Experimental Synchronization Monitoring of I/Q Data and Pulse-Carving Temporal Misalignment for a Serial-Type 80-Gbit/s RZ-DQPSK Transmitter

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Abstract: We experimentally demonstrate a monitoring method for determining misalignment between the I/Q data streams and between the data and pulse-carving in an 80-Gbit/s serial RZ-DQPSK transmitter. We show a dynamic-range of 8 dB for I/Q data misalignment and 6 dB for data to carver misalignment.

OCIS codes: (060.2330) Fiber optics communications; (060.5060) Phase modulation;

1. Introduction

Multi-level modulation formats are increasingly important given their inherent spectral efficiency and consequent tolerance to chromatic dispersion. Furthermore, phase-shift-keying (PSK) methods tend to have better sensitivity and more nonlinearity tolerance than on-off-keying (OOK), and return-to-zero (RZ) can often provide better sensitivity than non-return-to-zero (NRZ) formats. Moreover, differential phase techniques tend to be easier to implement than coherent detection that utilizes a local oscillator. Given these issues, RZ differential-quadrature-phase-shift-keying (RZ-DQPSK) has emerged as an exciting candidate for sensitive, efficient and robust data transmission over optical fiber [1]. In DQPSK, the in-phase (I) and quadrature-phase (Q) data streams are simultaneously transmitted during a single symbol time. It is important to note that some of the most dramatic transmission results to date use RZ-DQPSK [2].

In general, due to unavoidable optical/electronic device aging and temperature variation induced drift, maintaining the correct timing within the data transmitter is critical. This problem becomes far more significant for the complex RZ-DQPSK transmitter, in which: (i) multiple modulators must be monitored, (ii) I and Q data must be temporally aligned, and (iii) the RZ pulse carver must be synchronized to the data. Therefore, a laudable goal would be to have an easy-to-detect time-misalignment error signal that can be used in a feedback loop to maintain optimal system performance, such that any time misalignment between the I and Q data streams, as well as synchronization between the RZ pulse carver and the bit transitions, can be readily monitored.

DQPSK transmitters are typically configured in one of two types: (a) parallel, in which I and Q are generated using a parallel nested I/Q modulator, and (b) serial, in which I and Q are generated using two cascaded modulators [3]. Parallel-type DQPSK transmitters tend to be difficult to implement at high data rates because of their required path length matching and increased complexity. The serial-type transmitter relieves these restrictions for high-data-rate usage, although serial-type transmitters tend not to have as sharp phase transitions as the parallel type. There have been reports for monitoring of time misalignment/synchronization for simple RZ-DPSK transmitters [4-6] and for a 20-Gbit/s RZ-DQPSK parallel-type transmitter [7]. However, these approaches cannot be applied to the serial-type RZ-DQPSK transmitter. It would be quite advantageous to monitor the time misalignment/synchronization in the serial-type RZ-DQPSK modulator, especially at high data rates.

In this paper, we analyze and demonstrate a synchronization monitoring technique for I/Q time misalignment and pulse carving misalignment for 80-Gbit/s serial RZ-DQPSK data generation. The optical clock tone power of DQPSK signal at the symbol rate is measured using an optical spectrum analyzer (OSA) to monitor I/Q data misalignment. The radio frequency (RF) clock tone power of RZ-DQPSK is measured using a photodiode and a RF spectrum analyzer to monitor the carver misalignment. We demonstrate an 8 dB monitoring-power-dynamic-range (MPDR) for I/Q data misalignment and 6 dB for carver misalignment. With the monitor information, a simple feedback loop could be built to automatically align and maintain alignment in a serial RZ-DQPSK transmitter.

2. Concept

The concept of misalignment monitoring for a serial RZ-DQPSK transmitters is shown in Fig.1 (a) and (b). For parallel RZ-DQPSK, the location of intensity dips at the points of phase transits changes with I/Q misalignment, so RF clock tone power change could be observed to monitor I/Q misalignment when directly detecting the DQPSK signal [7]. For serial RZ-DQPSK, only phase changes with the increase of I/Q misalignment while the intensity stays constant, so the method for parallel DQPSK scheme could not be applied. Nevertheless, frequency chirp is induced with the presence of phase change, which results in a change in the optical spectrum, as shown in Fig. 1 (a). By monitoring the optical clock tone at the symbol rate, we can determine the I/Q data misalignment. RZ-DQPSK has a sinusoidal-like waveform and with a strong RF clock tone at the symbol rate (Rs) when the data and carver are aligned. However, when the carver and data are misaligned, the waveform distorts and the RF clock tone at Rs decreases correspondingly, so the misalignment between data and carver can be monitored by measuring the change in RF clock tone power, as shown in Fig. 1 (b).

