Introduction

Bending Losses

Optical fibers exhibit additional propagation losses when they are bent. The bending loss can be classified in terms of micro-bending or macro-bending.

The micro bending losses are repetitive small scale fluctuations in the radius of curvature of the fiber axis. They are caused either by non-uniformities in the manufacturing of the fiber or by non-uniform lateral pressures created during the cabling of the fiber as seen in Fig 1. An increase in attenuation results from micro bending because the fiber curvature causes repetitive coupling of energy between the guided modes and the leaky or non-guided modes in the fiber. Micro bending losses can be minimized by placing a compressible jacket over the fiber. When external forces are applied to this configuration, the jacket will be deformed but the fiber will tend to stay relatively straight.

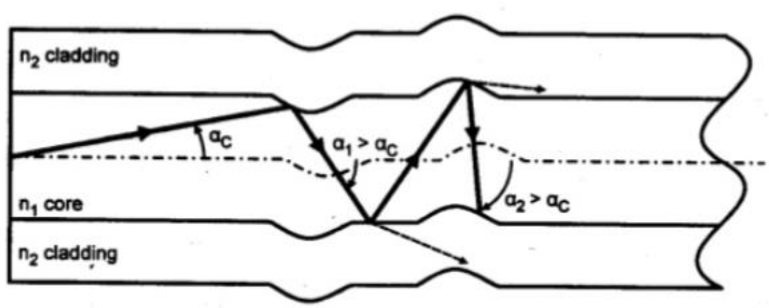


Fig 1. Losses due to micro bending.

Another form of bending loss in optical fiber results is the macro-bending loss. The macro-bending loss occurs when the fiber bend radius is large compared to the fiber diameter. When an optical fiber is subjected to a gentle bend over a large arch, light energy in the fiber starts to leak out of the optical fiber.

When a ray of light inside a straight fiber core strikes the outside wall of the fiber at an angle of incidence (to the fiber axis) less than the critical angle θc. it will be totally internally reflected and contribute to the propagation of light along the fiber as seen in Fig 2.

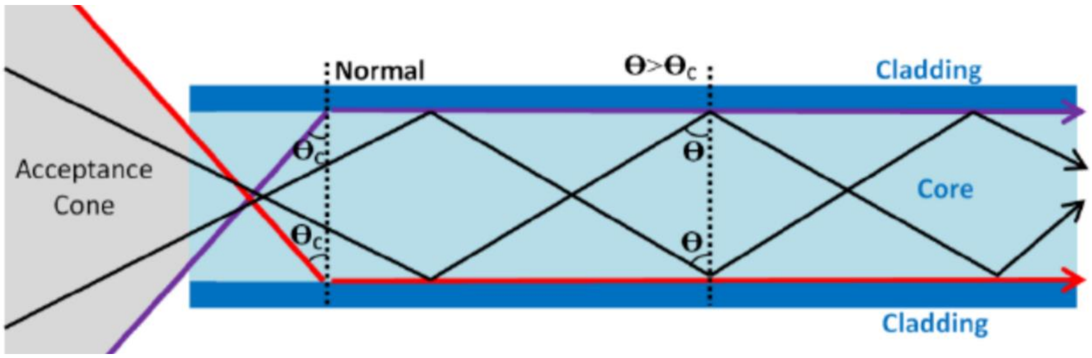
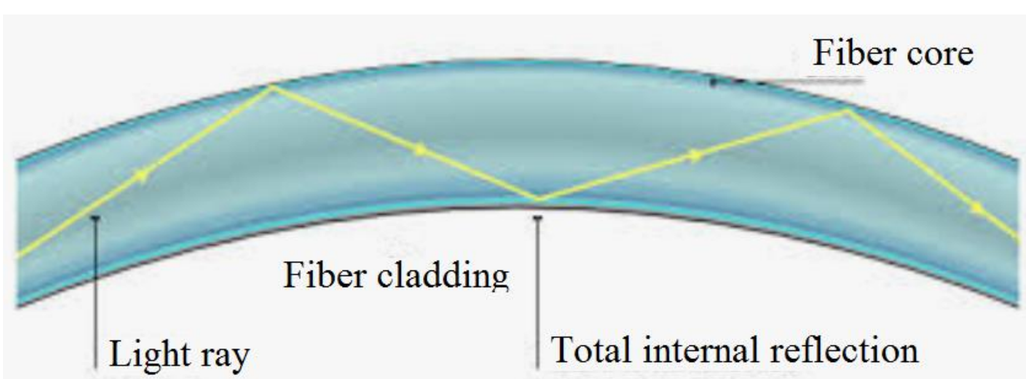
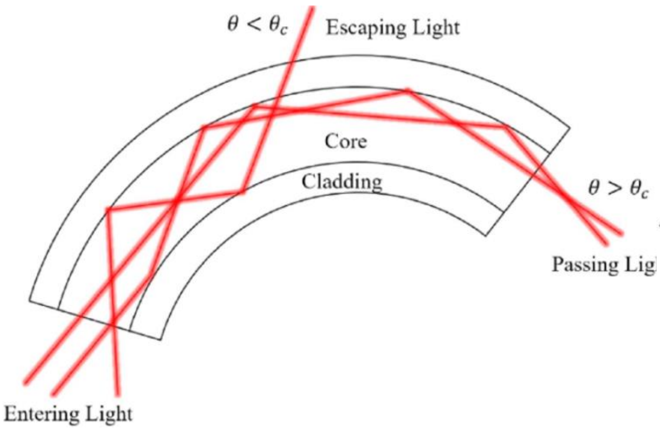


