NAVAL POSTGRADUATE SCHOOL
Monterey, California

Fiber Optics Experiment 1
FIBER PARAMETERS

Purpose: In this lab experiment we will measure three important fiber parameters: tensile strength, numerical aperture, and fiber loss.

Equipment:
Micrometer
Ruler (metric)
Graph paper
Protective eye glasses
Uniphase HeNe laser (mounted on optical bench holder)
Optical mount for fiber and connector
No-Nik wire stripper (127 Am-Silver handles)
Cleaning alcohol and Kimwipes
Length of fiber with connectors
HP E6000A Optical Time Domain Reflectometer (OTDR)
Set of three optical fiber reels connected/spliced together

Procedure:

A. **Tensile strength:** Glass fibers are theoretically stronger than strands of steel of the same diameter. In practice, the strength of glass fibers is about 1/100 of the predicted tensile strength. This is primarily due to surface flaws on the glass produced during manufacturing. Tiny flaws on the surface of the glass will propagate into the glass under stress, resulting in the fracture of the fiber. The presence of moisture in the flaw will serve to accelerate the crack-growing process and the fracture of the fiber.

   A simple method of measuring the tensile strength of uncabled glass fiber is as follows:

   1. If you are not already wearing glasses, put on the protective glasses provided. (The fiber is brittle and small pieces may fly out unexpectedly during handling and cutting.)

   2. Cut approximately 20 cm of fiber off of the reel in the lab. Using the No-Nik fiber strippers provided, carefully strip the clear plastic jacket off the length of fiber. (Hints: Strip only in the direction of the arrow inscribed on the strippers. Clean out the jaws of the stripper after each piece. Remove only 1 inch at a time to avoid breaking the fiber. The bare fiber is relatively fragile, so handle carefully. The ends of the fiber can be jagged and can easily cut skin. Be careful of the fiber ends.)

3. Tie a simple overhand knot in the fiber and lay it on the 10x10 per cm graph paper.

4. Carefully tighten the knot, noting the diameter of the loop as it becomes smaller. When the fiber breaks, record the loop diameter. (Note: once the fiber breaks, there is no going back to check your values!)

5. Using the micrometer, measure the outside diameter of your glass fiber. (It should be 0.125 mm.) You may now remove your safety glasses.

6. The tensile strength (breaking force per unit area) can be approximated by the equation:

$$S = \frac{E D_{\text{fiber}}}{D_{\text{loop}}}$$

   where $E = 1.7\times10^{7}$ psi is the Young's modulus of glass, D_{fiber} is the fiber diameter, and D_{loop} is the measured diameter of the fiber loop at breaking. (Note: $1\ \text{psi} = 6.895\times10^{3}\ \text{nt/m}^{2}$)

   Calculate the tensile strength of your fiber in both psi and nt/m^2.

7. Calculate the breaking strength of your fiber (in newtons *and* in pounds) using the result of Steps 5 and 6. This is the predicted tensile force that will break the fiber.

8. Comment on the possible methods that could be used to increase tensile strength. What are the tradeoffs?

B. **Numerical aperture:** As discussed in class, the numerical aperture of a fiber is a useful parameter in fiber-optic link design and applications. It allows the engineer to determine the characteristics of the light that a fiber can capture and that exits the fiber, and determines the coupling efficiencies between fiber, source, detector, and connectors. We define $\text{NA} = \sin\theta_{\max}$ where $\theta_{\max}$ is the maximum angle of the cone of light acceptance of a fiber.

We will use a simple arrangement to estimate the NA of a fiber. For accurate measurement of NA, all modes should be equally excited and cladding modes should be eliminated. We will pass our fiber through a serpentine path to stimulate uniform distribution of power among the modes.

Our simplified method for estimating the NA is as follows:

1. You should find the equipment set up as shown in Figure 1. (Note: Aligning the focused laser spot into the fiber is tedious. Please do not disturb the setup by

jarring it. Also use the power supply switch on the side of the table to turn the laser off and on; do *not* use the switch on the back end of the laser!)

