Chapter-1

Basic concept of optical fiber

Introduction:

Definition:

- **An optical fiber** is a thin, flexible medium capable of guiding an optical ray. Various glasses and plastics can be used to make optical fibers. The optic fiber is used to carry the light beam from one place to another. The lowest losses have been obtained using fibers of ultra pure fused silica. Its working is based on principle of Total Internal Reflection.
- **Another definition: An optical fiber** is a glass or plastic fiber that carries light along its length.

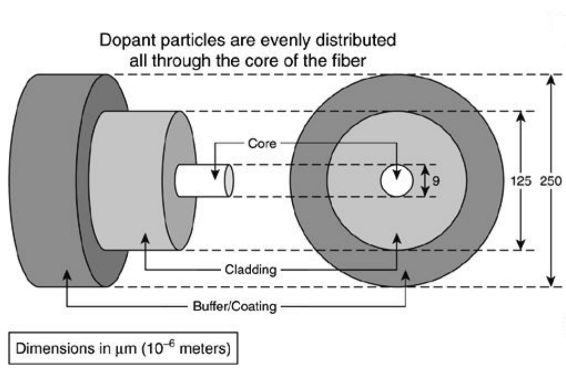
Construction/ Different parts:

- The fiber consists of the following:

i. **Core (n_1):** Core is the highly refractive central region of an optical fiber through which light is transmitted. Diameter of core in use with single mode fiber is **8 to10 µm** and with multimode fiber is between **50 to 62.5 µm**. The core is made of silica glass or plastic.

ii. **Cladding (n_2):** Outer optical material surrounding the core that reflects the light back into the core. Its index of refractive is lower than the core. The diameter of the cladding surrounding core is **125 µm.**

iii. **Coating or Buffer coating or jacket** (applied by the fiber manufactured to protect the core and cladding): Plastic coating that protects the fiber from damage and moisture. Standard size is **250µm-900µm.**



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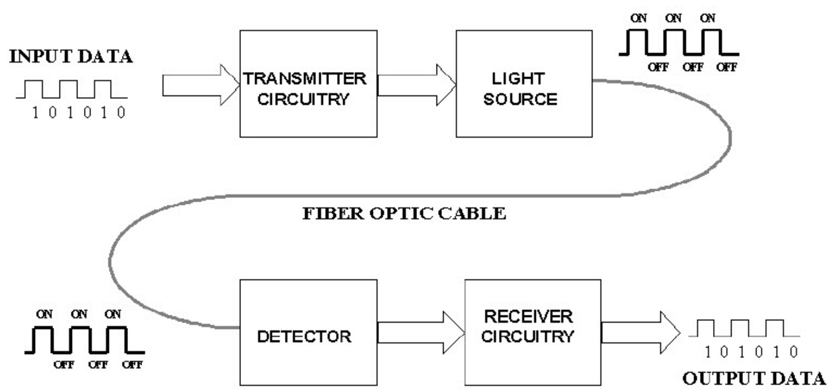
How a Fiber Optic Communication Works?

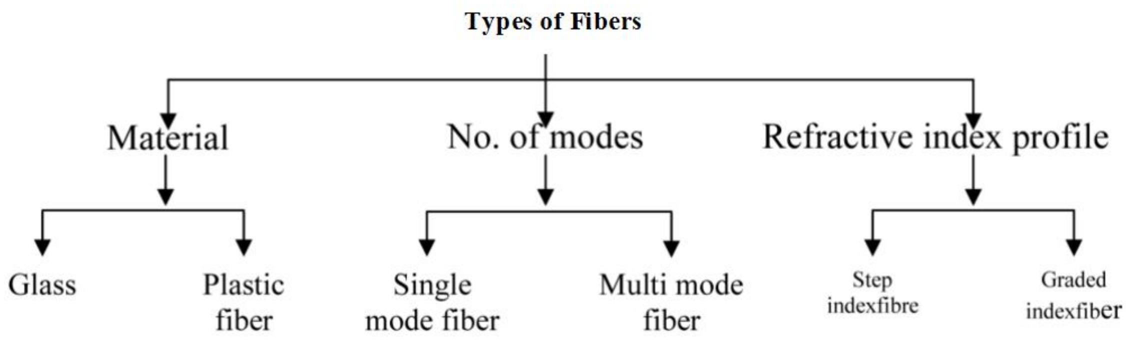
- Unlike copper wire based transmission where the transmission entirely depends on electrical signals passing through the cable, the fiber optics transmission involves transmission of signals in the form of light from one point to the other. Furthermore, a fiber optic communication network consists of transmitting and receiving circuitry, a light source and detector devices like the ones shown **in the figure.**

- When the input data, in the form of electrical signals, is given to the transmitter circuitry, it converts them into light signal with the help of a light source. This source is of LED whose amplitude, frequency and phases must remain stable and free from fluctuation in order to have efficient transmission. The light beam from the source is carried by a fiber optic cable to the destination circuitry wherein the information is transmitted back to the electrical signal by a receiver circuit.



- The Receiver circuit consists of a photo detector along with an appropriate electronic circuit, which is capable of measuring magnitude, frequency and phase of the optic field. This type of communication uses the wave lengths near to the infrared band that are just above the visible range. Both LED and Laser can be used as light sources based on the application.

Different types of fibers and their properties:



Glass and Plastic fibers

Based on materials in which the fibers are made it is classified into two types as follows:

i. **Glass fibers** : If the fibers are made up of mixture of metal oxides and silica glasses are called glass fibers**.**

Examples:-

(i) **Core:** SiO_2 ; **cladding:** $P_2O_3 - SiO_2$

(ii) **Core**: $GeO_2 - SiO_2$; **cladding:** SiO_2

ii. **Plastic fibers:** If the fibers are made up plastics which can be handled without any care due to its toughness and durability it is called plastic fiber.

Examples:-

The plastic fibers are made by any one of the following combinations of core and cladding.

(i) Core: Polymethylmethacrylate**; cladding:** co-polymer.

(ii) Core: Polystyrene; **cladding:** Methyl methacrylate**.**

Single and multimode fibers

Mode is described by the nature of propagation of electromagnetic waves in a wave guide. Based on the modes of propagation the fibers are classified into two types viz.

(i) Single mode fibers

(ii) Multi mode fibers

Single mode fibers

a. It has very small core diameter so that it can allow only one mode of propagation and hence **called single mode fibers.**

b. The cladding diameter must be very large compared to the core diameter. Thus in the case of a single mode fiber; the optical loss is very much reduced.

c. It is used to transmit one signal per fiber (used in telephones and cable TV).

Structure

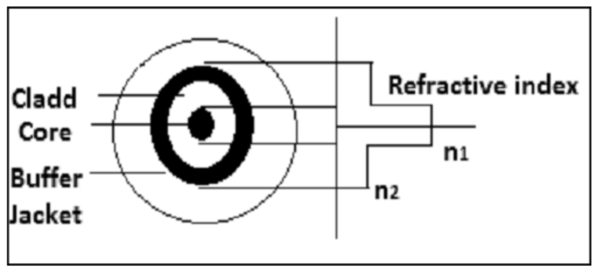
Core diameter: 5 – 10 μm

Cladding diameter: Around 125 μm

Protective layer: 250 to 1000 μm

Numerical aperture: 0.08 to 0.10

Band width: More than 50 MHz km



Multi-mode fibers:

a. Here the optical dispersion may occur.

b. They are made by multi-component glass materials.

c. The core diameter is larger than the diameter of the single mode fibers, so that it can allow many modes to propagate through it and **hence called as multimode fibers.**

d. It is used to transmit many signals per fiber (used in computer networks, LANs).

Structure:

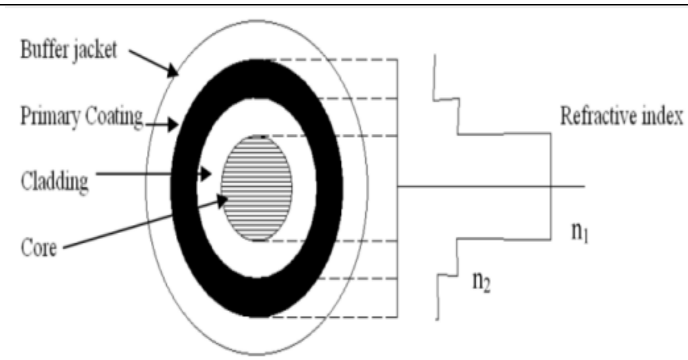
Core diameter:50 – 350 μm

Cladding diameter: 125 – 500 μm

Protective layer: 250 to 1100 μm

Numerical aperture: 0.12 to 0.5

Band width: Less than 50 MHz km



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Step index and graded index fibers:-

Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types, viz.

(i) Step index fiber

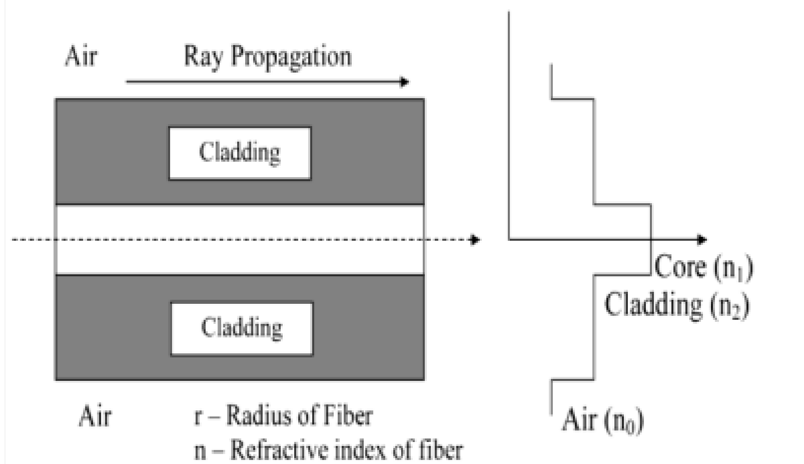
(ii) Graded index fiber

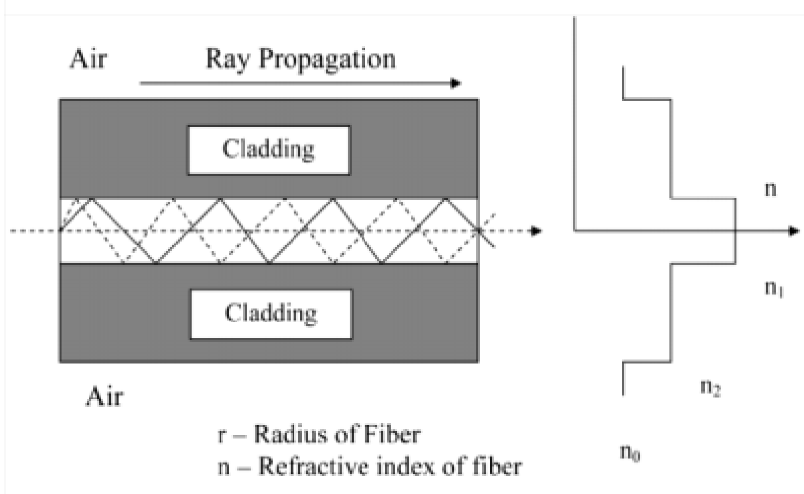
Step index fiber

Here the refractive indices of air, cladding and core vary step by step and hence it is called as step index fiber. There are two types of step index fibers. They are,

(i) Step index single mode fiber –there is dispersion will occur.

(ii) Step index multi mode fiber -- there is intermodal dispersion will occur.





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Graded index fiber

Here the refractive index of the core varies radically from the axis of the fiber. The refractive index of the core is large along the fiber axis and it's gradually decreases thus it is **called as graded index fiber**.

Here the refractive index becomes small at the core – cladding interface. In general the graded index fibers will be of multimode system. The multimode graded index fiber has very less intermodal dispersion compared to multimode step index fiber.

Comparison of Step index fiber and Graded index fiber

Sr. No.	Parameter	Step index fiber	Graded index fiber
1.	Data rate	Slow.	Higher
2.	Coupling efficiency	Coupling efficiency with fiber is higher.	Lower coupling efficiency.
3.	Ray path	By total internal reflection.	Light ray travels in oscillatory fashion.
4.	Index variation	$\Delta = \frac{n_1 - n_2}{n_1}$	$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$
5.	Numerical aperture	NA remains same.	Changes continuously with distance from fiber axis.
6.	Material used	Normally plastic or glass is preferred.	Only glass is preferred.
7.	Bandwidth efficiency	10 – 20 MHz/km	1 GHz/km
8.	Pulse spreading	Pulse spreading by fiber length is more.	Pulse spreading is less
9.	Attenuation of light	Less typically 0.34 dB/km at 1.3 μm.	More 0.6 to 1 dB/km at 1.3 μm.
10.	Typical light source	LED.	LED, Lasers.
11.	Applications	Subscriber local network communication.	Local and wide area networks.

Why optical fiber?

Because of rapidly increasing demands for telephone communications throughout the world, multi conductor copper cables have become not only very expensive but also an inefficient way to meet these information requirements. The following examples illustrate and emphasize the reasons for using optical fibers:

(i) The lightweight and non-corrosiveness of the fiber make it very practical for aircraft an automotive application.

(ii) A simple fiber can handle as many voice channels as a 1500-pair cable can.

(iii) The spacing of repeaters from 35 to 80 Km for fibers, as opposed to form 1 to 1.5 Km for wire, is a great advantage.

(iv) Fiber is immune to interference from lightning, cross talk and electromagnetic radiation.

Need of fiber optic communication

- Fiber optic communication system has emerged as most important communication system. Compared to traditional system because of following requirements :
    i. In long haul transmission system there is need of **low loss** transmission medium. ($\approx 0.25\,\text{dB}\,@1550\,\text{nm}$)
    ii. There is need of compact and least weight transmitters and receivers.
    iii. There is need of increased span of transmission.
    iv. There is need of increased bit rate-distance product.
    v. It has very high bandwidth ($\approx 30\,\text{THz}$)
- A fiber optic communication system fulfills these requirements, hence most widely acceptation.

General Optical Fiber Communication System

- Basic block diagram of optical fiber communication system consists of following important blocks.
    i. Transmitter
    ii. Information channel
    iii. Receiver.
- Fig. 1. shows block diagram of OFC system.

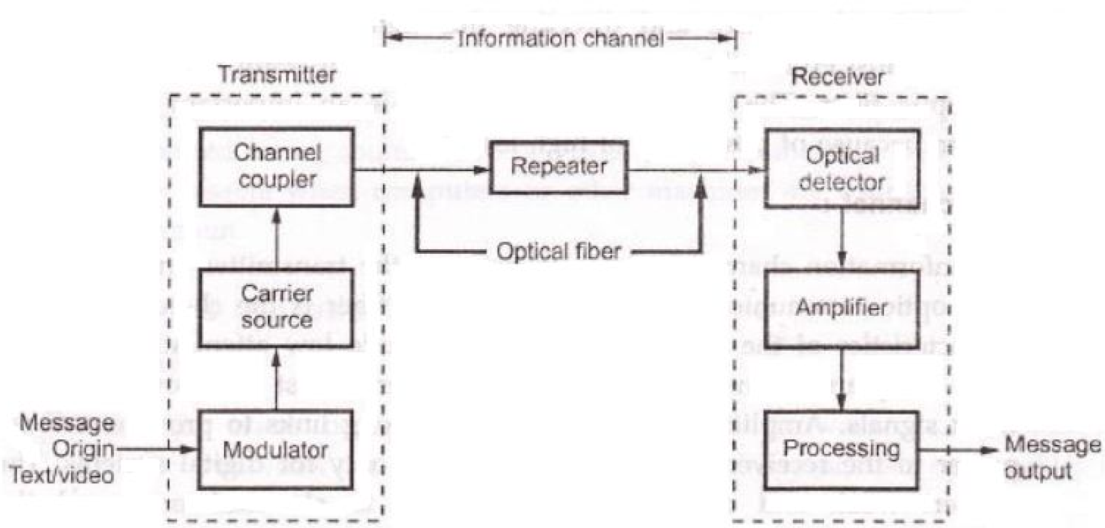

Fig. 1: block diagram of OFC system.

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Message origin:

i. Generally message origin is from a transducer that converts a non-electrical message into an electrical signal.

ii. Common examples include microphones for converting sound waves into currents and video (TV) cameras for converting images into current.

iii. For data transfer between computers, the message is already in electrical form.

Modulator:

- The modulator has two main functions.

i. It converts the electrical message into the proper format.

ii. It impresses this signal onto the wave generated by the carrier source.

iii. Two distinct categories of modulation are used i.e. Analog modulation and digital modulation.

Carrier source:

i. Carrier source generates the wave on which the information is transmitted. This wave is called the carrier.

ii. For fiber optic system, a laser diode (LD) or a light emitting diode (LED) is used. They can be called as optic oscillators, they provide stable, single frequency waves with sufficient power for long distance propagation.

Channel coupler:

i. Coupler feeds the power into the information channel. For an atmospheric optic system, the channel coupler is a lens used for collimating the light emitted by the source and directing this light towards the receiver.

ii. The coupler must efficiently transfer the modulated light beam from the source to the optic fiber.

iii. The channel coupler design is an important part of fiber system because of possibility of high losses.

