OZ OPTICS LTD.

APPLICATION NOTE

POLARIZATION MEASUREMENTS

OZ OPTICS FAMILY OF POLARIZATION MAINTAINING COMPONENTS, SOURCES, AND MEASUREMENT SYSTEMS

INTRODUCTION

Thank you for considering OZ Optics for your polarization maintaining applications. Here at OZ, we pride ourselves for being your expert on all aspects of polarization maintaining fiber optics, including fibers, connectors, patchcords, components, sources, and measurement systems.

This application note is intended to provide the user with essential information on characterizing and connectorizing polarization maintaining (PM) fiber optic devices. This includes PM fiber theory, measuring output extinction ratios, connector standards, essential equipment, and test procedures.

APPLICATIONS

- Interferometers
- Integrated optics
- Fiber Amplifiers
- DWDM systems
- Circulators
- Coherent Telecommunications

Polarization Extinction Ratio Meter

Polarized Source

THEORY OF OPERATION

Definition of Polarization

One very useful property of light that is now being utilized in fiber optics is the phenomena of *polarization*. Many fiber optic applications today are affected by the polarization of the light traveling through the fiber. These include fiber interferometers and sensors, fiber lasers, and electro-optic modulators. E/O modulators in particular have seen remarkable growth in recent months, thanks to their use in high speed switching systems. On the other hand, many systems show polarization dependent losses (PDL's), which can affect system performance. Thus, analyzing, controlling, and manipulating the polarization state of light in fiber has become increasingly vital.

Figure 1 shows three different possible types of polarized light. In the simplest case, *linearly polarized light,* the electric field just vibrates up and down in a specific direction. In most applications, it is this form of polarization we are interested in and wish to preserve.

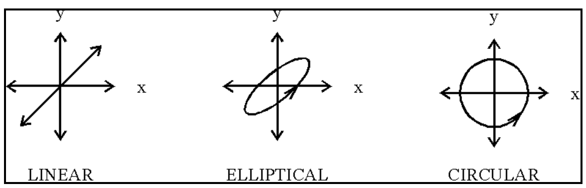

Figure 1: Examples of polarized light.

While in theory one can produce perfectly linearly polarized light, in practice this is not the case. To measure the quality of the polarized beam, one must measure its polarization *extinction ratio* (ER).

To measure the extinction ratio of a polarized beam, one must transmit the beam through a rotatable polarizer and onto a detector. As you rotate the polarizer, the output signal will vary in intensity. If the maximum and minimum intensities are measured in milliWatts, then the extinction ratio of the output beam is given by:

$$ER = 10 \log\left(\frac{P_{max}}{P_{min}}\right)$$

where Pmin and Pmax are the measured maximum and minimum signal intensities.

Polarization Maintaining Fibers

When a normal fiber is bent or twisted, stresses are induced in the fiber. These stresses in turn will change the polarization state of light traveling through the fiber. If the fiber is subjected to any external perturbations, say changes in the fiber's position or temperature, then the final output polarization will vary with time. This is true for even short lengths of fiber, and is undesirable in many applications that require a constant output polarization from the fiber.

To solve this problem, several manufacturers have developed polarization maintaining fibers (PM fibers). These fibers work by inducing a difference in the speed of light for two perpendicular polarizations traveling through the fiber. This *birefringence* creates two principal transmission axes within the fiber, known respectively as the fast and slow axes of the fiber. Provided the input light into a PM fiber is linearly polarized and orientated along one of these two axis, then the output light from the fiber will remain linearly polarized and aligned with that axis, even when subjected to external stresses. A one meter long connectorized patchcord constructed with PM fiber can typically maintain polarization to at least 30dB at 1550 nanometers when properly used.

Figure 2 shows a variety of polarization preserving core/cladding structures presently used in the industry. The dashed lines in the drawings show the slow axis within each structure. More recently there has been the development of polarizing fibers. These fibers only transmit light that is polarized along the transmission axis of the fiber.

