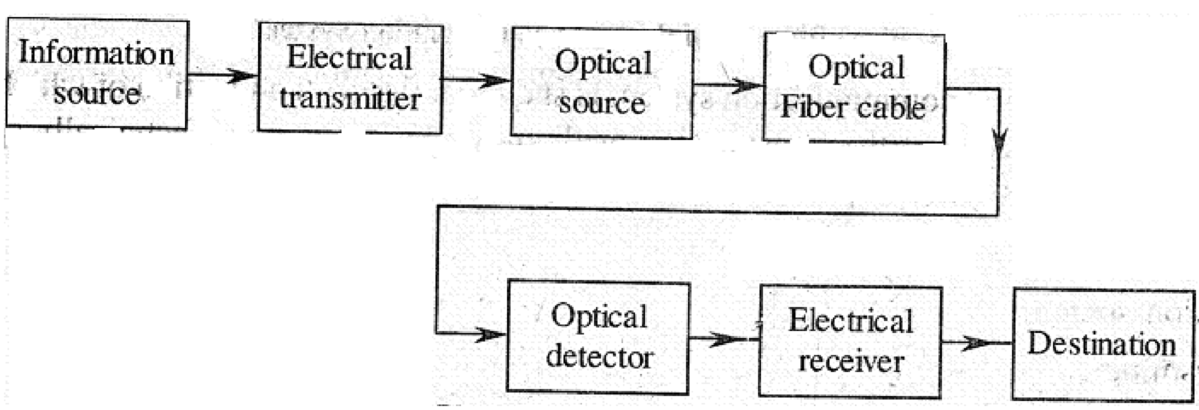
UNIT 1

1. What are the various elements of an optical communication system? Explain each element in brief?

Ans:

Optical Fiber Communication System:

The figure 1.1 shows a block schematic of the different elements in an optical fiber communication system. The carrier is modulated using analog information signal. The variation of light emitting from the optical source is a continuous signal. The information source provides an electrical signal to the transmitter. The transmitter comprises electrical stage. The electrical stage (circuits) drives an optical source. The optical source output is a light which is intensity modulated by the information. The optical source converts the electrical signal into an optical signal. The source may be either semiconductor laser or Light Emitting Diode (LED). The intensity modulated light signal is coupled to fiber. The fiber which is made up of a glass acts as a channel between the transmitter and receiver.



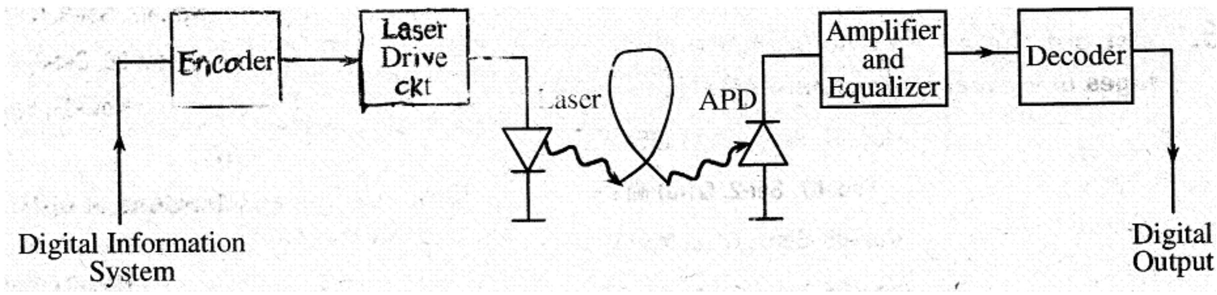
1.1 General Block Diagram of a Optical Communication System

At the receiver the optical signal is detected by the optical detectors such as PIN diode and Avalanche photodiode.

Sometimes photo transistors and photo conductors are used for converting an optical signal into electrical signal. The electrical signal is again processed and given to the transducer to get the original information.

