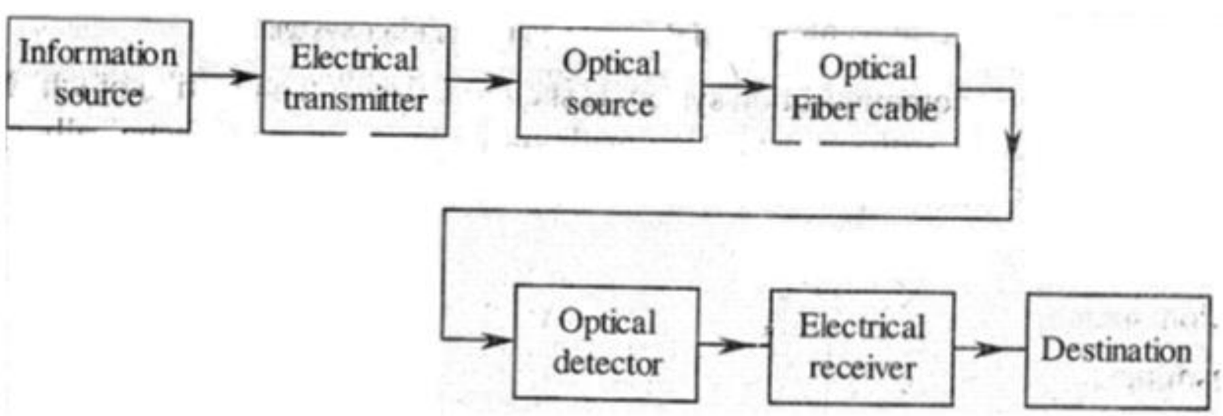
UNIT-I

OBJECTIVES:
Overview of optical fiber communication - Historical development, the general system, advantages of optical fiber communications. Optical fiber wave guides- Introduction, Ray theory transmission, Total Internal Reflection, Acceptance angle, Numerical Aperture, Skew rays, Cylindrical fibers- Modes, V-number, Mode coupling, Step Index fibers, Graded Index fibers, Single mode fibers- Cut off wavelength, Mode Field Diameter, Effective Refractive Index, Related problems.

OPTICAL FIBER COMMUNICATION SYSTEM:

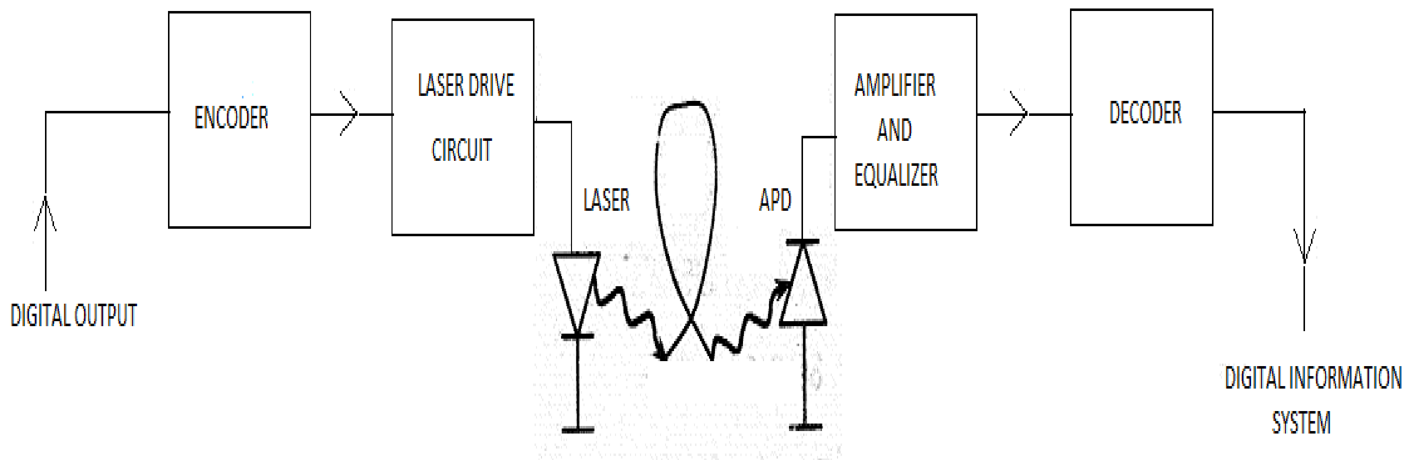
The below figure shows a block schematic of the different elements in an optical fiber communication system. The carrier is modulated using analog information signal. The variation of light emitting from the optical source is a continuous signal. The information source provides an electrical signal to 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.



