

## Technical Note 003

### Polarization extinction ratio measurement

#### 1. Purpose

The polarization extinction ratio, also abbreviated PER, defines the optical characteristics of connectors using polarization maintaining fibre, also abbreviated PM fibre.

#### 2. References

The reference for the polarization extinction ratio measurement is following:

- International Standard IEC 61300-3-40 'Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3.40: Examinations and measurements – Extinction ratio of a polarization maintaining fibre pigtailed connector'

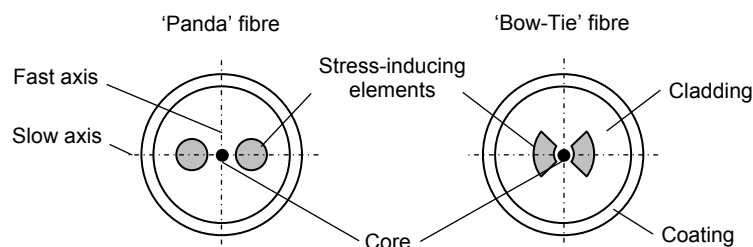
Diamond SA, Losone (Switzerland), has developed a specific manufacturing process and a validated measurement method for PM components. The polarization extinction ratio measurement method applied at the Test & Calibration Laboratory STS 333 / SCS 101 at Diamond SA, Losone (Switzerland), has been validated by the Swiss Accreditation Service, Wabern (Switzerland).

Other references describing polarization maintaining fibre optics technology are following:

- Eugene Hecht, 'Optics', 3<sup>rd</sup> Edition, 1998, Addison Wesley Longman Inc., USA
- Dennis Derickson, 'Fiber optic test and measurement', 1998, Prentice Hall Inc., USA
- Christian Hentschel, 'Fiber optics handbook', 1989, Hewlett-Packard GmbH, Germany

#### 3. Physics of polarization maintaining fibre

The birefringence characteristics of PM fibres is given by stress-inducing elements or by an asymmetric design in the PM fibre. The birefringence defines the two main axis in the PM fibre, the slow axis and the fast axis. Examples of the cross section of PM fibres with stress-inducing elements is given in figure 1.



**Figure 1:** Examples of a cross section of two PM fibre types, 'Panda' fibre (left in figure) and 'Bow-Tie' fibre (right in figure), with their stress-inducing elements.

The stress-inducing elements cause a small change of the fibre index  $\Delta n$  in the fibre core in the two perpendicular axis, the slow axis and the fast axis.

If the electrical field of light oscillates in one of the two main axis, its amplitude is maintained along the PM fibre. Otherwise the phase of the electrical field between the two main axis would not be maintained and would be influenced by the fibre length, by the wavelength of the transmitted light and by external mechanical and thermal stress on the fibre.

The maintaining of the polarization is therefore only possible, if linear polarized light is coupled into one of the two main axis. Every other polarization state is a combination of the two main polarization states and therefore the phase difference along the fibre and consequently at the fibre output would not be maintained. For this reason the light shall be coupled at the fibre entrance parallel to the slow axis or to the fast axis.

In order to achieve an optimal coupling of the light into a PM fibre, a stress-free positioning and an accurate orientation of the main axis of the PM fibre in the fibre optic connector is therefore needed.

#### 4. Orientation of polarization maintaining fibre

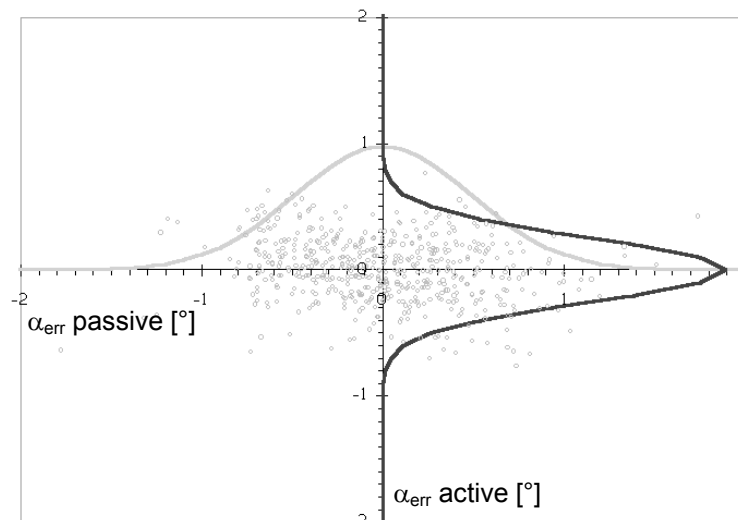
Two main methods for the orientation of PM fibre are known, the passive orientation method and the active orientation method.

The passive orientation method is based on the geometric orientation of the PM fibre axis with a visual identification of the position of the stress-inducing elements in the fibre cross section (geometrical main axis).

On the contrary, the active orientation method is based on the identification of the PM fibre main axis through measurement of the polarized light signal (optical main axis).

