# 4.0 PROJECT #4: SINGLE-MODE FIBERS II

**(Est. Time Required: 2:30 / 3:30 hrs.*)**

Where an introduction to single-mode fibers was made in **Project #3**, we will now look at propagation in fibers with a small V-number. The student will start with a fiber having a V-number slightly greater than 2.405. Such a fiber is a multimode fiber, but the number of allowed modes is small enough so that they may be individually identified when the output of the fiber is examined. Following that, a highly birefringent, polarization-preserving single-mode fiber will be considered, and its beat length measured.

## 4.1 FIBERS WITH V > 2.405

In **Section 0.3.1** it was seen that if the V-number of a fiber is less than 2.405, then only a single mode may propagate in the fiber waveguide. This single mode is the $HE_{11}$ mode or, in the linearly-polarized mode theory for weakly-guiding waveguides (also discussed in **Section 0.3.1**), the $LP_{01}$ linearly polarized mode.

When V > 2.405, other modes may propagate in the fiber waveguide, as shown in **Fig. 4.1** (which is a repeat of **Fig. 0.15**). The first such linearly-polarized mode, which comes in at V=2.405, is the $LP_{11}$ mode, the next-lowest order mode in the weakly-guiding approximation.

When V is just slightly greater than 2.405, only the $LP_{01}$ and the $LP_{11}$ modes may propagate. However, when V=3.832, two more linearly-polarized modes are now allowed to propagate. These are the $LP_{21}$ mode and the $LP_{02}$ mode.

The electromagnetic field distributions of these modes are shown in **Fig. 4.2** (which is a repeat of **Fig. 0.14**). If we have a fiber with the proper V-number, these modes can be selectively launched by varying the position and angle at which a tightly-focused beam of the proper wave- length is projected onto the fiber core. When this is done, the near-field of the fiber output can be inspected and the field distributions of the individual modes can be identified.

Newport's F-SS fiber is a specialty fiber designed to be a single-mode fiber at a wavelength of 1550 nm. It has an NA of 0.29-0.31 and a core radius of 2.1 μm. In this project, a HeNe laser will be used to selectively launch different linearly-polarized modes into a length of Newport F-SS fiber.

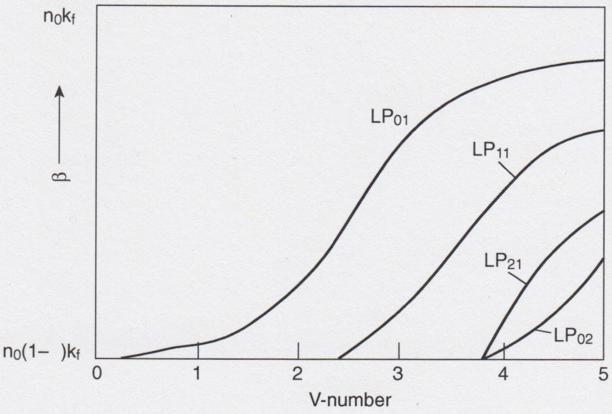
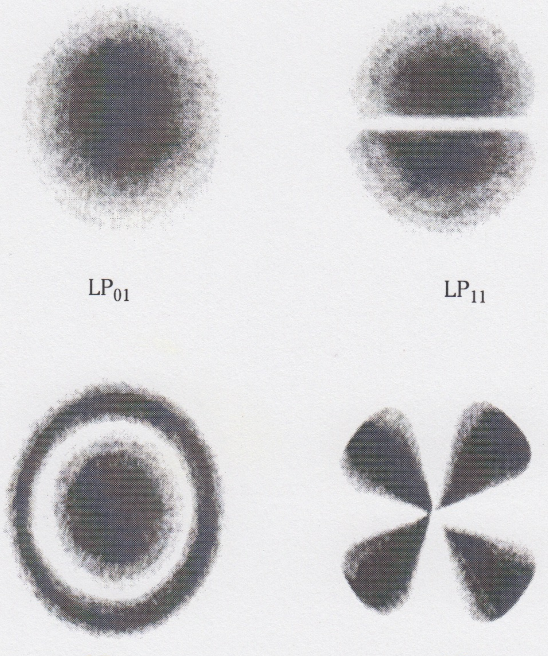


**Figure 4.1. Low order linearly polarized modes of an optical fiber. Compare with Fig. 0.13 (this is a repeat of Fig. 0.15).**



$LP_{01}$ $LP_{11}$

$LP_{02}$ $LP_{21}$

**Figure 4.2. Irradiance pattern of some low order linearly polarized modes (this is a repeat of Fig. 0.14).**

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* *Instructor's Note: Two time durations are estimated for the completion of this project. The first time estimate of 2:30 hours assumes that Project #3 has just been conducted, and the rough alignment of laser and couplers are still intact. The longer time estimate of 3:30 hours assumes that this project is being conducted from scratch.*

## 4.2 POLARIZATION-PRESERVING FIBERS

The mode which propagates in a single-mode fiber, the fundamental $HE_{11}$ mode, is actually a degenerate combination of two orthogonally-polarized components. In a perfectly symmetric, circular fiber, these components travel at the same velocity; that is, they have identical propagation constants. If the fiber is not perfectly symmetric, then the two polarization components have different propagation constants. The difference in their propagation constants, $\delta\beta$, is known as the birefringence of the fiber. The properties of birefringent fibers were discussed in detail in **Section 0.3.3**.

