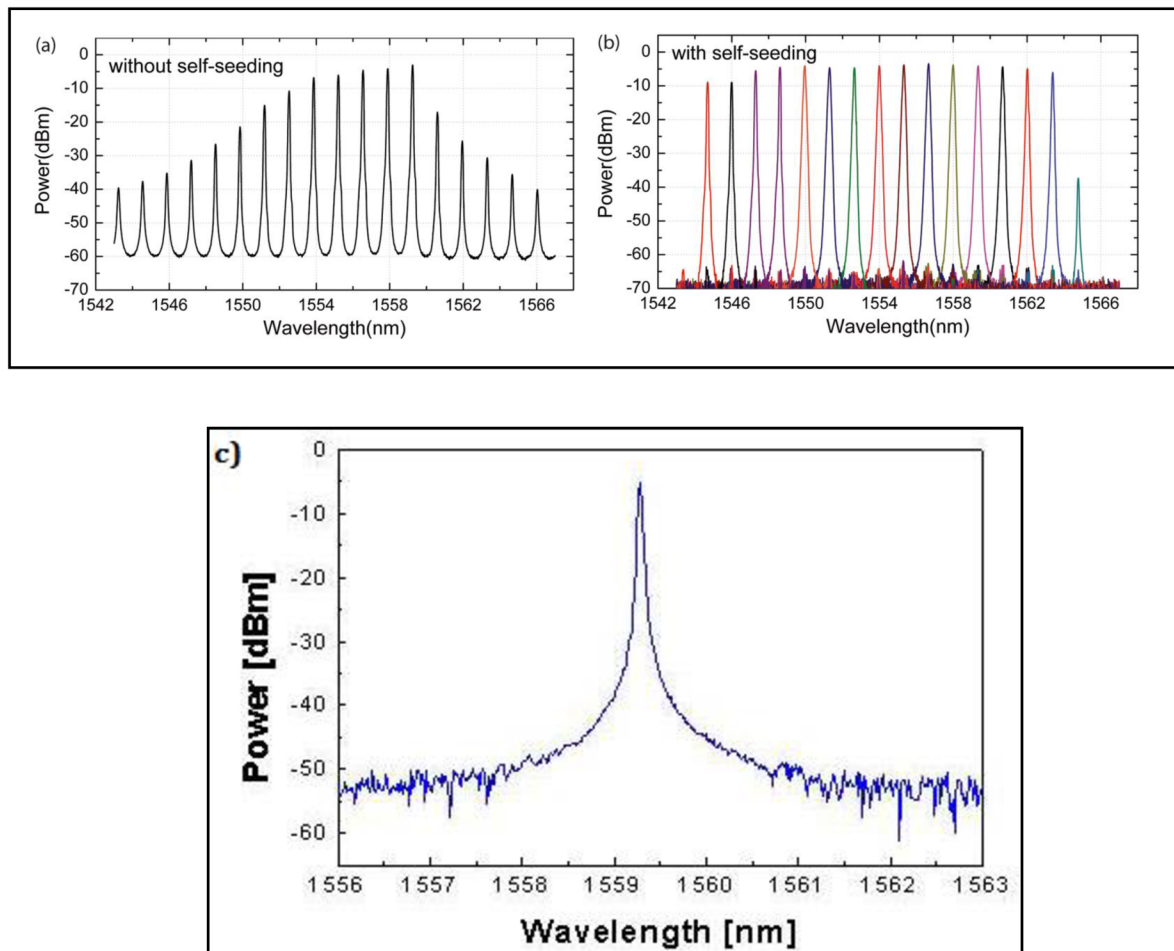


Fig. (3.3) a) b) FP laser. c) DFB laser [20],[22].

Requirements for radiation sources:

- power must be at least such that the transmitted signal is passed through optical fiber and the detector was able to received signal with sufficient accuracy to detect.
- The source must allow the appropriate modulation, in order to achieve the desired baud rate.
- Transmission Systems xWDM are very demanding on the stability of the different carrier frequencies, it is therefore necessary that the spectral line source

of radiation does not change due to changes in ambient temperature or other circumstances. It must also be narrow enough not to interfere in neighboring channels.

- Another requirement of the source of radiation is minimal self-noise. CWDM technology uses radiation sources without the need for cooling. The values for the individual wavelength channels are given in values of 1271 nm, 1291 nm, etc. This is due to changes in the nominal central wavelength depending on the temperature, which is for example 1470 nm in the temperature range $0-70^{\circ}\text{C} + / - 3\text{ nm}$. The operating temperature of the laser is 35°C ; the nominal value is not measured at 20°C [20].

3.1.1 DFB lasers

This kind of laser diodes with distributed feedback, the active area periodically structured as a diffraction grating. The structure is composed of a one-dimensional interference grating that provides optical feedback to the laser and uses Bragg variance. DFB laser diode used two discrete mirrors forming the optical cavity (as in standard laser diodes). The grid acts as a selective control of wavelength for at least one of the mirrors and provides feedback, which reflects light back into the cavity and thus forms a resonator. The grid is designed to reflect only a narrow band of wavelengths (SML). This is in contrast Fabry -Perot laser chip which consists of two mirrors forming a feedback. In this case, a broadband mirror, and the laser operates at multiple longitudinal modes simultaneously, or simply jumps between longitudinal modes. The temperature change of the DFB laser diode is caused due to change in refractive index depending on temperature. This dependence is caused by changing the “bandgap” (the area between the valence and conduction layer of solids, where electrons can exist) semiconductor laser with temperature and thermal expansion. The change of the refractive index on the wavelength changes the selection grid structure and therefore the wavelength of the laser output - tunable laser TDL (Tenable Diode Laser). Tuning range is usually about 6 nm at a temperature change at 50 K [20], [23]. By changing the supply current is also tunable laser, since the change of supply current temperature changes inside the DFB. These lasers are cooled with DWDM Pelletier cells, which results in large power consumption [20], [23]. Lasers with distributed feedback used in optoelectronics are phase shifted in the middle of the reflective bands. When the laser is set up

correctly, it works in SLM mode at a distance of tens of kilometers is basically limited temporary noise -induced coherence heterodyne [20], [23].

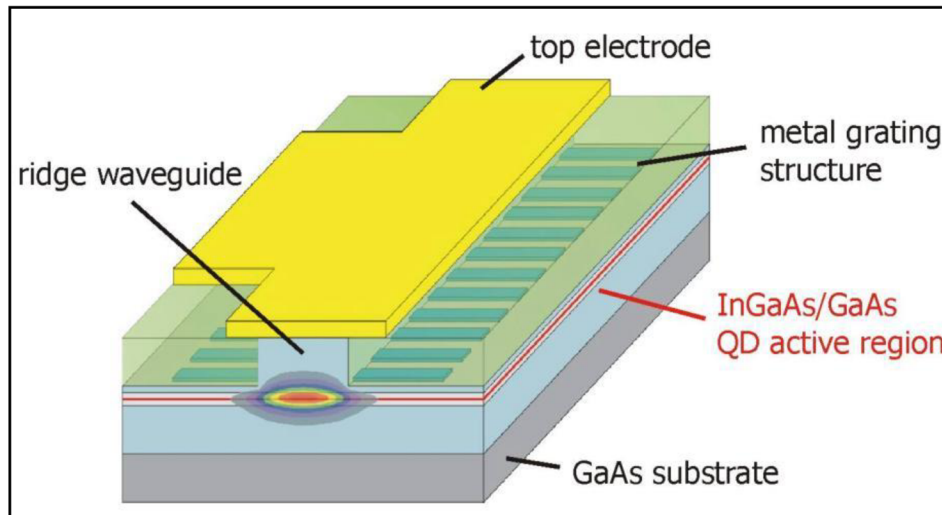


Fig. (3.4) Structure of the DFB laser [25].

3.1.2 FP lasers

Fabry - Perot laser consists of two highly reflecting half mirror, which is located at a distance l on opposite sides of a semiconductor material, including the active area. Fabry - Perot cavity reflects the light back and forth, creating a standing wave. In order to achieve improved directivity of radiation is semipermeable resonator only from one side. FP lasers can operate in single- mode and multimode [19], [20].

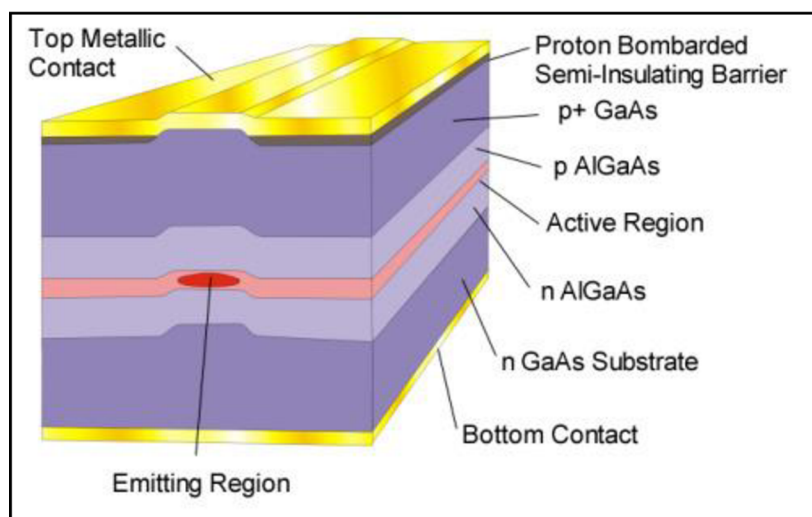


Fig. (3.5) Structure of the FP laser [25].

3.1.3 Optical Radiation Detectors

The detectors are elements needed to detect and demodulate the optical signal. The impact of the optical signal to the photodetector, and its conversion to power signal that the optical layer. To own the detection occurs after demultiplexing xWDM signal into sub- signals. For telecommunication purposes, use PIN photodiodes and avalanche photodiodes APD (Avalanche - Photodiode). These detectors must be compatible with other elements of optical transmission chain must meet certain parameters and design. Among the most important parameters include, example high sensitivity in the use of the band, a little self-noise, fast response time, insensitivity to changes in temperature and supply voltage, small size [19], [20].

3.1.4 PIN photodiode

- Widespread.
- Fast Response.
- Large quantum yield of 68-80 % [19], [20].
- Based on the principle of optical excitation of free charge carriers and recombination processes.

3.1.5 Avalanche photodiode APD

- Greater sensitivity compared to PIN.
- Complicated and expensive production.
- The need to preload voltage.
- Increased levels of noise voltage.
- Based on the process of multiplication of free carriers based on ionization in a strong electric field.

For bidirectional communication, it is necessary that at the transmitter and receiver are contained both the detector and the radiation source and a filter for distribution of wavelengths for the two directions of transmission. The element that contains all of these parts is called the active optical element [20], [24].

3.1.6 Optical amplifiers

Optical amplifiers are difference than repeaters do not require conversion into electronic form, are independent of the transmission speed, the amplified signal is analogue or digital. Given that

all the contributory amplified optical signal xWDM channels simultaneously, so they are independent of the protocol and bit depth. In the xWDM systems use optical fiber amplifier EDFA (Erbium Doped Fibers Amplification) and type Raman amplifiers. For CWDM system is possible using EDFA amplify only 1-2 channels.

3.1.7 EDFA amplifier

EDFA amplifier consists of a pump laser and a special active, erbium- doped fiber (EDF) length units to tens of meters. This thread is welded into the optical path through a directional coupler. Over the next input directional couplers is introduced into the EDF pumping channel of the pump laser. Due to radiation from the pump laser is to excite the carbon -doped element (erbium) to higher energy levels. This temporarily stored energy obtained from the pump laser. Releasing the passage of the transmitted signal occurs when the energy causes the stimulated emission of radiation of the same wavelength and phase. In addition to stimulated emission, however, there is also spontaneous emission, which is a parasitic phenomenon has resulted in noise. Under normal conditions, however, it exceeds the high stimulated emission. These amplifiers allow the amplification level of the transmitted signal to 50 dB [19], [20]. Normally, only the amplified C-band, but also produces amplifiers which allow amplification of the C + L band simultaneously. EDFA amplifiers cannot be used in zones O, E and S, because it would rise to $\frac{1}{4} \lambda$ distortion.

EDFA is typically deployed in the following [19], [20]:

- As a Booster, which is placed behind the optical transmitter and its function, is to amplify the signal to the maximum level, which is possible to make fibers.
- In - line amplifier positioned on the optical path at the point where the signal level is weak, the signal is amplified there again to the maximum level.
- Preamplifier, which is placed before the optical receiver. Amplifies a low level signal to a level suitable for the optical receiver.
- Compensation for losses that occur in PON networks due to signal distribution of the splitter (hub) between multiple threads. Connects to the front splitter, so that each level divided by the signal was the same as the incoming signal to the splitter. It is also used in most analogue networks CATV (Cable Television Analogue).

EDFA amplifier generally allows light amplification of one optical channel. However, to be usable even in xWDM systems, further improvements are necessary. Gain wave amplifier is

not the same for each wavelength, but forms a certain spectral band. To be deployed on xWDM EDFA system, it is imperative that the amplifier gain was approximately constant over the range of xWDM signal, then a sufficient gain at low noise figure, thermal stability and reliability. For comparison, the gain spectrum at a constant value is used attenuators - the attenuators.

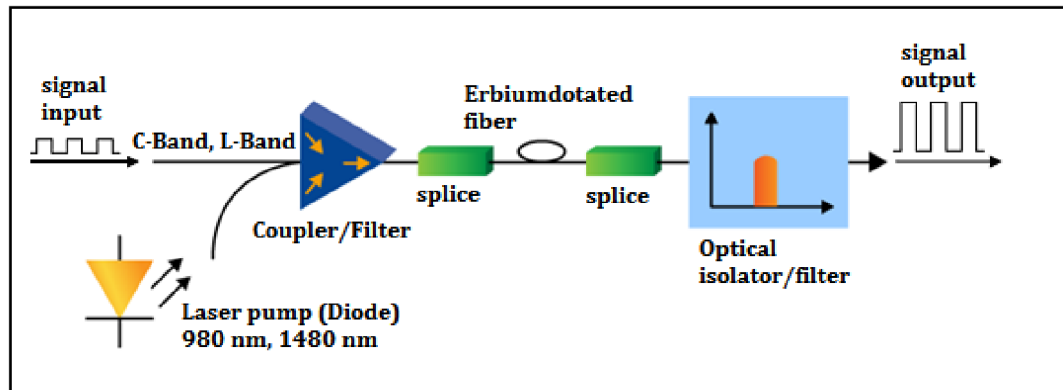


Fig. (3.6) EDFA amplifier [26].

3.1.8 Raman amplifier

For this amplifier gain occurs within the it's own fiber, thus not need special fibers as in the case of the EDFA. Its function is based on the Raman scattering of particles of the waveguide material. It is basically only a laser radiation source is connected to the optical path. For these types of amplifiers are achieved maximum gain 15-20 dB [19], [20]. Allows amplification of the signal of any wavelength, depending on the selected pump laser (e.g., 1450 nm to 1550 nm band). It is placed at the end of the transmission fiber and the laser pump radiation spreads against the signal amplifier.

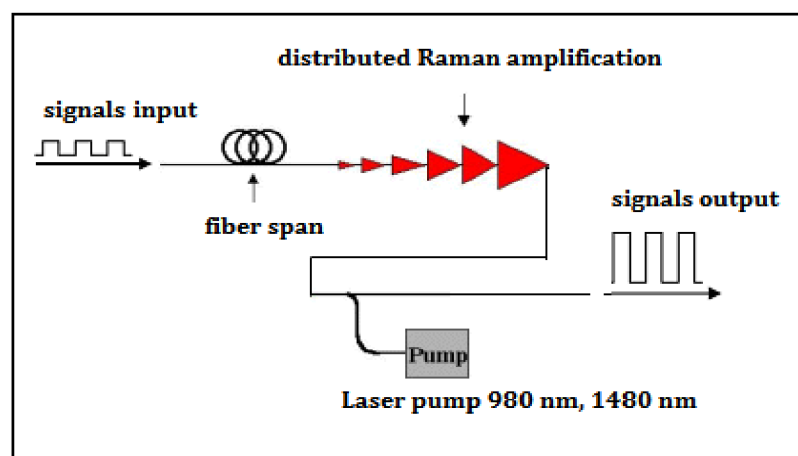


Fig. (3.7) Raman amplifier [27].

3.2 Passive elements

The main function of multiplexers and demultiplexers is the association of light beams from different sources into a single fiber and back-dividing. Distribution of the light beam into sub-beams according to wavelength is performed in the demultiplexer. Multiplexer must include selective elements (filters) if the spacing between channels of small (DWDM) filters always includes a demultiplexer. When duplex communication over a single fiber, it is necessary to connect couplers to prevent cross talk between the transmitter and receiver [19], [20].

Systems dielectric filters:

Selective interference filters these filters, depending on the wavelength cause either reflects light waves from the filter (channel does not belong to a given receiver) or a light wave passes. This is done until the last optical channel from the original xWDM signal reaches the final receiver. The construction of the filter is performed 10-40 thin layers of dielectric material with alternately changing refractive index. Insertion loss muldexes consisting of these filters increases approximately proportionally with the number of transmitted wavelengths, so they are suitable for systems with fewer channels [19], [20].

Dispersion filters

To spread the light of these filters occurs on optical gratings or prisms. When the prism decomposition occurs undesirably doubling refraction at the boundary surfaces, whereby the light of different wavelengths refracted at different angles. Therefore, it is preferable to use grids, which also enable the processing of multiple channels. Insertion loss muldexes optical lattice with an increasing number of channels changes only slightly [19], [20].

Fiber Bragg grating FBG (Fiber Bragg Grating)

This grating is formed e.g. molecular epitaxy in a wave structure, which has to be connected to the fiber. Output WDM signal is then radiated in several discrete directions, each direction corresponding to a specific frequency band [19], [20].

3.2.1 Waveguides arranged in a grid AWG

AWG (Arrayed Waveguide Grating) multiplexers / de-multiplexers are planar components based on field waveguides. Reflect array at the input waveguide to the output waveguides of the fields on the basis of wavelength. Waveguides arranged in a grid are often also referred to as wavelength routers - Waveguide Grating Routers (WGRs) or as optical phased array - Phased

Arrays (PHASARs). Along with selective filters and fiber Bragg grids are the most important part of WDM networks [20], [28]. The thread is welded to the waveguide, which is much extended, and after a short distance continues several parallel narrow waveguides. These waveguides are twisted so as to produce approximately centered ARCs, but they are not equally long. After that, reconnect to the wide waveguide, which after a short distance to the mouth again narrow waveguides. These branches are the same number as contributory channels in the input signal [19], [20]. Input (single-mode) waveguide channel flows into the planar waveguide region, where it acts essentially as a point source. For it, the radiation in the planar waveguide starts and creates a circular wave front. On the opposite side are located the mouth of a series of channel waveguides, which capture radiation. Until all channels and enters the radiation with the same phase. The system is arranged so that the mean wavelength of the de-multiplexer is an optical length of the channels differ by integer multiples of the wavelength. At this wavelength, therefore performs optical radiation from the channels in the output section of the planar waveguide with the same phase (phase difference corresponding to the even increments of π are not reflected). Output mouth series of waveguides formed equal-phase area like the input channels. Radiation is therefore in the output section of a planar concentrated in the mouth of the centre output waveguide. When small change in wavelength, phase shifts between the individual output channels is altered so that the resulting output equal-phase area rotates by an angle proportional to the change of wavelength, and the radiation is focused to a different output channel. Thus, there is a separation of wavelengths [19], [20], [33]. The device can be used "in reverse" also merging wavelengths from different sources into a single output fiber. For the AWG are used muldexes supervisory channeling (Out of Band), which is independent of the C / DWDM data transmission. For this purpose, usually reserved wavelength of 1510 nm and a data channel with transmission speeds up to $100 \text{ Mbps} \cdot \text{s}^{-1}$.

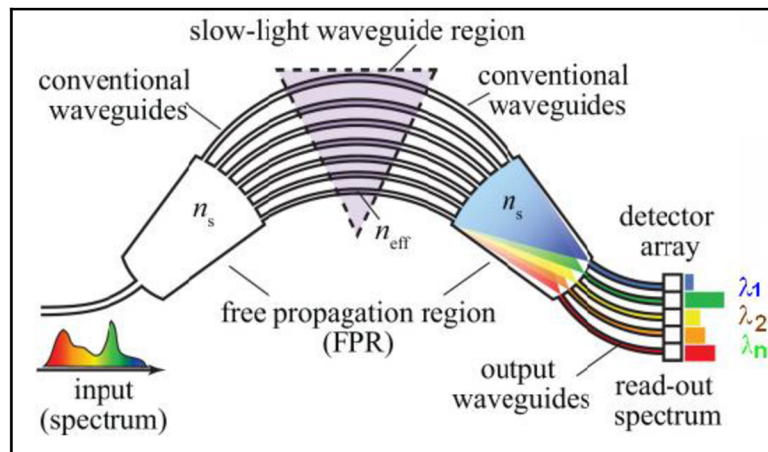


Fig. (3.8) AWG [31].