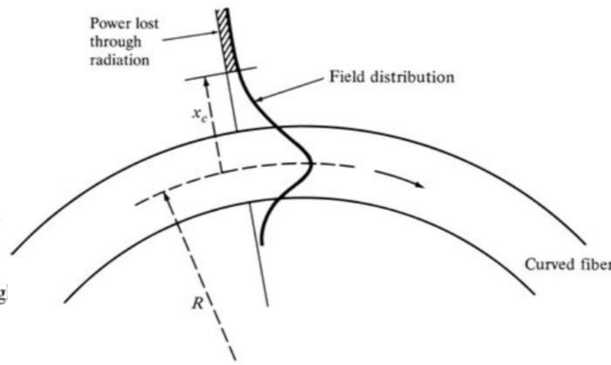
Fig 2. Total internal reflection

Macro bending losses occur when the fiber cable is subjected to a significant amount of bending above a critical value of curvature as seen in Fig 3. For slight bends, the loss is extremely small and is not observed. However, as the radius of curvature decreases, the loss increases exponentially until at a certain critical radius of curvature loss becomes observable. Typically, these losses rise very quickly once a certain critical bend radius is reached. If the bend radius is made a bit smaller once this threshold point has been reached, the losses suddenly become extremely large. It is known that any bound core mode has an evanescent field tail in the cladding which decays exponentially as a function of distance from the core. Since this field tail moves along with the field in the core, part of the energy of a propagating mode travels in the fiber cladding.



(a)





(b) (c)

Fig 3. (a) A gentle bend fiber, no loss, (b) Geometrical illustration of macro-bend loss, (c) The radiation filed distribution in the macro bend fiber.

Numerical Aperture

Optical fiber is made up of two different layers of plastic or glass. In this lab, we are using plastic. The two layers have different indices of refraction. The inner layer, the core, always has a higher index of refraction than the outer layer, the cladding. Thus, the total internal reflection is guaranteed for the light traveling in the fiber.

On the other hand, the angle of incidence of the light at the entrance of the fiber is important. On the other hand, the angle of incidence of the beam at the entrance of the fiber is important. The angle of incidence or in other words, acceptance cone angle is related to Numerical Aperture (NA).

$$NA = \sin(\theta_o)$$

MEASUREMENT OF BENDING LOSSES AND NUMERICAL APERTURE IN OPTICAL FIBER

Numerical aperture is a basic descriptive characteristic of a specific fiber. The numerical aperture depends on the refractive indices n_1 and n_2 of the core and the cladding. Using Snell's law, the acceptance cone angle within which light will be accepted into and guided through fiber is,

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

$$\theta_o = \mathit{arg}\ \sin\left[(n_1^2 - n_2^2)^{1/2}\right]$$

For example, consider an optical fiber with the refractive indices of the core and cladding equal to 1.45 and 1.43, respectively. If you calculate the acceptance cone angle, you can see that it equals to 13.89°.

Bending Loss Measurements

Procedure:

1. Remove the **fiber-optic monitor transmitter and receiver** from your monitor training set. Set the transmitter to FIXED TONE (400 Hz), and turn the analogue gain of the receiver to a minimum.

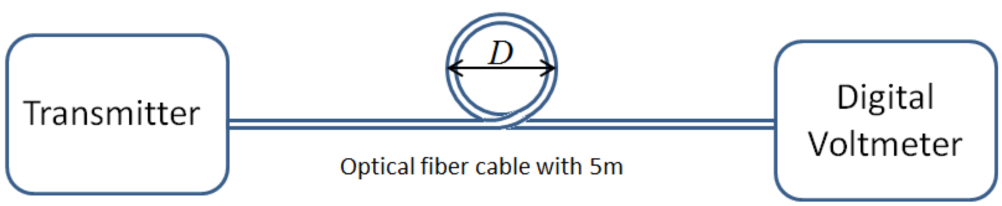
2. Connect an a.c. voltmeter which can measure a.c. values down to, or below, a tenth of a millivolt, to the ANALOGUE OUTPUT socket of the receiver. A Digital Volt Meter (DVM) with a 200mV a.c. scale is ideal for this purpose. (The Mean Power Monitor socket should be left unconnected for best measurement accuracy).