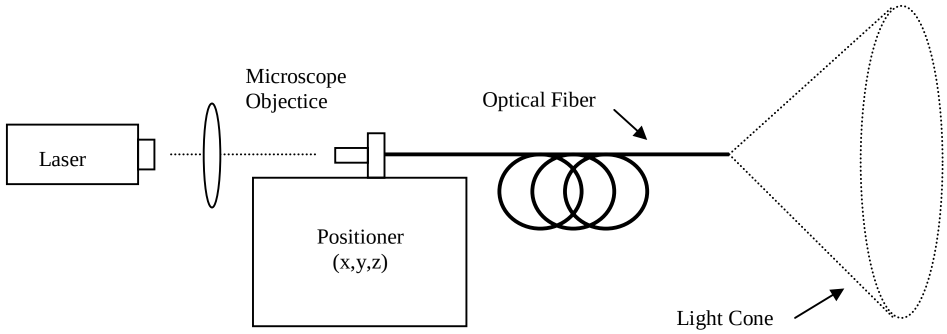

Figure 1: Equipment Setup for Numerical Aperture

2. Turn on the laser. (Warning! Do not stare back into the laser for a prolonged period.) The light from the fiber end should fall on the graph paper. (If the spot of light on the graph paper is not bright enough, use the x-y-z positioner to gently align the fiber core with the focused laser beam to achieve maximum brightness and uniformity. When this is observed, you are exciting all of the higher order modes of the multimode fiber. Some rings might be observed because the excitation is not uniform.)

3. Measure the diameter of the largest ring or circle of light on the paper and the fiber-paper distance. Repeat twice for differing distances from the paper.

4. Using these measurements and the definition of NA, calculate the NA of the fiber for each of your measurements and compute the average value of the NA.

C. **Fiber losses and OTDRs:** We will measure the losses of a fiber system comprised of three serially connected fibers located on reels under the table. We will use the HP E6000A Mini-OTDR. The OTDR has a high-power pulsed laser output which sends a pulse of 850 nm wavelength light down an attached fiber. By monitoring the back-scattered light (which returns to the source) as the pulse travels down the fiber with a sensitive detector, the OTDR provides a means by which losses along the length of the fiber can be determined.

The pulse energy reflected from the end of the fiber or other points of discontinuity is used to measure the length of the fiber to these locations. In the OTDR the measured reflections are plotted on the computer screen against a distance scale determined by the measured delay between the time the pulse was sent out and the time the reflections are received. This time is combined with the operator-entered refractive index of the fiber to convert the time of pulse propagation to a distance equivalent. The resulting distance and reflection intensity information is plotted on the computer screen as shown in Figure 2 .

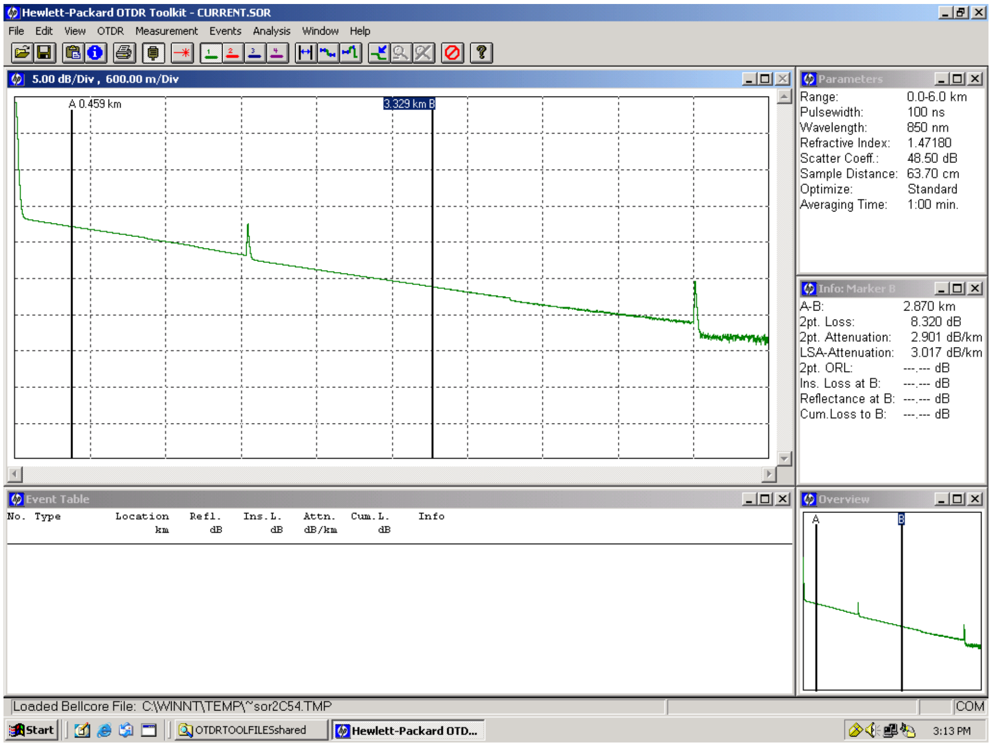

Figure 2: OTDRTOOL Application with Measurement Results

DANGER This pulsed laser source emits invisible radiation that may be dangerous to the eye. Do not turn on the OTDR without having a fiber attached to the output. Do not look directly into the output end of the fiber under test. There is no danger to the skin.