The most important technology used to implement waveguide AWG nowadays is “silica - on- silicon (SOS) ” technology and semiconductor technology Indium phosphide (InP) [20], [28].

3.2.2 ROADM

ROADM (reconfigurable optical add / drop multiplexer). It is an optical device enabling to allocate (DROP) of the signal spectrum xWDM the plurality of channels simultaneously can place precisely divided by channels including channels from another direction (ADD), which have the same wavelengths as channels are excluded.

Order ROADM elements determine how many interfaces element has. Classic ROADM are 2nd order because they have two interfaces, known as W (west) and E (east) [20], [29]. If we want to deploy ROADM networks with polygonal topology, it is essential that higher order (you multiple interfaces). Fully configurable ROADM has no restrictions between all interfaces can therefore switch to any channel to another. This technology has been developed, although it is, but it is currently quite unaffordable. The core muldex is a digital distributor, which is implemented spatiotemporal coupling field. This allows time to resolve themselves selected position of the line signals a score demultiplexed signals on the interface. The cascade Add / Drop Multiplexer is to be expected that the accumulated optical noise in ducts. This fact should be considered when designing networks [20], [29]. The most common use resolve they selves muldexes are circular network, which among other things because of these possible backup operation. Another typical application ROADM muldex are access networks with line structure

with continuous muldexes placed by service node gradually up to the end muldexes [20], [29]. Flexibility ROADM element indicates the resolve itself ratio which indicates the ratio between the total number off-divisible channels and the total number of channels. If the number is higher, its mean's the multiplexer greater flexible. The latest ROADM can configure the interface based on the software configuration, unlike conventional static multiplexers requiring expensive manual intervention for changes [20], [29]. If the ROADM switch allows any wavelength, and is referred to as "Colorless." If this does not, then it is referred to as "color". If it is necessary to reconfigure connections to another channel, and we ROADM type of color, it means that it must be switched to another physical port, which in practice requires manual switching of fiber optic cables and often temporary disconnection of other terminal equipment. U-type colorless ROADM is possible to reconfigure any channel on any port. Also capable of preventing collision situations because they can be used other than the original wavelength for different parts of the transmission chain. Other division multiplexers ROADM are the "direction (directional) " and " Omni-directional (omnidirectional)." The advantage compared to omnidirectional directional is the possibility channel switching port on either side of (W, E) [20], [29].

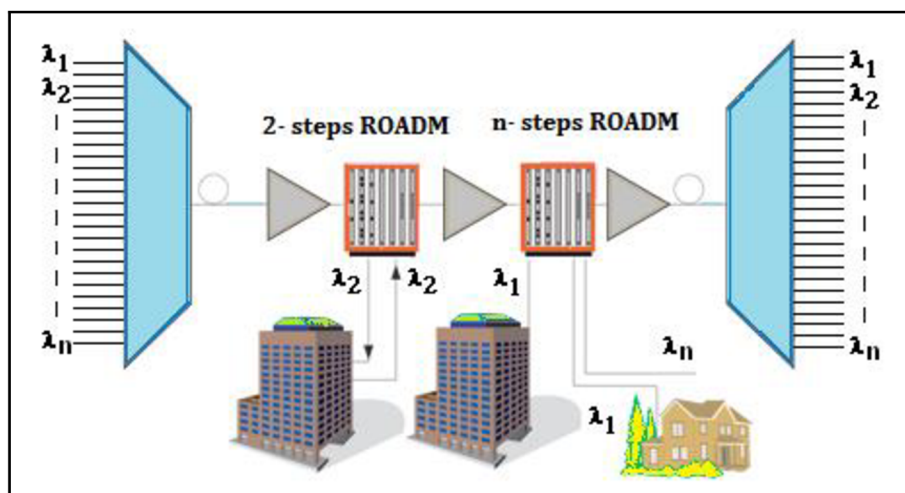


Fig. (3.9) Example of a ROADM.[20].

3.2.3 Optical circulators

An optical circulator is a passive device that is used to merge / divide the optical signal on the same wavelength. It is essentially a component that is able to distinguish the optical signal on the direction of propagation in an optical fiber. By default, a three-port device, said first input port is routed to the port and a second input from the second port is directed to the third port. The

advantage is the high isolation between ports 45 to 50 dB, attenuation below 1 dB polarization independence and low crosstalk due to reflection is necessary to use APC angled connector [20],[21],[33].

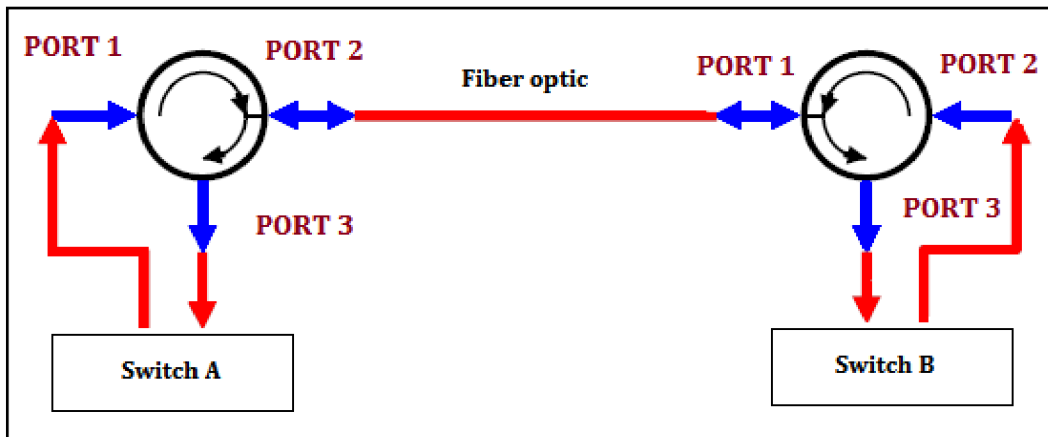


Fig. (3.10) Application of optical circulator [20], [21].

3.2.4 Interleaver

Optical interleaver is a passive three-port optical device that is used to merge two DWDM channels (odd and even) into one composite interlaced signal. For example, two DWDM signals with a grid of 100 GHz using an interleaver are merged into a single DWDM signal with a grid of 50 GHz [20], [21]. The device can be used in the reverse direction in the optical de-interleaver, which divides the DWDM signal into odd and even-numbered channel. The optical interleaver is based on multiple -beam interference.

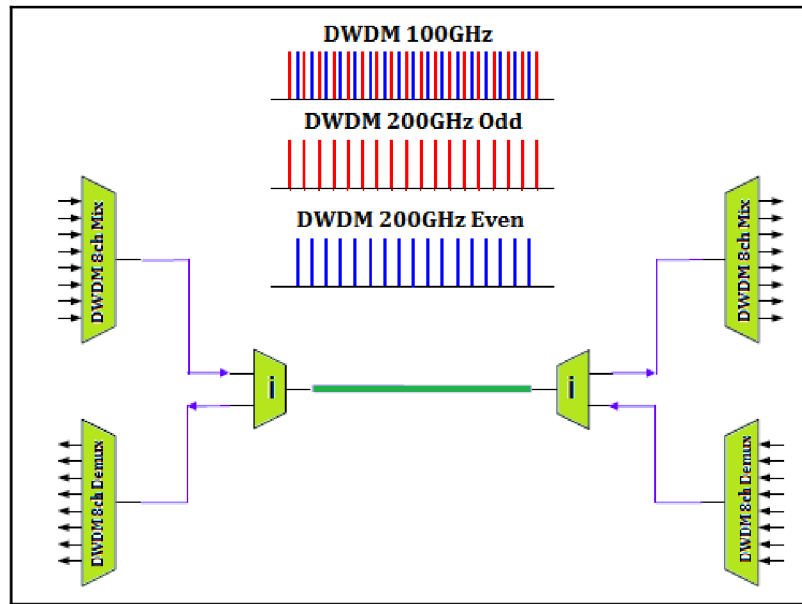


Fig. (3.11) Interleaver [29].

3.2.5 Splitters

It's a device with one input port and multiple output ports. The input signal is divided between output ports and allows the users to share a single optical fiber (thus bandwidth). In the opposite direction - by signals from multiple ONTs connected to a single fiber. Splitters are passive devices because they require no external energy sources [20], [30].

Tab. (3.1): The dependence of the attenuation on the number of ports [20], [30], [33].

Number of ports	splitter attenuation [dB]
2	3
4	6
8	9
16	12
32	15
64	18

Because divides input signal each splitter certain decline. Its size is the number of output ports. In FTTH networks may be involved one or more splitter splitters arranged in cascade, which depends on the topology. Splitters are also used in the WDM -TDM - PON networks [20], [30]. Regardless of the topology, but must meet certain maximum attenuation, which is defined

by ITU-T, see table (3.1) as above. According to the technology of production is divided onto the two groups [20], [30], and [33].

PLC (Planar Lightwave Circuit) - are produced by planar technology. Use in splitters with a plurality of output ports. Technological procedure is the silicon substrate can produce the desired structure and achieve up to 128 output ports.

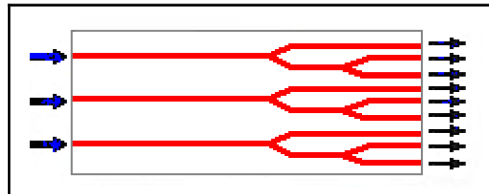


Fig. (3.12) Planar splitter [20].

FBT (Fused Taper Bionic) - fusion method splitter is produced by connecting optical fibers at high temperatures and pressures, there is a melting sheath and core get very close together. This technology can produce only 2-4 bundles of fibers that are possible to achieve the plurality of output ports sort cascaded for its selves.

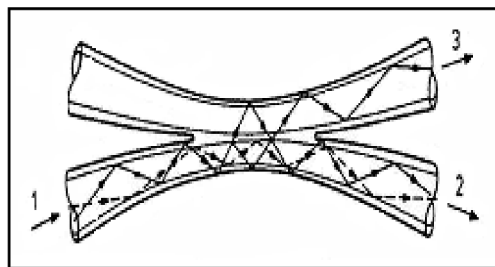


Fig. (3.13) Fusion splitter [30].

3.2.6 Other active and passive elements

Optical transceivers

These elements are connected to the chassis of the switch and operate as transmitter / receiver. The advantage is that it is not necessary at the outset to invest in expensive element of fully wired precious optimal ports. Individual transceivers gradually added as needed. When you change the configuration is not necessary to change the entire active element, but simply replace individual transceivers. They provide high modularity in the design, installation, and during the administration of the system.

Chromatic dispersion compensators

For DWDM system causes dispersion of the shape of the modulating signal - overlap of adjacent pulses, and thus interference. On the receiving side, therefore, can interfere with the signal

evaluation. CD (chromatic dispersion) has a significant impact on bridging distance, max transfer rate and maximum number of channels. For this reason it is necessary to compensate for the CD already optimal transmission route. The methods used [20], [22], and [33]:

- DCM module - fiber with a negative CD are used to compensate the positive dispersion.
- Use of fiber CD + and CD - turns in the cable.
- FBG (Fiber Bragg Grating) - charged Bragg gratings.

3.3 Classification multiplex systems used in optoelectronics

Time multiplex

It is based on the principle of allocation signal to a specific time interval, which works on both the transmitter and receiver. The path is regularly according to pre -defined and well-known procedure, sub- channels allocated to a known and defined periods of time.

Frequency multiplex

The transmission channel provides a wider frequency band than that needed for a single communication. It is possible this channel into sub-channels and these can then run independently. This creates the group - formed by transferring individual signals in the higher frequency bands. Thus formed groups are modulated onto the optical signal. The possibilities of these multiplex parameters are limited sources of radiation

Electronic multiplex

After the optical fiber is transmitted instead of the binary signal multistate signal. The baud rate increases by n times.

Surround (fiber) multiplex

It is the simplest of all multiplexing techniques, and is implemented by increasing the number of optical fibers for the transmission of signals.

Wavelength division multiplex

Multiple optical signals are simultaneously transmitted in a single optical fiber by using different wavelengths which are transmitted by different sources.

Hybrid multiplex

It uses a combination of electronic and wavelength division multiplexing. In theory, this allows maximum use of the transmission capacity of the fiber.

3.4 Wavelength division multiplex (WDM)

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e., colors) of laser light. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity. The term wavelength-division multiplexing is commonly applied to an optical carrier (which is typically described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency). Since wavelength and frequency are tied together through a simple directly inverse relationship, in which the product of frequency and wavelength equals c (the propagation speed of light), the two terms actually describe the same concept [16], [20].

3.4.1 WDM systems operating principle

A WDM system uses a multiplexer at the transmitter to join the signals together and a demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer. The optical filtering devices used have conventionally been etalons (stable solid-state single-frequency Fabry–Perrot interferometers in the form of thin-film-coated optical glass). Modern systems can handle up to 160 signals and can thus expand a basic 10 G bit*s⁻¹ system over a single fiber pair to over 1.6 Tbit*s⁻¹ [16], [20].

WDM systems are popular with telecommunications companies because they allow them to expand the capacity of the network without laying more fiber. By using WDM and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure without having to overhaul the backbone network. Capacity of a given link can be expanded simply by upgrading the multiplexers and demultiplexers at each end.

This is often done by use of optical-to-electrical-to-optical (O/E/O) translation at the very edge of the transport network, thus permitting interoperation with existing equipment with optical interfaces. Most WDM systems operate on single-mode fiber optical cables, which have a core diameter of 9 μm . certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 μm . Early WDM systems were expensive and complicated to run. However, recent standardization and better understanding of the dynamics of WDM systems have made WDM less expensive to deploy. Optical receivers, in contrast to laser sources, tend to be wideband devices. Therefore the

demultiplexer must provide the wavelength selectivity of the receiver in the WDM system. WDM systems are divided into different wavelength patterns, conventional/coarse (CWDM) and dense (DWDM). Conventional WDM systems provide up to 8 channels in the 3rd transmission window (C-Band) of silica fibers around 1,550 nm. Dense wavelength division multiplexing (DWDM) uses the same transmission window but with denser channel spacing. Channel plans vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 12.5 GHz spacing (sometimes called ultra-dense WDM). Such spacing are today only achieved by free-space optics technology. New amplification options (Raman amplification) enable the extension of the usable wavelengths to the L-band, more or less doubling these numbers. Coarse wavelength division multiplexing (CWDM) in contrast to conventional WDM and DWDM uses increased channel spacing to allow less sophisticated and thus cheaper transceiver designs. To provide 8 channels on a single fiber CWDM uses the entire frequency band between second and third transmission window (1310/1550 nm respectively) including both windows (minimum dispersion window and minimum attenuation window) but also the critical area where OH scattering may occur, recommending the use of OH-free silica fibers in case the wavelengths between second and third transmission window should also be used. Avoiding this region, the channels 47, 49, 51, 53, 55, 57, 59, 61 remain and these are the most commonly used. WDM, DWDM and CWDM are based on the same concept of using multiple wavelengths of light on a single fiber, but differ in the spacing of the wavelengths, number of channels, and the ability to amplify the multiplexed signals in the optical space. EDFA provide efficient wideband amplification for the C-band, Raman amplification adds a mechanism for amplification in the L-band. For CWDM wideband optical amplification is not available, limiting the optical spans to several tens of kilometers [16], [20].

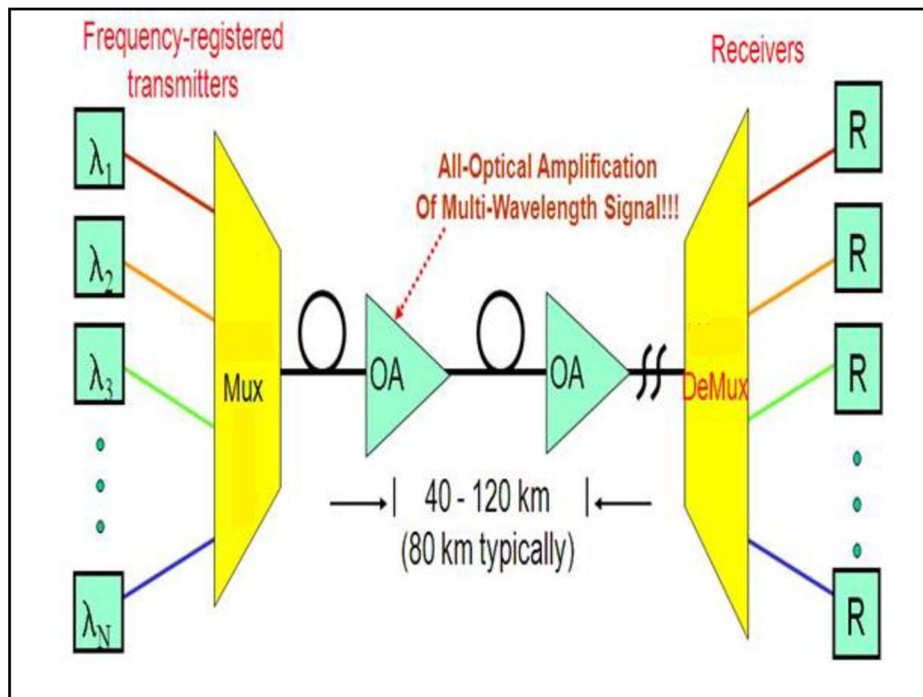


Fig. (3.14) Principle of wavelength division multiplexing [15], [20].

3.5 Technology WWDM

WWDM wavelength division multiplexing (Wide Wavelength Division Multiplex). Among the older technology, but still is sometimes used because it is more affordable than variant CWDM or DWDM and in some cases is sufficient. The most commonly used are only four wavelengths of around 850 nm (for multimode fibers) and in the region around 1310 nm (single mode fiber) [12]. The spacing between the individual wavelengths is > 20 nm. WWDM technology is most often used for transmission of 10Gbit Ethernet Gbit and [19], [20].

3.6 Technology DWDM

Wavelength Division Multiplexing DWDM is one of the most sophisticated systems that are used in optoelectronics. The spacing between channels is only 0.8 nm, theoretically up to 0.1 nm (ultra DWDM). Consequently, it allows transmitting in a single optical fiber tens of channels. The channels are transmitted by optical fibers in parallel and independently. It highly increases the transmission capacity of optical communications. Today's DWDM systems can transmit between 2.5 and $10 \text{ Gbit} \cdot \text{s}^{-1}$ in a single optical channel and operate normally these 96 channels on a single physical link. DWDM technology is the first layer and is independent of the

transmitted protocol. It can be multiplexed slow protocols to high-speed 10 Gbit Ethernet. Thus can be passed adjacent different protocols and multiplexed together into a single thread.

The advent of this technology was made possible mainly due DFB lasers (Disturbed feedback) with extremely narrow spectral line, further EDFA (Erbium Doped Fiber Amplifier) amplifier and highly selective spectral filters. These devices are very sensitive to frequency and temperature stability. This is one of the reasons why this technology is very expensive [20]. ITU-T Recommendation G.694.1 "Spectral grids for WDM applications : DWDM frequency grid" specifies individual transmission channels in the wavelength range from 1490 nm (200.95 THz) to 1620 nm (186.00 THz) (called S , C and L band) . DWDM grid pilot based on the normalized frequency 193.1 THz [19], [20]. From this frequency depends on the grid spacing of the individual channels in the range of 100 GHz, 50 GHz, 25 GHz (ultra DWDM), in development is already 12.5 GHz [3]. For proper functionality and quality of transmission is necessary that the wavelength is not deviate from the prescribed wavelength of more than 0.2 carrier spacing , which corresponds to a tolerance of ± 0.16 nm to 100 GHz grid [19], [20].

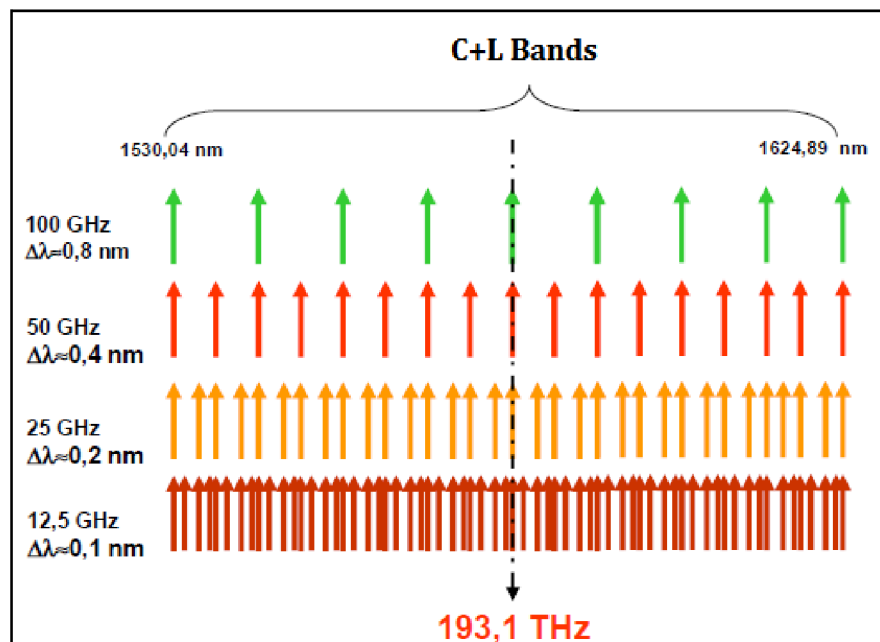


Fig. (3.15) DWDM Rasters [20], [32].

