

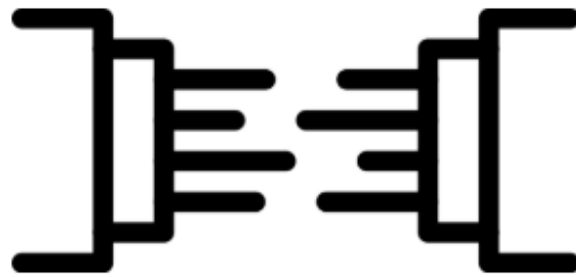
FIBER OPTIC COMMUNICATION SYSTEM: **Basic Component & Network Systems**

“A first step to become Fiber Optic
Technical Expert from TVET IR4.0
Educator Perspective”

 **2025**



FIBER OPTIC COMMUNICATION SYSTEM: Basic Component & Network Systems



Author

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PREFACE

Alhamdulillah, praise and gratitude to Allah for His countless blessings this book, **Fiber Optic Communication System: Basic Component & Network Systems** has been successfully published. We would like to extend our sincere appreciation to Politeknik Merlimau, Politeknik Mersing & Politeknik Ungku Omar for giving us an opportunity to write and publish this book. Our special thanks go to Jabatan Pendidikan Politeknik & Kolej Komuniti for providing a platform for us to share our knowledge with others. This book is written specifically for students and educator who want to learn more about fiber optic communication systems and improve their skills. Fiber optic technology is known as the most efficient and reliable communication medium, offering many advantages compared to other transmission methods. This book is a continuation of the previous volume, ***Fiber Optic Communication System: Introduction to Fiber Optic***. It discusses the core components of fiber optic systems and provides an overview of the network systems involved in fiber optic communication. It is our hope that this book will serve as a useful reference and help readers gain a clearer and deeper understanding of this important technology.

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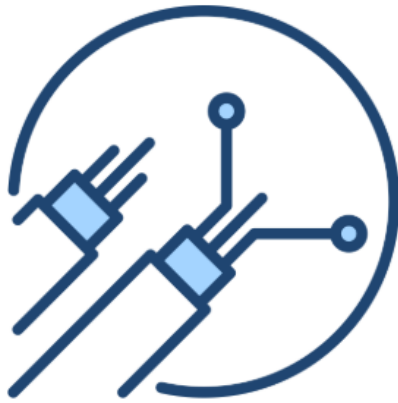
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TOPIC 1:

FUNDAMENTALS OF FIBER OPTIC COMMUNICATION COMPONENTS



1.0 BASIC CONCEPTS FOR FIBER OPTIC COMMUNICATION SYSTEMS

Fiber-optic communication transmits information by encoding data onto light pulses, which then travel through ultra-thin glass or plastic fibers. Unlike copper cables where electrical currents carry signals, the optical medium exploits the principles of total internal reflection to guide light with very low attenuation.

Because optical fibers are not electrical conductors in their natural state, a complete fiber-optic link requires a sequence of specialized stages to convert, transmit, amplify, and reconvert signals. Figure 1.1 on the next page illustrates this process in a block-diagram format. The eight fundamental components of a fiber-optic communication system are listed below and will each be described in detail:

- i. Information Signal (voice, video, data)
- ii. Coder or Converter
- iii. Light Source
- iv. Fiber Optic Cable
- v. Light detector
- vi. Amplifier
- vii. Shaper
- viii. Decoder

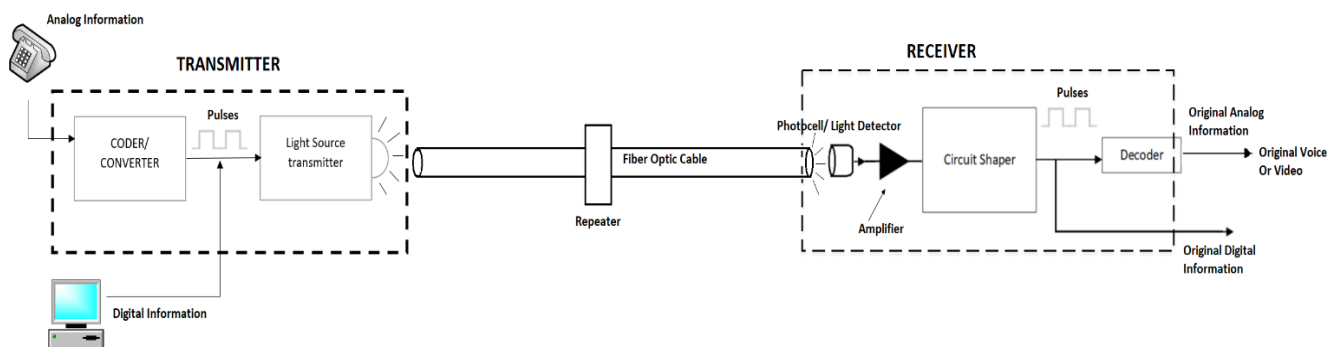


Figure 1.1: Fiber Optic Communication System Block Diagram.

i. Information Signal

The transmitter takes the raw information signal, whether it's voice, video, or digital data, and prepares it for transport over the chosen communication channel. The original analog waveforms (such as a person speaking into a microphone or a broadcast television feed) are first sampled and encoded as a series of digital pulses. This digitization process not only standardizes the signal for high-speed, long-distance transmission, but also enables advanced error detection, compression, and encryption techniques. Once the data stream is in pulse form, it can be effectively modulated onto the physical medium, such as a wireless link, coaxial cable, or optical fiber, guaranteeing a reliable and interference-resistant transfer from sender to recipient.

ii. **Coder or Converter**

A coder or converter circuit will transform the information signal when it is input into digital signals. The actual circuit is an analog to digital converter, or ADC. Consequently, it transforms analog signals into digital signals that are proportionate. The circuit for the light source transmitter receives the input signals directly if they are digital signals.

iii. **Light Source**

The light-source stage employs high-performance optical emitters, most commonly the FOCUS-type LEDs (Light Emitting Diodes) or injection laser diodes (ILDs), such as InGaAsP solid-state lasers. In some designs, infrared emitters (operating around 850 nm, 1310 nm, or 1550 nm) are selected to take advantage of lower fiber attenuation and dispersion characteristics. The light source's role is to turn our digital data, those in binary 1s and 0s into flashes of light. Every time a "1" comes in, the LED or laser lights up; for a "0," it switches off. It does this on-and-off switching as fast as the data needs it to, and how quickly it can blink sets the top speed for sending information. In this way, the pattern of light pulses directly carries our binary data through the fiber, letting it travel long distances with very little loss.

iv. **Fiber Optic Cable**

In a fiber optic communication system, the fiber optic cable carries the light pulses that represent our data from one end to the other. As those pulses move through cable's core, very little of the light is absorbed, so loss of signal, called attenuation, stays extremely low even over long distances. This allows for a wider bandwidth, hence, enabling the cable to handle more channels simultaneously and transmit a larger amount of information. That is why fiber cables can support huge data loads, making them perfect for applications that demand fast and dependable transmission across great lengths.

v. **Light Detector**

A photodetector, also called a light detector or photocell, sits at the end of the fiber and captures the stream of light pulses. Acting as a transducer, it converts each pulse into a matching electrical signal in the form of current or voltage. The resulting waveform mirrors the original light pattern in its changes over time. Once the signal is in electrical form, it can be amplified, filtered, and decoded so that the receiver can reconstruct the data that was sent.

vi. **Amplifier**

The amplifier raises the amplitude of the weak electrical signal from the detector. Next the shaper processes the waveform to restore pulse shape and reduce noise.

vii. **Shaper**

The shaper circuit takes the boosted electrical signals and restores them to their original digital pulse form. During this process, any distortion is corrected and unwanted noise is removed. As a result, the output pulses match the timing and amplitude of the data as it was sent, ready for reliable decoding.

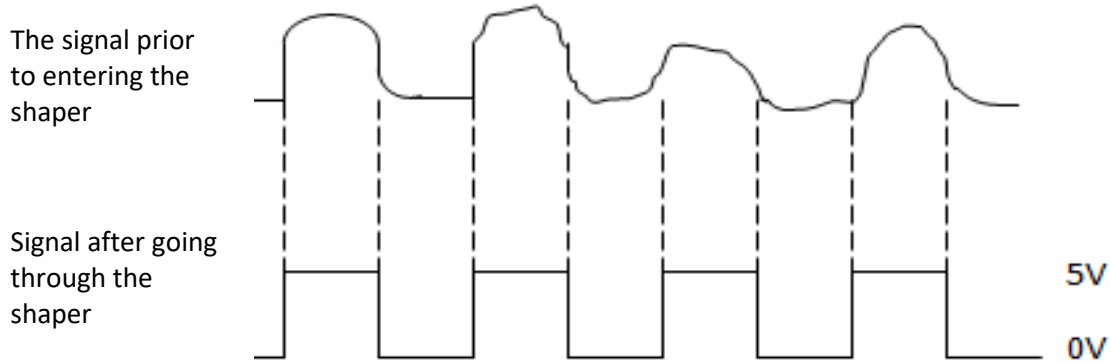


Figure 1.2: Pulse signal appearance after entering the shaper

viii. **Decoder**

The signals are connected to the decoder on the receiver portion. In reality, it is an analog to digital converter (ADC) circuit that transforms digital signals, such as computer data, voice, or video, into proportional analog signals. The output of the shaper circuit can be used directly to generate digital signals for computers.

1.1 MAIN COMPONENTS IN THE FIBER OPTIC COMMUNICATION SYSTEMS

An optical fiber communication system is made up of three (3) main elements:

- a. Optical Sources
- b. Optical Receivers
- c. Source-to-fiber coupling and terminating

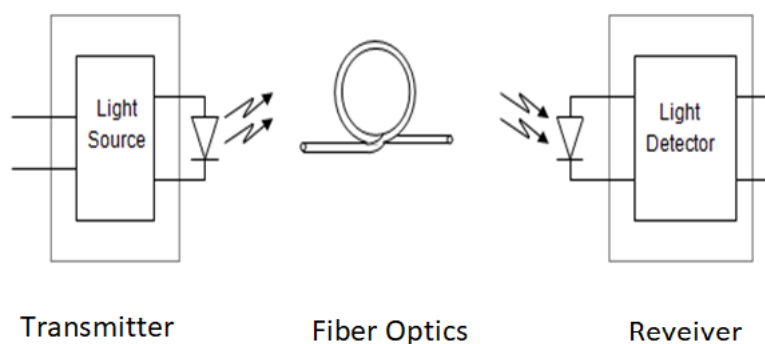


Figure 1.3: Basic Components of an Optical Fiber System

a. Optical Source

Electrical input signals are transformed into corresponding optical signals by an optical source, also known as an optical transmitter, and then sent via optical fibers. A light source and related drive circuitry usually make up the transmitter. For a light source to work efficiently, it needs to fulfill the following specifications. It needs the functionality of turning on and off at lightning speeds, often in the order of millions to billions of times every second.

- I. Its emission of light should be at a wavelength which an optical fiber can transmit with minimal loss.
- II. The light source must be capable of coupling sufficient optical energy into the fiber.
- III. The optical power output should be adequate to ensure successful transmission over the intended fiber length.
- IV. The performance of the light source should remain stable across a range of temperatures to ensure reliability.
- V. The manufacturing cost of the light source should be economical to make fiber-optic systems cost-effective.

b. Optical Receiver

A light detector or optical receiver must transform the light traveling through a fiber optic cable into an electrical signal. It processes and extracts the carried data. Semiconductor photodiodes, also known as photodetectors, are the most widely used detectors because they generate current in response to incident light. The receiver's primary job is to transform optical signals into electrical signals. These make up an optical receiver. Photodiode semiconductor (photodetector) which produces current in response to incident light.

- i. An amplifier.
- ii. Signal Conditioning Circuit.

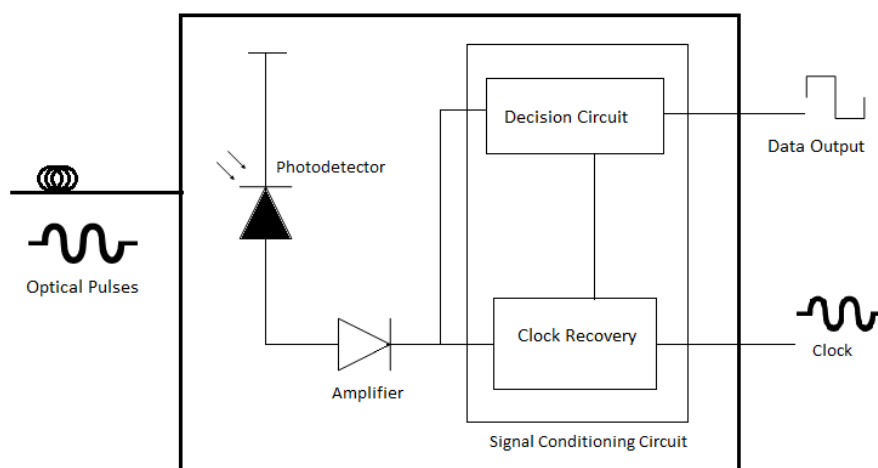


Figure 1.4: Optical Fiber Receiver

c. Source -to-fiber coupling and terminating: Connector and Splicing

Fiber termination makes it simple to join fiber strands and to route optical signals where they need to go. It serves two main purposes: allowing fibers to be cross connected as needed and distributing light wave signals across a network. There are two common ways to terminate the fiber: using a connector or performing a splice. Connectors offer a fast and reusable way to link and unlink fibers, while splices create a permanent, low-loss joint by fusing the glass ends together.

I. Connector

Connectors are components used to join two optical fibers, creating a temporary connection between fibers or connecting fibers to network equipment. These connectors are attached to the ends of optical cables or devices, allowing them to be easily plugged and unplugged from other cables or devices. An optical fiber connector terminates the fiber's end and provides a faster alternative to splicing for connecting or disconnecting fibers. It functions by mechanically aligning and coupling the cores of the fibers to ensure efficient light transmission. High-quality connectors minimize light loss caused by reflection or core misalignment. Connectors are a type of fiber optic hardware installed at the cable's end, forming a cable assembly or pigtail. They are commonly used to link the cable assembly to receivers, transmitters, transceivers, or other devices such as light sources and housings.

