An experiment of automatic PMD compensation in 40-Gb/s RZ optical communication system

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An experiment of adaptive polarization mode dispersion (PMD) compensation for 40-Gb/s return-to-zero (RZ) optical communication system is reported. In the experiment, degree of polarization (DOP) is used as feedback signal and particle swarm optimization (PSO) method is adopted as logic control algorithm. The compensation time is about 200 ms, the compensated differential group delay (DGD) is up to 30 ps, and bit error rate (BER) of 10^{-9} is reached when PMD compensation is employed.

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Polarization mode dispersion (PMD) is becoming to be the dominant factor of signal degradation in high-speed (10 Gb/s and beyond) optical communication systems. Consequently, there is a large interest in techniques to compensate or mitigate the effects of PMD[1−5]. Because of its statistic nature, PMD always changes randomly. Therefore, compensation techniques must be adaptive. The techniques of monitoring PMD and control algorithm are most important for an adaptive PMD compensation system. In this paper, degree of polarization (DOP) of the received optical signal is used as monitoring signal and particle swarm optimization (PSO) method is adopted in logic control algorithm, adaptive PMD compensation for 40-Gb/s return-to-zero (RZ) format optical communication system is successfully realized. The searching process is finished within sub-second time, the compensated differential group delay (DGD) is up to 30 ps.

Figure 1 shows the experimental setup.

In the experiment, 1560-nm light pulses are produced by an actively mode-locked fiber ring laser, in which the key components are semiconductor optical amplifier (SOA) and electro-absorption (EA) modulator. 2^7-1 pseudo-random bit sequence (PRBS) comes from a pulse pattern generator (D3186, ADVANTEST Corporation). 10-Gb/s RZ signal is generated by using $LiNbO_3$ modulator. Using the technique of optical time division multiplexing (OTDM), 40-Gb/s signals are produced, which can be observed by oscilloscope, as shown in Fig. 2(a). In order to use DOP as PMD monitoring, it is required to ensure that all of the multiplexed 40-Gb/s optical pulses have the same polarization states, so a polarization controller (PC) is used before fiber delay line for each channel, and at the output port a polarizer is adopted. By adjusting PC to make the output power reach maximum value, the goal of making all the optical pulses in each channel with the same polarization state is realized. The PMD emulator consists of a PC and a section of polarization maintain fiber (PMF) with 15-ps differential group delay (DGD). The compensator is composed of a voltage-controlled fiber squeezer PC and a fixed delay line PMF, DGD of which is 15 ps. The three cells of the fiber squeezed PC are voltage-controlled ($0-10$ V). The feedback signal used for the compensator is DOP, which is estimated by an in-line polarimeter. By using PSO algorithm the logic control unit adjusts the three cells of electro-PC to search the optimum for DOP to reach the global maximum. Through an EA demultiplexer, the 10-Gb/s output signals are demultiplexed from 40-Gb/s

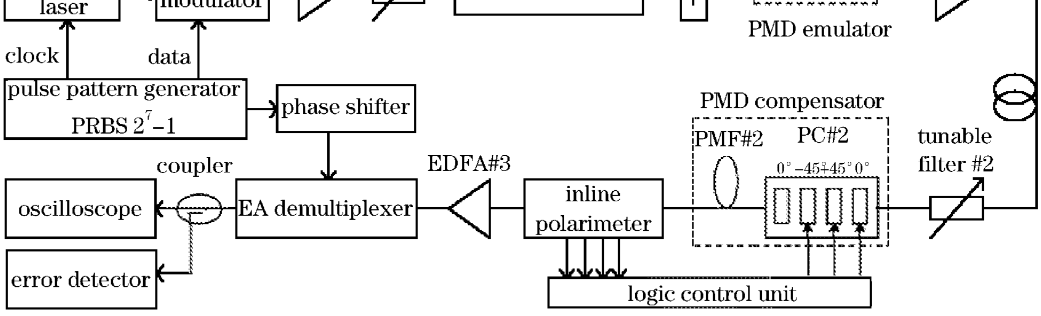


Fig. 1. Experimental setup. EDFA: erbium-doped fiber amplifier; MUX: multiplexer.

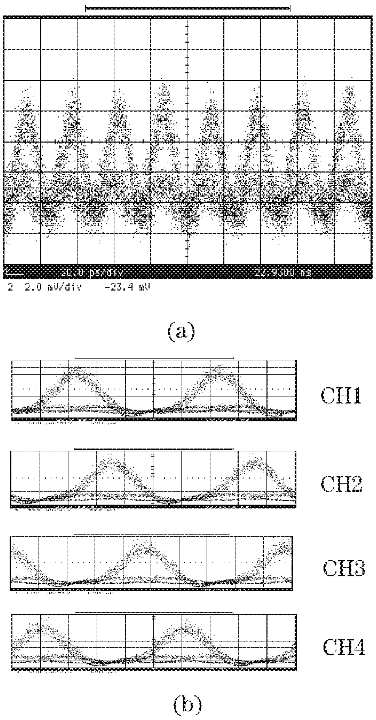


Fig. 2. (a) Back-to-back 40-Gb/s OTDM signal; (b) four demultiplexed 10-Gb/s signal with PMD compensation.

