Distributed fiberoptic PMD compensation of a 60 ps differential group delay at 40 Gb/s

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Abstract: Optical polarization mode dispersion equalization of 2.4 bit durations of differential group delay is demonstrated for the first time to our knowledge, using a distributed fiberoptic compensator. We believe much of the existing fiber network can be upgraded even to 40 Gb/s and RZ signal format.

Motivation

Polarization mode dispersion (PMD), especially in installed fiber, broadens optical pulses in a time-variant manner and therefore impedes the development of highest-capacity, long-haul communication systems.

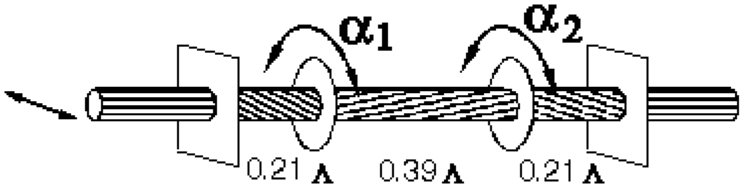
It is commonly believed that, if any relief other than regeneration can be found, it will be limited to 1st-order differential group delays (DGDs) on the order of one bit duration. This is certainly true for compensators with just one or a few differential group delay (DGD) sections and polarization transformers /1–5/. However, distributed equalizers with mode converters embedded in a birefringent waveguide /6, 7/ are less restricted in this respect because a larger number of polarization transformers can be implemented without introducing significant loss or cost.

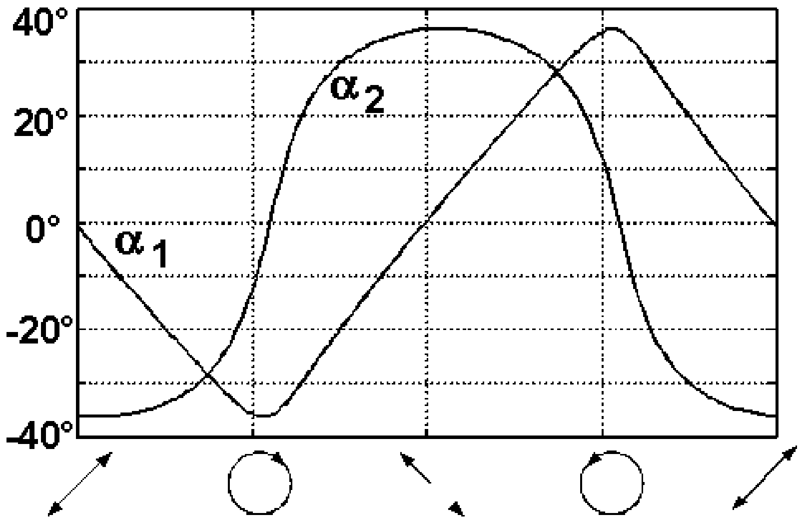
While the best reported previous result for compensated DGD was 1.7 bit durations at 20 Gb/s /6/ we report here on compensation of 2.4 bit durations of DGD at 40 Gb/s using RZ signals. This is challenging because the compensator must have at least the DGD to be compensated, thereby introducing a total DGD exceeding 5 bit durations in our case. On the other hand it is rewarding because 1.4 times more tolerable DGD means the transmission fiber may be twice as long.

Compensator

A ~ 320 m long polarization-maintaining fiber with a large beat length of Λ = 23 mm was pulled through the hollow axes of 64 stepper motors, grouped as 32 pairs along the fiber /6/. The total compensatory power was 77 ps of DGD. Each twister pair can convert a horizontal principal state-of-polarization to half amount into its orthogonal, with endlessly adjustable coupling phase. The fiber twist angles needed to perform this operation are shown in Fig. 1. Smaller twist angles correspond to less mode coupling.

Figure 1: Twist angle pairs needed for half mode conversion of horizontal input polarization