The main advantages of DWDM:

- Only one fiber is sufficient for the transfer of up to 96 (and theoretically more) data channels.
- Theoretically reach up to 100 km without signal amplification.
- Readiness for emerging new technologies.
- Easy expandability for additional data channels.
- Backup to optical level to minimize potential downtime.
- Easy expansion by other sites DWDM / CWDM, possibility to create different logical topologies.
- Management through supervisory channel supports SNMP (Simple Network Management Protocol) - A protocol for network management.
- Multiple uses of existing optical fibers.

For use in metropolitan and access networks, it is appropriate to narrow the DWDM technology only to bandwidth utilization, “C”, which is located in the region 1530-1565 nm. For this zone there are suitable and affordable components (EDFA amplifiers, etc.).

Tab. 3.2: Table wavelengths of the band "C" 100 GHz DWDM ITU- T G.694.1 [20], [21], [33].

Ferency [THz]	Channel DWDM {ITU-T}	nm
192,5	925	1557,36
192,6	926	1556,55
192,7	927	1555,75
192,8	928	1554,94
192,9	929	1554,13
193,0	930	1553,33
193,1	931	1552,52
193,2	932	1551,72
193,3	933	1550,92
193,4	934	1550,12
193,5	935	1549,32
193,6	936	1548,51
193,7	937	1547,72
193,8	938	1546,92
193,9	939	1546,12
194,0	940	1545,32
194,1	941	1544,53
195,2	952	1535,82
195,3	953	1535,04
195,4	954	1534,25
195,5	955	1533,47
195,6	956	1532,68
195,7	957	1531,90
195,8	958	1531,12
195,9	959	1530,33

3.7 Technology CWDM

The multiplex CWDM, this technology was created as a cheaper option than DWDM. Elements used in CWDM require accurate and technologically sophisticated components as DWDM. The spacing between channels is substantially larger. Standard ITU - T G - 694.2 - "Spectral grids for WDM applications: CWDM wavelength grid" defines the amount of space each channel wavelengths for use in CWDM technology so that it can be used as a source of radiation, laser diodes not requiring refrigeration. Individual wavelengths have been selected so as to be compatible with conventional used wavelengths 1310 nm and 1550 nm [20], [21].

Standard G - 694.2 assumes the use of uncooled laser sources with a total tolerance from nominal central wavelength in the range of $+ / - 6-7$ nm. Due to the tolerance that is allowed standard, in practice the bandwidth is stabilized in the range of 6.5 nm as used for CWDM filter,

and the tolerance for the wavelength of laser diodes for the entire range of working temperatures [20],[21]. Other standard CWDM technology - ITU - T Recommendation G. 695 " Optical interfaces for coarse wavelength division multiplexing applications" describes the recommended parameters of the optical interface due to the mutual compatibility of CWDM devices from different manufacturers [20],[21].

CWDM allows the use of 18 channels, but only when using the fiber type G.652.C / D, which allow operation over the entire wavelength range and thus use all the bandwidth, including an extended zone E, which is between the wavelengths of 1360-1460 nm [20],[21]. Using conventional fiber G.652.A / B can use transmission channels only 12th.

Tab. (3.3) Table CWDM wavelengths according to ITU-T standard G.694.2 [20],[21],[33].

Channel CWDM {ITU-T}	Nominal wavelengths [nm]	Range
27	1270	O
29	1290	
31	1310	
33	1330	
35	1350	
37	1370	E
39	1390	
41	1410	
43	1430	
45	1450	
47	1470	S
49	1490	
51	1510	
53	1530	
55	1550	C
57	1570	L
59	1590	
61	1610	

CWDM is currently applied in most metropolitan networks, which preferably may be combined with DWDM technology and create the topology with a high potential bandwidth. CWDM allows to transmit in each channel Gbit Ethernet at distances up to 80 km , STM -16 with a transfer rate of $2.5 \text{ Gbit} \cdot \text{s}^{-1}$ within 50 km [20],[21],[33].

The main advantages of CWDM:

- Easy to deploy on existing fiber routes.
- Low cost technology compared to DWDM.
- Lower energy and space requirements compared to DWDM.

- CWDM channel can be used for transmission to 8 DWDM channels.
- Simple management.
- Wide range of transmitters, such as SFP, XFP, etc. for different distances.
- Tolerance medium waves. Channel length: 6-7 nm.

4 The general layout of optical access networks

Solution optical transmission is divided into two basic groups [20], [30]:

1. Point - point (Point - To - Point, P2P).
2. Multipoint architecture (Point - to - multipoint, P2MP).

When transmission based on P2P architecture, are branching signal, active elements, so this network is called active - **AON (Active Optical Network)**. For architecture P2MP the branching signal using passive adapters - splitters, then the network is referred to as **PON (Passive Optical Network)**. In this diploma work, attention will be concentrate on **PON** networks, for a closer approximation AON see [20], [30].

File FTTx optical access network consists of many kinds, with each network varies depending on how far the optical fiber installed, or the ratio between copper and fiber access network components. On top of this pyramid stands networks labelled FTTH (Fiber to the Home), which is an optical fiber tightened to the end user. The second, yet probably the most used method is a variant FTTB (Fiber To The Building) where the optical fiber to the building and tight end , participants are then connected to the network via an internal metallic distribution. More on the distribution networks, FTTx see [20], [30].

Classification of optical access networks [20], [30]:

Depending on the ratio of fiber and copper access networks, optical access network FTTx distributed:

- FTTH (Fiber To The Home) - Optical fibers are introduced to the objects of end users.
- FTTB (Fiber To The Building) - Optical fibers are brought into the buildings of end users, who are then connected via the internal network.
- FTTC (Fiber To The Curb) - when the fibers are introduced into the local distributor and from the end, participants are connected with metal cable.

- FTTO (Fiber To The Office) - Optical fibers are introduced into the space of end users with high bandwidth requirements.
- FTTCab (Fiber To The Cabinet) - Optical fibers are introduced to the device (Computers).
- FTTN (Fiber To The Node) - Optical fiber is applied to the distribution cabinet and hence can be connected to several hundred relatives of participants using metallic cables.

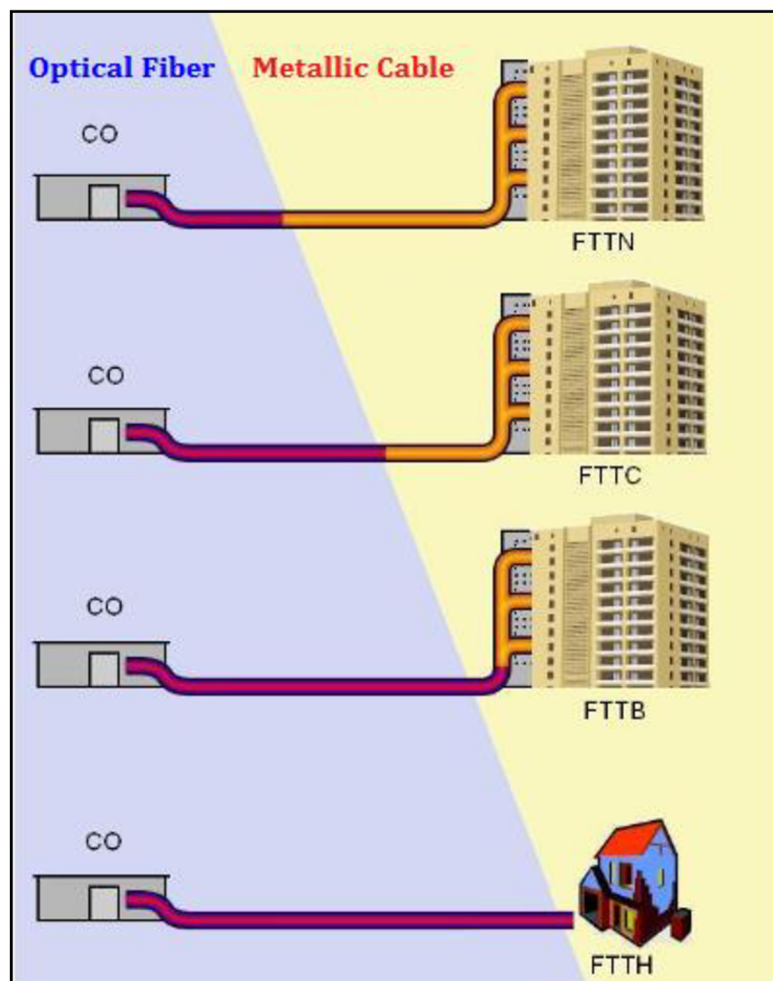


Fig. (4.1) Optical access network FTTx [34].

Basic functional units forming the access network [20], [30]:

OAN (Optical Access Network) = optical access network, which is the set of all optical distribution networks connected to one optical line- endings OLT.

OLT (Optical Line Terminal) = optical line termination, provides a network interface functions between networks providing telecommunications services and network access (network device on the side of the operator).

ONU (Optical Network Unit) = optical termination unit provides functions at the interface between copper and fiber network parts (equipment on the customer side).

ONT (Optical Network Terminal) = optical network terminal, providing the subscriber interface between the terminal and the access network participants (devices on the client side).

OLT, ONT and ONU are active network elements.

ODN (Optical Distribution Network) = optical distribution network, or a set of devices for signal transmission between the OLT and ONU (ONT).

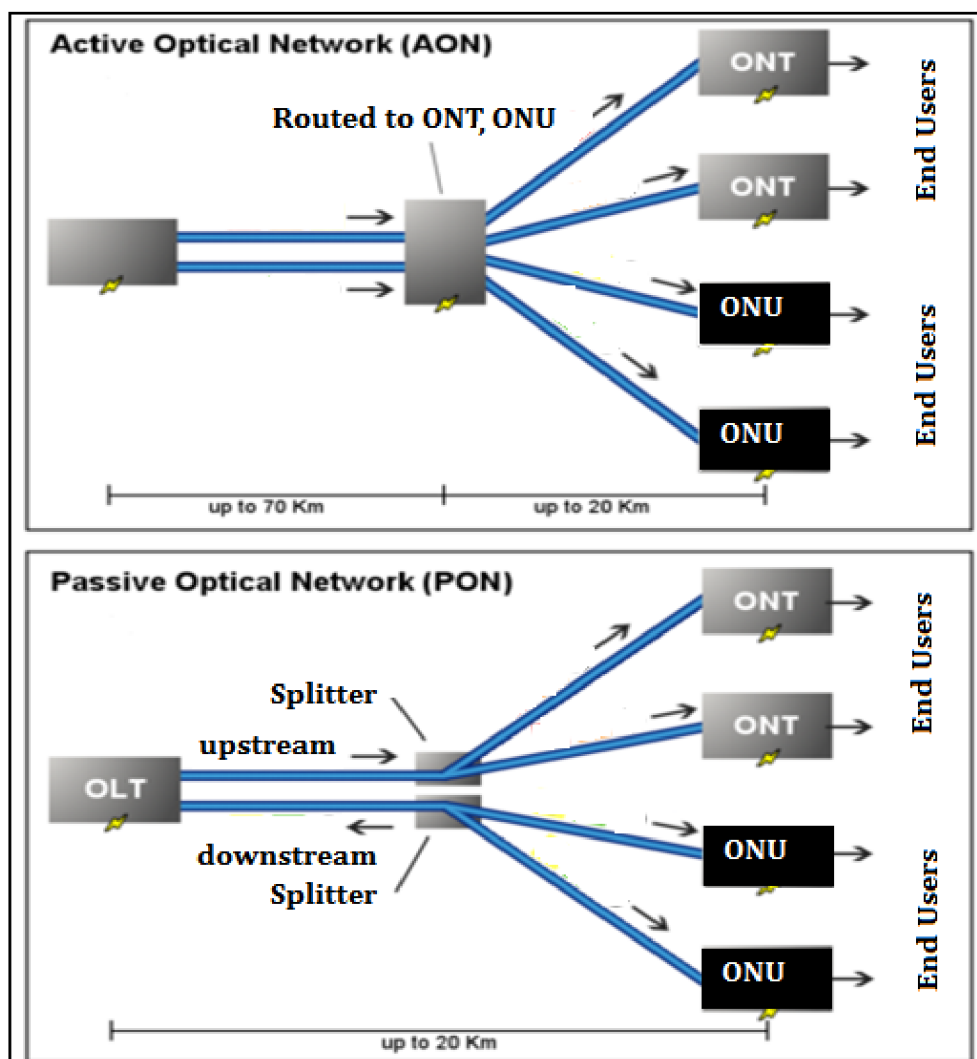


Fig. (4.2): The basic functional units forming the access network [34].

4.1 Active Optical Network (AON):

This solution is preferred dedicated channel for each user, which is full duplex and connects it to the access platform (router, switch). The optical network P2P can be viewed in two ways, in terms of physical connection point - a point or also in terms of logic circuit point - point. In the case of a physical connection point - the point is to each end user dedicated their fiber, whereas the logical connection point - the point is to each end user dedicated his channel. Examples include network WDM - PON, where the physical topology of PON, but the logical topology is P2P. The advantage is seamless solutions and low availability of services at the access line, which produces no aggregation and allows standard solutions based on optical Ethernet. AON can be used at greater distances than the PON; the limit is approximately 80 km depending on the number of end-users [20], [30]. The maximum number of end users is determined by the number of the active elements. The disadvantage is contrary to high investment costs that result from:

- The need to install point-to- point between each customer and access platform (large amounts of fiber, welding, fiber optic connectors, couplings, etc.)
- High power consumption energy (approximately 8-times more than P2MP)
- the existence of access aggregation platforms, which must be sufficiently scalable to potential customers in the region,
- needs a large space to close the connection of all customers, with sufficient margin for future upgrades (13-times more space compared to P2MP).

The easiest scheme of active optical network (AON) as following:

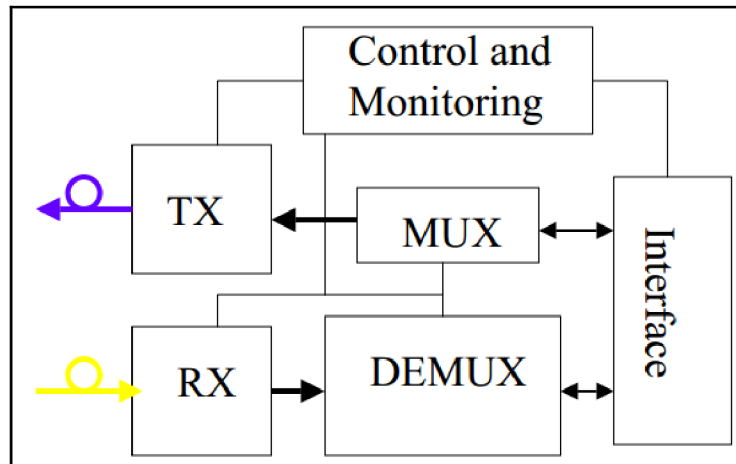


Fig. (4.3) The scheme of AON WDM [35].

4.1.1 Architectures of FTTH & Advantages of P2P vs P2MP/PON

Fiber To The Home (FTTH) can get Fiber Cable up to the Desk of a person accessing Internet at home & they can send and receive signals on the same fiber strand, the closer look at the two popular architectures that seek to dominate the FTTH market – P2P (Point to Point) & P2MP / PON (Point to Multi-point), along with some advantages of each.

Need for Speed, seems to be the priority of the day and with steep competition from 3.9/4G technologies & even satellite technologies that are racing ahead for providing faster broadband, the terrestrial broadband providers have responded with FTTH – Fiber To The Home at times.

FTTH technologies can give a minimum of 100 Mbps per house, if Point to Point technologies are used. Heck, they can even go up to 1 Gbps or 2.5 Gbps per house with currently available technology. Some applications that might be sent to your home via Fiber cables include High Speed Internet, Cable TV, On-Demand IPTV, HD Content, Movie Streaming, Telephone System, Multiplayer Gaming, Video Conferencing, 3D, Virtual Reality. Obviously, this technology requires service providers to lay fiber cables at all those places where existing copper telephone lines run today [36].

4.1.2 FTTH Architectures – P2P & P2MP/PON

There are two popular architectures used with FTTH – The Point to Point (P2P) Connectivity Architecture which uses all Active Components throughout the chain & Point to Multi-Point (P2MP)/ Passive Optical Network (PON) Connectivity Architecture which uses Passive Optical Splitters at the aggregation layer.

If we look closely at the diagram fig.(4.4), both the architectures are similar on the Central Office (CO) side and the Residential Complex side. They differ only in the Aggregation points (in the middle) [36].

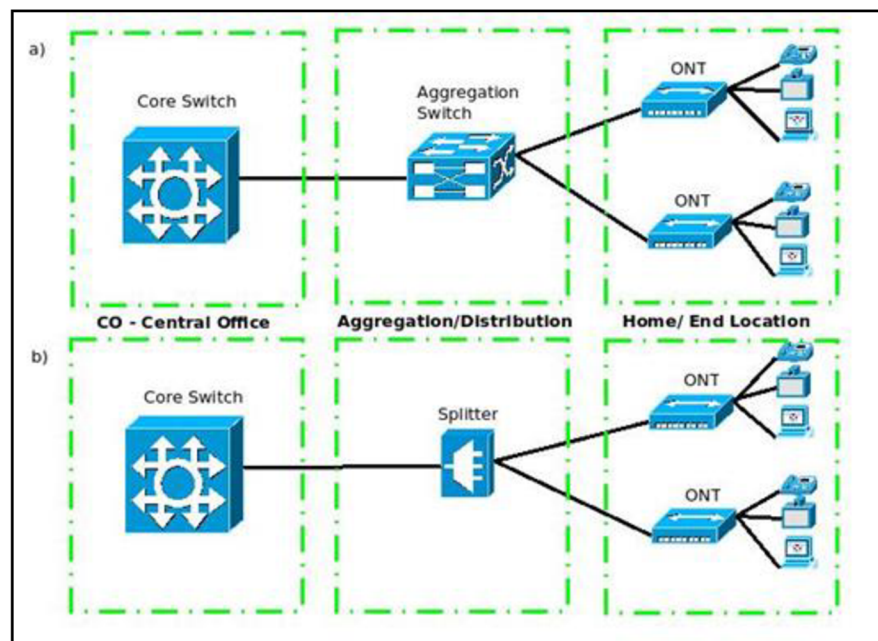


Fig. (4.4) Diagram P2P/P2MP in FTTH connection a) – Point To Point (P2P) FTTH architecture (using Active aggregation switch) b)- Point To MultiPoint (P2MP) FTTH architecture (using passive fiber splitter)

[36].

The Point to Point (P2P) architecture has a Core Switch at the Central Office which connects over optical fiber cables to an Aggregation Switch at the Distribution Points. These locations are typically our street corners, etc. The aggregation switches have many fiber ports and each port will directly connect to an ONT (Optical Network Termination points) placed at the residential localities using fiber cables. Typically, just outside the home or even inside it, in

some cases. From here, subscribers can use any access technology like Cat x cables/ wireless access points to complete the connection to their PC's, and other devices [36].

The Point to Multi-point (P2MP)/ Passive Optical Network (PON) architecture is the same, except in the distribution points. Instead of the Active Switches with Fiber Ports, Passive Splitters are used. These splitters do not require any power supply and they can divide an optical signal into 32, 64 or even 128 shared connections. The same signal is transmitted to all the houses beyond the splitter, but each ONT's in each house knows how to decipher the information meant only for itself. Of course, the ONT's used in P2P are different from the ones used in P2MP. Also, the total bandwidth is shared between all these shared connections. There are different types of PON like GPON used more in America; EPON used more in Asia, etc. [36].

The advantage of P2P & P2MP used in FTTH technology as these:

a) Advantages of P2P technology for FTTH:

1. The bandwidth in each port of the aggregation switch is dedicated to individual homes and there is no sharing of bandwidth. So, higher bandwidth per port (and hence per home) can be achieved through this technology.
2. This technology provides symmetrical bandwidth (equal bandwidth for upstream/ downstream) which is critical for some applications like HD Video Conferencing, Peer-to-Peer file sharing, etc.
3. P2P Technology is a standard technology and the bandwidth can be limited/ controlled per port and hence each house can have a bandwidth plan tailored to its requirements.
4. P2P technology can carry signals over a longer distance using fiber (100+ KM compared to 20+ KM for P2M). Trouble shooting faults is easier and can be done using OTDR (optical time domain reflect meter).
5. This technology is better for viewing Video On Demand/ Streaming video using multi-casting [36].

b) Advantages of P2MP/PON technology for FTTH:

1. Irrespective of all the propaganda all over the Internet, P2MP technology is less expensive to implement and maintain. It uses less active ports to terminate fiber and uses lesser fiber cables.