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.

DIGITAL FIBER OPTICAL COMMUNICATION SYSTEM:



BLOCK DIAGRAM OF DIGITAL OPTICAL FIBER COMMUNICATION

The above 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.

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 is used.
10. Optical fibers are more reliable and easy to maintain.

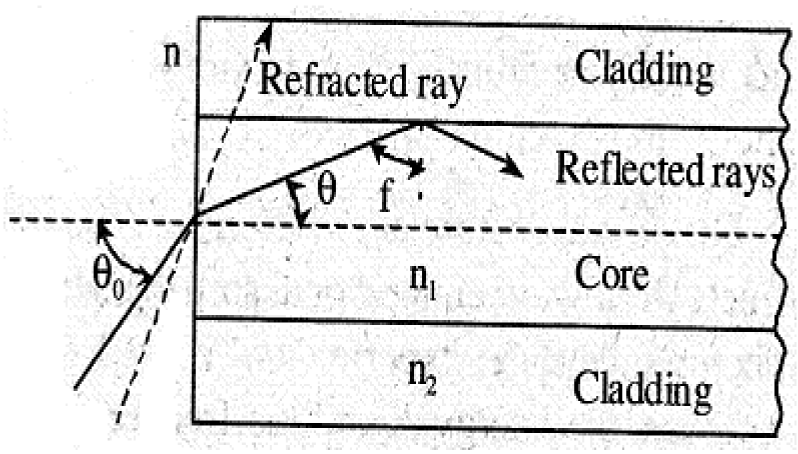
DISADVANTAGEOUS OF OPTICAL FIBERS COMMUNICATION:

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.

RAY REPRESENTATION:

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.



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 '$\theta 0$'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} .

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

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

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

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

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

PROBLEMS

***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.

Solution:

Given

NA = 0.2

$n_1 = 1.59$

(i) The acceptance by the water is

Refractive index for water n =1.33

$NA = n \sin \theta_a$

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

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 $n_1 = 1.59$

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

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

$n_2^2 = 2.081$

$n_2 = 1.44$

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

Different Types of Optical Fibers:

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

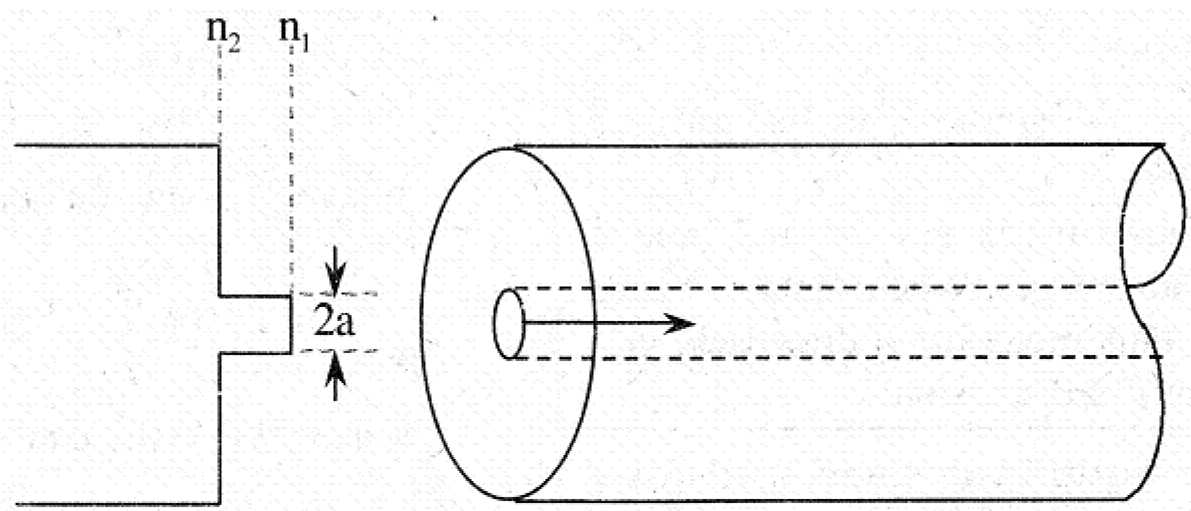
(ii) Graded index fiber.