Information channel:

i. The information channel is the path between the transmitter and receiver. In fiber optic communications, a glass or plastic fiber is the channel. Desirable characteristics of the information channel include low attenuation and large light acceptance cone angle. Optical amplifiers boost the power levels of weak signals. Amplifiers are needed in very long links to provide sufficient power to the receiver. Repeaters can be used only for digital systems. They convert weak and distorted optical signals to electrical ones and then regenerate the original digital pulse trains for further transmission.

ii. Another important property of the information channel is the propagation time of the waves travelling along it. A signal propagating along a fiber normally contains a range of optic frequencies and divides its power along several ray paths. This results in a distortion of the propagating signal. In a digital system, this distortion appears as a spreading and deforming of the pulses. The spreading is so great that adjacent pulses begin to overlap and become unrecognizable as separate bits of information.

Optical detector:

i. The information being transmitted is detector. In the fiber system the optic wave is converted into an electric current by a photodetector. The current developed by the detector is proportional to the power in the incident optic wave. Detector output current contains the transmitted information. This detector output is then filtered to remove the constant bias and then amplified.

ii. The important properties of photodetectors are small size, economy, and long life, and low power consumption, high sensitivity to optic signals and fast response to quick variations in the optic power.

Signal processing:

i. Signal processing includes filtering, amplification. Proper filtering maximizes the ratio of signal to unwanted power. For a digital system decision circuit is an additional block. The bit error rate (BER) should be very small for quality communications.

Message output:

i. The electrical form of the message emerging from the signal processor are transformed into a sound wave or visual image. Sometimes these signals are directly usable when computers or other machines are connected through a fiber system.

Differentiate between glass and plastic fiber cables.

Fiber optic cables are made from glass and fiber. Glass has the lowest loss but it is brittle.

Plastic is cheaper and more flexible but has high attenuation.

Advantages of optical fiber communication:

i. Large information capacity
ii. Long distance transmission
iii. Small size and low weight
iv. Electrical isolation
v. Immunity to crosstalk and EMI
vi. Increased signal security
vii. Enhanced safety
viii. Ruggedness and flexibility
ix. System reliability and easy maintenance
x. Low cost

Disadvantages of Optical Fiber Communications:

i. **High initial cost**
   - The initial cost of installation or setting up cost is very high compared to all other system.

ii. **Maintenance and repairing cost**
   - The maintenance and repairing of fiber optic systems is not only difficult but expensive also.

iii. **Jointing and test procedures**
   - Since optical fibers are of very small size. The fiber joining process is very costly and requires skilled manpower.

iv. **Tensile stress**
   - Optical fibers are more susceptible to buckling, bending and tensile stress than copper cables. This leads to restricted practice to use optical fiber technology to premises and floor backbones with a few interfaces to the copper cables.

v. **Short links**
   - Even though optical fiber cables are inexpensive, it is still not cost effective to replace every small conventional connector (e.g. between computers and peripherals), as the price of optoelectronic transducers are very high.

vi. **Fiber losses**
   - The amount of optical fiber available to the photodetector at the end of fiber length depends on various fiber losses such as scattering, dispersion, attenuation and reflection.

Uses of optical fibers

i. To transmit the information of telephone communication, computer data, etc. which are in the form of coded light signals

ii. To transmit the optical images (Example : Endoscopy)

iii. To act as a light source at the inaccessible places.

iv. To act as sensors to do mechanical, electrical and magnetic measurements.

- **Five basic categories of application have important for optical fiber:**

(i) Long-haul trunks.

(ii) Metropolitan trunks.

(iii) Rural exchange trunks.

(iv) Subscriber loops.

(v) Local area networks.

Chapter-2

Optical Fiber Measurements

Introduction:

- The communication engineers need the fiber characteristics to design the optical fiber link with an efficient waveguide without any loss or dispersion. Similarly, the fiber manufactures need the fiber characteristics for further development.
- Generally, the fiber **attenuation measurement** are used to determine repeaters spacing and light source power.
- **Dispersion measurements** are used to determine the maximum bit rate.
- **Refractive index profile measurement** are to know the number of modes propagating the fiber and to determine its numerical aperture.

Various optical fiber measurements:

i. Fiber attenuation measurements

ii. Fiber dispersion measurements

iii. Fiber refractive index profile measurements

iv. Fiber cutoff wavelength measurements

v. Fiber numerical aperture measurements

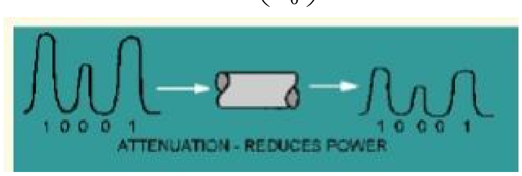
vi. Fiber diameter measurements

Fiber attenuation measurements:

Definition:

- Attenuation in an optical fiber is caused by absorption, scattering and bending losses.
- **Attenuation** is the loss of optical power as light travels along the fiber**. In other words,** Attenuation is the transmission loss, can be measured as the difference between the output signal power and input signal power. It can be expressed in dB as below:

$$\text{Attenuation loss, } \alpha = 10\log_{10}\left(\frac{P_1}{P_0}\right)$$



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- **Signal attenuation** is defined as the ratio of optical input power (P_i) to the optical output power (P_0).
- Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector.
- The following equation defines signal attenuation as a unit of length:

$$\text{Attenuation or attenuation coefficient, } \alpha = \left(\frac{10}{L}\right)\log_{10}\left(\frac{P_i}{P_0}\right)$$

- Signal attenuation is a log relationship. **Length (L)** is expressed in kilometers. Therefore, the unit of **attenuation is decibels/kilometers (dB/km).**
- Each mechanism of loss is influenced by fiber-material properties and fiber structure. However, loss is also present at fiber connections i.e. connector, splice, and coupler losses.

Methods for the measurement of attenuation of fiber:

- Generally, the fiber **attenuation measurement** are used to determine repeaters spacing and light source power. Three main methods are used for attenuation measurements:

1. **Insertion loss method or Non-destructive method.**
2. **Cut-back method or Differential method or Destructive method:**
   A commonly used technique for determining the total fiber attenuation per unit length **is the cut-back or differential method.**
3. **Optical Time-Domain Reflectometry (OTDR) or Non-destructive loss measurement method**: This technique is often called **Backscatter Measurement method or Rayleigh scattering method.**

- The first two-methods perform two-point (end to end) measurements and the last performs a one –ended characterization. Some of methods are standardized.

Insertion Loss Method:

Definition:

- **Insertion Loss (IL) is defined as** the total decrease in power between the input and output terminal of the Device under Test (DUT) (e.g. an optical fiber).
- **The insertion loss method** is a non-destructive method, which can be used to measure the attenuation across a fiber, passive component or an optical link.

Principle:

In this method, the output powers, transmitted by two different length of the given fiber are measured. The loss of power in the longer fiber is then subtracted from the power lost in the shorter fiber.

Alternatively: Principle:

In this method, the output power from a source fiber and reference fiber is measured directly. Then, a measurement is obtained with the fiber under test added to the system. The difference between the two results provides the attenuation of the fiber. The purpose of the first or reference measurement is cancel out as much as possible, the losses caused by the various patch cables.

Features:

i. Non-destructive.

ii. Requires access to both fiber ends.

iii. Tolerance: $\pm 0.5\,\text{dB}$.

Assumptions:

In this method the following assumptions are made:

i. Input and output coupling losses are constant.

ii. Losses are uniformly distributed.

iii. For multimode fibers, all modes are equally excited.

Construction and Working:

i. The insertion loss technique consists of a stable laser source and a stable, accurate, optical power meter.

ii. The power P_2 of the laser source is sent into the DUT (e.g., an optical fiber) and the power P_3 is measured at the far end.

iii. The attenuation is given by the ratio of the two power levels as

$$A(\text{dB}) = 10\log\left(\frac{P_3}{P_2}\right) \quad \text{..........(1)}$$

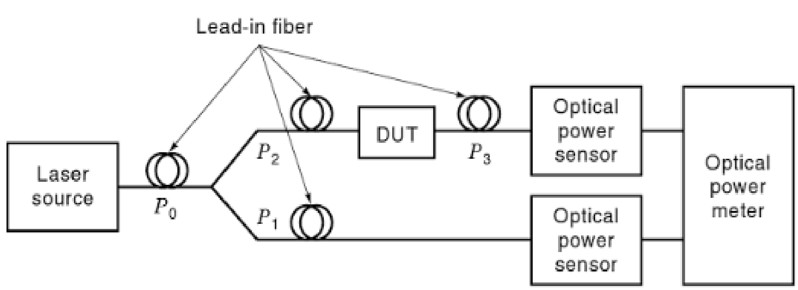

Figure-2: Principle of the insertion loss method

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iv. To achieve more accurate measurements in the first phase, the power of the source is directly measured and is remeasured in the second phase with the DUT inserted. More sophisticated measuring systems use a configuration shown in fig.1

v. A second power sensor measures the power level of the source instantaneously by as power divider.

vi. In this configuration the power stability of the source is less important because P_1 is always used as a reference. By using cooled detectors, a dynamic range up to 90 dB is achieved.

vii. The accuracy of the measurements is determined by the following factors:

a) The power level and wavelength stability of the source

b) The calibration and stability of the power sensors

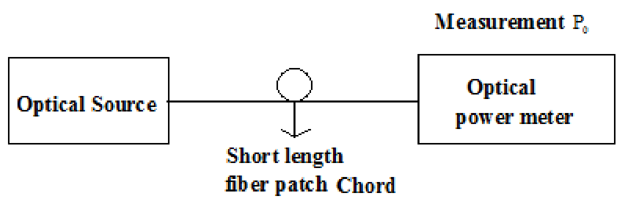
c) The reproducibility of the connectors

d) The linearity of the detectors.

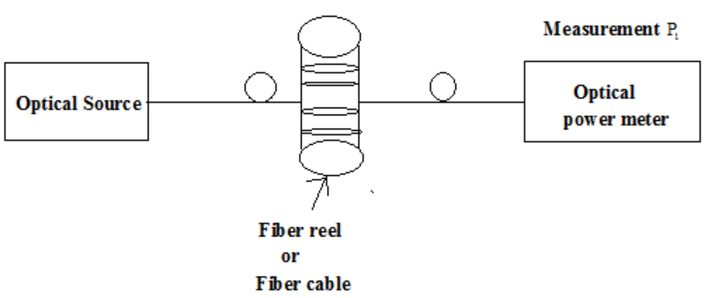
viii. The measurement uncertainties for the insertion loss technique are on the order of 0.9 dB including the connector reproducibility. Sophisticated systems reach over a limited dynamic range of 50 dB and uncertainity of 0.2 dB.

Alternatively:

Construction and Working:



(a)



(b)

Figure-3: Insertion Loss method.

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Figure-3(a): an optical source is connected to an optical power meter using a fiber patch chord of very short length (say 1m). Let, the power detected by the power meter be P_0 in this case.

Figure-3(b): The same source is connected to the optical power meter using fiber reel or fiber cable whose attenuation is to be measured.

Let, the power detected by the power meter be P_1 in this case. The attenuation coefficient (α) in dB/Km of the fiber reel can now be estimated as:

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_0}{P_1}\right)$$

Where, L is the length in Km of the fiber reel.

The above method is referred to as the insertion loss method of determining the attenuation of a fiber reel or fiber cable.

Cut back method:

- A commonly used technique for determining the total fiber attenuation per unit length **is the cut-back or differential method**.
- The cutback method is the most accurate measurement, but it is also destructive and cannot be applied in the field. For this reason, it is not used during installation and maintenance. Testing using the cutback method requires first measuring the attenuation of the length of the fiber under test. Then, a part of the length of the fiber is cutback from the source and the attenuation is measured as reference. Subtracting the two values provides the attenuation of the cut fiber.

Principle:

This method for measuring the attenuation coefficient of an optical fiber. It involves comparing the optical power transmitted through a long section of test fiber to the power present in a short section, without any disturbance to the input conditions.

Construction and Working:

- Light from a halogen lamp or white light source is couple into the experimental fiber having length about 1 km.
- The lens placed in front of the source focuses the light on to the interference filter or monochromatic prism or grating.
- The light with a given wavelength is incident on the chopper which is used to convert d.c light into square pulses of light (a.c). It also sends the reference signal to the lock in amplifier. Monitor is used to view the intensity of the optical beams.
- The cladding mode strippers are connected at the input end and output end of fiber.
- The cladding mode stripper is used to remove the cladding light or cladding modes.
- Then the jacket fiber is placed in an index matching liquid whose refractive index is slightly higher than that of cladding.

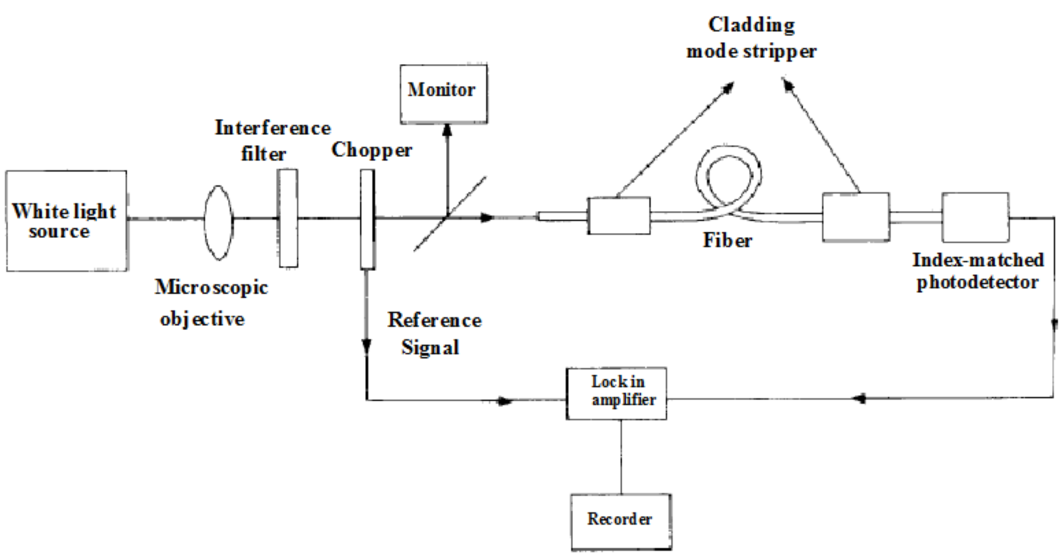


Figure -4: A typical experimental arrangement for the measurement of spectral loss in optical fibers using the cut-back technique

- This arrangement is **called cladding mode stripper** which will attenuate the light propagating through the cladding. After travelling through the fiber of **1Km** length, the given height reaches the index matched photodetector whose output is given to the lock amplifier.
- The lock amplifier delivers a output to the recorder or nanovoltmeter. Then the fiber is cut back, leaving typically **2m** of the fiber and the experiment is repeated.

- In this case the output power is noted $P_2(\lambda)$ is noted. This procedure is repeated for other wavelength also. Thus the fiber attenuation at a given wavelength 'λ' is given by,

$$A(\lambda) = \frac{10}{L}\log_{10}\left[\frac{P_2(\lambda)}{P_1(\lambda)}\right]................(1)$$

Where,

L is the length of the fiber cut back in **Km**.

$P_1(\lambda)$ and $P_2(\lambda)$ are output optical powers at specific wavelength from original and cut back length respectively.

- In the case of multimode fibers, there are mode scrambler used to get the uniform intensity distribution among all the modes and order sorting filter acting as a mode selector to determine the fiber loss for each mode.

Alternatively:

Construction and Working:

- Cutback technique is a destructive method of measuring attenuation. It requires access to both ends of fiber as shown in Fig. 5.

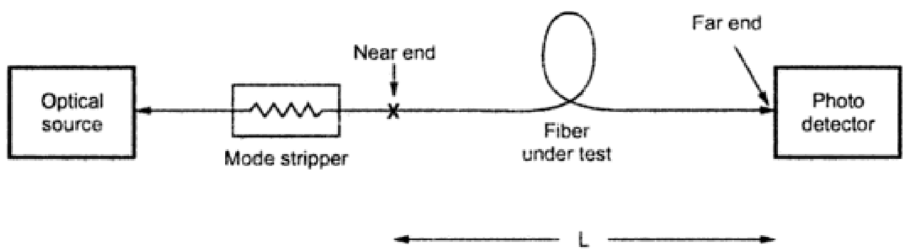


Figure-5: Principle of Cutback method.

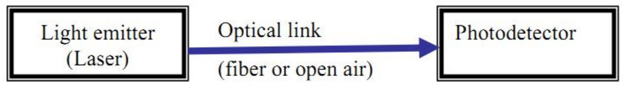
- Firstly, the optical power is measured at the output (far end) of fiber. Then without disturbing the input condition, the fiber is cut-off few meters from the source and output power at near end is measured.
- Let P_F and P_N are the output powers at far end and near ends of fiber respectively. Then attenuation in dB per kilometer is given by expression.

$$\alpha = \frac{10}{\mathrm{L}} \cdot \log_{10}\frac{P_N}{P_F}$$

- Where, *L* is separation length of two measurement points (in km).

Facts to know: Mode Stripper: The mode stripper acts as a filter to unwanted modes generated by the source and allows only those modes to pass which are well confined within the core.

Photodetector/ Optical detector: A photodetector is an optoelectronic device that absorbs optical signal and converts them into electrical signals, which can then amplified and processed. The photodetector is as essential an element of any fiber optic system as the optical fiber or the light source. Photodetectors can dictate the performance of a fiber optic communication link.