II. Splices

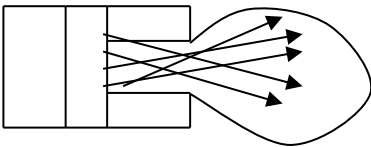
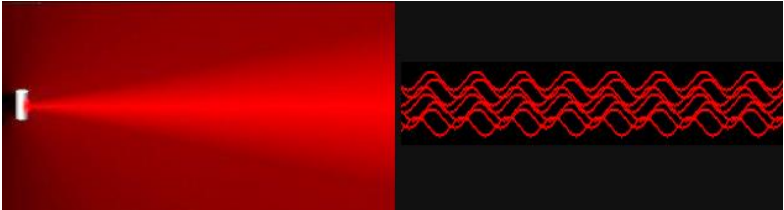
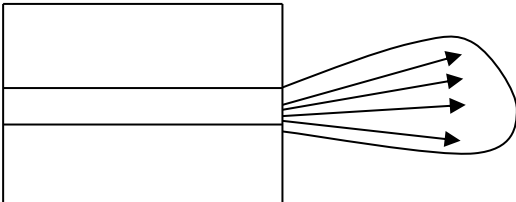
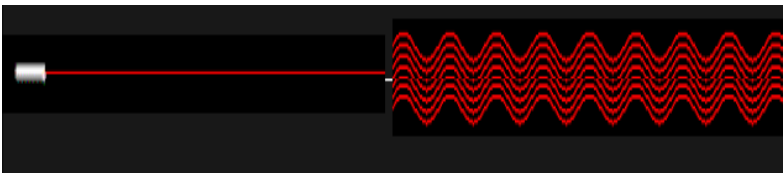
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1.2 OPTICAL SOURCES

Fiber optic communication systems usually use two main devices to generate light:

- I. Light Emitting Diode - (LED)
- II. Injection Laser Diode - (ILD)

Two light sources are coherent if their waves are of the same frequency, are in constant phase relation, and are synchronized throughout the duration of observation.

An LED emits light at random and is an incoherent light source.	 The diagram shows a rectangular block representing an LED. Multiple arrows originate from different points on its right face and diverge in various directions, illustrating the random emission of light. Incoherent Radiation  The photograph shows a red light source on the left emitting a broad, diffuse beam of light. On the right, a close-up of the light waves shows multiple overlapping, out-of-phase red sine waves, indicating a lack of coherence. Incoherent source by LED
A coherent light source with a precise and consistent pattern of light emission is an injection laser diode (ILD).	 The diagram shows a rectangular block representing an ILD. Three parallel arrows originate from the right face and travel in the same direction, illustrating the precise and consistent emission of light. Coherent Radiation  The photograph shows a red light source on the left emitting a very narrow, sharp beam of light. On the right, a close-up of the light waves shows multiple parallel, in-phase red sine waves, indicating high coherence. Coherent source by Laser

Light Emitting Diode (LED)

Parts of gallium (Ga), aluminum (Al), arsenic (As), and phosphorus (Ps) are utilized in the production of LEDs which are a form of junction diodes. The procedure of LEDs light emission is spontaneous emission.

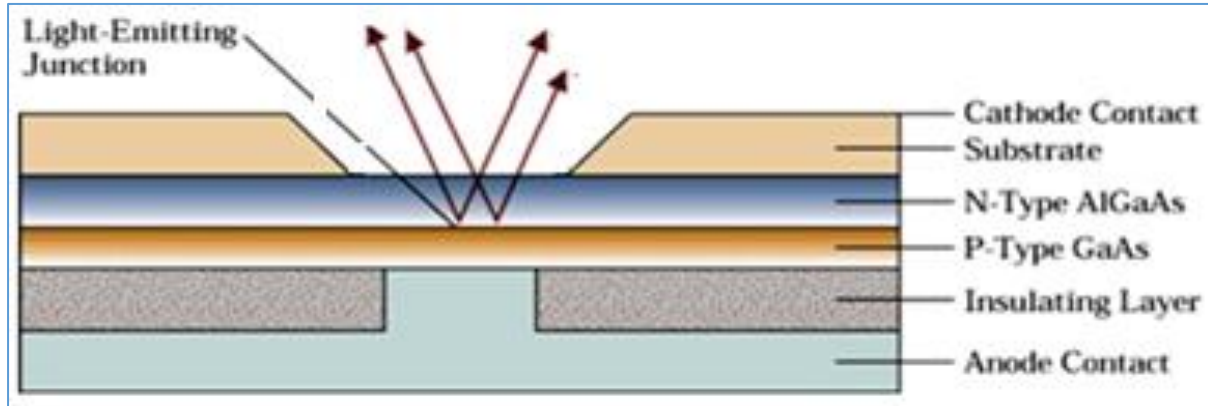
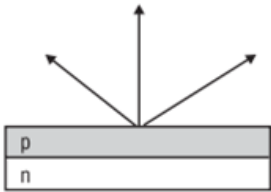


Figure 1.5: LED structure

When a diode is in forward bias condition, current is allowed to flow through the diode. Inside the n-type region, electrons move to the p-type region where they recombine with holes at the p-n junction. Each recombination releases energy which is in the form of a photon generating light exactly at the junction. This light is then transmitted through an output lens or aperture. Light-emitting diodes may emit radiation in the infrared, or visible spectrum, depending on the semiconductor materials used.

The LED structures types can be classified as:

- a. Surface Emitting diode
- b. Edge Emitting Diode

Surface Emitting Diode	Edge Emitting Diode
A Surface Emitting Diode is a more affordable form of an LED. Unlike traditional LEDs which emit light from the edges of the object, a Surface Emitting Diode radiates light from a flat surface. This type of light emission is diffused over a wider area.	An edge-emitting LED shares structural similarity with a laser diode. The light is released spontaneously after being created and focused along a small stripe. The optical ray originates from a tiny region near the facet's edge.
	

Fundamentals of Photonics, 2000 University of Connecticut

(<https://forum.huawei.com/>, 2018)

Injection Laser Diode (ILD)

Laser diodes, also known as injection laser diodes or referred to by the abbreviations LD or ILD, carry some redundancy in their names. Structurally, they resemble light emitting diodes: both consist of layered semiconductor materials forming a p-type and an n-type region joined at a junction. In a laser diode, however, the junction is placed between reflective end faces that form an optical cavity. This design amplifies light by stimulated emission, producing a tightly focused, coherent beam. In contrast, a basic diode LED emits spontaneous light in many directions without requiring an optical resonator.

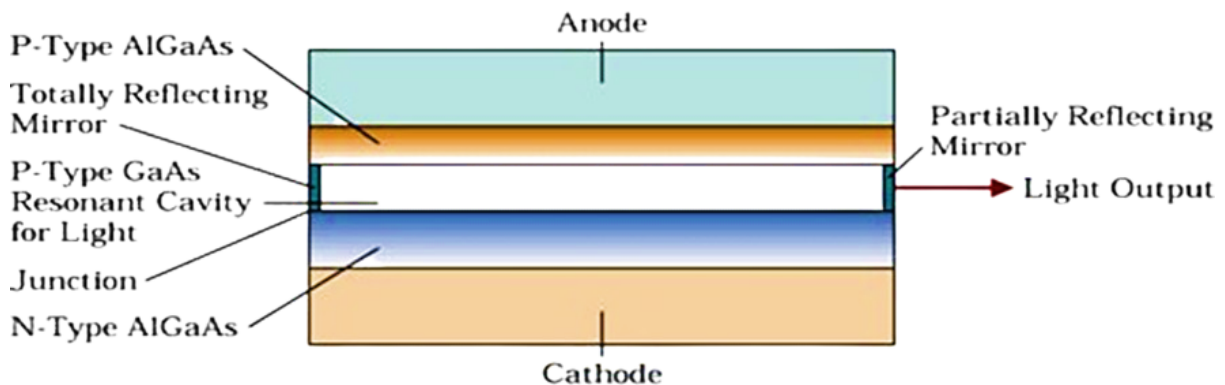


Figure 1.6: ILD structure

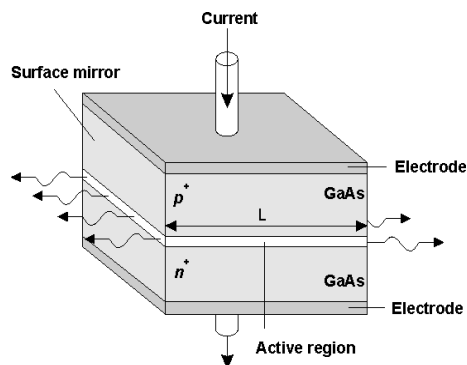
Both generate light when electrons and holes merge at a forward-biased junction, but a laser diode does so with a greater current. Light emission from laser diodes is via stimulated emission, allowing them to generate intense light with a high output power.

The type of laser diode commonly used in fiber optics:

- Distributed feedback (DFB) laser**
- Fabry Perot (FP) laser**
- Vertical-Cavity Surface-Emitting Laser (VCSEL)**

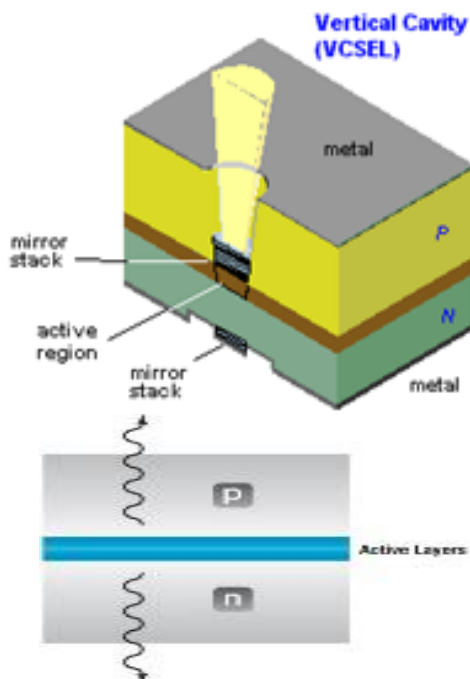
Distributed feedback (DFB) laser	
(Goff., 2010)	A DFB is a type of diode laser that emits a single wavelength. Near the diode's p-n junction, there is a diffraction grating that permits only the specified wavelength of light to pass. For the case of DWDM systems which transmit multiple closely spaced wavelengths through a single fiber, it is critical that the output lengths be very narrow.

Fabry Perot (FP) laser



The semiconductor laser which is FP (Fabry-Perot) laser diode is a type of laser diode which is a semiconductor laser of basic level. This device employs the semiconductor as the gain medium in a Fabry-Perot laser cavity, which is produced by cleaving the two ends of the semiconductor in the direction of the crystal axis, thus forming laser mirrors. In a type of Fabry-Perot cavity called resonant cavity, very small region of a junction of two types of semiconductors, p-type and n-type, roughly one micrometer in width, the lasers photons are contained and kept bouncing back. In the polished end, the laser light is eventually emitted. Enhanced Light is emitted from the refined end. To assist in light confinement, the remaining ends are left roughened.

Vertical-Cavity Surface-Emitting Laser (VCSEL)

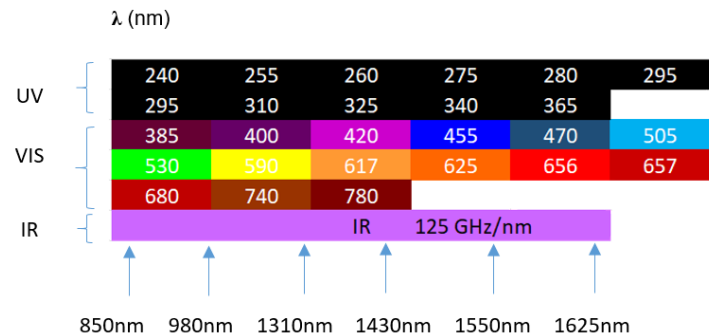


Vertical-Cavity Surface Emission Laser (VCSEL) diodes are form of laser diodes which emit light vertically or perpendicular to the active layer. This feature allows many emitters to be placed in close proximity to each other. As such, VCSELs are advantageous in systems requiring a large number of emitters in a small footprint. They are more compact than traditional F-P laser diodes.

LED & ILD Wavelengths

The wavelength of the emitted light depends on the chemical makeup of the diode.

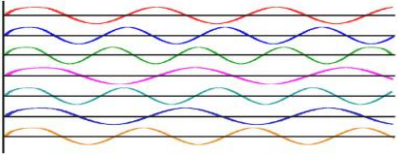
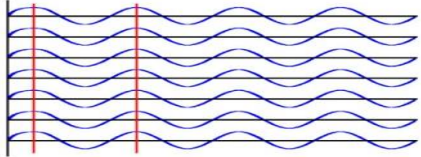
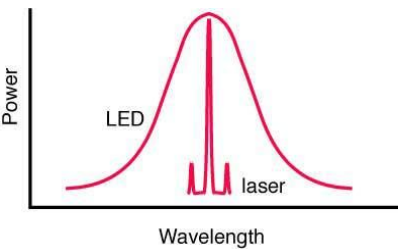
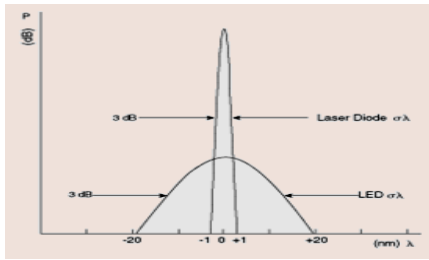
Material	Wavelength range (nm)
GaAs	750-900
GaAlAs	800-900
InGaAs	1000-1300
InGaAsP	900-1700
Gallium (Ga), Aluminum (Al), Arsenic (As), Phosphorus (Ps) Indium (In)	



In communication-based LEDs, GaAs (810-870 nm) and GaAsP (1300 nm) are used the most. While some laser diodes are capable of emitting near infrared light (NIR) laser, most of these diodes are capable of emitting light in the mid-infrared spectrum, and a small number are capable of emitting red and blue light. The most common laser diode semiconductors are:

- Gallium Arsenide (GaAs): produces infrared light between 750 and 900 nm
- Indium Gallium Arsenide Phosphide (InGaAsP): produces infrared light between 1200 and 1700 nm

Differentiation Between LED & ILD		
CHARACTERISTICS	LED	LASER DIODE
Light Generation	Spontaneous Emission	Stimulated Emission
Output Power	Low	High
Output Light	They can only be connected to multimode fiber because they are not highly directional (having large numerical apertures, or NA). The incapacity to enter the fiber optic cable with all the light resulting in a low overall efficiency.	In single-mode fiber, a relatively directional coupling efficiency of roughly 50% is made possible. makes single-mode fiber possible, which enables transmission over much longer distances.