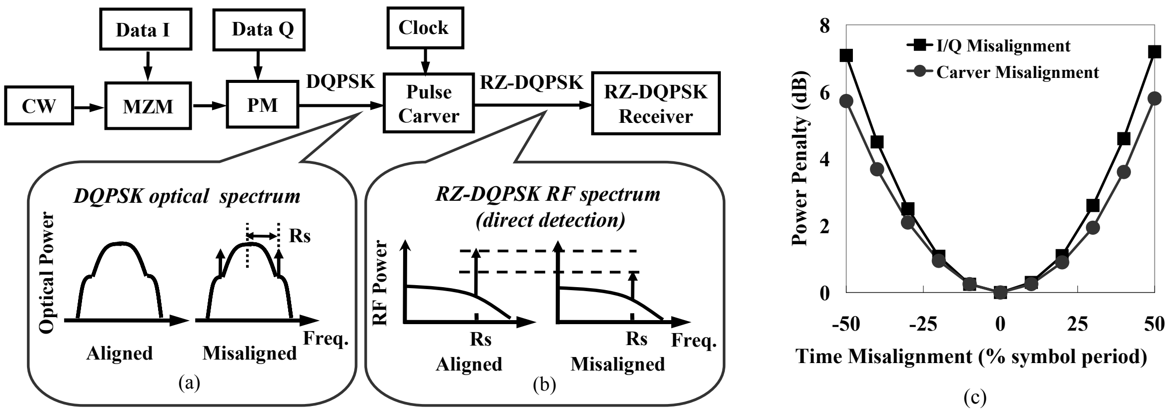


Fig.1 Conceptual diagram of misalignment monitoring for a serial RZ-DQPSK transmitter. (a) Optical clock tone power at the symbol rate increases with I/Q misalignment. (b) RF clock tone power at the symbol rate decreases with clock/data misalignment. (c) Simulated power penalty at 10^{-9} BER versus timing misalignments in an 80-Gbit/s serial RZ-DQPSK transmitter.

Fig.1 (c) shows the simulated system power penalty at a bit error rate (BER) of 10^{-9} induced by I/Q timing misalignments in an 80-Gbit/s system using serial generated RZ-DQPSK. Note that the power penalty increases rapidly when time misalignment exceeds ±10% of the symbol period, which corresponds to 2.5 ps in 80-Gbit/s RZ-DQPSK systems. Time drifts of 2~5 ps have been observed when heat was applied to the pulse carver driver [4], which causes about a 1 dB power penalty to an 80-Gbit/s serial RZ-DQPSK system as shown in Fig. 1 (c). Furthermore, a change of 50 degrees in temperature will result in a propagation time delay of 2 ps in a 1 m-long standard single mode fiber between the pulse carver and data modulator [4]. Therefore, the misalignment monitoring in the transmitter is critical to maintain the system performance.

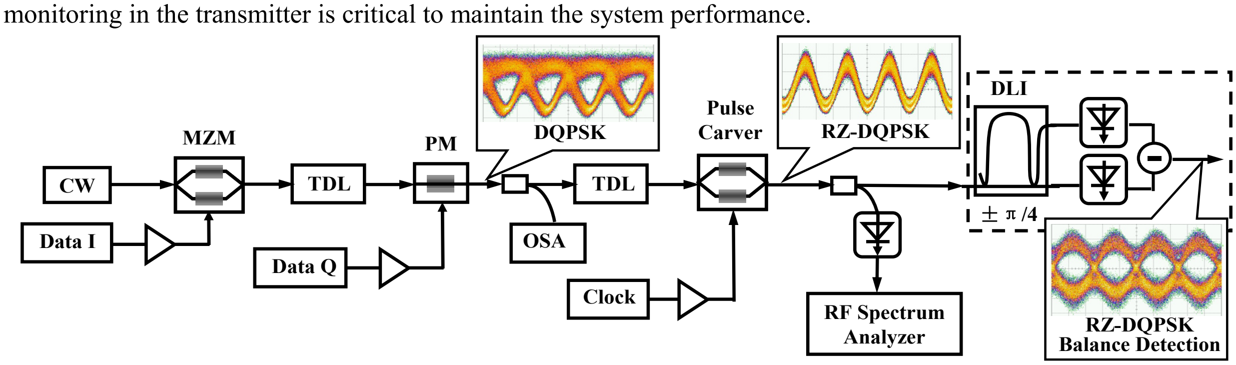


Fig.2 Experimental setup for 80-Gbit/s serial RZ-DQPSK transmitter monitoring. CW: continuous wave; MZM: Mach-Zehnder modulator: PM: phase modulator; TDL: tunable delay line; OSA: optical spectrum analyzer; DLI: delay line interferometer.