Interference: A systematic attenuation and reinforcement of the signal amplitude by an undesirable signal.

Interference filter: A filter design to control the spectral composition of an optical signal through interference.

Optical chopper: An optical chopper is a device that interrupts a light beam at periodic intervals.

Alternatively:

Construction and Working:

- The cutback method is the most accurate technique, but it is destructive. This method was developed to measure the attenuation of fibers as a function of the wavelength. Using a light source combined with a monochromator, a fiber can be tested at any wavelength from 800 nm to 1600 nm with a spectral width of 3 nm.
- The light from the source is projected into the fiber by a lens.
- The power $\mathrm{P}_2(\lambda)$ is measured at the far end of the fiber (test length l_1) by using a cooled detector. Then the fiber is cutback to a short length of 2m to 3m without changing the projecting conditions, and the power $\mathrm{P}_1(\lambda)$ is recorded.
- If the power loss in the short length of fiber is assumed to be negligible, the attenuation is given by the following equation:

$$\mathrm{A}(\lambda) = 10\log_{10}\left[\frac{P_2(\lambda)}{P_1(\lambda)}\right]\text{.................}(1)$$

- Assuming a uniform fiber, the attenuation coefficient per unit length of the fiber is given by

$$\alpha(\lambda) = \frac{A(\lambda)}{(l_1 - l_2)}\text{...............}(2)$$

- Where, l_1 and l_2 are original and cut back length respectively(in km).
- The achieved uncertainty for cable length of several kilometers is about 0.02 dB/km for multimode fibers and 0.04 dB/km for single mode.

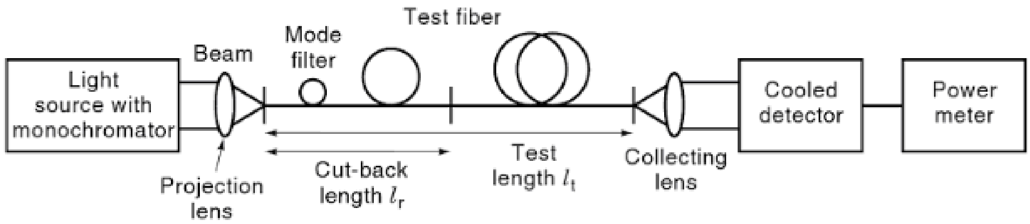


Figure-6: principle of the cutback method.

Facts to know: <u>Mode filter</u>: An apparatus used to measure the attenuation properties of optical fiber.

Advantage:

i. This method is very accurate and simple.

Drawback or Limitation:

i. This method cannot be utilized to find the fiber attenuation in a working fiber optic link.

ii. It is a destructive testing method.

iii. Its cover distances up to 1 km.

Optical Time Domain Reflectometers (OTDR):

- An Optical Time Domain Reflectometer (OTDR) is optical radar. This instrument sends a light pulse down the fiber and measure the time delay between launched and returned pulses. This time delay is a measure of the distance from the transmitter to a given reflection point. The longer the distance, the less light power returned because of attenuation; thus, the OTDR builds a trace of power versus distance.
- **In other words,** An OTDR is the instrument which is used both in laboratory and field measurements for determining fiber attenuation , joint losses and detecting fault losses. When the fiber attenuation varies with distance, then the OTDR is the only instrument which can measure the fiber attenuation along the fiber optics link.
- The OTDR measurement is a **non-destructive measurement.**

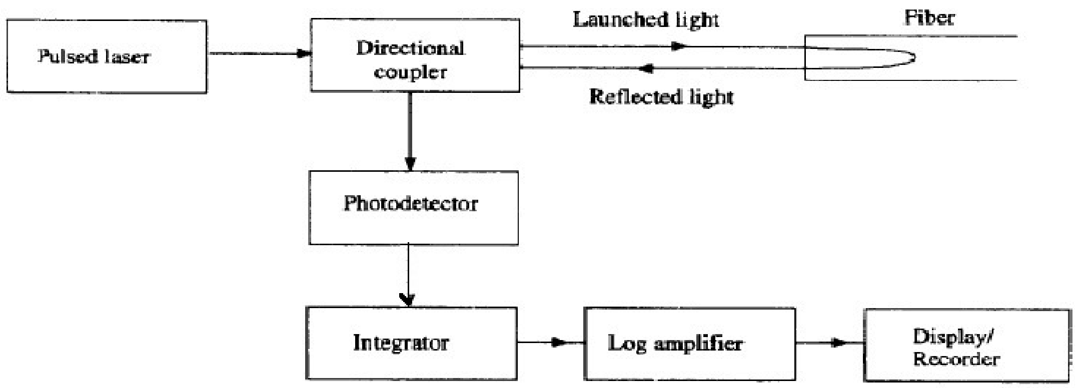


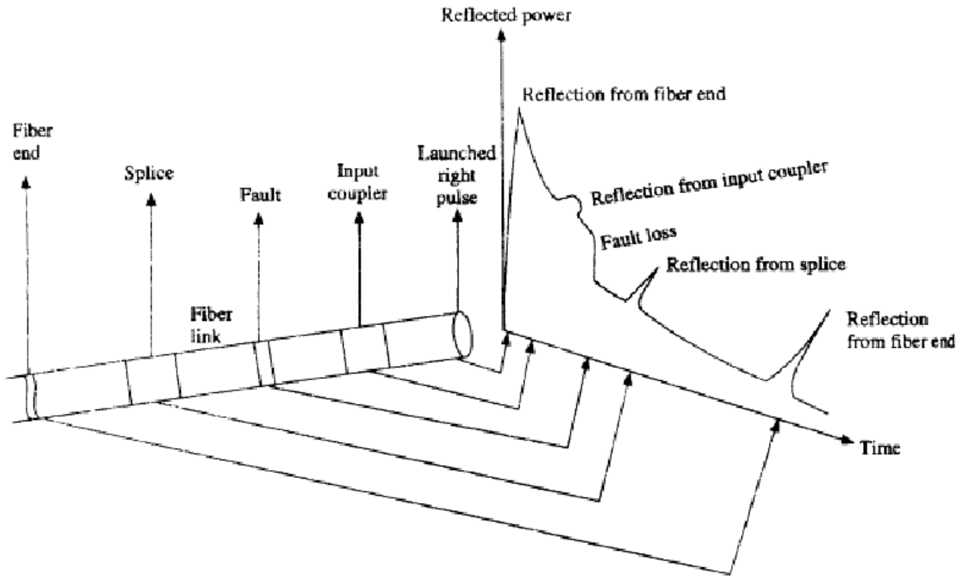
Figure-7: Principle of OTDR

Principle:

- This method is often called **the backscatter method**. It is based on the measurement and analysis of the fraction of light which is reflected back within the numerical aperture of the fiber due to Rayleigh scattering.

Construction and working:

- A light pulse from a pulsed laser is launched into the fiber through a directional coupler. The back scattered light from the fiber is received by a photo detector like APD, through the directional coupler.
- A box car integrator is mainly used to improve S/N ratio by taking arithmetic average over a number of measurements taken at one point within the fiber.
- The signal from the integrator is fed to the logarithmic amplifier and its output is given to the recorder in dB.
- The recorder will display the averaged measurements for successive points within the fiber.
- The initial peak is caused by the reflection at the fiber end.
- The reflection from the input coupler is as small increase in the reflected power. There is a long tail caused by Rayleigh scattering of the input pulse as it travels through the fiber link in the forward direction.
- Due to presence of a fault in the fiber link. There is a sudden decrease of reflected power.
- Next peak is caused by splice or joint. Finally there is a peak due to Fresnel reflection of the fiber end where the reflected power is more than that of splice.



Advantage:

i. The location of breaks in the fibers is located by analyzing the reflected light.

ii. Using the same analysis, total loss of the system along with losses at connectors, splices can be measured.

iii. There are different factors causing reflection of light. One of the factors is Rayleigh scattering. So when the reflection is of small amount then it is due to Rayleigh scattering. This loss can be measured by analyzing the reflected light.

Drawback or Limitations:

i. Limited Accuracy
ii. Limited application
iii. Dead zones
iv. Cost
v. Dynamic range of about 35 dB and cover distances up to 65 km.

Application:

i. Length measurement

ii. Location of faults.

iii. Attenuation of fiber (dB/km).

iv. Attenuation produced by connectors, splices.

v. Discrete attenuation.

Typical Specification:

i. Wavelength: 800nm

ii. Pulse width: 10ns and 100ns.

iii. Repetition rate: 10 Kbps.

Facts to know: Splices: The splices are generally permanent fiber joints, whereas connectors are temporary fiber joints. Splicing is a sort of soldering**. In other words,** For longer distance communication, we have to connect one fiber with other fiber and mean while the losses must be minimized. The process of connecting the two fibers for permanent requirement is called Splicing. **The requirements of splices are:**

i. Should cause low attenuation
ii. Should be strong & light in weight
iii. Should have minimum power loss
iv. Should be easy to install

Fiber dispersion measurements:

Definition:

- An optical signal/ pulse get distorted as it travels along the fiber length. Optical signal/pulse spreading in fiber is **referred as dispersion/ Dispersion is defined** as pulse spreading in an optical fiber. *(**Or** Dispersion is the spreading of the signal. The spreading limits how fast data can be transmitted along the fiber. The receiver unable to distinguish between input pulses caused by the spreading of each pulses*).
- Dispersion reduces the effective bandwidth for transmission.
- As a pulse of light propagates through a fiber, elements such as numerical aperture, core diameter, refractive index profile, wavelength, and laser line width cause the pulse to broaden.
- Dispersion increases along the fiber length. The overall effect of dispersion on the performance of a fiber optic system is known as Intersymbol Interference (ISI). Intersymbol interference occurs when the pulse spreading caused by dispersion causes the output pulses of a system to overlap, rendering them undetectable.
- Dispersion is measured in picoseconds per nanometer per kilometer.
- **In other words,** Dispersion occurs when a pulse of light is spread out during transmission on the fiber. A short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible. (In most communications systems bits of information are sent as pulses of light. 1 = light, 0 = dark. But even in analogue transmission systems where information is sent as a continuous series of changes in the signal, dispersion causes distortion.)

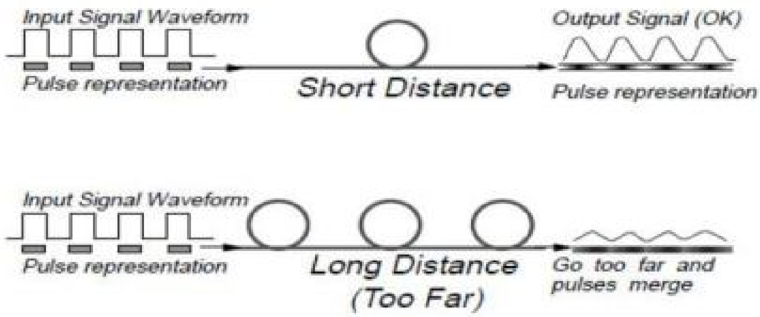


Figure-8: Effect of Dispersion

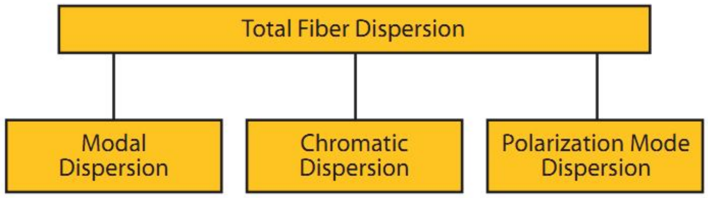
Types of fiber dispersion:

There are three main types of dispersion:

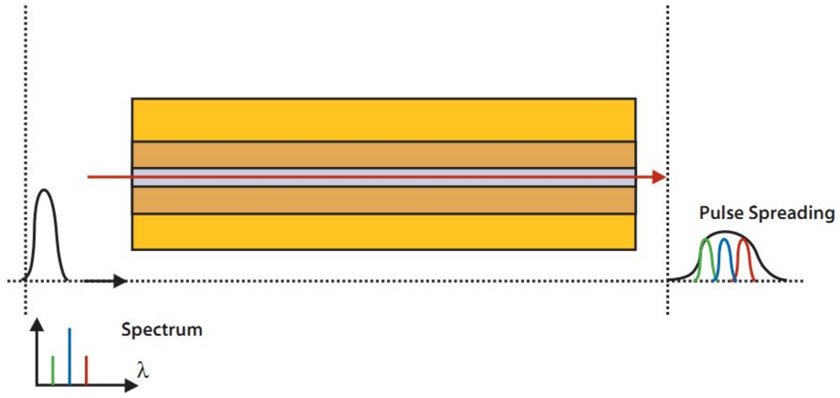
i. Material dispersion or chromatic dispersion or Intramodal dispersion.

ii. Intermodal dispersion or Modal Dispersion.

iii. Polarization mode dispersion.



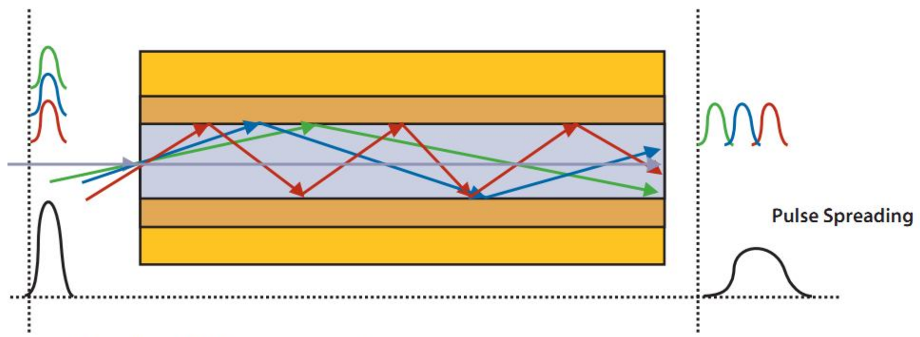
i. **Material dispersion or chromatic dispersion or Intramodal dispersion: Chromatic Dispersion (CD) is** pulse spreading due to the fact that different wavelengths of light propagate at slightly different velocities through the fiber because the index of refraction of glass fiber is a wavelength-dependent quantity; different wavelengths propagate at different velocities.



Chromatic dispersion caused by different wavelengths in a light source

ii. **Intermodal dispersion or Modal Dispersion:**

Modal dispersion is defined as pulse spreading caused by the time delay between lower-order modes and higher-order modes. Modal dispersion is problematic in multimode fiber, causing bandwidth limitation.



Modal dispersion in step-index multimode fiber

iii. **Polarization mode dispersion:**

Polarization Mode Dispersion (PMD) occurs due to birefringence along the length of the fiber that causes different polarization modes to travel at different speeds which will lead to rotation of polarization orientation along the fiber.

Polarization mode dispersion (or differential group delay) effects on a fiber

Methods for the measurement of dispersion of fiber:

- **Dispersion measurements** are used to determine the maximum bit rate.
- There are different methods to measure the dispersions effects. Such as :
  - i. intermodal dispersion in time domain,
  - ii. intermodal dispersion in frequency domain,
  - iii. chromatic dispersion and
  - iv. Polarization mode dispersion.

Time domain dispersion measurement:

- Dispersion measurement gives an indication of distortion to optical signals as they propagate down the fiber.
- Dispersion effect may be characterized by taking measurements of impulse response of fiber in time domain or baseband frequency response in frequency domain.
- The most common method for time domain measurement of pulse dispersion in multimode optical fibers is illustrated in Figure-9.
- Short optical pulses (of duration $\approx 200-400\,\text{ps}$) are launched into the fiber from suitable source (e.g. AlGaAs-Aluminum Gallium Arsenide injection laser) using fast driving electronics. The pulse travels down the length of fiber under test (typically 1-2 km) and are broadened due to various dispersion mechanisms.
- The pulse coming out of the test fiber (typically 1-2 km) is then detected by an Avalanche photodetector (APD) and is measured in a sampling oscilloscope.

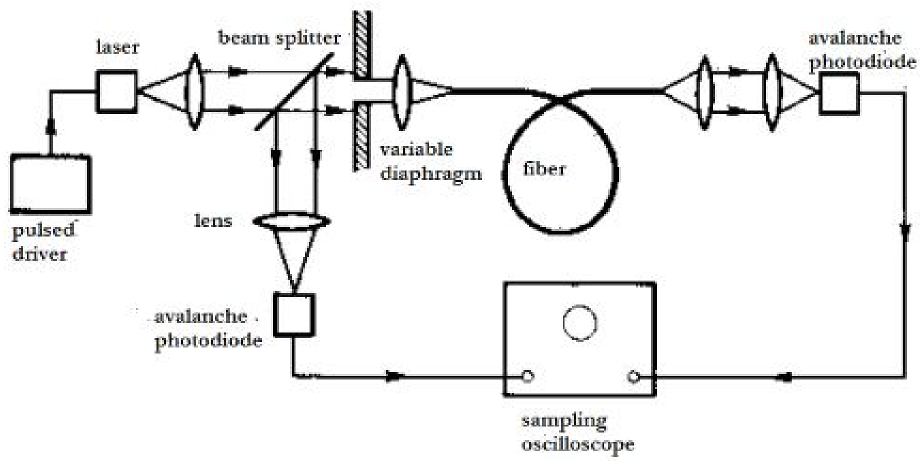


Figure-9: Experimental arrangement for making multimode fiber dispersion measurements in the time domain.