2. Give the block diagram of a digital optical communication system and explain the function of each block?

Ans: Digital Fiber optical Communication System:



2.1 Block Diagram Of Digital Optical fiber Optic Link

Figure shows a schematic of a typical digital optic fiber link. The input is given as digital signal from the information source and it is encoded for optical transmission in the encoder. The encoder, encodes or modulates the digital signal as in the case of simple communication system where we are using a message signal in which the signal is in analog form, but here the signal is in digital form which is encoded i.e., modulated in the encoder. The laser drive circuit directly modulates the intensity of semiconductor laser with the encoded digital signal. Hence a digital optical signal is launched into the optical fiber cable. At the receiver we have to decode the digital optical signal for which we are using another Avalanche Photo Diode (APD) as detector. The avalanche photo diode detector is followed by a front-end amplifier and equalizer or filter to provide gain as well as linear signal processing and noise bandwidth reductions. Then the signal is passed through the decoder to get original digital information which is transmitted

3. Distinguish between optical fiber communication system and conventional communication system? And List out the advantageous and disadvantage of optical fiber communication?

Ans:

Optical Fiber Communication System	**Conventional Communication System**
1. Requires a bandwidth of 10^{13} to 10^{16} Hz.	1.Requires a bandwidth of 500 MHz
2 .Light weight.	2. Heavier in weight.
3. Immune to R.F. interference.	3. Needs external shielding.
4. Electrical isolation.	4. Exhibits earthing problems.
5. Low loss of about **0**.2 dB/km.	5. Loss of about 10dB/km.
6. Secure signal propagation.	6. Signal can be tapped easily.

7.Due to increased bandwidth higher data	7. Low data rates compared to optical fiber.

Advantageous Of Optical Fibers Communication:

1. Information bandwidth is more.
2. Optical fibers are small in size and light weighted.
3. Optical fibers are more immune to ambient electrical noise, electromagnetic interference.
4. Cross talk and internal noise are eliminated in optical fibers.
5. There is no risk of short circuit in optical fibers.
6. Optical fibers can be used for wide range of temperature.
7. A single fiber can be used to send many signals of different wavelengths using Wavelengths Division Multiplexing (WDM).
8. Optical fibers are generally glass which is made up of sand and hence they are cheaper than copper cables.
9. Optical fibers are having less transmission loss and hence less number of repeaters are used.
10. Optical fibers are more reliable and easy to maintain.

Disadvantageous Of Optical Fibers Communication:

1. Attenuation offered by the optical fibers depends upon the material by which it is made.
2. Complex electronic circuitry is required at transmitter and receiver.
3. The coupling of optical fibers is difficult.
4. Skilled labors are required to maintain the optical fiber communication.
5. Separated power supply is required for electronic repeaters at different stages.

4. Compare the advantages and disadvantages of guided optical communication lines with that of microwave systems?

Ans:

Optical Communication System	Microwave System
1. Uses glass optical fibers or plastic optical fibers for transmission.	1. Uses co-axial cable or microwave waveguides for transmission.
2. Low weight, hence large transmission distance or same weight of microwave link.	2. Heavier than optical fibers.
3. Large bandwidth of range 10^{13} tol0^{16}Hz.	3. Bandwidth is lesser in the range of 10^{8} to 10^{10}Hz.

4. Electrically isolated, hence no shielding is required.	4. Prone to electrical disturbances and hence, shielding for reducing RE interference.
5. Low loss of 0.2dB/km.	5. A considerable loss of 5 dB/km.
6. Large spacing between repeaters about 1 in 300 km.	6. Spacing distance between repeaters is less, is suitable only for short distance if waveguides are used.
7. Because large bandwidth, higher data rate of the order of terabits per second.	7. Data rates of mega bits per second can be obtained.
8. Message security is obtained.	8. Signal can be tapped easily.
9. No cross talk, hence many fiber communication channels can be packed inside one single cable.	9. If shielding is not done properly, cross talk is introduced.