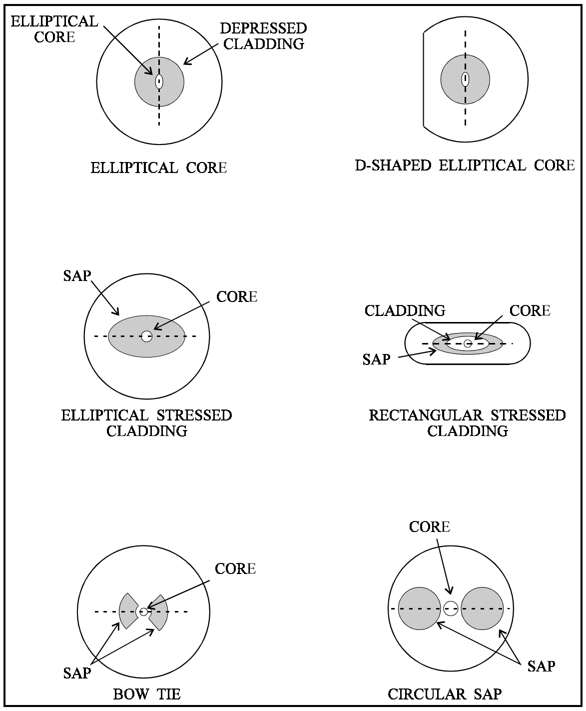

Figure 2: Examples of polarization preserving fiber core structures.

Naturally, how well a PM fiber maintains polarization depends on the input launch conditions into the fiber. Perhaps the most important factor is the alignment between the polarization axis of the light with the slow axis of the fiber. Assume that we have a perfectly polarized input beam into an ideal fiber, misaligned by an angle θ with respect to the slow axis of the fiber. (See Figure 3) The maximum possible value of the output extinction ratio is thus limited by:

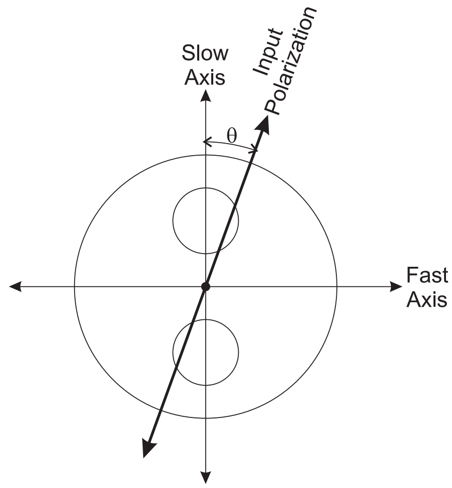

Figure 3: Angular Alignment Mismatch Between Polarized Light and Fiber

$$ER \leq -10 \log (\tan^2\theta)$$

Thus to achieve output extinction ratios greater than 20dB, the angular misalignment must be less than 6 degrees. For 30dB extinction ratios, the angular misalignment must be less than 1.8 degrees.

More generally, suppose that the input source is not ideally polarized, but instead is polarized to a value ER_0, and that the unwanted light leaking through is incoherent in nature. In this case, we can treat the unwanted light as a background signal, and that these background signals accumulate at each junction in the system. (See figure 3). If we assume that the unwanted polarization is much less than the actual signal, we can calculate the final output extinction ratio after each connection, ER_{final}, from the formula:

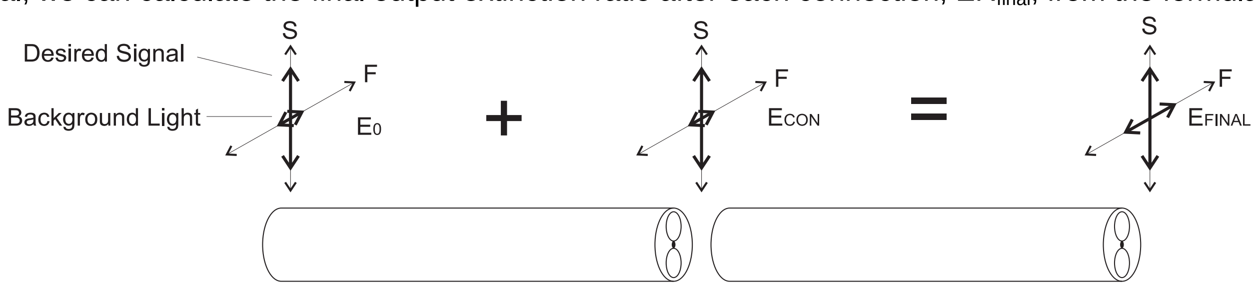

Figure 4: Degradation of Polarization at a Connection

$$ER_{final} = -10 \log (10^{-ER_0/10} + 10^{-ER_{con}/10})$$

Where ER_{con} is the limiting extinction ratio across the connection due to misalignment errors. For instance, if the source extinction ratio, ER_0, is 30dB, while the connector misalignment limits the extinction ratio to 25dB, the resultant extinction ratio, ER_{final}, will be measured as 24dB. In general, to ensure accurate measurements of extinction ratios within a component, the source should be polarized at least 10dB better than your measurement range. This is also true for the polarizers used to measure the polarization.

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.

Polarization Maintaining Connectors

Given the importance of the alignment of the PM axis across a connection, the choice of connector is especially important. The most common type of PM connector in use is a variation of the NTT-FC style connector. FC connectors have a positioning key, to preserve the angular orientation of the fiber. The industry standard is to align the slow axis of the fiber with the connector key.

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. The key dimensions being used are based on FC angle polished connector (APC) standards. Unfortunately, two APC standards are currently on the market, a narrow, or reduced key design, and a wide key design. The two dimensions are incompatible with one another, so it is important know beforehand which design you are using. Table 1 lists the key dimensions used by several PM connector manufacturers. Most will offer the alternate design as an option, so ask beforehand.

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

Table 1: Connector Key Tolerances

To help distinguish PM connectors from singlemode connectors, most manufacturers now use a blue strain relief boot, or add a blue dot or stripe to a standard boot. A proposal is now underway 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.

As the marketplace evolves, PM patchcords using other connector types are beginning to appear. For instance, SC connectors are becoming a more popular choice. In all cases, there must be a key or similar structure to act as a reference, and tight tolerances must be kept to ensure that the ferrules cannot rotate.

CHARACTERIZING POLARIZATION MAINTAINING COMPONENTS

Equipment Required

Suppose we want to test a device, such as a patchcord, to determine both the device performance and the connector quality. To do so you need the following equipment:

- A highly polarized source, preferably at least 30 to 40dB. The source should provide at least 0.1 mW of useful optical power, and have a means to rotate the orientation of the output polarization, and indicate the output angle. OZ Optics provides highly polarized fiber optic stable sources (PFOSSes), which meet these requirements.
- A polarization extinction ratio meter. Such a meter measures both the polarization extinction ratio and polarization axis of the output light. Alternatively, a rotatable polarizer, with an angle readout can be used to perform the same operation manually. OZ Optics offers both extinction ratio meters and manual polarization analyzers for these measurements.
- A reference patchcord, able to maintain polarization to at least 30dB, to check the measurement system, and to test the PM connector characteristics.
- A compatible polarization maintaining bulkhead receptacle, to check the connector characteristics.
- A mandrel, about 50mm in diameter, to wrap the fiber around, in order to stress the fiber to stimulate external perturbations.
- (Optional) One or more bare fiber adaptors, to attach unterminated fibers to either the source or the extinction ratio meter.

How To Measure The Extinction Ratio Of A PM Fiber

The following method outlines how to measure the extinction ratio of a spool of polarization maintaining fiber, without any connectors on the ends of the spool.

1. Turn on the polarized source and allow the source to warm up for ten to fifteen minutes. Adjust the polarizer until the angle reading matches the keyway reference angle, as marked on the source
2. Unwind two or more meters of fiber from both ends of the spool. Ensure that the fiber is not sharply bent as it leaves the spool.
3. Strip and cleave the fiber ends using standard procedures, and insert the ends into bare fiber adaptors.
4. Form a loop about 10cm in diameter in the middle of the input end of the spool. Tape the loop to the table using three pieces of scotch tape. This is done to ensure that the fiber does not accidentally rotate during the test. Do the same thing to the output end of the fiber. The spool should now look the same as Figure 5 below. Attach the fiber to the polarized source and if necessary, adjust the coupler for optimum coupling efficiency
5. Attach the output end of the test fiber to the extinction ratio meter. Note the current readout of the polarization extinction ratio.
6. Rotate the polarizer on the polarized source to further improve the extinction ratio readout to the best possible level.
7. Slowly wrap the fiber for three wraps around the mandrel. This may result in a slight reduction in the extinction ratio readout. Note the worst case readout while wrapping the fiber, then unwrapping the fiber