- Beam splitter triggers the oscilloscope for input pulse measurement.
- The broadened output pulse duration (τ_0) is then measured.
- Then the fiber is cutback (as in the measurement of attenuation) and pulse duration$(\tau_i)$is measured again with the help of the sampling oscilloscope and the pulse dispersion is then by comparing the measured pulses.
- The impulse response is then approximately calculated as:

$$\tau_f^{\,2}(3\text{dB}) \cong \tau_0^{\,2}(3\text{dB}) - \tau_i^{\,2}(3\text{dB})\text{....................}(1)$$

- Where $\tau_i(3\text{dB})$ and $\tau_0(3\text{dB})$ are the 3 dB pulse duration at the fiber input and output, respectively, and $\tau_f(3\text{dB})$ is the duration of the fiber impulse response again measured at half the maximum amplitude.
- Hence the pulse dispersion in the fiber (commonly referred to as the pulse broadening when considering the 3 dB pulse duration) in ns km^{-1} is given by:

$$\tau_f(3\text{dB}) \cong \frac{\sqrt{\tau_0^{\,2}(3\text{dB}) - \tau_i^{\,2}(3\text{dB})}}{L} \text{.....................(2)}$$

$\tau_i(3\text{dB})$, $\tau_0(3\text{dB})$ and $\tau_f(3\text{dB})$ are measured in **ns** and L is the fiber length in **km**.

- The equation (1) approximation becomes equality for Gaussain pulses.
- Alternatively, one can first compute the Fourier Transforms of the output and input pulses.
- If the variations of the corresponding amplitudes (in dB) with frequency are represented by $B_0(f)$ and $B_i(f)$, respectively, then one may estimate

$$B_F(f) = B_0(f) - B_i(f) \text{.......................(3)}$$

- The presence of a large number of modes in a multimode fiber leads to a dependence of the measured B.W on input launch conditions.

<u>Frequency domain measurement:</u>

- Frequency domain measurement is the preferred method for acquiring the bandwidth of multimode optical fibers.
- It utilizes a similar pulsed source to that employed for the time domain measurements shown in Figure- 10.
- However, the sampling oscilloscope is replaced by a spectrum analyzer which takes the Fourier transform of the pulse in the time domain and hence displays its constituent frequency components.
- In frequency domain, the source is sinusoidally amplitude modulated at various frequencies and the corresponding depth of modulation at the output (in dB) of a long (1-2 km) length of the fiber is measured.
- The same measurements are again taken after cutting back about 1-2m of the fiber and one obtains $B_i(f)$ (in dB).
- The frequency response is given by the following equation:

$B_F(f) = B_0(f) - B_i(f)$ and the 3-dB B.W is the lowest f for which $B_F(f) = -3dB.$

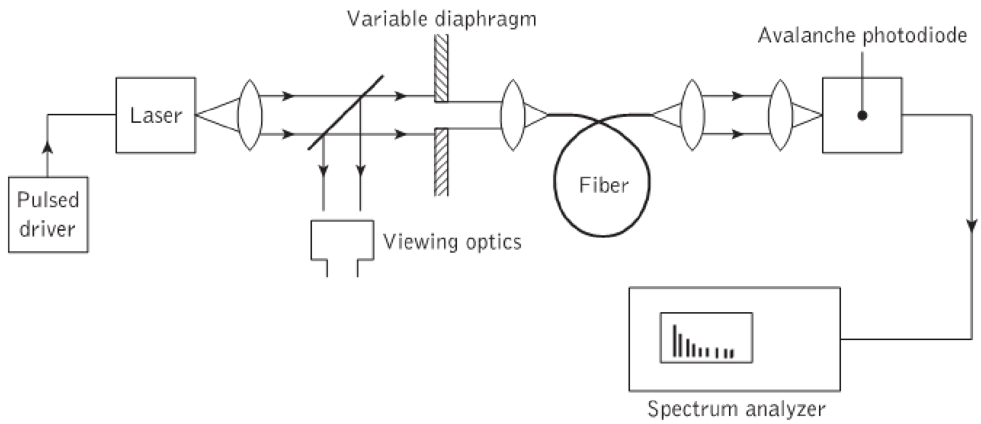


Figure-10: Experimental setup for making fiber dispersion measurements in the frequency domain measurement using a pulse laser source

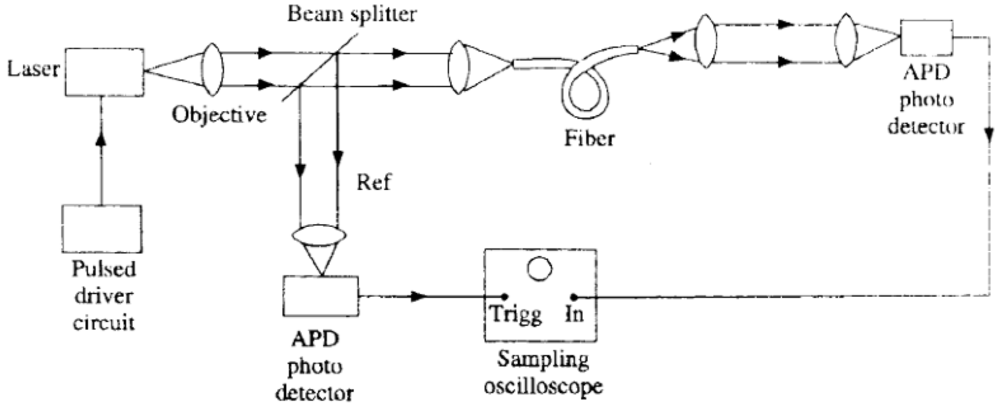
Facts to know: Optical spectrum analyzers (OSA) are instruments that measure the Optical Power as a function of Wavelength or frequency.

Avalanche photodiode: Electron-hole generation is achieved through absorption. At reverse bias close to breakdown voltage, the initially generated electron-hole pairs collide with ions to generate more electron-hole pairs. The process is referred to as avalanche current multiplication.

Alternatively:

Dispersion measurements:

- Dispersion is measured in terms of pulse broadening.
- **There are two types of fiber dispersions**. One is intermodal dispersion and the other is intra modal (or) chromatic dispersion.
- Both dispersion measurements can be performed using the same light source.
- Intermodal dispersion measurement is made by the monochromatic laser with narrow spectral width. This intermodal dispersion is dominant in the multimode fibers. The intra nodal dispersion measurement is made by the injection laser whose frequency or line width increases with respect to time.



Construction and Working:

- The laser with driver circuit gives short narrow pulses of light.
- The laser light is focused onto the beam splitter.
- The beam splitter is used for triggering the oscilloscope and for input pulse with measurement. One of the beams passing through the beam splitter is again focused into the fiber under measurement. Normally its length is 1 km.
- The focused output laser beam is incident on the avalanche photodiode and it gives the output pulses.
- The input pulse and output pulse are displayed separately on the screen of sampling oscilloscope and they are in Gaussian shape.

Facts to know: Beam Splitter:

- An optical device design to split a beam of light into two or more beams.
- A beam splitter, made of glass plate is inclined at an angle of 45° used to split the single beam into two beams.
- A beam splitter is used to split the source radiation equally between the two mirrors which direct the beams such that interference fringes are produced during recombination.

Refractive index profile measurement:

Definition of index profile:

- The index profile of an optical fiber is a graphical representation of the magnitude of the refractive index across the fiber.

Definition of refractive index profile:

- The form and rate of change of refractive index of an optical fiber **is known as refractive index profile.**
- **The refractive index profile** describes the value of refractive index as a function of radial distance at any fiber diameter. Fiber refractive index profiles classify single mode and multimode fibers as follows:

  i. Multimode step-index fibers
  ii. Multimode graded-index fibers
  iii. Single mode step-index fibers
  iv. Single mode graded-index fibers

- **In a step-index fiber,** the refractive index of the core is uniform and undergoes an abrupt change at the core-cladding boundary. Step-index fibers obtain their name from this abrupt change **called the step change in refractive index.**
- **In graded-index fibers,** the refractive index of the core varies gradually as a function of radial distance from the fiber center.

Facts to know: Refractive index: Characteristics of the refractive property of a medium is called refractive index.

Avalanche photodetector (APD): A photodiode capable of amplifying the generated photocurrent when reverse biased.

- **Refractive index profile measurement** are to know the number of modes propagating the fiber and to determine its numerical aperature. Different techniques used for measurement of fiber refractive profile. **Such as:**

  i. Interferometric method
  ii. Transmitted near-field method **or** Near Field Scanning Method
  iii. Refracted near field Method **or** Refracted ray method.

Interferometric method:

Definition of Optical Interferometer:

- Interferometer is an optical device used for optical path comparison. (
- **Optical interferometers** are the instruments that rely on interference of two or more superimposed reflections of the input laser beam. These are one of the most common optical tools that are used for precision measurements, surface diagnostics, astrophysics, seismology, quantum information, etc.
- An interferometer measures interference fringes which contain information on the structure and position of the object.

Facts to know: Optical path: An optical path is defined as the product of the distance (d) traveled by a ray through a medium and refractive index of that medium.

Function of Interferometer:

i. Recording of the signal (observation of an object located at the direction S with telescopes separated by baseline B).

ii. Optical path matching (compensation of the geometrical delay with the delay lines d1, d2).

iii. Addition of signals (electric fields) from interferometer elements (telescopes).

iv. Fringe detection, measurement of contrast and phase.

Definition of Interference microscopes:

- An interference microscope is a microscope that utilizes light interference phenomena to create two superimposed images of an object, making possible the observation of transparent objects without using the staining technique.

Principle of the Mach–Zehnder interferometer:

- The principle of classical interferometry by choosing the Mach–Zehnder interferometer (Figure-11).

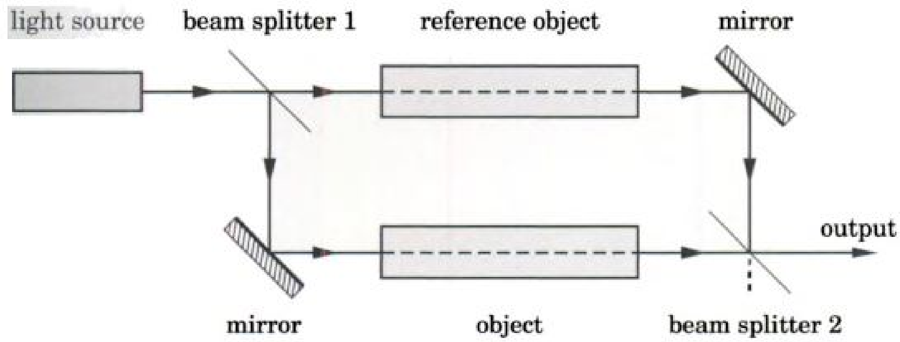


Figure-11: Principle of the Mach–Zehnder interferometer.

- The beam of a light source is divided at a **beam splitter 1**. One of the beams is directed through the transparent (or clear) object to be investigated, the other one through a reference object for comparison.

- Both beams are combined by **beam splitter 2** and thus brought to interference. From the interference pattern, variations in the phase front of the object as compared to the reference object can be determined. Often just a plane wave is taken as the reference wave. Only transparent (or clear) objects can be investigated. The Mach–Zehnder interferometer is used for measuring slight changes in the refractive index of transparent objects.

- **Areas of application** are fluid flow, shocks waves, heat transfer and diffusion, to name the most important ones.

Facts to know: Beam Splitter:

- An optical device design to split a beam of light into two or more beams.
- A beam splitter, made of glass plate is inclined at an angle of 45º used to split the single beam into two beams.
- A beam splitter is used to split the source radiation equally between the two mirrors which direct the beams such that interference fringes are produced during recombination.

Construction and Working of Interferometric method:

- **Interferometric method** involves use of interference microscopes (e.g. Mach–Zehnder, Michelson).
- The technique usually involves the preparation of a thin slice of fiber (slab method) which has both ends accurately polished (or pure) to obtain square (to the fiber axes) and optically flat surfaces.
- The slab is often immersed in an index-matching fluid, and the assembly is examined with an interference microscope.
- **Two major methods** are then employed, using either a transmitted light interferometer (Mach–Zehnder) o**r** a reflected light interferometer.
- In both the methods, light from the microscope travels normal to the prepared fiber slice faces (parallel to the fiber axis), and differences in refractive index result in different optical path lengths (or bandwidth).
- As shown in below figure, when the phase of the incident light is compared with the phase of the emerging light, a field of parallel interference fringes is observed.
- The fringe displacement for the points within the fiber core is then measured using parallel fringes in fiber cladding as a reference.
- The refractive index between two points can be measured from fringe shift ***q*,** (number of fringe displacement)

$$\delta n = \frac{q\lambda}{x}$$

- Where, x is the thickness of slab.

  λ is the incident optical wavelength.

  δ is difference in refractive index.

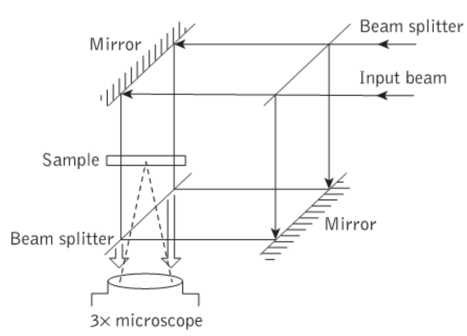


Figure -12: The principle of the Mach–Zehnder interferometer.

Limitation:

i. The time required to prepare the fiber slab.

- However, another interferomatric technique has been developed which requires no sample preparation. In this method the light beam is incident to the fiber perpendicular to its axis; **this is known as a transverse shearing interferometry.**

Transmitted near-field method or near- Field Scanning Method

- The near-field scanning or transmitted near-field method utilizes the close resemblance that exists between the near-field intensity distribution and the refractive index profile, for a fiber with all the guided modes equally illuminated.
- When a lambertian source like tungsten filament lamp or LED is used to excite all the guided modes, then $\frac{P_D(r)}{P_D(0)}$ can be expressed as a function of refractive indices. The equation is:

$$\frac{P_D(r)}{P_D(0)} = C(r,z)\left[\frac{n_1^2(r) - n_2^2}{n_1^2(0) - n_2^2}\right]$$

- Where,

$P_D(r)$ is the near field optical power at a distance 'r' from the core axis.
$P_D(0)$ is the optical power at the centre of the core.

$n_1(r)$ and $n_1(0)$ are refractive indices at the core axis and at a distance r from the core axis respectively.

n_2 is the cladding refractive index.

C(r, z) is a correction factor, is a compensation for any leaky mode present in short test fiber.

Experimental set up for the near field scanning measurement:

- The output from a Lambertian source is focused onto the end of the fiber using a microscope objective lens.
- The magnified image of the output end of the fiber is obtained by a lens arrangement and is then passed through chopper.

- The near field of the output of the chopper is scanned transversely by a PIN detector (PIN photodiode).
- The detector output is amplified by a pre-amplifier.
- The chopper and the pre-amplifier are linked with the lock-in- amplifier. So the phase sensitive detected signal is further amplified and hence the profile is plotted directly on an X-Y recorder.
- However, the profile must be corrected with regard to C(r, z) as illustrated in figure-14.

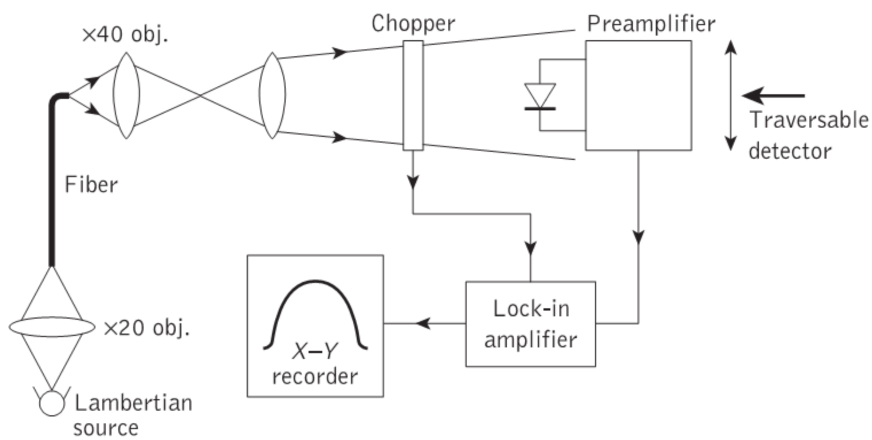


Figure-13: Experimental setup for the near-field scanning measurement of the refractive index profile.

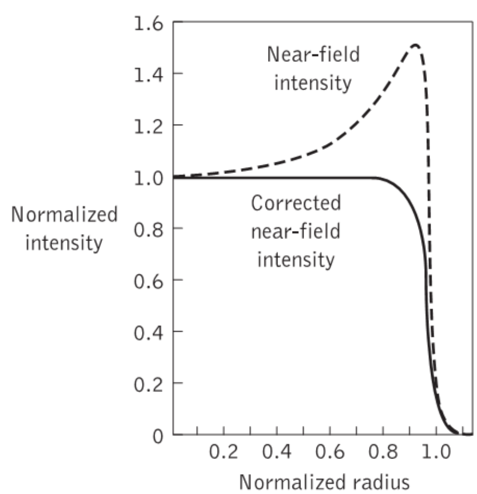


Figure-14: The refractive index profile of a step index fiber measured using the near-field scanning method, showing the near-field intensity and the corrected near-field intensity.

