NAVAL POSTGRADUATE SCHOOL
Monterey, California

EC 3550 | Fiber Optics Experiment 1 | 4/99 Po

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 holder)
Optical mount for fiber and connector
No-nik wire stripper (127 μm—Silver handles)
Cleaning alcohol and Kimwipes
Reel of white plastic-jacketed fiber
Reel of orange-jacketed optical fiber with connector on ends
Length of fiber with connectors
Antel Optronics model AOC10 Optical Time Domain Reflectometer (OTDR) (mounted in a 486 PC)
Tektronix FiberMaster OTDR
Set of three optical fiber reels 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 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 15 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. Remove only 1 cm 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.

5. Using the micrometer, measure the outside diameter of the glass fiber. You may now remove the safety glasses.

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

$$S = \frac{E \times (\text{fiber diameter})}{(\text{loop diameter at breaking})} \tag{1}$$

   where $E = 1 \times 10^7$ psi is the Young's modulus of glass. (Note: 1 psi $= 6.895 \times 10^3$ nt/m^2.)

7. Calculate the breaking strength of your fiber (in newtons *and* in pounds) using the result of steps 3 and 4. This is the 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: Numerical aperture is a useful parameter in fiber optic 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 NA $= \sin\theta_{\max}$ where $\theta_{\max}$ is the maximum angle of the cone of light acceptance of a fiber.

To accurately measure NA, a goniometer (i.e., a rotating arm) and x-y plotter should be used (but we will use a simpler arrangement). The fiber, illuminated by an LED, is fixed to the goniometer base to establish the zero position for the recorder measurements. A photodetector is fixed at the movable end of the goniometer arm and positioned so that it is looking at the output of the fiber in the center. The relative received power is measured and plotted as a function of angle over a range of $\pm 90°$. The NA can be estimated by measuring the angle at which the radiated power is 10% of the maximum radiated power.

For accurate measurement of NA, all modes should be equally excited and cladding modes should be eliminated. In a long fiber (>100 meters) the cladding modes would be removed by attenuation; in a short fiber, *mode stripping* should be used. This is accomplished by stripping a short length (a few cm) of the fiber down to the glass cladding near the transmitter end and immersing this length in an epoxy with the same index of refraction as the cladding. In this region all of the cladding modes will escape and be removed from propagation.

Our simplified method for estimating the NA is as follows:

1. Set up the equipment as shown in Figure 1.

2. Turn on the laser (Warning! Do not stare at the laser beam 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 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.

4. Using these measurements and the definition of NA, calculate the NA of the fiber.

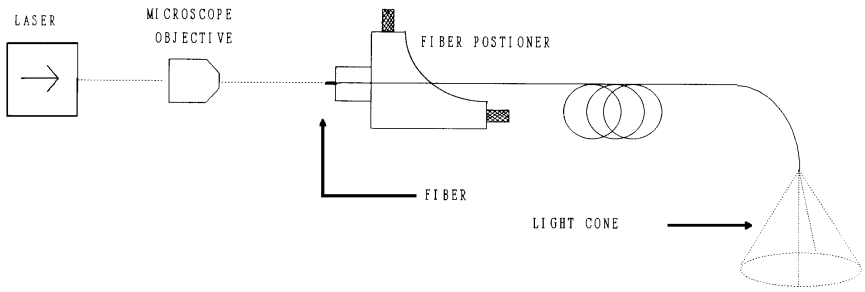

Figure 1: Experimental setup for NA measurement.

C. Fiber losses and OTDRs: We will measure the losses of a fiber system comprised of three serially connected fibers located on the reels under the OTDR computer table. Two OTDRs will be used to provide operating characteristics of the fiber at different wavelengths. The first OTDR to be used is in the form of a plug-in computer card from Antel Optronics. This OTDR has a high-power pulsed laser output which sends a pulse of 850 nm wavelength light down an attached fiber. By monitoring the backscattered 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 Antel 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.

> **DANGER!! This pulsed laser source emits invisible radiation that is 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. Connect the optical fiber to the OTDR output on the back of the PC and turn on the PC.

2. Type `cd otdr`, then `AOC10` to bring up the OTDR program. The OTDR will first go into a calibration loop during which time you will see a flashing "LASER ON" indicator. (This message is flashed any time the OTDR is putting out laser pulses to warn the operator of potentially hazardous laser radiation. When the laser is being pulsed, precautions must be taken to avoid exposure to the beam by capping the OTDR output or by having the test fiber connected to it.)

3. After OTDR calibrates itself, you are presented with a choice of fibers to test. Using the arrow keys select the fiber type "AT&T 850 multi-mode" and press enter.