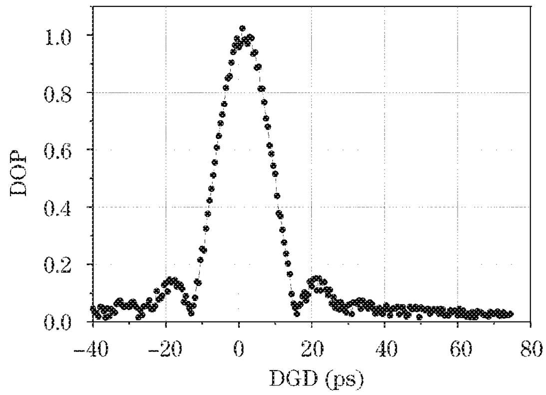


Fig. 3. The experimental result of DOP versus DGD.

signals. Adjusting the phase shifter, every channel signal can be obtained, as shown in Fig. 2(b). Then signals are divided into two branches: one is for error bit detection (D3286, ADVANTEST Corporation), the other is sent to an oscilloscope (HP 83480) to show the eye diagrams.

In the experiment, DOP is used as feedback signal. The experimental result of DOP versus DGD for 40-Gb/s RZ format with power splitting ratio $\gamma = 0.5$ is shown in Fig. 3. It shows that DOP could be a good indicator of PMD.

Bit error rate (BER) is one of the important factors to evaluate performance of transmission system. In order to illustrate the transient performance of the compensator, the relationship between BER and DOP is necessary. While BER measurement will take a long time, DOP is easily and rapidly obtained, so we measure the BER under the condition of different DOP values, which are obtained by randomly changing PCs in PMD emulator or in compensator. The results are shown in Fig. 4, there is a extreme result, synchronization error, which is to say the error detector fails to synchronize with the input signal because the waveform is distorted so much that the receiver cannot extract the synchronous clock signal. From Fig. 4, we find that BER will reach 10^{-9} level when DOP is beyond 0.89.

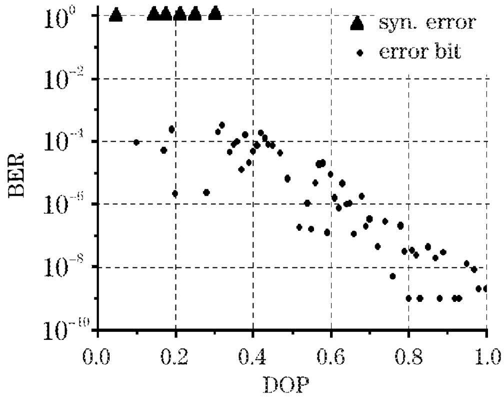


Fig. 4. The relationship between BER and DOP.

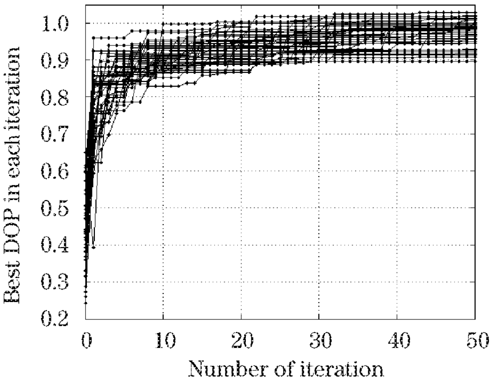
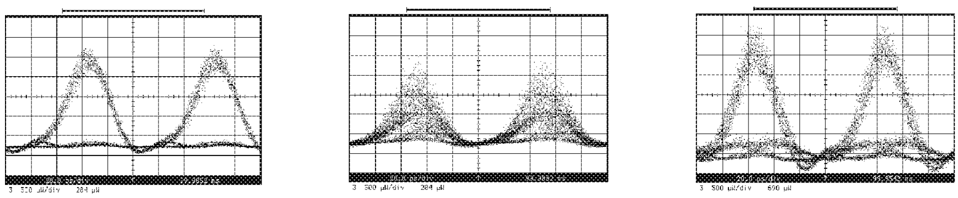


Fig. 5. Best DOP versus number of iteration.

The logic control algorithm is one of the key factors that determine the speed of adaptive PMD compensation. A compatible algorithm should have the ability of rapid optimum searching without being trapped in sub-maximum and robust to noise. We adopt an artificial intelligence searching algorithm termed PSO, which has been verified to be effective in PMD adaptive compensation[6−8].

We repeat the experiment of optimum searching with 50 different initial conditions. The searched best DOP in fifty iterations are shown in Fig. 5. From Fig. 5, we find that the DOP is beyond 0.89 within 20 iterations (equal to 200 ms, each iteration need 10 ms, which is measured by reading the timer in the computer) and the fastest searching only needs 3 iterations (about 30 ms). It shows that PSO has fast and powerful capacity of searching the global-optimum.

The whole procedure of adaptive PMD compensation was observed with the oscilloscope. The typical eye diagrams before and after the searching process are shown in Fig. 6. Figure 6(a) is the eye diagram of 10-Gb/s signals of optical source; Fig. 6(b) shows the eye diagram of the demultiplexed signals before PMD compensation with



(a) (b) (c)

Fig. 6. Eye diagrams to show the procedure of adaptive PMD compensation.

DOP value of 0.23; Fig. 6(c) gives the eye diagram of one of the demultiplexed signals after compensating with DOP value of 0.98. After compensation, every channel demultiplexed signals' eye digram is opened, as shown in Fig. 2(b). The whole time of searching process is about 200 ms. If the PC in PMD emulator is changed at random, system will turn back to the state as Fig. 6(c) in 200 ms, which means the adaptive PMD compensation is realized.

We have made a successful experiment of adaptive PMD compensation for 40-Gbit/s RZ optical communication system. The compensated differential group delay was up to 30 ps and the BER reached 10^{-9} level after compensation. Adaptive compensation time was about 200 ms, the quasi-real-time PMD compensation was realized.

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