Automatic polarization mode dispersion compensation in 40 Gb/s optical transmission system

D. Sandel, M. Yoshida-Dierolf, R. Noé (1),

A. Schöpflin, E. Gottwald, G. Fischer (2)

(1) Universität Paderborn, Optical Communications and High-Frequency Engineering

Warburger Str. 100, D-33098 Paderborn, Germany

(2) Siemens AG, Public Networks, Hofmannstr. 51, D-81379 München, Germany

Phone: +49 5251 60 3454, Fax: +49 5251 60 3437, Email: noe@uni-paderborn.de

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Abstract: *Polarization mode dispersion impedes development of high capacity optical trunk lines but can be compensated by an adaptive compensator in the receiver. Using three PMD penalty extraction signals differential group delays exceeding one bit duration are compensated in a 40 Gb/s optical transmission system for the first time.*

Introduction: In upgrading of existing optical transmission lines to ≥ 10 Gb/s data rates polarization mode dispersion (PMD) is a serious problem, especially in ‘old’ fibers. Recent publications have shown ways how to compensate PMD, or overcome it to first order by input polarization control [1–4]. At least at 40 Gb/s the differential group delay (DGD) of a transmission line may easily exceed one bit duration *T*. The unambiguous detection of such long DGDs is a problem which has not been addressed so far. Here we demonstrate automatic compensation of 30 ps of DGD in a 40 Gb/s optical transmission system, using three PMD penalty extraction signals.

Penalty extraction: In [1] the output power of a bandpass filter (BPF) centered at half the clock frequency indicated PMD-related eye closure. Fig. 1 depicts the calculated behavior of this signal as a function of 1st order DGD for the case of equal powers in either principal state. Two cascaded 1st order BPFs with individual $Q = 10$ were assumed. DGDs above one bit duration *T* can not be detected unambiguously because of the non-monotonicity. A 3rd order Bessel lowpass filter with a 0.125/*T* bandwidth provides a smooth response up to about 3*T*. However, the signal slope is so flat that small DGDs which still can cause nonnegligible penalties can practically not be detected. Also shown are the output powers of BPFs with center frequencies of 0.25/*T* and 0.125/*T*. Now, if thresholds are introduced (dashed lines), below or above which the receiver switches between the 3 BPF output power signals (fat curves), then DGDs of up to 4*T* can be detected unambiguously while an excellent search sensitivity for small DGDs is retained. Alternatively, a suitable linear combination of the three signals can be used.

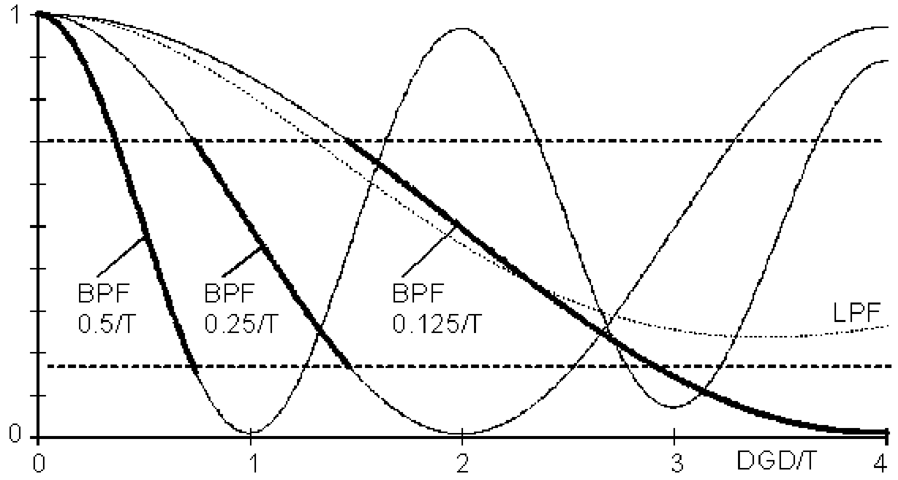


Fig. 1: PMD penalty extraction signals as a function of 1st order DGD. BPFs centered at 0.5/*T*, 0.25/*T*, 0.125/*T*, and LPF with 0.125/*T* cutoff frequency. Combination (fat) of BPF signals through thresholds (dashed) is piecewise monotonic.

