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PMD mitigation application of MZI-SOA based optical 2R regeneration in the receiver

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Abstract: We propose a new application of the MZI-SOA-based optical-2R regeneration, which can exactly compensate for the PMD penalty resulting from 35ps-DGD in a 10Gb/s system with 18dB OSNR/0.1nm. This demonstrates the effectiveness of optical-2R in the receiver for PMD mitigation.
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1. Introduction

As the transmission data rate increases, the polarization mode dispersion (PMD) of installed fiber networks raises serious concerns. The perfect compensation of dynamic PMD is especially difficult for higher order PMD effects [1]. To avoid network outages caused by PMD without using complicated compensators, the fiber transmission system requires additional margin for this impairment. However, bit-rate upgrades of the installed system can leave insufficient amount of margins for this purpose. To increase the system margin or tolerance for PMD, several techniques have been developed, such as inserting distributed Raman amplification [2], using forward error correction (FEC) codes with higher coding gain [3], and inserting optical regeneration devices [4, 5]. The papers [4, 5] investigated highly nonlinear fiber based optical 2R (re-amplifying and re-shaping) regenerators for PMD mitigation and chromatic dispersion tolerance. Among many such technologies, the MZI-SOA based optical 2R regenerator is one of the most promising candidates for PMD mitigation due to its compact size, robust operation [6], and relatively low power requirements. In fiber networks with performance limited by PMD, the EDFA-induced ASE noise and PMD-induced jitter noise degrade the signal in both amplitude and time domains. Due to the nonlinear transfer function, the MZI-SOA can suppress amplitude domain ASE noise effectively [6] and increase the penalty margin for the time domain jitter noise distortion.

In this study, we investigated the BER penalty margin created by the MZI-SOA for a 10Gb/s NRZ signal and measured the tradeoff between the performance improvement by the optical 2R regeneration and the performance degradation by the PMD-induced jitter noise. Consequently, we proposed an insertion of an MZI-SOA based optical 2R regenerator in the receiver end to achieve PMD mitigation.

2. Experimental setup

Figure 1 shows the experimental setup. It consists of three parts: the optical transmitter, the fiber transmission emulator, and the receiver module with 2R regeneration function. The optical transmitter, an Agilent 83433A 10Gb/s lightwave transmitter centered at 1555.44 nm, takes the output of the pulse pattern generator and produces a 10Gb/s optical NRZ signal with a 2^{31}-1 PRBS. In the fiber transmission emulator, the polarization scrambler first scrambles the polarization of the signal to a Degree of Polarization (DOP) of 5% with a modulation frequency of around 1MHz, emulating the polarization of the signal after a long field fiber transmission. Then, the polarization-scrambled signal experiences 0ps, 20ps, 30ps, or 35ps differential group delay (DGD) in the PMD emulator. The

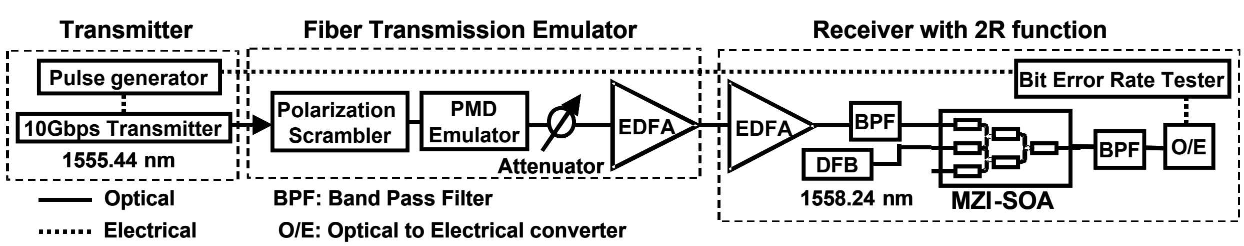

Figure 1: Experimental setup of PMD margin generation by MZI-SOA

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final stage of the fiber transmission emulator is comprised of an optical attenuator, an EDFA, and an optical band-pass filter (BPF). The attenuator decreases the signal power going into the EDFA and fixes the EDFA's output OSNR at 18 dB or 20 dB (0.1 nm resolution bandwidth), emulating the OSNR degradation of the signal after field fiber transmission. Then, the BPF filters out the out-of-band ASE noise and forwards the signal to the receiver module. In the receiver, another EDFA functions as a pre-amplifier and boosts the signal power to approximately 0 dBm to meet the MZI-SOA's requirement. The MZI-SOA, consisting of 6 SOAs arranged in 3 stages, optically regenerates the degraded signal and converts its wavelength to 1558.24nm simultaneously, using the cross-phase modulation effect. The output OSNR is 38.9dB/0.1nm. The setup does not utilize an ITU-grid laser diode since identification of the signal wavelength before the O/E converter is unnecessary. After the BPF filters out the wavelength conversion output, the O/E converter (Agilent 83434A 10Gb/s lightwave receiver) converts the signal to electrical and sends it to the BERT for the BER measurements.

