Automatic PMD Compensation at 40 Gbit/s and 80 Gbit/s Using a 3-Dimensional DOP Evaluation for Feedback

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Abstract: We demonstrate that polarization scrambling combined with DOP evaluation enables PMD compensation without feedback fading due to varying input polarization. PMD of an installed fiber as well as PMD of an emulator was successfully compensated.
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Introduction

Signal degradation due to polarization mode dispersion (PMD) is a matter of increasing importance [1,2] since per-channel bit rates have passed the 40 Gbit/s mark and are heading towards 80 Gbit/s and higher [3,4]. In a 40 Gbit/s system one bit slot has a duration of 25 ps, hence even low PMD of modern fibers can cause severe signal distortions and degradation of BER performance. Also PMD of buried fiber spans show temporal fluctuations making a static compensation impossible, but requiring an active compensation using a feedback control loop. A well-known problem of PMD compensators used so far is sensitivity fading of the feedback signal induced by varying input polarization (SOP). In our experiment we use a 3-dimensional analysis of the degree of polarization (DOP) of the received data signal in order to provide PMD compensation of an installed fiber as well as compensation of an emulator for any input polarization. Usually, a DOP measurement does not yield a proper estimate of the PMD because of its dependence on input polarization [5]. We overcome this limitation by using a polarization scrambler at the fiber input. In this way we gain information on the instantaneous principal states (PSP) as well as on first-order and second-order PMD of the fiber link. A 3-dimensional DOP detection for generating a feedback signal seems attractive since it works at any modulation format and even for bit rates as high as 160 Gbit/s without the need of high-speed electronics.

Concept of PMD determination and compensation

In the presence of PMD, the DOP of a modulated signal is reduced [5]. The amount of reduction depends on the amount of first and higher order PMD, the spectral bandwidth of the signal and the input polarization. Particularly the dependence on input polarization causes problems because a DOP measurement at the output is insensitive to first-order PMD if the input SOP matches the fiber PSP. In this case a delay line compensator usually cannot track the differential group delay (DGD) of the fiber span. This misadjustment becomes relevant as soon as the input SOP moves away from the fiber PSP. If the adjustment cannot be corrected instantaneously the bit error rate (BER) will increase rapidly. Polarization scrambling at the fiber input and continuous DOP-evaluation is a solution to these problems. We use a pair of piezo-driven fiber squeezer causing the input polarization to cover the whole Poincaré sphere within 18 ms. At the fiber output a Stokes polarimeter monitors the variation of the polarization state including the DOP. This polarimeter acquires 140 SOPs in 18 ms and displays the measured SOPs on the Poincaré sphere, where the DOP determines the length of a Stokes vector. The measured SOPs form an ellipsoid whose shape reveals information about the system's PMD and PSP.

In a first-order PMD-disturbed system the DOP is equal to unity for input polarizations matching the PSP. The more the input SOPs differ from the PSP, the more the DOP is reduced.
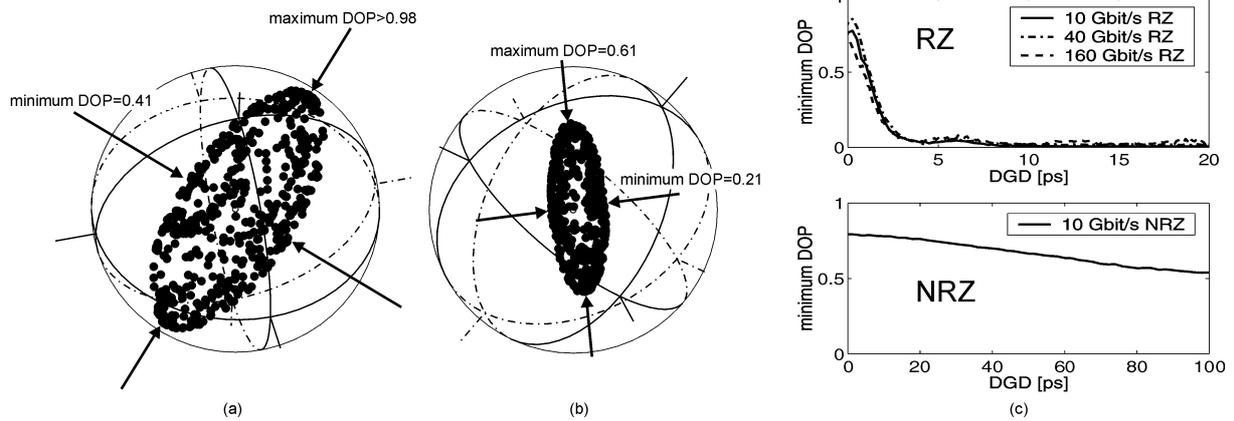
Fig. 1. Measured DOP reduction with scrambled input polarization of a 40Gbit/s RZ signal. (a) first-order PMD of 1.25 ps (b) second-order PMD, concatenation of two unaligned birefringent sections (6ps and 4ps DGD). (c) Sensitivity of the DOP reduction as a function of (first-order) DGD.