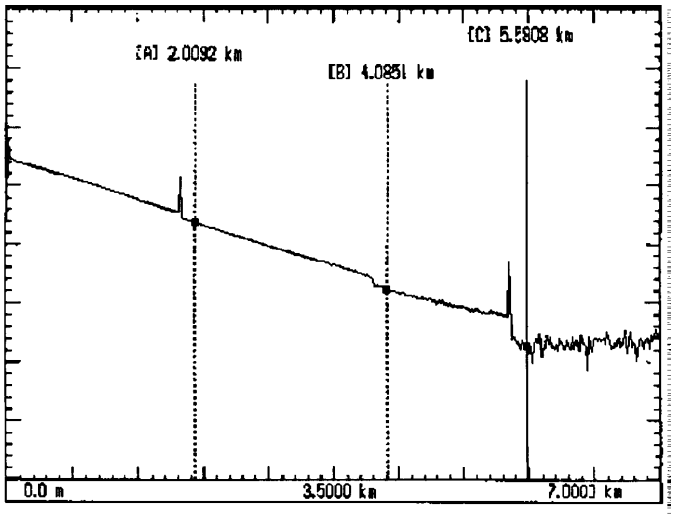

Figure 2: Sample screen display from the Antel OTDR.

4. Type `P` (for "pulse width") and use the up and down arrow keys to select "medium" pulse width.

5. Type `R` (for "range") and use the up and down arrow keys to select "10.000 km".

6. Type `V` (for vertical div.) and use the down arrow key to select "1.00 dB". Then use the up arrow key to select "5.00 dB". This will place the trace in the center of the screen.

7. Type `L` (for time limit) and use the up and down arrow keys to select "2 minutes". This is the amount of time over which the OTDR will average backscattered light measurements to filter out noisy responses.

8. Type `F3` for "average". At this time, the OTDR will start sending pulses down the fiber and measure the received backscattered light. When the two-minute sampling interval is completed, the PC will sound a chime alert.

9. Measure the lengths and fiber losses of each fiber segment.:

   (a) Use the right and left arrow keys to adjust your cursors throughout the rest of the experiment. Type `A` (for the A cursor) and move it the far left (beginning of the fiber). Then type `B` (for the B cursor) and move it to just before the reflected pulse in the fiber segment's trace. This marks the end of the segment. (This pulse is left of the "C" cursor in Fig. 2.)

   (b) Look at the "Marker A-B:" information display at the bottom of the plot. This indicator provides the distance between the points marked by the A and B cursors as well as the loss between the two points and a normalized Loss/Unit measurement. Record these measures of the link losses for each fiber segment.

D. Splice Loss Measurement: 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 in two separate sections and as such, presents a discontinuity in the refractive index as the light pulse passes out of the first fiber, through an air gap, and into the second. This break in the fiber causes an increase in the amount of light reflected back to the OTDR from that point. The heightened reflection then shows up as a spike in the OTDR backscatter trace.

1. Position the A and B cursors around the reflected pulse measurement from the first splice. Press `H` to vary the horizontal divisions on the trace and zoom in on the splice. Move the cursors as close as possible to the spike while keeping them on the flatter parts of the trace. The goal here is to measure the reflected backscatter from the fiber before and after the splice, without including any of the reflected energy from the splice itself. Once the cursors are positioned, use the "Marker A-B:" readout again to record the loss across the connector joint.

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 mechanical splice and results in much less optical energy being reflected back toward the source from the joint. Using the method outlined in the section above, measure and record the distance to this fusion splice and the splice loss.

3. Hit `ESC` until you have exited the program.

E. Comparison of Fiber Loss Characteristics at Different Wavelengths: Now you will measure the loss characteristics at a different wavelengths (1300 nm and 1550 nm) for the purposes of comparison with your previous measurement at 850 nm.

1. Connect the fiber to the second OTDR, a Tektronix TFP2 FiberMaster which operates at either 1300 or 1550 nm wavelengths (as selected by the operator). If the OTDR is not already powered up, turn it on and wait for the warm-up cycle to complete.

2. The operator keys are located along the right edge of the display. Press the following keys in order: "MASS STORAGE"; "LOAD"; "YES"; "EXIT".

3. Press the "start/stop" button on the upper right corner of the OTDR control panel. The LED to the left of the connector output will flash, indicating that the laser is on. This OTDR will plot backscattered light measurements on its integral display in a manner similar to that of the PC-based OTDR, averaging the data over a sample interval.

4. After the LED has stop flashing indicating that the sampling operation is complete, move the cursor to the reflected pulse from the end of the fiber system by rotating the control knob clockwise.

5. Press the control key labeled "two-point". The distance in the fiber between the two cursor locations, the loss between the two cursor locations, and the loss per unit distance are indicated on the display. Record these values for each of the three pieces of fiber in sample at both 1300 and 1550 nm and compare with the measurements taken from the other OTDR for 850 nm operation.

6. Use the two-point method to measure the losses at the two fiber connections at each wavelength.

Report: Each group should submit a brief (but complete) report summarizing its measurements. 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.