Small differences in the identification of the main axis using the two methods can be explained with small stress differences in the PM fibre or with other external stress sources, as for example glued parts. Those stress differences have consequences on the orientation of the main axis in the PM fibre but they are invisible to optical microscope analysis.

Figure 2 shows a comparison of the results of the measurement of the orientation error angle  $\alpha_{err}$  of one of the main axis. The PM fibre was oriented using the active orientation method and afterwards its orientation error angle was measured using both methods, the passive orientation method respectively the active orientation method.



**Figure 2:** Comparison between the distribution of the orientation error angle measured with the measurement setup for the passive orientation respectively with the measurement setup for the active orientation on the same PM fibre.

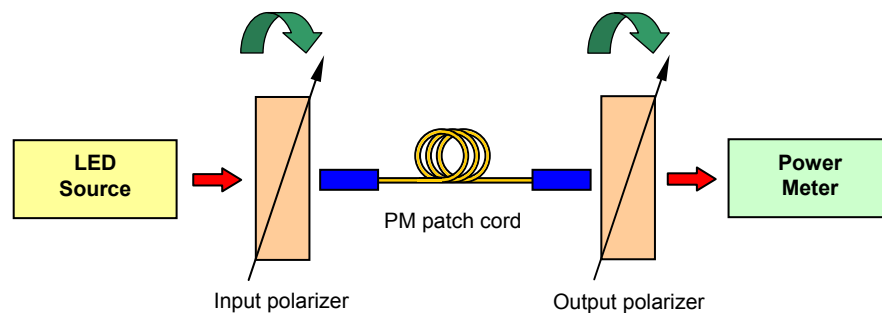
The showed comparison gives an indication upon the accuracy and the repeatability that can be achieved with the active orientation method respect to the passive orientation method.

### 5. Active orientation method

The manufacturing and measurement technology for PM components developed at Diamond SA, Losone (Switzerland), allows to reach the precision in the fibre core concentricity, as for standard SM applications, with the supplementary PM fibre orientation, which is necessary for PM applications.

The design of the PM ferrule allows a stress-free fixation of the PM fibre and the mechanics of the PM connector allows a precise orientation of the ferrule in the connector body.

The applied principle in the active orientation of the PM fibre is the so called method of cross polarizers. Figure 3 shows a schematic representation of the applied method.



**Figure 3:** Schematic representation of the PM fibre orientation respectively measurement method using cross polarizers.

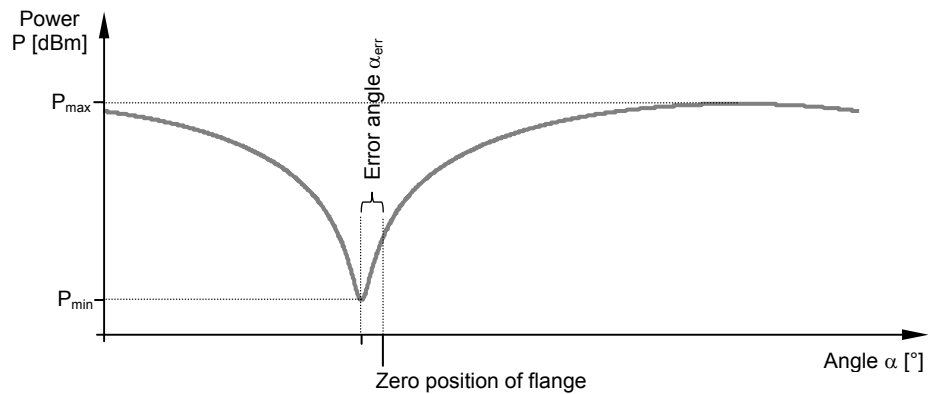
The use of the cross polarizers method implies a preliminary pre-orientation of the PM fibre of the PM connector on the input side, in that way light can be coupled into the correct main axis.

The cross polarizers method needs the use of a light source with low coherence. Through rotation of an angle of 180° of the polarizer at the output side, the output power level as function of the coupling angle is measured. In this way the angle, at which the minimum power level is measured, can be determined. The polarizer at the output side is then maintained in this position, the polarizer at the input side is rotated again in order to find the minimum output power level. This will then correspond to the correct coupling angle at the input side of the PM patch cord.

The polarization extinction ratio PER is a parameter which quantifies the optical characteristics of PM connectors. The polarization extinction ratio is given by the logarithmic function of the minimum output power level  $P_{min}$  and the maximum output power level  $P_{max}$ , which are measured through variation of the output angle  $\alpha$ . The formula for the polarization extinction ratio PER is given in (1).

$$PER = -10 \cdot \log \left( \frac{P_{min}}{P_{max}} \right) \tag{1}$$

The zero position (reference position) of the PM connector during the polarization extinction ratio measurement is given by a calibrated connector adapter. The difference between the zero position of the calibrated connector adapter and the position of the minimum measured power level is defined as error angle  $\alpha_{err}$ . Figure 4 shows a graphical representation of the error angle  $\alpha_{err}$ .



