APPLICATION NOTE

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 the thermal stress, mechanical stress, and irregularities of the fiber core. Generally, the light at the output end of the fiber is elliptically polarized with varying degrees of ellipticity and with the major elliptical axis at an arbitrary angle relative to some reference orientation. Therefore, to properly input light from 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 polarization sensitive device.

One method to accomplish such tasks 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 passes through the phase retarders and is then refocused by a second lens to couple the light either to the input 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 cost. Second, the phase retarders are expensive, resulting in high material cost. Third, the phase retarders and microlenses have to be anti-reflection coated or angle polished to prevent back reflection, further increasing the manufacturing cost. Finally, because the light has to be coupled out of the fiber and then refocused into the fiber, the insertion loss is high. Additionally, the phase retarders are wavelength sensitive, rendering the entire device sensitive to wavelength variations in the input light.

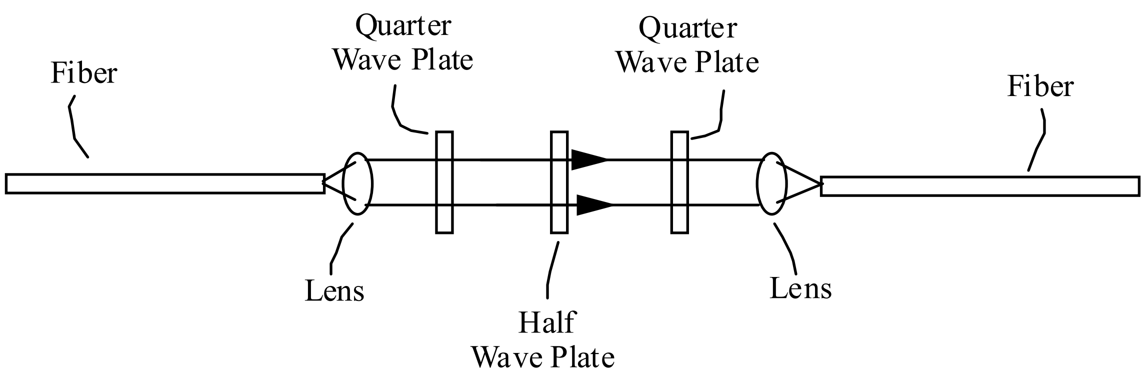

Figure 1 Structure of polarization controller based on bulk phase retarders

"Fiber coil" polarization controllers [1] that 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 optic 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 coil radius 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 couple the light out of the fiber to use them; therefore, the need for 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, the material cost is 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 precise adjustment is difficult to accomplish in this device because the radii of the fiber coils are difficult to change once created. Finally, the device is wavelength sensitive, again due to the difficulty of changing the radius of the fiber coil.