3. Experimental results and discussion

Figure 2 shows the eye diagrams for each DGD amount (0ps, 20ps, or 35ps) before and after 2R regeneration with 18dB/0.1nm OSNR. Before the 2R regeneration, the ASE noise that causes distortion on the mark level closes the eye vertically, and the jitter noise translated from the DGD closes the eyes horizontally in proportion to the DGD value. The 2R regeneration effectively suppresses the ASE noise, recovering the OSNR to 39dB/0.1nm. Also, the eye diagrams show clearer mark levels. In particular, with 35ps DGD, the 2R regeneration almost doubles the eye height, creating an opening that nearly matches that before 2R with 0ps DGD. However, due to the pattern-dependence of the MZI-SOA device, the jitter noise increases slightly after 2R regeneration (the jitter RMS increases from 6.5ps to 6.7ps RMS, from 9.6ps to 11ps, and from 15.4ps to 16.9ps for signals with 0ps, 20ps, and 35ps DGD, respectively). In the future, 3R regeneration with re-timing is expected to suppress the jitter noise and solve this problem.

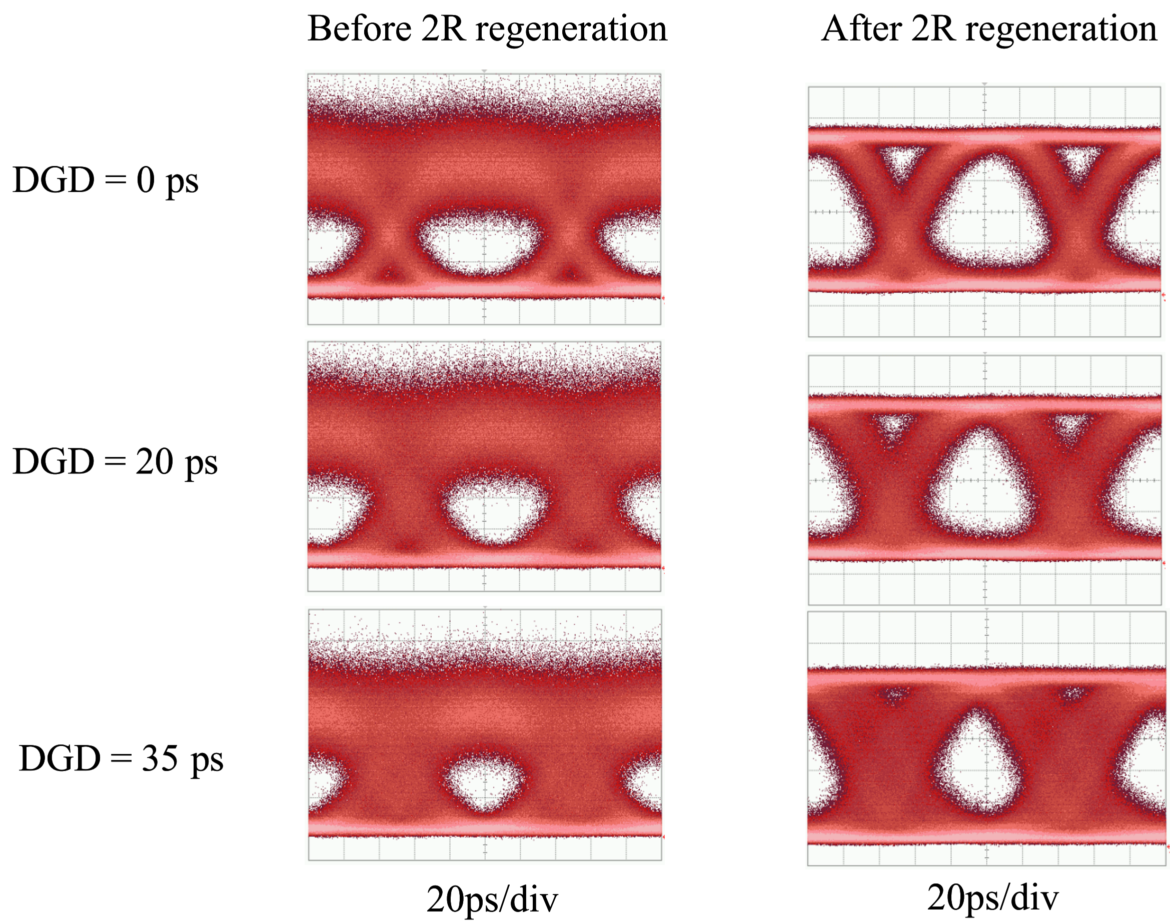

Figure 2: Eye diagrams before and after 2R regeneration with 0. 20 or 35ps DGD (18dB OSNR/0.1nm)