**Figure 4:** Output power level P of the PM connector as function of the angle  $\alpha$  respect to the fibre main axis during a measurement with the cross polarizers method. Represented also a fictive error angle  $\alpha_{err}$  of the PM connector respect to the zero position of the connector adapter.

The used measurement setup is composed by a low coherence light source, two motorised polarizers, at the input respectively at the output side, with adapter for different connector families, an optical head and a control station. The cross polarizers method allow a precision in the orientation angle in PM fibre of about  $\pm 0.8^\circ$ . Figure 5 shows the measurement setup.



**Figure 5:** Measurement setup for the orientation of PM components using the cross polarizers method.

## 6. Measurement example

The error angle of two mated PM connectors causes a degradation of the polarization extinction ratio. A small amount of the polarized light is coupled outside the main axis and therefore the light polarization cannot be completely maintained.

The polarization extinction ratio can be represented as function of the coupling error angle. The larger the error angle is, the larger the amount of not further coupled power and the smaller the polarization extinction ratio value.

The formula for the theoretical polarization extinction ratio  $PER_{theo}$  as function of the error angle  $\alpha_{err}$  of two coupled PM fibres respectively PM connectors is given in (2).

$$PER_{theo} = -10 \cdot \log [\tan^2(\alpha_{err})] \tag{2}$$

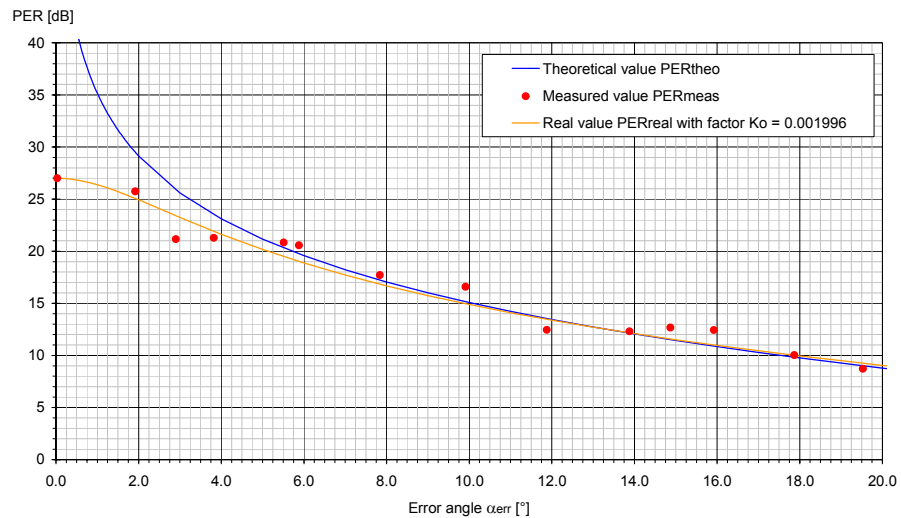
Theoretically, with an error angle equal to zero, the coupled PM fibres would show an infinitely high polarization extinction ratio value. In practice such a situation cannot be achieved, the PM fibre itself has a limited polarization extinction ratio value.

All deviation from the ideal situation when describing the polarization extinction ratio can be modelled using a so called correction factor. The formula which expresses the real polarization extinction ratio  $PER_{real}$  as function of the error angle  $\alpha_{err}$  of two coupled PM fibres respectively PM connectors is given in (3).

$$PER_{real} = -10 \cdot \log [\tan^2(\alpha_{err}) + K_0] \tag{3}$$

Where  $K_0$  represents the correction factor.

In order to verify the mentioned formulas, PM connectors with different error angles were assembled and measured with the cross polarizers method. Figure 6 shows the theoretical polarization extinction ratio  $PER_{theo}$ , the measured polarization extinction ratio  $PER_{meas}$  on PM connectors and the real polarization extinction ratio  $PER_{real}$  modelled with a correction factor  $K_0 = 0.001996$  as function of the error angle  $\alpha_{err}$  respect to the main axis of the PM connector.



**Figure 6:** Theoretical polarization extinction ratio  $PER_{theo}$ , measured polarization extinction ratio  $PER_{meas}$  and real polarization extinction ratio  $PER_{real}$  modelled with a correction factor  $K_0$  as function of the error angle  $\alpha_{err}$  respect to the main axis of the PM connector.

In the showed example the correction factor  $K_0 = 0.001996$  was calculated for a polarization extinction ratio value of 27 dB at an error angle  $\alpha_{err} = 0^\circ$ . In figure 6 is visible a good approximation of the real polarization extinction ratio  $PER_{real}$  modelled with a correction factor  $K_0$  respect to the measured polarization extinction ratio  $PER_{meas}$ .

In this case, the polarization extinction ratio measurement showed a standard deviation of 1.07 dB on the measured polarization extinction ratio values respect to the modelled curve, which gives a good indication upon the accuracy achievable with the cross polarizers method.