Polarization-maintaining fiberoptic systems require specialized fiber and connectors and careful assembly and alignment to achieve optimal performance.

Accurate alignment preserves polarization

Omur Sezerman and Garland Best

Laser Focus World

The performance of many fiberoptic components and systems is affected by the polarization of the light traveling through the fiber. These include fiber interferometers and sensors, fiber lasers, and electro-optic modulators. Many systems also suffer from polarization-dependent losses that can affect system performance. Understanding how to control the polarization of light in a fiberoptic system and how to properly use polarization-maintaining (PM) components is vital for successful results.

Polarized light can be classified as linearly polarized, elliptically polarized, or circularly polarized (see Fig. 1). The simplest form of polarized light is linearly polarized light, in which the electric field oscillates in a single plane of vibration. In theory, one can generate perfectly linearly polarized light, but in practice this is not the case.

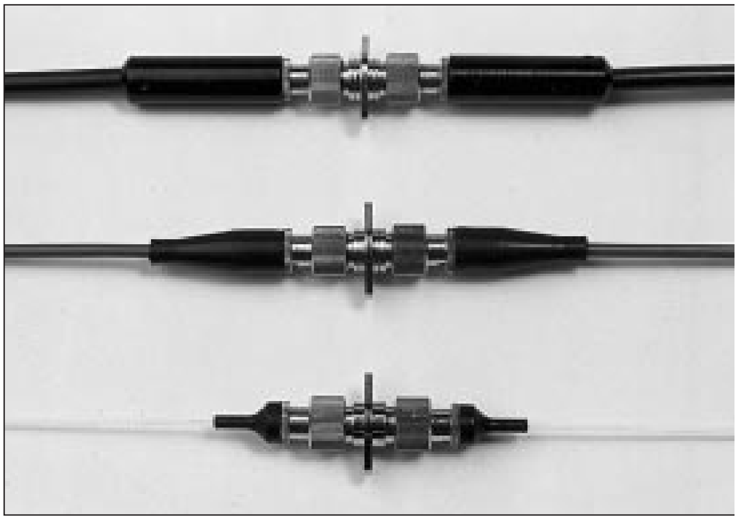
The polarization-extinction ratio gives a measure of the portion of the beam that is linearly polarized along a single axis. The extinction ratio can be measured by directing a beam through a polarizer mounted on a rotation stage and onto a detector. Light polarized parallel to the transmission axis of the polarizer will pass through to the detector, whereas light polarized orthogonal to the transmission axis will be blocked. The output signal registered by the detector will vary in intensity as the polarizer is rotated, and the extinction ratio is defined as

$$ER = 10 \log (P_{max}/P_{min})$$

where P_{min} and P_{max} are the measured maximum and minimum signal intensities in milliwatts.

Polarization and fiberoptics

Bending or twisting optical fiber induces stresses in the material that in turn cause phase changes in the polarization state of the light traveling through the fiber. If the fiber is subjected to external perturbations such as changes in position or temperature, the polarization of the output beam will vary as a function of time. This is true for even short lengths of fiber and is undesirable in many applications such as sensing and telecommunications, which require a constant output polarization from the fiber.



OZ OPTICS

Polarization-maintaining connectors feature a positioning key aligned to the slow axis of the fiber. The key permits the connector to be mated only with another connector or component at a single angular orientation.

To address variations in the output beam, manufacturers have developed PM fibers. In PM fiber, light polarized along one axis of the fiber travels at a different rate than light polarized orthogonal to that axis. This birefringent behavior creates two principal transmission axes within the fiber, known as the fast and slow axes. If the light input to a PM fiber is linearly polarized and oriented along either the fast or the slow axis, the fiber output will remain linearly polarized and aligned with that axis, even when the fiber is subjected to external stresses. A 1-m-long connectorized patchcord constructed with PM fiber, for example, can typically maintain polarization to at least 30 dB at 1550 nm.

A variety of polarization-preserving core/cladding structures are currently used in the industry (see Fig. 2). The

OMUR SEZERMAN is CEO and GARLAND BEST is vice president of engineering at Oz Optics Ltd., Unit #219 Westbrook Rd., West Carleton Industrial Park, Carp, Ontario, Canada K0A 1L0.

dashed lines in the drawings show the slow axis within each structure. More recently, manufacturers have developed polarizing fibers, which only transmit light polarized along the transmission axis of the fiber.