Thus the measured output SOPs form an ellipsoid whose long axis has a length of unity and points into the direction of the PSPs, as demonstrated by the experimental data depicted in Fig. 1a. In a second-order PMD-disturbed system (i.e. a system consisting of two unaligned birefringent sections) the long axis of the ellipsoid is shorter than unity (Fig. 1b), depending on the amount of second-order PMD. The relationship between DOP degradation and (first-order) DGD derived from our experiment is shown in Fig. 1c for different bit rates and modulation formats. These curves give an estimate of how sensitively a PMD compensator using the 3-dimensional DOP-evaluation as a feedback signal can match the PMD of the fiber link. It is obvious that the sensitivity depends strongly on the pulse shape. The sensitivity for the RZ signals used in our experiments is in the sub-picosecond range due to the short pulse width of 1.2 ps for 10, 40 and 160 Gbit/s. For the 10 Gbit/s NRZ system we used, the sensitivity is much lower due to the larger pulse width. This illustrates the beneficial fact that sensitivity of the feedback signal scales with decreasing pulse width. Fig. 1c also shows that ASE of fiber amplifiers causes a partial depolarization even if no PMD is present. A compensator using a maximum-search algorithm is not affected, however ASE complicates a quantitative estimation of the system's PMD if the intensity of the ASE is unknown.

Experiment

Testing the compensation scheme and demonstrating its properties was done with two experimental setups: a first-order PMD emulator and an installed SMF link. Both of them are shown in Fig. 2a as the lower and upper path of the transmission line, respectively. In both cases a polarization-insensitive receiver, as presented in [6], was used. To demonstrate the basic operation of the compensator we used an 80 Gbit/s RZ transmitter [7] and the first-order PMD emulator. With the emulator set to a DGD of 3 ps the transmission system showed severe BER degradation (Fig. 2b). At 6 ps no BER curve is shown since no detection was possible.
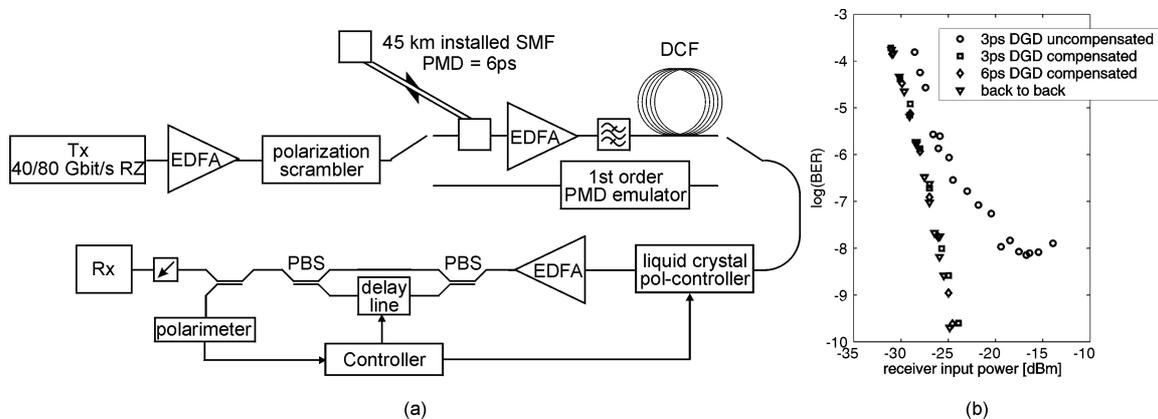
Fig. 2. (a) Experimental setup. (b) Compensator performance with first-order PMD emulator at 80 Gbit/s RZ modulation.
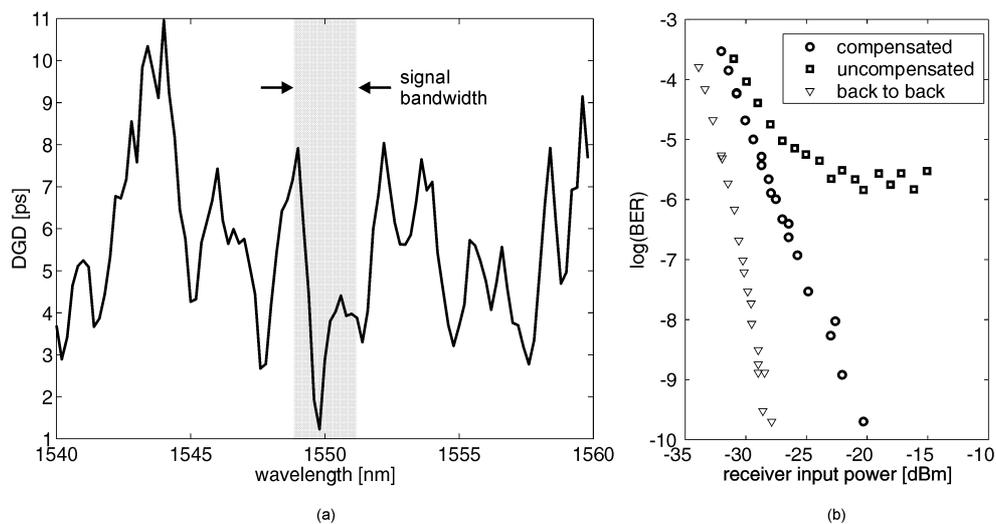
Fig. 3. (a) Spectral dependence of DGD of 45 km installed SMF. (b) Compensator performance at 40 Gbit/s RZ over installed fiber link. The compensator chose a DGD of 2.8 ps as optimum setting.