Disadvantages

Optical Communication System	Microwave System
1. Expensive transmitter and receiver.	1. Simple and less expensive transmitter and receiver.
2. Difficult coupling.	2. Easy coupling.
3. Power transmission depends upon the quantum efficiency of light source (LED or LASER).	3. Output power is directly coupled to the transmission line.
4. Unable to excite the terminal device directly.	4. Able to operate the terminal device directly.

5. Write in detail about ray optics?

Ans: Ray optics is used for representing the mechanism of a ray which propagates through an ideal multimode step index optical waveguide. There are two types of rays, the skew rays and meridional rays which propagate through a fiber.

The path of meridional can be tracked very easily as they are confined to a single plane. Meridional are described in two classes. They are,

(i) Bound rays

(ii) Unbound rays.

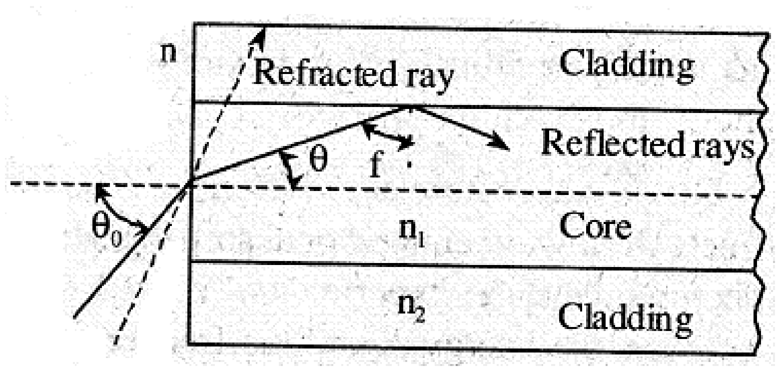
Bound rays are those rays which are trapped in a core and they move along the fiber whereas unbound rays are those rays which get refracted out of the fiber.

Skew rays are those rays which follow helical path but they are not confined to a single plane.

We know that skew rays are not confined to a particular plane so they cannot be tracked easily.

Analyzing the meridional rays is sufficient for the purpose of result, rather than skew rays, because skew rays lead to greater power loss.

Now coming to ray theory, we need to consider meridional rays. Representation of meridional rays is given below.



5.1 Ray Representation of Meridional Rays in an ideal step index optical wave guide.

From the medium of refractive index 'n' which is at an angle 'θ_0'with respect to fiber axis, the light enters the fiber core. If the light strikes at such an angle then it gets reflected internally and the meridional ray moves in a zig zag path along the fiber core, passing through the axis of the guide. Now by using Snell's law the minimum angle 'ϕmin' supports total internal reflection for meridional ray is given by

If the ray strikes the core-cladding interface at an angle less than ϕmin then they get refracted out of the core and they will be lost from the cladding.

By applying Snell's law to the air-fiber face boundaries, we get θ_{max}

$n \sin \theta_{max} = n_1 \sin \theta_c = (n_1^2 - n_2^2)^{1/2}$

Where $\theta_c = \Pi/2 - \theta_0$ (From the figure)

So, the rays whose entrance angle 'θ_0' is less than the 'θ_{max}' will be reflected back in to core cladding interface.

Numerical aperture for a step index is given by the formula

$N.A = n \sin \theta_{max}$

$= (n_1^2 - n_2^2)^{1/2} = n_1\sqrt{2\,\Delta}$

6. An optical fiber has a NA of 0.20 and a cladding refractive index of 1.59 Determine

(i) The acceptance angle for the fiber in water which has a refractive index of 1.33

(ii) Critical angle at the core cladding interface.