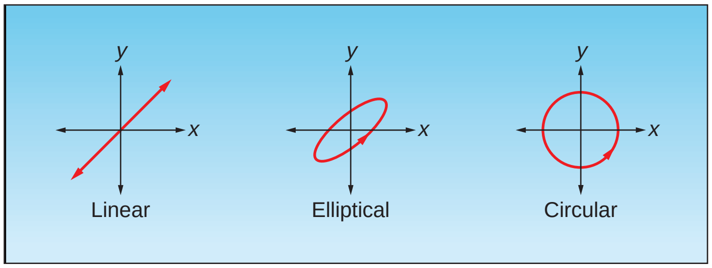


FIGURE 1. In polarized light, the electric-field oscillation remains in a single plane (linear polarization, left), rotates azimuthally while changing magnitude (elliptical polarization, middle), or rotates azimuthally while maintaining a constant magnitude (circular polarization, right).

The ability of a PM fiber to maintain polarization depends on the conditions under which light is launched into the fiber. Perhaps the most important factor is the alignment of the polarization axis of the light with the slow axis of the fiber. For a perfectly polarized input beam, misaligned by an angle θ with respect to the slow axis of an ideal fiber, the extinction ratio is

$$\mathrm{ER} \leq 10 \log (\tan^2 \theta)$$

To achieve an output extinction ratio greater than 20 dB, the angular misalignment must be less than 6°; to achieve an extinction ratio of approximately 30 dB, the angular misalignment must be less than 1.8°.

Fiber-to-source alignment

Meeting such strict tolerances requires system integrators to use careful alignment techniques. The typical alignment configuration consists of the laser, coupling optics, the PM fiber, a polarizer mounted on a rotary platform, and a fiber link to an optical power meter (see Fig. 3). The fiber-to-source alignment should first be adjusted to optimize coupling efficiency. Next, the maximum and minimum fiber output through the polarizer should be measured with an optical power meter, and extinction ratio calculated. The fiber connector should be rotated by a small increment, and the measurement process repeated. This should be iterated until the measured extinction ratio reaches a maximum value.

The type of source used can affect the measurement. Incoherent sources tend to produce a static, averaged measurement of the extinction ratio. Such sources are often used by manufacturers in testing assembled fiber patchcords, for example, to characterize performance. If the product is intended for use with a coherent source, however, such measurements can be misleading. Measurements taken of the same fiber aligned to a coherent source often will produce a lower worst-case measurement than for the incoherent source when the fiber is flexed, even when the fiber is ideally aligned.

An ideal source for use in polarization-sensitive applications would be one that is polarized to at least 40 dB and with a linewidth on the order of tens of nanometers. Such a source does not produce coherence effects—interference effects between the light on the slow axis and the fast axis that create variations in the P_{max} and P_{min} measurements and can falsely influence extinction ratio measurements. Most lasers, including diode lasers, are polarized to only about 25 dB and have a linewidth of about 1 nm, so coherence effects come into play during the alignment process.

To eliminate measurement inaccuracies caused by coherence effects, the fiber must be stressed during alignment. Mechanical stress induces a phase change in the light along the slow axis of the fiber, changing the interference between the slow axis and the fast axis. The point of the test is to seek the worst-case result. Failure to do so can result in wildly optimistic results.

The fiber should be bent slightly, or wrapped around a mandrel with a diameter of at least 50 mm, and the minimum output power through the polarizer measured. Ideally there should be no change or even a slight decrease in the minimum output power; it is common, however, for this value to increase slightly as a result of changing interference effects. If the increase is only one or two decibels, then the polarization axis is correctly aligned. If the increase is larger, the connector should be readjusted.

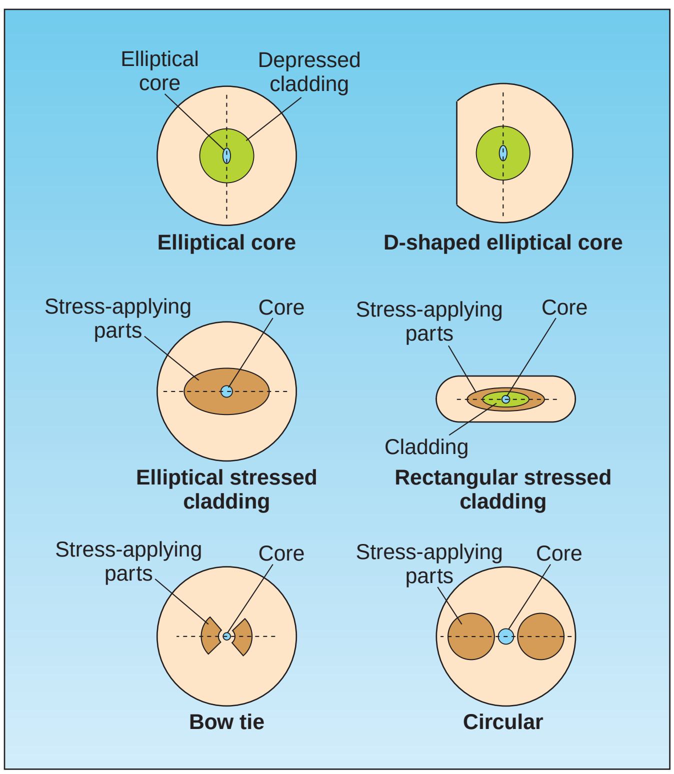


FIGURE 2. Polarization-maintaining fibers feature a variety of core and cladding designs. Stress-applying parts within the fiber structure impart mechanical stress to the material to differentiate it into fast and slow axes.

