Polarization mode dispersion compensation at 20 Gb/s with fiber-based distributed equalizer

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

C. Glingener, C. Scheerer, A. Schöpflin, G. Fischer (2)

(1) Universität Paderborn, FB 14/850, Warburger Str. 100, 33098 Paderborn, Germany (noe@uni-paderborn.de)

(2) Siemens AG, Information and Communication Networks, 81359 München, Germany

Indexing Terms: Optical Communications, Polarization Mode Dispersion

> ***Abstract:*** *Ideal equalization of polarization mode dispersion can be expected from an equalizer that mirrors the differential group delay profile of a transmission line. We successfully operate a PMF-based 77 ps compensator at 20 Gb/s.*

Motivation: After fiber attenuation and chromatic dispersion, polarization mode dispersion (PMD) is the next biggest obstacle in the development of highest-capacity, long-haul optical communication systems. Unlike the foregoing, PMD is intricate to tackle because it may vary as a function of time. Previous work to compensate PMD has focused on selecting a principal state of the transmission line [1] or implementing a compensator consisting of a small number of differential group delay (DGD) sections, separated by polarization transformers [2–5]. Electronic PMD equalization is likewise possible [6].

The problem of cascading a large number of DGD sections in a compensator seems not to have been attacked so far, probably due to the coupling losses between DGD sections and polarization transformers. Here we present a fiber-based, distributed PMD compensator.

Compensator: In a discretized model, PMD can be characterized by a sequence of vectors in the 3-dimensional space of normalized Stokes vectors, each having a length equal to the DGD of a particular fiber section. The directions of adjacent vectors differ according to the polarization transformation present between the principal states (PSP) of the respective adjacent fiber sections. The addition of the vector sequence forms a DGD profile which characterizes PMD. Accurate, broadband modeling requires the number of fiber sections and DGD vectors to be very large. A perfect PMD compensator could consist of a large number of short DGD sections, separated by polarization transformers. These would be adjusted such that the vectorial DGD profile of the compensator follows the profile of the transmission line in reversed order, whereby pairs of adjacent vectors of equal lengths and opposite directions cancel. An excess of total DGD of the compensator over that of the transmission line is not of concern because some adjacent compensator sections can be made to cancel each other.

It can be shown that the polarization transformers need to be able to transform a PSP of a DGD section into any state-of-polarization. For reliable operation, this transformation should be endless. It can further be shown that a finite number of mode coupling sections in a birefringent waveguide, such as twisted polarization-maintaining fiber (PMF) [7], is capable of this transformation. One out of many suitable implementations in PMF contains two cascaded sets of 2 variable and 2 fixed twisting points (Fig. 1). Each polarization transformer contains 4 adjacent stepper motors which turn these 2× 2 variable twisting points. The twisted PMF lengths are given as fractions of the beat length Λ . Statistical theory even predicts that exact lengths become unimportant if the number of twisters is approximately doubled.

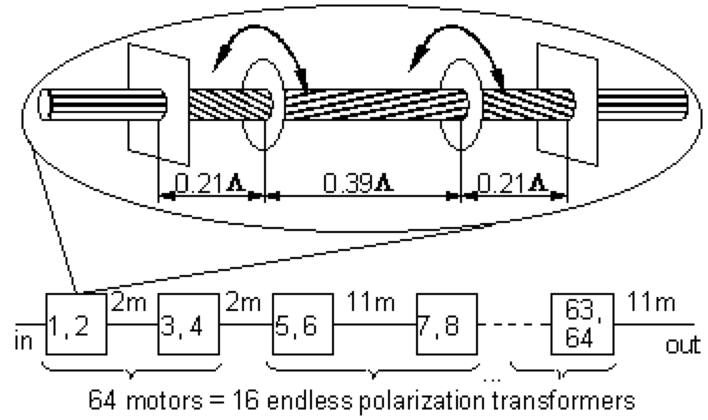

Fig. 1: Fiberoptic PMD compensator

A 322 m long piece of PMF with a mean beat length of Λ = ~ 21.6 mm @ 1550 nm and a corresponding DGD of 0.24 ps/m was pulled through the hollow axes of 64 stepper motors. The fiber was fixed inside and outside the axes to define twist sections. Fiber lengths were 2 m between the first 3 adjacent motor pairs, and then 11 m. A total DGD of 77 ps could thus be commanded, with available degrees-of-freedom corresponding to ~ 16 endless polarization transformers and DGD sections. Attenuation was 2.2 dB, mainly determined by connector and splice losses.