Facts to know: **Optical chopper:** An optical chopper is a device that interrupts a light beam at periodic intervals. By varying the frequency of operation of the chopper it can be used for various applications. The first ever optical chopper was invented in the 1800s and was used to measure the speed of light.

The chopper consists of a mechanical disc that rotates at a certain speed. In order to improve the performance of the chopper high precision and stable mechanical components must be chosen. This worksheet will provide details on the working principle, construction and applications of optical beam choppers.

Working Principle
A light beam is made to fall on the chopper's rotating disc. The disc is rotated at a particular frequency; as a result the light beam is interrupted (chopped) at regular intervals. The nature of the slots on the disc and the frequency of rotation determine the interval at which the beam is chopped.

Construction and Types of Optical Choppers

The optical chopper consists of a mechanical chopper disc with shutters. This disc is rotated at various speeds by using a motor. The classification of choppers is done based on the frequency of operation as – variable frequency rotating disc chopper, fixed frequency tuning fork chopper and optical shutters.

Applications

Typical applications of optical choppers are as below:

- Optical spectrometers, ion neutron beam instruments
- Modulation of intensity of optical signals
- Wheel speed sensors
- Anti-lock braking systems.

Lock-in amplifier:

A **lock-in amplifier** is a type of amplifier that can extract a signal with a known carrier wave from an extremely noisy environment. It is used to improve the SNR. The device is often used to measure phase shift, even when the signals are large and of high signal-to-noise ratio and do not need further improvement.

Optical amplifier: A circuit designed to amplify photon energy.

Optical pre-amplifier:

An optical amplifier at the input of an optical receiver required to amplify a weak optical signal to the level specified by receiver sensitivity.

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An optical pre-amplifier is used at the end of the optical fiber link in order to increase the sensitivity of an optical receiver (or Pre-amplifier is used at the other end of a link to amplify the signal level for it to be detected over or above the thermal noise of the receiver.)

A pre-amplifier should satisfy the following requirements:

- Low noise level
- High B.W
- High dynamic range
- High sensitivity and
- High gain

Refracted near-field method:

- The refracted near-field (RNF) or refracted ray method is complementary to the trans-mitted near-field technique but has the advantage that it does not require a leaky mode correction factor or equal mode excitation.
- It provides the relative refractive index differences directly without any external calibration or reference samples.
- It is the most commonly used technique for the determination of the fiber refractive index profile.

Experimental Configuration:

- A short length of fiber is immersed in a cell containing a fluid of slightly higher refractive index.
- A small spot of light typically emitted from a 633 nm He–Ne laser for best resolution is scanned across the cross-sectional diameter of the fiber.
- Light escaping from the fiber core partly results from the power leak-age from the leaky modes which is an undesirable quantity and is blocked using an opaque circular screen.
- Any light leaving the fiber core below a minimum angle **θ** is prevented from reaching the detector by the opaque screen. Figure below shows experimental arrangement.

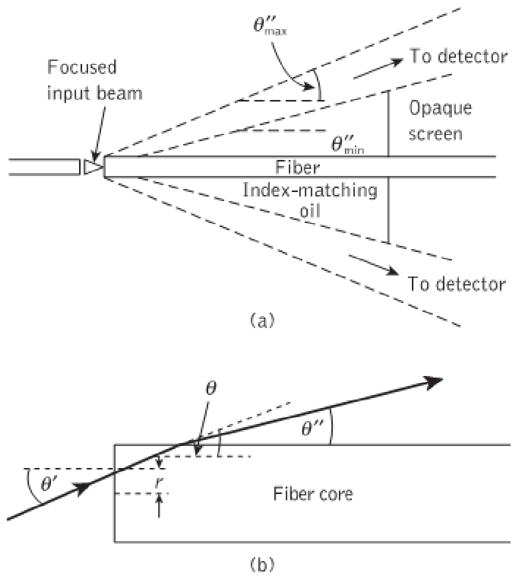

Figure -15: Refracted near-field method for the measurement of refractive index profile: (a) experimental arrangement; (b) illustration of the ray trajectories.

<u>**Facts to know: Leaky modes :**</u>
Leaky modes are the modes that are partially confined to the core region and attenuate continuously by radiating their power out of the core as they propagate along the fiber.

Alternatively:

Refracted near field technique:

- One direct method to measure the refractive index profiles of fibers is the refracted near field technique. This measurement typically has spatial resolution of less than **1µm** and a resolution in refractive index of less than **0.0002**.
- The refracted near field technique consists of focusing a laser beam onto the end of the test fiber and recording the refracted power above a certain angle defined by a disc placed behind the fiber.
- The power is recorded as a function of spot position. Using a linear calibration factor, the refractive index profile of the fiber can be obtained directly from the refracted power.
- **The main disadvantage of this technique** is that the fiber must be cleaved (or divide/split/cut) perpendicular to the axis of the fiber and the end face must be flat and contamination (or impurity) free.
- **The advantage of this technique is that** a computer algorithm is not required to determine the refractive index from the measure data. For this reason, the technique is fast, simple and requires a minimum of hardware.

Fiber diameter measurements:

Significance of maintaining the fiber outer diameter constant:

- It is essential to maintain the fiber outer diameter constant. Any diameter variation may cause excessive radiation losses and make accurate fiber to fiber connection difficult.

Outer diameter:

- Any diameter variations may cause excessive radiation losses and make accurate fiber–fiber connection difficult. On-line diameter measurement systems are required which provide accuracy better than 0.3% at a measurement rate greater than 100 Hz (i.e. a typical fiber drawing velocity is 1 ms -1).
- The most common on-line measurement technique uses fiber image projection (shadow method) and is illustrated in Figure-16.

Construction and Working:

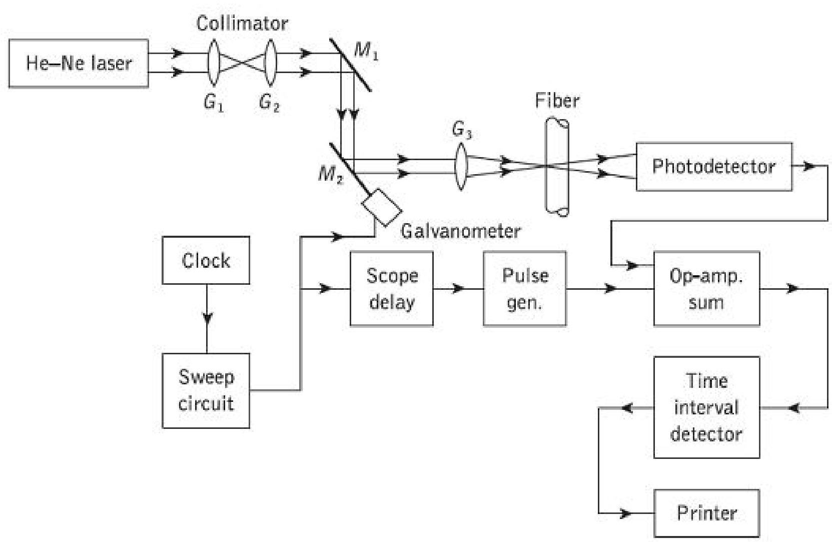

Figure -16: The shadow method for the on-line measurement of the fiber outer diameter.

- **In this method** a laser beam is swept at a constant velocity transversely across the fiber and a measurement is made of the time interval during which the fiber intercepts the beam and casts a shadow on a photodetector.
- The beam from a laser operating at a wavelength of 0.6328 μm is collimated using two lenses (G1 and G2).
- It is then reflected off two mirrors (M1 and M2), the second of which (M2) is driven by a galvanometer which makes it rotate through a small angle at a constant angular velocity before returning to its original starting position.

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- Therefore, the laser beam which is focused in the plane of the fiber by a lens (G3) is swept across the fiber by the oscillating mirror, and is incident on the photodetector unless it is blocked by the fiber.

- The velocity $\frac{ds}{dt}$ of the fiber shadow thus created at the photodetector is directly proportional to the mirror velocity $\frac{d\phi}{dt}$ following:

$$\frac{ds}{dt} = l\frac{d\phi}{dt}$$

- Where, l is the distance between the mirror and the photodetector.

- The shadow is registered by the photodetector as an electrical pulse of width W_e which is related to the fiber outer diameter d_0 as:

$$d_0 = W_e \frac{ds}{dt}$$

- Thus the fiber outer diameter may be quickly determined and recorded on the printer.

- This measurement method gives faster diameter measurements; involve the analysis of forward or backward far-field patterns which are produced when a plane wave is incident transversely on the fiber. They tend to give good accuracy.

- This technique generally requires measurement of the maxima in the center portion of the scattered pattern from which the diameter can be calculated after detailed mathematical analysis.

Core Diameter:

Definition: The core diameter for step index fibers is defined by the step change in the refractive index profile at the core–cladding interface.

In other words, the core diameter is measured by measuring the power distribution in the near field region close to the fiber end face, when the distance between the fiber end face and detector is in the micrometer range.

The core diameter (D) is defined as the diameter at which the intensity is 2.5% of the maximum intensity.

Explanation:

- The techniques employed for determining the refractive index profile (interferometric, near-field scanning, refracted ray, etc.) may be utilized to measure the core diameter.

- There is need to define the core as an area with a refractive index above a certain predetermined value if refractive index profile measurements are used to obtain the core diameter.
- Core diameter measurement is also possible from the near-field pattern of a suitably illuminated (all guided modes excited) fiber. The measurements may be taken using a microscope equipped with a micrometer eyepiece similar to that employed for off-line outer diameter measurements.
- However, the core–cladding interface for graded index fiber is again difficult to identify due to fading of the light distribution towards the cladding, rather than the sharp boundary which is exhibited in the step index case.

Chapter-3

Applications and Future developments

Introduction

- Optical fiber systems have made tremendous impact on transmission and communication systems.
- The improvement of communication systems has been further enhanced by the development of superior light sources and detectors as well as low loss optical fibers.
- In order to appreciate the many areas in which the application of light wave transmission via optical fiber may be beneficial, it is useful to review the advantages and special features provided by this method of communication. **The primary advantages using optical fiber for transmission are given below:**

    i. Enormous potential bandwidth

    ii. Small size and light weight

    iii. Ruggedness and flexibility

    iv. Immunity to interference and crosstalk,

    v. Total electrical isolation in the transmission medium

    vi. Low transmission loss and dispersion,

    vii. High signal security,

    viii. System reliability

    ix. Low cost

    x. Reduced power consumption and wide scope of system expansion etc.

    xi. These are the main advantages that have made optical fiber communication system such an indispensable part of modern life.

- **Use of fibers for Optical Communication does have some drawbacks in practice:**

    i. The fragility (or brittleness/ weak) of bare (or empty) fibers.
    ii. The small size of the fibers and cables which creates some difficulties with splicing and forming connectors.
    iii. Some problems involved with forming low loss T-couplers.
    iv. Some doubt in relation to the long-term reliability of optical fibers in the presence of moisture.
    v. An independent electrical power feed is required for any electronics repeaters.
    vi. New equipment and field practices are required.
    vii. Testing procedures tend to be more complex.

- **Due to its variety of advantages, optical fiber communication system has a wide range of applications in different fields namely:**

    i. **Public network applications:** The public telecommunication network provides a variety of applications for optical fiber communication systems like

    a. Trunk Networks

    b. Junction Networks

    c. Local Access Networks

    d. Submerged Systems

    e. Synchronous systems etc

    ii. **Military applications:** Military applications can be used in military mobiles **such as** aircraft, shift and tanks.

    iii. **Civil applications:** These transmission techniques may be utilized on railways and along pipe and electric power lines.

    iv. **Consumer applications:** Major application is within automotive electronics.

    v. **Industrial applications:** Optical fiber systems are successfully applied in nuclear testing applications.

    vi. **Optical sensor systems**: Optical sensor systems can be employed for monitoring and telemetry in industrial environments.

    vii. **Local area networks**: Optical fiber communication technology is finding application with LANs to meet the on-site requirements of large commercial organizations.

    viii. **Computer applications**: Some of the major applications of fiber optics for computer applications are listed below:

    a. Fibre optics for PC to PC communication.

    b. Fiber optics in computer networking.

    c. Fibre optics in Internet.

    d. Optical Computing.

Public network applications:

- The public telecommunication network provides a variety of applications for optical fiber communication systems like

  a. Trunk Networks or Toll network

  b. Junction Networks or Interoffice network.

  c. Local Access Networks

  d. Submerged Systems

  e. Synchronous systems etc

- The suitability of optical fibers for transmission first made an impact in this area.
- The current plans of the major PTT administrations around the world feature the installation of increasing numbers of optical fiber links as an alternative to coaxial and high frequency pair cable systems.

A**. Trunk Networks** or **Toll network**

Definition:

The term trunk refers to transmission line that runs between nodes or networks and supports large traffic loads.

Explanation:

- The trunk or toll network is used for carrying telephone traffic between major trunk terminals situate and urban stations.
- The primary requirement of this high capacity transmission system (at least several Gbit/s) with minimum cost per circuit.
- The transmission distance for trunk system can vary from 20 Km to over 100Km and occasionally as much as 1000Km.
- Therefore low attenuation at transmission link (Trunk) is desirable to minimize the number of repeater stations as well as cost.
- The optical system is distinctly advantageous for this because of its increased B.W and Repeater spacing.

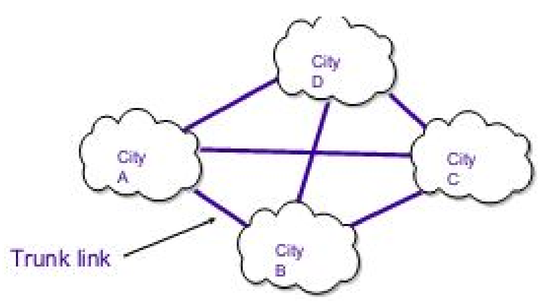

Figure-17: Trunk network or Toll network.

- Also the optical fiber system is most economic compared to the other transmission systems.
- Furthermore digital transmission through optical links is more economic with low error and higher SNR.
- This aspect of cost reduction leads to the use of optical links for interoffice or junction network.
- The speed of operation has also enhanced to a great extent with the digital transmission and optical links.
- **Table-1 indicates** the typical optical power budget for a 140 Mbit/see trunk system operating over 8km of multimode graded index fiber at the wavelength of **0.85 µm.**
- **Table-2 shows** the typical optical power budget for high performance **140Mbit/sec** single mode fiber system operating over **27.3 km** at a wavelength of **1.3µm.**

Table-1:

Mean power launched from the laser transmitter (butt Coupling)	-4.5 dB
APD receiver sensitivity at 140 Mbit/sec (BER10^{-9})	48.0 dB
Total system margin	43.5 dB
Cabled fiber loss (8×3 dB/Km)	24.0 dB
Splice losses (9×0.3 dB each)	2.7 dB
Connector loss (2×1 dB each)	2.0 dB
Dispersion equalization penalty	6.0 dB
Safety margin	7.0 dB
Total system loss	41.7 dB
Excess power margin	1.8 dB

Table-2:

Table 11.2 Optical power budget for 140 Mbit s^{-1} single mode fiber trunk system operating over 27.3 km at a wavelength of 1.3 µm

Mean power launched from the laser transmitter	−6 dBm
PIN–FET hybrid receiver sensitivity at 140 Mbit s^{-1} at 1.3 µm wavelength (BER 10^{-9})	−36 dBm
Total system margin	30 dB
Cabled fiber loss (27.3×0.6 dB km^{-1})	16.4 dB
Splice losses (27×0.15 dB average)	4.1 dB
Connector loss (2×1.5 dB)	3.0 dB
Dispersion equalization penalty	0 dB
Safety margin	6.0 dB
Total system loss	29.5 dB
Excess power margin	0.5 dB

<u>**Facts to know:**</u> <u>**Node:**</u> A node is a point where one or more communication lines terminate and /or where stations are connected. Stations also can be connected
<u>**Network:**</u> A network directly to a transmission line is a collection of interconnected stations.

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B. Junction Networks or Interoffice network:

- The junction or interoffice network usually consists of routes within major conurbations over distances of typically **5-20 km.** Junction network is very advantageous for the transmission of optical fiber due to the generally shorter link lengths.
- Optical fiber junction systems are often able to operate using no intermediate repeaters whilst alleviating (or mitigating) duct (or path) congestion in urban areas.
- The operating wavelength of junction network **is 0.88μm** and its distances up to **12 km.**
- In Europe, the transmission rates of optical fiber systems in the junction network is **8 Mb/s** and its busy routes is **34 Mb/s.**
- A number of proprietary (or ownership) systems predominantly (or mainly) operating at **8 Mb/s** using both injection laser and LED sources via multimode graded index fiber to APD detectors in the UK with repeater spacing between **7.5** and **12 km.**
- When a **2B3B** code is used in the junction network, then its duty factor is **8Mb/s** and when a **7B8B** code is used in the junction network, then its duty factor is **140 Mb/s.**

C. Local Access Networks:

Definition of access network:

- An access network encompasses connections that extend from a centralized switching facility to individual businesses, organizations, and homes.