Property of Light	Incoherent light - Internal order is absent from the light beam. 	Coherent light - Each of these separate waves is always "in phase," or in step, with the others. This indicates that there is significantly less modal dispersion and that the light is ostensibly on a single frequency. 
Spectral Width	Wider (40-190 nm) Their bit rate-distance is significantly limited by the increased fiber dispersion caused by this. 	Narrower (0.00001 to 10 nm) Lowers the impact of chromatic dispersion, enabling high bit rates. 
Transmission Speed	10-100 it/s	>100Mbit/s
Bandwidth	Moderate (<250MHz) or around 200 Mb/s Given their inherently lower output power and bandwidth limitations, LEDs are often utilized in short distance multimode systems operating at lower data rates, in the hundreds of MHz range.	High (>10GHz) or 10 Gb/s Because LD's spectral width is smaller, it is capable of long distance and high bandwidth communication.
Transmission Wavelength	660 – 1650 nm Typically used at the 850-nm and 1310-nm	780 – 1650 nm Primarily used at 1310 nm and 1550 nm.
Fiber Type	Multimode only	Single-mode, Multimode
Life Time	Longer	Long

LEDs are used only with multimode fiber because the light they emit spreads out over a wide angle and their power output is much lower than laser sources. This broad emission pattern cannot be focused into the tiny core of single mode fiber, and the lower intensity limits both transmission distance and data rate. Multimode fiber, with its larger core diameter, can capture and guide the diverging light from an LED, making it a practical choice for shorter links and more cost-effective installations.

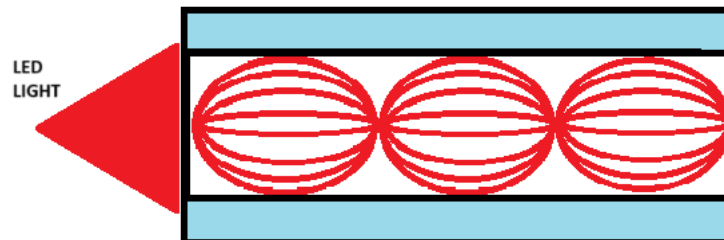


Figure 1.7: Led Light Emission

Laser sources excel on long distance links that carry large amounts of data at high speed. Their narrow, focused beams fit precisely into the tiny core of a single mode fiber, which makes it simple to align the light and reduces losses at the connection point. This efficient coupling preserves signal strength over many kilometers and supports much higher data rates.

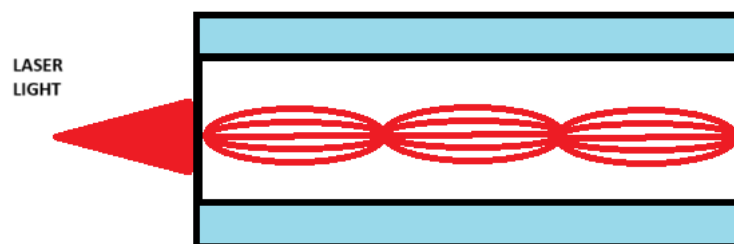


Figure 1.8: Laser Light Emission

Precaution

- Lasers have powerful optical output that can easily harm the eye.
- A fiber connected to a laser or laser light should never be examined.
- Before disconnecting the fibers, make sure that every laser source is turned off.

Typical Optical Sources for Different Types of Fiber

DEVICE TYPE	WAVELENGTH (nm)	POWER INTO FIBER (dBm)	BANDWIDTH	FIBER TYPES
LED	850, 1300	-30 to -10	<250 MHz	MM
Fabry-Perot Laser	850, 1310 (1280-1330) 1550 (1480-1650)	0 to +10	>10 GHz	MM, SM
DFB Laser	1550 (1480-1650)	0 to +25	>10 GHz	SM
VCSEL	850	-10 to 0	>10 GHz	MM

1.3 OPTICAL RECEIVER

For light to be processed and the data carried to be extracted, light detectors or an optical receiver must transform the light traveling through a fiber optic cable into an electrical signal. Two devices that are commonly used are:

- a. **PIN Photodiode**
- b. **Avalanche Photo Diode (APD)**

The most widely used detectors are semiconductor photodiodes, also known as photodetectors, which react to incident light by producing current.

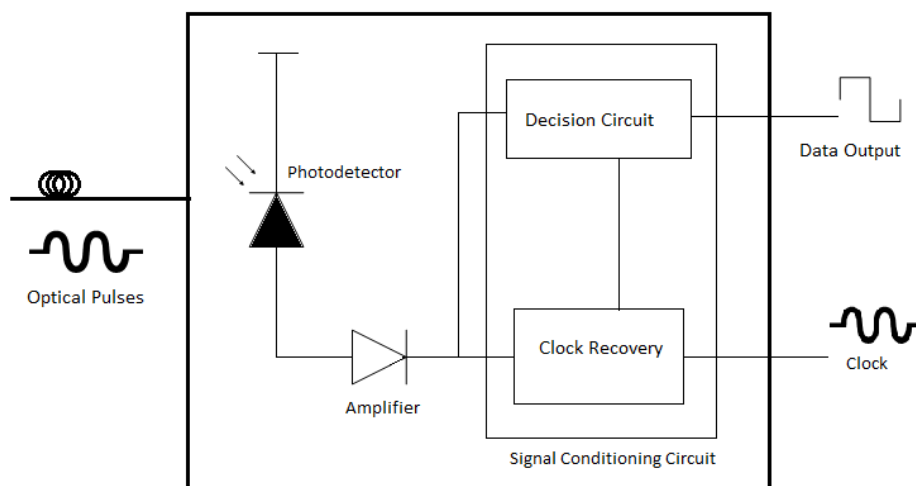


Figure 1.4: Optical Fiber Receiver

The primary task of a receiver is to change the optical signal into an electrical signal. An optical receiver consists of:

- i. A semiconductor photodiode (or a photodetector) that generates a current when light strikes it.
- ii. An amplifier, which boosts the photodiodes output current.
- iii. Signal conditioning circuitry that improves the quality of output signals.

A junction photodiode operates much like a standard signal diode but is designed to convert light into current. In the absence of light, a small reverse bias stops any current from flowing. When photons enter the depleted junction region, they generate electron-hole pairs and produce a measurable photocurrent. This makes the diode an efficient light sensor with fast response.

PIN Photodiode

It involves a heavily doped intrinsic layer surrounded by thin p-type and n-type regions. One of the notable characteristics of PDs is that the depletion layer, which is primarily formed by the intrinsic layer, is the region where photon absorption takes place.

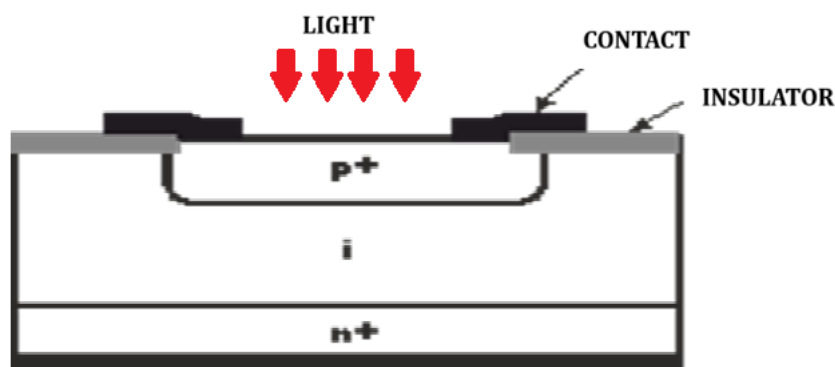


Figure 1.9: PIN Photodiode Structure

The absorption of incoming photons occurs primarily in the thick intrinsic layer of the pin photodiode, which turns it into electron hole pairs leading to both high quantum efficiency and responsive pin photodiodes. Since the depletion region is defined by layer thickness instead of the applied voltage, only a small, five-volt reverse bias is needed. This configuration achieves rapid response and high-power efficiency, resulting in wide bandwidth capability and strong signal conversion.

Avalanche Photodiode (APD)

The Avalanche Photodiode structure is relatively similar to PIN photodiode structure.

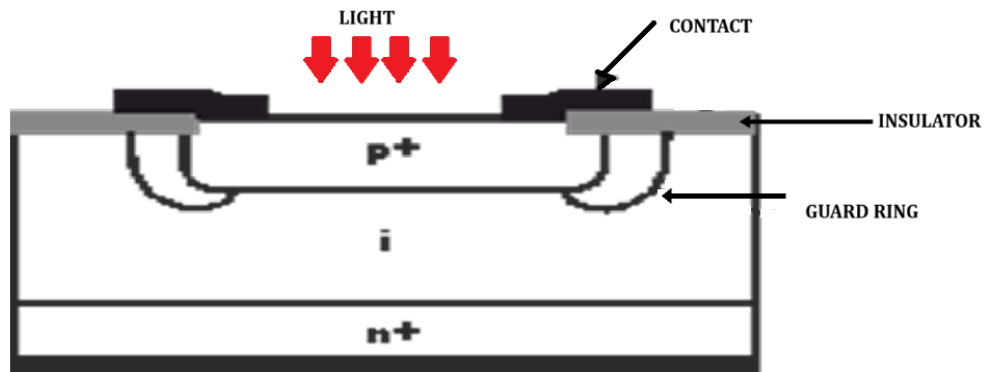


Figure 1.10: APD Photodiode structure

To stop surface breakdown from occurring when the avalanche photodiode is operating under high reverse bias, a guard ring is placed around the diode junction. In APDs, a high reverse bias is usually applied, sometimes exceeding one hundred volts, to the active region of the diode. This reverse bias creates a strong electric field which helps in the acceleration of electrons produced by the incident photons during the device traversal. When these high-energy electrons collide with the crystal lattice, they knock loose additional carriers, creating more electron-hole pairs and boosting the photocurrent. This chain reaction, known as avalanche multiplication, continues until the carriers leave the active area, giving the photodiode its built-in gain.

Typical Performance Characteristics of Detectors

Parameter	Silicon		Germanium		InGaAs	
	PIN	APD	PIN	APD	PIN	APD
Wavelength range (nm)	400 – 1100	400 – 1100	800 – 1800	800 – 1800	900 – 1700	900 – 1700
Peak (nm)	900	830	1550	1300	1300 (1550)	1300 (1550)
Responsivity ρ (A/W)	0.6	77-130	0.65-0.7	3-28	0.63-0.8 (0.75-0.97)	
Quantum Efficiency (%)	65 – 90	77	50-55	55-75	60-70	60-70
Gain (M)	1	150-250	1	5-40	1	10-30
Excess Noise Factor (x)	-	0.3-0.5	-	0.95-1	-	0.7
Bias Voltage (-V)	45-100	220	6-10	20-35	5	<30
Dark Current (nA)	1-10	0.1-1.0	50-500	10-500	1-20	1-5
Rise Time (ns)	0.5-1	0.1-2	0.1-0.5	0.5-0.8	0.06-0.5	0.1-0.5

1.4 FACTOR INFLUENCING RECEIVER PERFORMANCE

Due to the fact that the photodetector has to deal with an optical signal that is frequently weaker and more distorted, it must satisfy certain performance conditions. Such requirements will include a high degree of sensitivity, a low degree of noise, the ability to work with low amplitude signals, and faster response time. The performance of the photodetector is directly related to the performance of the optical signal. Moreover, the detector will be dealing with signals that are seriously altered at the photodetector, and it is necessary to guarantee a strong enough response to the event of a signal coming through that will be detected. Photodetector characteristics include:

- The received light signal's emission wavelength range is highly sensitive
- The least amount of noise that is added to the signal.
- A fast reaction time in order to manage the intended data rate.

The following variables impact on the performance of the receiver:

- a) The receiver's responsivity function or the dynamics of the responsivity function
- b) The spectral response range or its particular bandwidth
- c) Response time
- d) The sensitivity demonstrated by the receiver

a) Detector's Responsivity or Dynamic Range

The ratio of the incident optical power in watts to the output photocurrent in amperes from the optical detector is known as responsiveness. The wavelength of the incident light and the detector's effectiveness in reacting to that wavelength determine its responsivity. High receiver sensitivity is equivalent to high responsivity. Responsivity, which links the photocurrent produced to the incident optical power, is a helpful metric for describing detector performance. Responsivity is frequently expressed as $\mu\text{A}/\mu\text{W}$ since input powers in fiber optic communication systems are typically in the microwatt level.

b) Spectral Response Range or Bandwidth

A given incident light level generates a photocurrent that is influenced by the wavelength. Quantum efficiency and photosensitivity are two terms that can be used to describe this relationship between wavelength and photoelectric sensitivity, which is known as the spectral response characteristic.

c) Response time

There are multiple factors that affect a photodiode's and its output circuitry's response time. The two most important of these are the detector's active area thickness and RC time constancy. The time needed for the generated electrons to exit the detector's active region is correlated with the detector's thickness. The electron transit time is the name given to this duration. The transit time will increase with the thickness of the detector's active region.

d) Receiver Sensitivity

The lowest possible optical power level which can achieve a certain level of operation is referred to as the receiver's sensitivity. In the case of digital systems, the communication rate is measured using the bit rate, and performance is measured using the bit error probability. In the case of performance evaluation of analog communications, signal-to-noise ratio (SNR) of the signal is used, and the rate of communication is determined based on the bandwidth of the electrical signal which is to be transmitted.

- **Digital Transmission: Bit Error Rate (BER)**

The bit error rate is defined as the frequency of errors in a transmission system. In a sequence of a specific number of bits, this translates as the number of errors that take place. For simplicity, the definition of bit error rate can be simplified with the formula below:

$$\text{BER} = \frac{\text{Number of Errors}}{\text{Total Number of Bits Sent}}$$

A high signal-to-noise ratio along with an appropriate distance between the transmitter and receiver usually leads to a very low bit error rate, often negligible and imperceptible to the system. If noise becomes detectable, the bit error rate may need to be addressed.