Experiment: Four mutually delayed 10 Gb/s 2^7-1 symbol PRBS signals were electrically multiplexed into a 40 Gb/s data stream and amplified [5]. A 1551 nm laser signal was externally modulated in a $LiNbO_3$ modulator, then amplified to +12 dBm. A variable optical attenuator simulated the link loss. Two polarization-maintaining fiber (PMF) pieces of 20 and 10 ps DGD, respectively, and manual polarization transformers simulated the PMD of a fiber link. The PMD compensator had three PMF sections of 10 ps DGD and three polarization transformers. Each consisted of three fiber loop elements working as λ /4, λ /2, λ /4 waveplates, endlessly rotatable [6] by stepper motors. The receiver had an optical preamplifier, a photodiode, amplifiers, and a combined demultiplexing and clock recovery circuit. BER was measured on one out of four 10 Gb/s data streams. For PMD penalty extraction the amplified photodetected signal was also fed into bandpass filters with 20, 10, and 5 GHz center frequencies, and associated amplifiers and power detectors. A PC worked as a controller and generated the stepper motor driving signals.

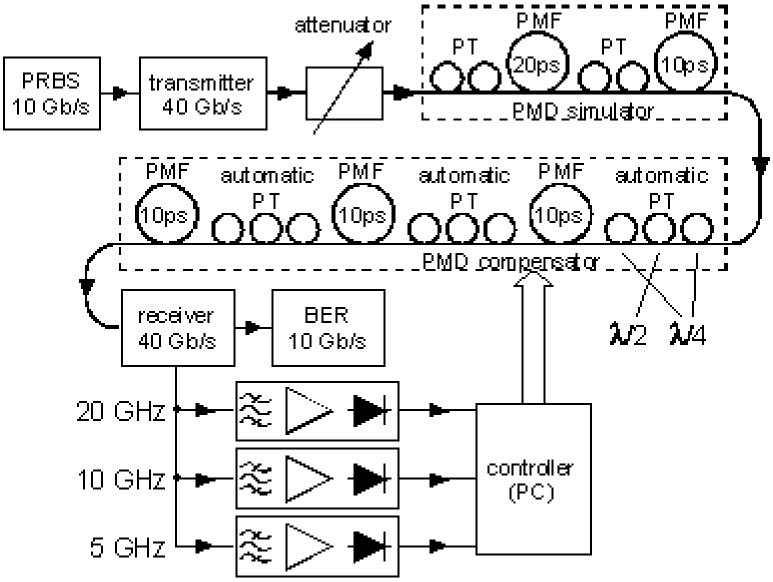
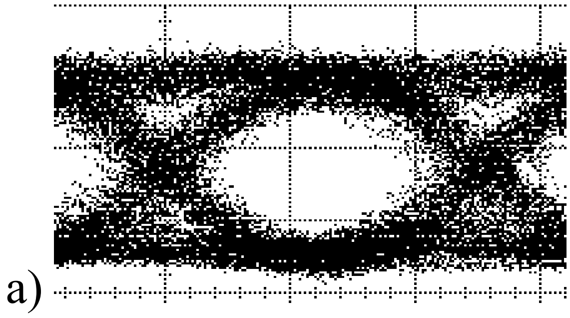


Fig. 2: 40 Gb/s transmission setup with PMD compensation

Without any PMF a good eye diagram was achieved (Fig. 3a). With PMD simulator and unadjusted PMD compensator in place the eye was closed (Fig. 3b). However, with automatic control an open eye was readily obtained (Fig. 3c). A gradient (peak search) algorithm maximized a linear combination of the 3 control signals.