2. The fiber splitters don't require power supply and hence they can be placed anywhere on the field according to the project requirements. So, there is more installation flexibility.
2. With encryption, each connection can be secured/ isolated to a good extent.
3. It gives higher downstream bandwidth, and lower upstream bandwidth similar to current broadband technologies. But both of them are sufficiently and considerably high (GPON, for example, can give up to 2.5 Gbps of downstream bandwidth & 1 Gbps of upstream bandwidth, but that is shared among 32/64 users).
4. One can use traditional / digital set-top boxes to see TV through fiber cables using PON technology as these signals can be carried on an additional wavelength. These set top boxes are less expensive to buy when compared to IP set-top boxes.
5. The passive splitters are more rugged and can be used even in industrial environments, unlike the air-conditioning comfort needed for fiber switches [36].

4.2 Passive Optical Network (PON)

This network allows many users to share a single fiber without any active elements between OLT and ONT. The source signal is transmitted from the OLT to the splitter (splitter), which is located near the end users. The passive splitter is used to connect normally 32 or 64 of end users (it is given by the network infrastructure).

Each subscriber device is then terminated ONT. OLT provides voice and data transmissions incoming signal at wavelength 1490 nm or 1550 nm for CATV, while ONT ensures transmission of upstream signals at a wavelength of 1310 nm allows the transmission of just one fiber, without causing interference [26].

The disadvantage of this network is more complex solutions low quality of service for end customers, aggregation and limited maximum transmission rate. In all other parameters of the network is more advantageous than the P2P and are therefore often used modification PON networks [20], [24], [33].

Active elements are in CO (Central Office), at customer, in repeaters, switches and etc. All that equipment adds cost and complexity to the network.

Passive Optical Network (PON) which had no active components between CO and customer. Passive equipment has no electrical power needs, it guides the traffic signals contained within specific optical wavelengths.

Voice, video and data traffic flows (triple play) can be easily implemented using different wavelengths. And particular equipment used is GPON - GPON equipment.

In PON there are no active optical elements at any intermediate points along the network path see example of connecting in Fig. (4.5) shown down [37].

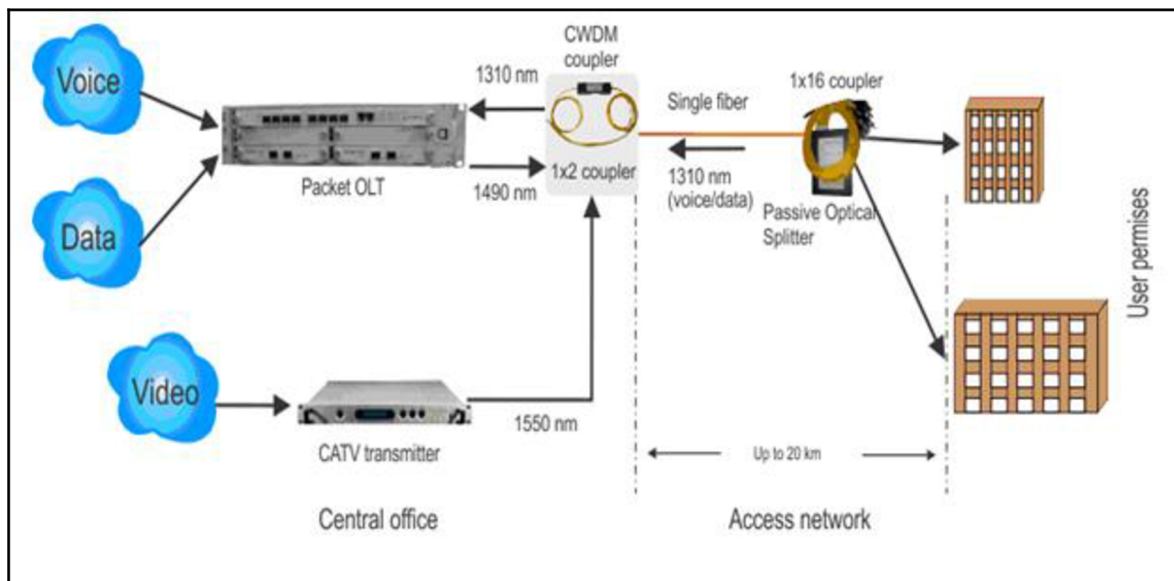


Fig. (4.5) PON without active optical elements [37].

An FTTH architecture consists of a passive optical network (PON), without any active components. In a PON, the customers share a line. From the OLT (Optical Line Terminal) at the central office, a fiber optic cable to the street cabinet (street cabinet) is brought close to the participant, from this point to be connected to the same fiber with a passive optical splitter 32 to 64, 128 customers.

The subscriber access is via an optical network termination (ONT = Optical Network Terminal). This point-to-multipoint structure significantly reduces the installation, maintenance and operating costs.

The OLT provides telephone and Internet in the downstream transmission at 1490 nm wavelength and the ONT transmit at 1310 nm upstream along the same fiber. In addition, the

OLT may be connected to a WDM (wavelength division multiplexing) coupler, to provide in addition to telephone and internet video services as well (triple play) of a fiber.

The video signal is only in the downstream direction the usual manner at 1550 nm wavelength is fed (traditional analog video) [38].

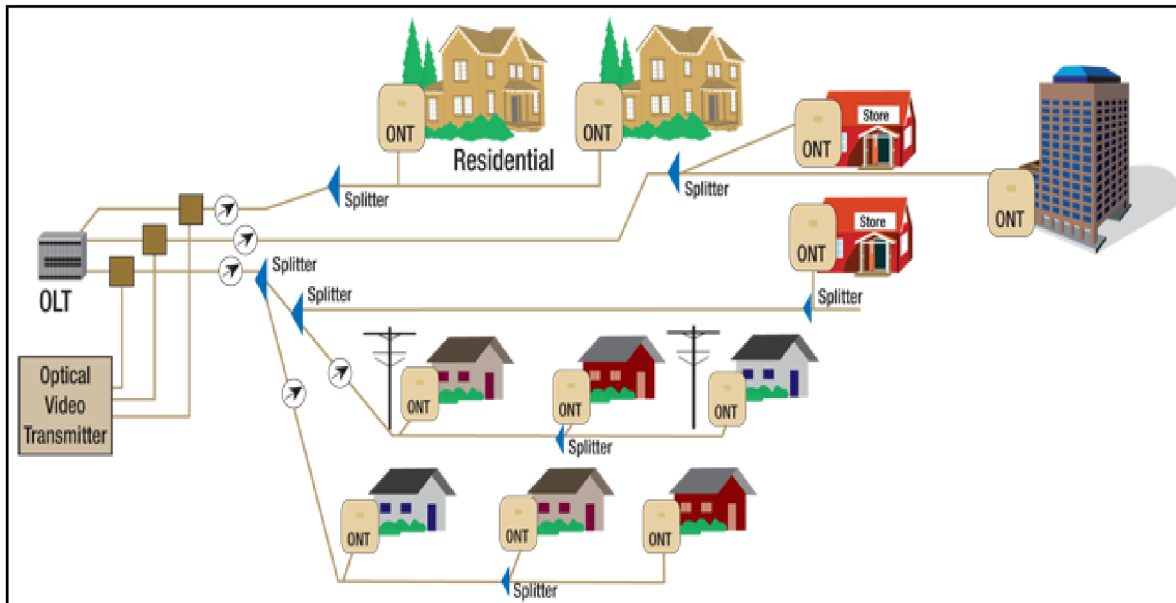


Fig. (4.6) Delivery of triple play services over a PON with high bandwidth [38].

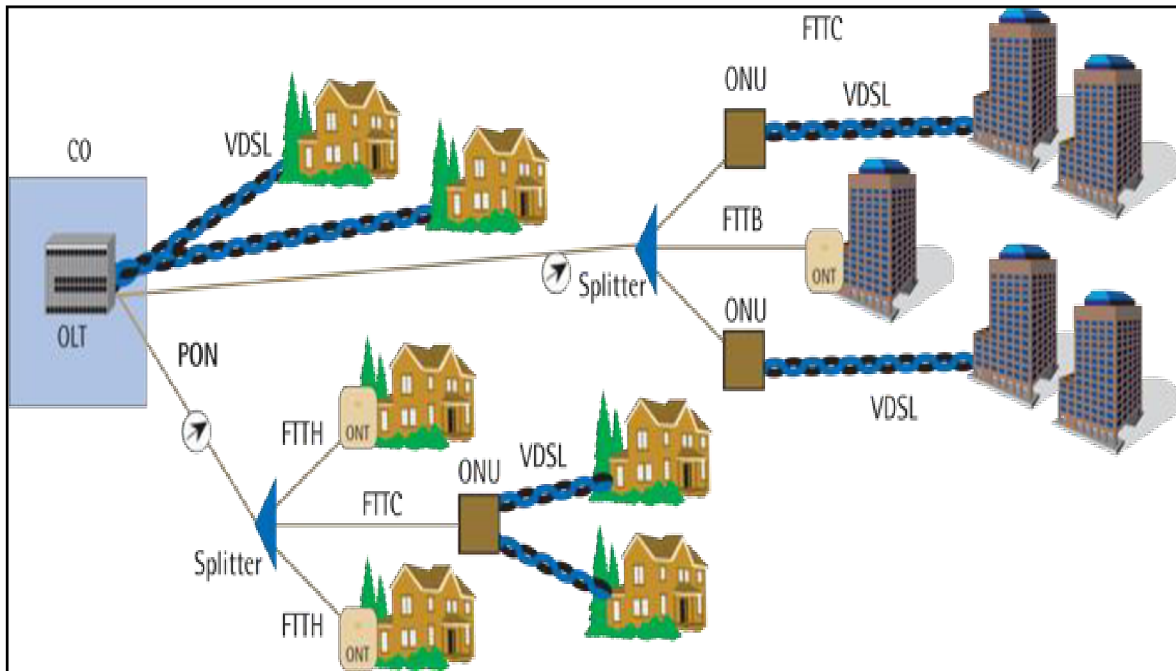


Fig. (4.7) FTTH, FTTB and FTTC - Triple Play services over PON [38].

Most PONs, for the distance less than 20 kilometers are configure like shown in fig. (4.8). The numbers of splitters and split levels varies with the vendor and the system. Split ratios are usually 1:32 1:64 or 1:128 but could be higher.

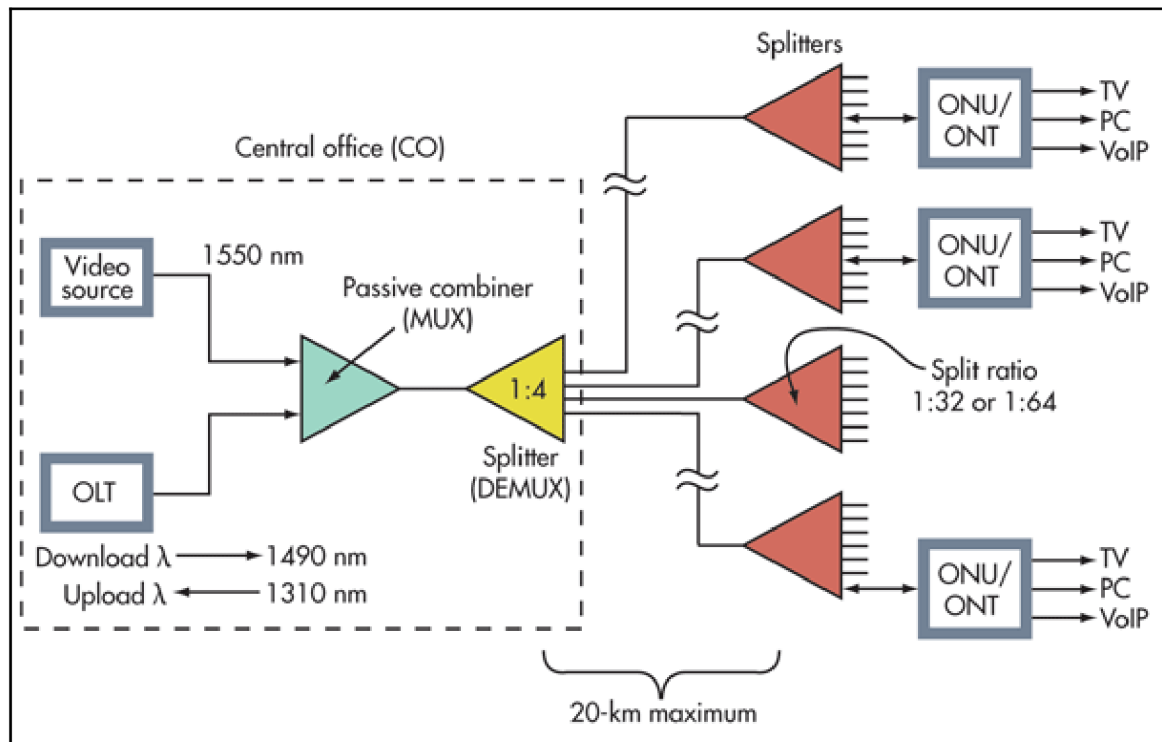


Fig. (4.8) Configure PON for less than 20-km in 1:32, 1:64 [39].

4.3 PON networks are divided into:

4.3.1 APON (ATM Passive Optical Network)

APON is a fiber network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. While an active optical network (AON) can cover a range to about 100 km (62 miles), a PON is typically limited to fiber cable runs of up to 20 km (12 miles). PONs also is called fiber to the home (FTTH) networks [20], [24], 30, [33].

The term FTTx is used to state how far a fiber run is. In FTTH, x is for home. You may also see it called FTTP or fiber to the premises. Another variation is FTTB for fiber to the building. These three versions define systems where the fiber runs all the way from the service provider to the customer. In other forms, the fiber is not run all the way to the customer. Instead, it is run to an interim node in the neighbourhood.

This is called FTTN for fiber to the node. Another variation is FTTC, or fiber to the curb. Here too the fiber does not run all the way to the home. FTTC and FTTN networks may use a customer's unshielded twisted-pair (UTP) copper telephone line to extend the services at lower cost. For example, a fast ADSL line carries the fiber data to the customer's devices [20], [24], [33].

The typical PON arrangement is a point to multi-point (P2MP) network where a central optical line terminal (OLT) at the service provider's facility distributes TV or Internet service to as many as 16 to 128 customers per fiber line. Optical splitters, passive optical devices that divide a single optical signal into multiple equal but lower-power signals, distribute the signals to users. An optical network unit (ONU) terminates the PON at the customer's home. The ONU usually communicates with an optical network terminal (ONT), which may be a separate box that connects the PON to TV sets, telephones, computers, or a wireless router. The ONU/ONT may be one device [20], [24], [33].

In the basic method of operation for downstream distribution on one wavelength of light from OLT to ONU/ONT, all customers receive the same data. The ONU recognizes data targeted at each user. For the upstream from ONU to OLT, a time division multiplex (TDM) technique is used where each user is assigned a timeslot on a different wavelength of light. With this arrangement, the splitters act as power combiners. The upstream transmissions, called burst-mode operations, occur at random as a user needs to send data. The system assigns a slot as needed. Because the TDM method involves multiple users on a single transmission, the upstream data rate is always slower than the downstream rate [20], [24], [33].

4.3.2 GPON (Gigabit PON) - (BPON- Broadband)

Over the years, various PON standards have been developed. In the late 1990s, the International Telecommunications Union (ITU) created the APON standard, which used the Asynchronous Transfer Mode (ATM) for long-haul packet transmission. Since ATM is no longer used, a newer version was created called the broadband PON, or BPON. Designated as ITU-T G.983, this standard provided for $622 \text{ Mbit}\cdot\text{s}^{-1}$ downstream and $155 \text{ Mbit}\cdot\text{s}^{-1}$ upstream.

While BPON may still be used in some systems, most current networks use GPON, or Gigabit PON. The ITU-T standard is G.984. It delivers $2.488 \text{ Gbit}\cdot\text{s}^{-1}$ downstream and $1.244 \text{ Gbit}\cdot\text{s}^{-1}$ upstream [20],[24],[33].

GPON uses optical wavelength division multiplexing (WDM) so a single fiber can be used for both downstream and upstream data. A laser on a wavelength (λ) of 1490 nm transmits downstream data. Upstream data transmits on a wavelength of 1310 nm. If TV is being distributed, a wavelength of 1550 nm is used.

While each ONU gets the full downstream rate of 2.488 Gbit*s⁻¹, GPON uses a time division multiple access (TDMA) format to allocate a specific timeslot to each user. This divides the bandwidth so each user gets a fraction such as 100 Mbit*s⁻¹ depending upon how the service provider allocates it.

The upstream rate is less than the maximum because it is shared with other ONUs in a TDMA scheme. The OLT determines the distance and time delay of each subscriber. Then software provides a way to allot timeslots to upstream data for each user.

The typical split of a single fiber is 1:32 or 1:64. That means each fiber can serve up to 32 or 64 subscribers. Split ratios up to 1:128 are possible in some systems.

As for data format, the GPON packets can handle ATM packets directly. Recall that ATM packages everything in 53-byte packets with 48 for data and 5 for overhead. GPON also uses a generic encapsulation method to carry other protocols. It can encapsulate Ethernet, IP, TCP, UDP, T1/E1, video, VoIP, or other protocols as called for by the data transmission. Minimum packet size is 53 bytes, and the maximum is 1518. AES encryption is used downstream only.

The latest version of GPON is a 10-Gigabit version called XGPON, or 10G-PON. As the demand for video and over the top (OTT) TV services has increased, there is an increasing need to boost line rates to handle the massive data of high-definition video. XGPON serves this purpose. The ITU standard is G.987 [20].

XGPON's maximum rate is 10 G bit*s⁻¹ (9.95328) downstream and 2.5 G bit*s⁻¹ (2.48832) upstream. Different WDM wavelengths are used, 1577 nm downstream and 1270 nm upstream. This allows 10-Gbit/s service to coexist on the same fiber with standard GPON. Optical split is 1:128, and data formatting is the same as GPON. Maximum range is still 20 km. XGPON is not yet widely implemented but provides an excellent upgrade path for service providers and customers [20].

4.3.3 EPON (Ethernet PON)

The Institute of Electrical and Electronic Engineers (IEEE) developed another newer PON standard. Based on the Ethernet standard 802.3, EPON 802.3ah specifies a similar passive network with a range of up to 20 km. It uses WDM with the same optical frequencies as GPON and TDMA. The raw line data rate is $1.25 \text{ Gbit} \cdot \text{s}^{-1}$ in both the downstream and upstream directions. You will sometimes hear the network referred to as Gigabit Ethernet PON or GEAPON [20].

EPON is fully compatible with other Ethernet standards, so no conversion or encapsulation is necessary when connecting to Ethernet-based networks on either end. The same Ethernet frame is used with a payload of up to 1518 bytes. EPON does not use the CSMA/CD access method used in other versions of Ethernet. Since Ethernet is the primary networking technology used in local-area networks (LANs) and now in metro-area networks (MANs), no protocol conversion is needed.

There is also a 10 Gbit Ethernet version designated 802.3av. The actual line rate is $10.3125 \text{ Gbit} \cdot \text{s}^{-1}$. The primary mode is $10 \text{ Gbit} \cdot \text{s}^{-1}$ upstream as well as downstream. A variation uses $10 \text{ Gbit} \cdot \text{s}^{-1}$ downstream and $1 \text{ Gbit} \cdot \text{s}^{-1}$ upstream. The 10-Gbit/s versions use different optical wavelengths on the fiber, 1575 to 1580 nm downstream and 1260 to 1280 nm upstream so the 10 Gbit's system can be wavelength multiplexed on the same fiber as a standard 1 Gbit's system [20]. Standard EPON is based on the transmission of Ethernet frames of fixed length of 2 ms. This standard is sometimes also referred to as GEAPON, where G denotes gigabit transfer speeds. Standard was designed by the IEEE under the name IEEE 802.3ah. Supports data rates of $1.25 \text{ Gbps} \cdot \text{s}^{-1}$ symmetrically. Two-way traffic can be solved again using separate threads or Wavelength Division. Towards the user is assigned a wavelength 1480 nm - 1500 nm, and the downstream wavelength range 1260 nm - 1360 nm. Maximum branching ratio is 1:32 and the physical network reach 20 km [20], [24], [32], [33].

4.3.4 10GEAPON (10 Gigabit EPON)

Standard comes directly from the standard APON / BPON. It is defined by ITU - T G.984.1. The data is used ATM cells and GEM protocol. ATM cells and GEM frames or their fragments are transmitted together within a fixed length of 125 microseconds; this allows a packet-oriented

transmission service and Ethernet IP. The Standard defines the baud rate $1.244 \text{ Gbit}\cdot\text{s}^{-1}$ or $2.488 \text{ Gbit}\cdot\text{s}^{-1}$ symmetrically or asymmetrically $2.488 \text{ Gbit}\cdot\text{s}^{-1}$ to the user and $1.244 \text{ Gbit}\cdot\text{s}^{-1}$ in the direction from the user. GPON is compatible with the APON / GPON, therefore, to maintain support transmission speeds $155.52 \text{ Mbit}\cdot\text{s}^{-1}$ and $622.08 \text{ Mbit}\cdot\text{s}^{-1}$. As with APON / BPON to separate the transfer direction using two separate fibers, or wave division. Upstream assigned wavelength $1260 \text{ nm} - 1360 \text{ nm}$, and in the downstream wavelength range $1480 \text{ nm} - 1500 \text{ nm}$. Standard allows a maximum strip ratio of 1:64, and a maximum range of 20 km network [20], [24], [32], [33]. Standard 10GEPON nowadays optical networks are built based primarily on standards GPON, EPON and recently also 10GEPON, which differ in the protocol used on the other (connection) layer model RM - OSI, shared transmission speeds, the demands on the performance of the optical distribution network and other parameters. Standard was established only in 2009 under the name IEEE 801.3av. It is backward compatible with EPON, which allows its introduction into existing passive network without major investments.