1. First, connect the optical fiber and the serial cable to the OTDR, then turn on the OTDR.

2. Log-in on the PC using your NPS network account. The OTDR used in this lab can be controlled from the manufacturer-supplied software installed on the PC. The serial-port connection between the PC and the OTDR facilitates bi-directional communication.

3. On the desktop, double click on the icon for “Shortcut to OTDRTOOL.” When the application opens, select OTDR→Connect. This will set up communication between the OTDR and the PC.

4. Select “Measurement”→”Run/Settings”. In the new window (see Figure 3), select “Recall” and choose the file “LAB1.SET” to load the required parameters for the particular fiber we are using (as shown in Fig. 3)..

5. Click Start to begin the measurement. Observe the green status bar at the bottom of the window to determine the progress of the measurement.

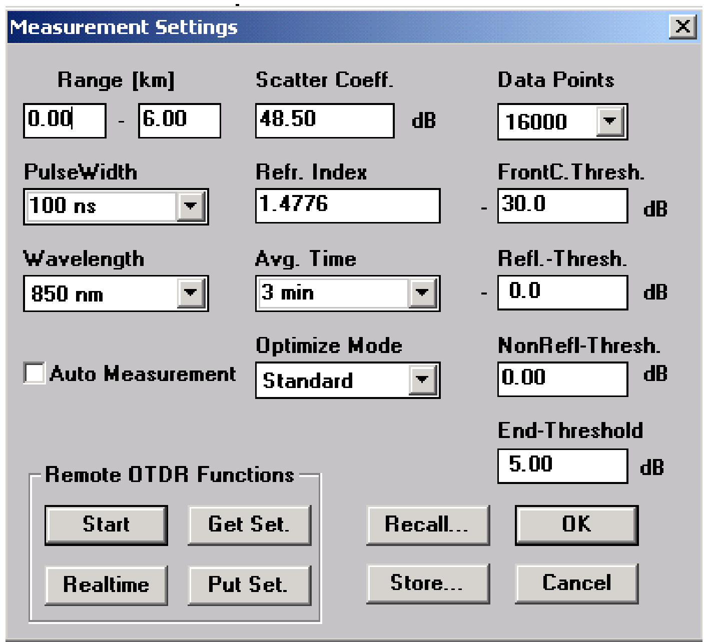

Figure 3: Measurement Settings Window

6. At the completion of the measurement, the fiber trace will appear in the application window. Using the "A" and "B" cursors, determine the following:

   - Total length of the three spools of optical fiber
   - For each segment: length, 2-pt loss, and attenuation parameter.
   - Use "Shift+PrtScreen" to capture an image of the fiber trace. Save it in your network drive for inclusion in your report.

   Note: You can click and drag the mouse over a region to zoom in the fiber trace.

D. **Coupling Loss and Splice Loss Measurement with OTDRs:** This fiber system is comprised of three lengths of optical fiber. The first piece is joined to the second through a sleeve which holds the two connectorized ends together. This method of connecting leaves the fibers with an air gap between the two sections and as such, presents a sharp discontinuity in the refractive index as the light pulse passes into the air-gap and then into the second fiber. (The air gap is too short to be resolved with out OTDRs.) These discontinuities in refractive index causes a sharp reflection back to the OTDR from that point. The heightened reflection then shows up as a spike in the OTDR backscatter trace.

   1. Use the mouse pointer to position the A and B cursors around the reflection from the connector junction. With the mouse, click and drag a

box around this region to zoom in on the connector junction. Readjust the A and B cursors as required. Obtain a measurement (in dB) for the coupling loss. Does the measurement for the "length" (distance between A-B) of the connector junction make intuitive sense to you? Include an image of the connector junction in your report.

(Note: the resolution of length along the fiber is determined by the one-half the pulse width. The optical pulse is too long to provide an accurate reading of the air gap, so you may discard the measured position values of the cursors; we are only interested in the dB loss between them.)

2. Move the cursors to the splice joining the second and third fiber segments. This connection is made using a fusion splice where the two pieces of fiber are melted together into one. This method avoids the discontinuity experienced with the air-gap and results in much less optical energy being reflected back toward the source from the joint. Using the method outlined in the above, measure and record the splice loss. Capture an image of the splice union for your report.

Report: Each group should submit a brief (but complete) report summarizing its measurements. Reports should be in word-processor form with the appropriate measurements, calculations, descriptions and electronic figures, as required to document the groups' work and findings. This report is due one week after completion of the laboratory exercise. Note that it is *not* necessary to repeat the instructions or procedure described in the experiment procedure.