An experiment of PMD compensation in 40-Gb/s PSBT transmission system

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An adaptive polarization mode dispersion (PMD) compensation experiment is reported in a 40-Gb/s phase shaped binary transmission (PSBT) communication system, with the use of a new digital signal processor (DSP)-based optical PMD compensator. PMD tolerance is found to be enhanced by 8 ps after PMD compensation with 1-dB optical signal-to-noise ratio (OSNR) penalty. Under the condition of fast change of states of polarization up to 85 rad/s in the fiber link, the performance of our PMD compensator undergoes the bit error ratio (BER) test for as long as 10 h.

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For 40 Gb/s and higher bit rate fiber-optical communication systems, polarization mode dispersion (PMD) is a major obstacle that limits system performance. Furthermore, the traditional modulation formats such as on-off-keying (OOK) are not valid. Therefore, it is necessary that a superior modulation format and PMD compensation is applied in high-speed optical transmission system[1,2].

Compared with OOK modulation formats, the phase shaped binary transmission (PSBT) format has higher chromatic dispersion (CD) tolerance, better non-linear tolerance, and higher reconfigurable optical add-drop multiplexer (ROADM) tolerance. Its performance is as well as that of differential quadrature phase-shifted keying (DQPSK) while the implementation is much simpler. There is a minor change to the transmitter of OOK, and we can still use the photo diode as the receiver for direct detection. It could be a promising choice in high-speed dense wavelength division multiplexing (DWDM) systems[3−5].

In this letter, the experiment of PMD compensation in a 40-Gb/s PSBT transmission system is set up. The bit error ratio (BER) is recorded to evaluate the performance of the optical PMD compensator (OPMDC).

The schematic of the whole transmission system is shown in Fig. 1. At the transmitter, continuous-wave (CW) light generated from a laser at center frequency of 193.1 THz is modulated by two cascaded modulators to produce 40-Gb/s PSBT signals. The first Mach-Zehnder modulator (MZM) is driven by data signals to produce duo-binary non-return-to-zero (NRZ) format. The second MZM acts as a pulse carver, which is driven by clocks. Then the signals are fed into a PMD emulation unit. The PMD emulation unit consists of a polarization scrambler (PS) and a piece of polarization maintaining fiber (PMF) with differential group delay (DGD) of 30 ps. The PS in front of the PMF is used to change the inputting state of polarization (SOP). Then amplified spontaneous emission (ASE) noise is coupled into the link to adjust the optical signal-to-noise ratio (OSNR) penalties. The one-stage PMD compensator contains a high-speed electrically controlled polarization controller (PC), a variable delay line, an in-line polarimeter, and a logic control unit based on digital signal processor (DSP). The DGD of variable delay line can vary from –45 to 45 ps. The polarimeter is used to instantaneously measure Stokes parameters and the degree of polarization (DOP) in the fiber link. With the use of the local particle swarm optimization (PSO) algorithm, the logic control unit adjusts the voltages of the PC to search and track the optimum DOP[6−9]. At the receiver, a regular photo-diode detector is used to detect the PSBT signals, and the inverter acts as a decoder. Moreover, forward error correction (FEC) is employed in the transmitter and receiver. OSNR is measured before the signals enter the PMD compensator.

The process of real-time adaptive PMD compensation includes two stages—searching and tracking. First, the searching algorithm works to find global optimum from any initial PMD condition. Then the tracking algorithm start working to track the changed optimum. The algorithm adopted in the logic unit is very important. In the experiment, we adopted the modified PSO as the searching algorithm and the cross tracing algorithm as the tracking algorithm.

Compared with the other published algorithms for PMD compensation[6,7], the main improvement contained in this letter is taking the cross tracing algorithm instead of the PSO as the tracking algorithm. In the experiment, we have compared the effectiveness of PSO tracing and the cross tracing algorithm by recording the average iteration number and each feedback time-consuming in 50 tracing processes. We set the threshold of searching function value (DOP) to 0.98, and let the algorithm run 50 times. Each time the maximum number of iteration is 50. If the DOP is larger than the threshold

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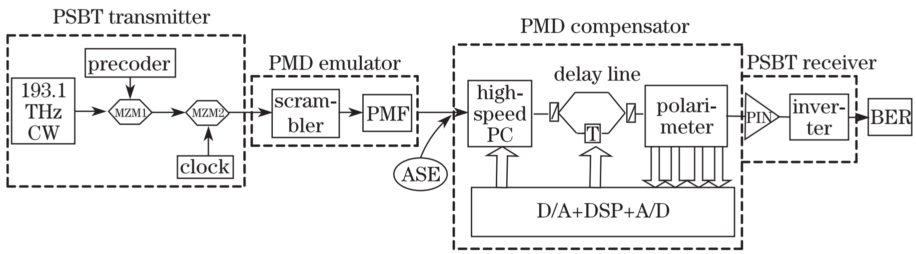

Fig. 1. Schematic diagram of PMD compensation system. D/A: digital/analog, A/D: analog/digital.

value, the tracking algorithm breaks up and the number of iteration is recorded. The results are shown in Fig. 2. It can be seen that, in the case of using PSO tracing, the average number iteration of searching is about 3.54, and that the time-consuming for each feedback is 39.64 μs, while in the case of using cross tracing, the average number iteration of searching is about 1.76, the time-consuming for each feedback is 25.8 μs. It can be concluded that the cross tracing algorithm is a better tracing algorithm for PMD compensation.

