High-Speed Data and Pulse-Carver Alignment in RZ-OOK Systems Using Delay Tap Asynchronous Waveform Sampling

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Abstract *A novel technique for monitoring the alignment status between pulse carver and data modulator in RZ-OOK systems is proposed and experimentally demonstrated. Both the magnitude and direction of such timing misalignment can be successfully determined.*

Introduction

Return-to-zero (RZ) is the preferred data modulation format for high bit-rate ultra long-haul (ULH) dense wavelength-division multiplexed (DWDM) optical transmission systems [1]. The RZ-OOK signal is usually generated by feeding an optical pulse train into a data-driven optical intensity modulator, or feeding the intensity modulated signal into a pulse carver. In order to generate RZ-OOK 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 intensity modulator may drift over time [2][3]. Timing misalignment between pulse carver and data modulator can cause severe pulse distortion, as shown in Fig. 1. Therefore it is essential to monitor the alignment between the pulse train generator and the modulator during the operation of the system because the monitoring signal can serve as a feedback control for automatic alignment.

In [2], it has been proposed to monitor the modulation alignment status in RZ-OOK system by measuring the RF spectral null power. However, the misalignment direction cannot be determined. Another scheme [3] uses optical spectral asymmetry as indicators to measure the alignment status. However, this scheme may not be applicable when dual-drive Mach-Zehnder interferometer (DD-MZI) is used as data modulator in the system, because no chirp is induced in DD-MZI.

In this paper, we describe and experimentally demonstrate a new modulation alignment monitoring scheme in RZ-OOK systems based on delay-tap asynchronous waveform sampling. The scheme is simple, low-cost, has no particular sampling rate or stability requirements, applicable to any kind of intensity modulator, and able to determine both the magnitude and direction of modulation misalignment.

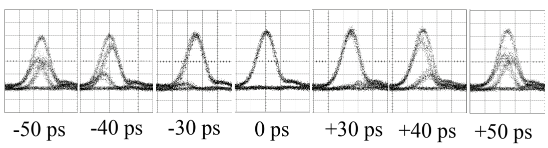

Fig. 1. Eye diagrams for different timing misalignment

Delay-tap asynchronous sampling

The proposed alignment monitoring scheme is based on the delay-tap asynchronous waveform sampling technique [4] as illustrated in Fig. 2. Signal samples are taken at a rate of $1/T_s$, which can be much slower than the system clock. Each sample point consists of two measurements (x and y) separated by a fixed time delay Δt. The x and y values are then plotted in pairs to form a two-tap scatter plot as shown in Fig. 2(b). Since this plot provides signal waveform characteristics similar to eye diagram, misalignment status can be observed from its evolution, which will be discussed in details in next section.

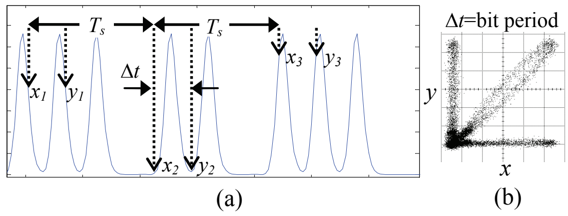

Fig. 2. (a) Delay-tap asynchronous sampling. T_s=sampling period, Δt=timing offset within each sample. (b) Two-tap scatter plot for RZ-OOK signal at Δt=bit-period

Experimental setup and results

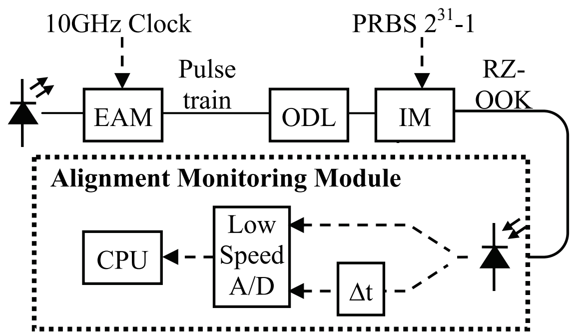

Fig. 3. Experimental setup. EAM: electro-absorption modulator; ODL: optical delay line; IM: intensity modulator

Fig. 3 shows the experimental setup used to investigate the proposed scheme, a CW light at 1547 nm was carved into a 10-Gb/s pulse train with a pulse width of 28 ps via an electro-absorption modulator (EAM), driven by a 10-GHz sinusoidal clock signal. The pulse train was then modulated with a 10-Gb/s

NRZ PRBS of pattern length 2^{31}-1 using a LiNbO3 Mach-Zehnder intensity modulator (IM). The optical delay line (ODL) was used to provide different misalignments between the pulse carver and data modulator. At the output of the RZ-OOK transmitter, the signal was fed into a delay-tap asynchronous sampling system in which the signal was first detected using a photo-detector. Then the detected signal was split into two branches with relative delay of Δt, before being sampled by a 50-MHz triggered low-speed analog to digital converter. Finally, a computer was used to collect and analyze the samples. In our experiment, Δt was set to be exactly one bit period (100 ps).

