Feed-Forward Approach for Automatic PMD-Compensation at 80 Gbit/s over 45 km Installed Single Mode Fiber

H. Rosenfeldt (1), R. Ulrich (1), E. Brinkmeyer (1), U. Feiste (2), C. Schubert (2), J. Berger (2), R. Ludwig (2), H. G. Weber (2), A. Ehrhardt (3)

(1) Technische Universitaet Hamburg-Harburg FSP 2-03 Optische Kommunikationstechnik, D-21073 Hamburg, Germany (rosenfeldt@tu-harburg.de)
(2) Heinrich-Hertz-Institut Berlin GmbH, Einsteinufer 37, D-10587 Berlin, Germany (hgweber@hhi.de)
(3) T-Nova GmbH, Goslarer Ufer 35, D-10589 Berlin, Germany

Abstract: We report 80 Gbit/s transmission over 45 km installed fiber employing automatic PMD-compensation. A feed-forward controller adjusted the DGD of the PMD compensator in a single step avoiding the need for dithering.

Introduction

Polarization mode dispersion (PMD) causes severe signal impairments in high bit-rate optical transmission systems. Since there is still no established method for compensating PMD, telecommunication companies cope with this problem by using selected low-PMD fibers and reducing the transmission distance. In OTDM systems with bit-rates significantly higher than 40 Gbit/s, PMD limitations cannot be overcome by this approach since PMD reduces the signal quality even with low-PMD fibers.

A critical issue in every adaptive control system is its response time. Previous investigations have shown that a response time in the millisecond range is desirable for PMD-compensation [1]. If the parameters of the equalizing unit have to be dithered to find the optimum settings, this implies that the response time of the equalizing elements has to be shorter by an order of magnitude.

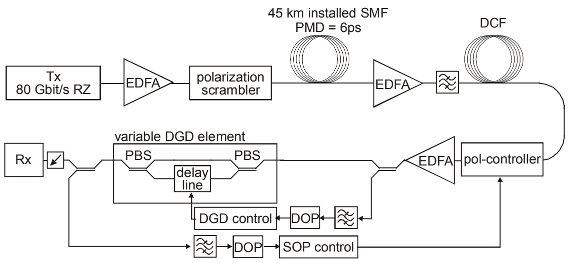
We reduce this requirement for the differential group delay (DGD) element of the compensator by applying feed-forward control in an open loop. In our experiment, the link DGD is continuously measured and fed forward to a variable DGD element in order to set the appropriate DGD of the compensator in a single step. Continuous DGD monitoring is realized by a polarization-resolved evaluation of the degree of polarization (DOP) combined with a polarization scrambler at the fiber input [2]. In this way the DGD of the link can be monitored at any time and the dependence on the input polarization is eliminated.

Using this PMD compensator, we performed the first error-free transmission of an 80 Gbit/s RZ data signal over a PMD-compensated installed fiber link of 45 km length with an average DGD of 6 ps.

DGD Measurement

In presence of PMD the DOP of the received signal is reduced. The amount of reduction depends not only on the DGD but also on the power-splitting ratio γ of the two principal states of polarization (PSP). The reduction is maximum for γ=0.5. Recent concepts propose to use the DOP as a quality signal in a feedback control loop [3,4]. Since the reduction of the DOP depends on the power-splitting ratio γ, it is not possible to derive the link DGD from the measured DOP alone. Thus these concepts maximize the DOP by dithering all parameters of the equalizing unit.

Figure 1: Experimental Setup



However, it is desirable to measure the DGD and the PSP of the fiber directly so that an equalizing unit can move directly to the appropriate state in a single step avoiding the need for dithering.

We applied this concept to the DGD control of our PMD compensator by using a polarization scrambler at the fiber input and by monitoring the DOP and the state of polarization (SOP) at the fiber output [2]. Since the scrambler causes the input polarization to cover the whole Poincaré-sphere within 18 ms, the minimum DOP occurring within that time interval belongs to a power-splitting ratio of 0.5 and allows to derive the link DGD. The PSPs can be determined by monitoring the SOP with the largest DOP within that time interval. [2,5].

Figure 2: Measured DOP response curve (squares: without bandpass filter, circles: with 1.2 nm bandpass filter), solid lines: simulation results.