For both emulator settings the controller found the optimum compensator settings after approximately 100 regulating steps by maximizing the length of the shortest axis of the measured ellipsoid. After settling the compensator DGD of the compensator matched the emulator DGD with an accuracy of approximately 0.2 ps. As expected, the BER performance after compensation met the back-to-back performance.

For the field experiment we used an installed link of SMF of 45 km length in the city of Berlin. The chromatic dispersion has been compensated at the fiber output using dispersion compensating fiber. The PMD of the fiber link has been measured using a commercial PMD analyzer. The results in Fig. 3a show that second-order PMD effects are not negligible within the signal bandwidth. The BER performance illustrated in Fig. 3b shows that no error-free detection has been possible without PMD compensation. Even in spite of higher order PMD the controller was able to find optimum settings of the (first-order) compensator. The BER performance after settling of the compensator is also shown in Fig. 3b. It is obvious that after compensation error-free detection is possible. The residual penalty may be explained by the effect of second-order PMD as well as a sub-optimal compensation of chromatic dispersion.

Conclusions

We have successfully applied an automatic PMD-compensator in a field experiment over 45 km installed fiber of the Deutsche Telekom. The presented results show that the combination of polarization scrambling and continuous DOP measurement offers the opportunity for bit rate insensitive compensation of PMD. The 3-dimensional DOP evaluation of the received data signal is applicable for different modulation formats and yields information on status and evolution of PSP as well as first-order and second-order PMD of the link. The sensitivity of the DOP degradation 'accommodates' to the pulse shape, i.e. for shorter pulses sensitivity is increased. Moreover our scheme does not need high-speed electronics which is particularly advantageous at bit rates higher than 40 Gbit/s.

References

[1] F. Heismann, D. A. Fishman, D. L. Wilson, "Automatic Compensation of First-Order Polarization Mode Dispersion in a 10 Gb/s Transmission System", Proc. ECOC'98, Madrid, Spain Vol. I, pp. 529-530 (1998)
[2] H. Rosenfeldt, R. Ulrich, U. Feiste, R. Ludwig, H.G. Weber, A. Ehrhardt, "PMD compensation in 10Gbit-s NRZ field experiment using polarimetric error signal", Electronics Letters 36(5), pp. 448-449 (2000).
[3] B. Mikkelsen et al., "160 Gb/s TDM Transmission Systems", Proc. ECOC 2000, Munich, Germany, Vol II, pp 125-128 (2000).
[4] U. Feiste et al., "160 Gbit/s Transmission over 116 km Field-Installed Fiber Using 160 Gbit/s OTDM and 40 Gbit/s ETDM", paper ThF3, OFC 2001.
[5] N. Kikuchi, S. Sasaki, "Polarization-Mode Dispersion (PMD) Detection Sensitivity of Degree of Polarization Method for PMD Compensation", Proc. ECOC'99, Nice, France Vol. II (WeA1.3), pp. 8-9 (1999).
[6] C. Schubert et al., "160 Gb/s Polarization Insensitive All-Optical Demultiplexing using a Gain-Transparent Ultrafast-Nonlinear Interferometer (GT-UNI)", submitted to OAA (2001).
[7] U. Feiste et al., "Unrepeatered 80 Gbit/s RZ single channel transmission over 160 km of standard fiber at 1.55 µm with a large wavelength tolerance", OFC'99, San Diego, USA, FI1 (1999).