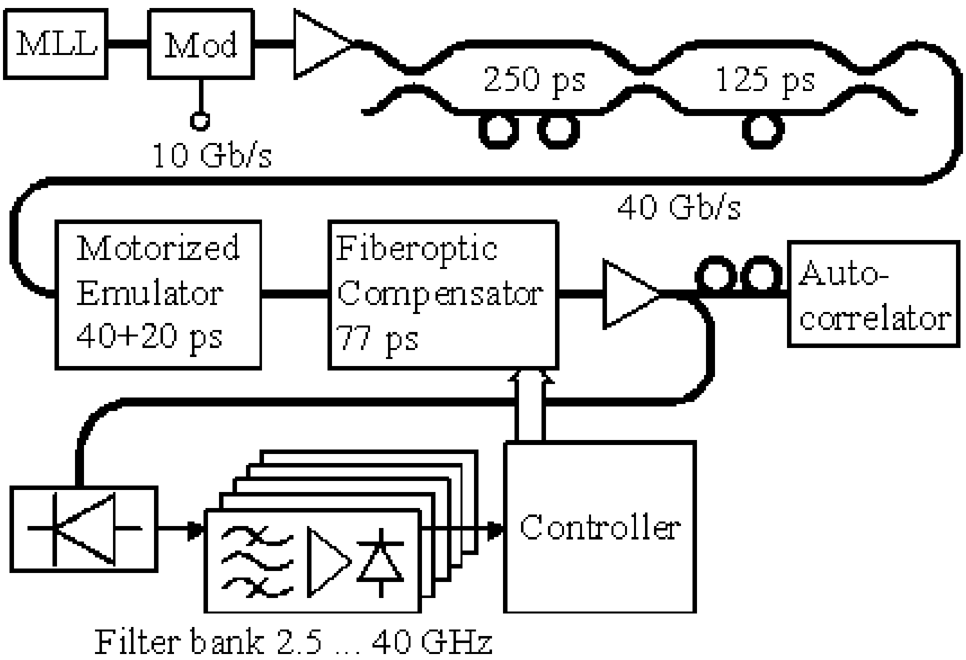


With at least half mode coupling accessible in each twister pair the equalizer is able to bend these "joints" of its DGD profile (i.e, the concatenation of PMD vectors) by at least 90° in any direction in the 3-dimensional space of normalized Stokes vectors.

Transmission system

A 10 GHz modelocked Ti:Er:LiNbO3 waveguide laser (MLL) /8, 9/ was used as an optical source (Fig. 1). It emitted a stable train of 5.9 ps (FWHM) pulses at λ = 1561 nm with a time-bandwidth product of 0.56. It was externally modulated at 10 Gb/s.

Figure 2: Experimental setup



With two delay lines and couplers the data signal was optically multiplexed to 40 Gb/s. A subsequent polarizer made sure the 40 Gb/s signal was fully polarized. A PMD emulator simulated a transmission fiber. It consisted of a 40 and a 20 ps DGD piece of polarization-maintaining fiber (PMF), preceded, separated and followed by a total of 8 motorized fiber loop devices (λ /4, λ /2, λ /4 groups). PMD was compensated in the fiberoptic 77-ps equalizer.

At the receive end the signal was detected in a 40 GHz photodiode (u2t Innovative Optoelectronic Components). The electrical signal was amplified and then analyzed in a filter bank which contained 5 bandpass filters with center frequencies ranging from 2.5 to 40 GHz. The 40 GHz filter was a spectrum analyzer tuned to the clock line. The lowpass-filtered signals were read into a PC which worked as a controller. A SHG autocorrelator was used to monitor the received pulse width.

Experiment

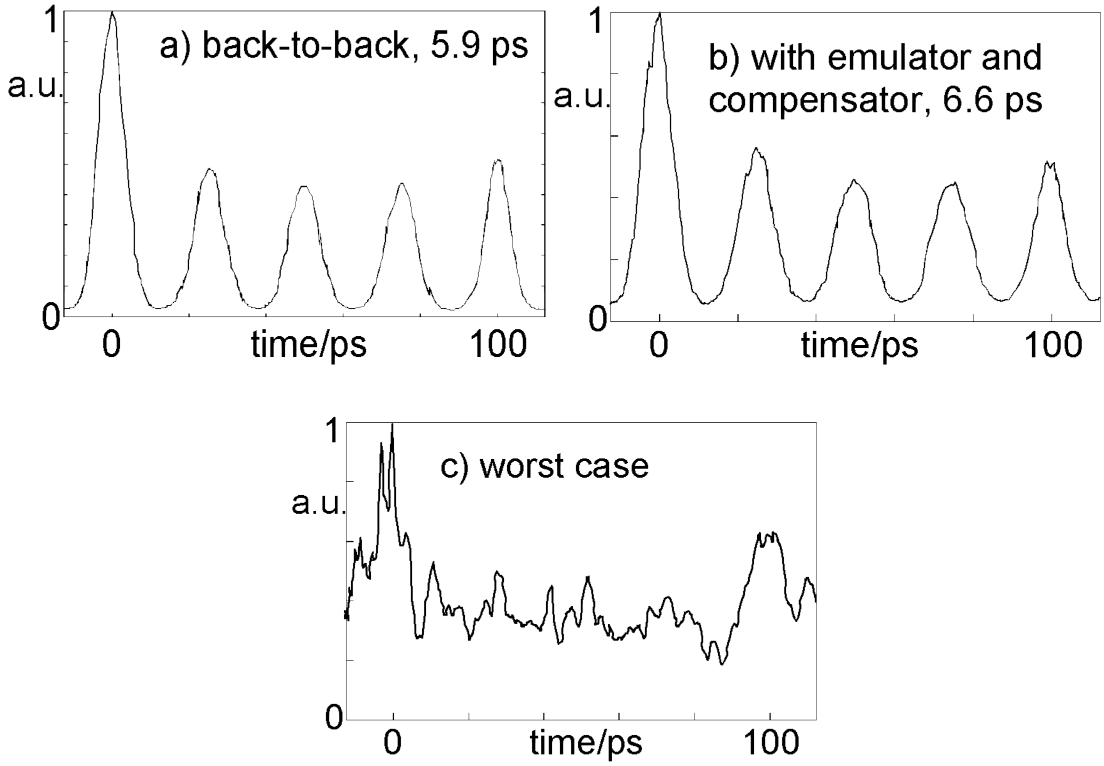
The optical autocorrelator is polarization-dependent and slow, and for this reason it can only measure at static PMD. The measurements were therefore repeated several times, and polarization was always adjusted for highest PMD-induced pedestals or sidelobes.

