FIBER OPTICS
EXPERIMENT NO.6

Experiment No.6 (a)

Objective/Aim: To determine the numerical aperture of a given multimode optical fiber.

Apparatus used: Laser diode with power supply, microscope objective (MO), V grooves with fiber holder, detector, multimode plastic optical fiber, micro ammeter, post mount stand and screen.

Formulae used:

The numerical aperture (NA) of an optical fiber is defined as,
$NA = \sin \Theta$,

where Θ is the acceptance angle and can be written as,
$\Theta = \tan^{-1} (D/2d)$.

Here,
D = Diameter of the spot produced on the screen, and
d = Distance between the output end of the fiber and screen.
Thus,

$$\boxed{NA = \sin \Theta = \sin [\tan^{-1} (D/2d)]}$$

Theory:

Propagation of light:

An optical fiber consists of a core that is surrounded by a cladding as shown schematically in figure 1.

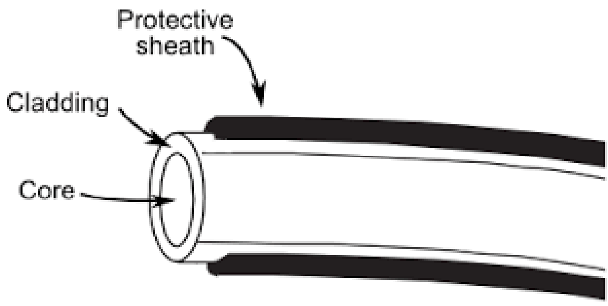


Figure 1: Core and cladding with refractive index n_1 and n_2, respectively. Here $n_1 > n_2$ to ensure total internal reflection.

The core is used for the transmission of optical signals while the cladding is used for confining those signals within the core. In order to guide the optical signals with in the core of the fiber, the refractive index of the core (n_1) is deliberately kept higher than that of the cladding (n_2).

In order to understand the transmission process in more detail, consider figure 2.

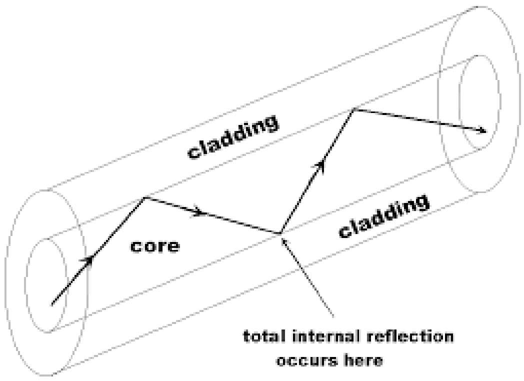
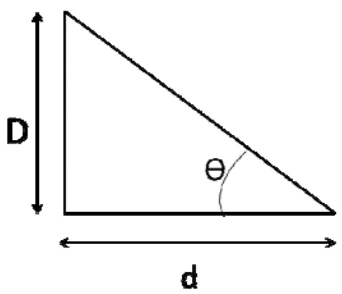


Figure 2. Propagation of light in an optical fiber.

The light ray enters the core and then reaches the core cladding boundary where it intersects the boundary at an incident angle greater than critical angle (Note that we are talking about the incident angle at the core-cladding boundary and this is different from the air to fiber incident angle) . This will lead to **total internal reflection (TIR)** and the ray will be reflected back into the core. This process of TIR will be repeated till the end of the fiber.

Before we discuss further, please note that the acceptance angle of an optical fiber is the maximum angle of a ray (against the fiber axis) hitting the fiber core which allows the incident light to be guided by the core (through repeated TIR). The sine of that acceptable angle is called the numerical aperture, and it is essentially determined by the refractive index contrast between core and cladding of the fiber, assuming that the incident beam comes from air or vacuum.
Thus,
Acceptance angle (Θ) = $\sin^{-1}$ (NA)



Here
D = Diameter of the spot produced on the screen
d = Distance between the output end of the fiber and screen
Θ = Acceptance angle

It can be seen from above figure that acceptance angle of an optical fiber is given as,
$\Theta = \tan^{-1} (D/2d)$

Numerical aperture (NA)

It indicates the maximum angle at which a particular fiber can accept the light that will be transmitted through it. The higher the NA of optical fiber, the larger will be the cone of incident light that can be coupled into the core of the optical fiber as shown in figure 3.

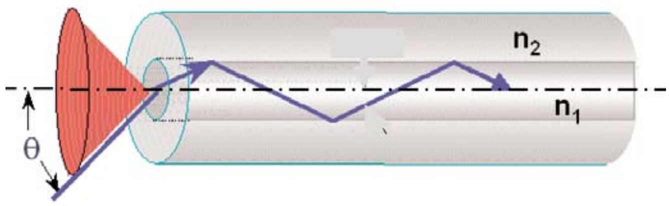


Figure 3. Numerical aperture defines the maximum angle at which light can be launched into a fiber

Multimode fibers have a large NA. This is a major advantage of the multimode fiber as it enables them to be used with relatively low-cost optical components and light sources. In contrast, single-mode fibers, which have small NA, typically use narrow width lasers as power sources and carry only one mode of propagation.

