A Novel Technique for Modulation Alignment Monitoring in RZ-DPSK Systems Using Off-Center Optical Filtering

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Abstract: A novel high-speed polarization-independent off-center optical filtering technique for monitoring alignment status between pulse generator and data modulator in RZ-DPSK systems is proposed and demonstrated. A monitoring dynamic range of 3.35 dB is achieved experimentally.
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1. Introduction

Recently, return-to-zero differential phase-shift keying (RZ-DPSK) has attracted much research interest for its better tolerance against impairments due to fiber nonlinearities and 3-dB sensitivity improvement with balanced detection, compared with return-to-zero on-off keying (RZ-OOK) [1]. The RZ-DPSK signal is usually generated by feeding an optical pulse train into a data-driven optical phase modulator, or feeding the phase modulated signal into a pulse carver. In order to generate RZ-DPSK signal properly, the peak of the RZ pulses should be aligned to the middle of the data bit period. However, due to temperature variation and device aging, the relative time delay between the pulse carver and the optical phase modulator may drift over time. For example, time delay drift of 2~5 ps in a 40-Gb/s RZ-DPSK transmitter may cause around 1-dB power penalty [2], [3]. Therefore, it is essential to monitor the alignment between the pulse train generator and the optical phase modulator.

Much research work has been done on the pulse-carver and data alignment monitoring in RZ-OOK systems [2], [3], but little on RZ-DPSK systems. In [4], it has been proposed to monitor the alignment status in RZ-DPSK system by measuring the power variation after a polarizer, which is induced by the reduction of signal’s degree of polarization (DOP) due to the timing-misalignment after propagation in an intentionally introduced finite differential group delay (DGD). However, measurement error might be incurred under polarization fluctuation of the incoming signal. In addition, the reported monitoring power dynamic range was smaller than 0.2 dB, which is susceptible to noise and environmental changes.

In this paper, we propose a novel alignment monitoring technique between the pulse carver and the data modulator (LiNbO₃ phase modulator) in RZ-DPSK systems, which can achieve much better monitoring dynamic range. The operation principle is based on the property that frequency chirp is always induced at the phase transient edge after data modulation by the phase modulator. Therefore, an off-center optical filter can be employed to capture the chirp induced, due to misalignment, at the rising and the falling edges of the RZ-DPSK signal. By monitoring the optical power at the optical filter output, the alignment status can be obtained. This scheme is simple, low-cost, polarization independent, and has high monitoring sensitivity. A monitoring dynamic range of 3.35 dB has been achieved experimentally.

2. Proposed Alignment Monitoring Scheme

As shown in Fig. 1(a), when the pulse appears in the middle of the data bit period, there is no timing misalignment between the pulse carver and the data modulator, which corresponds to the perfect alignment status. However, when there is a certain misalignment between the pulse carver and the data modulator such that part of the pulses enters the phase transient region between the data bits, phase variation occurs inside the pulses and induces frequency shift,
which is given by \( \Delta f = \Delta \theta / 2 \pi \Delta t \), where \( \Delta f \) is the induced frequency shift and \( \Delta \theta / \Delta t \) is the rate of phase variation. Therefore the signal spectrum is broadened. This broadening is determined by the rise and fall times of the phase modulation, i.e. \( \Delta \theta / \Delta t \), and the timing misalignment. The worst misalignment case is that the pulses appear at the transition edge of phase modulation, so that the modulated pulses experience the maximum phase variation and hence the maximum spectrum broadening. Fig. 1(b) illustrates the operation principle of the proposed alignment monitoring scheme. By filtering out a narrow slice from the edge of the signal spectrum, as shown in Fig. 1(b), any misalignment-induced spectrum broadening will be translated into an increased output power from the optical filter. Thus, the degree of misalignment between the pulse carver and the data modulator can be monitored by simple power monitoring after the filter. The filter offset was chosen to be the position with maximum monitoring power variation within half-bit-period misalignment range.

As shown in Fig. 2, the typical RZ-DPSK transmitter consists of a continuous-wave (CW) laser, an electro-absorption modulator (EAM) for pulse carving and an optical phase modulator. The optical pulse train generated by a clock-driven EAM is modulated via a data-driven optical phase modulator. At the output of the RZ-DPSK transmitter, a portion of power is tapped off and fed into the proposed alignment monitoring module, which only consists of an optical band-pass filter (BPF) and an optical power meter. The passband of the optical filter is adjusted to be offset from the signal center wavelength. The output power of the filter serves as a monitoring signal of the timing misalignment.

