Experimental Nonlinear Cancellation of Polarization-Mode Dispersion

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1. Introduction

Dispersion is an important factor in determining the maximum obtainable bit rate*distance product. In installed fibers, thanks to chromatic dispersion management, it seems that polarization-mode dispersion (PMD) will be the main limiting factor, especially in the upgrade scenario from 2.5 Gb/s to 10 Gb/s.

The impact of PMD on lightwave systems has been extensively studied [1]. The first-order effect is a delay in the signal of one polarization relative to the other polarization. In the case of direct detection the signals add powerwise (because of their orthogonal polarization), so that the electrical current is the linear combination of the individually received signals. The second order appears as a distortion due to a cross coupling between the two polarizations.

Many ways, both optical and electrical, have been proposed to overcome the PMD-induced penalty. Optical compensation of the first order using birefringent fibers has already been demonstrated [2]. Electrical techniques, including linear equalization, non-linear equalization and other more sophisticated schemes have been proposed [3-4]. Equalization has already been implemented using an analog tapped delay line [5]. In this paper, we report the use of a nonlinear-canceller (NLC) decision circuit to ameliorate the effects of polarization-mode dispersion.

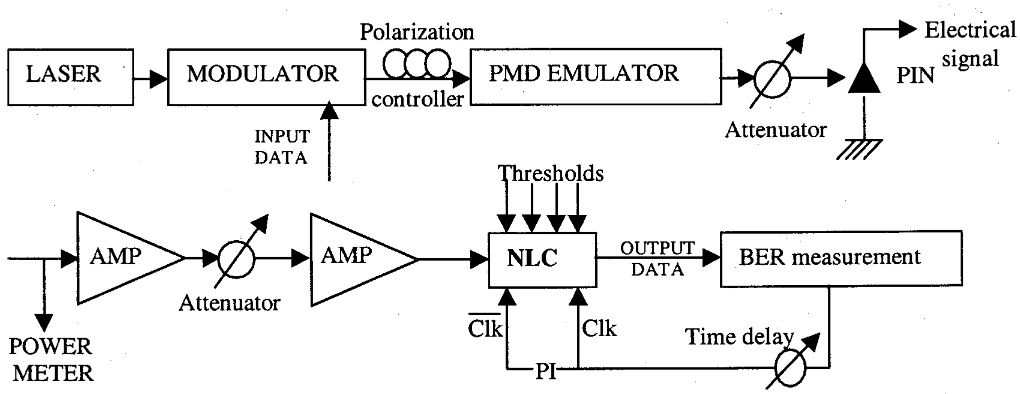

Fig. 1. Lightwave system experimental setup

2. System

The experimental setup is shown in Fig. 1. The output of a laser is externally modulated to generate either a 5-Gb/s or 10-Gb/s optical signal in non-return-to-zero (NRZ) format. This signal is passed through a polarization controller into a commercial PMD emulator (described below). The output signal is received by a PIN photodiode and electronically amplified. The decision circuit is the NLC. The phase of the clock used to drive the NLC is manually adjusted for the best performance.

The PMD emulator is a structure with two arms. The incoming light, falling on a beam splitter is divided into two parts. One polarization is delayed with respect to the other. Another beam splitter then brings the two orthogonal components back together. We have therefore a Michelson structure but with two orthogonal polarizations, insuring no coherent interference. The range of delay is -50 ps to +250 ps. The splitting ratio in the two arms can be set by adjusting the input-polarization state.

The NLC (or decision-feedback equalizer, DFE) is an integrated circuit that contains four separate decision circuits sharing the same clock [6]. Each circuit has its own manually adjusted threshold. At the decision time the output of one of the decision circuits is automatically chosen based on the two previously decided bits. This means that after the pattern xy is received, the decision of the circuit corresponding to the pattern xy is output. The threshold of this circuit is manually optimized to match the intersymbol interference (ISI) due to such a pattern. Indeed, for each set of two previous bits the threshold is adjusted to match the midpoint of the expected values for 0 and 1. For comparison purposes, the NLC can be used as a normal decision circuit by setting all the thresholds to the same level.