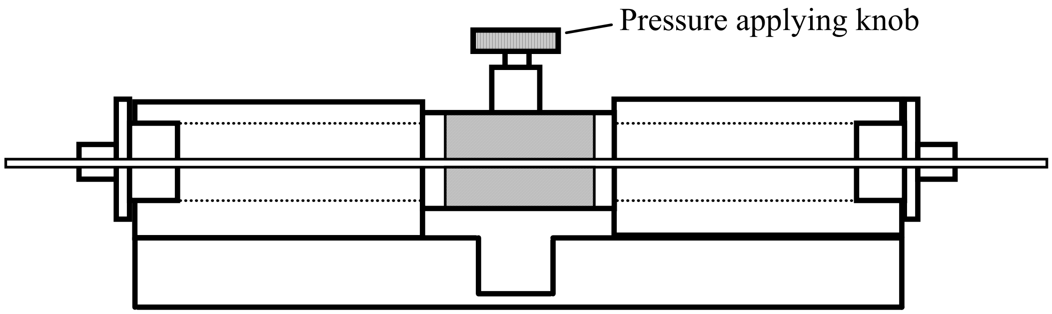

Figure 2 Structure of PolaRite™ polarization controller

Newport Corporation's **PolaRite™** Polarization Controller is designed specifically to convert input light of arbitrary polarization to output light of any desired polarization. Compared with a polarization controller made of bulk phase retarders, its advantages are that it has no intrinsic loss, no intrinsic back reflection, simple construction, and low cost due to its all-fiber construction. Its advantages over the "fiber coil" all-fiber polarization controller include its small size, insensitivity to wavelength variations, insensitivity to fiber variations, and insensitivity to vibrations. In addition, polarization control using the **PolaRite™** polarization controller requires adjustment of only two variables, compared with three variables in the "fiber coil" controller, resulting in easier, quicker operation of the device.

As illustrated in Fig. 2, the device consists of a strand of single mode fiber, a rotatable fiber squeezer (center section), and two stationary blocks to hold the fiber in place (left and right). The center section of the fiber strand is sandwiched between two plates in the fiber squeezer. Turning the knob on the fiber squeezer clockwise applies pressure to this section of the fiber, producing a linear birefringence in the squeezed 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:

$$\delta \sim 6 \times 10^{-5} \frac{F}{\lambda d} \text{ rad m}^{-1} \qquad (1)$$

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

Under 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 the slow and fast axes 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 so as to alter the incident polarization angle of the light with respect to the slow axis of the fiber center portion. At the same time, 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.

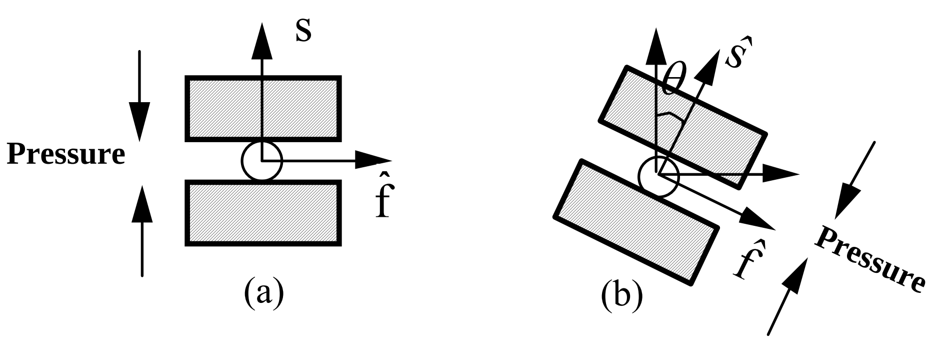

Figure 3

To minimize this effect, 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, rotating the squeezer, and finally re-applying pressure to the fiber squeezer. In this way, for a physical rotation of θ degrees, the net change of the incident angle between slow axis of fiber center portion and input polarization is also θ degrees. This rotate-without-twist procedure is recommended for coarse polarization adjustment. 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 a section of fiber, the rotatable fiber squeezer causes that section of fiber to act as a wave plate of variable retardation and rotatable birefringent axes, otherwise known as a Babinet-Soleil compensator [7]. If one chooses the slow and fast axes of the squeezed fiber section 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:

$$\begin{bmatrix} e^{-i\frac{\Gamma}{2}} & 0 \\ 0 & e^{i\frac{\Gamma}{2}} \end{bmatrix}, \tag{2}$$

where $\Gamma \equiv 2\pi \Delta n l / \lambda = \delta l$ 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 the slow axis and fast axis. In the same coordinate system, the Jones vector of an arbitrary input polarization is:

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

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, ϕ is the phase retardation between these two components, $E \equiv \sqrt{E_f^2 + E_s^2}$, and $\alpha \equiv \tan^{-1}(E_f / E_s)$.

The Jones vector of the output light field after the squeezed fiber center portion can be written as:

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

where $\chi = \tan\alpha e^{i(\phi+\Gamma)}$. 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 $\mathrm{Re}(\chi)$ vs. $\mathrm{Im}(\chi)$. Because each point of 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.

