PolaRITE™ Polarization Controllers

In fiber optic communication and sensing systems, many devices, such as interferometers and electro-optic modulators, are polarization sensitive. In order for these polarization sensitive devices to function properly, the polarization state of the input light must be precisely aligned with a particular axis of these devices. Unfortunately, the polarization state of light propagating in a length of standard circular fiber varies along the fiber due to the random birefringence induced by thermal stress, mechanical stress, and irregularities in the fiber core. Generally, at the output end of the fiber, the light is elliptically polarized, with varying degrees of ellipticity, and with the major elliptical axis at an arbitrary angle relative to some reference orientation. To properly connect such a strand of standard fiber to a polarization sensitive device, one must first convert the arbitrarily polarized light from the standard fiber to linearly polarized light and align it with the correct axis of the device.

One method to accomplish such a task is to use a combination of several bulk phase retarders, as shown in Fig. 1. Because the bulk phase retarders only function properly with collimated light, the light from the fiber must first be collimated using a microlens. The collimated beam will then pass through the phase retarders and then be refocused using a second lens to couple the light to the fiber pigtail of the polarization sensitive device, or directly to the device. These phase retarders are free to rotate independently to generate the desired linear polarization. Unfortunately, such a device is inherently high cost and high loss. First, the collimation, alignment, and refocusing process is time consuming, resulting in high labor costs. Second, the phase retarders are expensive, resulting in high material costs. In addition, the phase retarders and microlenses have to be anti-reflection coated or angle polished to prevent back reflection, creating extra manufacturing costs. Finally, because the light has to be coupled out of the fiber and then refocused into a fiber, the insertion loss is high. Additionally, the phase retarders are wavelength sensitive, making the device sensitive to wavelength variations in the input light.

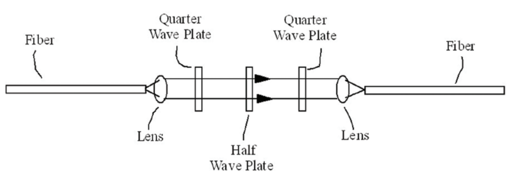

Fig. 1

"Fiber coil" polarization controllers[1] which use a combination of all fiber phase retarders are also available for polarization control in fiber optic systems. In such a device, the half wave and quarter wave phase retarders are actually made of optical fiber coils. Coiling the fiber induces stress on the fiber, and therefore produces birefringence in the fiber coil via the photoelastic effect. The amount of birefringence is inversely proportional to the radius squared of the coil. By adjusting the radius of the coil and the number of turns in the coil, any desired fiber wave plate can be created. Because the phase retarders are made of fiber, it is not necessary to bring the light out of the fiber; therefore, the time consuming process of collimation, alignment, and refocusing is eliminated. In addition, because fiber phase retarders are much less expensive than bulk phase retarders, material costs are also greatly reduced. However, the "fiber coil" polarization controller is far from perfect. First, it is bulky. Current commercial polarization controllers of this kind have a height of 6 cm and a length of 30 cm. It is therefore difficult to use such devices in situations where size is of importance, such as in commercial optical receivers and transmitters. Second, because the fiber's diameter and material properties vary from batch to batch and from vendor to vendor, the birefringence of the fiber coils varies from fiber to fiber and has to be adjusted accordingly. However, such a precise adjustment is difficult to accomplish in this device because the radius of the fiber coils is difficult to change once created. Finally, the device is wavelength sensitive, again due to the difficulty of changing the radius of the fiber coil.

General Photonics Corporation's patented PolaRITE™ Polarization Controller is designed specifically for converting input light of an arbitrary polarization to output light of any desired polarization. Compared with a polarization controller made of bulk phase retarders, it has the advantages of no intrinsic loss, no intrinsic back reflection, simple construction, and low cost, due to its all fiber construction. Compared with a "fiber coil" all fiber polarization controller, it enjoys an edge in compactness, insensitivity to wavelength variations, insensitivity to fiber variations, and insensitivity to vibrations. In addition, the PolaRITE™ only has two knobs to control, compared with three knobs in the "fiber coil" controller, resulting in easier operation and reduced adjustment time for the device.