Multimode fiber

Those fibers that carry more than one mode of propagation of light are known as multimode fibers as shown in Figure 4.

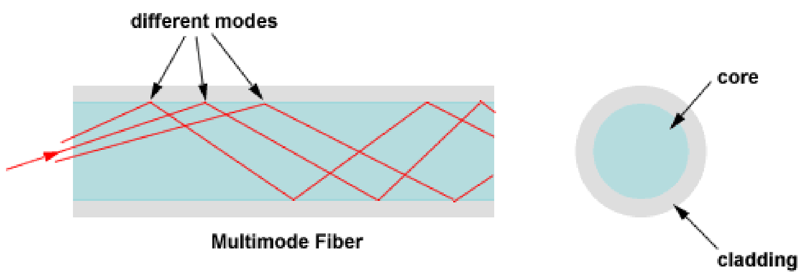


Figure 4: Illustration of multimode fiber carrying different modes of propagation of light

From the above figure, it can be seen that there are several modes of propagation of light that enter the fiber with different angles to the fiber axis. Rays that enter with a shallower angle travel by a more direct path and arrive sooner than those entering at steeper angles (which reflect many more times off the core/cladding boundaries as they travel the length of the fiber) and this arrival of different modes of the light at different times are called dispersion of modes or pulse dispersion.

Step index and Graded index multimode fibers

There are two types of multimode fibers. One is step index multimode fiber and the other is graded index multimode fiber. The difference between these two multimode fibers can be understood on the basis of their refractive index profiles as shown in Figure 5.

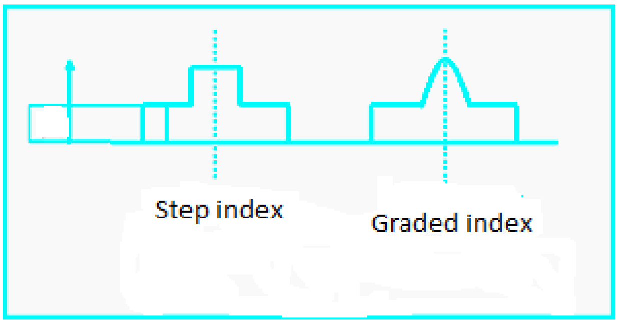


Figure 5: The refractive index profile difference between Step index and Graded index multimode fiber

Due to the difference between refractive index profiles, the propagation of light will also take place in different ways as shown in Figure 6.

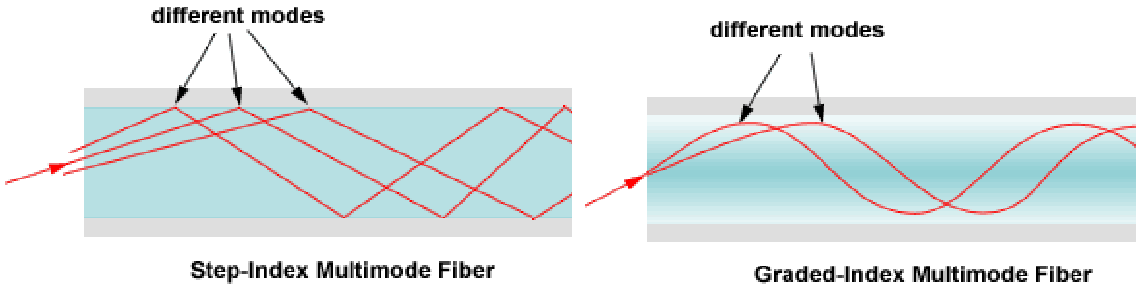


Figure 6: Light transmission in a Step index multimode fiber and a graded index multimode fiber

Step index multimode fibers are mostly used for imaging and illumination while Graded index multimode fibers are used for data communications and networks carrying signals up to moderate distances, typically not more than a couple of kilometers.