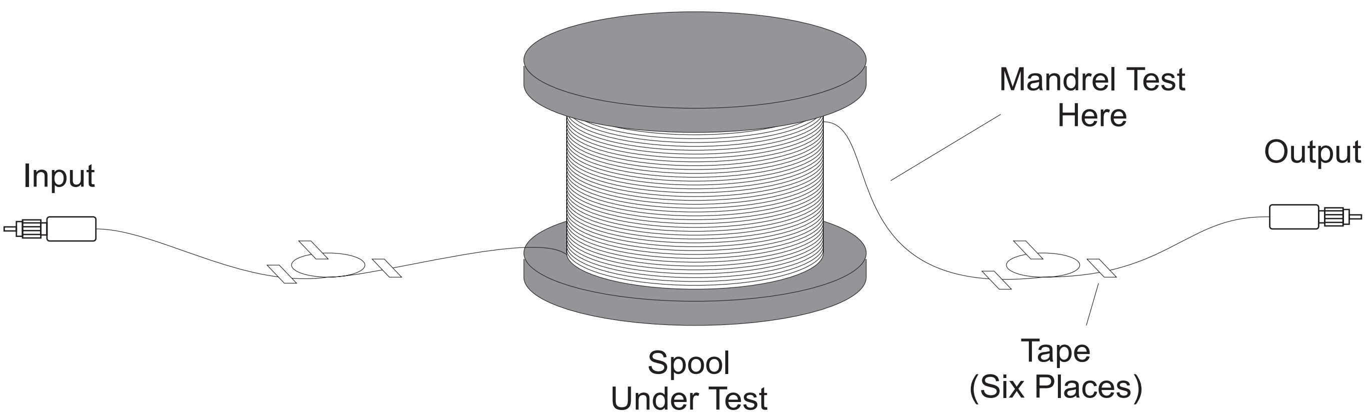

Figure 5: Preparation of A Fiber Spool For Measurement

8. If the increase is less than one or two dBs, then the light is being launched along the polarization axis of the fiber. Ideally there should be no change or even a slight decrease in the minimum power.
9. If the increase is greater than two dBs, or if the worst case reading is worst than the minimum acceptance level, then repeat steps 6 and 7. If the fiber still fails, then clean both fiber ends with a lint free tissue and acetone, then repeat steps 2 to 7. If the fiber still fails, then reject it.
10. Reverse the input and output ends and remeasure the extinction ratio of the spool. Use the worst of the two readings as the actual extinction ratio of the fiber.

How To Align and Measure Polarization During a Fusion Splice

The following procedure outlines how to align the polarization axis of a fiber during a fusion splice for optimum polarization extinction ratio. It also explains how to evaluate the splice performance after the splice.

This procedure assumes that one can view the endfaces of the PM fibers in the fusion splicer prior to splicing, to determine the orientation of the slow axis of each fiber. If not, then a microscope viewer is required to see the stress rods at the splice.