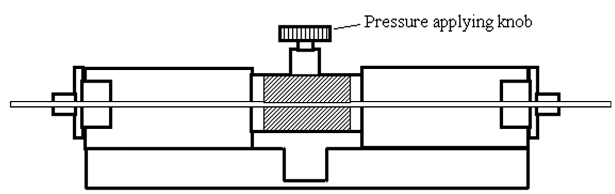

Fig. 2

As illustrated in Fig. 2, the device consists of a strand of single mode fiber, a rotatable fiber squeezer (center), and two fiber-holding blocks (left and right). The center portion of the fiber strand is sandwiched in the fiber squeezer. Turning the knob on the fiber squeezer clockwise will apply a pressure to the fiber center portion and produce a linear birefringence in this portion of fiber. According to previous studies[2,3] the amount of birefringence δ per unit length is proportional to the applied pressure and is given by the equation:

$$\delta \sim 6\times10^{-5}\frac{F}{\lambda d} \quad \text{rad m}^{-1} \qquad (1)$$

where F is the applied force in Newtons, d is the fiber diameter in meters, and λ is the wavelength of light in µm.

With applied pressure, the fiber center portion acts as a birefringent wave plate with its slow axis in the direction of applied pressure, as shown in Fig. 3a. The retardation between slow axis and fast axis can be varied between 0 and 2π by changing the applied pressure.

When the rotatable fiber squeezer is rotated while pressure is applied, the fiber center portion is also rotated, altering the incident polarization angle of the light with respect to the slow axis of the fiber center portion. On the other hand, the rotation will also cause the segments of fiber at the left and right sides of the fiber squeezer to twist in the opposite senses. This twist-induced optical activity will rotate the incident polarization by an angle of $\Theta'=\eta\Theta$ in the direction of twist, where Θ is the physical rotation angle, shown in Fig. 3b, and η is a coefficient of twist-induced optical activity. For single mode fibers, η is on the order of 0.08[4-6]. Consequently, for a physical rotation of Θ degrees, the net change of the incident angle between the slow axis of the fiber center portion and the input polarization is $(1-\eta)\,\Theta$ degrees.

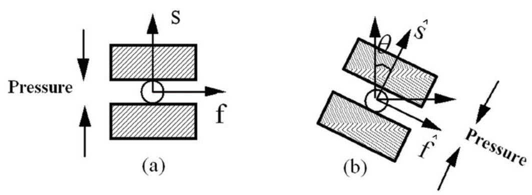

Fig. 3

Preferably, one may rotate the fiber squeezer without causing the left segment and the right segment to twist, by first releasing the pressure on the fiber squeezer, then rotating the squeezer, and finally applying pressure to the fiber squeezer again. In this way, for a physical rotation of Θ degrees, the net change of the incident angle between the slow axis of the fiber center portion and the input polarization is also Θ degrees. This rotate-without-twist procedure is recommended for coarse adjustment of polarization. When the output polarization is close to the desired state, the rotate-with-twist procedure can be used to fine tune the output polarization.

By applying pressure to the fiber center portion, the rotatable fiber squeezer causes the fiber center portion to act as a wave plate of variable retardation and rotatable birefringent axes, or as a Babinet-Soleil compensator [7]. If one chooses the slow and fast axes of the squeezed fiber center portion as a coordinate system, as shown in Fig. 3, the Jones matrix describing the birefringence of the squeezed fiber center portion can be written as:

$$\begin{bmatrix} e^{-i\frac{\Gamma}{2}} & 0 \\ 0 & e^{i\frac{\Gamma}{2}} \end{bmatrix} \qquad (2)$$

where $\Gamma \equiv 2\pi\Delta nl/\lambda = \delta l$ is the phase retardation of the squeezed fiber center portion. In this expression, l is the length of the squeezed fiber center portion and Δn is the index difference between slow axis and fast axis. In the same coordinate system, the Jones vector of the arbitrary input polarization is:

$$\vec{E}_{in} = \begin{bmatrix} E_s \\ E_f e^{i\phi} \end{bmatrix} = E\begin{bmatrix} \cos\alpha \\ \sin\alpha e^{i\phi} \end{bmatrix} \qquad (3)$$

where E_s is the amplitude of the light field projected on the slow axis, E_f is the amplitude projected on the fast axis, ø is the phase retardation between the two components, $E \equiv \sqrt{E_f^2 + E_s^2}$, and $\alpha \equiv \tan^{-1}(E_f/E_s)$