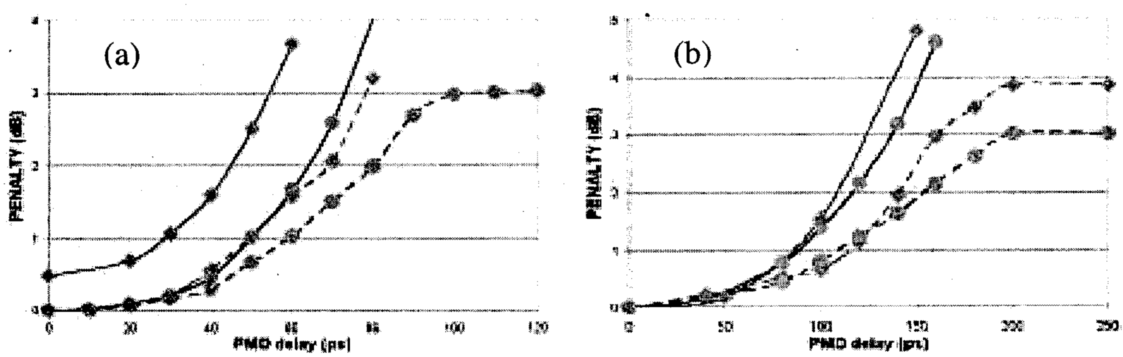

Fig. 2. Penalty versus PMD delay for a 50/50 split, case 10 Gb/s (a), case 5 Gb/s (b)
NLC: dash lines, Normal receiver: plain lines; Simulation: blue circles, experiments: red diamonds

3. Results

We investigated receiver performance for three splitting ratios in the PMD emulator. The three cases were ratios of 50/50, 75/25 (first incoming pulse containing 3/4 of the total power) and 25/75 (inverted case). In each case, the delay between the two copies was varied, and the PMD-dependent penalty was measured using bit-error-rate (BER) measurements. The NLC was run first as a normal decision circuit (all thresholds equal) and then optimally adjusted for each delay. Our experimental results were compared to the results of a computer simulation.

At 10 Gb/s for the 50/50 case, Fig. 2-a, the average improvement amounted to over 20 ps in PMD delay for a given penalty. At 10 Gb/s the experimental and simulation results diverge somewhat. Note especially a remaining improvement for the NLC in the case where the differential delay is zero. This is probably due to the limited bandwidth of our NLC. It acts as a low-pass filter, reducing the opening of the eye, even without PMD. By optimally adjusting the decision levels, this type of ISI can also be reduced by the NLC. To address this issue we also ran the experiment at 5 Gb/s, where we obtained a very good match of the simulation with the experiment. Fig. 2-b shows that, using the NLC, the PMD-induced penalty reaches a constant value after a full bit period (the eye is closed for a normal receiver). We can expect this constant value to last as long as the impairments stay in the range of the NLC, here two bit periods. The small difference from the theoretical value of 3 dB can be attributed to distortions introduced by the device we used.

Fig. 3 shows the theoretically expected asymmetrical behavior of the NLC. It is clear that the NLC works well in the 75/25 case, since it deals only with previously decided bits. However, when the small copy of the signal arrives first (25/75), the ISI is due to future bits. We make our decision using the big pulse but the ISI due to the small pulse cannot be taken into account since it has already arrived; e.g. we know the value of the ISI only one bit after our decision. Note that the 25/75 curve should lie on top of the normal receiver curve, but the NLC cancels other distortions, as already discussed, leading to some performance improvement. This asymmetrical behavior of the NLC requires the addition of a device such as a feed-forward equalizer to manage the ISI due to future bits, as shown in [3].

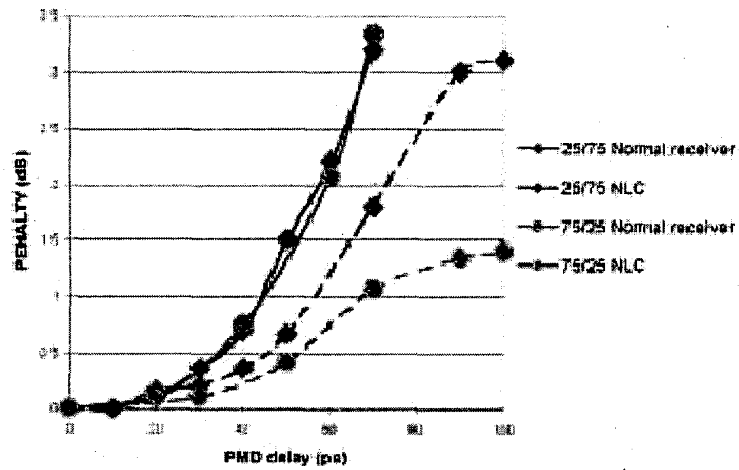

Fig. 3 Experimental Penalty versus PMD at 10 Gb/s.

4. Conclusions

We demonstrated the electronic nonlinear cancellation of first-order polarization-mode dispersion at 10 Gb/s, gaining an average improvement of over 20 ps in the PMD delay for a given penalty. At 5 Gb/s, we verified that we could reduce an infinite penalty due to first-order PMD to a 3-dB penalty as long as the impairments stay in the two-bit range of the NLC. Furthermore we confirmed that the NLC can improve performance for other types of impairments such as low-pass filtering. This should be extremely useful especially if we consider higher-order PMD.

References

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