1. Set the fusion splicer to the **manual** splicing setting. This is necessary to measure and set the polarization alignment of the fibers after aligning the fibers for minimum loss, but before actually fusing the fibers together. You can still use the automatic alignment capabilities of the fusion splicer to optimize the losses, if possible.
2. Prepare the input fiber by following the procedure outlined in steps 1 to 9 in the procedure ***How To Characterize The Extinction Ratio Of A PM Fiber***, above. Record the current extinction ratio of the input fiber, ER_0
3. Leave the input end of the fiber still connected to the source. Strip and cleave the output end of the fiber for fusion splicing, as described in the fusion splice manual. Insert it into the fusion splicer.
4. Strip and cleave the end of the second fiber for fusion splicing. Insert it into the fusion splicer.
5. Using the microscope viewer on the fusion splicer, inspect the fibe endfaces being spliced together. Rotate the fibers until the stress rods are roughly aligned.
6. Attach the output end of the second fiber to the extinction ratio meter. If the output end does not have a connector, then use a bare fiber adaptor, and form a loop about 10cm in diameter in the middle of the output end of the second fiber. Tape the loop to the table using three pieces of scotch tape. This is done to ensure that the fiber does not accidentally rotate during the test.
7. Align the fibers in the fusion splicer for minimum losses. **Do not splice the fibers at this point.**
8. If your fusion splicer uses a local injection and detection (LID) system to align the fibers, then release the fibers from the LID system. The LID system interferes with the polarization maintaining properties of the fibers.
9. Note the current readout of the polarization extinction ratio. Rotate the second fiber within the fusion splicer to further improve the extinction ratio readout to the best possible level.
10. Slowly wrap the second fiber for three wraps around the mandrel. This may result in a slight reduction in the extinction ratio readout. Note the worst case readout while wrapping the fiber, then unwrapping the fiber
11. If the increase is less than one or two dBs, then the light is being launched along the polarization axis of the fiber. Ideally there should be no change or even a slight decrease in the minimum power.
12. If the increase is greater than two dBs, or if the worst case reading is worst than the minimum acceptance level, then repeat steps 9 to 11. If the extinction ratio still fails, then clean both fiber ends with a lint free tissue and acetone, then repeat steps 2 to 7. If the extinction ratio still fails, then there must be a problem with the second fiber. Test it as per the procedure ***How To Characterize The Extinction Ratio Of A PM Fiber***,
13. Assuming that the extinction ratio is good, realign the fibers for minimum splice loss
14. Fuse the fibers together.
15. Repeat steps 8 to 11 above to determine the final extinction ratio of the system, ER_{FINAL}.
16. If desired, one can extrapolate the limiting extinction ratio of the fusion splice, ER_{CON}, based on the equation given on page 6 of this document. However, in cases where the fusion splice is very good, random measurement errors in the initial and final ER readings may produce either inaccurate or even invalid results.

How to Characterize a Polarization Maintaining Connector

The following procedure describes how to measure the output extinction ratio of light from a fiber optic connector or patchcord, and determine the connector loss and alignment versus known references.

To check insertion losses, an optical power meter is also required.

1. Turn on the polarized source and allow the source to warm up for ten to fifteen minutes. Adjust the polarizer until the angle reading matches the keyway reference angle, as marked on the source
2. Attach the fiber to the polarized source and if necessary, adjust the coupler for optimum coupling efficiency
3. Attach the output end of the test fiber to the extinction ratio meter. Note the current readout of the polarization extinction ratio.
4. Rotate the polarizer on the polarized source to further improve the extinction ratio readout to the best possible level.
5. Slowly wrap the fiber for three wraps around the mandrel. This may result in a slight reduction in the extinction ratio readout. Note the worst case readout while wrapping the fiber, then unwrapping the fiber
6. If the increase is less than one or two dBs, then the polarization axis is correctly aligned. Ideally there should be no change or even a slight decrease in the minimum power.
7. If the increase is greater than two dBs, or if the worst case reading is worst than the minimum acceptance level, then repeat steps 4 to 5. If the patchcord still fails, then clean both fiber ends with a lint free tissue and acetone, then repeat steps 2 to 5. If the patchcord still fails, then reject it.
8. Note the polarization angle readout. It should also read the desired angle (normally zero degrees), to within the desired tolerances. If not, then reject it.
9. Disconnect the output end of the patchcord from the extinction ratio meter.
10. (Optional) Measure the output power from the fiber using an optical power meter.
11. Connect the PM master fiber to the test patchcord using the bulkhead connector.
12. (Optional) Measure the output power from the combined patchcords. The change in power is the optical loss.
13. With the Master fiber still attached to the patchcord being tested, repeat steps 5 to 7. The combined system should still meet minimum specifications for the extinction ratio.

Note: The polarization performance of a patchcord is not the same in both directions. If the connector on the output end of a patchcord is stressed, the output polarization will be changed. Most often the output polarization will be rotated with respect to the polarization axis of the fiber. As a result one will measure a good extinction ratio, with a slight rotation. This rotation angle will depend on the exact wavelength being used. Bending the fiber will not affect the output, because the stress occurs after the region being bent.

However, if the same connector is used as an input, then the polarization state is perturbed before it enters the fiber. Now bending the fiber does affect the output polarization. Therefore the measured polarization will be worse when a poor connector is used on the input side than on the output side.

Thus to properly measure the behavior of a fiber, measure it in both direction.