(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.

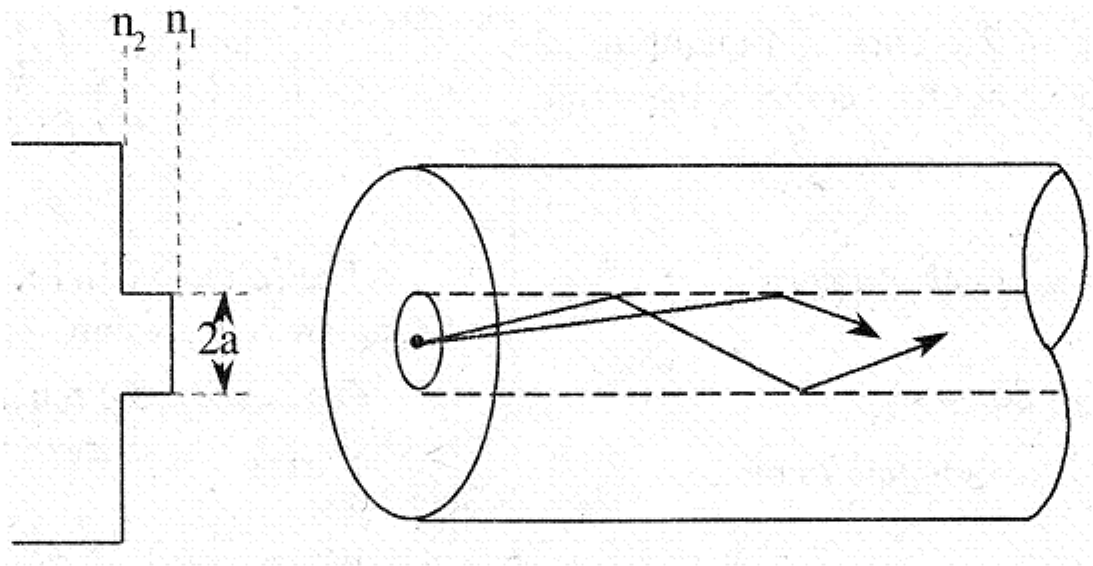
Single mode step index fiber is shown below,