Supports baud rate $10.3125 \text{ Gbit}\cdot\text{s}^{-1}$ symmetrically or asymmetrically when the upstream transmission rate is $10.3125 \text{ Gbit}\cdot\text{s}^{-1}$ and in the opposite direction $1.25 \text{ Gbit}\cdot\text{s}^{-1}$. Posting in both directions is solved as in the previous cases, using wave division. To transmit data to the user is used wavelength $1575 \text{ nm} - 1580 \text{ nm}$. In the opposite direction of the $1260 \text{ nm} - 1280 \text{ nm}$ symmetric service and $1260 \text{ nm} - 1360 \text{ nm}$ for asymmetric service. Physical network range is 20 km and the maximum branching ratio of 1:32. By changing the physical distance can change the branching ratio and vice versa [20], [24], [32], [33].

4.4 WDM PON

Passive network based on the classic time division is gradually approaching its maximum limit. Therefore, the next generation optical access networks certainly based on the principle of wavelength multiplex combined with time division (using passive splitters). From the beginning it will probably apply more CWDM systems due to lower prices. Then it will be only a matter of time before this technology will be combined with DWDM.

4.4.1 Types of possible implementation of WDM - PON

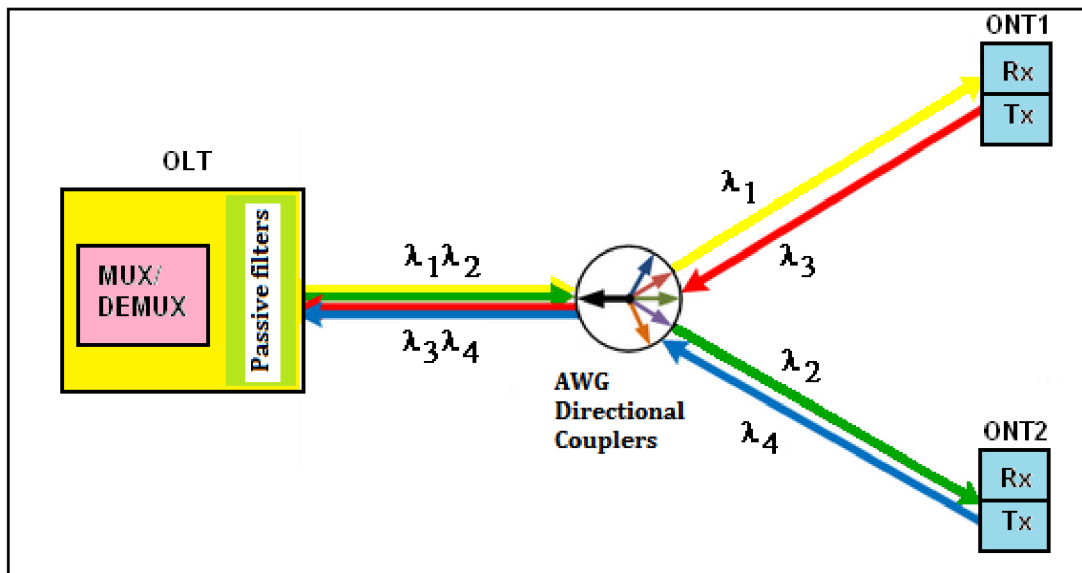
- The first variant considered only fixed wavelength assigned to all end units. It means, the network will use the classic splitter and downstream signal will spread to all the end users. ONT contains a fixed filter that divides its designated carrier wavelength.

In the upstream direction will each have their individual ONT unit emission wavelength, which will transmit outgoing data streams. In terms of logical topology is a network of point-to-point. ONT units are tuned to have one common wavelength, which is used for the broadcast. The disadvantages of this implementation are similar to conventional PON networks, the downstream is necessary to prevent the interception of various encryption methods. Fixed assignment of wavelengths makes network inflexible to changes as transmission capacity is used uneconomically. Another disadvantage is that the network cannot be two units communicating on the same wavelength [20], [32], and [33].

- The second variant used instead of conventional directional coupler splits AWG (Arrayed Waveguide Grating). The difference from the previous version is obvious in the downstream direction the signal is coming through AWG divided into individual wavelengths, whose support to designated units ONT spreading in separate ducts. In the upstream direction is the same principle as in the first variant. Each unit of ONT sends the data streams to its dedicated wavelength. The advantage of this variant is notably lower insertion loss than conventional AWG coupler splitters; this value is around 5 dB regardless of the number of wavelengths. Further advantages result from the removal of the filters in the ONT unit, which means a reduction in the total attenuation. If this variant is used in units of DFB lasers.

- Third feasibility of WDM PON is based on the combination of conventional AWG and splitters or cascade sort. This combination then uses the separation of optical signals based on the wavelengths (in AWG) combined time division (time slots in splitter) represents the maximum bandwidth utilization. All this topology leads to a universal plan Fiber Channel network. The use of universal ONT units and optional wavelengths also serves the channel allocation to units based on the current needs and requirements. This mechanism is called DWA (Dynamic Wavelength Assignment) [20].

- Fourth feasibility of WDM PON is again based on the principle of AWG coupler, the difference is in the ONT units. It is used in them FP laser optically hinged on stimulation wavelength coming from the AWG [20], [30]. Incoming light beam passes through a filter where the incoming direction of the separated signal, and continues to the receiving part ONT. The other part of the light beam passes through the filter further on FP laser. By hanging FP laser stimulation wavelength changes the spectrum of FP laser, which was originally made up of periodic waves, the spectrum with narrow spectral line, which makes it possible to use a FP laser transmitter for WDM - PON system.



Fig(4.9) WDM - PON using a directional coupler AWG [20].

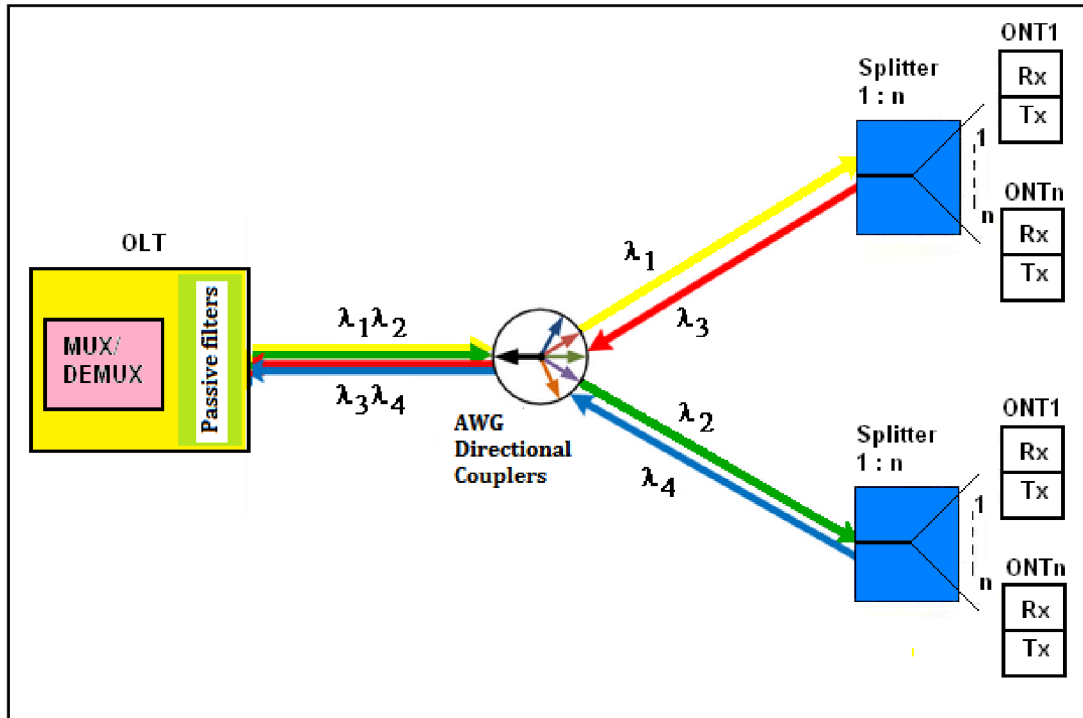


Fig.(4.10) WDM PON using a combination of AWG and splitters [20].

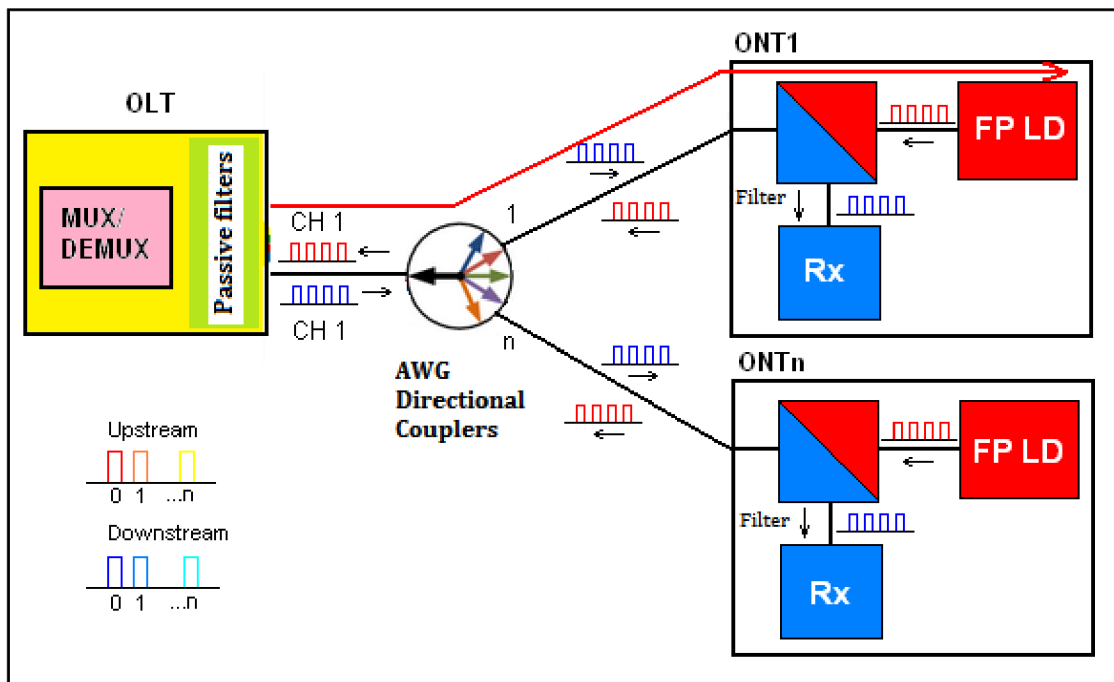


Fig. (4.11) WDM - PON using FP lasers ONT units [20].

4.4.2 Description of the example proposed topology GPON

This easy example of topology consists of a device to the provider (OLT), the distribution network (ODN) and from the device to the end user (ONT). The overall wiring diagram is included in Annex A [20].

OLT

Unit OLT and ONT for duplex operation include both the optical transmitter and receiver. In this case, the topology of an optical transmitter the following parameters:

- Wavelength of 1550 nm,
- Transmit power of -3 dBm,
- Transfer rate of 2.5 Gbit*s-1,
- NRZ modulation.

Power -3 dBm was chosen because of the optical paths 20 km and a small number of end users. The optical receiver consists of a PIN photodiode, low-pass filter (Bessel filter), buffer selector and 3R regenerator (element ensuring the recovery of the desired signal level). Lowpass filtered high frequency noise buffer selector is used for simulation purposes (to select the iteration, which has release). For two-way traffic circulator is used.

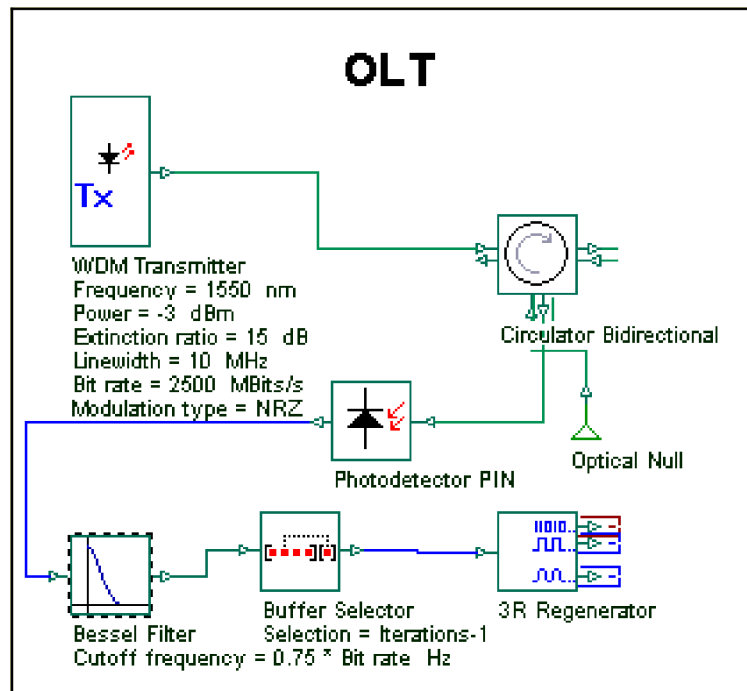


Fig. (4.12) The GPON OLT [20].

ODN

The optical distribution network consists of 20 km of optical fiber with parameters corresponding fiber G.652.C / D, i.e., insertion loss 0.2 dB / km and chromatic dispersion of 16.75 PS / nm / km. Elements marked as OD (Optical Delay) is used again for simulation purposes and are necessary for two-way traffic. Another essential element of the passive optical network splitter with a branching ratio of 1:4. Its insertion loss is approximately 6 dB. The exact value of the software calculates automatically [20].

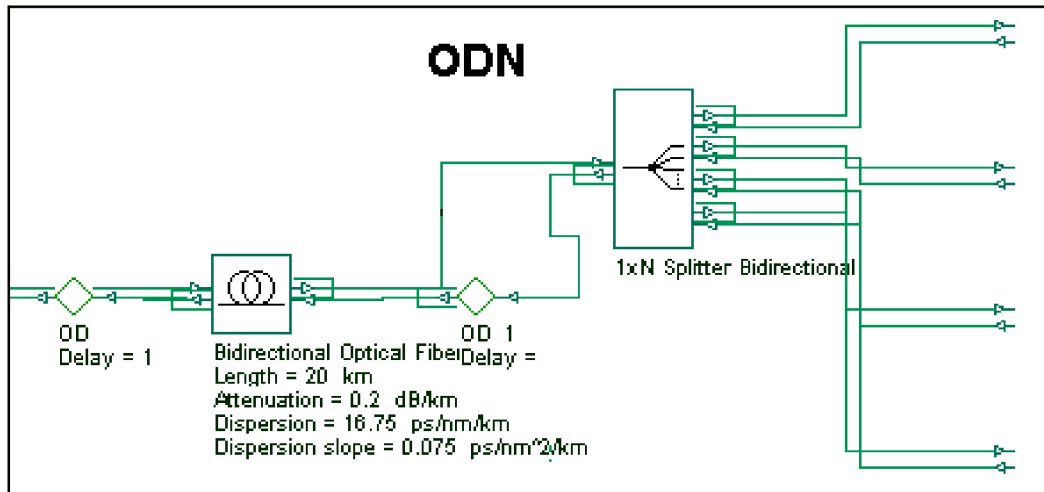


Fig. (4.13) The optical distribution network with GPON [20].

ONT

Optical terminating units are formed again, the transmitting and receiving parts. The receiving part consists of a PIN diode and a Bessel filter. The transmitter has a wavelength difference of the same characteristics as the OLT. The wavelength in this case is 1300 nm. Part ONT units are also 3R regenerators, which are connected to the Bessel filters. In real involvement would have to be used and the ONT unit circulator to provide bi-directional transmission over a single fiber [20].

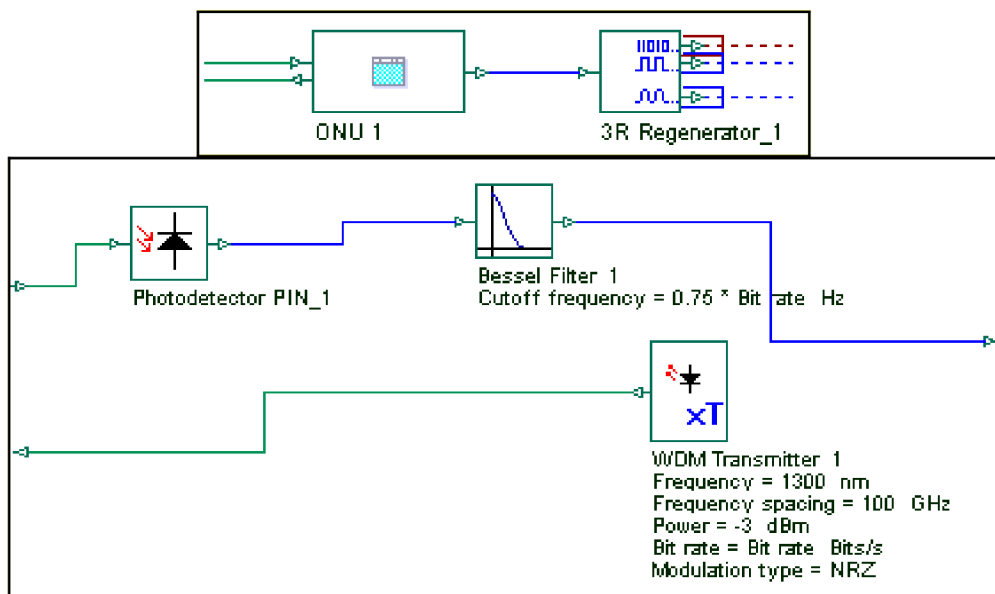


Fig. (4.14) The internal layout of units for GPON ONT [20].

4.5 The Loss Budget & testing types

4.5.1 Cable plant link loss budget analysis

In order to operate properly, a fiber optic network link must have an adequate loss margin. That is, the total loss in the installed cable plant must be less than the tolerable loss of the transmitters and receivers in the transmission equipment being used. Figure (4.15) graphically illustrates the link loss parameters. During the design phase, the cable plant loss must be estimated, based on average component specifications and the total cable length, to ensure the chosen equipment will work properly. Ideally, there should be at least 3 dB less loss in the cable plant than the link dynamic range to allow for component degradation and potential restoration splicing. Loss budget analysis calculation and verification of a fiber optic system's operating characteristics includes all items in the cable plant, such as fiber length, number of connectors and splices, and any other passive components such as optical splitters. Optical loss is the key parameter for loss budget analysis, but bandwidth must be considered in some high bit-rate multimode systems such as FDDI (Fiber Distributed Data Interface), where a maximum cable length is specified regardless of optical loss. Prior to implementing or designing a fiber optic circuit, a cable plant loss analysis is required. Prior to system turn up, test the circuit with a source and fiber optic power meter to ensure that it is within the loss budget [7], [8], [10].

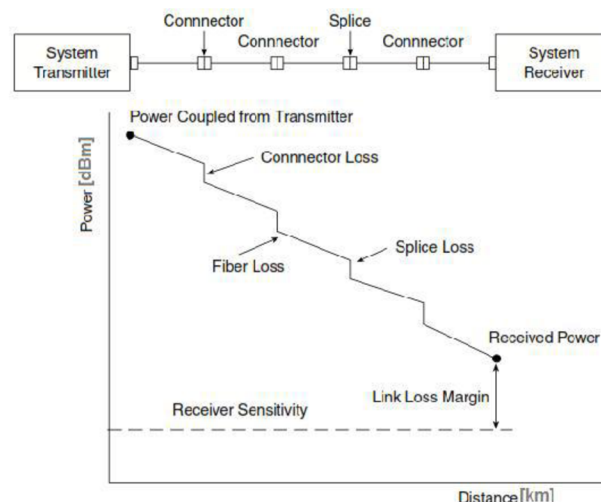


Fig. (4.15) Fiber optic link loss budget [7],[8].