Ans:

Given

NA = 0.2

n_1 =1.59

(i) The acceptance by the water is

Refractive index for water n =1.33

NA = n sin θ_a

$\theta_a = \sin^{-1}$ (NA/n) = $\sin^{-1}$(0.2/1.59) = 8.64^0

Therefore the acceptance angle is = 8.64^0

(ii)Critical angle at core cladding interface is

We know that,

NA= $(n_1^2 - n_2^2)^{1/2}$

We known that

NA = 0.2 and n_1 =1.59

$0.2 = (1.59^2 - n_2^2)^{1/2}$

$0.447 = (1.59^2 - n_2^2)$

n_2^2=2.081

n_2 = 1.44

$\theta_c = n \sin^{-1}(n_2/ n_1) = 1.33 \sin^{-1}(1.44/ 1.59) = 86.33^0$

7. Define an optical fiber. Explain in detail different types of optical fibers giving neat sketches?

Ans: A dielectric waveguide that operates at optical frequencies is known as optical fiber. It is generally available in cylindrical form.

Fiber Types

There are two fiber types

(i) Step index fiber

(ii) Graded index fiber.

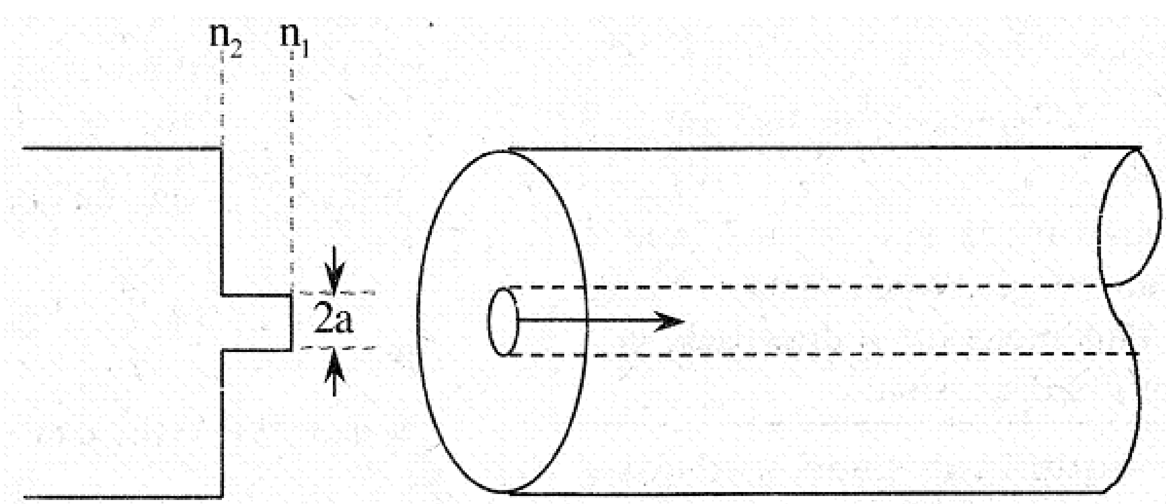
(i) Step Index Fiber

Step index fiber is further divided in two types,

1. Single mode step index fiber

2. Multi mode step index fiber.

Single mode step index fiber is shown below,

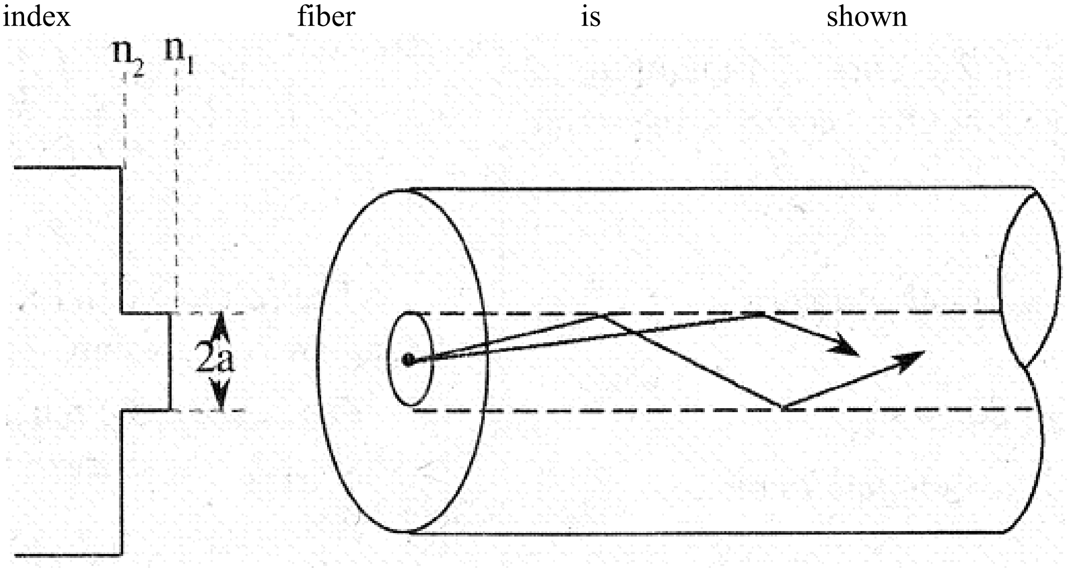


7.1 Single Mode Step index Fiber