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,

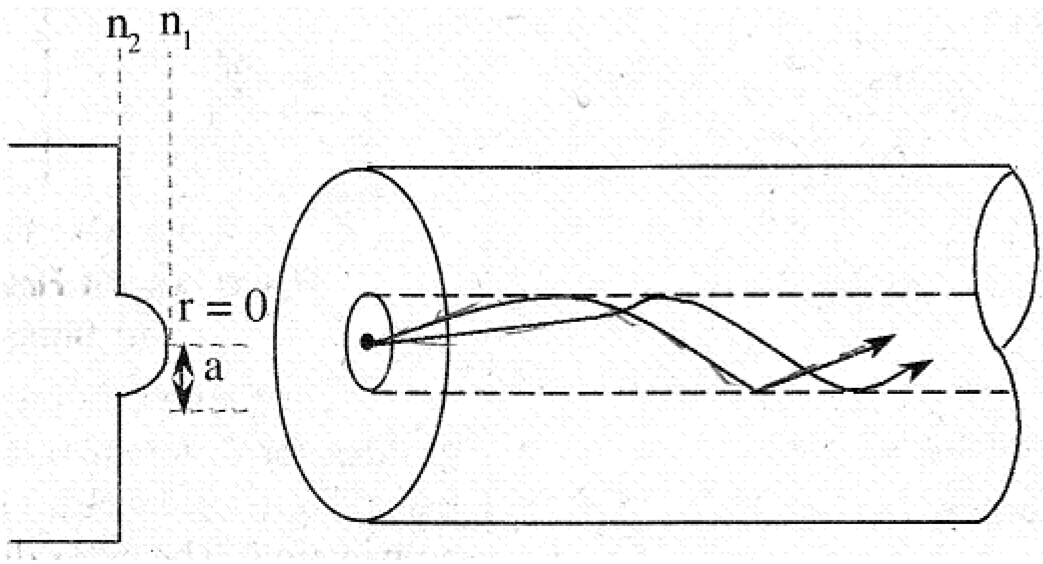


Multi Mode step index fiber

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,



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.

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 n1 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 n1 and with a cladding of refractive index n2 which is lower than n1, then we can say

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

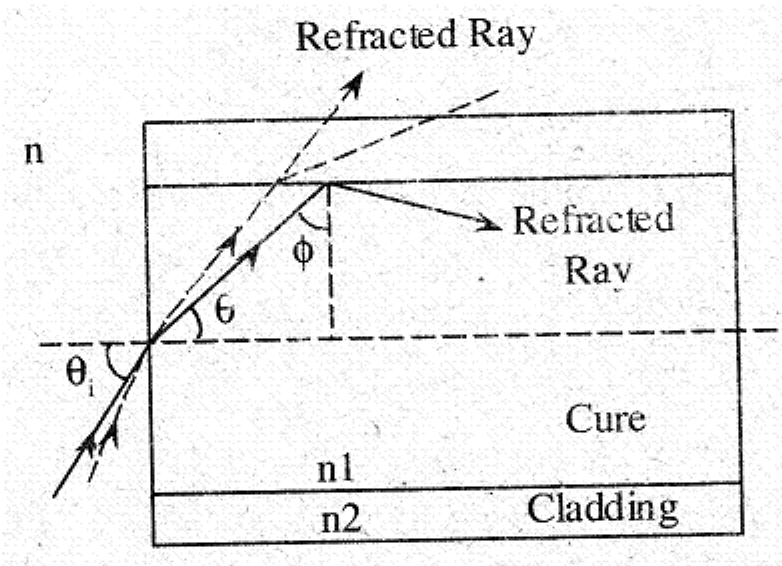
Where 'A' is called the core-cladding index difference, when a light ray enters the fiber core from a medium of refractive index at an angle θ and strikes the core-cladding boundary at a normal angle Φ such that it results m total internal reflection. Then the angle Φ should not be less Φmin than given by Snell's law, Sin Φmin = n2 / n1

By applying Snell's law to air-fiber face boundary and using equation it can be related to maximum entrance angle Φmax given by,

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

Therefore for step index the numerical aperture is given by,

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



Step Index Fiber

(ii) Graded-Index Fiber:

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

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

Δ 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,

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

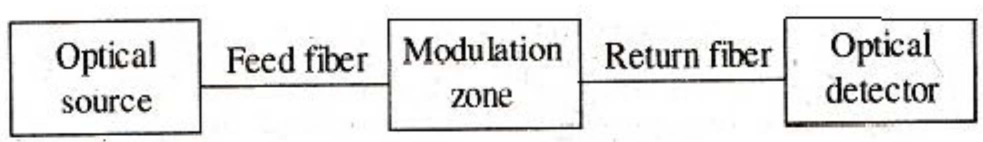
Where, r is the radial distance from the centered the fiber V is the radius of core a is dimensionless parameter defining the shape of index profile and NA (0) is axial numerical aperture defined as,

$$\text{NA}(0) = (n^2(0) - n_2^2)^{1/2}$$

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.