The fiber-optic implementation has the advantage of being tailorable to almost any DGD. However, the principle could also be realized in X-cut, Y-propagation $LiNbO_3$, where required DGD and polarization transformers would be integrated on one chip by simply cascading a number of TE-TM transformers [8].

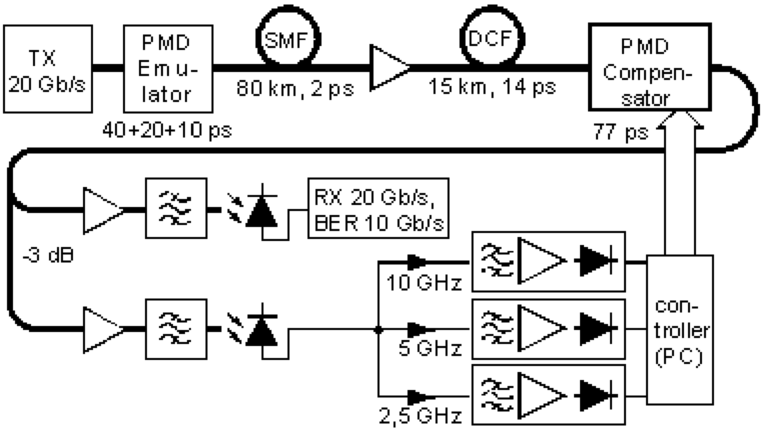

Fig. 2: 20 Gb/s transmission setup

Experiment: A 20 Gb/s transmission system [9] was used to test the compensator (Fig. 2). The data signal was transmitted through a PMD emulator, 80 km of standard fiber (SMF) with a DGD of 2 ps, and 15 km of chromatic dispersion compensating fiber (DCF) with a DGD of 14 ps. The emulator contained 3 PMF pieces with 40, 20 and 10 ps DGD, preceded and separated by motorized endlessly rotatable fiber coils. In the receiver the power spectral densities at frequencies 10, 5 and 2.5 GHz were measured by bandpass filters and subsequent power detectors. For convenience this was done by optical power splitting to an extra photodiode. A linear combination of these signals indicated PMD distortions. A peak search algorithm operated the 64 stepper motors. The response time of the whole compensator was ~1 s.

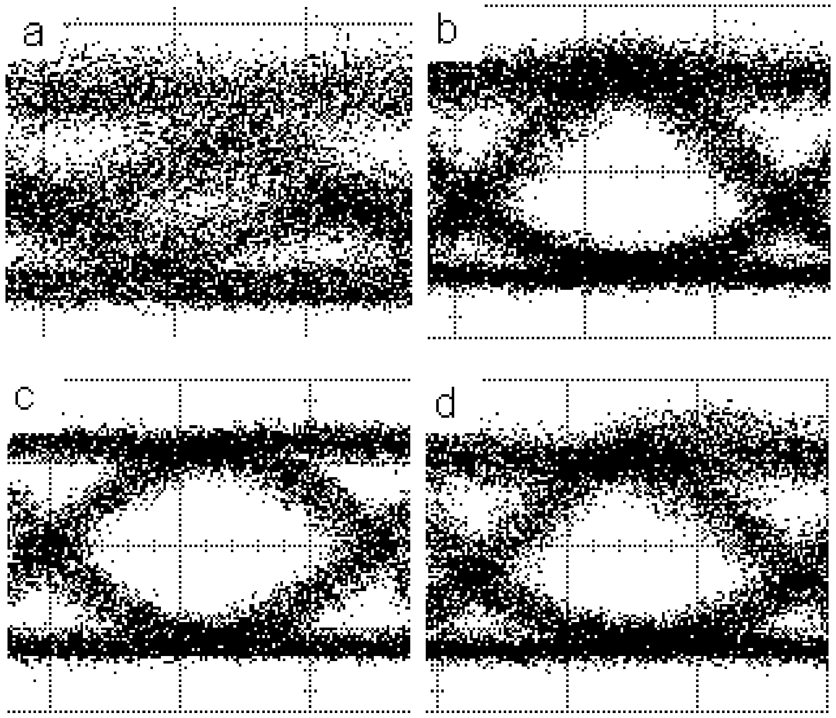

Fig. 3: 20 Gb/s eye diagrams: a) PMD distortion; b) compensator alone; c) back-to-back; d) with emulator (40+20+10 ps), SMF (2 ps), DCF (14 ps), and compensator (77 ps)

In all performed experiments the eye pattern was usually closed (example: Fig. 3a) unless the compensator was in operation. In a first test the other fibers were left out, and the compensator was used alone (eye diagram: Fig. 3b). The receiver sensitivity was -28 dBm which is comparable to back-to-back operation (Fig. 3c). Measured BER (of a 10 Gb/s electrically demultiplexed channel) was stable unless the compensator was turned off (Fig. 4a). Then PMD emulator and fibers were inserted (Fig. 3d). 8 motorized fiber coils rotating at different speeds and thermal drift provided endless PMD variations with up to 86 ps of total DGD. When the compensator was stopped the BER increased drastically, but it dropped down when the compensator was turned on again (Fig. 4b). – With increased power (-25 dBm) operation was error-free.