After the squeezed fiber center portion, the output light field can be written as:

$$\vec{E}_{out} = E\begin{bmatrix} e^{-i\frac{\Gamma}{2}} & 0 \\ 0 & e^{i\frac{\Gamma}{2}} \end{bmatrix}\begin{bmatrix} \cos\alpha \\ \sin\alpha e^{i\phi} \end{bmatrix} = Ee^{-i\Gamma/2}\cos\alpha\begin{bmatrix} 1 \\ \chi \end{bmatrix} \qquad (4)$$

where $\chi = \tan\alpha e^{i(\varphi+\Gamma)}$. Because α can be varied from 0 to $\pi/2$ by rotating the fiber squeezer, and Γ can be changed from 0 to 2π by changing the pressure on the fiber center portion, χ can take any value on the complex plane $Re(\chi)$ vs. $Im(\chi)$. Because each point in the complex plane is associated with a polarization state[8], the rotatable fiber squeezer is capable of generating any output polarization from an arbitrary input polarization.

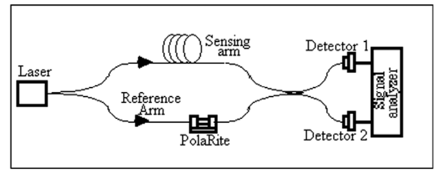

Fig. 4 Using a PolaRITE to maximize the detection sensitivity of a sensor system based on a Mach-Zehnder interferometer. Here the polarization state of the reference arm is adjusted so that the maximum interferometric visibility is detected by the signal analyzer.

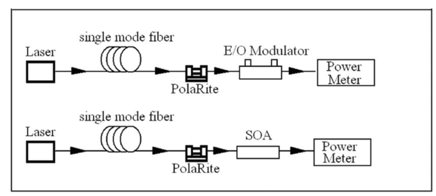

Fig. 5 Using a PolaRITE to adjust the state of the polarization so that it is aligned with the operating axis of the modulator or semiconductor optical amplifier (SOA). When the polarization is adjusted correctly, the maximum optical power is received by the power meter.

Referring to Fig. 4 and Fig. 5, the following procedures are recommended for the adjustment of the PolaRITE™ polarization controller:

1) Apply a pressure to the center portion of the fiber strand by tightening the knob on the rotatable fiber squeezer while monitoring the interferometric visibility, in the case of Fig. 4, or the output power, in the case of Fig. 5. If applying a pressure causes a significant increase in monitored interferometric visibility or optical power, then keep on going until the monitored visibility or optical power starts to decrease.

2) Rotate the rotatable fiber squeezer while maintaining the pressure to fine tune the output polarization. Adjust the pressure and orientation of the rotatable fiber squeezer iteratively until a maximum monitored visibility or optical power is obtained. This is the indication that the desired polarization is achieved.

3) If applying a pressure causes little change in monitored visibility or optical power, or causes the visibility or optical power to decrease, then release the pressure and rotate the center portion to a new position. Repeat step 1 and 2 if turning the knob causes a significant increase in monitored visibility or optical power.

Polarization Maintaining Fiber Adapter

Polarization maintaining (PM) fibers are widely used in fiber optic sensors and other applications where a particular, stable polarization is required. Because many polarization sensitive devices are pigtailed with polarization maintaining fibers, a device for connecting PM fibers is of great importance.

A PM fiber is a strongly birefringent fiber with predetermined slow and fast axes. If the polarization of input light is linear and aligned with one of the axes, it will remain unchanged after propagating in the fiber. However, if the input polarization is not linear, or is linear but not aligned with the axis, the polarization will go through periodic changes along the fiber, and the output from the fiber will be elliptically polarized, with the ellipticity and orientation determined by the fiber length.

Connecting two PM fibers is a difficult task, which involves precise alignment of fiber axes while maintaining low connection loss. Fusion splicers exist for splicing PM fibers. However, they are very expensive, and not practical for field installations. Connectors have been introduced previously for connecting PM fibers. In such connectors, fibers have to be precisely aligned with an orientation key of the connector. Consequently, assembly of such PM connectors requires large capital investment and is time consuming. In addition, connectors from different manufacturers may have different orientation key positions, making it difficult to connect fibers connectorized by different vendors. Finally, because all connectorizations have to be done by the connector manufacturer, devices have to be sent back and forth between the device manufacturers and the connector manufacturers, resulting in long delay times and increased damage rates.