- **Analog Transmission: Signal to Noise Ratio (SNR)**

Signal to noise ratio, or SNR, indicates the amount by which the signal level exceeds the noise level. At an optical receiver's output, SNR is simply the signal power to noise power ratio. Thus, it is an important indicator of receiver performance.

$$\text{SNR} = \frac{\text{signal power}}{\text{noise power}} = \frac{i_{\text{signal}}^2 R_L}{i_{\text{noise}}^2 R_L}$$

where:

$$i_{\text{noise}}^2 = i_t^2 + i_s^2 + i_d^2$$

1.5 NOISE FACTOR IN THE OPTICAL RECEIVERS

Unwanted signal components that tend to interfere with the signal's processing and transmission in a physical system are known as noise. A detection system's noise is caused by a variety of factors. There are many different sources of noise, and it can start in any part of the receiver in an electrical or optical form. The most important noise is produced by the photodiode. The three most common kinds are:

- i. Shot noise
- ii. Dark current noise, and
- iii. Thermal/Johnson noise.

a) Thermal Noise

Thermal noise is caused by the dissipation of heat in the detector resistance, as well as the random motion of electrons. Because of the random motion of electrons, the photocurrent shows fluctuations which is termed as thermal noise. In the process of photo detection, thermal noise is usually the main source of noise. This is the definition of thermal noise.

$$i_t^2 = \frac{4KT\Delta f}{R}$$

where:

K is Boltzmann's constant (**1.38×10^{-23}**)

T is the temperature in Kelvin

Δf is the bandwidth

R is the load resistance

b) Shot Noise

A small current referred to as "shot noise" occurs due to the randomness inherent in the photon-to-electron conversion process. Any form of photocurrent generated, inclusive of 'dark' photocurrents, will have a shot noise component. When compared to other devices, avalanche photodiodes exhibit greater shot noise because of their increased multiplication factor. This can be expressed as:

$$i_s^2 = 2qI\Delta f$$

where:

I = is the average current (including dark current)

q = electron charge (1.59×10^{-19} C)

c) Dark Current Noise

Dark current refers to the small current that flows in the absence of light striking the photodetector. The current results from the combination of surface recombination and bulk leakage from thermally-excited electrons in the depletion region. The noise associated with dark current increases with temperature and the voltage across the device. Dark current noise can be expressed by:

$$i_d^2 = 2qI_d\Delta f$$

where:

I_d is the dark current

Example of Noise Factor in Receiver Performance

Let us consider a system with an LED and a PIN photodetector. The photodetector has a dark current of 2 nA. The bandwidth of the receiver is 10MHz and the temperature is 300°K. The input signal power is 2×10^{-12} W. Determine power of shot noise, thermal power noise and SNR.

Solution:

$$\begin{aligned}\text{Shot noise Power} &= 2 q I_d \text{ BW} \\ &= 2 (1.59 \times 10^{-19}) (2 \times 10^{-9}) (10 \times 10^6) \\ &= 6.36 \times 10^{-21} \text{ W}\end{aligned}$$

$$\begin{aligned}\text{Thermal noise power} &= K T \text{ BW} \\ &= (1.38 \times 10^{-23}) (300) (10 \times 10^6) \\ &= 4.14 \times 10^{-14} \text{ W}\end{aligned}$$

$$SNR = \frac{P_s}{P_n} = \frac{2 \times 10^{-12}}{(6.36 \times 10^{-21}) + (4.14 \times 10^{-14})} = 48.309$$

$$SNR_{dB} = 10 \log 48.309 = 16.84 \text{ dB}$$

1.6 SOURCE-TO-FIBER COUPLING AND FIBER OPTIC TERMINATION

The types of connector in fiber optic system are:

- a) Ferrule Connector (FC)
- b) Straight Tip Connector (ST)
- c) Subscriber Connector (SC)
- d) Lucent/Local Connector (LC)

a) Ferrule Connector (FC)

FC connector is a simplex-only, screw-on type connector. These connectors are available in single mode or multimode versions. In addition, it has a 2.5 mm ferrule. The ferrule may be a steel or ceramic steel-embedded, spring-loaded or floating.



Figure 1.11: Ferrule Connector (FC)

It provides reliable connection and disconnection without requiring precise optical alignment and was developed specifically for telecommunications use. A threaded coupling ensures a durable, long-lasting joint, and the design minimizes signal loss for long-distance single mode links. This connector is commonly found on test equipment and can also support high-quality multimode applications when needed. However, SC and LC connectors are gradually replacing it in most installations. After that, the tip is usually polished using a technique known as "physical contact" polish to create a rounded surface. Because of their surface profile, the fibers only touch at their cores when they are mated, enabling low-loss transmission.

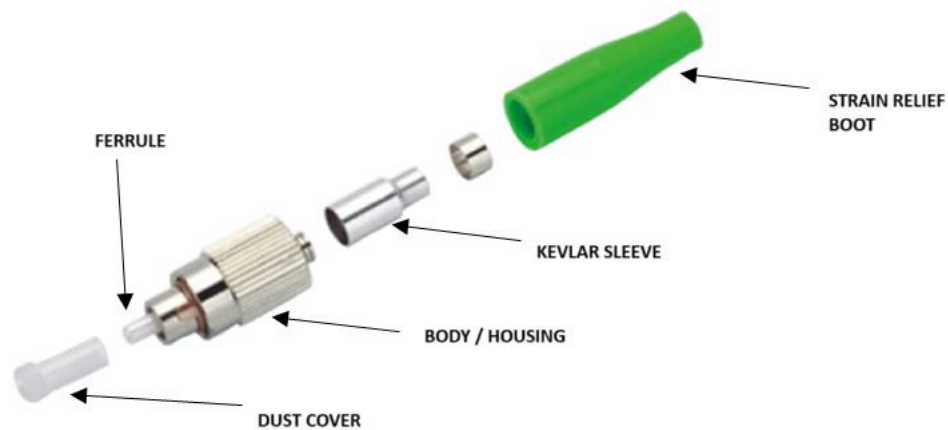


Figure 1.12: Ferrule Connector Part

STRAIN RELIEF BOOT

- Restricts flexing at the rear of the connector and also serves to fasten the connector to the cable.

BODY / HOUSING

- Plastic or metal portion of a connector that contains the coupling/attachment mechanism (Push-Pull, Bayonet or screw thread).

FERRULE

- Segment of a connector made of metal, ceramic, zirconia, or plastic that is designed to ensure a narrow aperture greater than 125 micrometers which aligns and concentrates the fiber in the connector.

DUST COVER

- Help to protect the ferrule and fiber optic end from dust, dirt and scratch when not in use.

KEVLAR SLEEVE

- Wrapping a layer of Kevlar (strength member) in fiber cable to provide mechanical strength and prevent direct pull on the fiber

b) Straight Tip (ST) Connector

The ST connector uses a twist on bayonet mechanism to provide simplex connections for both single mode and multimode fibers. A long cylindrical 2.5 mm ferrule which is typically ceramic but sometimes made of polymer or metal, secures the fiber in place.

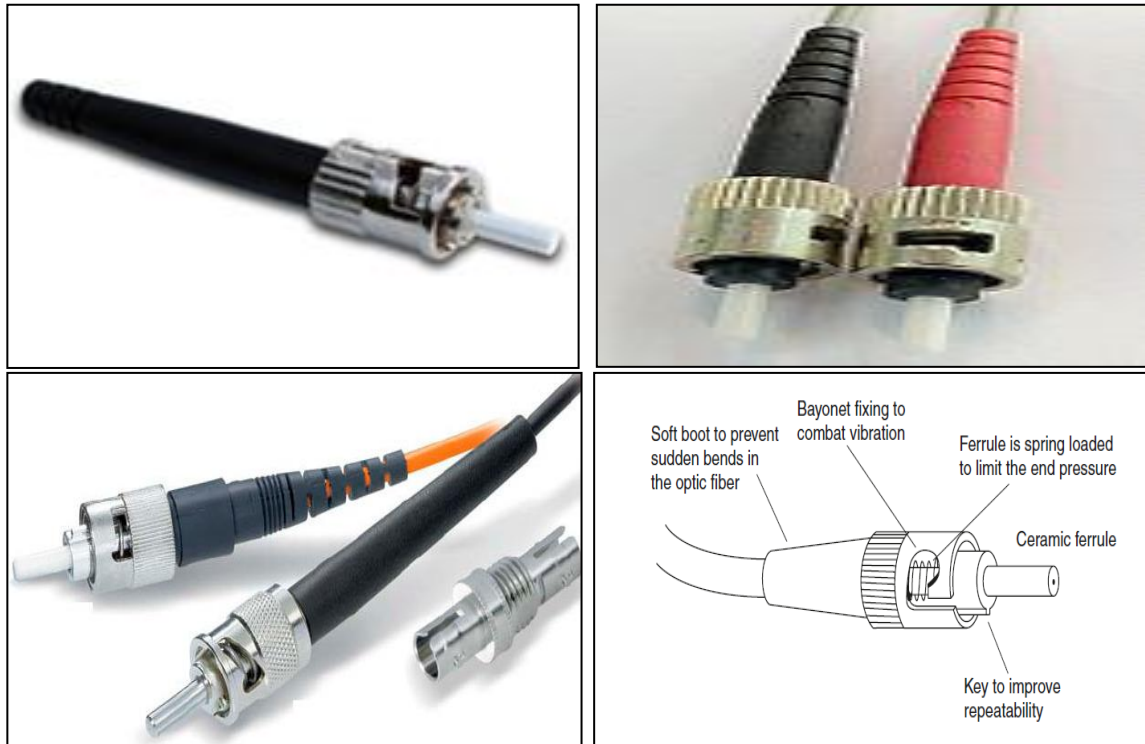


Figure 1.13: Straight Tip Connector (ST)

ST connectors remain as some of the earliest optical fiber connectors employed in optical networking and serve to join and protect the two optical fiber slices with precision. For multimode networks, as in the case with numerous buildings and university campuses, ST is likely the predominant connector used. These connectors also find extensive use in data centers, in short to medium distance network interconnections, as well as in military and security applications.

c) Subscriber Connector (SC)

The SC connector uses a snap in mechanism and supports both simplex and duplex communication. It is available for both single mode and multimode fiber. Featuring a 2.5 mm ferrule, it delivers exceptional performance and has become widely adopted. Although it was standardized in TIA-568A and initially cost about twice as much as the ST type, its reliability and ease of use have driven its popularity.

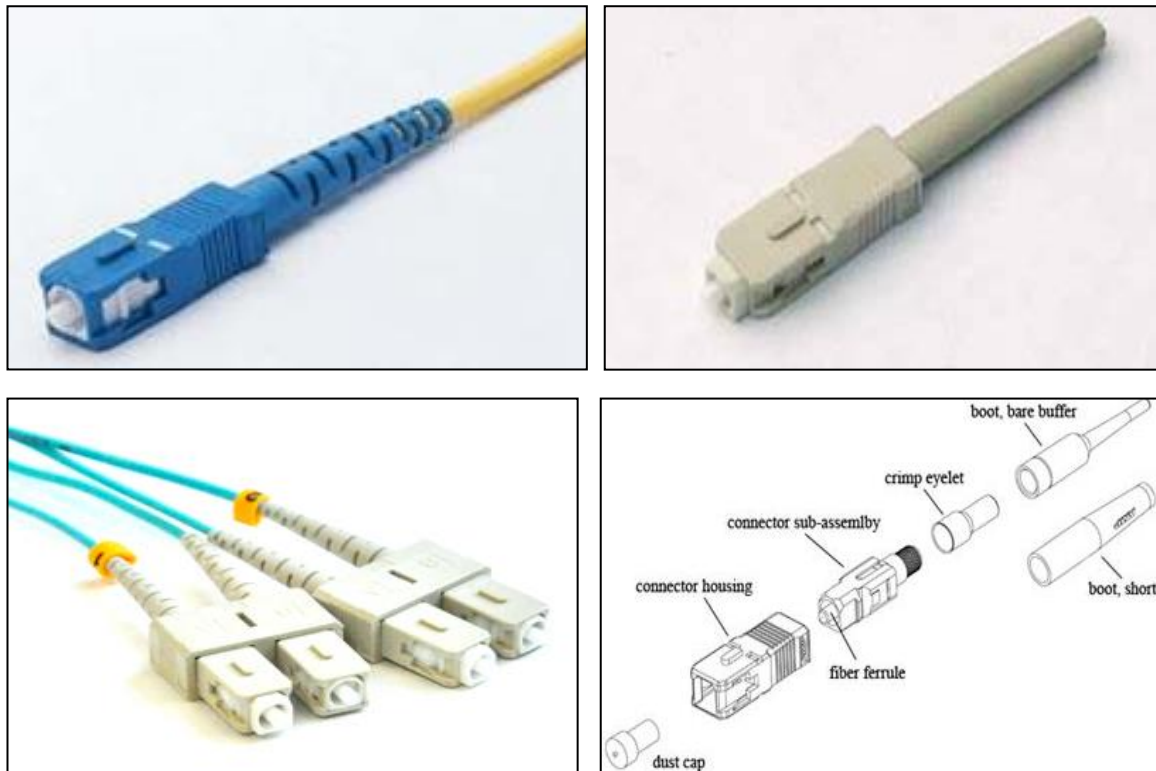


Figure 1.14: Subscriber Connector (SC)

It is a snap-in connector which can be latched onto with a simple push-pull motion. Simplex SC connectors can be clipped together by a reusable duplex holding clip, which allows the creation of duplex SC connectors.

d) Lucent/Local Connector (LC)

Often referred to as "little connectors", LC connectors are dual (simplex and duplex) with a push and latch mechanism reminiscent of RJ connectors. Offered in single mode as well as multimode. LC is a type of small form factor connector with a 1.25 mm ferrule which is half the size of SC. However, it is a standard ceramic ferrule connector and can be terminated with virtually any adhesive.