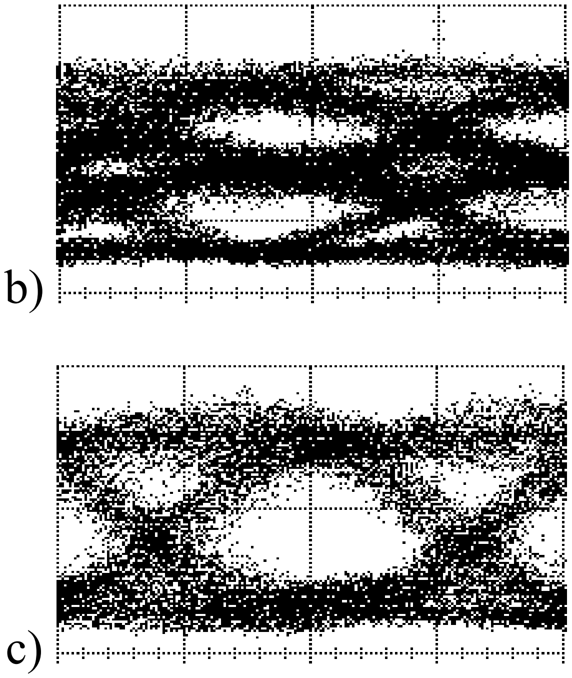


Fig. 3: 40 Gb/s eye diagrams: back-to-back (a); with PMD simulator and unadjusted compensator (b); with PMD simulator and working PMD compensation (c)

If any one of the three control signals was used alone compensation failed repeatedly, and the eye diagram remained closed. This can be understood from the fact that the total added DGD of PMD simulator and compensator was 60 ps, more than 2*T*. On the other hand, the combination of 5 and 10 GHz BPF signals was sufficient to attain a relative optimum, but it was degraded with respect to the case of all 3 signals being available.

The BER was recorded as a function of time. After initial convergence nearly error-free operation was observed (Fig. 4a). The ability of the system to recover from disturbances was assessed separately. Manual changes of fiber loop settings caused a momentarily high BER but were quickly compensated thereafter (Fig. 4b).

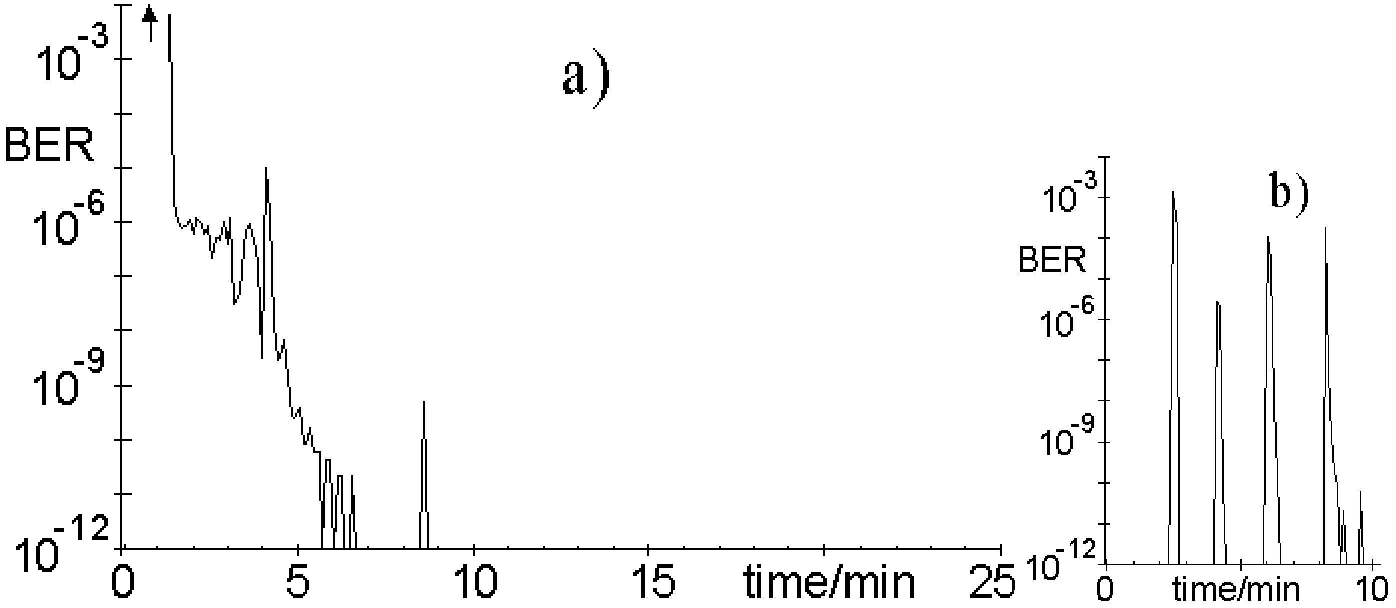


Fig. 4: BER records as a function of time: initial PMD compensation convergence (a); responses to four manual changes of fiber loop settings (b)