The PolaRITE™ described above can be used to connect two strands of PM fibers. The linear polarization from the input PM fiber can be rotated to align with the slow (or fast) axis of the receiving PM fiber by properly adjusting the pressure and the orientation of the rotatable fiber squeezer. However, because the PolaRITE™ has non-polarization maintaining pigtails, disturbances to the pigtails will cause the polarization to change and destroy the polarization alignment.

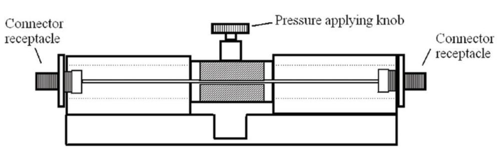

Fig. 6

General Photonics Corporation's solution to this problem is to eliminate the non-PM fiber pigtails of the PolaRITE™. As shown in Fig. 6, the patented PolaRITE™ PM Fiber Adapter has both ends connectorized with receptacles to receive standard FC/PC, FC/APC, SC, angled SC, ST, angled ST connectors, or any type of connectors of the user's choice. By doing so, the standard fiber used to construct the device is completely contained in an enclosure, isolated from external disturbances. In addition, the pressure of the fiber squeezer can be pre-adjusted so that the pressure-induced retardation is half wave for a specified wavelength. The PM fibers to be connected only need to be connectorized with corresponding standard connectors, without special attention to the orientation of the retardation axes of the PM fiber. To use the PolaRITE™ PM fiber adapter, simply fasten the two connectors onto the receptacles at each end of the PolaRITE™ PM fiber adapter and rotate the center portion of the adapter until the desired polarization is received by the receiving fiber, as shown in Fig. 7.

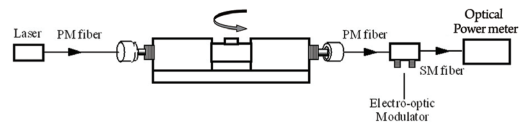

Fig. 7

The PolaRITE™ PM fiber adapter can also be used as a variable attenuator if it is connected to a polarizer, a piece of polarizing fiber, or a device with a strong polarization dependent transmission (such as a $LiNbO_3$ waveguide made by proton exchange process), as shown in Fig. 8. Variable attenuation is obtained by simply rotating the fiber squeezer at the center.

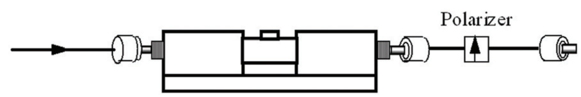

Fig. 8

REFERENCES

1. H. C. Lefevre, "Single-mode Fiber Fractional Wave Devices and Polarization Controllers," Electronics Letters, Vol. 16, No. 20, pp. 778-780, 1980).

2. A. M. Smith, "Single-mode fiber pressure sensitivity," Electronics Letters, Vol. 16, No 20, pp 773-774 (1980).

3. J. Sakai and T. Kimura, "Birefringence and Polarization Characteristics of Single-Mode Optical Fibers under Elastic Deformations," IEEE Journal of Quantum Electronics, Vol. QE-17, No. 6, pp 1041-1051 (1981).

4. R. Ulrich and A. Simon, "Polarization optics of twisted single-mode fibers," Applied Optics, Vol. 18, No. 13, pp 2241-2251 (1979).

5. A. Smith, "Birefringence induced by bends and twists in single-mode optical fiber," Applied Optics, Vol. 19, No. 15, pp 2060-2611 (1980).

6. M. Monerie and L. Jeunhomme, "Polarization mode coupling in long single-mode fibers," Optical and Quantum Electronics, Vol. 12, pp 449-461 (1980).

7. M. Born and E. Wolf, Principles of Optics, New York: Pergamon Press, Sixth edition, 1980, pp. 693-694.

8. A. Yariv and P. Yeh, Optical Waves in Crystals, New York: John Wiley & Sons, 1984, pp. 61-62.