Figure 1.15: Lucent Connector (LC)

The LC connector is a small form factor connector whose size matches that of an RJ 45 plug. It delivers excellent performance, especially for single mode transmission, and is commonly found on fiber patch cords. LC connectors appear in many systems, including telecommunications backbones, local area networks, data center links, cable television feeds, fiber-to-the-home installations, and premise distribution. The latch mechanism resembles a familiar telephone plug and snaps into place with a clear click, making insertion and removal intuitive. Although all LC connectors share the same basic design, compatibility between parts from different manufacturers is not guaranteed. Variations in the number of components, termination methods, choice of materials, and use of epoxy can affect ease of installation. In addition, performance parameters such as operating temperature range, mechanical durability, return loss, and insertion loss may differ from one vendor's product to another.

What is the difference between a single mode connector (ST, SC etc) and a multimode connector?

Single mode and multimode connectors differ in two main ways. First, the color of the strain relief boot: multimode boots are usually black or beige, while single mode boots are often blue or white. Second, the ferrule material and bore size. Single mode connectors almost always use zirconia (ceramic) ferrules with a center hole of about 126 microns. Multimode connectors may use zirconia, composite plastic, or nickel-silver ferrules with holes around 127 to 128 microns. Though the difference in diameter is small, fitting a larger multimode ferrule onto single mode fiber can cause a noticeable increase in insertion loss.

Comparison of Connectors

Connector	Insertion Loss	Repeatability	Fiber Type	Applications
FC 	0.5dB – 1.00 dB	0.20dB	SM, MM	Datacom, Telecommunications
FDDI 	0.20dB – 0.70 dB	0.20dB	SM, MM	Fiber Optic Network
LC 	0.15dB (SM) 0.10dB (MM)	0.20dB	SM, MM	High Density Interconnection
MT Array 	0.30dB – 1.00dB	0.25dB	SM, MM	High Density Interconnection
SC 	0.20dB – 0.45dB	0.10dB	SM, MM	Datacom
SC Duplex 	0.20dB – 0.45dB	0.10dB	SM, MM	Datacom
ST 	0.40dB (SM) 0.50dB (MM)	0.40dB (SM) 0.20dB (MM)	SM, MM	Inter-/ Intra- Building, Security, Navy

Types of Adapters used in Fiber Optic System

Fiber patch cables and fiber optic connectors are connected via fiber optic adapters. The sides and shape of the fiber optic adapters are designed to match the connectors because the adapters must fit the appropriate connectors. Due to the variety of connectors, there are numerous types of fiber optic adapters. Fiber adapters come in two varieties: female to male and female to female. Hybrid fiber optic adapters, like the LC to SC hybrid adapter, are designed to accommodate two distinct types of fiber connectors. Simplex and duplex fiber optic adapters are available. A ceramic (zirconia) or phosphor bronze cylindrical sleeve sits in the middle of the adapter.

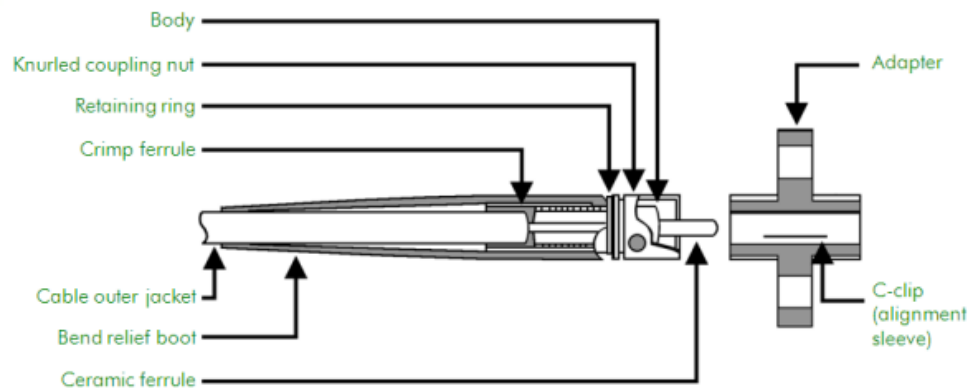


Figure 1.16: Parts of a Fiber Optic Connector

(Elmont Rd, 2009)

Ferrules insert into the sleeve and connect together. As for the connector bodies, the adapter body provides mechanisms to hold them with snap-in, push and latch, twist on, or screwed on. In fiber optic systems, the following adapter types are classified as:

FC Adapter

FC connectors with a screwed-on mechanism.



Figure 1.17: FC Adapter

ST Adapter

To join two connectors, a mating adapter is used. The connector is inserted into the adapter's spring-loaded bayonet socket and twisted to lock in place. Proper seating of ST connectors, which rely on spring tension for retention, is essential. If optical loss remains high, disconnect and reinsert the connectors to improve alignment.



Figure 1.18: ST Adapter

SC Adapter

It plugs into the adapter with a very positive click action, telling us it is already engaged.

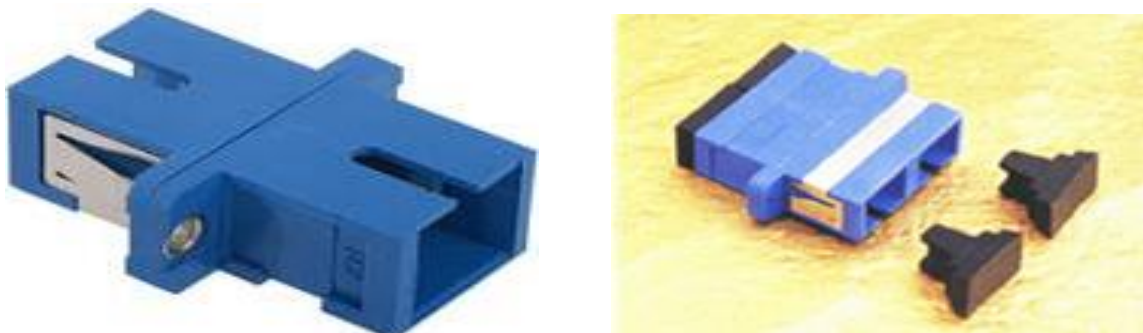


Figure 1.19: SC Simplex Adapter & SC Duplex adapter

LC Adapter

There are two types of LC adapters: simplex and duplex. They have labeled polarity, a selection of mounting orientations, and self-adjusting panel latches.

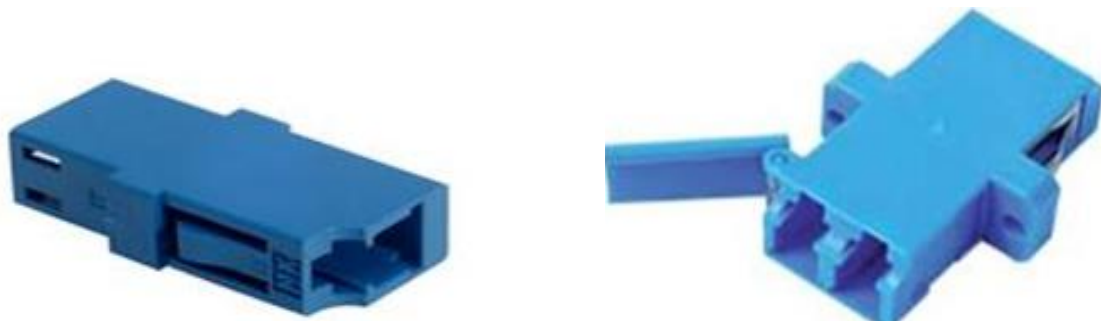


Figure 1.20: LC Simplex adapter & LC Duplex adapter

Mating Dissimilar Connectors

The ST, SC, and FC connectors can be interconnected because they all use the same 2.5 mm ferrule specification. A hybrid adapter, such as the one showed in Figure 1.21, is required to facilitate their coupling.

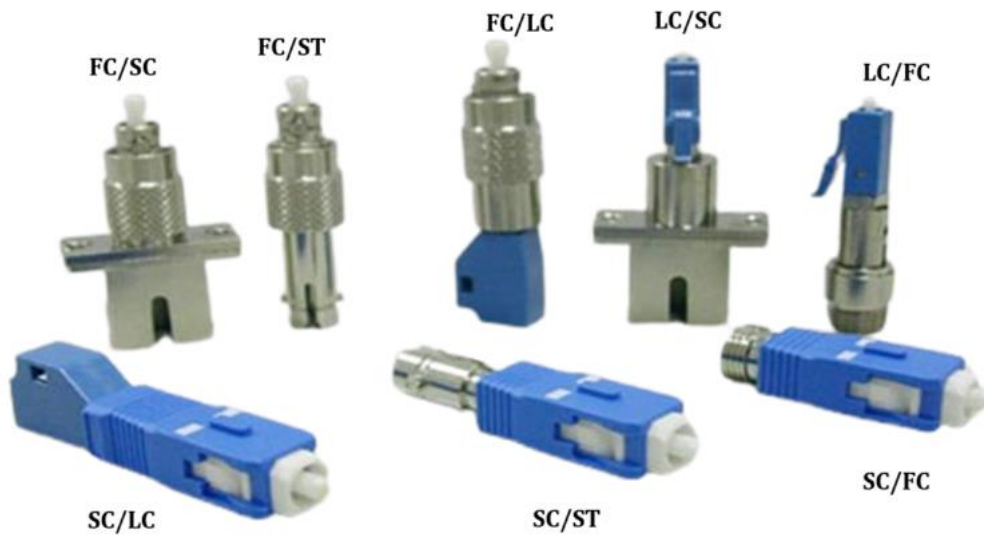


Figure 1.21: Hybrid Adapter

1.7 FIBER SPLICING

The process of splicing raw optical fibers entails the direct connection of the two fibers without the use of any connectors. Fiber optics splicing methods can be grouped under two categories:

- a) Arc Fusion splicing
- b) Mechanical splicing

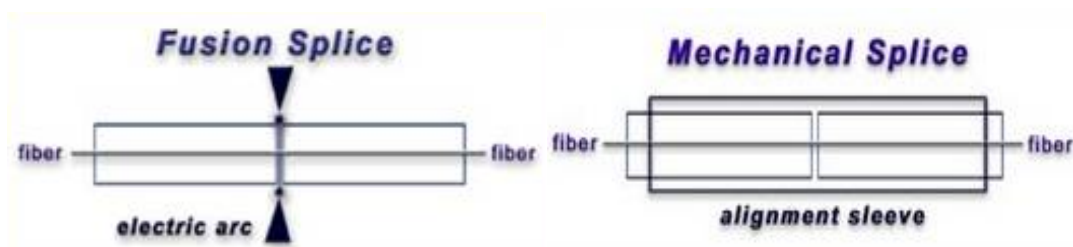


Figure 1.22: Fiber Splicing

(Connect, 2024)

Both techniques are significantly better than fiber connectors with regards to insertion loss.

- Arc fusion splice with fiber optic cables - insertion loss is less than 0.1dB.
- Mechanical splice with fiber - insertion loss is less than 0.5dB.

a) Arc Fusion Splicing

Fusion splicing is the most widely used technique because it creates a reliable, strong joint between two fiber ends with very low insertion loss and almost no back reflection. The process is performed automatically by a fusion splicer machine, which is typically large, costly, and highly precise. In the hands of a well-trained technician, fusion splicing can consistently achieve insertion loss below 0.1 dB for both single mode and multimode fibers.



Figure 1.23: Fusion Splicer

The optical fiber fusion splicer performs optical fiber fusion splicing in two steps:

- i. Ensure that the two fibers are precisely aligned.
- ii. To melt the fibers and weld them together, create a small electric arc.

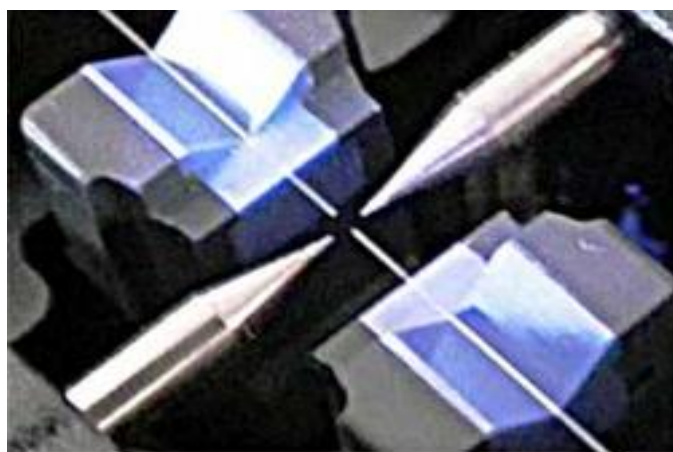


Figure 1.24: Generates Spark (high temperature heat)

b) Mechanical Splicing

In mechanical splicing, two fibers are joined using mechanical methods and tools end to end. Clamping two fiber ends or gluing them together uses index matching gels, and transparent adhesives which are used for mechanical splicing. Fiber ends are joined using transparent adhesives which are also known as epoxy resins and are used for index matching and sealing mechanical splices. Crimping or holding fibers in place, mechanical splicing is known to have higher reflectance losses than fusion splicing. Also noted is lower pull-out strength and lower fiber retention.

Mechanical Splice



(SYOPTEK, 2008-2016)

The basic protection sleeve required by a fusion splice is less expensive than the splice component itself, which includes a precision alignment mechanism. The most common applications for mechanical splices are multimode fiber splicing in a building installation or quick, temporary restoration. The benefit of mechanical splices is that they can be made without the need for a costly machine.

The Characteristics between Arc Fusion Splicing and Mechanical Splicing

CHARACTERISTIC	ARC FUSION	MECHANICAL
Fiber alignment mechanism	Machine is used to precisely align the two fiber ends then the glass ends are "fused" or "welded" together using some type of heat or electric arc.	Simply alignment devices to hold the two fiber ends in an alignment fixture with a transparent gel or optical adhesive.
Loss and back reflection	Lower loss (Typical loss: 0.1 dB) and less back reflection	Higher loss (Typical loss: 0.3 dB) and greater reflectance
Fiber types	(SM) Primarily used with single mode fiber	(SM & MM) Work with both single and multimode fiber.