Any PMD compensator consisting of fixed-DGD sections may exhibit secondary maxima of the control signal, even if the control signal behaves monotonically. They disappear only if the number of sections becomes very large or if their DGDs are variable. However, if it is sufficient to overcome 1st order PMD then the input polarization of the link can be controlled [2]. To do so, the PMD simulator was removed, and the first polarization transformator of the compensator was used for control. The rest of the compensator, 3 × 10 ps of DGD and two formerly automatic polarization transformers, worked now as a PMD simulator. The initial eye pattern, completely closed, is seen in Fig. 5a. With input polarization control good BER performance was again obtained. However, PMD was not fully removed which can be seen from a somewhat distorted eye diagram (Fig. 5d).

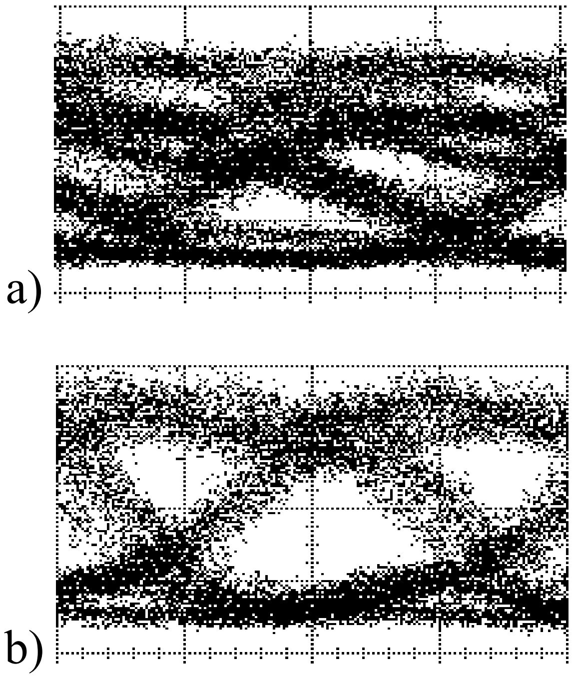


Fig. 5: 40 Gb/s eye diagrams: with PMD simulator (a); with PMD simulator and working input polarization control (b)

Future improvements could consist in finding a particularly robust combination of PMD penalty extraction signals and in optimizing the compensator structure to exclude secondary maxima or minimize their possible influence. Nevertheless this is, to our knowledge, the first time that DGD values exceeding one bit duration have been compensated.

Summary: We have automatically compensated 30 ps of polarization mode dispersion in a 40 Gb/s transmission system by a 3 × 10 ps compensator or input polarization control. Bandpass filters centered at 20, 10 and 5 GHz have been used to unambiguously extract PMD-induced penalties.

References:

[1] T. Takahashi, T. Imai and M. Aiki: "Automatic compensation technique for timewise fluctuating polarization mode dispersion in in-line amplifier systems", Electron. Lett. 17th February 1994, vol. 30 no. 4, pp 348-349

[2] T. Ono, S. Yamazaki, H. Shimizu, and K. Emura: "Polarization control method for suppressing polarization mode dispersion influence in optical transmission systems", J. Lightwave Techn. May 1994, Vol. 12 No 5, pp. 891-898

[3] M. Yoshimura, T. Kudo and T. Ozeki, "Polarization Mode Dispersion Equalization", Proc. OEC ‘94, 14E-12, pp. 258-259, Makuhari Messe, Japan, 1994

[4] J. Patscher and R. Eckhardt: "Component for second-order compensation of polarization-mode dispersion", Electron. Lett. 19th June 1997, vol. 33 no. 13., pp. 1157-1159

[5] W. Bogner, E. Gottwald, A. Schoepflin and C.-J. Weiske: "40 Gbit/s unrepeatered optical transmission over 148 km by electrical time division multiplexing and demultiplexing", Electronics Letters, vol. 33, 1997, pp. 2136-2137

[6] T. Matsumoto, and H. Kano: "Endlessly rotatable fractional-wave devices for single-mode-fiber optics", Electronics Letters, vol. 22, 1986, pp. 78-79