<u>Experimental Setup</u>:

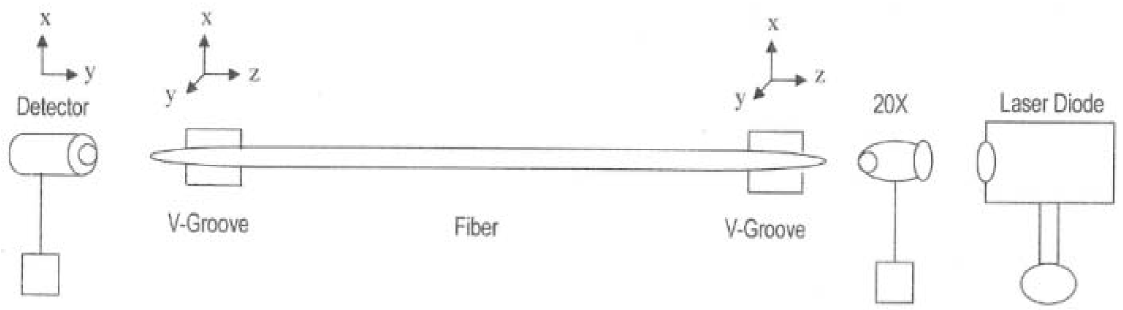


Figure 7: Experimental set up for the calculation of numerical aperture

Procedure:

This is a direct and quick estimation of numerical aperture.

1. Draw the several concentric circles on a simple graph paper and paste it on one side of the screen by cello tape. (You can also measure the diameters directly from the graph paper, but you need to be very careful in recognizing the diameter in that case).
2. Replace the detector by screen placed normal to the fiber axis keeping the set-up same as in above figure. The screen is positioned in the far field in such a way that a line extending the axis of the fiber on the screen would have passed through the center of these circles drawn on the graph paper.
3. Adjust the fiber end which is mounted on the XYZ stake towards or away from the screen so that the emerging light spot fill completely one of the circles.
4. Note this diameter let us call it D_1, which is measured accurately
5. Repeat the experiment for other values of d (the distance between screen and the tip of the fiber) and calculate the corresponding diameters D_2, D_3, etc.
6. Calculate NA for different values of d and then calculate the mean value of NA.

Observations:

Least count (L.C.) of the scale used for measuring d = 0.5/100 mm = 0.005 mm

S. No.	Distance between the screen and the tip of the fiber (d) in mm	Diameter of the circle(D) in mm
1.		
2.		
3.		

Calculations:

$NA = \sin \Theta = \sin [\tan^{-1} (D/2d)]$

Results:

1. The numerical aperture of the given multimode fiber measured experimentally is ………..
2. The numerical aperture of the given multimode fiber, as measured by the manufacturer is …….

Experiment no.6 (b)

Object: To measure the power loss at a splice between two multimode fibers and to study the variation of splice loss with Longitudinal and Transverse misalignments of the given fibers.

Apparatus used: Transverse and Longitudinal misalignment on post with all items as given in experiment no.6 (a)

Formulae used:

Power loss in decibels = $20 \log_{10} (I_0/I)$ dB

Where

I_0 = Maximum current at the detector end

I = Current obtained at the detector end for the subsequent misalignments

Theory:

The power loss is due to the attenuation of transmitting signal or light pulse. During transit, light pulse loses some of its photons thus reduces the amplitude. Attenuation for a fiber is usually specified in decibels per kilometer.

$$\text{Power loss in decibels} = 10 \log_{10} (P_0/P) \text{ dB}$$

(Where P_0 is the maximum power at the detector end when there is no misalignment between the fibers and P is the reduced power when the misalignment occurs)

As power is directly proportional to the square of the current, hence power loss can also be written as,

$$\text{Power loss in decibels} = 20 \log_{10} (I_0/I) \text{ dB}$$

Experimental Setup:

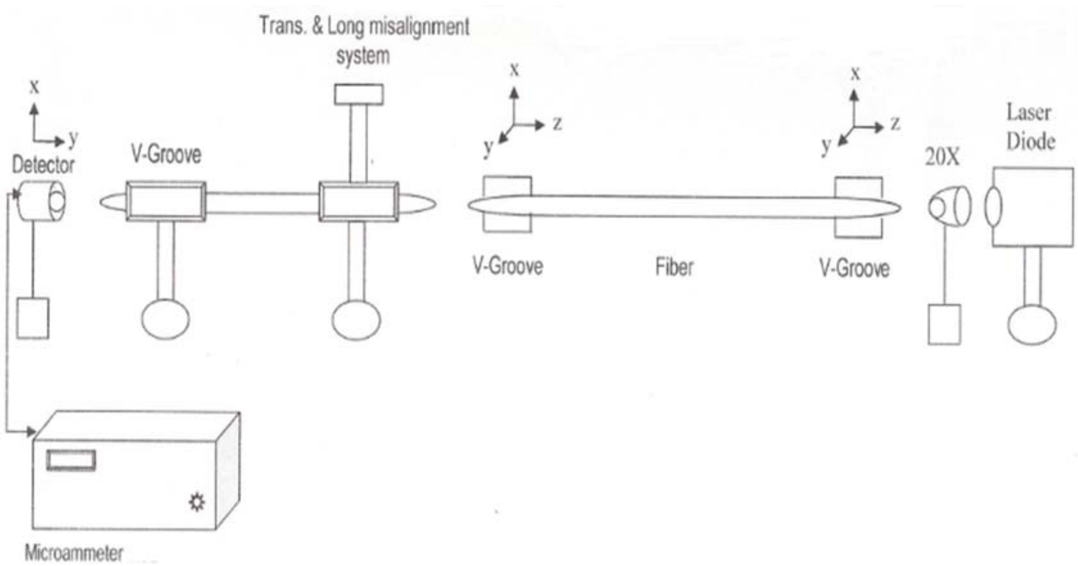


Figure 8: Experimental set up for the calculation of power loss at a splice between two multimode fibers