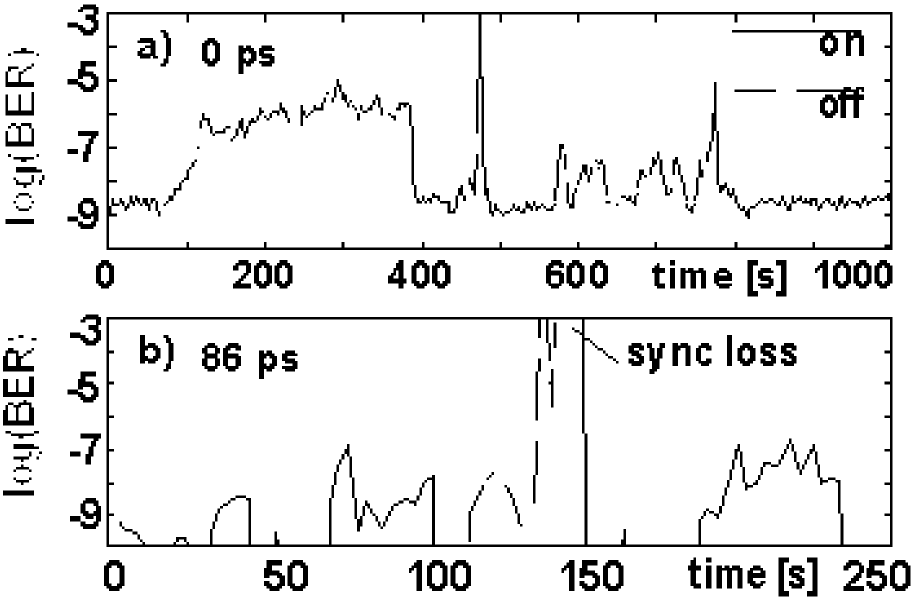

Fig. 4: BER vs. time with compensator on/off for different DGD values of transmission span

The fact that total DGDs of 0 or up to 86 ps could be tolerated validates the principle of a compensator with fixed DGD sections. Indeed, the compensator also worked well in other situations, e.g., with 10 + 10 ps of DGD to be compensated. It worked even when these additional pieces of PMF were added to the normal setup (106 ps of DGD to be compensated in the worst case) but only when the fiber coils were not rotated.

Conclusions: A fiberoptic distributed PMD equalizer with 2.2 dB insertion loss has been used to successfully compensate DGDs between 0 and 86 ps in a 20 Gb/s transmission experiment.

References

1. T. Ono et al.: "Polarization control method for suppressing polarization mode dispersion influence in optical transmission systems", IEEE J. Lightwave Technology 12 (1994) 5, pp. 891-898
2. J. Patscher, R. Eckhardt: "Component for second-order compensation of polarization-mode dispersion", Electron. Lett. **33** (1997) 13, pp. 1157-1159
3. F. Heismann et al.: "Automatic compensation of first-order polarization mode dispersion in a 10-Gb/s transmission system", ECOC ’98, Madrid, Spain, WdC11
4. T. Takahashi et al.: "Automatic compensation technique for timewise fluctuating polarization mode dispersion in in-line amplifier systems", Electron. Lett. **30** (1994) 4, pp. 348-349
5. M. Yoshimura et al.: "Polarization Mode Dispersion Equalization", OEC ‘94, 14E-12, pp. 258-259, Makuhari Messe, Japan, 1994
6. D. Schlump et al.: "Electronic equalization of PMD and chromatic dispersion induced distorsion after 100 km standard fiber at 10 Gbit/s", ECOC ’98, Madrid, Spain, WdC14
7. R. Ulrich, A. Simon: "Polarization optics of twisted single-mode fibers", Applied Optics **18** (1979) 13, pp. 2241-2251
8. F. Heismann, R. Ulrich: "Integrated-optical single-sideband modulator and phase shifter", IEEE J. Quantum Electronics, **18** (1982) 4, pp. 767-771.
9. W. Bogner et al.: "20 Gbit/s TDM nonrepeatered transmission over 198 km DSF using Si-bipolar IC for demultiplexing and clock recovery", ECOC ’96, Oslo, Norway, p.203-6 vol.2