Explanation:

- The local access network or subscriber loop connects telephone subscribers to the local switching centre or office.
- Possible network configurations are shown in **figure-21** and include a ring, tree and star topology from the local switching centre.
- **In a ring network (Fig.21 (a))** any information fed into the network by a subscriber passes through all the network nodes and hence a number of transmission channels must be provided between all nodes. This may be supplied by a time division multiplex system utilizing a broadband transmission medium.
- **The tree network,** which consists of several branches as indicated in **figure-21 (b)**. The tree network can transmit a number from one place to another place through a transmission channels. The advantage of this network is much more than the ring network. In ring network, the number of subscribers is limited.
- **The star network,** which provides a separate link for every subscriber to the local switching centre as indicated in **figure-21 (c).**

- The amount of cable required is considerable increased over the ring or tree network, but is depend on the reliability and availability for the subscribers. Thus all local and rural telephone networks utilize a star configuration.
- **In star network**, the narrowband local access network of twisted pairs is connected with optical fiber. Star network can be provided wideband services (e.g. videophone, television, stereo hi-fi, facsimile, data, etc.). This would reduce the quantity of fiber cable required for subscriber loops.
- The cost of optical fiber cable may be reduced towards the cost of copper twisted pairs with the large production volume required for local access networks.
- The use of optical fibers in local access networks have been carried out in several countries including France (the Biarritz project), Japan (the Yokosuta field trial), Canada (the Elie rural field trial) and Germany (BIGFON-wideband integrated fiber optic telecommunications network; a total of ten projects in seven towns).
- These field trials utilized star configurations providing a full range of wideband services to each subscriber through the use of both analog and digital signals on optical fibers.
- In the United Kingdom a small Fibrevision (Cable TV) network was installed in Milton Keynes using a switched star configuration. This led to the implementation of a cable TV fiber switched star network (SSN) by British Telecom in the Westminster Cable TV franchise area.
- Using the experience gained on the project, British Telecom have designed a modified switched star network which incorporates telephony services to take single-mode fiber through the local access network to the subscriber premises. **This active network is known as the broadband integrated distributed star** (BIDS), a schematic of which is provided in **figure-22**.
- BIDS collects broadband signals and then transmits to a number of hub-sites on **1.3μm** single-mode fiber super-primary links. Each fiber is capable of carrying up to **16 TV** channels using analog FM modulation to the hub-site which would normally be located at the local telephone exchange.
- The initial concept of telephony on a passive optical network (TPON) is illustrated in **figure-23**.The fiber operating mode of telephone exchange of TPON is **1.3μm.**

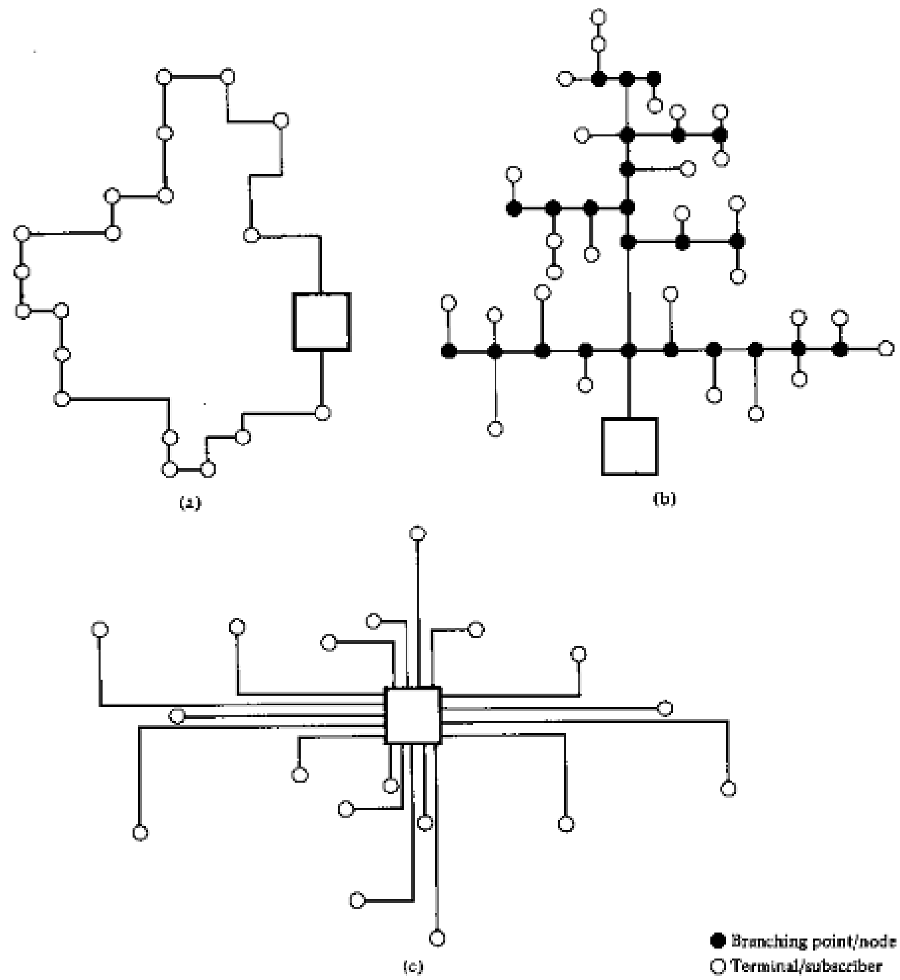


Figure-21: Local access network configuration; (a) ring network; (b) tree network; (c) star network.

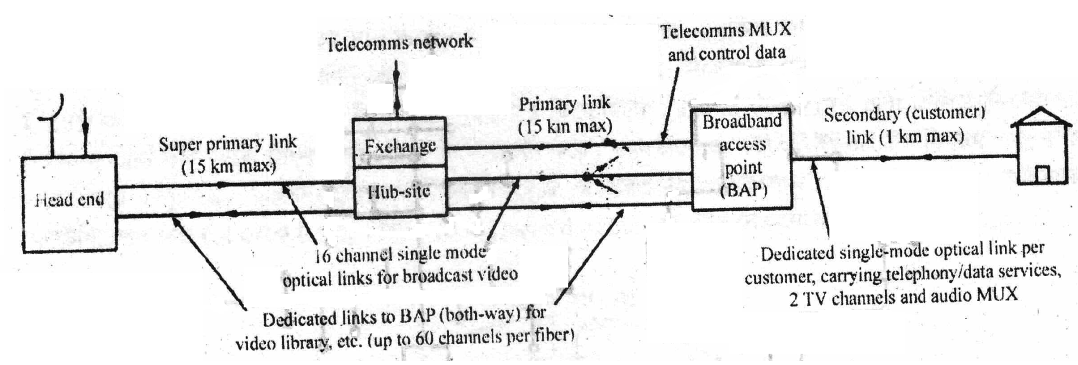


Figure-22: Broadband integrated distributed star (BIDS) network.

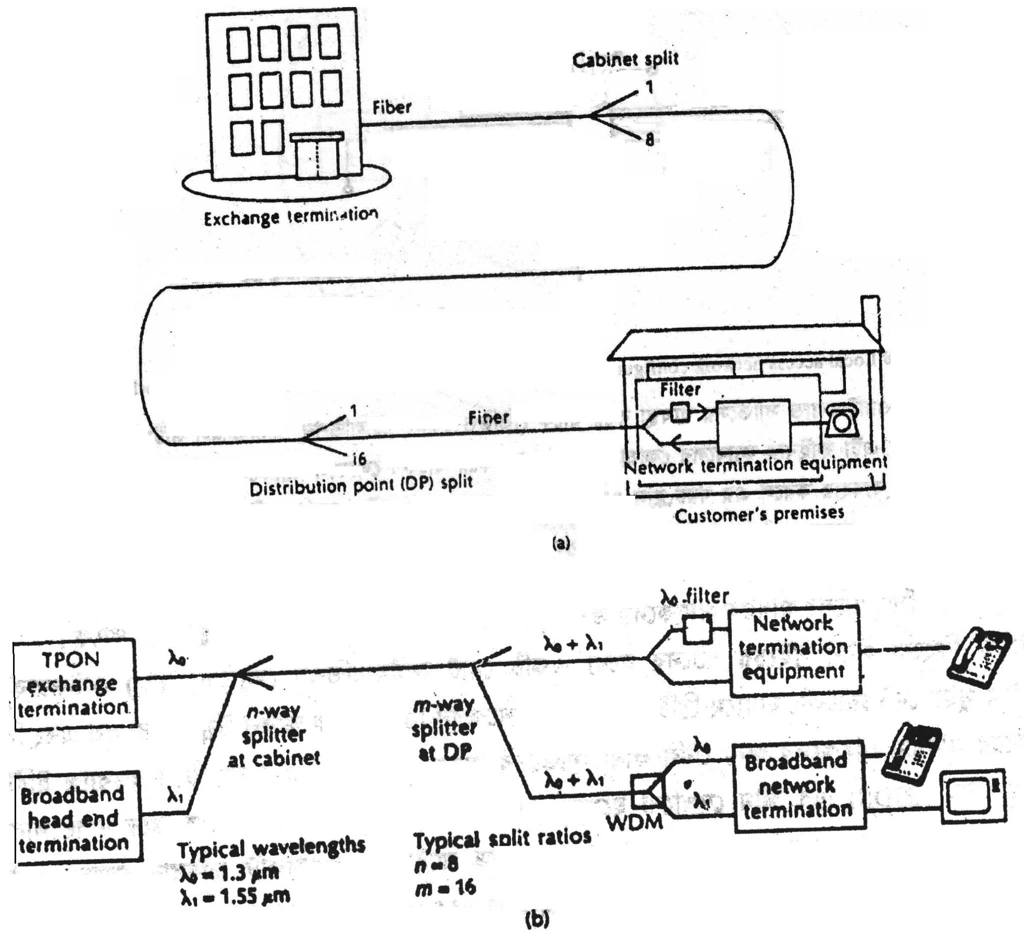
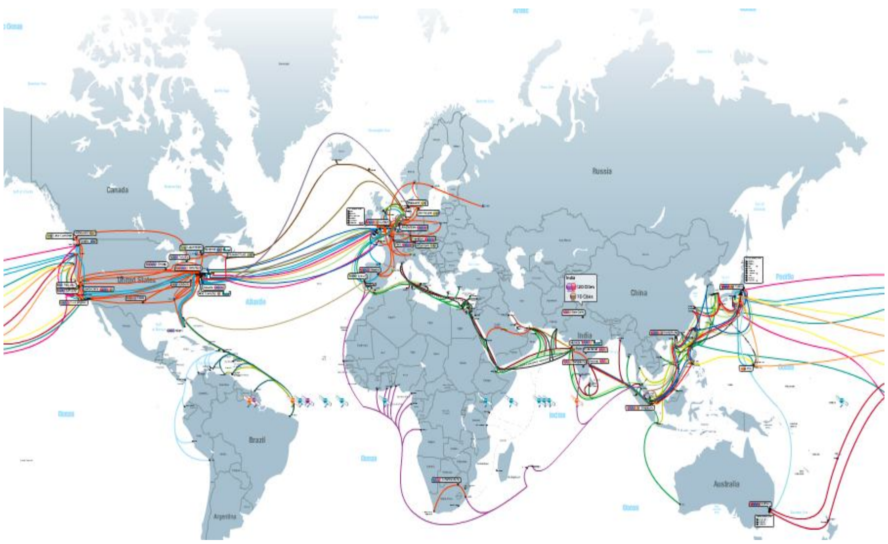


Figure-23: Passive Optical local access network; (a) telephony on a passive optical network (TPON) configuration; (b) broadband passive optical network (BPON) upgrade.

D. Submerged or undersea or submarine systems

- Undersea cable systems are an integral part of the international telecommunications network.
- Undersea cable systems of shorter routes are utilized especially at Europe. Longer routes, such as across the Atlantic, provide route diversity in conjunction with satellite links.
- The requirements of submerged systems and their capacities are steadily increasing.
- In this context, digital optical fibre communication systems exhibits substantial advantages over current analogue frequency division multiplexing (FDM) and digital pulse code modulation (PCM) coaxial cable systems.
- High capacity coaxial cable systems require high quality, large diameter cable over-come attenuation. Still it requires the repeater spacing of around 5 Km.
- In comparison to this, single mode optical fiber systems operating at 1.3μm or 1.55 μm allow repeater spacing of 25 km to 30 km or even longer.

- **The first generation** of single-mode submerged optical fiber systems was first introduced in 1980 at Scotland and Japan using 10 km cable and 140 Mb/s transmission rate. Major problems related to deep sea cable structure and strength as well as component reliability were gradually overcome, and short-haul submerged systems were operative at UK, France, United States, Japan and European countries using transmission rate of 280 Mb/s and 400 Mb/s.
- In 1988, repeater service was introduced in transoceanic optical fibre systems. This single-mode fibre systems operate at a wavelength of 1.3µm r with a transmission capacity of 560Mbit/s (two fibers at 280 Mb/s each) and with repeater spacing of around 50km. Subsequently two more single mode fiber systems of 1.3 µm were deployed across Atlantic and Pacific each operating at 420 Mb/s.
- **Second generation submerged systems** transmitting at a wavelength of 1.55µm have been successfully demonstrated. For example, the UK-Netherlands 12 link using single-mode fibre operating at a wavelength of 1.55 µm was installed in 1989 over an unrepeated distance of 155 km. However, the transmission rate per fibre was limited to 140Mbit/s.



E. Synchronous systems or Synchronous Network:

Definition:

- An optical fiber communications links interface operating over a single mode fiber at the 1300 nm wavelength window and at 52 Mb/s, 155 Mb/s and 622 Mb/s transmission rates (a standard for optical fiber communication). **Or** SONET (Synchronous Optical Network) is an optical transmission interface originally proposed by Bellcore and Standardized by ANSI

- **In other words,** Synchronous optical network (SONET) is a standardized digital communication protocol that is used to transmit a large volume of data over relatively long distances using a fiber optic medium. With SONET, multiple digital data streams are transferred at the same time over optical fiber using LEDs and laser beams. SONET is a product of the American National Standards Institute (ANSI).

Important characteristics, similarities and differences between SONET and SDH:

i. SONET is a synchronous network.

ii. SDH is also a synchronous network with optical interfaces.

iii. SONET is a set of standard interfaces on an optical synchronous network of elements that conform to these interfaces.

iv. A SONET interface defines all layers, from physical to the application layer.

v. SDH is a set of standard interfaces in a network of elements that conform to these interfaces.

vi. Like SONET, SDH interfaces define all layers, from physical to the application layer.

The SONET standard addresses the following specific issues:

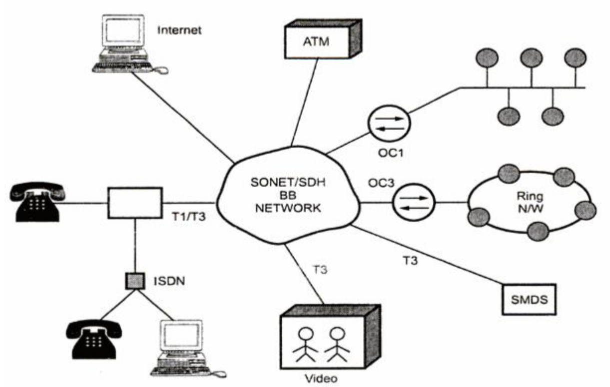
i. Establishes a standard multiplexing format using any number of 51.84Mbps signals as building blocks.

ii. Establishes an optical signal standard for interconnecting equipment from different suppliers.

iii. Establishes extensive operations, administration and maintenance capabilities as part of the standard.

iv. Defines a synchronous multiplexing format for carrying lower level digital signals.

- Fig. 24 shows SONET/SDH network services.
- Voice, video data, internet and data from LAN'S, MAN'S, and MAN'S will be transported over a SONET or a SDH network.
- The SONET network is also able to transport asynchronous transfer mode (ATM) payloads. These systems, called broadband can manage a very large aggregate bandwidth or traffic.



SONET and SDH Rates

- The SONET specification defines a hierarchy of standardized digital data rates. SONET and SDH rates are defined in the range of 51.85 to 9953.28 Mbps and higher rates at 40 Gbps are also under study.

SONET		SDH		
Electrical	Optical	ITU-T	Data rate (Mbps)	Payload rate (Mbps)
STS-1	OC-1		51.84	50.112
STS-3	OC-3	STM-1	155.52	150.336
STS-9	OC-9	STM-3	466.56	451.008
STS-12	OC-12	STM-4	622.08	601.344
STS-18	OC-18	STM-6	933.12	902.016
STS-24	OC-24	STM-8	1244.16	1202.688
STS-36	OC-36	STM-12	1866.24	1804.032
STS-48	OC-48	STM-116	2488.24	2405.376
STS-96	OC-96	STM-32	4876.64	4810.752
STS-192	OC-192	STM-64	9953.28	3621.504

1) Sts-1 = Synchronous transport signal – 1
2) OC = Optical carrier
3) STM = Synchronous transport module
4) ITU-T = International Telecommunication Union Telecommunication Standardization Sector.

- When the SONET signal is in its electrical nature, it is known as synchronous transport signal level N (STS-N). The SDH equivalent is called synchronous transport module level N (STM-N).

- After its conversion into optical pulses, it is known as optical carrier level N (OC-N).

- In SONET, N takes the value 1, 3, 12, 48 and 192 with corresponding bit rates at 51.48, 155.52, 622.08, 2488.32 and 9953.28 Mbps.