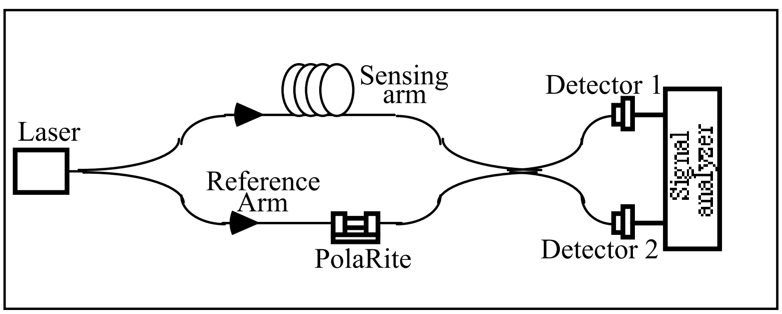

Figure 4 Use of a PolaRite™ to maximize the detection sensitivity of a sensor system based on a Mach-Zehnder interferometer. Here the polarization state of the reference arm is adjusted so that the maximum interferometric visibility is detected by the signal analyzer.

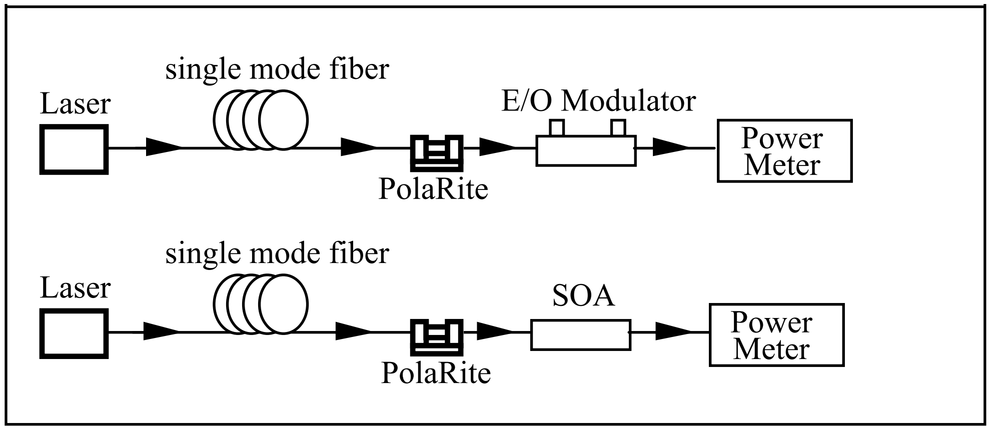

Figure 5 Use of a PolaRite™ to align the state of polarization of input light with the operating axis of a modulator or semiconductor optical amplifier (SOA). When the polarization is adjusted correctly, the optical power received by the power meter is maximized.

Referring to Fig. 4 and Fig. 5, the following procedures are recommended when using the **PolaRite™** polarization controller:

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

2) Fine tune the output polarization by rotating the rotatable fiber squeezer while maintaining the pressure achieved at the end of step 1 (do not adjust the center knob). Adjust the pressure and orientation of the rotatable fiber squeezer iteratively until the maximum monitored visibility or optical power is obtained. This is the indication that the desired polarization has been achieved.

3) If applying 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 that require a particular stable polarization state. 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 highly birefringent fiber with predetermined slow and fast axes. If the polarization of input light is linear and aligned with one of the axes, it remains unchanged after propagation in the fiber. However, if the input polarization is not linear or is linear but not aligned with one of the axes, the polarization varies periodically along the fiber, and the output from the fiber is in general 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 for PM fibers exist. However, they are very expensive and not practical for field installations. Connectors for connecting PM fibers have also been previously introduced. 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 an increased damage rate.

The **PolaRite™** polarization controller described above can be used to connect two strands of PM fiber. 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, any disturbance of the pigtails will cause the polarization to change and destroy the polarization alignment.