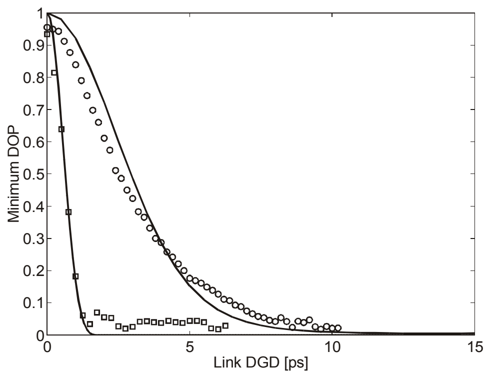


Figure 3: BER performance

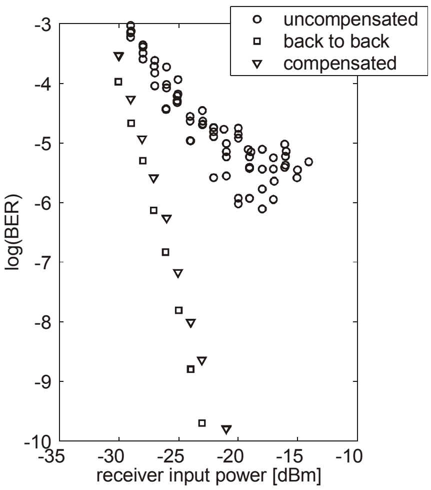
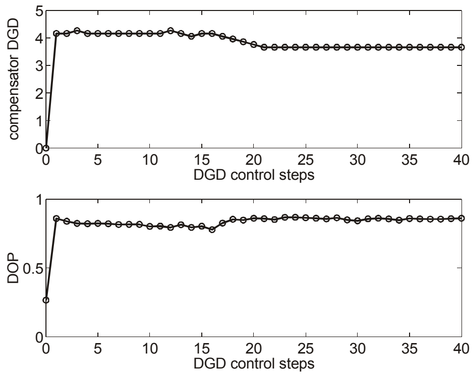


Figure 4: Control steps of the compensator DGD.



Experimental Setup

Fig. 1 shows the setup of the field experiment. We used an 80 Gbit/s OTDM transmission system operating at 1550 nm with 1.2 ps RZ pulses [6]. The transmission link comprised 45 km standard single mode fiber installed in the city of Berlin. At the output of the link the dispersion was compensated by means of a slope compensating DCF module. The mean DGD of the fiber link was about 6 ps and the instantaneous values varied between 3 ps and 12 ps.

To provide DGD detection at the fiber output the polarization at the fiber input was scrambled to cover the Poincaré-sphere in 18 ms.

The PMD-compensator comprised two controllers, one for the motor-driven variable DGD element and one for the polarization controller which was based on piezo-driven fiber squeezers. The variable DGD element was controlled by continuously measuring the minimum DOP at the input of the delay line. A stored response curve was used to calculate the link DGD. This value directly controls the DGD of the compensator in a feed-forward structure. The second controller used the measured DOP at the delay line output for feedback control. The settings of the polarization controller were dithered to increase the minimum DOP measured within intervals of 18 ms.

Instead of using two polarimeters, we used a single polarimeter and a fast MEMS switch for selecting the signal at the compensator input and output alternatively.

Experimental Results

The variation of the minimum DOP with DGD was strongly dependent on the pulse shape. Therefore calibration measurements were performed to find the exact response function (Fig. 2). As we used short pulses in the experiment, the DOP was very sensitive to DGD variations and decreased to zero for a DGD larger than 2 ps. This made DGD measurements beyond this value impossible. We used an optical bandpass filter (bandwidth = 1.2 nm) to smoothen the response function and extended the measurement range to about 7 ps. It should be noted that in an RZ system there are several DOP maxima at multiples of the bit period.

Due to the 8 x 10 Gbit/s multiplexing scheme used in this OTDM system [6], adjacent pulses were not strongly coherent with respect to each other and the next maximum appeared at a delay of 100 ps. Therefore no ambiguities occurred within a DGD range of 100 ps.

Fig. 3 depicts the bit-error rate (BER) performance of the system (pattern length: 2^7-1). At the operating wavelength the instantaneous DGD was about 3.7 ps. Without PMD-compensation, an error floor occurs at a BER of 10^{-6} and no error-free transmission was possible. With PMD-compensation, we obtained error free transmission with a penalty of less than 1 dB as compared to the back-to-back measurements. Fig. 4 shows the control steps of the compensator DGD. After activation, the compensator sets the DGD immediately to a value of 4.2 ps and the BER performance is improved significantly. This value is 0.5 ps away from the optimum. This is tolerable for an 80 Gbit/s system since it corresponds to only 4% of the bit period. However 20 more steps are performed to adaptively find the optimum value of 3.7 ps.

Conclusion

We report error-free 80 Gbit/s RZ data transmission over an installed fiber link using a PMD-compensator. To our knowledge, this is the first demonstration of a PMD-compensator at 80 Gbit/s.

We demonstrated that a feed-forward approach for PMD compensation avoids the need for dithering and allows the compensator DGD to be adjusted in a single step. DOP evaluation combined with polarization scrambling provides access to link parameters such as DGD and PSP. In future applications the currently non-used knowledge on PSP could be exploited to apply feed-forward control also for the polarization controller.

/1/ H. Bülow et al., Proc. OFC'99, San Diego, CA (WE4), pp. 83-85 (1999)

/2/ H. Rosenfeldt et al., Proc. OFC'2001, Los Angeles, CA (Postdeadline Papers, PD27), (2001)

/3/ N. Kikuchi, Journal of Lightwave Technology 19(4), pp. 480-486 (2001)

/4/ S. Lanne et al., Proc. OFC'2001, Los Angeles, CA (TuP3), (2001)

/5/ J. M. Fini et al., Proc. OFC'2001, Los Angeles, CA (WAA6), (2001)

/6/ U. Feiste et al., OFC'99, San Diego, USA, FI1 (1999).