3. Connect a long length (5 meter) of optical cable between the transmitter and receiver. The layout of this cable should be like a straight line. Its ends should be clean in order to achieve a good measurement accuracy.

4. To ensure there is no optical overload at the receiver, reduce the transmitted output level (turn the OUTPUT POWER control anti-clockwise) until the voltmeter reading is just below 1.00V (RMS or sine—RMS--equivalent). Then take the voltmeter reading (= VREF). For optimum accuracy, it is best to take this initial reading after the units have been switched on for five minutes or more, so that equilibrium conditions are reached.

Check the electrical noise level by switching off the transmitter and noting the voltmeter reading (=VA). VA will normally be zero if the DVM specified in Step 2 is used.

5. Now create a ring with only one turn in the middle of the optical fiber cable as seen in the figure. Make sure that the diameter of the ring is 10 cm. You can use a tape to fix the ring. Be careful not to bend excessively when forming the ring. Otherwise, do not forget that the cable may break.



6. Now take the voltmeter reading (=V0) and note it.

7. Then, carefully reduce the diameter of the ring to 8 cm without changing any settings. Again, take the voltmeter reading (=V0) for 8cm and note it.

8. Repeat the procedure in step 7 for 6 cm and 4 cm diameter.

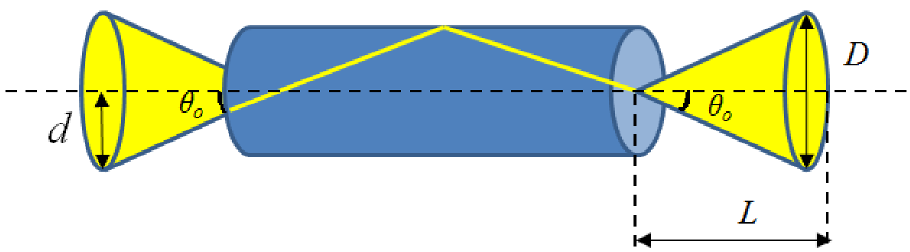
9. Sketch the output voltage V0 versus the diameter of the ring for a range of 4-10 cm.

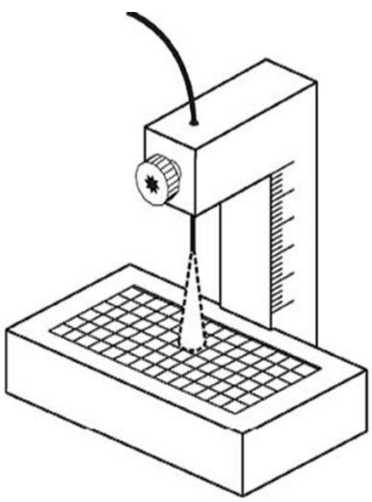
10. Write down your comments about how the loss of macro bending changes with the diameter.

Measurement of the Numerical Aperture

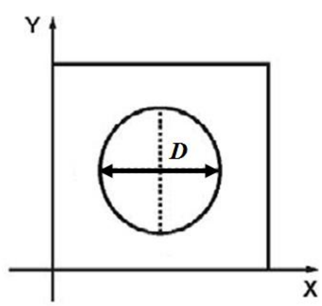
The objective of this experiment is to measure the numerical aperture (NA) of optical fiber. In this experiment, a very simple method for measuring the numerical aperture (NA) is proposed.

NA can be calculated by investigating the light leaving the fiber





$$Sin(\theta_0) = D/2L$$



Procedure:

1. We should use visible laser light for this experiment. But we will use visible led light for security. So, remove the **fiber-optic transmitter** from your **fiber optic educator training** set. Switch on the transmitter and switch over to analogue. (The transmitter's output indicator and high radiance red diode).

2. Place a white millimetric paper on a flat surface. Place the fiber with 0.5 m length in the vertical position on the paper as shown in the figure. Connect the other end of the fiber to transmitter.

3. Set the transmitter output power to maximum level. Reduce the distance between the fiber and the paper to try to obtain a light spot in the form of a circle.

4. Find the most appropriate position where the edges of the light spot begin to sharpen by adjusting the distance between the fiber and the paper. If you reduce the distance further, the center of the spot is too bright. In this case you must increase the distance.

5. Calculate the NA and the angle of acceptance of the fiber using the formula.

6. Write down your comments about measurement results.