The typical dimension of core is 8 to 12 µm and cladding is 125 µm.

In step index fiber, the refractive index of the core is uniform and at the cladding boundary, it undergoes a step change.

In single mode step index fiber, there is only one mode of propagation. The multimode step index fiber is shown below,



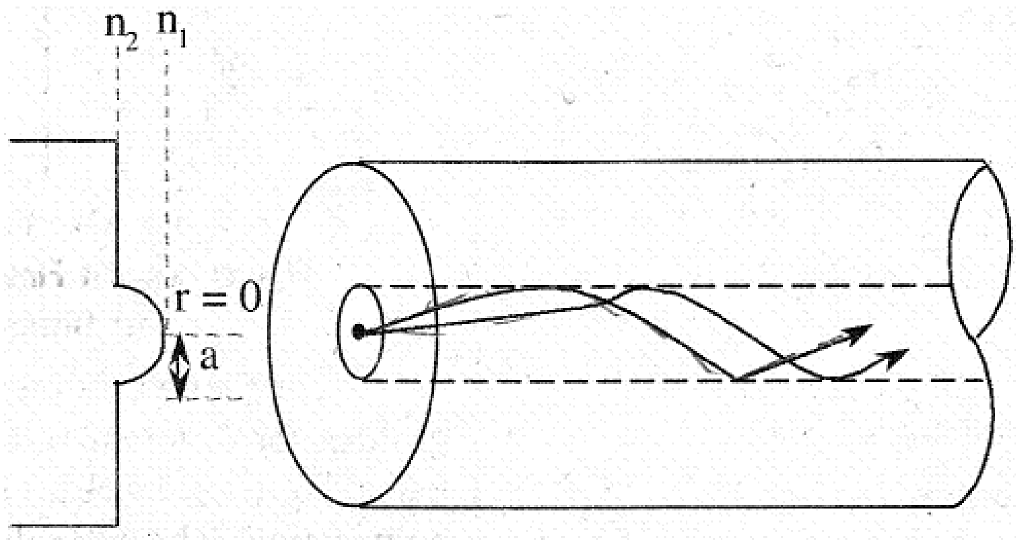
7.2 Multi Mode step index fiber

In multimode step index fiber, hundreds of modes are present.

The typical dimension of core is 50 to 200 µm and cladding is 125 to 400 µm. Multimode fiber has several advantages, which includes, the transmitting the light directly in to fiber using LED.

Graded Index Fiber

Graded index fiber also contains single mode and multimode. The multimode graded index fiber is shown below,



7.3 Multi Mode Graded Index Fiber

In graded index fiber, the refractive index of the core is made to vary as a function of radial distance taken from the center of the fiber.

The dimension of its core is 50 to 100 µm and cladding is 125 to 140 µm.

In both cases (step index and graded index) multimode has several advantages. When compared with single mode, however, multimode has a drawback, that is, it suffers from inter model dispersion.