SONET/SDH Network

- The SONET/SDH network consists of nodes or network elements (NE) that are interconnected with fiber cable over which user and network information is transmitted. Fig. 25 shows SONET network

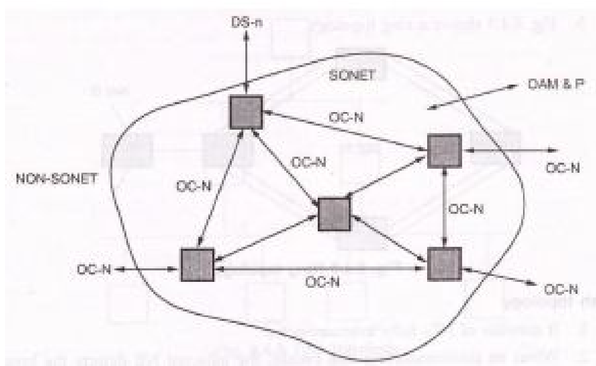


Figure-25: SONET Network

- SONET NEs may receive signals from a variety of facilities such as DS1, DS3, ATM, Internet and LAN/MAN/WAN. They also may receive signals from a variety of network topology.

- SONET NEs must have a proper interface to convert the incoming data format into the SONET format.

Military application:

- Military applications of fiber optics abound. They include:
    i. Communications.
    ii. Command and control links on ships and aircraft.
    iii. Data links for satellite earth stations and
    iv. Transmission lines for tactical command-post communications.
- The important fiber characteristics are low weight, small size, EMI rejection and no signal radiation.

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- On aircraft and ships the reduced shock, fire and spark hazards are significant assets.
- The high resistance to corrosion justifies the use of fibers at sea either aboard ship or in the ocean. For field applications, lightweight fibers speed cable replacement.
- Tactical communications range from short-distance links (connecting field shelters) to long-haul links (60 km path length can occur). A novel application is the fiber-guided missile. The fiber is payed out while the missile is in flight. Sensors on the missile transmit video information through the fiber to a ground control van. Commands are transferred back to the missile from the van, again along the fiber.

Alternatively:

Military application:

- The optical fiber technology offers several advantages of low weight, small size, and long life, immunity of Electromagnetic Interferences (EMI) and electromagnetic pulses (EMP) interference, data security, and long life besides easy layout of cables indoor and outdoor applications.
- The transmission of large data and information over single mode fiber offers great benefits and so, Optical fiber communication is used in defense applications due to security of data and large bandwidth.
- Following major applications are reported by military users:
    - i. Land application for transmission of low and high speed data information.
    - ii. Launching of light guided missiles in sea water and recording video data.
    - iii. Satellite to satellite communication using light wave space communication.
    - iv. Data transmission over fiber in aircraft, ships, tanks and vehicles.
- The feasibility study is carried out for 2 Mb/s optical data on the commercial and fighter helicopters to achieve control, data transfer in avionic weapons on board and internal data systems. Similarly, an optical communication system working at 2.4 kb/s and 64 kb/s is installed in Harrier aircrafts as per MIL standard MIL-STD-1553 B data bus. This **called as Fly-by-light** capability.
- Various optical fiber sensor and their systems are used in military vehicles to provide monitoring functions of different equipments on moving vehicles.
- Some fiber optical sensors are deployed in border areas to detect movement of human beings and vehicles. These optical sensors are pressure sensing devices and immediately detect movement of persons/vehicles with 100% reliability.

- Fiber guided weapon systems make full use of optical sensors, optical fiber cable to provide 100% kill capability. The front nose end of missile consists of a TV camera using CCD devices which take and send pictures of enemy targets.
- The optical fiber cable is attached with the end of missile and transmits video signal to the control and monitoring station even if the tank/enemy target is moving, it controls the trajectory and hits the target.
- Optical networks in ring or star configurations are realized and used by army frequently during war and peace time.
- Time division multiplexing (TDM) in bus networks are deployed successfully. The optical data bus was installed in Jaguar and Mirage aircrafts using LED source, single mode fibers and PIN photodiode.
- The system has performed in hazardous conditions and some more improvements are being incorporated by smaller radii of curvatures and by using loose buffer cable concept.
- Laser ring gryros are installed in the aircrafts to sense the rotation of the aircrafts very precisely.
- Two clockwise and counter-clockwise waves of light are allowed to interface and balance at zero rotation.
- If there is any rotation in the aircrafts then is a phase change between two waves and it is detected precisely.

Civil application:

- The introduction of optical fiber communication systems into public network has stimulated its applications in public utility organizations that provide their own communication facilities over moderately long distances. These transmission techniques are utilized in signaling, information and communication services at railways and analog pipe and electrical power lines.
- Although high capacity transmission is not required in these applications, optical fiber provides low cost implementation and enhanced protection in harsh environments, especially from Electromagnetic Interferences (EMI) and electromagnetic pulses (EMP).
- Optical systems are suitable for video transmission and hence commercial television signal transmission is incorporated with fiber networks. These applications include short distance links between studios and outside broadcast vans or receiving aerials and close circuit television (CCTV) links for security and traffic surveillance.

- Optical fiber communication is also incorporated at larger networks for cable and common antenna television (CATV) providing the advantages of bandwidth and unrepeatered transmission distance over conventional video links.
- Various techniques may be used for video transmission including:
    i. Baseband intensity modulation,
    ii. subcarrier intensity modulation (FM-IM),
    iii. pulse analog technique (PFM-IM) and
    iv. Digital pulse code modulation (PCM-IM).
- Generally on larger CATV networks digital transmission preferred as it allows time division multiplexing as well as greater repeaterless transmission. It avoids problems of nonlinearities of optical sources. However digital transmission is not always economic due to the cost of terminal equipments.

Consumer application:

- A major consumer application of optical fiber systems is at automobile electronics. Microprocessors and microcontroller are now widely used in automobile electronics to provide the features of convenience such as power windows, seat controls and control panels.
- Optical links are of low cost and weight and immuned to Electromagnetic Interferences (EMI) noise and hence may be routed through fuel tanks and magazines similar to military mobiles.
- Other consumer applications where optical systems may be useful are the home appliances based on microprocessors and microcontrollers technology.

Industrial application:

- Majority of the fiber optical applications are found in the following areas:
    i. Optical fiber LAN and WAN (steel, cement, clothe, sugar, similar industries).
    ii. Optical fiber LAN up to 6 km operating in hazardous (or dangerous) industries and coal mines (chemical, nuclear, etc.
    iii. Synchronous/asynchronous digital transmission at rates from dc to 32 Mb/s and with bit error rate (ber) of less than 10^{-9} and high reliability.
    iv. Analog transmission from dc to 10 MHz with higher order of linearity and minimum noise.
    v. Transmission of data and information with accuracy over long distances.

- Such optical fiber based telemetry systems are already operational in large industries.
- LED and multimode fiber with PIN diodes are used for 100 m to 6 km ranges whereas single frequency lasers, single mode fibers and APD diodes are used in long distance communication and data transmission. These systems are available at low cost and provide reliable telemetry and control communication in tough industrial environments where Electromagnetic Interferences (EMI) and electromagnetic pulses (EMP) may cause problems if we use metallic cable lines. These systems are providing reliable solutions for effective communications.
- The optical fiber telemetry system is successfully used in nuclear power plants and nuclear testing applications. These wideband systems are used to record nuclear radiations produced by gamma ray sources.

Optical sensor systems: Optical sensor systems can be employed for monitoring and telemetry in industrial environments.

Definition:

- A **fiber optic sensor** is a sensor that uses optical fiber either as the sensing element ("intrinsic sensors"), or as a means of relaying signals from a remote sensor to the electronics that process the signals ("extrinsic sensors").
- Fibers have many uses in remote sensing. Depending on the application, fiber may be used because of its small size, or because no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using light wavelength shift for each sensor, or by sensing the time delay as light passes along the fiber through each sensor.
- Time delay can be determined using a device such as an optical time-domain reflectometer and wavelength shift can be calculated using an instrument implementing optical frequency domain reflectometry.
- Fiber optic sensors are also immune to electromagnetic interference, and do not conduct electricity so they can be used in places where there is high voltage electricity or flammable material such as jet fuel. Fiber optic sensors can be designed to withstand high temperatures as well.
- Fiber optic sensors are excellent candidates for monitoring environmental changes and they offer many advantages over conventional electronic sensors as listed below:
    i. Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry.
    ii. Inability to conduct electric current.
    iii. Immune to electromagnetic interference and radio frequency interference.
    iv. Lightweight.
    v. Robust, more resistant to harsh environments.

vi. High sensitivity.

vii. Multiplexing capability to form sensing networks.

viii. Remote sensing capability.

ix. Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.

Fiber optic sensor principles

The general structure of an optical fiber sensor system is shown in figure-26. It consists of an optical source (Laser, LED, Laser diode etc), optical fiber, sensing or modulator element (which transduces the measured to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc).

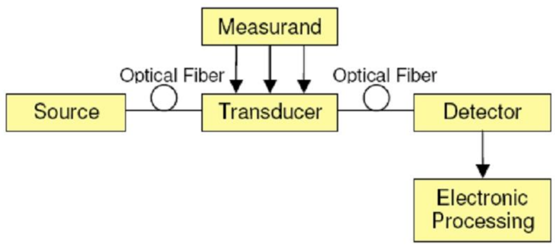

Figure-26: Basic optical fiber sensor system.

Classification of fiber optic sensors:

Fiber optic sensors can be classified under three categories:

i. The sensing location,

ii. The operating principle, and

iii. The application.

1. **Based on the sensing location**, **a fiber optic sensor can be classified as:**

   i. Intrinsic Fiber-Optic Sensors

   ii. Extrinsic Fiber-Optic Sensors

2. **Based on operating principles, fiber optic sensors are classified into three types:**

   i. Intensity based

   ii. Phase based

   iii. Polarization based

3. **Based on application, fiber optic sensors are classified into three types such as:**

   i. Chemical Sensor

   ii. Physical Sensor

   iii. Bio Medical Sensor

- **Optical fibers can be used as sensors to measure**

   i. Strain,
   ii. Temperature
   iii. Pressure

Intrinsic type fiber optic sensors:

- **In intrinsic type fiber optic sensors,** sensing takes place within the fiber itself. The sensors depend on the properties of the optical fiber itself to convert an environmental action into a modulation of the light beam passing through it. Here, one of the physical properties of light signal may be in the form of frequency, phase, polarization; intensity. The most useful feature of the intrinsic fiber optic sensor is, it provides distributed sensing over long range distances. The basic concept of the intrinsic fiber optic sensor is shown in the following figure.

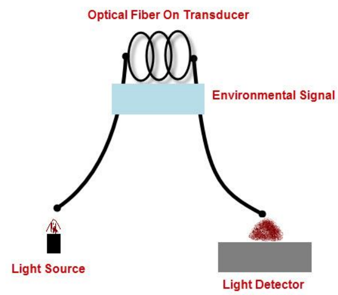

Figure-27: Intrinsic Type Fiber Optic Sensors**.**

Extrinsic Type Fiber optic Sensors:

In extrinsic type fiber optic sensors, the fiber may be used as information carriers that show the way to a black box. It generates a light signal depending on the information arrived at the black box. The black box may be made of mirrors, gas or any other mechanisms that generates an optical signal. These sensors are used to measure rotation, vibration velocity, displacement, twisting, torque and acceleration. The major benefit of these sensors is their ability to reach places which are otherwise unreachable.

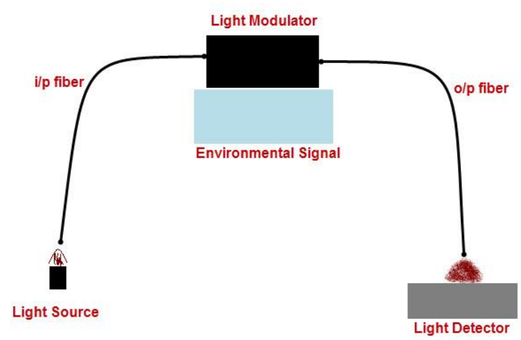

Figure-28: Extrinsic Type Fiber optic Sensors

The best example of this sensor is the inside temperature measurement of the aircraft jet engine that uses a fiber to transmit a radiation into a radiation pyrometer, which is located outside of the engine. In the same way, these sensors can also be used to measure the internal temperature of the transformers. These sensors provide excellent protection of measurement signals against noise corruption. The following figure shows the basic concept of the extrinsic fiber optic sensor.

Intensity based Fiber Optic Sensor

Intensity based fiber optic sensors require more light and these sensors use a multi-mode-large core fibers. The shown figure gives an idea about how the light intensity work as a sensing parameter as well as how this arrangement makes the fiber to work as a vibration sensor. When there is a vibration, there will be a change in light inserted from one end to another end and this will make the intelligence for measuring the vibration amplitude.

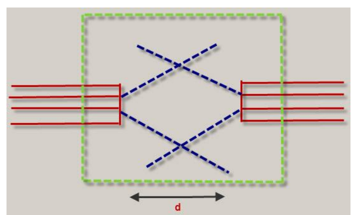

Figure-29: Intensity based Fiber Optic Sensor

In the figure, the closer fiber optic and vibration sensor depend on the light intensity in later parts. These sensors have many limitations due to variable losses in the systems that do not occur in the environment. These variable losses include loses due to splices, micro & macro bending losses, loses due to connections at joints, etc. The examples include intensity-based sensors or microbend sensor and evanescent wave sensor. The advantages of these fiber optic sensors include low cost, ability to perform as real distributed sensors, very simple to implement, possibility of being multiplexed, etc. The disadvantages include variations in the intensity of the light and relative measurements, etc.

Displacement sensor (Extrinsic Sensor):

Principle:

- Light is sent through a transmitting fiber and is made to fall on a moving target. The reflected light from the target is sensed by a detector with respect to intensity of light reflected and the displacement of the target is measured.

Description:

- It consists of a bundle of transmitting fibers coupled to the laser source and a bundle of receiving fibers coupled to the detector.
- The axis of the transmitting fiber and the receiving fiber with respect to the moving target can be adjusted to increase the sensitivity of the sensor.

Working:

- Light from the source is transmitted through the transmitting fiber and is made to fall on the moving target.
- The light reflected from the target is made to pass through the receiving fiber and the same is detected by the detector.
- Based on the intensity of light received, the displacement of the target can be measured, (i.e.) If the received intensity is more, then we can say that the target is moving towards the sensor and if the intensity is less, we can say that the target is moving away from the sensor.

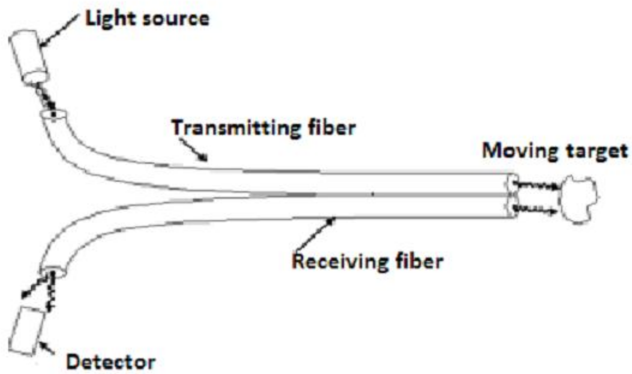

Figure-30: Optical displacement sensors

Polarization based Fiber Optic Sensor

Polarization based optical fibers are important for a certain class of sensors. This property can be simply modified by various external variables and thus, these types of sensors can be used for the measurement of a range of parameters. Special fibers and other components have been developed with exact polarization features. Generally, these are used in a variety of measurements, communication and signal processing applications.

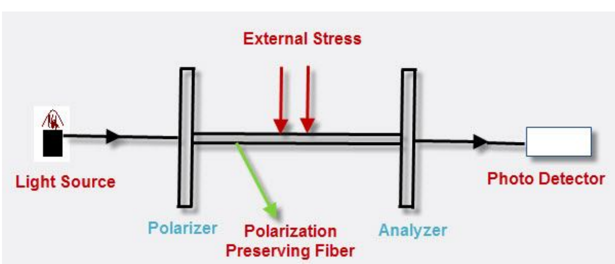

Figure-31: Polarization based Fiber Optic Sensor

The optical setup for a polarization-based-fiber-optic sensor is shown above. It is shaped by polarizing the light from the light source through a polarizer. The polarized light is started at 45o to the selected axes of a length of birefringent polarization protecting fiber. This section of the fiber is served as sensing fiber. Then, the phase difference between the two polarization states is changed under any external disturbances such as stress or strain. Then, according to the external disturbances, the output polarization is changed. Thus, by considering the output polarization state at the next end of the fiber, the external disturbances can be detected.

Phase based Fiber Optic Sensor

These types of sensors are used to change emitter light on information signal wherein the signal is observed by the phase based fiber optic sensor. When a light beam is passed through the interferometer, then the light separates into two beams. Wherein one beam is exposed to the sensing environment and the other beam is isolated from the sensing environment, which is used as a reference. Once the two separated beams are recombined, then they get in the way with each other. The most commonly used interferometers are Michelson, Mach Zehnder, Sagnac, grating and polarimetric interferometers. Here, the Mach Zehnder and Michelson interferometers are shown below.