Procedure:

1. Set the experiment schematically as shown in Figure 8 as follows.
2. Take a second piece of multimode fiber, referred as receiving fiber.
3. Mount one end of the receiving fiber in the V groove on Transverse and Longitudinal misalignment system and the other end of the fiber is coupled to a detector through the V groove mounted on the other post.
4. Align output end of the transmitting fiber mounted on X-Y-Z stack to the one end of the receiving fiber mounted on Trans and Long misalignment system with the help of X-Y-Z stack. And align other end of the receiving fiber to the detector with the help of X-Z stack to get maximum current in the micro-ammeter. Note the maximum current as I_0.

5. **For Longitudinal misalignment**

Now the X-Y-Z stack on which the output end of the transmitting fiber is mounted is manipulated to induce longitudinal offset.

(a) Move away the output end of the transmitting fiber by X-Y-Z stack into the field of view of the receiving fiber gradually to couple light from the transmitting fiber and micro ammeter through the detector.

(b) The fiber could be moved in step of 1 mm of the graduated scale of X-Y-Z stack and measure the corresponding current in the micro ammeter for each setting of the fiber end. Record these readings in table as given below. Continue the measurement till the output current becomes zero.

(c) Calculate the power loss as dB= 20 $\log_{10}(I_0/I)$

(d) Plot a graph for Longitudinal misalignment (mm) versus Power loss (dB).

<u>Observations for longitudinal misalignment</u>:

Current at the minimum longitudinal misalignment I_0 = ……..μA

S. No.	Micrometer reading in mm (in Horizontal direction)	Corresponding detector current(I) in μA	Coupling loss in dB
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			

6. **For the transverse misalignment**

   Now the Trans and Long misalignment on which the input end of the receiving fiber is mounted is manipulated to induce Transverse offset. In actual practice for measuring transverse offset loss, it is recommended that the receiving fiber be moved away from the transmitting fiber (in transverse direction) till the micro ammeter reading reduced almost zero (i.e. register only ambient light).

(a) Again align the system to get the maximum current in micro ammeter I_0.

(b) Move the receiving input fiber's end gradually into the field of view of the transmitting fiber to couple light from the transmitting fiber to the micro ammeter through the detector.

(c) The fiber could be moved in step of 0.25 mm of the graduated scale of micrometer fitted with the Trans and Long misalignment system and measure the corresponding current in the micro ammeter for each setting of the fiber end. Record these readings in table as given below. Continue the measurement till the output current becomes zero.

(d) Calculate the power loss as dB= 20 log (I_0/I)

(e) Plot a graph for Transverse misalignment (mm) versus Power loss (dB).

<u>Observations for transverse misalignment</u>:

Current at the minimum transverse misalignment I_0 = ……..µA

S. No.	Micrometer reading in mm (in Vertical direction)	Corresponding detector current in (I) µA	Coupling loss in dB
1.			
2.			
3.			
4.			
5.			

Results:

1. Graph shows the splice loss with Longitudinal and Transverse offset in a given fiber.
2. These measurements would reveal that longitudinal offset is more tolerable off-set in terms of achieving a low loss fiber splice.

Questions for viva:

1. What are the values of optical frequencies?
2. What is the typical core diameter for single mode and multimode step index fibers?
3. What is the wavelength of laser diode used in this experiment?
4. Distinguish between critical and acceptance angles.
5. Explain the phenomenon of total internal reflection.
6. Explain numerical aperture.
7. What is pulse dispersion?
8. Give some applications of Graded index multimode fibers.
9. List some significant losses in optical fibers.
10. Discuss the uses of optical fibers.
11. What is a wave guide? Do you think optical fiber is a wave guide? If yes, how TIR helps you to construct this wave guide.
12. Can you tell us for which distances these types of optical fibers are used for communication: (a) Single mode step index, (b) multi-mode step index, (c) multi-mode graded index plastic optical fiber.
13. Why don’t we use air as cladding?

References:

1. Optics by Ajoy Ghatak, Tata Mcgraw Hill.
2. An introduction to fiber optics by Ghatak and Thyagrajan, Cambridge University Press.
3. Optics and photonics: An introduction by Smith and King, Wiley-Blackwell.