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# Study of Non- Linear Polarization Rotation and Optical Switching in Optical Fibers

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ABSTRACT

This paper presents the study of non- linear polarization rotation and optical switching in optical fibers. Also, present a way to obtain the polarization coupling length, an important parameter for the PMD probability distribution. This parameter is obtained from measurements and modeling of the nonlinear polarization rotation in optical fibers. Results for different types of fibers are presented.
**Keywords:** Optical components, Optical fibre, Polarization coupling.

## I. INTRODUCTION

It is well known that single-mode communication fibers are birefringent and that the orientation and the amount of birefringence are randomly distributed along the fibers. The corresponding polarization mode dispersion (PMD) becomes therefore a statistical quantity, and not only its mean value but also its probability distribution is important to assess the inferred system impairments. This distribution depends on two parameters: the (mean) local birefringence B and the polarization coupling length h, which is the distance over which the E field loses memory of its initial projection over the local polarization eigenstates [1-4]. In fibers having a length L long compared to h, the probability distribution is Maxwellian with a mean PMD value of B, whereas for coupling lengths approaching the fiber lengths, the PMD statistic can change considerably. It is therefore important to have knowledge not only of the overall PMD but also of h and the beat length $L_b$. In this section we present a novel way to directly infer the polarization coupling length from measurements of the nonlinear polarization rotation (NPR) in a fiber.

## II. PRINCIPLE OF OPERATION

In a dielectric medium, an intense elliptical input pulse induces birefringence via the optical Kerr effect - due to the different amounts of intensity along the major and minor axis of the polarization ellipse. In an isotropic medium this self-induced birefringence leads to polarization ellipse self-rotation. In an optical fiber however, the situation is more complex due to the presence of the local intrinsic birefringence. The polarization changes are hard to predict in that case as the linear and nonlinear birefringences interact in a complicated manner. In general, the linear birefringence will however be much larger than the induced nonlinear one, and the evolution of the polarization vector y in a polarization maintaining fiber can then be approximated by:

$$\partial_z\psi \approx i\omega B_{eff}\sigma_\theta\psi = \omega(B - \frac{\alpha}{2}m_\theta(0))\sigma_\theta\psi \quad (1)$$

where sq accounts for a linear birefringence with axis $\omega = n_2P/(3cA_{eff})$, $n_2$ is the nonlinear Kerr coefficient, P the power, and $A_{eff}$ the effective area. $m_\theta(z)$ is defined as the projection of the SOP on the birefringent axis at the position z along the fiber. The term $B_{eff}$ takes into account for the linear birefringence B and the nonlinear birefringence. The solution for Eq. (1) is straightforward, and corresponds to a rotation of the input polarization vector around the linear birefringence axis $\omega_0$, with a rotation angle θ given by $\omega = B_{eff}z$. In principle the NPR can now be measured by varying the input power P and observing the corresponding change in the output SOP. However, an inherent problem for this kind of measurements is the instability of the output SOP at the exit of the fiber. Due to temperature changes and drafts in the fiber environment the dominant linear birefringence B strongly fluctuates and completely covers the nonlinear induced change. We have recently proposed a method for measuring NPR by removing the overall linear birefringence -and therefore also its fluctuations- in a purely passive way by employing a Faraday mirror (FM) and a double pass of the fiber under test. Doing so, the nonlinear birefringence (leading to NPR) was shown to remain unaffected, i.e. the NPR of the forward and backward paths add up. This allows to measure NPR both in polarization maintaining (PM) fibers and in standard fibers. However, the random variations of the intrinsic local birefringence axis in a standard fiber reduce the NPR. This reduction is due to the increased probability that the NPR action along each fiber's piece where the birefringence is constant, is compensated for by another. The situation becomes more complex, and we therefore resort to numerical simulations. The fiber is modeled as a concatenation of linearly birefringent trunks -for which Eq. (1) holds - with a constant physical length $L_C$. The amount of birefringence of these trunks is fixed (i.e. equal in all trunks), whereas its orientation is driven by a white noise process $g_0(z)$ characterized by a dispersion $\sigma_{WN}$. For each single trunk, Eq. (1) is used to calculate the output SOP from the input one, which is calculated from the output SOP of the previous trunk according to the relative axis orientations.