In the experiment, the PS is set to scan rate 8 of HP11896A, which means the average SOP variation is about 85 rad/s[10]. OSNR is set to 13.8 dB. We recorded the SOP and DOP before and after PMD compensation. The results are shown in Fig. 3. It can be seen that, the variation of SOP and DOP are very large without PMD compensation, as shown in Fig. 3(a). After PMD compensation, they become very small, and tend to be a constant value; the results are presented in Fig. 3(b). It indicates that PMD compensation is valid in the case of fast SOP changing.

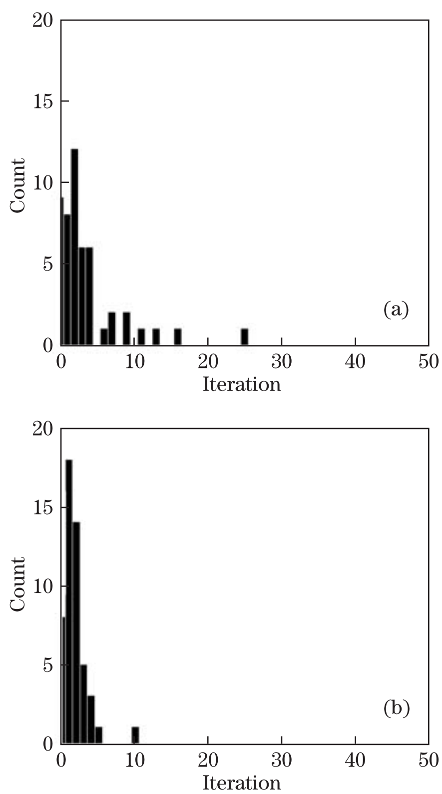

Fig. 2. Feedback number in 50 times tracing processes. (a) PSO tracing; (b) cross tracing.

On the other hand, with fast SOP change and the PMD compensation, the BER is measured at the receiver for 10 h, as shown in Fig. 4. The results

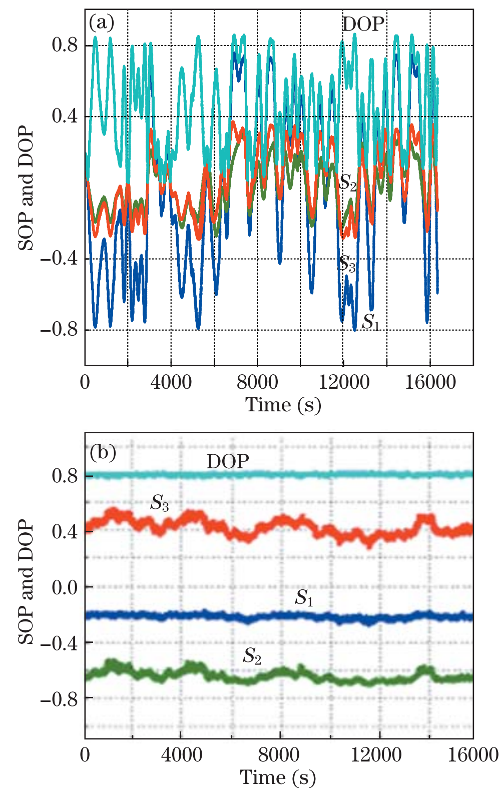

Fig. 3. SOP and DOP variation (a) before PMD compensation (b) after PMD compensation.

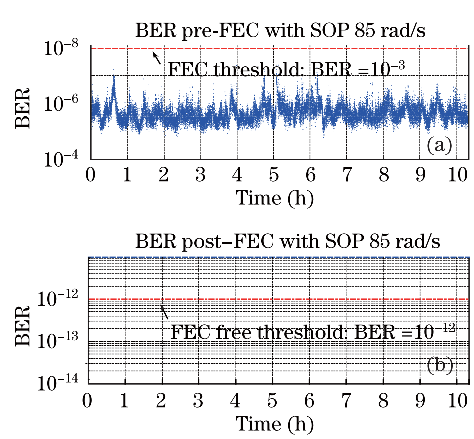

Fig. 4. BER variation (a) pre-FEC and (b) post-FEC.

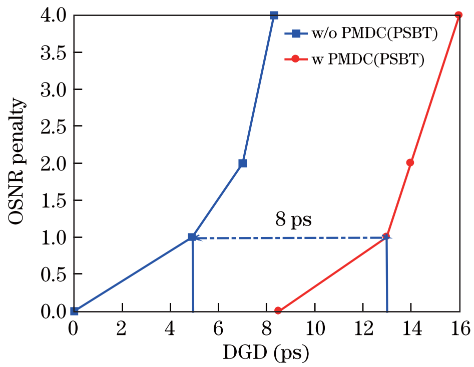

Fig. 5. OSNR penalty at BER = 2×10^{-3} versus DGD for 40-Gb/s PSBT.

show that BER pre-FEC is under 2×10^{-3} and BER post-FEC is close to zero ($<10^{-12}$) after PMD compensation. It is confirmed that the performance of PMD compensator is robust for PSBT modulation format.

We also measured the OSNR penalties at BER = 2×10^{-3} for different DGDs in the 40-Gb/s PSBT system with and without PMD compensation. The results are shown in Fig. 5. It is shown that the tolerance to PMD of the 40-Gb/s PSBT system can be increased from 5 to 13 ps by using the PMD compensator with 1-dB OSNR penalty. Therefore, it can be concluded that the PMD compensator significantly increases the PMD tolerance of the system.

In conclusion, the performance of OPMDC in the 40-Gb/s PSBT transmission system is studied under the condition of fast SOP change. The long time performance of OPMDC is tested by measuring BER over 10 h. Experimental results show that the tolerance of PMD in the 40-Gb/s PSBT system is increased up to 13 ps with 1-dB OSNR margin.

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