3. Experiments and results

A CW light at 1558 nm was carved into a 10.61-Gb/s pulse train with a pulse width of 28 ps via an EAM, driven by a 10.61-GHz sinusoidal clock signal. The pulse train was then modulated with a 10.61-Gb/s NRZ PRBS of pattern length 2^{31}-1 using a LiNbO\(_3\) phase modulator. For direct detection of DPSK signals, a single-ended Mach-Zehnder delay interferometer (MZDI) with 94-ps arm delay was employed in front of a PIN photodiode, having an electrical bandwidth of about 11 GHz.

First, we investigate the power penalty induced by misalignment in RZ-DPSK systems. With reference to the receiver sensitivity with perfect alignment at bit-error-rate (BER) =10\(^{-9}\), the power penalty at different timing misalignment between the pulse carver and the data modulator was obtained, shown as the solid symbols in Fig. 3(a). The degraded eye diagrams due to misalignment with (i) -32 ps and (ii) 32 ps are shown in the insets of Fig. 3(a), which corresponds to around 4-dB power penalty. Notice that when the timing misalignment exceeds -15 ps, the power penalty increases rapidly. The timing alignment range of -15 ps to +15 ps is referred as the misalignment tolerance range, which is affected by the rise and fall times of phase modulation, pulse shape and duty cycle of the
pulse train. The similar behavior was obtained in BER performance, shown as the open symbols in Fig. 3(a). The BER was measured under different timing alignment with a received optical power of -20.9 dBm. Fig. 3(b) shows the optical spectra and eye diagrams for the case without misalignment (inset (i) of Fig. 3(b)) and with 47-ps misalignment (inset (ii) of Fig. 3(b)), which corresponds to the worst case when the pulse is drifted to the edge of the data bit. Compared with the perfect alignment case, the eye is severely degraded, and the spectrum is noticeably broadened.

In the proposed monitoring module, a small amount of the modulated signal (10%) was tapped off and sent to an off-center optical band-pass filter with a passband of 0.22 nm. Fig. 4(a) shows the monitoring power dynamic range (MPDR), which is defined as the ratio of the output power for half-bit-period, 47-ps, misalignment (the worst case) to the output power for perfect alignment. A maximum MPDR of 3.35 dB was obtained when the optical filter was placed at 0.5-nm offset from the signal center wavelength. Compared with the DOP-based alignment monitoring scheme proposed in [4], in which the MPDR is 0.2 dB, the proposed scheme shows a significant improvement of around 3.15 dB on MPDR, thus substantially improving the monitoring sensitivity. Meanwhile, it eliminates the polarization control for the signal before being launched into the monitoring module. The asymmetry of the curve is attributed to the difference between the phase variation at the rising and the falling edges, which can also be verified by the asymmetric spectrum (solid line) shown in Fig. 3(b).

Fig. 4(b) shows the detected monitoring signal power versus the timing misalignment when the filter offset is set to 0.5 nm. Within the timing alignment range of -15 ps to +15 ps, i.e. the misalignment tolerance range, the monitoring signal exhibits a minimum power. This can be further manifested in Fig. 3(a), as the misalignment penalty also approaches to zero in this region. Once the timing misalignment is > +20 ps or < -20 ps, the power of the monitoring signal drastically increases with a slope of ~± 0.15dB/ps as shown in Fig. 4(b). This again matches the abrupt change in the power penalty curve for misalignment > +20 ps or < -20 ps as depicted in Fig. 3(a). Thus, with the monitoring module in the RZ-DPSK transmitter, it can effectively circumvent the potential power penalty induced by misalignment between the pulse-carver and the data modulator.

4. Conclusion
We have proposed and experimentally demonstrated a simple and robust off-center filtering technique to monitor the alignment between the pulse carver and the data modulator in RZ-DPSK systems. Compared with previous DOP-based monitoring scheme, a higher monitoring power dynamic range of 3.35 dB is achieved with suitable filter offset, thus resulting in a higher monitoring accuracy and sensitivity. The proposed module can be easily integrated with existing RZ-DPSK transmitter to implement automatic alignment by feeding back the monitoring signal into the signal generator to adjust the relative time delay. This improves the transmitter’s performance against environmental changes. The simple alignment monitoring approach features high monitoring dynamic range, high-speed operation, polarization independence and easy integration with transmitter for synchronization feedback control. This work was partially supported by a grant from the Research Grants Council of Hong Kong SAR, China, (Project No. CUHK4240/04E).

References