agating parallel to the z-axis. When a plane wave is incident on the end face of a fiber, then we can be sure that all of the light launched into the fiber has the same incident angle, $\theta$, in Fig. 1.4.

If the fiber end face is then rotated about the point O in Fig. 1.4, we can then measure the amount of light accepted by the fiber as a function of the incident angle, $\theta$.

Fig. 1.5 shows the light accepted by a Newport F-MLD fiber as a function of acceptance angle using the method just described. The point where the accepted radiation has fallen to a specified value is then used to define the maximum incident angle for the acceptance cone. The Electronic Industries Association uses the angle at which the accepted power has fallen to 5% of the peak accepted power as the definition of the experimentally determined NA. The 5% intensity points are chosen as a compromise to reduce requirements on the power level which has to be distinguished from background noise.

Note that in Fig. 1.5, the radiation levels were measured for both positive and negative rotations of the fiber and the NA was determined using one half of the full angle between the two 5%-intensity points. This eliminates any small errors resulting from not perfectly aligning $\theta = 0$ to the plane wave laser beam. The NA obtained in this test case was 0.29, which compares well with the manufacturer's specification of NA = 0.30.

1.4 REFERENCES


1.5 MEASURING NUMERICAL APERTURE

A detailed derivation of the expression for the NA of a fiber was given in Section 0.2.3. Recalling Eq. 0.9, the NA of a fiber, in the weakly-guiding approximation, was found to be

$$NA = n_{core} \sqrt{2\Delta},$$

where $n_{core}$ is the refractive index of the core of a step-index fiber or the refractive index at the center of the core of a graded-index fiber, and $\Delta$ is the fractional index difference,

$$\Delta = (n_{core} - n_{clay})/n_{core}.$$

As an example, a typical multimode communications fiber may have $\Delta \approx 0.01$, in which case the weakly-guiding approximation, which assumes $\Delta << 1$, is certainly justified. For silica-based fibers, $n_{core}$ will be approximately 1.46. Using Eq. 1.1, these values of $\Delta$ and $n_{core}$ give $NA = 0.2$. This gives a value of 11.5° for the maximum incident angle in Fig. 0.8 and a total cone angle of 23°. Values of NA range from about 0.1 for single-mode fibers to 0.2-0.3 for multimode communications fibers up to about 0.5 for large-core fibers.

The way in which light is launched into the fiber in the method used here to measure the fiber NA is shown in Fig. 1.4. The light from the laser represents a wave front propagating in the z-direction. The width of the laser beam, ~1 mm, is much larger than the diameter of the fiber core, 100 μm in this case. In the neighborhood of the fiber core, the wave front of the laser light takes on the same value at all points having the same z, so we say that we have a plane wave prop-

![Figure 1.5. Plot of the data taken in the measurement of the NA of the Newport F-MLD fiber.](image-url)
Figure 1.7. Laboratory set-up for determination of fiber NA.

1. Bolt the Model 807 Laser Mount to the Model 340C Clamp, using 1/4-20 bolts from the SK-25 Screw Kit. Place the 340C Clamp on the Model 41 Short Rod. Mount this on the LS-22 Breadboard. Place the Model U-1301P HeNe Laser into the 807 Mount. Tighten the set screw. Do not overtighten as this will damage the laser. Plug the laser power supply into a 110V wall outlet. Plug the cord from the laser head into the power supply. Note that the plug from the laser head to its power supply can only be inserted one way. The laser is turned on at the key switch on the front of the power supply. The combination of the 807 Mount and the 340C Clamp will align the laser with a line of bolt holes on the table if the Model 41 Short Rod is properly mounted on the table. Check the laser alignment with the line of bolt holes and adjust the Model 41 Short Rod, if necessary.

2. Mount the RSX-2 Rotation Stage to the breadboard so that the beam from the HeNe laser passes over the center hole of the rotation stage. The RSX-2 Rotation Stage will have to be placed at an angle to the line of bolt holes in order to bolt it into place as instructed, as shown in Fig. 1.7. Mount the MPH-1 Micro-Series Post Holder on the rotation stage and place the MSP-1 Micro-Series Post in it, as shown in Fig. 1.7.

3. Prepare a fiber segment, ~2 meters long, with a good cleave at each end face. The FPH-5 Fiber Holder comes as part of the FP-1 Fiber Positioner. Insert one end of the fiber into an FPH-5 Fiber Holder (you will need to have stripped at least 3" of the jacket from the fiber in order to do this and the following step) and place this holder into its FP-1 Fiber Posi-

Figure 1.8. Approximate measure of the NA of a fiber.

4. Extend the tip of the fiber and orient the FP-1 Positioner so that the fiber tip is at the center of rotation of the stage. This is a critical step if an accurate value for the fiber NA is to be obtained.

5. Re-check the alignment of your light-launching system by making sure that the tip of the fiber remains at the center of the laser beam as the stage is rotated. This set up achieves plane-wave launching into the end of your fiber.

6. Mount the far end of the fiber in an FPH-5 Fiber Holder (taken from an FP-1 Fiber Positioner) and the FP-1 Fiber Positioner. You can get a quick approximate measure of the fiber’s NA with a 3x5 card placed a distance, L, away from the laser in a darkened room, as shown in Fig. 1.8. Measure the width, w, on the card of the spot out of the fiber and the distance, L, from the fiber to the card. The NA of the fiber is approximately sin⁻¹(½w/L). This is a quick method which is used when only an approximate measurement of a fiber’s NA is needed.

7. Mount the detector head of the Model 815 Power Meter so that the output beam from the fiber is incident on the detector head, as shown in Fig. 1.7. Make a hood of aluminum foil to keep stray room light off of the detector. You will find this to be necessary, because the power levels obtained in plane-wave launching are low. Block the laser beam and note the power measured by the power meter. This determines the stray light seen by the meter. You will need to subtract this amount from all of your data.

8. Measure the power accepted by the fiber as a function of the incident angle of the plane-wave laser beam. Use both positive and negative rotation directions to compensate for any remaining error in laser-fiber alignment.

9. Plot the power received by the detector as a function of the sine of the acceptance angle. Semi-log paper is recommended. Measure the full width of the curve at the points where the received power is at 5% of the maximum intensity. The half-width at this intensity is the experimentally determined numerical aperture of the fiber. Compare your results with the results of Step 6 and Fig 1.5.