4.5.2 Connector loss factors

Attenuation is the loss of signal or light intensity as it travels through an optical fiber transmission system. Attenuation in the optical fiber itself usually occurs as a result of absorption, reflection, diffusion, scattering, or dispersion of the photon packets within the fiber. However, losses also occur at splices and connections. The factors that cause attenuation in connectors or splices Figure (4.16) fall into two categories: intrinsic and extrinsic losses. Intrinsic losses occur from factors over which the craftsperson has very little control and are generally caused by engineering design or manufacturing flaws in the fiber itself. The more prominent intrinsic losses include:

1. Core eccentricity
2. Core ellipticity
3. Numerical aperture (NA) mismatch
4. Core diameter mismatch

Core eccentricity means that the exact center of the core center and the exact center of the cladding are not precisely the same, causing an overlap or underlap of fiber cores at a splice point. Core ellipticity (or ovality) is a departure from circularity. A very small variation in the roundness of a fiber core can affect the total system loss.

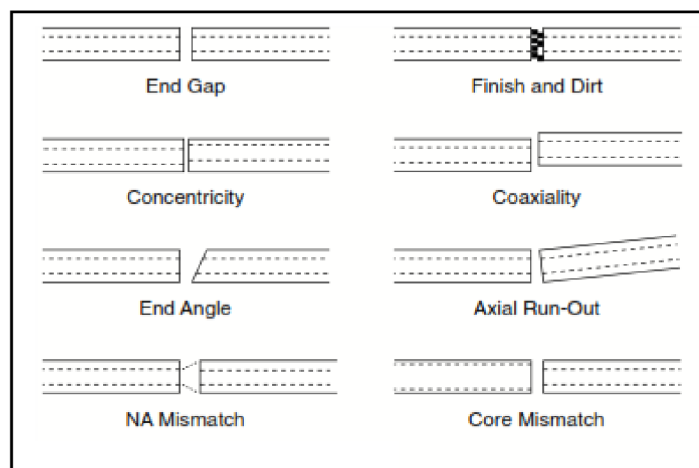


Fig. (4.16) Connector loss factors [7],[8].

Intrinsic loss through mismatch of NAs is not the fault of the craftsperson; however, care must be taken to butt the fibers as closely as possible to counteract this

mismatch. When splicing fibers having cores of different diameters, testing will show a significant loss when testing from the large core into the small core, and will show a supposed gain when testing from the small core into the large core. Extrinsic losses, on the other hand, are caused by the mechanics of the joint itself. Frequent causes of extrinsic loss attenuation at splicing points include:

- Misalignment of fiber ends caused by improper insertion techniques into splices and connectors.
- Bad cleaves and poor polishing techniques resulting in poor end face quality.
- Inadvertent air spaces between fibers at a splice or connection that have not been corrected with index-matching gel or liquid.
- Contamination caused by dirt, wiping tissue, cotton swabs, shirt sleeves, or airborne dust particles.
- Another loss mechanism is back reflection or reflectance and is measured as optical return loss Figure (4.17). As the light travels through the fiber, passing through splices and connections, finally arriving at the end point, some of that light is reflected back by fiber end faces at those man-made points. Optical return loss is generally only an issue with high-performance single mode networks but is now also an issue with multi-mode networks used for gigabit networks [7],[8],[10].

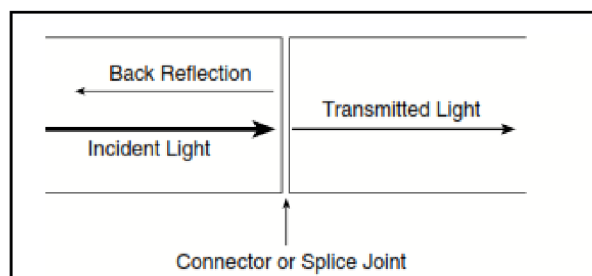


Fig. (4.17) Optical return loss [7],[8].

Cable plant passive component loss

Consider the link shown in Fig. (4.15), for operation at 1300 nm on multimode fiber.

Step 1: Fiber Loss at the Operating Wavelength

Tab. (4.1)

Cable length (km) Typical fiber loss:	2.0 km	
Fiber type	Single mode	
Wavelength (nm)	1300	1550
Fiber attenuation (dB/km)	0.35	0.25
Total fiber loss for system		
Operating on multimode: fiber at 1300 nm	2.0	

Step 2: Connector Loss

Tab. (4.2)

Typical connector loss	0.5dB
Total number of connector pairs	5 (including connectors on ends of cable.)
Total connector loss	2.5dB

Step 3: Splice Loss

Tab. (4.3)

Typical splice loss	0.05 dB
Total number of splices	1
Total splice loss	0.2d B

Step 4: Total Cable Plant Attenuation

Tab. (4.4)

Total fiber loss (dB)	2.0
Total connector loss (dB)	2.5
Total splice loss (dB)	0.2
Other (dB)	0
Total link loss (dB)	4.7

Equipment link loss budget calculation for active components

Step 5: From manufacturer's specification for active components

Tab. (4.5)

Operating wavelength (nm)	1300
Fiber type	MM
Receiver sensitivity (dBm at specified BER)	-31
Average transmitter output (dBm)	-18
Dynamic range (dB)	13
Recommended excess margin (dB)	3
Maximum cable plant loss (dB)	10

Step 6: Loss Margin Calculation

Tab (4.6)

Dynamic range (dB)	10
Cable plant link loss (dB)	-4.7
Link loss margin (dB)	5.3

This calculation must be verified by testing with a source of the proper wave length and a power meter after installation. In some cases, where the equipment may be operating on two different wavelengths or future upgrades are planned, testing at two wavelengths may be required. If the calculated and tested values differ considerably, but all the tested fibers in the cable are similar in loss, remember the specifications used for calculations are not exact. As long as proper operating margins are available, the cable plant should be acceptable [7], [8], and [10].

5 Practical & lab measurement of FTTH Network

Various laboratory measurements are routinely performed on telecommunication fibers to test their performance as components of fiber-optics communication systems. Some of these measurements are listed below.

Attenuation is the loss of optical power as a result of absorption, scattering, bending, and other loss mechanisms as the light travels through the fiber.

The total attenuation is a function of the wavelength λ of the light. The total attenuation A between two arbitrary points X and Y on the fiber is:

$$A(\text{dB}) = 10 \log \frac{P_x}{P_y}, \quad (1)$$

where P_x is the power output at point X . P_y is the power output at point Y . Point X is assumed to be closer to the optical source than point Y . The attenuation coefficient or attenuation rate α is given by:

$$\alpha \left(\frac{\text{dB}}{\text{km}} \right) = \frac{A}{L} \quad (2)$$

Here L is the distance between points X and Y .

The cutoff wavelength of a single mode fiber is the wavelength above which the fiber propagates only the fundamental mode. We need $V = k f a \text{ NA} = 2\pi a \text{ NA} / \lambda_0 < 2.405$. The cutoff wavelength of a single mode fiber is a function of the fiber's radius of curvature. Measuring the cutoff wavelength involves comparing the transmitted power from a test fiber with that of a reference fiber as a function of wavelengths.

The dispersion occurs because the index of refraction is a function of wavelength and different wavelengths of light travel through the fiber at different speeds. The chromatic dispersion of multimode graded-index and single mode fibers is obtained by measuring the time it takes pulses of light with different wavelengths to travel through a long piece of fiber. These measurements are made using multi-wavelengths sources such as wavelength-selectable lasers or multiple sources of different wavelengths.

The **reflectance** R is the fraction of the incident intensity that is reflected back into the source fiber at the point of the connection. The **return loss** RL is defined as

$$RL(dB) = -10 \log R. \quad (3)$$

The reflectance R is measured using an optical source connected to one input of a 2 X 2 fiber optic coupler. Light is launched into the component under test through the fiber optic coupler. The light reflected from the component under test is transmitted back through the fiber optic coupler to a detector connected to the other input port.

5.6 Testing FTTH networks during construction

During network construction, some testing occurs in the outside plant. When fiber is laid down new splices have to be done and tested using an OTDR. For accurate measurements, bidirectional OTDR measurements should be performed. For acceptance testing, it is important to test each segment of the construction. There are several testing methods, some of which are presented here. Each has specific advantages and disadvantages. Selecting the most appropriate method depends on the constraints faced:

Method 1: Use of optical loss test sets

This first method involves using an optical loss test set (OLTS), comprising two test sets that share data to measure insertion loss (IL) and optical return loss (ORL). First, the units should be referenced prior to measuring IL.

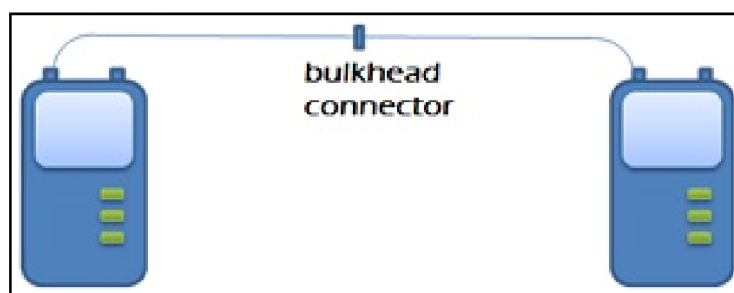


Fig.(5.1) Test sets should be referenced prior to measurement [40].

Next, ORL sensitivity is set by calibrating the minimum ORL that the units can measure. The limitation comes from the weakest part of the test setup, which is most likely to be the connector between the units and reference test jumper. Follow the manufacturer's instructions to

set the ORL sensitivity on both units and to reference the source and the power meter. Measurements can now be taken on the end-to-end network or any individual installed segment, such as the fibers between the FCP and the drop terminal. The purpose of the test is to identify any transposed fibers and to measure the IL and ORL to guarantee that the loss budget has been met.

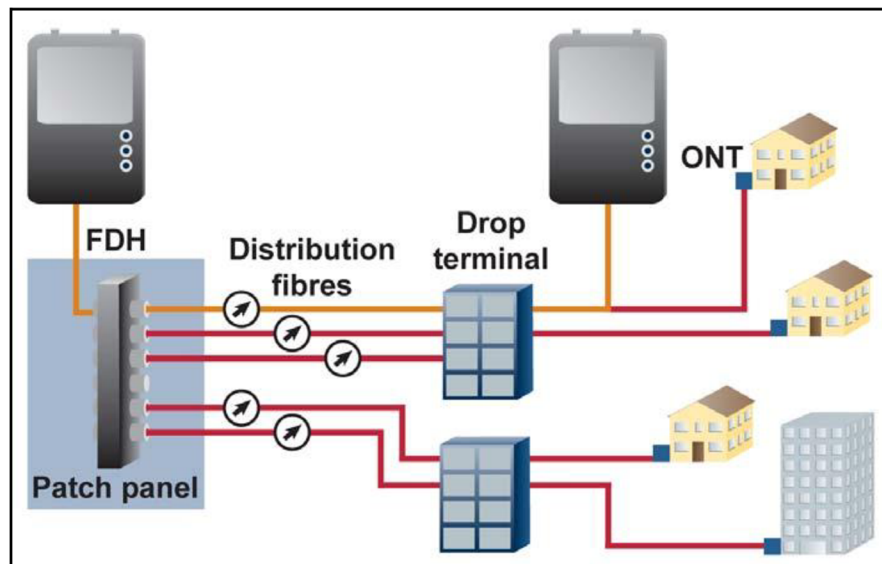


Fig. (5.2) Measuring distribution fiber IL and ORL using two OLTs [40].

These values only take into account two connections. FTTH networks often comprise of multiple connection points and, as reflectance values are very sensitive to dust and scratches, these values can easily be influenced by bad connections. For example, a single connector may generate an ORL of 40 dB, which would exceed the expected value for the entire network. For point-to-multipoint network, the ORL contribution of each fiber is attenuated by 30 to 32 dB due to the splitter's bidirectional loss.

Tab. (5.1) The advantage & disadvantage method (1).

Advantage of Method 1: OLTS	Disadvantages of Method 1: OLTS
Accurate IL and ORL measurement	Two technicians required (however with a point-to-multipoint network, a single OLTS close to the OLT can be used for all subscribers within the same network)
Bidirectional IL and ORL values	Communication required between technicians (when switching fibers)

Possibility to test every distribution fiber	A point-to-multipoint network requires, one technician to move from drop terminal to drop terminal
Macrobend identification during testing is performed at 1550 and 1310 nm or another combination of wavelengths including the 1625 nm wavelength	In the event of a cut fiber or macrobend, an OTDR is required to locate the fault
Transposed fiber identification on point-to-point networks	Impossible to detect transposed fiber on point-to-multipoint network
Fast testing	

Method 2: Use of an OTDR

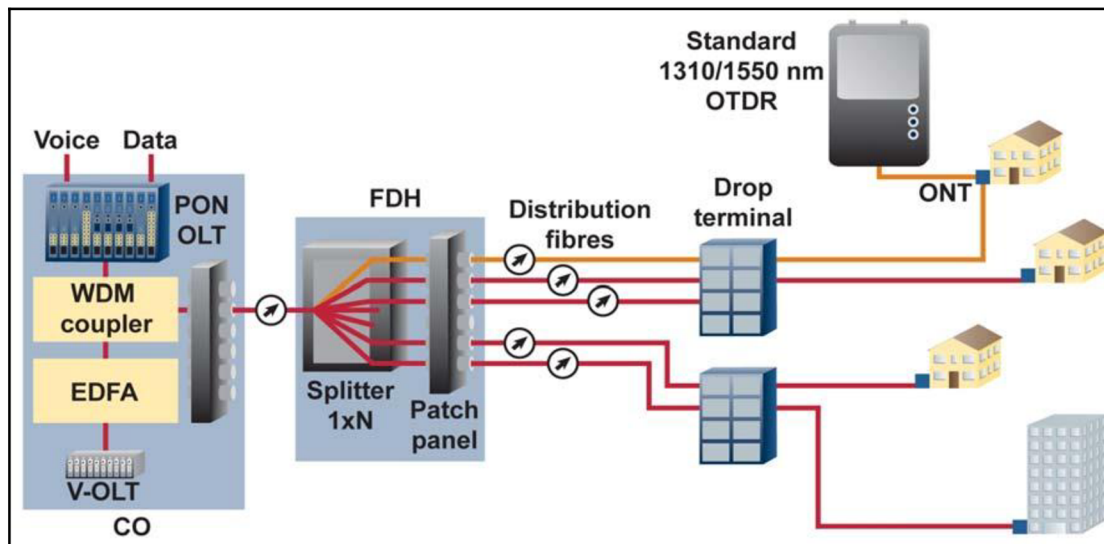


Fig. (5.3) Measurement method an OTDR [40].

This method uses an optical time-domain reflectometry (OTDR). Unlike an OLTS, the OTDR can identify and locate the position of each component in the network. The OTDR will reveal splice loss, connector loss and reflectance, and the total end to end loss and ORL. All fibers between the OLT and before the first splitter (transport side) may be tested to characterize the loss of each splice and locate macro bends. The test can be conducted to cover both directions. Post-processing of the results will be required to calculate the real loss of each splice (averaged between each direction).

The engineer can measure the loss of the splitter and the cumulative link loss, as well as

identifying whether any unexpected physical event has occurred before, or after, the splitter. Construction testing can significantly reduce the number of problems that occur after subscriber activation by certifying end-to-end link integrity.

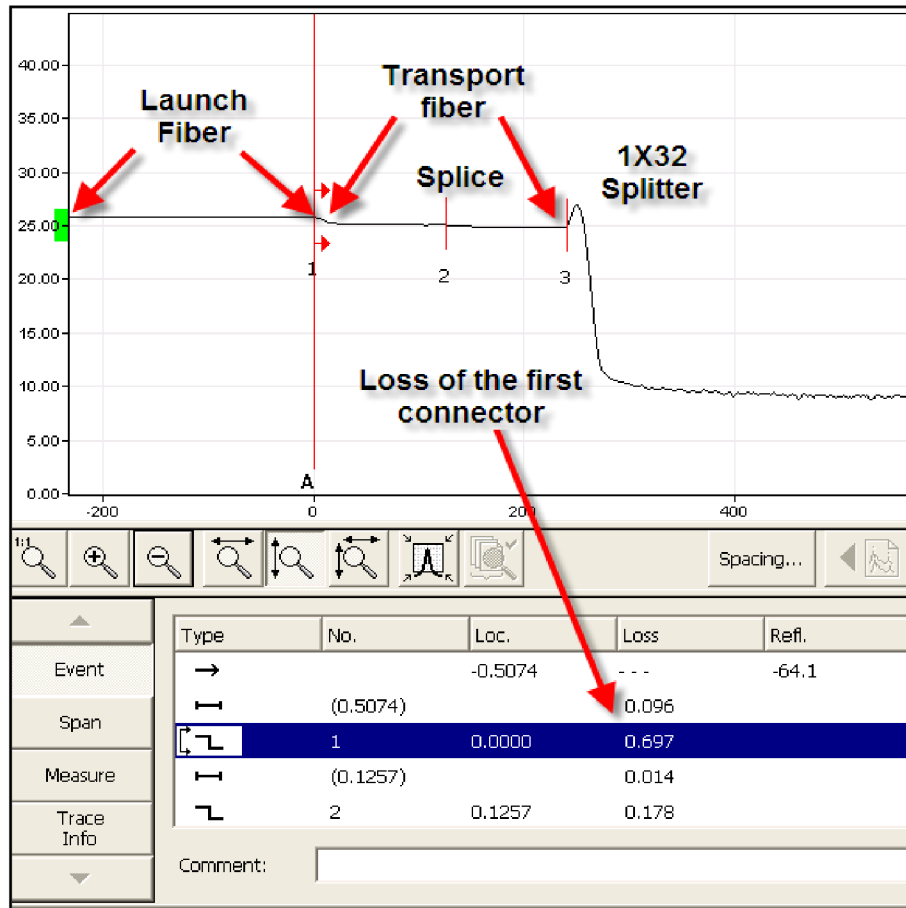


Fig. (5.4) Using a launch fiber makes it possible to characterize the first connector on any segment of the network. A pulse width of 300-500m will be sufficient for this test [40].

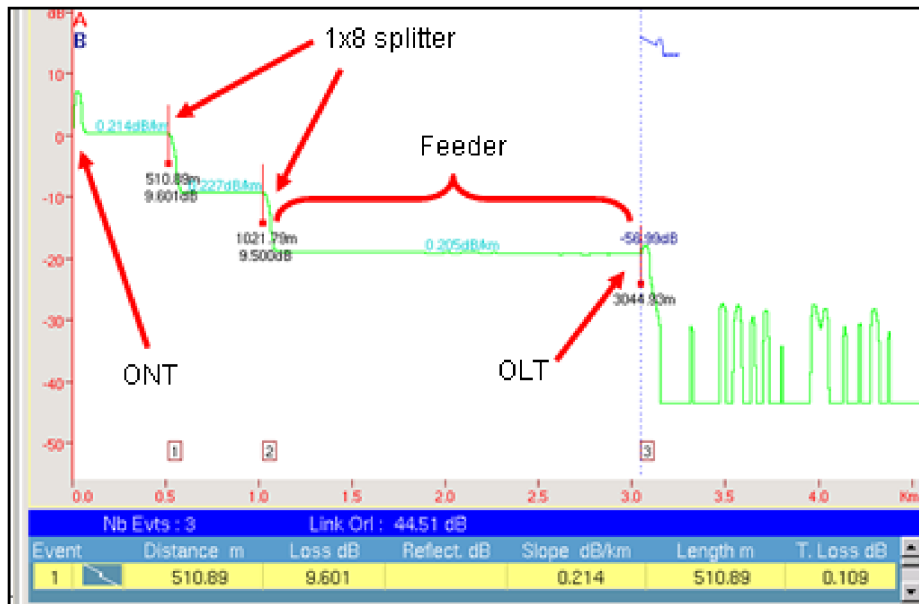


Fig. (5.5) PON optimized OTDR test from the ONT to the OLT [40].

Tab. (5.2) The advantage & disadvantage method (2).

Advantages of Method 2: OTDR	Disadvantages of Method 2: OTDR
Measures both IL and ORL values.	When testing after the splitter on the ONT side, the ORL is not measured in the right direction (opposite from the video signal).
Possible to test every distribution fiber.	The technician needs to move from drop terminal to drop terminal.
Macrobend identification during testing is performed at 1550 and 1310nm or another combination of wavelengths involving the 1625nm wavelength.	A skilled technician is required to interpret the trace.
In case of a cut fiber or macrobend, the fault can be located.	
Only one technician required.	
Fast testing	

5.7 The solution of the task

The task of practical part is to draft the connection resident housing units of 30 houses, boarding-house (10 rooms) and two shops, 20 km distant from exchange. I proposed two topologies – AON and PON. For both topologies were performed measurements of attenuation by direct method, OTDR, measurement of chromatic and polarization mode dispersion CD/PMD and finally I measured spectra of transmitted signals. For measurement were used devices and components listed in table below.

Tab. (5.3) List of measurement devices.

Name of device	Model
TP-Link Gigabit media converter	MC220L
GEPON Optical Network Unit ZYXEL (2x)	ONU-6040B-21
GEPON Optical Line Termination ZYXEL (1x)	OLT-1308S-22
EXFO OTDR	FTB-400-7200B
EXFO (CD-PDM)	FTB-200-FTB 5700
EXFO Power meter	FPM-600
EXFO Light source	FLS-600
EXFO Video Inspection Probe	P5
Optical Spectrum analyzer	MS-9740A

5.7.1 Active Optical Network:

AON was realized by two media convertors for simulation P2P fiber connection of active optical network. Between media convertors there was situated optical fiber G.652.D with length of 20 km. The realized topology is shown on fig. (5.11).