The SOP is therefore calculated piece by piece, with the projection $m_\theta$ being different for each new trunk. The final SOP will depend on the choice of the birefringence axis orientations of the trunks, with variations being larger in the limit of $L_C \rightarrow L$. We therefore made 200 runs for each specific trunk length to get a mean value of the NPR.

## III. EXPERIMENTAL SETUP

The experimental setup for the measurement of NPR for different test fibers is shown in Fig. 1. The light source consists of a distributed feedback laser (DFB) operated in pulsed mode at a wavelength of 1559 nm. Typically, pulses with a duration of 30 ns, a repetition rate of 1 kHz, and a peak power of up to 6 W (after amplification by an EDFA) are used. The light is then launched into the fiber under test (FUT) via a 90/10 coupler and a polarization controller (PC1). The coupler is inserted for the detection of the backward traveling light after the double pass of the FUT, with its 90% output port connected to the source in order to maintain high launch powers into the FUT. The polarization controller, PC1, allows to adjust the polarization of the light launched into the FUT, i.e. mq which is important for the strength of the NPR as demonstrated by Eq. (1). Note that for low launch powers (negligible NPR), the action of PC1 is removed by the Faraday mirror, and its setting is therefore of no importance in that case. The output SOP is examined by an analyzer consisting of a polarization controller PC2 and a polarizing beam splitter (PBS). To achieve a good sensitivity of the analyzer, it is calibrated for equal power in the two PBS output arms for low power launch signals where no NPR occurs. The two PBS output channels were monitored by a fast photodiode (200 ps response time) and a sampling scope. The measurements were then performed in the following way: for a given launch power, the polarization launched into the FUT was adjusted (PC1) to give the smallest possible output power at the monitored PBS channel. Consequently, the difference between the two PBS output channels is maximized, corresponding to a maximum value of the NPR.

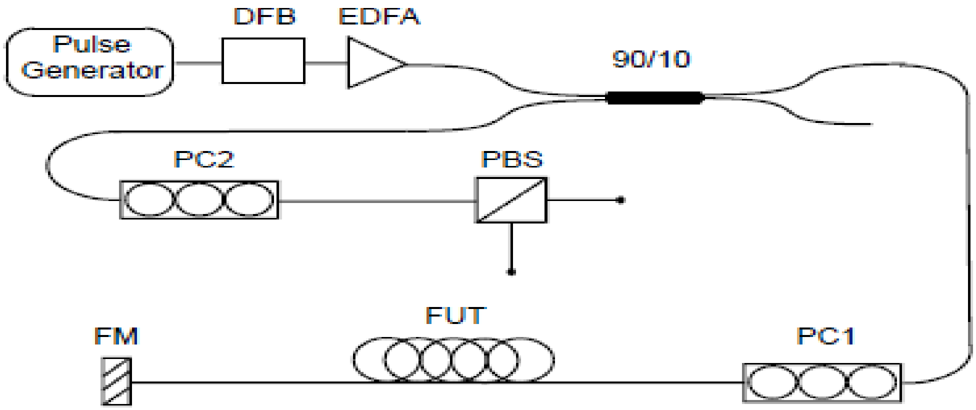


**Figure 1:** Experimental setup of the NPR measurement. DFB- distributed feedback laser, EDFA-Erbium doped fiber amplifier, PC- Polarization controller, FUT- Fiber under test, FM- Faraday mirror, PBS- Polarizing beam splitter.