8. Compare the fiber structure and numerical aperture in step index and graded index fiber?

Ans:

Fiber structure:

A fiber consists of a single solid dielectric cylinder of radius V and refractive index n{ called as core of the fiber. The core is surrounded by a solid dielectric cladding with refractive index n2 that is less than n_1 The variation of material composition of core give rise to the two commonly used fiber types (i). If the refractive index of the core is uniform throughout and undergoes an abrupt change at the cladding boundary then such a fiber is called step index fiber (ii). If the core refractive index gradually varies along the radial distance from the centre of the fiber and becomes equal to the refractive index of the cladding at the boundary, then such a fiber is called graded-index fiber.

The step-index and graded-index fibers are further divided into single mode and multimode fibers The core radius in single mode fiber is very small hence only one mode of propagation is possible and laser diode is-required to launch the light beam m the fiber. Multimode fibers has larger core radius and hence supports many hundreds of modes of propagation. Due to larger core radius a CED is sufficient to launch the light beam into fiber making it less expensive than single mode fibers. But multi mode fibers suffer from inter model dispersion.

Numerical Aperture:

There are two types of rays that can propagate through fiber, they are meridional rays and skew rays. Meridional *rays* are confined to the meridian planes of fiber which contains core axis whereas skew rays are not confined to a single plane, but instead tend to follow a helical path along the fiber. To obtain the general condition of ray propagation through fiber meridional rays are considered.

(i) Step-index Fiber

Consider a step index fiber with core radius 'a' and refractive index n_1 and with a cladding of refractive index n_2 which is lower than n_1, then we can say

$$n_2 = n_1(1-\Delta)$$

Where 'A' is called the core-cladding index difference, when a light ray enters the fiber core from a medium of refractive index at an angle θ and strikes the core-cladding boundary at a normal angle Φ such that it results m total internal reflection. Then the angle Φ should not be less Φ_{min} than given by Snell's law,

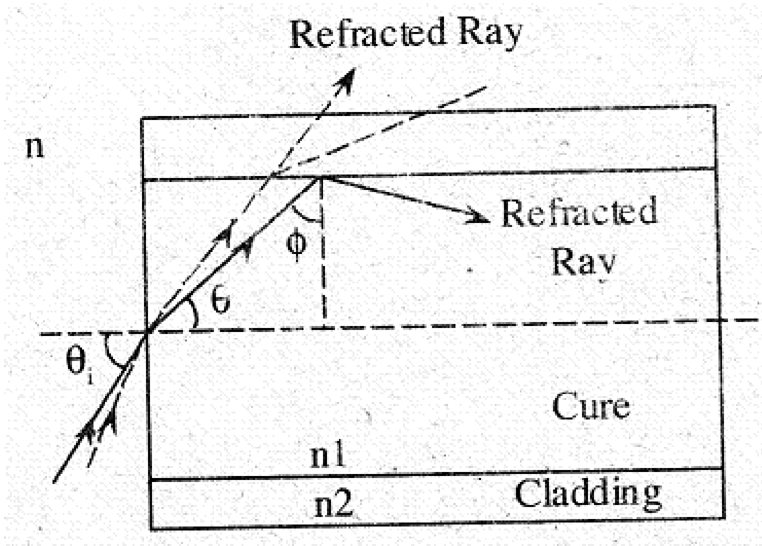
$$\text{Sin } \Phi_{min} = n_2 / n_1$$

By applying Snell's law to air-fiber face boundary and using equation (1) it can be related to maximum entrance angle Φ_{max} given by,

$$n \sin \Phi_{imax} = n_1 \sin \Phi_c = \sqrt{(\mathbf{n_1^2 - n_2^2})} \text{ where } \Phi_c = \Pi/2 - \Phi$$

Therefore for step index the numerical aperture is given by,

$$NA = n \sin \Phi_{imax} = \sqrt{(\mathbf{n_1^2 - n_2^2})} = n_1 \sqrt{\mathbf{2}\ \Delta}$$



8.1 Step Index Fiber

(ii) Graded-Index Fiber

For a graded index fiber the refractive index difference △ is given by,

$$\Delta = \frac{\mathbf{n_1^2 - n_2^2}}{2\mathbf{n_1^2}} = \frac{n_2 - n_1}{n_1}$$

△ is approximately equal in both step-index fiber and graded index fiber.