If light is launched with a linear component along each of the optical axes, the difference in propagation constants causes the net vector sum of the polarizations to vary periodically with distance along the fiber, as discussed in **Section 0.3.3**.

This sequence of alternating polarization states continues along the entire length of the fiber. The distance, $L_p$, over which the polarization rotates through an entire 360° is known as the beat length of the fiber. This is related to the birefringence by (repeating **Eq. 0-16**)

$$L_p = 2\pi/\delta\beta \tag{4-1}$$

As was discussed in **Section 0.3.3**, this beat length can be observed visually when visible laser radiation is launched into a birefringent fiber with its direction of polarization oriented at an angle of 45° with respect to the principal axis of the fiber. Scattering centers in the fiber emits dipole radiation. Since the radiation from a dipole is zero along its vibration axis, each time that the light becomes linearly polarized, there will be no scattering detectable when the fiber is observed with the line of sight along the vibration axis. This allows a direct measurement of $L_p$.

Polarization-preserving fibers have applications wherever the polarization of the transmitted light must be stable and well defined. These applications include fiber interferometric sensors, fiber gyroscopes, and heterodyne detection systems.

## 4.3 PARTS LIST

| Cat# | Description | Qty. |
|---|---|---|
| F-SS | 4/125 SM at 1550 nm Fiber, 20 meters | 1 |
| F-SPV | PM Fiber, 10 meters | 1 |
| R-30025 | 1.5 mW HeNe Laser | 1 |
| ULM-TILT | Laser Mount | 1 |
| 340-RC | Clamp | 1 |
| 41 | Short Rod | 1 |
| F-916 | Fiber Coupler (without lens) | 1 |
| FPH-S | Fiber Chuck | 2 |
| M-20X | 20X Objective Lens | 1 |
| F-CLI | Fiber Cleaver | 1 |
| FK-BLX | Allen Wrench Set | 1 |
| SK-25A | Screw Kit, ¼-20 | 1 |
| VPH-2 | Post Holder, 2" | 2 |
| SPV-2 | Post, 2" | 2 |
| FP-1A | Fiber Positioner | 1 |
| M-40X | 40X Objective Lens | 1 |
| FK-POL | Polarizer Sheet | 1 |
| F-STR-175 | Fiber Stripper | 1 |
| MH-2PM | Microscope Objective Mount | 1 |
| IMIC-1 | Fiber Inspection Microscope | 1 |

Additional equipment needed: Millimeter scale, magnifying glass.

## 4.4 INSTRUCTION SET

### 4.4.1 OBSERVING FIBER MODES

1. Prepare both ends of a segment of F-SS fiber ~2 meters in length as was done in **Project #1 (Section 1.6.1, Steps 1-3**). *Also reference additional alignment tips after Step 6 of this section.*

2. Couple the HeNe laser beam into the fiber using the F-916 coupler as described in **Project #3 (Section 3.6.1**), optimizing the coupling efficiency.

3. Insert the far end of the fiber into a post-mounted FP-lA Fiber Positioner. Insert the 40X microscope objective and FPH-S into the F-916 Fiber Coupler. The laboratory set-up for this part of the project is shown in **Fig.4.3**.

4. Use the M-20X microscope objective and the MH-2PM to image the output end of the fiber on a convenient near-by wall. The farther the imaging distance, the larger (and dimmer) the image will be.

5 Examine this projection of the near-field distribution of the fiber. Change the x-y adjustment of the fiber position in the F-916. This has the effect of changing the position and angle of the launch of the focused laser beam into the fiber. Notice how this causes the projection of the near-field distribution of the fiber output to change.

6. Sketch the near-field images that you are able to obtain. Compare them with the $LP_{lm}$ mode distributions shown in **Fig. 4.2**. Identify the patterns that appear to be pure $LP_{lm}$ modes and those which are combinations of two or more $LP_{lm}$ modes.