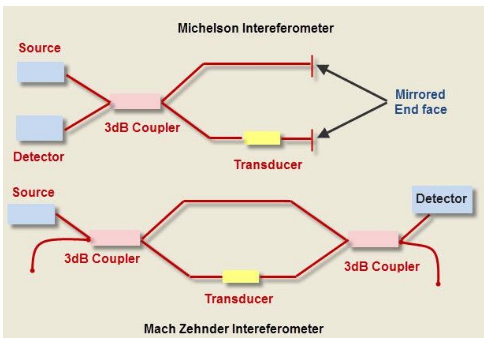

Figure-32: Phase based Fiber Optic Sensor

There are differences and similarities between the two interferometers. In terms of similarities, The Michelson Interferometer is frequently considered to be folded Mach Zehnder interferometer. The configuration of the Michelson interferometer requires only one optical fiber coupler. Because the light passes twice through the sensing and reference fibers, the optical phase shift per unit length of the fiber is doubled. Thus, the Michelson can essentially have better sensitivity. Another clear advantage of the Michelson is that the sensor can be interrogated with only a single fiber between the source and source detector module. But, a good-quality reflection mirror is required for the Michelson interferometer

Chemical Sensor

A chemical sensor is a device which is used to transform chemical information in the form of a measurable physical signal that is associated with the concentration of a certain chemical species. The Chemical sensor is an important component of an analyzer and may include some devices that perform the following functions: signal processing, sampling, and data processing. An analyzer may be an important part of an automated system.

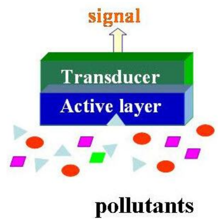

Figure-33: Chemical Sensor

The working of analyzer according to a sampling plan as a function of time acts as a monitor. These sensors include two functional units: a receptor and a transducer. In the receptor part, the chemical information is transformed into an energy that may be measured by the transducer. In the transducer part, the chemical information is transformed into an analytical signal and it does not show sensitivity.

Physical Sensor

A physical sensor is a device that is made according to the physical effect and nature. These sensors are used to provide the information about a physical property of the system. This type of sensors is mostly signified by sensors such as photoelectric sensors, piezoelectric sensors, metal resistance strain sensors and semiconductor piezo-resistive sensors.

Bio Medical Sensor

Biomedical sensor is an electronic device that is used to transfer various non- electrical quantities in biomedical fields into easily detectable electrical quantities. Due to this reason, these sensors are included in health care analysis. This sensing technology is the key to collecting human pathological and physiological information.

Figure-34: Bio Medical Sensor

Applications of Fiber Optic Sensors

- Fiber optic sensors are used in several areas. Specifically:

    i. Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size.

    ii. Monitoring the physical health of structures in real time.

    iii. **Buildings and Bridges:** Concrete monitoring during setting, crack (length, propagation speed) monitoring, prestressing monitoring, spatial displacement measurement, neutral axis evolution, long-term deformation (creep and shrinkage) monitoring, concrete-steel interaction, and post-seismic damage evaluation.

    iv. **Tunnels:** Multipoint optical extensometers, convergence monitoring, shotcrete / prefabricated vaults evaluation, and joints monitoring damage detection.

    v. **Dams:** Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring, and distributed temperature monitoring.

Local Area Networks (LAN):

- Optical fiber communication technology is finding application with LANs to meet the on-site requirements of large commercial organizations.

Definition:

- Many applications of fiber optic communication technology require networks in which a large number of users within local campus are interconnected in such a way that any user can access the network randomly to transmit data to any other user. Such networks are **called Local area networks (LANs). In other words,** a local area network (LAN) is generally defined as an interconnection topology entirely confined within a geographical area of a few square kilometers. It is therefore usually confined to either a single building or a group of buildings contained within a site or establishment (industrial, military, educational, etc.).
- Fiber optic cables are used in implementation of networks. Since the transmission distance is relatively short (less than 10 km), fiber losses are not at much concern for LAN applications. Use of fiber optic offers a large bandwidth.
- A local area network distributes information to several stations within a limited region (for example, all the stations are within one building). A variety of network topologies are available for local area networks by using fiber transmission. The commonly used topologies for LANs are –

    a. Ring topology

    b. Star topology

a. Ring topology

- In ring topology consecutive nodes are connected by point-to-point links to form a closed ring. Fig.18 shows ring topology.

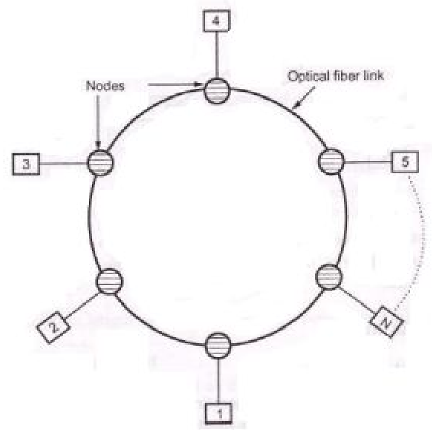

Figure-18: Ring topology.

- Each node can transmit and receive data by using a transmitter receiver pair. A token (predefined bit sequence) is passed around the ring. Each node monitors the bit stream to listen for its own address and to receive the data.

- The use of ring topology for fiber optic LANs is known as fiber distributed data interface (FDDI). FDDI operates at 100 Mb/s with multimode fibers. It can provide backbone services e.g. interconnection of lower speed LAN.

b. Star topology

- In star topology, all nodes are connected through point-to-point link to central node called a hub. Fig. 19 shows star topology.

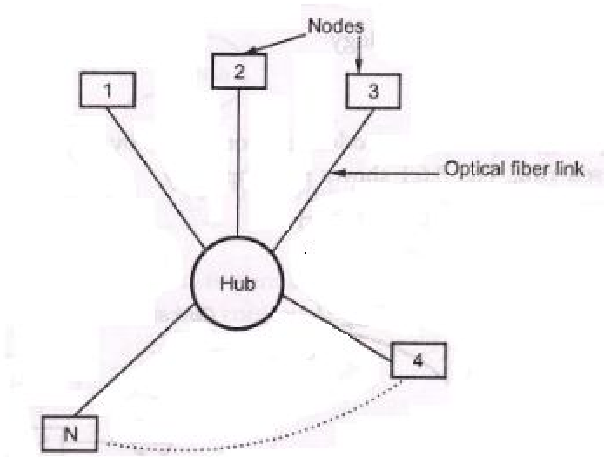

Figure-19: Star topology.

- LANs in star topology can further be classified into active star networks and passive star networks depending on whether the central hub is active or passive device.

Facts to know: Topology: The topology is the logical manner in which nodes are linked together by information transmitting channels to form a network.

Computer applications: Some of the major applications of fiber optics for computer applications are listed below:

a. Fiber optics for PC to PC communication.

b. Fiber optics in computer networking.

c. Fiber optics in Internet.

d. Optical Computing.

A**. Fiber optics for PC to PC communication:**

- PC to PC fiber optic communication deals with data transfer from one computer to another.
- An MAX 232 is employed to convert RS 232 logic from the serial port of computer to TTL logic, which is then sent to an optical transmitter circuit to transmit optical data via fiber optic cable.
- In fact, transmitter converts electronic information into pulses of light, a pulse represents one, while no pulse represents zero.
- At the receiver end, an optical receiver circuit receives data using a photo transistor and another MAX 232 again employed to convert TTL logic to RS 232 to receive data on the serial port at the receiving end of computer.
- Fig.3 shows block diagram of PC to PC fiber optics communication for data transfer between two PC, which can also be extended for data transfer among a set of computers in a computer network.

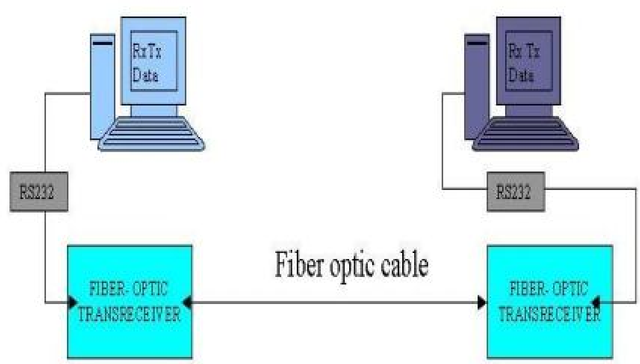

Figure-20: PC to PC fiber optics communication

B. Fiber optics in computer networking:

- **Computer networking** is defined as a network of many computers connected to each other for resource sharing, information interchange and communication purposes.
- By creating a computer network, devices like printers and scanners, various software, files and data that are stored in the network can be shared, as and when necessary. For example, a document can be printed on a printer from any computer connected in that network, so each computer need not require its own printer.
- It is established with integration of various computer hardware and software. The common hardware devices employed in computer network are routers, hubs, switches, network gateways, network firewalls and network interface card.
- There are broadly two types of computer networks: Local Area Network (LAN) and Wide Area Network (WAN).
- A LAN is a computer network that extends to a comparatively smaller area; say to one building or group of buildings in an organization within a restricted region. Most of the LANs connect personal computers and workstations. In a LAN, each computer has its own CPU in which it executes programs and is also capable of sharing the information with other computers in it. LAN is more significant and capable in transferring the data quickly at fast rates but the distances of transmission are limited.
- On the other hand, WAN enables the connectivity among many computers to transfer data in large geographical area, such as in a country or in a continent and even it can span across the world. So, offices in different countries can be interconnected through WAN. Speed of data transmission in WAN can be as low as a few Kbps or as fast as a few Gbps, depending on the technology adopted. Internet could also be called as largest WAN in the world.
- The majority of computer networks today use some type of cable to connect the computer systems and hardware that make up a network. Most cables used in computer networks can be categorized into three groups: coaxial, twisted pair and fiber optic.
- Coaxial cable consists of a central conductor surrounded by insulating material, which is then surrounded by a braided metal shield and an outer plastic jacket of the cable. In coaxial cable, the central conductor wire and the braided metal shield share the same central axis. Coaxial cable is effective at shielding data from Electro-Magnetic Interference (EMI) and is commonly used to enable a cable modem to connect to an Internet Service Provider (ISP).
- Twisted pair cable, which consists of multiple pairs of wires twisted around each other at specific intervals, is commonly used in computer networks. Fiber-optic cable transmits data via waves of light through glass as opposed to electrical current through copper wire.
- The main advantages of fiber-optic over twisted pair cable are distance and speed. Fiber optic cable can transmit data for hundreds of kilometers with very low transmission loss as opposed to only a few hundred meters with twisted pair cable.

- Similarly, it can carry multiple wavelengths of light simultaneously, which greatly increases the speed at which data can be transmitted in more secure and reliable manner.
- Fiber optic cables are already being used in a variety of ways, from delivering television signals at homes to transferring data between computers that are thousands of miles apart.
- As the computer networks are getting complex day by day, specifically for applications demanding high bandwidth and long distance of transmission, interconnections using optical fibers are indispensable choice.

C. Fiber optics in Internet

- The internet is a global system of interconnected computer networks that use the standard TCP/IP protocol to link several billion devices worldwide.
- It is a globally distributed network that consists of millions of private, public, academic, business and government switched networks, which operates without a central governing body.
- The Internet carries an extensive range of information resources and an extremely large number of services, such as applications of the World Wide Web (WWW), the infrastructure to support email, internet phone, audio, video and file transfer services and networks for file sharing. So WWW is one of the large numbers of services running on the Internet and Hyper Text Transfer Protocol (HTTP), is the main access protocol of the WWW and is the language used for information transfer.
- WWW browser software, such as Microsoft's Internet Explorer, Mozilla, Opera, Apple's Safari and Google chrome lets users navigate from one web page to another.
- The most prominent component of the internet is the Internet Protocol (IP), which provides addressing systems called IP addresses for all computers on the internet and enables internet working.
- The commercialization of internet started in 1990s, but has grown to such an extent that it has virtually impacted into every aspect of modern human life, creating the so called internet revolution.
- Today more than one third of the world's human population has used the services of the internet. Email is one of the most important communications service available on the internet. The internet allows computer users to remotely access other computers in the network with or without computer security.
- It is also widely used for social networking through face book, twitter and my space for fostering commercial and business connections through LinkedIn as well as for storing and transferring large amounts of data, whenever necessary. Common methods of internet access by users is either by dial-up with a computer modem via telephone circuits or by wireless or by broadband over coaxial cable and fiber optic cable. Broadband internet through fiber optic cable allows large amount of data transmitted at high speed for demanding applications like streaming and uploading online video, online gaming and multimedia applications.

- As the networks of internet is expanding rapidly and getting complex day by day, demand for high quality optical fibers with high bandwidth and long distance of transmission is increasing to meet the user expectations.

D. Optical Computing:

- An optical computer is a device that uses visible light or infrared beams to perform digital computations rather than electric current used in conventional computers.
- In the optical computer, micro sized optical fibers are fixed at chip level for transmission of data in the form of light.
- In the optical computing, information is sent from keyboard, mouse or other external sources to the processor.
- Processor sends these information through logic gates and switches to be programmed to different fiber optic cables depending on its final location and save them in the holographic memory.
- After information is saved, the program sends a command to the processor to receive them whenever required.
- The program receives the information and sends a signal back to the processor when the task is complete.
- A lot of research is going on worldwide to develop lower cost lasers, lower cost-receivers and associated optical components like optical switches, waveguides, optical routers and detectors as well as to make optical interconnections cheaper for widespread use inside computers.
- The silicon photonic chips could replace the electronic connections between a computer's key components, such as its processors and memory.

Advantages of Optical Computer: Advantages of optical computers compared to conventional computers are as under:

a. Higher performance.
b. Less consumption and less noise.
c. Less communication loss and flexible layout.

Future activities of optical fiber communication:

- In future, the equal or more than of 1500 pair cable will handle voice channels by a single fiber.
- Required raw material will more available.
- It will be not usually affected by nuclear radiation.
- The rates of flow of data will more than in present rates.
- The information of optical fiber will not radiate in any kinds of noise.
- In future, optical fiber will be more used in any communication systems.

Alternatively:

Future of optical fiber communication:

- Fiber optics communication is definitely the future of data communication.
- some of the envisioned future trends in fiber optic communication are:

i. All Optical Communication Networks :

- Fiber optic communication is envisioned to be completely in the optical domain where all signals will be processed in the optical domain, without any form of electrical manipulation.
- In such networks, all signals will be processed in the optical domain, without any form of electrical manipulation. Presently, processing and switching of signals take place in the electrical domain, optical signals must first be converted to electrical signal before they can be processed, and routed to their destination. After the processing and routing, the signals are then re-converted to optical signals, which are transmitted over long distances to their destination.
- The optical to electrical conversion and vice versa adds a delay in the network and is a limitation to achieving very high data rates.

ii. Multi – Terabit Optical Networks:

- Dense Wave Division Multiplexing (DWDM) paves the way for multi-terabit transmission. The need for increased bandwidth availability has led to the interest in developing multi-terabit optical networks.
- Researchers are looking at achieving higher bandwidth with 100Gb/s. With the continuous reduction in the cost of fiber optic components, the availability of much greater bandwidth in the future is possible.

iii. Intelligent Optical Transmission Network :

- Traditional optical networks are unable to adapt to the rapid growth of data services due to the unpredictability of dynamic allocation of bandwidth, they rely mainly on manual configuration of network connectivity, which is time consuming, and unable to fully adapt to the demands of the modern network.
- Intelligent optical network is a future trend in optical network development, and will have the ability to adapt to unpredictability of bandwidth allocation.

iv. Polymer Optic Fibers :

- Polymer optical fibers offer many benefits when compared to other data communication solutions such as copper cables, wireless communication systems, and glass fiber.
- In comparison with glass optical fibers, polymer optical fibers provide easy and less expensive processing of optical signals, and are more flexible.

v. **Improvement in Optical Amplification Technology :**

- Erbium Doped Fiber Amplifier (EDFA) is one of the critical technologies used in optical fiber communication systems.
- To increase the gain bandwidth of EDFA, better gain equalization technology for high accuracy optical amplification will be developed.
- To achieve a higher output power, high power pumping lasers with excellent optical amplification characteristics, and very low noise figure are envisioned to exist in the nearest future.

vi. **Improvements in Glass Fiber Design and Component Miniaturization :**

- Various impurities are added or removed from the glass fiber to change its light transmitting characteristics.
- The result is that the speed with which light passes along a glass fiber can be controlled, allowing for the production of customized glass fibers to meet the specific traffic engineering requirement of a given route. This trend is to be continued in the future, to produce more reliable and effective glass fibers.
- The miniaturization of optical fiber communication components is another trend that is most likely to continue in the future.

vii. Ultra – Long Haul Optical Transmission :

- In the area of ultra-long haul optical transmission, the limitations imposed due to imperfections in the transmission medium are subject for research. Cancellation of dispersion effect has prompted researchers to study the potential benefits of soliton propagation.
- More understanding of the interactions between the electromagnetic light wave and the transmission medium is necessary to proceed towards an infrastructure with the most favorable conditions for a light pulse to propagate.

viii. High – Altitude Platforms :

- Presently, optical inter satellite links and orbit-to-ground links exists, the latter suffering from unfavorable weather conditions.
- Current research explores optical communication to and from high altitude platforms. High altitude platforms are airships situated above the clouds at heights of 16 to 25Km, where the unfavorable atmospheric impact on a laser beam is less severe than directly above the ground.
- Optical links between high altitude platforms, satellites and ground stations are expected to serve as broadband back-haul communication channels, if a high-altitude platform functions as a data relay station.

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