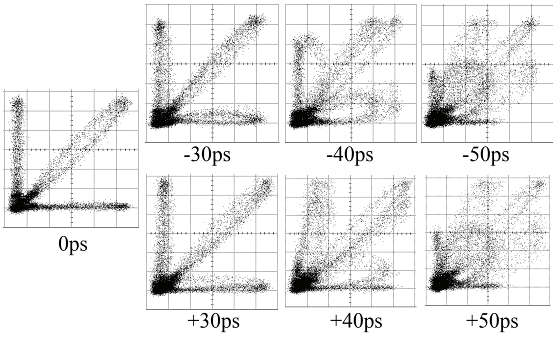

Fig. 4. Two-tap scatter plots for different modulation timing misalignments

Fig. 4 shows the two-tap scatter plots obtained at different modulation timing misalignments. For misalignment of 0 ps, the scatter plot has clear diagonal. Increasing misalignment to 30 ps starts to cause the sample points on the diagonal to disperse. In addition, the negative and positive misalignments induce different opposite rotational directions to the diagonal sample points. For example, the diagonal points of the -40-ps plot rotate in counter-clockwise direction, while that of the +40-ps plot rotate in clockwise direction. Note that the –50-ps and +50-ps cases are identical in 10-Gb/s systems since the bit period is equal to 100 ps.

The increasing dispersion and the rotation of the sample points on the diagonal offer a potential tool for monitoring the modulation misalignment status. We take two parameters to investigate this effect:

$$d = \frac{1}{n}\sum_i \sqrt{x_i^2 + y_i^2}\,\sin\left(\left|\frac{\pi}{4} - \arctan\frac{y_i}{x_i}\right|\right) \qquad (1)$$

$$t = \frac{1}{n}\sum_i \arctan\frac{y_i}{x_i} \qquad (2)$$

d represents the average distance of every sample points from the diagonal, while *t* represents the average angle of the sample points from the origin. For these two parameters we just consider top-right part of the plots so as to reduce the influence from the vertical and the horizontal edges, and *n* is the total number of considered sample points.

Fig. 5 (a) shows the experimentally obtained *d* and *t*. It is shown that *d* starts to increase when misalignment induced eye distortion starts to become significant at around 30 ps [5]. On the other hand, *t* can reflect the misalignment direction because it is larger than $\pi/4$ for negative misalignment while it is smaller than $\pi/4$ for positive misalignment. Therefore, by using both of the curves, both of the magnitude and direction of misalignment can be deduced. We have also performed simulation for the proposed scheme using OptSim^{TM} and the results are depicted in Fig. 5 (b). It is shown that the experimental results and simulation results agree very well.

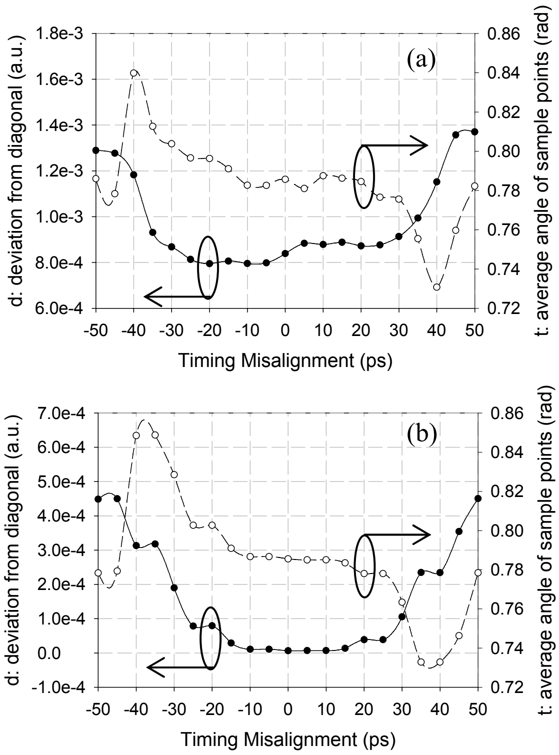

Fig. 5. d and t for different misalignment obtained by (a) experiment, and (b) simulation using OptSim^{TM}

Conclusions

We have proposed and experimentally demonstrated the use of delay-tap asynchronous waveform sampling technique to monitoring the alignment between the pulse carver and the data modulator in RZ-OOK systems. This scheme is simple, and is able to determine both the misalignment magnitude and direction. It is expected that the RZ-OOK transmitter robustness can be improved by integrating the proposed scheme to provide feedback control for automatic alignment.

References

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