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Figure 3 shows the bit-error-rate curves of 10Gbps signals before and after the 2R regeneration with 0ps, 20ps, 30ps or 35ps DGD (Left: 20dB/0.1nm OSNR, Right: 18dB/0.1nm OSNR). Both figures show error floors caused by a relatively low OSNR for this bit rate. The BER curves of signals with 0ps DGD before the 2R regeneration were measured as reference curves. Without introducing the DGD (0ps DGD), the 2R regeneration removes the ASE noise and shows clear performance improvement by generating a -0.8dB (20dB OSNR) or -2dB (18dB OSNR) negative power penalty. By loading a 20ps DGD, the performance after the 2R regeneration became worse for jitter increment. However, the negative power penalty is still valid for both OSNR cases. In the case of 20dB OSNR, the BER curve of the regenerated signal moves to the right of the reference curve with an emulated DGD of 30ps. In the case of 18dB OSNR, the BER curve of the regenerated signal with 35ps DGD overlaps with the reference curve. At this point, the performance improvement by the optical 2R is equivalent to the performance degradation by 35 ps DGD; the curve has an error floor below 1E-5, which means that the actual transmission system using the FEC can achieve error-free detection of a signal experiencing 18dB OSNR/0.1nm and 35 ps DGD. The 35 ps instantaneous DGD corresponds to 10.94 ps mean DGD, which in turn is equivalent to over 3000 km of 0.2 ps DGD fibers or about 800 km of 0.4ps DGD fibers. Equipping the receiver with this MZI-SOA based optical 2R regenerator could eliminate any concerns rising from PMD on this bit rate signal flow.

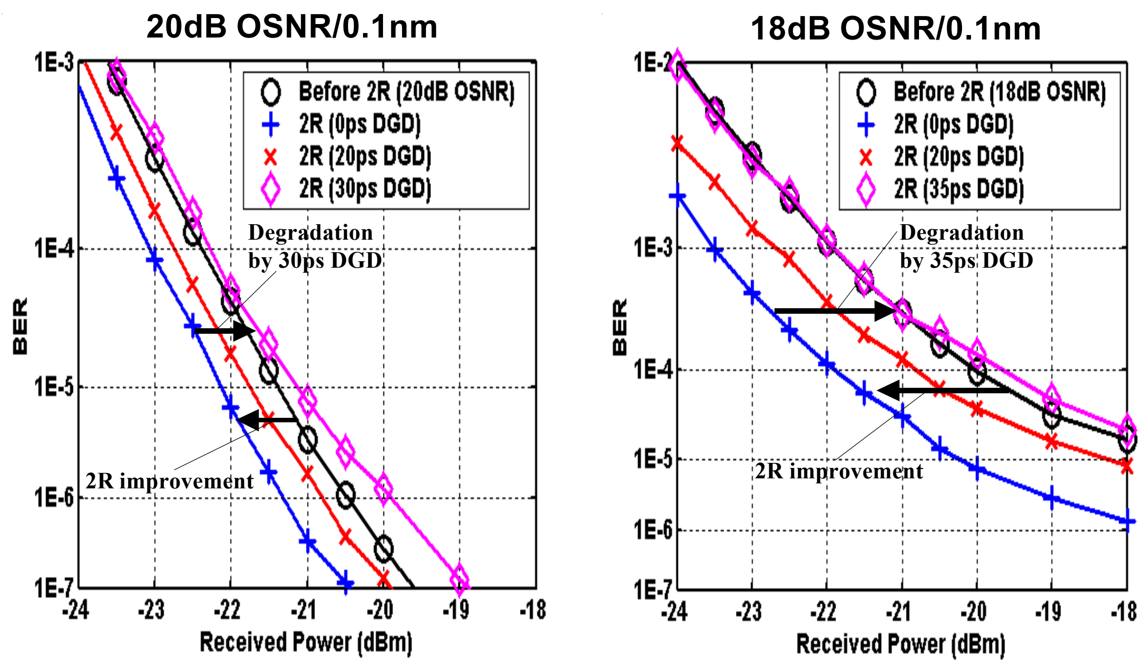

Figure 3: BER curves of 2R regeneration with 0, 20, 30 or 35ps DGD (Left: 20dB OSNR/0.1nm, Right: 18dB OSNR/0.1nm)

4. Conclusion

We investigated the tradeoff between the amplitude domain improvement by the MZI-SOA and the time domain degradation by the PMD-induced jitter noise. For the 10Gb/s NRZ signal with 18dB OSNR, the experimental results prove that equipping the receiver with an MZI-SOA based 2R regenerator can create a BER penalty margin for 35ps instantaneous DGD and error-free operation could be achieved with FEC coding.

5. References

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