APPLICATIONS OF OPTICAL FIBER:

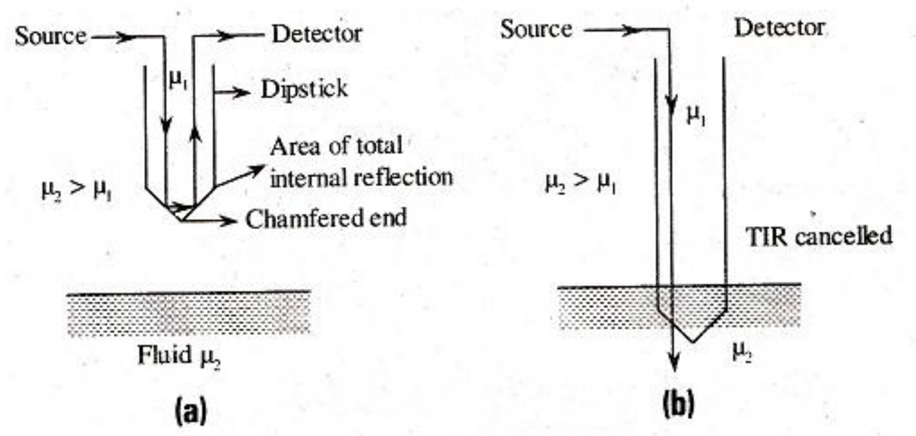
Optical fibers are used as sensing-elements (sensors) in instrumentation applications. Since, they have the advantage of efficient telemetry and control communication they can also work in electrically harsh environments and are free from EM interference. The optical fiber sensor system modulates a light 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 the below figure the light beam is modulated in any of its parameters, which includes optical intensity, phase, polarization, wavelength and spectral distribution.



Basic Optiacl Fiber Sensor System

OPTICAL FLUID LEVEL DETECTOR:

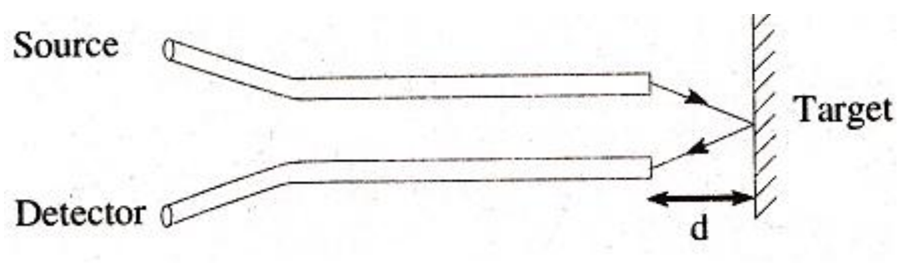
The below figure shows the functioning of a simple optical fluid level detector. It contains an optical source, optical detector, optical dipstick and fluid. The optical dipstick is formed by glass (with refractive index μ1) and fluid has a refractive index μ2. The refractive index of fluid is greater than refractive index of optical dipstick (μ1 > μ2). When the fluid does not touch the optical dipstick the light beam from optical source passes through the glass as shown in the below figure(a) .When the fluid touches the chamfered end, total internal reflection halts and the light is transmitted into the fluid as shown in the below figure(b). As a result, an indication of the fluid level is acquired at the optical detector.



Optical Fluid Level Detector

OPTICAL DISPLACEMENT DETECTOR:

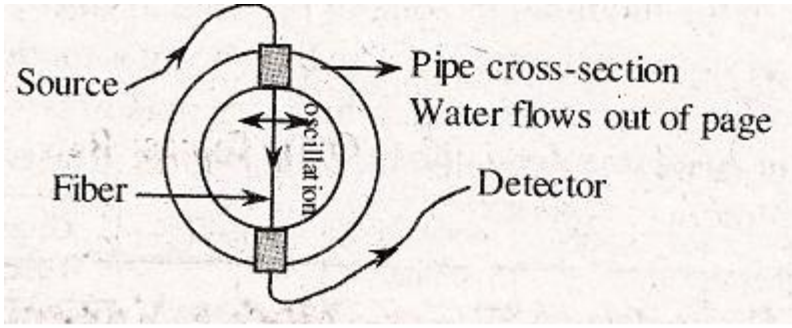
This is also implemented as extrinsic device. The received light ray is modulated by intensity. The reflected light from the target is received and the intensity of received light is proportional to distance/displacement of target. Thus, displacement is measured.



Optical Displacement Detector

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 passes 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



Optical Fiber Flow Meter

PROBLEMS

***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%**
?

Solution:

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, $V \le 2.4$

i.e., By using this relation,

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

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

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

$\lambda = 1.58\mu m.$