Numerical aperture of graded index fiber is a function of position across, the case end face, whereas, NA is step-index is constant across the core. The light incident on the fiber core at position *r* will propagate through fiber only if it is within the local numerical aperture of the fiber at that position given by,

$$\text{NA(r)} = \left\{(n^2(r) - n_1^2)^{\frac{1}{2}}\right.$$

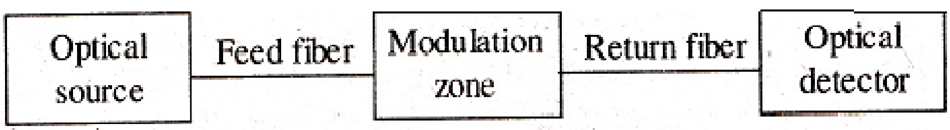
Where, r is the radial distance from the centered the fiber V is the radius of core a is dimensionless parameter defining the shape of index profile and NA(0) is axial numerical aperture defined as,

$$\text{NA}(0) = (\text{n}^2(0) - \text{n}_2^2)^{1/2}$$

from centre to core-cladding boundary i.e., at centre NA is equal to that of step index and gradually reduces until it becomes zero at the core-cladding boundary.

9. Give three applications of optical fiber in instrumentation and explain them with necessary figure?

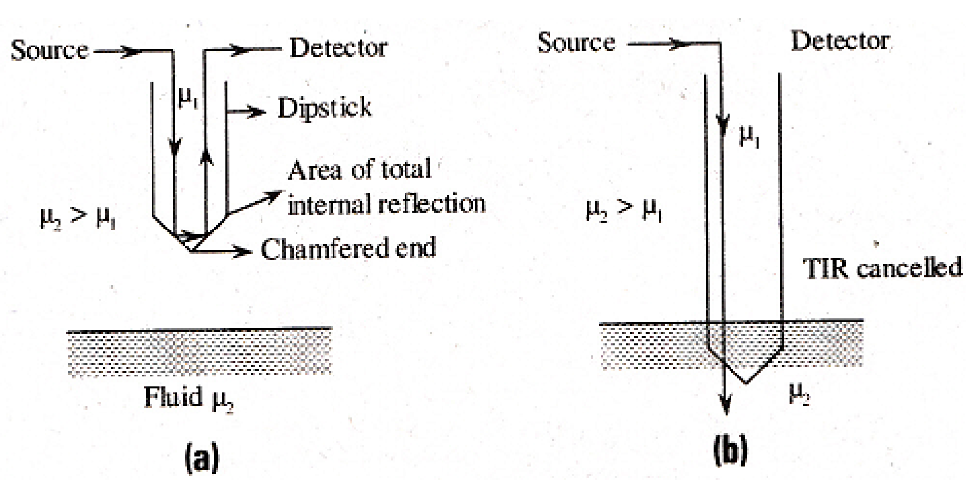
Ans: Optical fibers are used as sensing-elements(sensors) in instrumentation applications. Since, they have the advantage of efficient telemetry and control communication they can also work in electrically harsh environments and are free from EM interference.
The optical fiber sensor system modulates a light beam either directly or indirectly by the parameters like temperature, pressure, displacement, strain etc. Modulation is done in the modulation zone of the optical fiber sensor system as shown in figure 9.1. The light beam is modulated in any of its parameters, which includes optical intensity, phase, polarization, wavelength and spectral distribution.