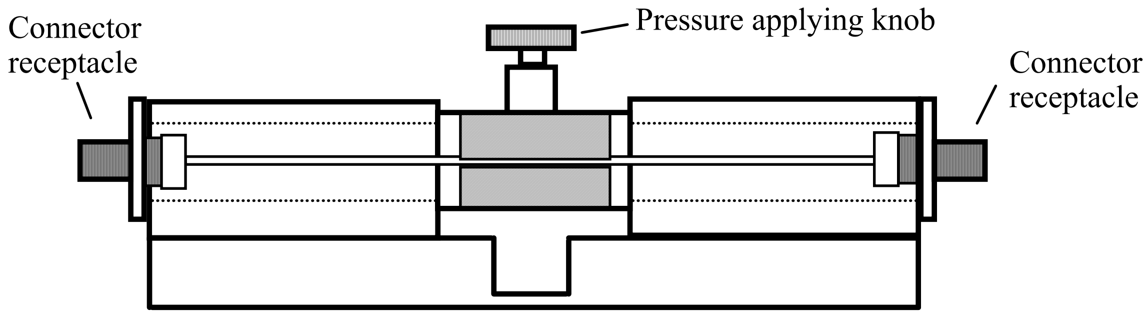

Figure 6 PolaRite™ PM fiber adapter

Newport 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. The standard fiber used to construct the device is thus completely contained in an enclosure, isolated from external disturbance. 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 need only be connectorized with corresponding standard connectors, without the need for special attention to the orientation of the retardation axes of the PM fiber. To use the **PolaRite™** PM fiber adapter, simply insert the two connectors into 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.

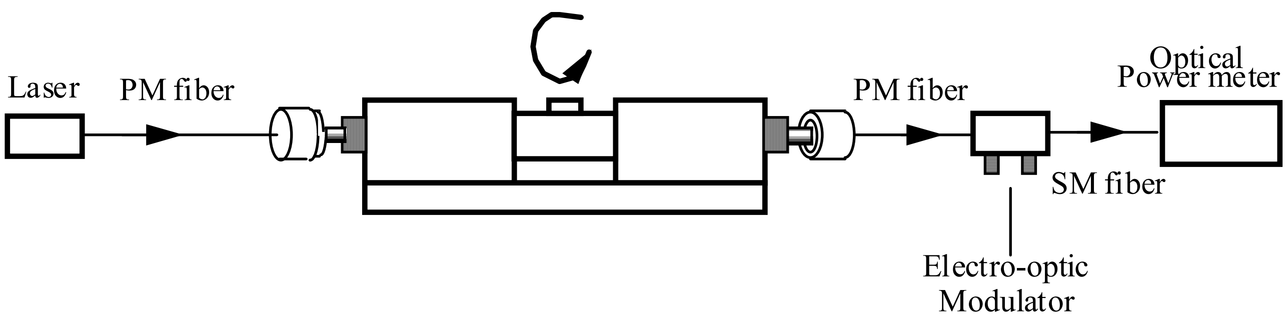

Figure 7 Use of a PolaRite™ PM fiber adapter to connect a PM output laser to a PM input EO modulator.

The **PolaRite™** PM fiber adapter can also be used as a variable attenuator when 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 the proton exchange process), as shown in Fig. 8. Variable attenuation is tuned by simply rotating the fiber squeezer at the center.

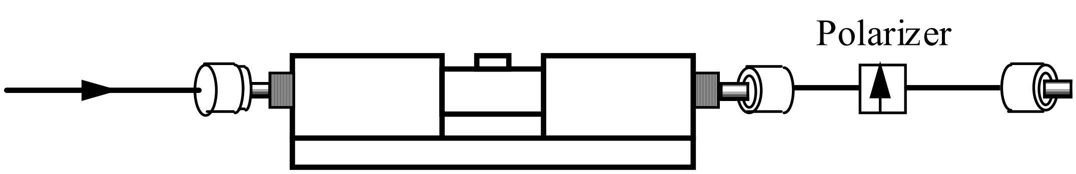

Figure 8 PolaRite™ PM fiber adapter used with a polarizer to form a variable attenuator

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