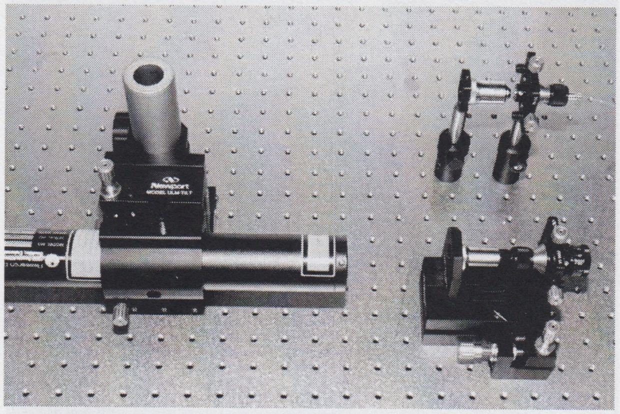

**Figure 4.3. Laboratory set-up for observing low order modes in a multimode fiber with low V-number.**

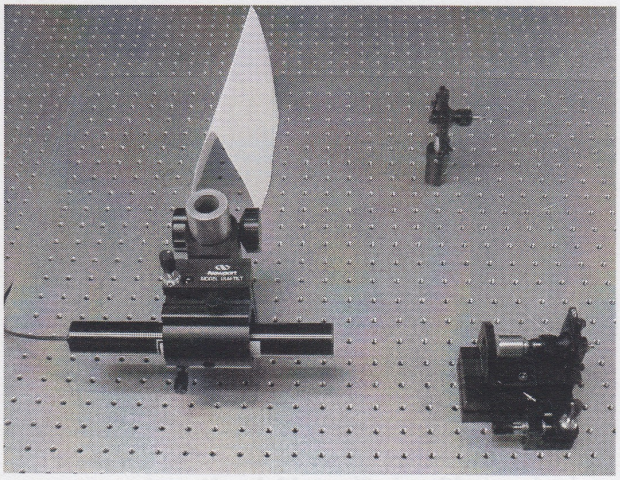

**Figure 4.4. Laboratory set-up for orienting the polarization axes of the polarization fiber with the graduations on the chuck from the F-916 Fiber Coupler.**

*Additional alignment tips -*

*What follows is a description of how to properly launch polarized light into PM fiber; also included is a simple way of reducing or eliminating unwanted higher-order modes. This procedure assumes the laser light is polarized. This can be achieved by placing the FK-POL polarizing sheet in front of the laser output.*

*1. Launch the beam into a cleaved end of PM fiber. Orientation of the polarization axis at this point should not be considered. As long as some output is observed at the far end, it is all right to proceed to step two.*

*2. Install the far end of the PM fiber into Newport's F-916 coupler. Look at the output of the far end of the PM fiber. Note the orientation of the elliptical output. Loosen the screw on the chuck and rotate it so that the major axis of the elliptical output is aligned with a convenient reference mark on the chuck (0° works well). This defines the slow axis of the fiber. Tighten the screw on the chuck.*

*3. Now take the output end, with the chuck and use it as the input end. Assuming you know the orientation of your beam, it is a simple matter to now align the slow axis of the fiber with the polarization axis of the beam. Again, using Newport's model F-916 coupler works well.*

*4. Align the beam with the fiber as with an ordinary single mode fiber, just keep the orientation of the fiber chuck constant.*

*5. Depending on the length of the fiber, unwanted fiber modes may be observed. These are weakly guided cladding modes, which may be reduced or eliminated by gently wrapping the fiber around a 0.5" diameter post.*

### 4.4.2 BEAT LENGTH OF A BIREFRINGENT FIBER

1. Strip and cleave both ends of a 1-2 meter segment of F-SPV fiber.

2. Be sure of the orientation of the polarization of the HeNe laser beam. Use the FK-POL Sheet Polarizer to check the laser's polarization axis. A method for determining the polarization axis of the sheet polarizer is given in **Section 9.6.2, Step 1**. Rotate the polarizer in front of the laser beam. When the power through the polarizer is a maximum, the plane of polarization of the laser is parallel to that of the sheet polarizer.

3. Insert an FPH-S chuck into the F-916 Fiber Coupler. Couple the HeNe laser light into the polarization-preserving fiber using the F-916 coupler, as was done in **Project #3** (**Section 3.6.1**).

4. Insert the far end of the fiber segment into another FPH-S chuck and insert it in the FP-1A. Loosen the set-screw on the knob of the fiber coupler and orient the chuck so that the major and minor axes of the slightly elliptical output spot are aligned with the 0° and 90° marks on the chuck. Tighten the set screw.

This is done so that the end of the fiber can be placed back into the F-916 coupler where the fiber axes is at a known orientation with respect to the polarization of the laser beam. The arrangement of the equipment should be like that shown in **Fig. 4.4**.

5. Place the now oriented fiber-end back into the F-916 fiber coupler. Orient the fiber at 45° with respect to the plane of polarization of the laser in the F-916 coupler.

6. Align the fiber to the laser beam as was done in **Project #3** (**Section 3.6.1**). Maximize the coupled power.

7. Strip a section of the middle of the fiber. Use a magnifying lens in a darkened room to observe the beats in the fiber. Alternating light and dark sections of the fiber will now be observed. Measure the beat length. The beat length of this fiber should be ~2mm.

8. Calculate the birefringence, δβ. Calculate the refractive index difference between the fast and slow axes, $\delta n = \delta\beta\ (\lambda_0/2\pi)$

9. Observe what happens as the orientation of the fiber axes to the plane of polarization of the laser beam is changed, and give a qualitative description of the results.