POLARIZATION-DEPENDENT LOSS STATISTICS IN RECIRCULATING LOOPS

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Abstract *We study the statistical distribution of the accumulated polarization dependent loss (PDL) in recirculating loops. The distribution is studied both experimentally and via numerical simulations; very good agreement is found between the two.*

Introduction

Long-haul fiber transmission systems operating at high bit rates (>10Gb/s) are severely affected from polarization dependent effects such as polarization mode dispersion (PMD) and polarization dependent losses (PDL). PMD gives rise to pulse broadening; PDL, along with polarization dependent gain, gives rise to fluctuating OSNR. The PDL is present not only in the fibers that constitute the link, but even in the optical components. Moreover, their coupling is randomly distributed along the link and only a statistical description of the total accumulated PDL can be given. Studies in this direction [1-2] demonstrate that the total accumulated PDL is Maxwellian distributed (when expressed in dB), and that the mean PDL accumulates linearly. But an interplay between PDL and PMD is often present and there is a need in studying their distributions, both combined and separately. A natural way is to reproduce long links in the laboratory using recirculating loops. Unfortunately, due to the intrinsic periodicity of the system (no inter-loop polarization decorrelation exist), polarization phenomena are unrealistically distributed. This was recently demonstrated for PMD [3]. Regarding the PDL, an analysis of the evolution of the state of polarization (SOP) in recirculating loops has been conducted [4]. But for what concerns the general problem of determining the statistical distribution of the PDL, no study was done at present. Here we report on an experimental study of the statistical distribution of the accumulated PDL. Numerical simulations and analytical theory (not presented here) are found in good agreement with the experimental data.

Experimental Setup

The experimental setup is shown in Fig.1. Different optical elements are present in the loop: three acusto-optical switches, a computer controlled polarization controller, a single mode fiber, an amplifier, a PDL emulator, a bandpass filter, and a coupler. The three switches (SW) control the loop. The computer controlled polarization controller (APC) allows to modify the total Jones matrix of the loop. The 12 km SMF fiber acts as a delay line for the loop. The EDFA compensates for the power loss of each recirculation, and its gain is equal to the total loop loss. In order to avoid as much as possible any power step variation inside the loop, the length of the loop is set such that after N circulations, the loop is immediately filled with another pulse. In this way the EDFA gain remains constant and the loop emulates correctly the response of a chain of EDFAs. The variable PDL emulator (PDLE) consists of an open beam launcher/collimator with a tilted glass plate inserted. The optical bandpass filter OBF is centered on the DFB laser's wavelength at 1550 nm with a 1.3 nm bandwidth, and reduces the ASE of the EDFA, otherwise growing at each recirculation. The 3dB coupler couples the light in and out the recirculating loop. The PMD of the loop is negligible.

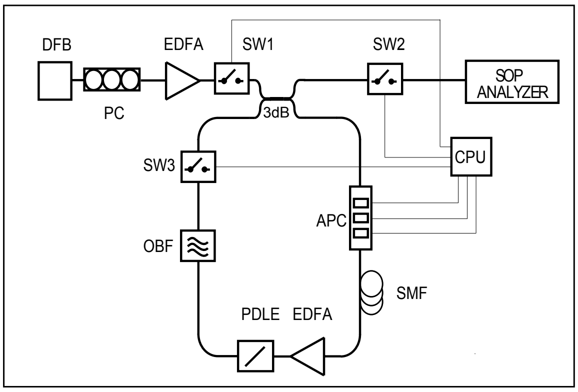

Figure 1. Experimental setup for the recirculating loop.

Experimental Results

The probability density distribution of the accumulated PDL is determined in the following way. We first make measurements from two up to ten circulations in the loop, with the APC uniformly scrambled between the measurements. One thousand samples (each one at a different polarization setting) are then measured for each number of recirculations through the loop. From this data, the probability density distributions are finally extracted. The PDL measurement principle (JMM) used to acquire the data is based on the method of Heffner [5].

The APC generates random uniformly distributed SOP on the Poincare sphere. Note that the APC used in the experiment introduces a setting dependent PDL (i.e. the PDL of the loop γ_{Loop} is a function of the different polarization settings of the APC).