Fig. 3a shows the back-to-back autocorrelation trace. Only the center and one half are shown because the other (mirrored) half is not accessible due to a limited scanning range. At delay multiples of the 25 ps bit period the autocorrelation signal has peaks. Due to the PRBS modulation these are half as high as the peak at zero delay. The FWHM is 8.3 ps, and this corresponds to a deconvolved 5.9 ps pulse width.

As a next step the PMD emulator and the compensator were inserted, and control was switched on. Now the autocorrelation trace indicated marginal pulse broadening to a deconvolved 6.6 ps width, together with a slightly increased pedestal (Fig. 3b).

For comparison we give also an autocorrelation trace for emulator plus compensator when the controller was made to minimize rather than maximize signal quality. In this case the original pulses essentially disappear due to PMD (Fig. 3c).

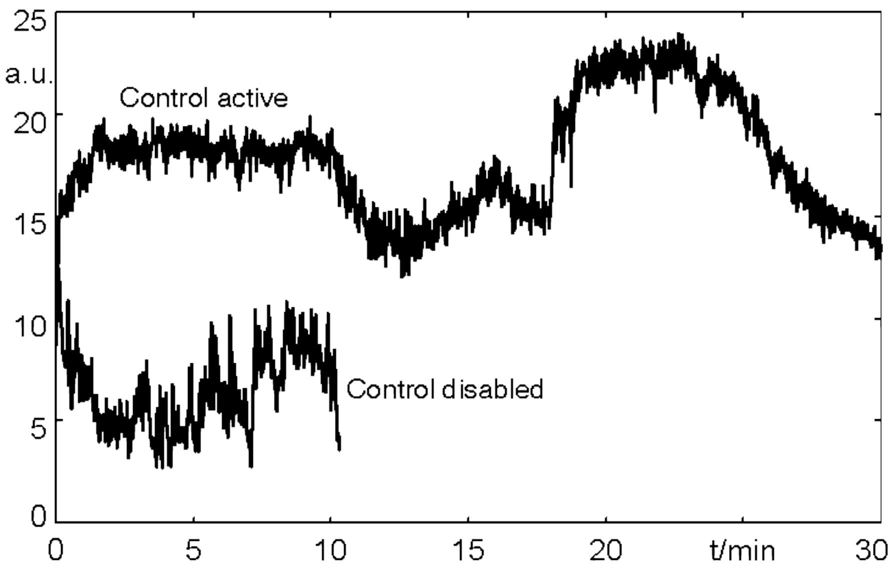
Figure 3: Autocorrelation traces



A dynamic measurement was made with the 40 + 20 ps emulator and the compensator. The motorized fiber polarization transformers were made to turn, each at a different speed and with alternating directions. Fig. 4 (top trace) shows an aggregate control signal which reflects, probably even in a pessimistic manner, the eye opening to be expected in a digital receiver. Part of the signal variations can be attributed to polarization dependence (~ 1 dB optical => ~ 2 dB electrical) of the components following the compensator. – Then control was stopped while the emulator coils continued to turn. The aggregate control signal varied at a substantially lower level (bottom trace, left).

The present experiment shows that 60 ps of DGD can be equalized at 40 Gb/s. Distributed PMD compensators in X-cut, Y-propagation Ti:LiNbO3 /7/ have a much faster response and should make the cost-effective upgrade of most existing fiber networks to 40 Gb/s possible.

Figure 4: Eye opening equivalent signal recorded while emulator is varied



Conclusions

A distributed fiberoptic PMD equalizer has been used to compensate for 2.4 bit durations of DGD, which is the highest reported value to our knowledgde. Data rate was 40 Gb/s, and the 5.9-ps RZ pulses of the modelocked Ti:Er:LiNbO3 waveguide laser were broadened only to 6.6 ps.

Acknowledgement

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