Applying Arc Fusion Splicing

After preparation and cleavage, the fiber ends are inserted into the fusion splicer's alignment fixtures. Electrodes heat the fiber ends, which are then brought together and fused at the touch of a button. There are five (5) fundamental steps.:

THE PROCEDURE OF FUSION SPLICING USING SPLICING MACHINE		
STEP 1	Put on the fusion splice protection sleeve.	
STEP 2	Strip the fiber. Strip back all fiber coatings down to the 125um bare fiber. Clean the bare fiber with 99% isopropyl alcohol.	
STEP 3	Cleave the fiber. The fiber needs to be cleaved with a high precision cleaver. Most splicing machines come with a recommended cleaver. Fiber cleaving is a very important step as the quality of the splice will depend on the quality of the cleave.	
STEP 4	Put the fibers into the fiber holders in the fusion splicer. Press the start button to start the fusion splicing.	
STEP 5	Heat shrink the protection sleeve to protect the splicing joint from moisture or other environmental hazards. An alternate method using clamp-on protectors.	

Almost all single mode splices are performed using fusion splicing. Splicing multimode fibers is difficult due to the steep graded index profile caused by the larger core and multiple glass layers. This is especially true for fibers of different manufacturers or types. Fusion splicing is done to one or multiple fibers at a time, and can also be performed on an entire ribbon cable piece.

SAFETY PRECAUTION FOR SPLICING PROCEDURE



WEAR SAFETY GLASSES

This is to keep fiber shards and splinters out of people's eyes, everyone in the vicinity needs to wear safety glasses with side shields. Safety glasses are still required for those who wear them.



NO FOOD or DRINK

Tiny glass fibers can be present in the air during the construction or installation of fiber optics. Glass fragments from a simple glass of water can travel down the oesophagus and into the throat, where they can cause internal bleeding and cuts.



WEAR PROTECTIVE APRONS

To lessen the amount of fiber particles that gather on personal clothing, all employees should be dressed in disposable lab aprons. Particles that gather on clothing can later be consumed through food, beverages, or airborne particles.



AVOID FIBER ENDS

There are some justifications for peering through a fiber cable, but caution must be used to make sure that light is visible through the cable. Use an optical tracer or continuity checker to see if the fiber is dark before peering into the end of a cable. The absence of a light source at the other end of the cable will be confirmed by a power meter.



CONTACT LENS WEARERS – BEWARE!

Wearers of contact lenses should exercise caution when handling fiber optics. They should thoroughly wash their hands before handling their lenses. Shards of glass have the potential to lacerate the surface of the eye.

**KEEP HANDS AWAY FROM FACE**

Avoid touching your face with your hands. Many people have the habit of touching their faces without any apparent reason. When working with fiber optics, this action must be avoided.

**WELL-VENTILATED AREA**

One essential element of a safe workplace is the ability to breathe clean air. Small splinters from the fibers can pierce the face's delicate skin and are extremely challenging to extract. When fiber optic cables are moved for any reason, the numerous tiny glass particles inside them become dislodged. The particles will be able to travel away from the workers handling the fibers in an area with adequate ventilation.

**NO FLAMMABLE MATERIALS**

Fusion splicers and curing ovens have the potential to ignite flammable materials. It is important to exercise caution to make sure that no hazardous materials are used close to this equipment.

**DISPOSE OF SCRAPS**

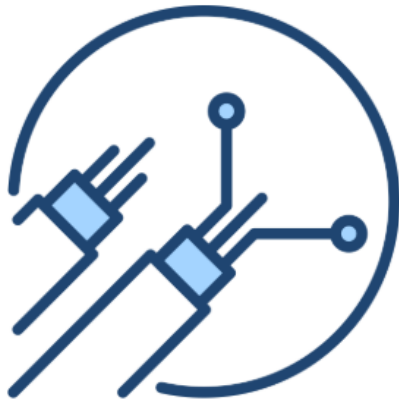
Unused fiber lengths should not be thrown on the ground as this poses a safety risk. Walking on those scraps can cause particles to become dislodged and release into the air, in addition to causing people to trip.

**CLEAN UP AFTERWARD**

Everyone's safety will be guaranteed by a methodical cleaning effort for the entire work area.

**DO NOT SMOKE**

When working with fiber optic systems, do not smoke.



TOPIC 2: FIBER OPTIC NETWORK & TRANSMISSION SYSTEMS



2.0 OPTICAL FIBER DIGITAL LINE SYSTEMS

What is Wavelength Division Multiplexing (WDM)?

According to recent technology of fiber optic, “Wavelength division multiplexing (WDM) is the second major fiber–optic revolution in the field of telecommunications”(Singal, 2018, p. 319). WDM is a technique of transmitting light with different wavelength on a fiber optic cable are called as Multiplexing Division Wavelength (WDM). Through this technique, data that contain in the lights with different wavelengths can be transmit simultaneously on a single cable fiber optic at a one time (Helen Xenos, n.d.). In other word, WDM also can be describe as WDM multiplies transmission capacity by allowing a single optical fiber to carry separate signals at multiple wavelengths (Singal, 2018).

Figure 2.1 depicts on how WDM transmit multiple wavelengths of fiber optic light into single cable optic cable simultaneously.

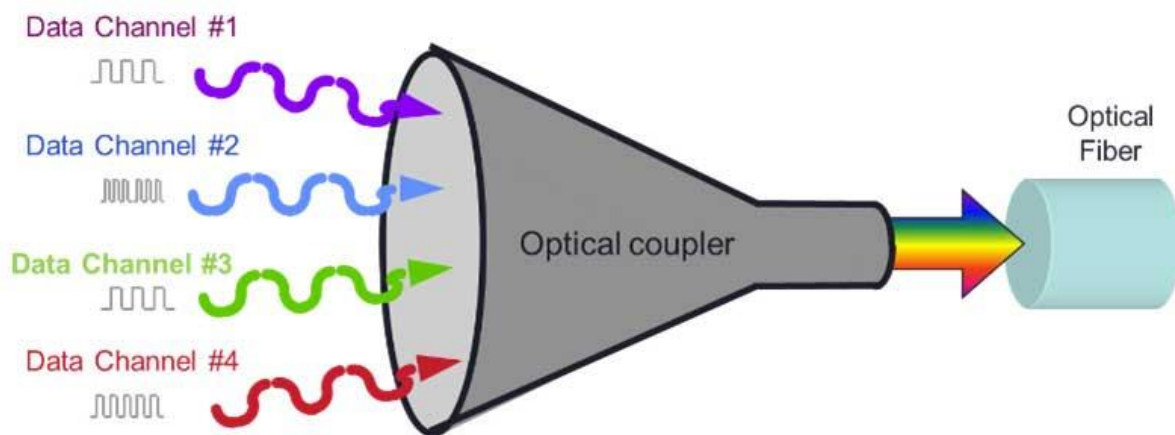


Figure 2.1: Wavelength Division Multiplexing (WDM) technique transmit multiple data with different type of light wavelength in a single fiber optic cable (Helen Xenos, n.d.)

Why WDM?

There are a few reasons why Wavelength Division Multiplexing (WDM) created by the experts as a solution like below: -

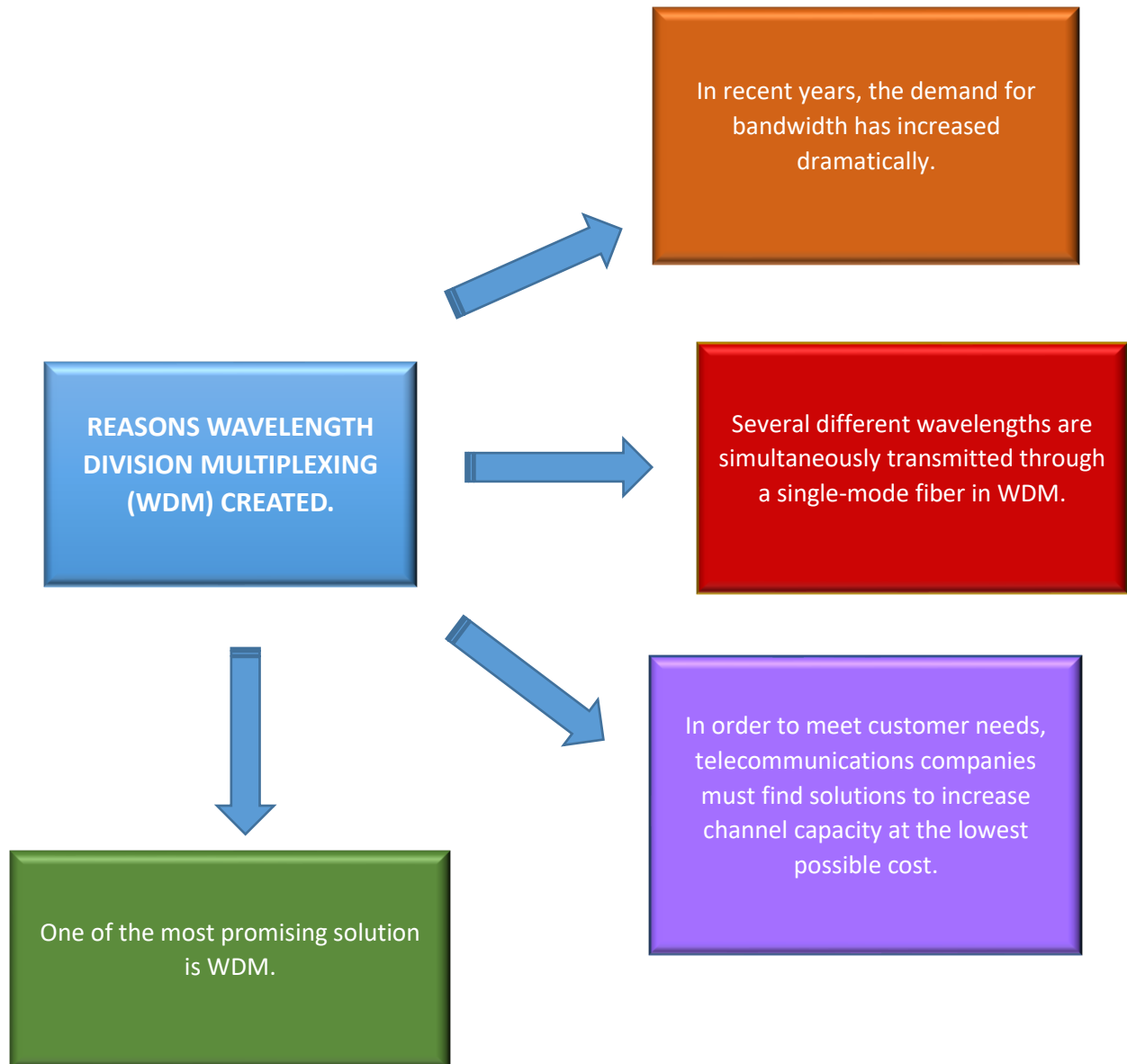


Figure 2.2: Reasons of WDM created.

2.1 PRINCIPLE OF WAVELENGTH DIVISION MULTIPLEXING (WDM)

Each data sends in fiber optic come with different types of wavelengths. These transmitted data are also known as user channel. In WDM, all the transmitted data will be combine using a multiplexer. The multiplexer works to combine user channels of different wavelengths and it is sent into a single fiber optic connection simultaneously.

Collisions between user channels also can be avoided because WDM sends these users channels got different wavelengths for each channel. Figure 3 depicts on how the user channel combine using multiplexer in WDM.

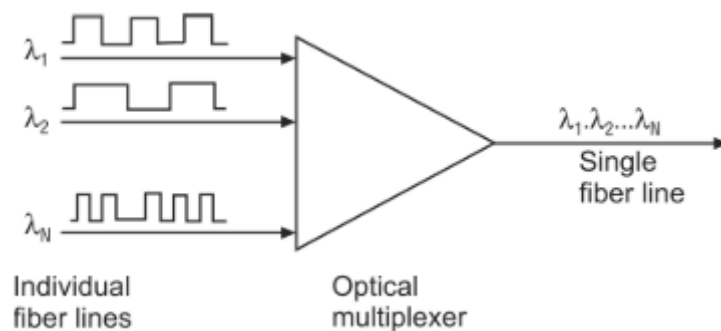


Figure 2.3: Multiplexer in WDM (Singal, 2018)

When the data from this combined user channel is about to reach its destination, it will be parsed using Demultiplexer. Through this demultiplexer process, the data will become standalone like before its combine at the multiplexer process. Figure 2.4 below explains the concept of how WDM works.

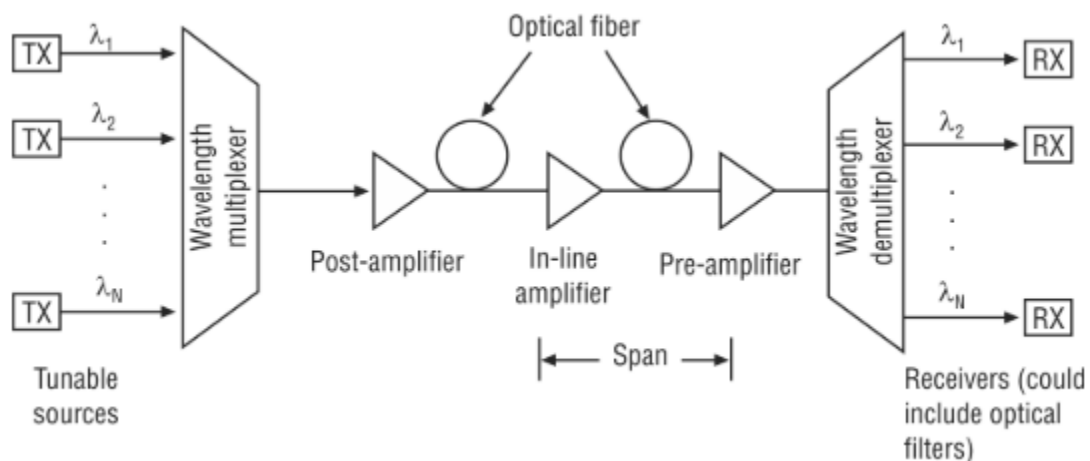


Figure 2.4: WDM principle concept (Singal, 2018).

WDM block diagram and function.

There are 4 main components depicted on the WDM block diagram in figure 5. Functionality for each component is different but it's related to each other. The components stated as below: -

a. Multiplexer

These components located at the transmitter area. Functioning with combining all the single user channel and transmitted together simultaneously on the fiber optic cable.

b. Demultiplexer

These components located at the receiver area. Functioning to parse all the combining user channel and transmitted to its destinations.

c. Optical Add/Drop Multiplexer

These components functioning to parse single or more combining signals that reach the destinations while other combining channels still in transmission process. It also functions to add the single user channel with the combining signal at the middle of signal transmission process.

d. Amplifier

These components functioning by amplifier the weak signal that suffer with degradations during transmission process.