9.1 Basic Optiacl Fiber Sensor System

(i) Optical Fluid Level Detector

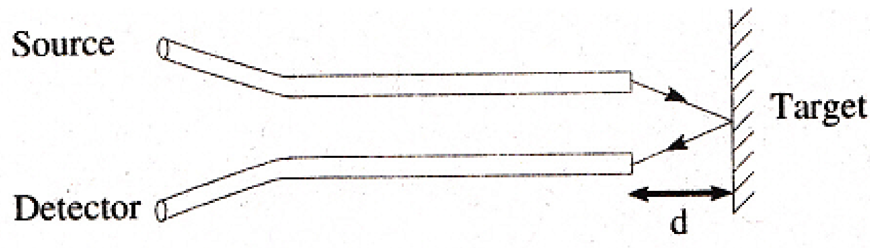
Figure (9.2) shows the functioning of a simple optical fluid level detector. It contains an optical source, optical detector, optical dipstick and fluid. The optical dipstick is formed by glass (with refractive index μ_1) and fluid has a refractive index μ2. The refractive index of fluid is greater than refractive index of optical dipstick ($\mu_1 > \mu_2$). When the fluid does not touch the optical dipstick the light beam from optical source passes through the glass as shown in figure 9.2(a). When the fluid touches the chamfered end, total internal reflection halts and the light is transmitted into the fluid as shown in figure 9.2(b). As a result, an indication of the fluid level is acquired at the optical detector.



9.2 Optical Fluid Level Detector

(ii) Optical Displacement Detector

This is also implemented as extrinsic device. The received light ray is modulated by intensity. The reflected light from the target is received and the intensity of received light is proportional to distance/displacement of target. Thus, displacement is measured.

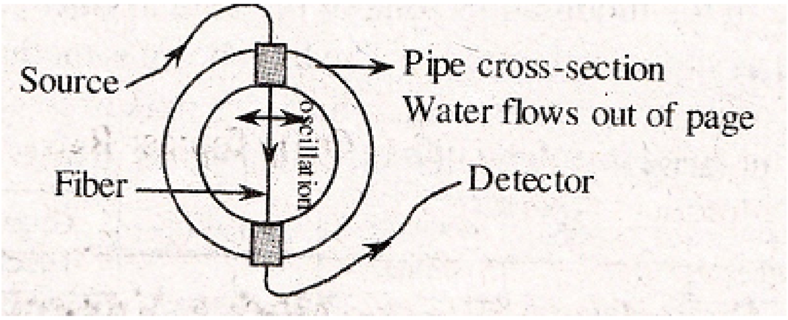


9.3 Optical Displacement Detector

(iii) Optical Fiber Flow Meter

This is implemented as intrinsic device, where the flow rate itself causes the modulation of light.

A multimode fiber is placed along the cross-section of flow pipe, so that liquid flow pass the fiber. Presence of fiber causes turbulence in the liquid flow as a result fiber oscillates and frequency of oscillation is directly proportional to flow rate. This oscillation gives a modulated light at the receiver. Thus, flow rate is measured



9.4 Optical Fiber Flow Meter

10. A single Mode step index fiber has a core diameter of 7µm and core refractive index of 1.49.Estimate the shortest wavelength of light which allows single mode operation when the refractive index difference for the fiber is 1% ?

Ans;

Given that

For a single mode step index fiber,

$n_1 = 1.49$

$2a = 7\mu m \Rightarrow a = 3.5\ \mu m$

$\Delta = 0.01$

We have

$n_2 = n_1 (1-\Delta)$

$= 1.49(1-0.01)$

$= 1.4751$

Therefore $n_2 = 1.48$

The condition to be fulfilled for a fiber to be single mode is that normalized frequency, $V \leq 2.4$

i.e., By using this relation,

$$V = \frac{2\Pi a}{\lambda}(n_1^2 - n_2^2)^{\frac{1}{2}}$$

$$2.4 = \frac{2\Pi a}{\lambda}(n_1^2 - n_2^2)^{\frac{1}{2}}$$

$$2.4 = \frac{2\Pi * 3.5}{\lambda}(1.49^2 - 1.48^2)^{\frac{1}{2}}$$

$\lambda = 1.58\mu m.$