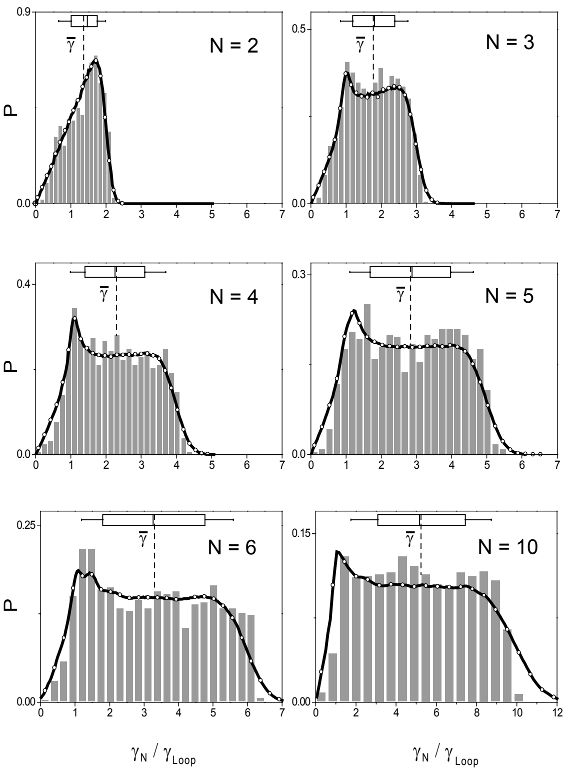

Figure 2. Probability density distribution for the accumulated PDL γ_N normalized to the PDL loop value γ_{Loop} ,for different number of recirculating loops (2-10). A box chart is shown on top of each inset. The vertical lines in the box denote the 25th, 50th, and 75th percentage values.

The distribution of the PDL values for the APC is found to be Gaussian (when expressed in dB), centered at 0.27 dB, and with standard deviation equal to 0.10 dB.

Considering the non negligibility of this value, we set the PDL emulator at a value quite larger compared to the intrinsic PDL value of the loop (1.20 dB, with a 0.10 dB standard deviation).

Having determined γ_{Loop} we switch out, by way of the extracting switch SW2, the recirculating pulse in which we are interested. The probability density distributions for the accumulated PDL γ_N normalized to the PDL loop value γ_{Loop}, are shown in Fig.2 for different numbers of recirculating loops (N=2-10). The grey bars are the experimental data, with a total number of measurements equal to 1000. The bold line is the theoretical probability density function obtained by convolution of the density function (determined via numerical simulations) and the Gaussian distribution function. Both experimental and theoretical histograms, are sampled with the same bin width histogram parameter. The agreement between the experimental results and the theoretical ones is excellent. A parameter that is interesting to extract from the probability distributions is the root mean square normalized accumulated PDL. The values obtained for the different number of loops are shown in Fig. 3 (open circles). The bold line corresponds to the theoretical fit of the data using the analytic formula, which derivation is not reported here

$$\sqrt{\left\langle {\gamma_N}^2 \right\rangle} = \gamma_{Loop}\sqrt{\frac{N^2+2}{3}} \; . \qquad (1)$$

From the fit (Chi-square goodness-of-fit accuracy χ^2 = 0.0001) we obtain a value for the loop PDL of (1.21 +/- 0.01) dB in complete accordance with the value as measured for the first loop. The accumulated average PDL increases almost linearly with the number of recirculations through the loop. This is in contrast to a randomized straight-line transmission link, for which the expectation value of the PDL grows as the square-root of the link length (thin line) [2].

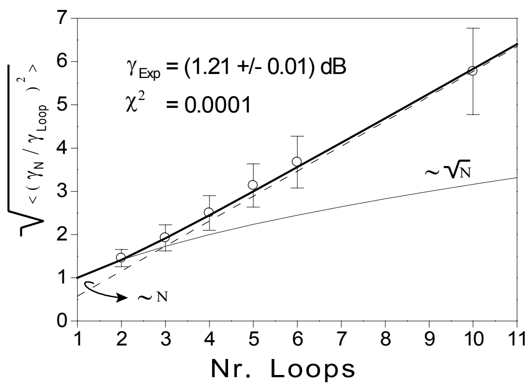

Figure 3. Root mean square normalized accumulated PDL as a function of the number of recirculations.

Conclusions

In this paper, we have experimentally derived the statistical distribution of the PDL in a recirculating loop.

We have conducted both an experimental investigation, and numerical simulations; the measured probability density distributions are in very good agreement with the predicted ones. The probability density distribution for the accumulated PDL is a linearly increasing function for two circulations through the loop. When instead the number of circulations increases, the PDL approaches a uniform distribution.

The mean accumulated PDL grows linearly with the number of circulations N, in contrast to a straight-line optical system.

References

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