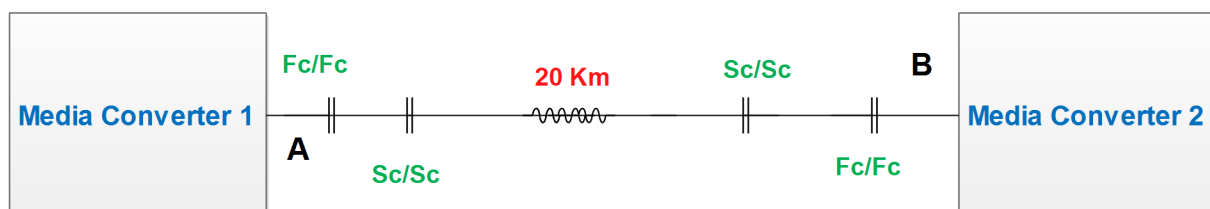


Fig. (5.6) Topology of AON.

Direct Method:

For this method I used EXFO OLTS measuring set (Power meter and Laser source). Measuring was performed for both directions A-B and B-A. As we can see in table X, the total attenuation was about 8.25 dB for wavelength 1310 nm and about 5.8 dB for 1550 nm. Total attenuation is given by fiber attenuation and attenuation of connectors which were also used. Different values for both wavelengths are given by dependence of attenuation on wavelengths (see Fig. 5.12).

Tab. (5.4) AON direct method.

Wavelength	A =====> B	B =====> A
1310 nm	8.11 dB	8.25 dB
1550 nm	5.93 dB	5.69 dB

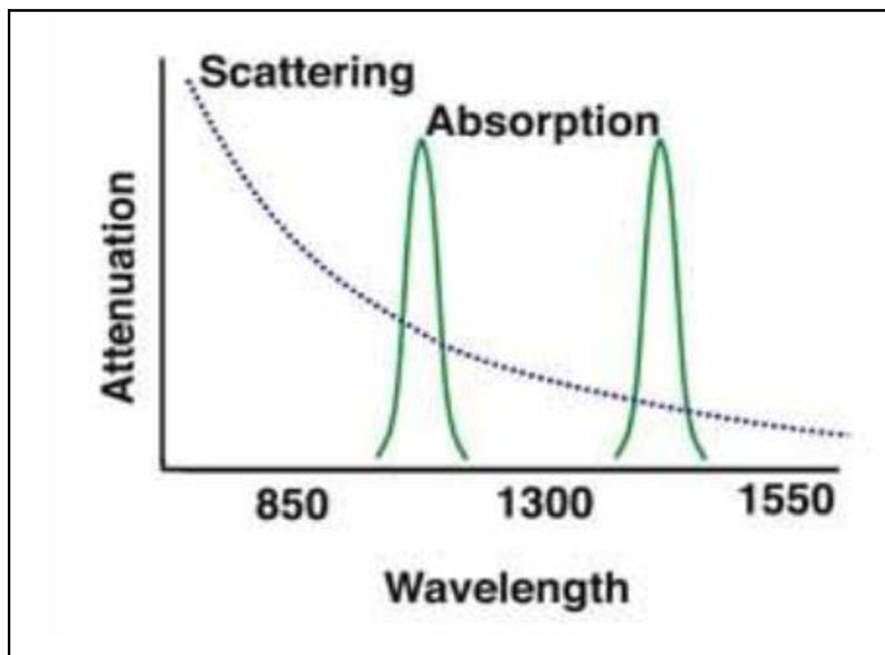


Fig. (5.7) Dependence of attenuation on the wavelength.

OTDR :

OTDR measurement was performed with EXFO measuring device FTB-7200. The measurement was done in both directions (which is generally recommended for measurement) and also for two typical wavelengths 1310 nm and 1550 nm. As we can see in figures 5.13 – 5.16, the graphical

outputs are almost the same. We can see launch fiber (event 1-2), attenuation given by connectors between launch fiber and measured fiber (event 2), then we can see attenuation of optical fiber the total length of 20 km. At the end of Graphs we can see reflection of the end of measured link. Different between all 4 graphical outputs is only in slope of OTDR slope for wavelength 1310 nm and 1550 nm. Table with concrete values is shown in report which was generated by special toolbox for post-processing of measured data. All reports are in Appendix A.

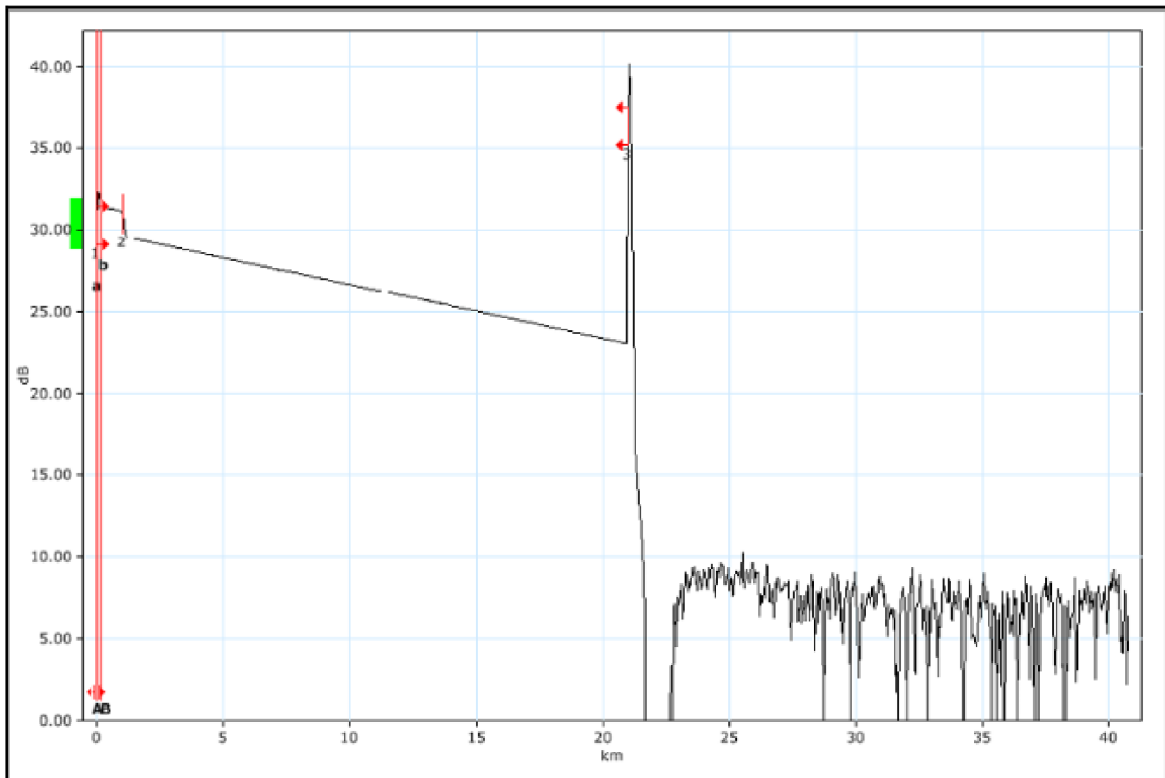


Fig. (5.8) OTDR at 1310 nm from A====>B.

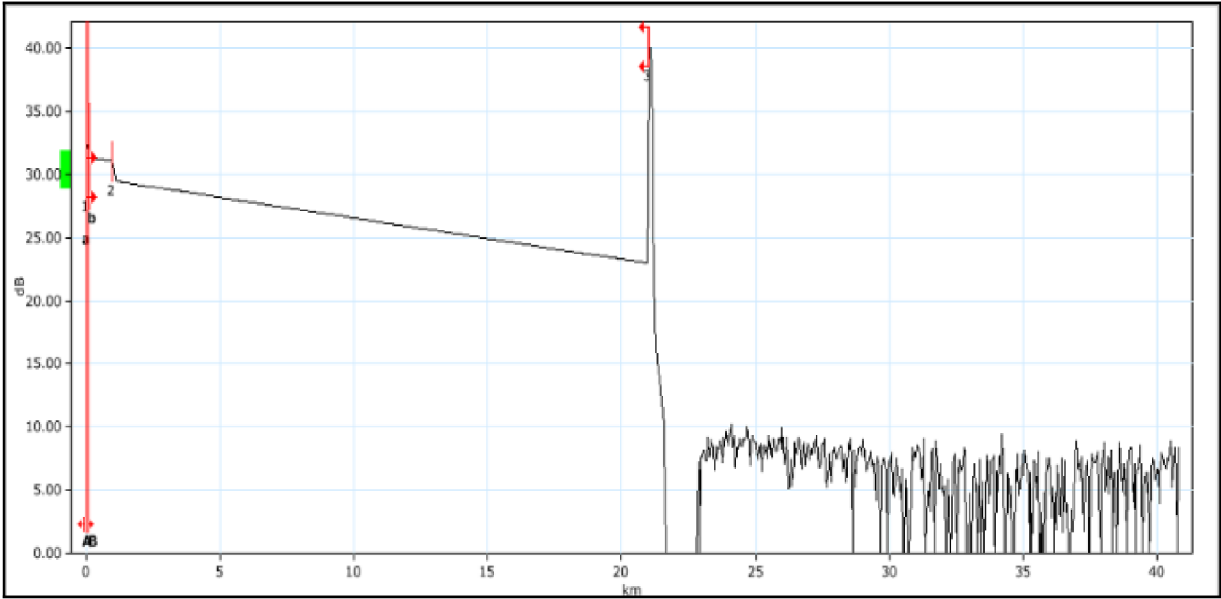


Fig. (5.9) OTDR at 1310nm from B==>A.

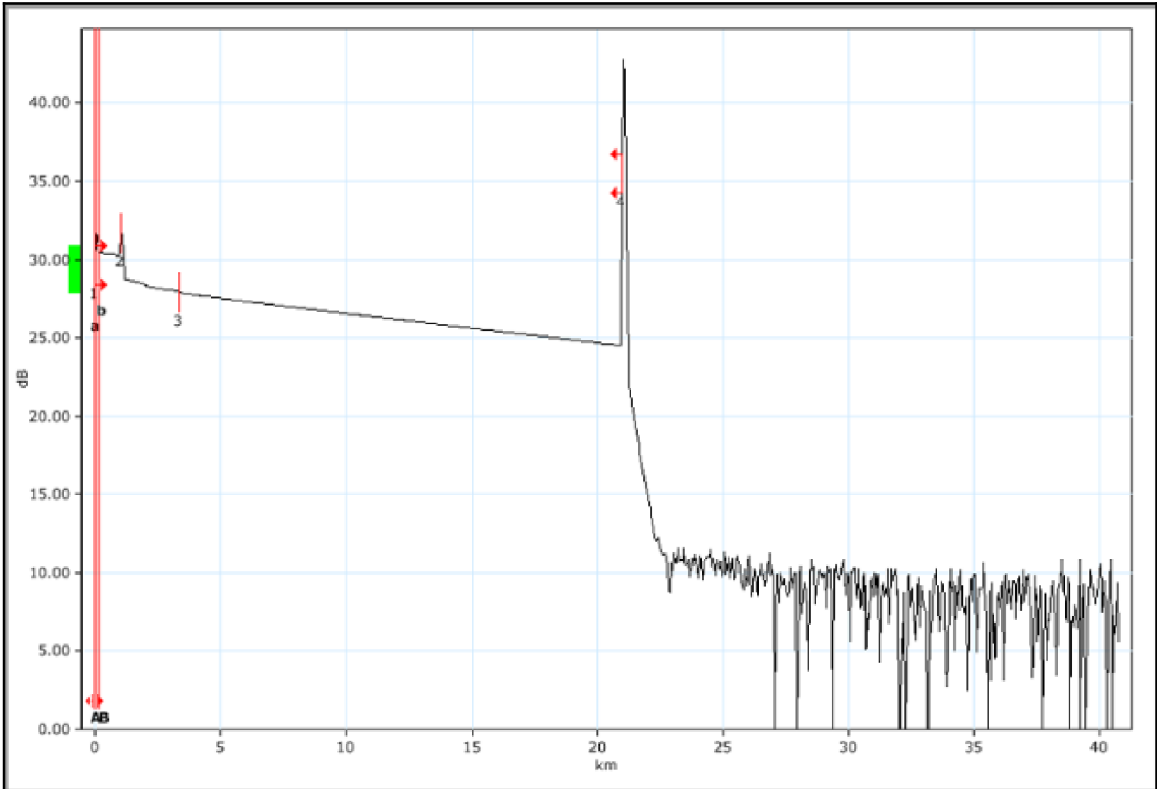


Fig. (5.10) OTDR at 1550nm from A==>B.

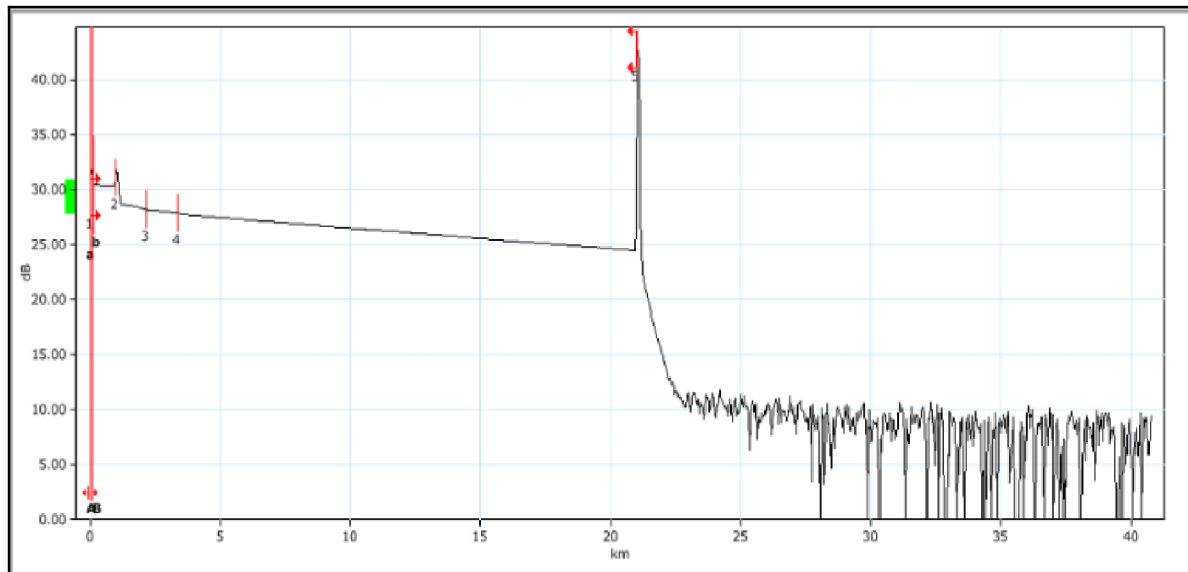


Fig. (5.11) OTDR at 1550nm from B====>A.

CD-PMD:

I also measured chromatic and polarization mode dispersion. Nowadays bitrates are becoming higher and higher and demands for measuring of dispersions are higher and higher. That’s why it is important to measure dispersions in the area of access networks also. Limits for coefficients are: 17 ps/(nm*km) for chromatic dispersions and 0,1 ps/ \sqrt{km} for polarization mode dispersions. As we can see from the table X, both coefficients are in the limit. Concrete outputs data are shown in report which was generated by special toolbox for post-processing of measured data. All reports are in Appendix X.

Tab. (5.5) CD-PMD results.

Direction	CD		PMD	
	Value [ps/nm]	Coefficient [ps/(nm*km)]	Value [ps]	Coefficient [ps/km ^{1/2}]
A-B	332.37	16.61	0.35	0.0782

OSA (OPTICAL SPECTRUM ANALAYZER) :

Measuring with optical spectral analyzes is important for xWDM networks. Our media convertors are based on WDM principle (they used only 1 fiber and both directions are created

by WDM – two wavelengths, one for each direction). As we can see in fig. 5.18, there is a bidirectional optical signal. Signal with higher power level is from the first media convertor and second one is from the second remote media convertor. This measurement was performed by coupler with dividing ration 90:10, where 10% of signal went to the OSA and 90 % of optical signal went to the optical link.

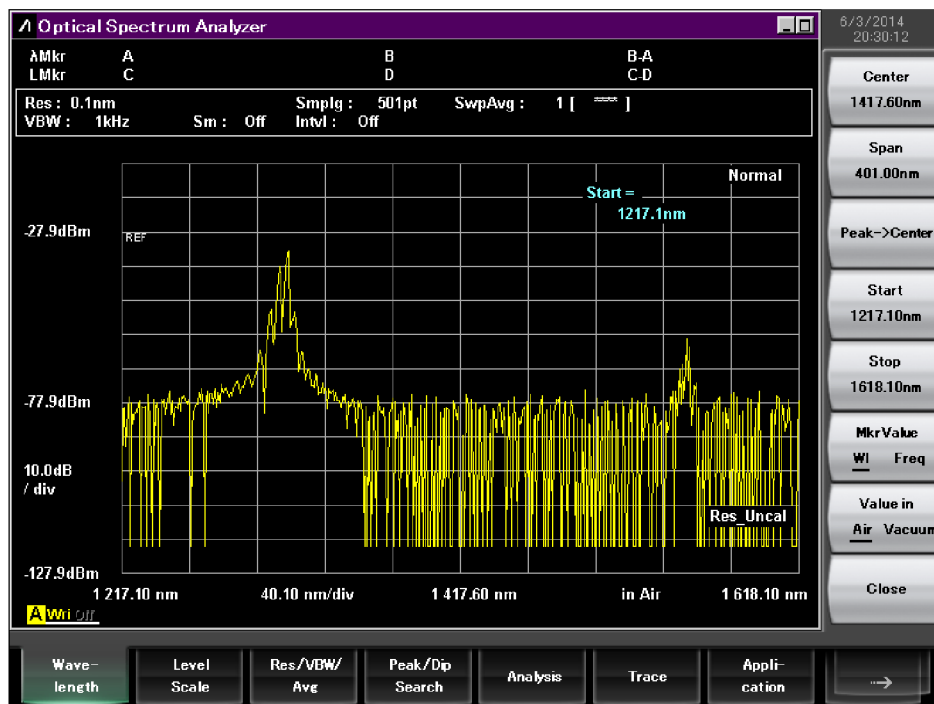


Fig. (5.12) OSA – media convertor.

5.7.2 PASSIVE OPTICAL NETWORK:

PON was realized by EPON technology Zyxel. The measured topology is shown on figure 5.19. OLT unit Zyxel was connected with first splitter 1:2 by 20 km of optical fiber G.652.D. First arm of 1:2 splitter was connected with second splitter 1:32 by 5 km of optical fiber. Second arm was connected with third splitter 1:8 by 1 km of optical fiber. ONU units were connected by patch cables. This topology simulate real passive optical network FTTH.

TOPOLOGY:

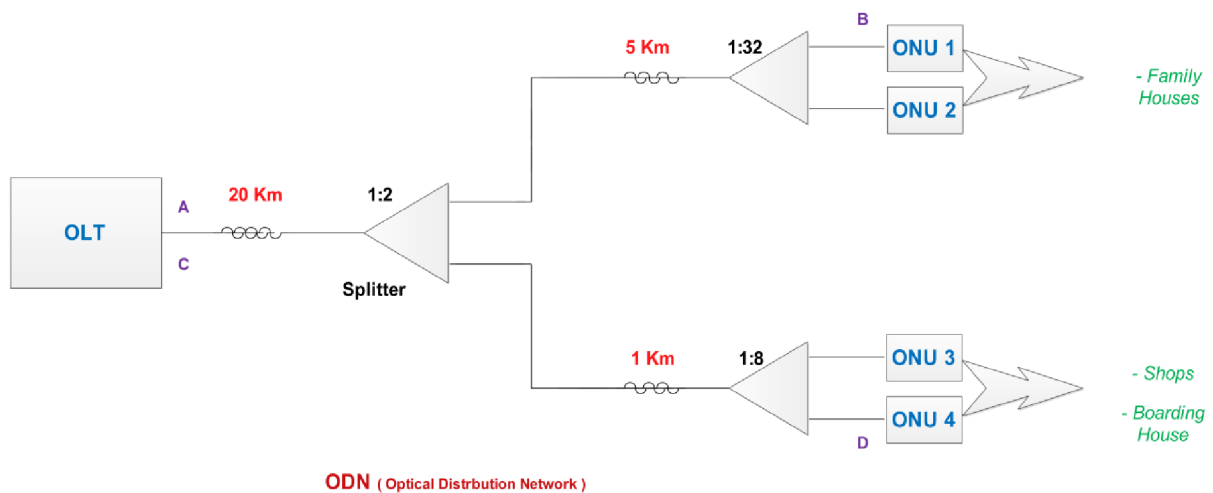


Fig. (5.13) Topology of PON network.