The best extinction ratio

that can be achieved depends on how well the fiber can be positioned with respect to the laser. Extinction ratios of 20 dB can easily be achieved by manually rotating the connector. If the connector is positioned with a precision rotary stage, extinction ratios of 25 to 30 dB are possible.

For product-testing purposes only, an alternate method for aligning the polarization axis is to place a half-wave plate on a rotary stage between the source and the optics that launch light into the fiber. The connector remains stationary, and the half-wave plate is rotated to align the polarization axis of the beam with the fiber. Extinction ratios of 35 dB or better can be realized with this technique.

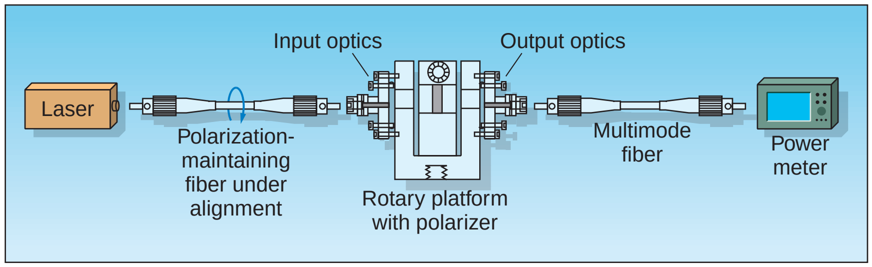


FIGURE 3. To achieve optimal source-to-fiber alignment in a polarization-maintaining system, the output from the PM fiber is passed through a polarizer and monitored by a power meter. The fiber is rotated to determine the angular alignment that provides best contrast between the maximum output power (polarizer oriented to transmit majority of beam) and minimum output power (polarizer oriented to extinguish majority of beam).

Polarization-maintaining connectors

The polarization-extinction ratio can be degraded by any stresses or microbends in the connectors, or by external optical components that do not maintain polarization properly. Special termination procedures, stress-free glues, and top-quality lenses and optics must be used to minimize these stresses and thus maintain the highest possible extinction ratios.

Given the importance of the alignment of the PM axis across a connection, the choice of connector is critical. The most common type of PM connector in use is a variation of the NTT-FC style connector. Such connectors have a positioning key—a narrow raised region that by industry convention is aligned to the slow axis of the fiber. The key restricts the connector to mating with other components or connectors at a single angular position, preserving the angular orientation of the fiber.

The tolerances between the key and keyway on standard FC connectors are too loose to accurately maintain angular alignment, so manufacturers have tightened the key dimension tolerances on PM connectors, based on FC angle-polished connector (APC) standards.

Connector-key tolerances

CONNECTOR TYPE	KEY WIDTH (mm)	KEYWAY WIDTH (mm)
R (reduced)	1.97–2.02	2.03–2.08
OZ Optics	1.98–2.02	2.03–2.07
Seikoh Gieken	1.98–2.02	2.03–2.07
Diamond SA	1.99–2.00	2.02–2.05
N (wide)	2.09–2.14	2.15–2.20
Seiko Instruments	2.09–2.14	2.15–2.20
Diamond SA	2.14–2.15	2.17–2.23

Two APC standards currently exist for components on the market: a narrow, or reduced-key design, and a wide-key design (see table). The two dimensions are incompatible with one another, so users should know beforehand the design being used. Most manufacturers will offer the alternative standard as an option, so be sure to ask before you purchase a connector.

To help distinguish polarization-maintaining connectors from single-mode connectors, most manufacturers now use a blue strain-relief boot, or add a blue dot or stripe to a standard boot. A proposal has been made to also identify the connector key width by engraving notches on the key and keyway. A single notch would identify a narrow key, while a double notch would identify a wide key.

Although working with polarization-maintaining fibers and patchcords may seem difficult, in reality it is not. All that is needed is a little attention to detail and some inexpensive equipment. With the trend toward common standards and the increasing range of applications, polarization-maintaining fiberoptics faces a bright future. ❏