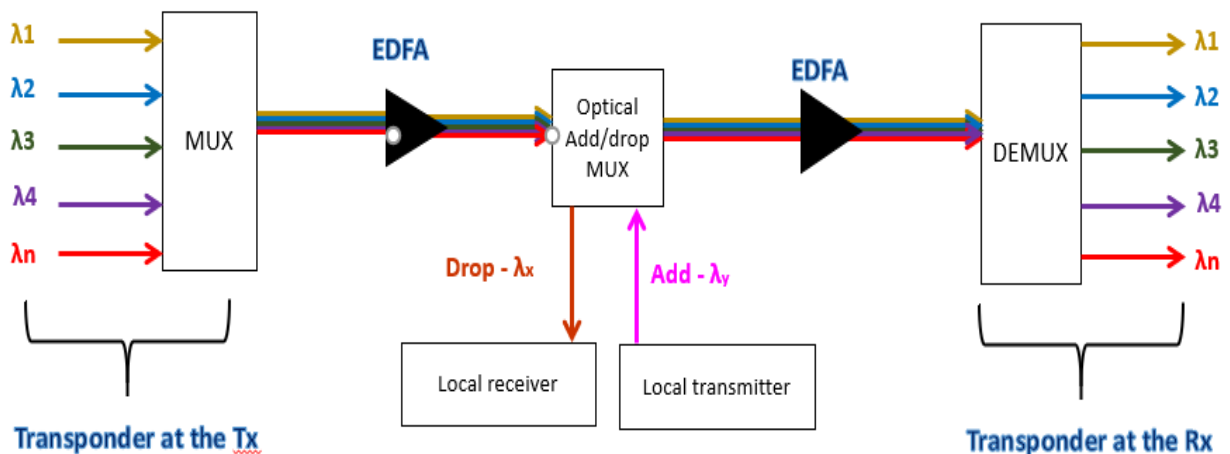


Figure 2.5: WDM Block Diagram.

Broadband WDM, WDM, Dense and Ultra Dense WDM.

Broadband WDM additionally called as Coarse WDM utilize 1300 nm and 1550 nm frequency for full duplex multiplexer with more extensive channel dispersing about 20nm – 25 nm. This sort of WDM offer 5 band types can be utilized which are band O, E, S, C and L. The expense per channel likewise low contrast and different kinds of WDM. The channel can be conveyed at one time is almost 18

channels. This WDM are reasonable to be use for short-pull information transmission application. The speed range for communicate the information is 40 to 100Gbps.



Figure 2.6: Coarse WDM channel spacing

Frequency Division Multiplexing utilize 1310 nm lasers frequency and combination with 1550 nm lasers frequency. On this WDM, two kinds of bands can be use which is O and C bands. The costing per channel likewise low. On channel conveyed, just can convey up to 2 channels all at once. Best applications that can be utilized on these sorts of WDM is application that related on Passive Optical Network (PON).

Thick WDM otherwise called narrowband WDM incorporates ultra-thick WDM utilize tiny spacings channels, 200 GHz or less recurrence channels. Just two bands appropriate on these sorts of WDM which is C and L bands. Cost to work for this WDM is higher contrast and others. The expense is higher is on the grounds that it can convey many channels all at once. This WDM utilized for long stretch information transmission applications in light of the fact that the qualities can communicate numerous channels. Table 1 beneath demonstrate correlation on CWDM, WDM and DWN characteristic.



Figure 2.7: Dense WDM channels spacing.

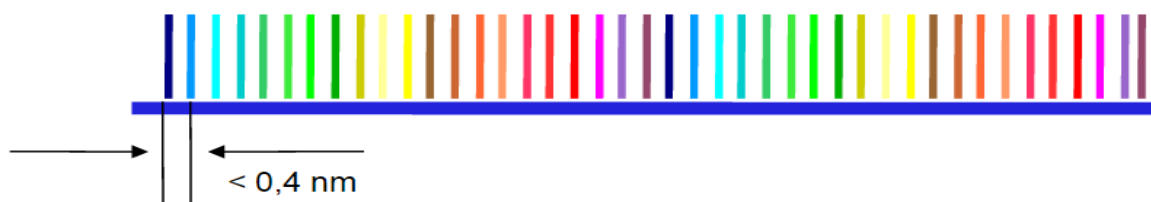


Figure 2.8: Ultra-Dense WDM channels spacing.

	Coarse WDM (includes WDM)	WDM	DWDM (includes ultra dense WDM)
Channel Spacings	Large, from 1.6 nm (200 GHz) to 25 nm	1310 nm lasers used in conjunction with 1550 nm lasers	Small, 200 GHz and less
Number of bands used	O,E,S,C and L	O and C	C and L
Cost per channel	Low	Low	High
Number of channels delivered	17-18 at most	2	Hundreds of channels possible
Best Application	Short-haul, Metro	PON	Long-haul

Table 2.1: Comparison table between Coarse WDM, WDM and DWDM

2.2 FIBER IN THE LOOP (FITL)

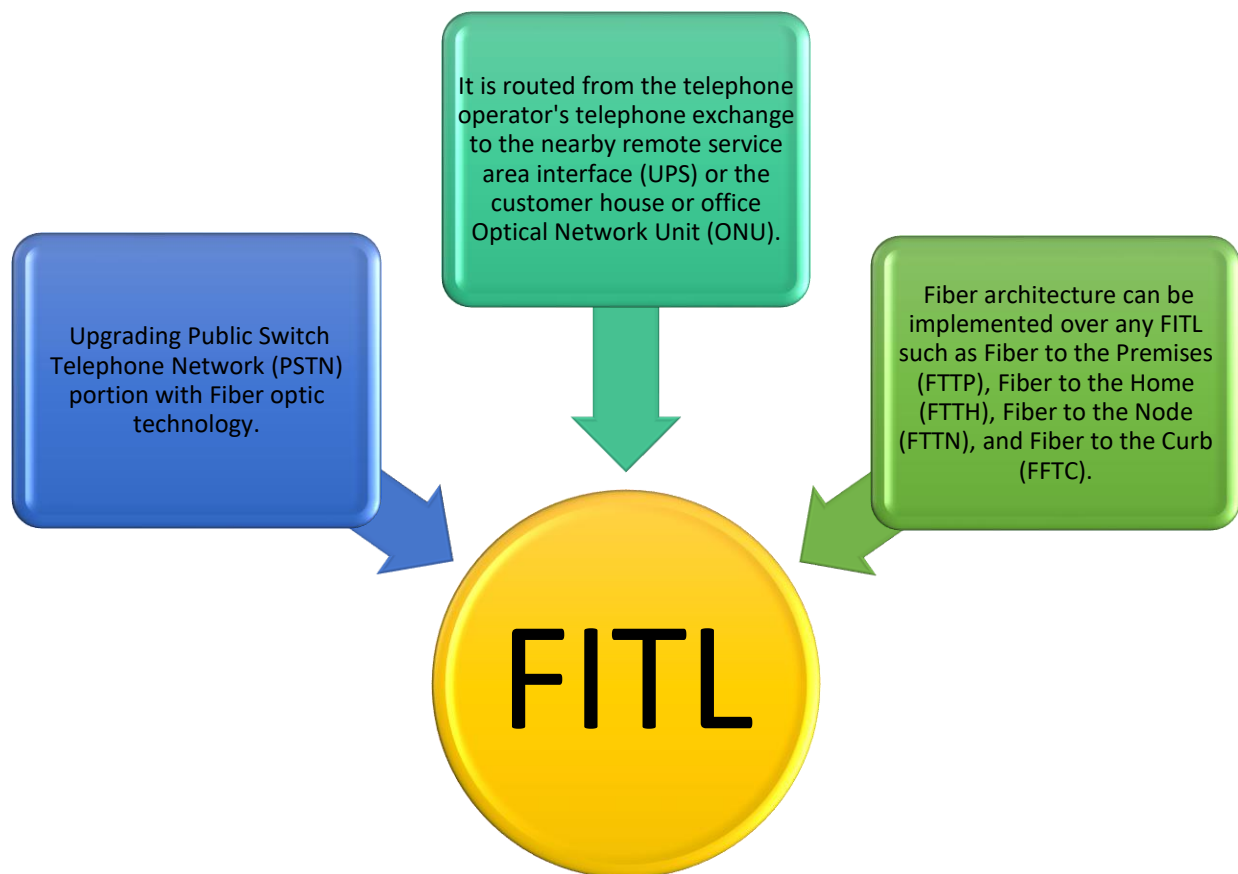


Figure 2.9: FITL all about.

FITL Architecture

The FITL architecture consists of a broadband network connected using fiber optics. This network consists of several types of fiber networks such as: -

- Fiber to the curb/node (FTTC),
- Fiber to the premises (FTTP),
- Fiber to the building (FTTB),
- Fiber to the home (FTTH).

Figure 2.10: below illustrate on Fiber-in-the loop architecture in broadband networks.

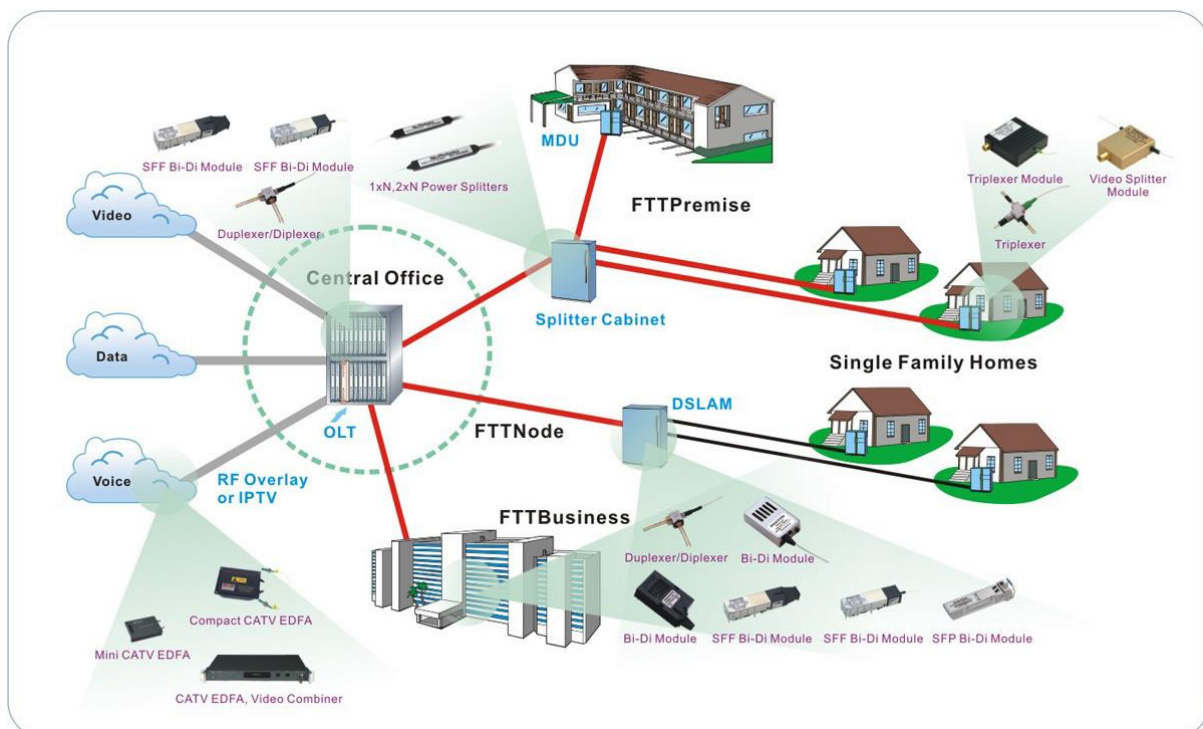


Figure 2.10: Fiber-in-the loop architecture in broadband networks (tutorialspoint.com, n.d.).

Types of Fiber-In-The Loop (FITL)

a. Fiber to the home (FTTH).

Fiber optic connection connect directly to the home and terminated at the box located outside of the house. The types of fiber connection offering end to end services direct to the customer home.

b. Fiber to the premises (FTTP).

These types of fiber connection same with fiber to the home connection oriented but the services are different. The services offer is used for small office home office (SOHO) environments.

c. **Fiber to the-building (FTTB).**

The fiber optic connection installation are terminated at the specific room or location that been determine by the building owner or company.

d. **Fiber to the curb/node (FTTC).**

The Fiber optic connection installation are terminated at the curb that been provided near to the customer area or environment.

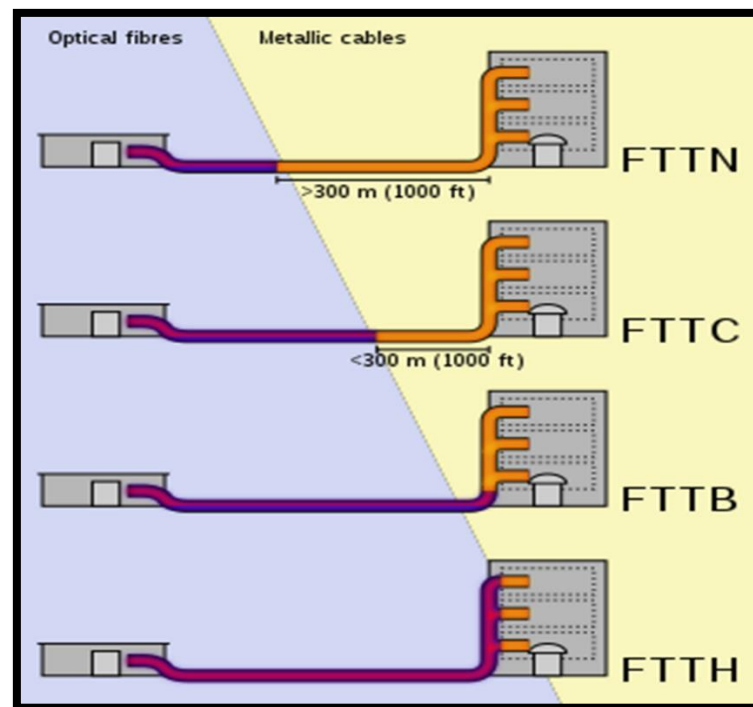


Figure 2.11: Schematic illustration on how FITL connection diagram. (Wikipedia, 2021)

2.3 PASSIVE OPTICAL NETWORK (PON)

Passive Optical Network also known as PON is the system that connect fiber optic cabling and switching the fiber optic signal directly to the end user without using any electrical switching devices. PON architecture depend on how the fiber optic cabling terminate where it can be FTTL, FTTC and FTTB.