Direct Method:

For this method I used EXFO OLTS measuring set (Power meter and Laser source) – the same like for direct method. Measuring was performed for both directions A-B and B-A. As we can see in table X, the total attenuation was about 29 dB for wavelength 1310 nm between measuring points A-B and B-A. Between measuring points C-D and D-C the attenuation was about 22 dB for 1310 nm. For the wavelength 1550 nm was the total attenuation about 25 dB between measuring points A-B and B-A. Between measuring points C-D and D-C the attenuation was about 18 dB. Total attenuation is given by fiber attenuation, attenuation of connectors and splitters which were also used. Different values for both wavelengths are given by dependence of attenuation on wavelengths (see Fig. 5.12).

Tab. (5.6) PON direct method.

Wavelength	A=====>B	B=====>A	C=====>D	D=====>C
1310 nm	29.29 dB	29.32 dB	24.34 dB	21.74 dB
1550 nm	25.61 dB	25.47 dB	17.99 dB	18.41 dB

OTDR:

OTDR measurement was also performed with EXFO measuring device FTB-7200. The measurement was done in one direction and also for two typical wavelengths 1310 nm and 1550 nm. As we can see in figures 5.20 – 5.23, the graphical outputs are almost the same. Important for OTDR measurement in PON networks is the way of measurement. In PON networks is not possible to measure in direction OLT-ONU. Thanks to splitters is not possible to see distribution of attenuation. Therefore I measured only in directions B-A and D-C which is adequate to ONU-OLT direction. We can see launch fiber, attenuation given by connectors between launch fiber and first splitter (1:32 for B-A and 1:8 for D-C), then we can see 5 km of optical fiber for B-A measurement and 1 km for D-C measurement. Then there is possible to see attenuation of the first splitter 1:2. Finally we can see 20 km of optical fiber between first splitter and OLT unit. There are evident reductions of optical power behind each splitter. Table with concrete values is shown in report which was generated by special toolbox for post-processing of measured data. All reports are in Appendix X. Thanks to the high total attenuation it was very difficult to set pulse width. It was used almost the maximum dynamic range of measuring OTDR device. That's why there is evident noise in all graphs.

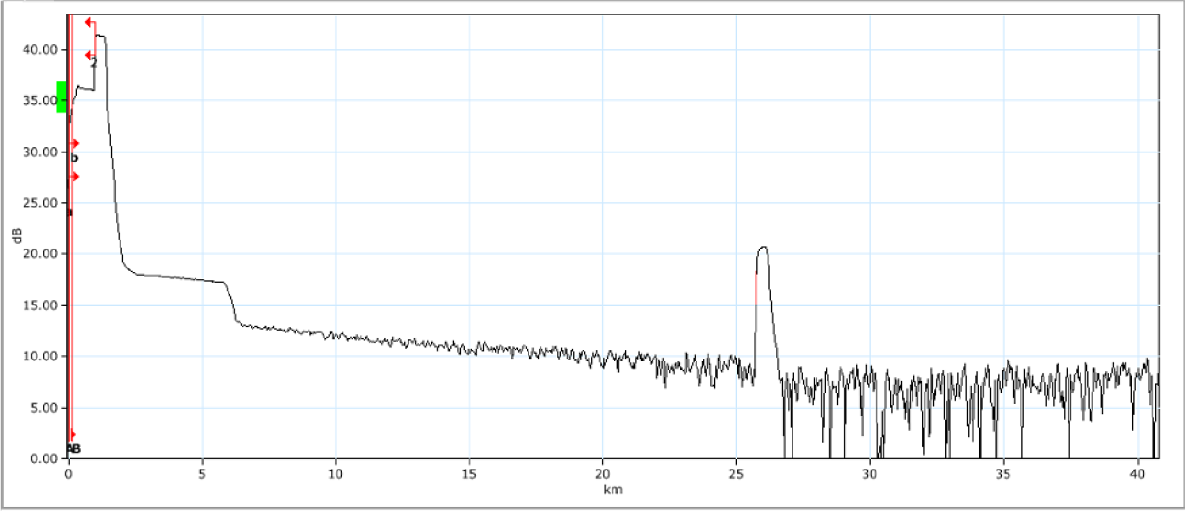


Fig. (5.14) OTDR at 1310nm B====>A.

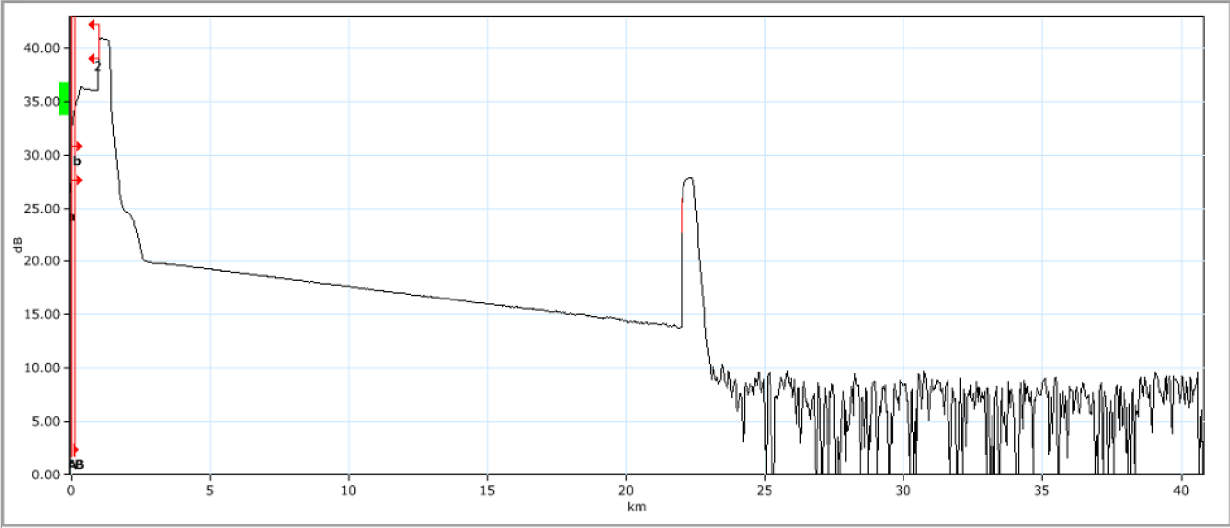


Fig. (5.15) OTDR at 1310 nm C====>D.

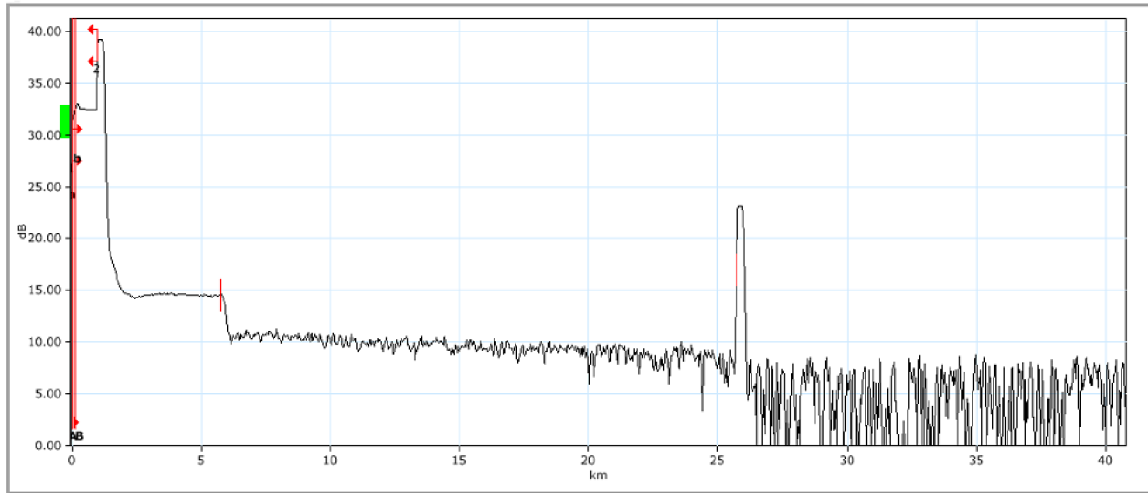


Fig. (5.16) OTDR at 1550 nm B====>A.

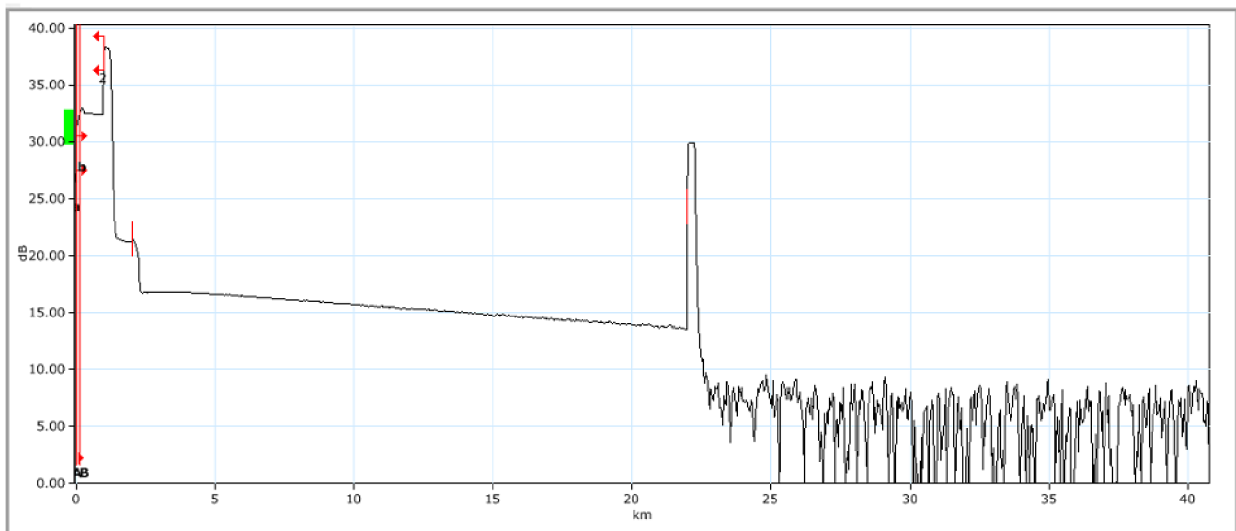


Fig. (5.17) OTDR at 1550 nm C====>D.

CD-PMD:

I also measured chromatic and polarization mode dispersion for PON. Nowadays bitrates are becoming higher and higher and there are new PON standards for 10 Gbit bitrates (XG-PON and 10GE-PON) and newer standards for higher bitrates (40 Gbps) are in draft. That's why it is important to measure dispersions in this area of access networks also. Limits for coefficients are: 17 ps/(nm*km) for chromatic dispersions and 0,1 ps/ \sqrt{km} for polarization mode dispersions. As we can see from the table X, both coefficients are in the limit. I measured dispersion for ways B-A and D-C. Concrete outputs data are shown in report which was generated by special toolbox for post-processing of measured data. All reports are in Appendix X.

Tab. (5.7) CD-PMD results.

Direction	CD		PMD	
	Value [ps/nm]	Coefficient [ps/(nm*km)]	Value [ps]	Coefficient [ps/km ^{1/2}]
B-A	418.82		0.36	0.0730
D-C	356.75	16.97	0.53	0.1163

OSA (OPTICAL SPECTRUM ANALAYZER):

Measuring with optical spectral analyzes is important for xWDM networks. OLT unit transmits optical signal on wavelength 1490 nm (downstream) and receive optical signal on wavelength 1310 nm (from ONU unit). As we can see in fig. 5.26, there is an optical signal from OLT unit. We can clearly see that this signal was created by DFB laser (because of narrow linewidth). This measurement was performed by coupler with dividing ration 90:10, where 10% of signal went to the OSA and 90 % of optical signal went to the optical link. The coupler was connected directly behind the OLT unit. This system with asymmetric coupler is necessary for this measurement. The reason is, that OLT unit must establish connection first, and then we can measure optical spectrum. On figure 5.27 we can see spectrum of optical signal, which was transmitted by ONU unit. Measurement was also performed with asymmetric coupler. We can see, that FP (Fabry-Perrot) laser is used in ONU units. For this laser is a typical multi-longitude spectrum. The reason is price – ONU unit must be cheap, so therefore it is used FP laser, which is much cheaper than DFB laser.

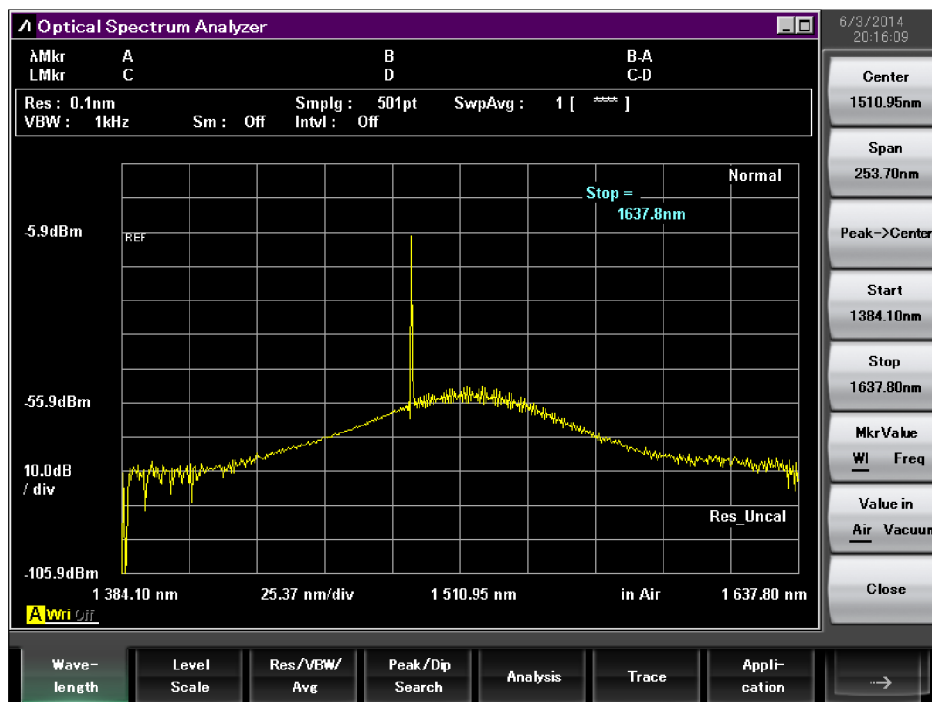


Fig. (5.18) OSA – OLT output.

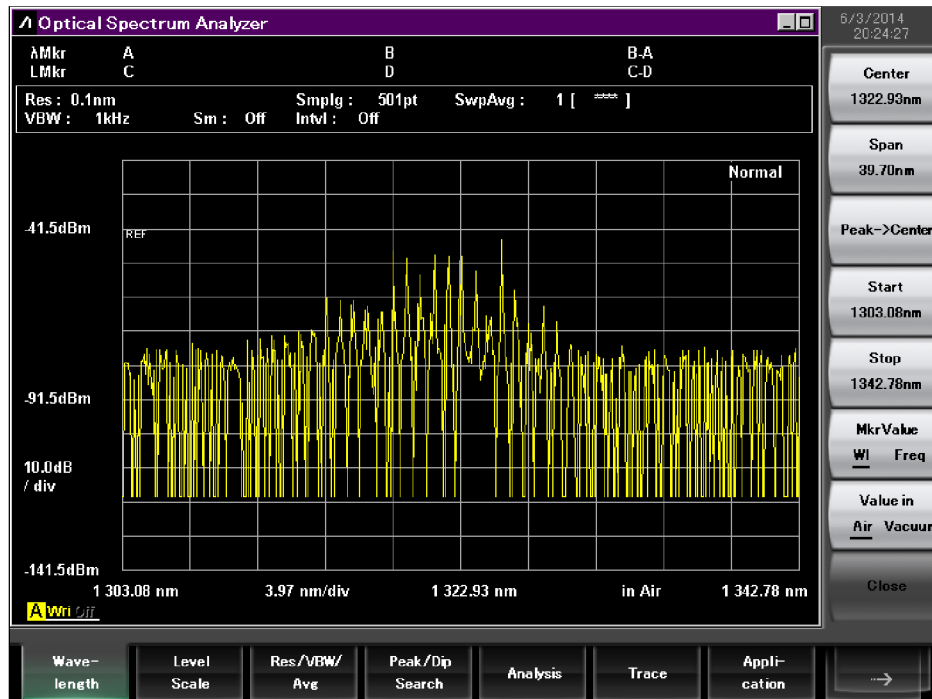


Fig. (5.19) OSA – ONU output.

Comparison of AON vs. PON

I measured the parameters for both conceptions of optical access networks. Dispersions were in limits in all cases – for access networks with bitrate smaller than 10 Gbps it is not necessary to compensate chromatic dispersion. I performed this measurement because of future deployment of next-generation PON's. The most significant different between both topologies was in attenuation. The biggest advantage of active optical network is smaller attenuation between CO (central office, where OLT units are usually situated) and ONU units. The reason is simply – there are no splitters in optical distribution network. Every subscriber has each fiber and bandwidth. On the other hand, the fiber management is very difficult and this technology is more expensive in comparison with passive optical networks. In PON's all subscribers share the total bandwidth.

6 Conclusions

The aim of this master thesis was to describe optical access technologies, especially FTTH networks, their design and measurement. “Fiber to the Home” is defined as a telecommunications architecture in which a communications path is provided over optical fiber cables extending from the telecommunications operator’s switching equipment to (at least) the boundary of the home living space or business office space, This communications path is provided for the purpose of carrying telecommunications traffic to one or more subscribers and for one or more services (for example Internet Access, Telephone and/or Video-Television).

Nowadays the access networks based on metallic lines and deficient in the bandwidth. Optical access networks FTTx are deployed very slowly in the world due to the cost. It is only the matter of the time when the metallic lines will be completely replaced by optical networks also in the area of access networks. The clear objective of telecom operators is the use of existing optical links at maximum, only competition forces them to invest to the new technologies.

At the beginning of the work the telecommunications in fibers optics was described. For example advantage of fiber optics technologies, types of optical fibers, connectors etc. In the next chapter the optoelectronic and telecommunications system like passive and active components were described. The next theoretical part is about general layout of optical access networks. In this chapter there are described active and especially passive optical network based on time division multiplex and wavelength multiplex also (GPONs, WDM-PONs, etc.). In theoretical chapters there was described wide range of fiber optic technologies.

The practical part is focused on design and measurements of active and passive optical network. I proposed measurement topologies for both variants and performed measurements in the laboratory of optical networks at the department of Telecommunications, Faculty of Electrical Engineering and Communication, Brno University of Technology. I proposed topologies similar to real conditions of FTTH networks. For active optical network two media convertors simulated P2P link of active network, and passive network was determined by EPON technology. For both topologies the parameters like attenuation, dispersion and spectrum were measured. Finally, both topologies were compared.

This thesis give the reader objective view to optical access networks as an important way for nowadays and future proof of telecommunications infrastructures. The measurement, which are necessary for this networks are also done and described including graphical outputs.

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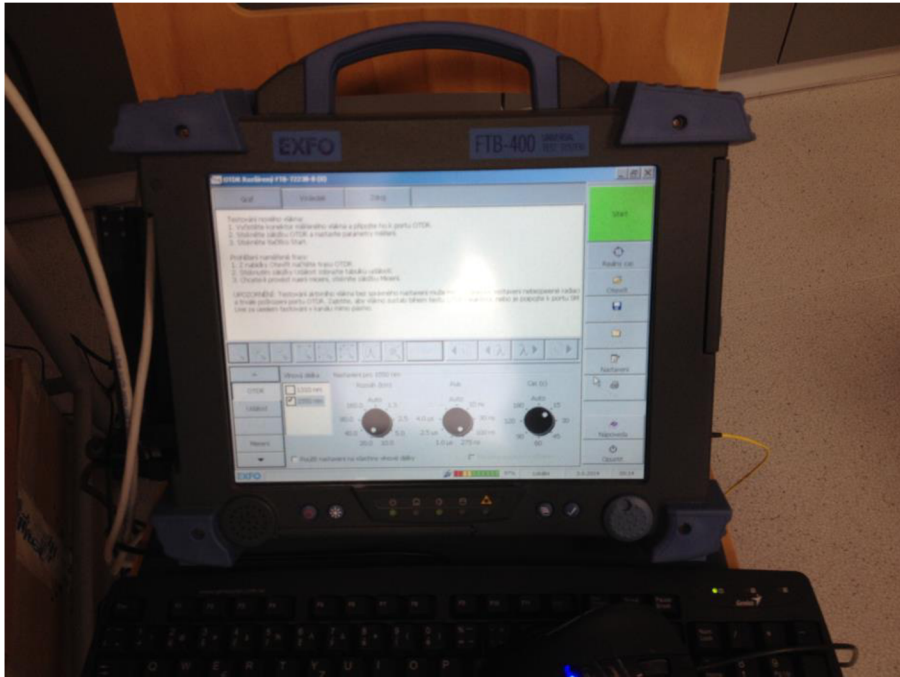
List of Appendixes

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Appendix A – Photos of the measurement components









Appendix B - Reports from OTDR