## IV. RESULTS AND DISCUSSION

We first measured the NPR in a PM fiber with a length of 200 m. The results indicate that the NPR manifests itself with a reduction of the power in the monitored PBS channel. The output power starts to decrease in spite of the linear increase that would be experienced in the absence of NPR. The measured data agree well with our model, in which m□(0) was varied in order to give a minimum output power from the PBS channel like in the experiment, and only one fiber trunk was used ($L_C$= fiber length L). The model curve for the PM fiber is shown in Fig. 2 (bold curve). Measurements were then made on different standard single mode fibers (SMF). The fiber lengths were typically 1 km (simulations were adjusted accordingly to each fiber length and $n_2/A_{eff}$ coefficient). Fig. 2 shows the results for 3 different SMF; fiber A and B with a PMD of .05 ps/km (open and full circles) and fiber C with a PMD of 1.9 ps/$\sqrt{km}$ (full squares). The three standard fibers clearly exhibit a different amount of NPR with the fiber C showing a NPR similar to a PM fiber (bold curve). In order to fit the experimental data, we have to introduce the polarization coupling length h. The coupling length is defined as the length at which the fiber autocorrelation function <cos[□(z) -□(0)]> is equal to 1/e.

For the discrete case (as in our simulations) in which each piece of fiber has a fixed length $L_C$, it's easy to show that h = $2L_C/\sigma_{WN}^2$. The fitting of the experimental data could then be made with two different free parameters; the length $L_C$ and the dispersion $\sigma_{WN}^2$ of the white noise process, providing h will remain constant. This is shown to be the case for our data as shown in the inset of Fig. 2. Here $L_C$ is varied between 5 and 200 m and $\sigma_{WN}^2$ between 10 and 70 degrees. The simulations show that for the three different fibers the coupling length can be estimated to be about 160 m for the fiber A and 300 m for the large PMD fiber (fiber B). A value of h<100 m is quite reasonable for a state-of-the-art, low PMD fiber. The coupling length of the SMF with high

PMD (fiber C), found to e about 1000 m, is surprisingly quite large, indicating that there might be well defined birefringent axes in that fiber.

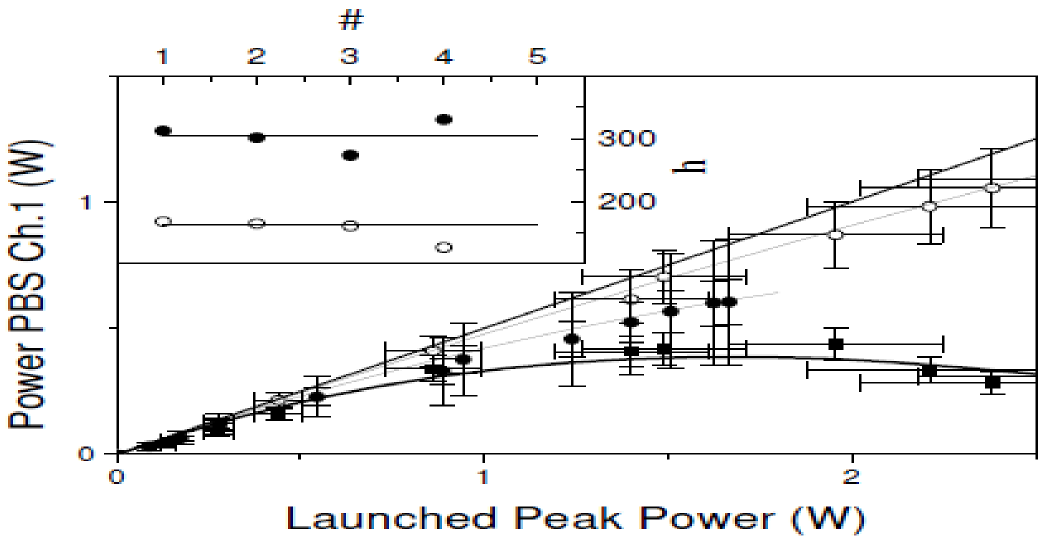


**Figure 2:** Minimum output power of PBS channel 1 as a function of the launched power. Symbols refer to the measured data fiber A (open circles), B (full circles), and C (full squares). Solid curve: prediction from our model. Straight bold line: prediction in the absence of any NPR. Bold curve: PM fiber. In the inset are shown the values of the calculated h for different $WN$ and L$C$ combinations giving curves that fits the experimental data.

## V. CONCLUSIONS

We presented measurements and a model of NPR in an optical fiber, allowing for direct determination of the polarization mode coupling length. Polarization coupling length values as low as 160 m in state-of-the-art low PMD fibers were found.

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