Passive Optical Network Benefits

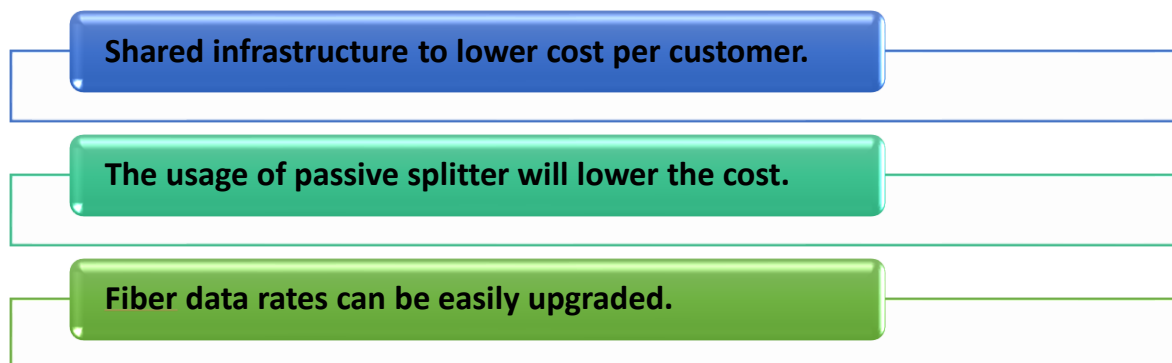


Figure 2.12: PON benefits.

Component Passive Optical Network

There are four main components on PON which are: -

- Optical Line Terminal (OLT),
- Optical Network Unit (ONU),
- Optical Network Terminal (ONT),
- Optical Splitter (OS).

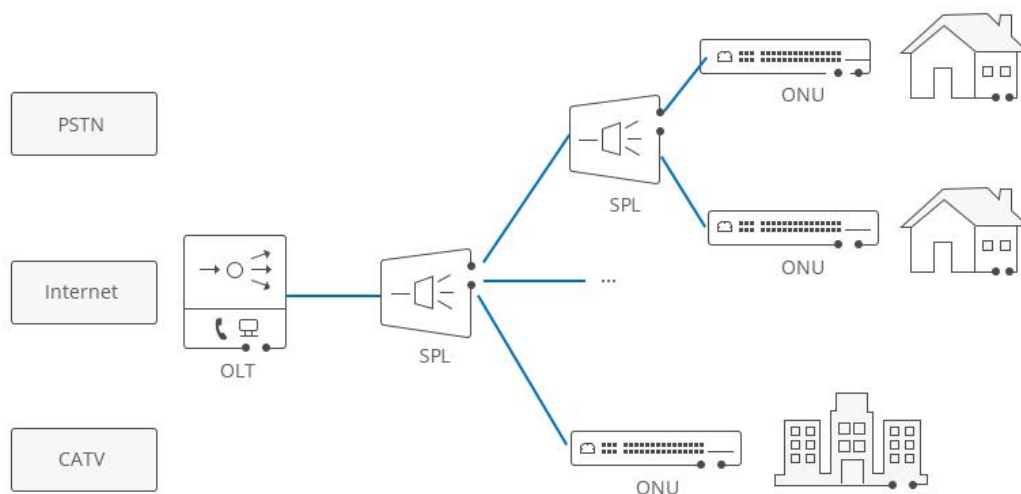


Figure 2.13: PON component logical diagram (Sheldon, 2015).

Optical Line Terminal (OLT)

An OLT sends downstream signal through a fiber with a splitter that distribute the signal among as many as 32 until 128 output fibers. The device that equips with Central Processing Unit (CPU) also allocate with Voice Gateway and Gateway Router uplink cards. Data signal with wavelength 1490 nm also can be transmitted using this device. Figure 2.14 below depicts on OLT device that available on the market right now.



Figure 2.14: Optical Line Terminal (OLT) (Telecomlead, 2017).

Optical Splitter (OS)

This splitter functioning to split fiber optic signal power into the output port that transmitted by the OLT. It comes with 8 or 32 output port that use to connect to the customer drop wire. Figure 2.15 below depicts on Optical Splitter devices.



Figure 2.15: Optical Splitter (Teleweaver, 2021)

Optical Network Terminal (ONT).

This device located after the termination point (TP). Functioning as a modem that translate fiber signal to the digital signal that connect to the router via ethernet cable. Figure 2.16 below depicts on ONT installation diagram.

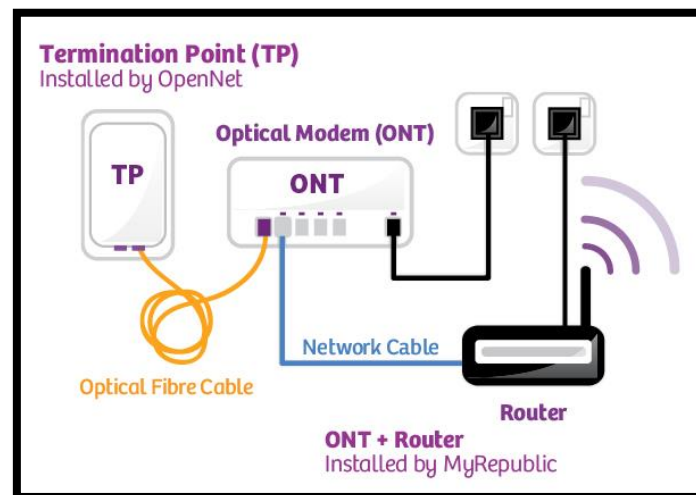


Figure 2.16: Optical Network Terminal (ONT) installation diagram (My Republic, 2021).



Figure 2.17: Optical Network Terminal (ONT) device (My Republic, 2021).

Optical Network Unit (ONU)

This device work together with OLT in Fiber to the home environment whereas allocated at user side in Gigabyte Ethernet PON (GPON) system. Comes with feature such as television broadcasting technology port, data's port, telephone port, full duplex mode with auto negotiation in ethernet port, Voice Over Internet Protocol and many more make this device is very good equipment in the fiber optic network. Figure 2.18 is one of the examples of ONT device.



Figure 2.18: Optical Network Terminal (ONT) device (Sheldon, 2015).

Fiber in the loop on Passive Optical Network (PON) environment.

Referring to the figure 2.19 below, PON fiber optic environment started with OLT devices that allocated at the Internet Service Provider (ISP) area. Then this OLT connected with fiber splitter to the ONT or ONU units to develops fiber in the loop (FITL) architecture such as FTTH, FTTB, FTTC or FTTP.

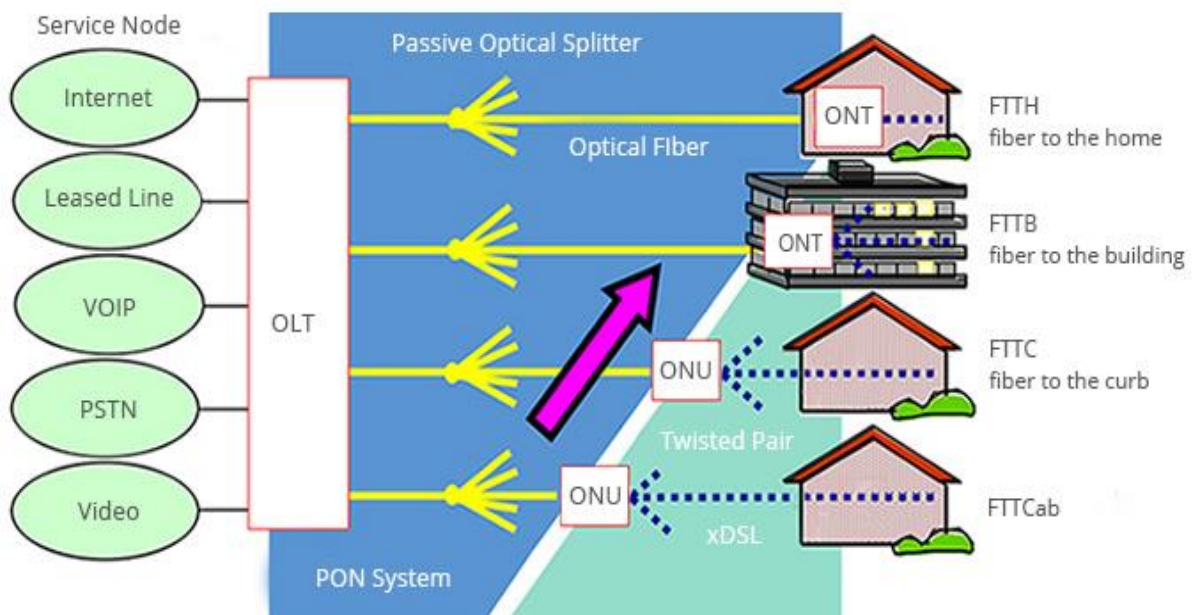


Figure 2.19: Basic of PON architecture (www.fiber-optic-cable-sale.com, 2015).

Types of PON:

There have various types of PON which are: -

- ATM PON (APON)
The earliest types of PON and it based on Asynchronous Transfer Mode (ATM) technology. Created to meets business application requirement in the business environment (carritech telecommunication, 2018).

- **Broadband PON (BPON)**
This types of PON support for Wavelength Division Multiplexing (WDM) technology. Based from APON with offered on 622 Mbps downstream and 155 Mbps Upstream. One of the best features for BPON is its support devices from different vendors to work with (carritech telecommunication, 2018).
- **Ethernet PON(EPON)**
This types of PON using Internet Protocol (IP) technology to send data, voice or video to the user. Becoming selection for many ISP companies around the globe, it offers ethernet speed until 1 Gigabits per second by using symmetrical bandwidth to deliver the data (carritech telecommunication, 2018).
- **Gigabyte Ethernet PON (GPON)**
This types of PON support for voice which are from ATM technology, Data from Ethernet technology and voice encapsulation technology. Capable to support bandwidth 1.25 Gigabits for downstream and 2.5 Gigabits for upstream

Table below illustrate the characteristic of APON, BPON, GPON and EPON.

Name	APON	BPON	GPON	EPON
Standard	ITU G.983.1	ITU G.983	ITU G.984	IEEE 802.3 ah
Protocol	ATM	ATM	ATM or Ethernet	Ethernet
Downstream bandwidth	155.-622Mbps	622Mbps	1.25 or 2.5Gbps	1.25Gbps
Upstream bandwidth	155.52Mbps	155 or 622Mbps	155 or 622Mbps 1.2 or 2.5Gbps	1.25Gbps
Downstream wavelengths	1550nm	Data 1480-1500nm Video 1550nm	Data 1480-1500nm Video 1550nm	1550nm
Upstream wavelengths	1300nm	1260-1360nm	1260-1360nm	1310nm
Distance	10km	10km	20km	20km

Table 2.2: Characteristic four main types of PON.

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AUTHOR'S PROFILE



Intan Shafinaz Binti Mohammad, a Senior lecturer at Politeknik Malaysia, has been teaching since 2008, with 17 years experience in higher education. She earned her Bachelor of Engineering (B.Eng) in Computer Engineering from Universiti Malaysia Perlis (2007) and later obtained her Master of Engineering (M.Eng) in Electrical Engineering from Universiti Tun Hussein Onn Malaysia (2013). Over the years, she has taught key subjects such as Fiber Optic Communication Systems, Computer System Architecture, Digital Electronics and Information & Communication Technology.

Her current focus is on creating effective teaching aids for Digital Electronics and Telecommunication Systems to enhance student learning outcomes. Support of her technical expertise, Intan Shafinaz holds multiple international fiber optic certifications from The Fiber Optic Association (FOA), which is CFOT, CFOS-H, CFOS-D, CFOS-W, and CFOS-T, this reflecting her advanced expertise in fiber optic technology. Additionally, she has completed industry recognized certifications from Telekom Malaysia, which is Proficiency CA1C and Proficiency CA2C. These credentials demonstrate her strong commitment to both academic and practical excellence in the field of fiber optics.



Mohd Fazlie Bin Yahya is a lecturer with 18 years of experience in the ICT field, supported by a strong educational background. He specializes in Fiber Optic Communication Systems, Open Source Server Administration, and Windows Server Administration. He holds a Diploma in Engineering Technology (Electronic) and a Diploma Kemahiran Malaysia in Industrial Electronics from the Japan-Malaysia Technical Institute (JMTI), as well as a Bachelor's Degree in Computer Science (Computer Networking) from Universiti Teknikal Malaysia Melaka.

Certified in fiber optic proficiency with Telekom Malaysia CA1C and CA2C certifications, Mohd Fazlie integrates theoretical knowledge with practical expertise to inspire and guide his students. His passion for teaching and technology is reflected in his engaging lectures, which emphasize real-world applications and hands-on learning. Currently, he is dedicated to empowering the next generation of IT professionals, nurturing their skills in emerging technologies and server management. His commitment to education and lifelong learning makes him a respected mentor in the academic community.



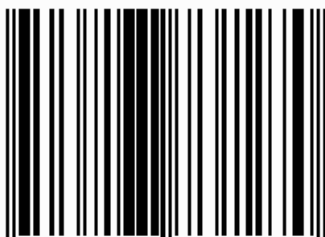
Nurul Najwa Binti Md Yusof is a senior lecturer at Jabatan Pendidikan Politeknik & Kolej Komuniti (JPPKK), bringing 20 years of dedicated experience in technical education. Her academic journey began at Universiti Tun Hussein Onn Malaysia (UTHM), where she earned her Bachelor of Engineering (B.Eng) in 2003 and a Master of Education (M.Ed) in 2004. She further advanced her expertise by obtaining a Master of Engineering (M.Eng) from Universiti Teknikal Malaysia Melaka (UTeM) in 2014. Currently, she is a doctoral candidate at Universiti Teknologi Malaysia (UTM), where her research focuses on millimeter-wave propagation systems.

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