3. Experimental Setup

Fig. 2 shows the monitoring configuration. The 80-Gbit/s RZ-DQPSK transmitter consists of a continuous-wave (CW) laser operating at 1554.52-nm, a 40-Gbit/s MZM followed by a 40-Gbit/s PM, which are driven by two 40-Gbit/s 2^{15}-1 pseudo-random binary sequences (PRBSs), and a pulse carver to generate a 50% duty-cycle pulse train driven by a 40 GHz sinusoidal clock. An optical coupler is used after the phase modulator to tap off a portion of the DQPSK signal to an OSA to monitor the I/Q misalignment. Another optical coupler is used after the pulse carver to monitor the carver misalignment. A 40 GHz photodiode and a RF analyzer are used to measure the RF clock tone power in the presence of carver misalignment. Optical tunable delay lines (TDLs) are used between modulators to control the time alignment between the I/Q data streams and between the data and pulse carving. The RZ-DQPSK signal is demodulated using a 40 GHz delay line interferometer (DLI) and then detected by a 40 GHz balanced photoreceiver. The eye diagrams at each stage are shown for the case of optimal alignment in Fig. 2.

4. Results and Discussions

Fig. 3 shows the measured optical clock tone power versus I/Q data misalignment. We can see from the curve that as the misalignment between the two data streams increases, the optical clock tone power decreases accordingly. From Fig. 3, we observe that this method allows for a MPDR of approximately 8 dB. Note that the relationship is fairly linear in the region of interest, i.e. around +/-25% symbol period (+/-6.25 ps). The change in optical clock tone power could also be measured using a narrow optical bandpass filter and a photodiode as opposed to an expensive OSA. Also, this method allows the RF power corresponding to I/Q misalignment to be obtained.

The plot in Fig. 4 shows the measured RF clock tone power at 40 GHz versus pulse carver misalignment when the data is perfectly aligned. We observe that the RF clock tone power at the symbol rate, i.e. 40 GHz, can vary by 6 dB. We also notice from the experiment that the waveform of RZ-DQPSK after direct detection does not change in the presence of I/Q data misalignment.

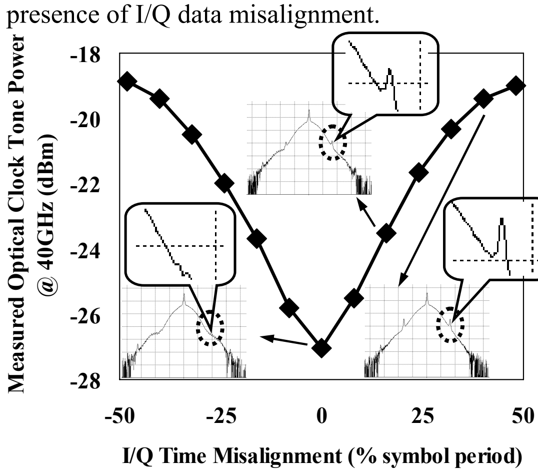


Fig.3 Measured 40 G optical clock tone power of 80-Gbit/s DQPSK optical spectrum versus I/Q data misalignment.

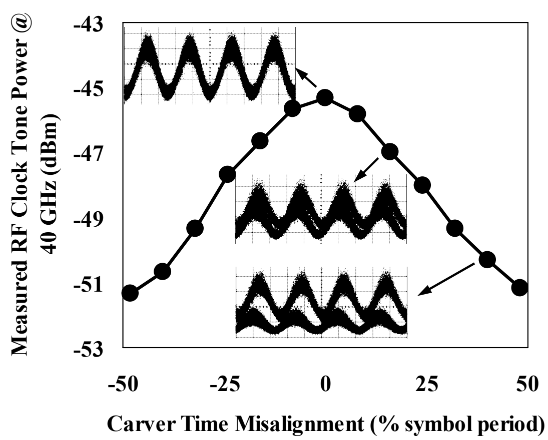
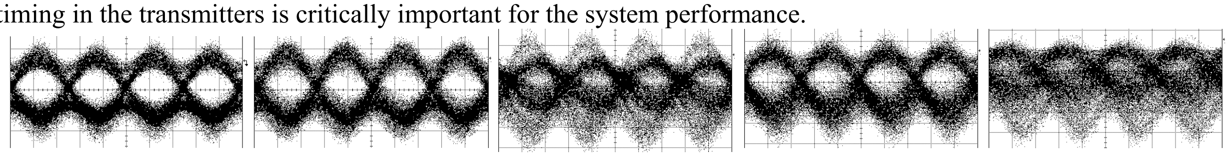


Fig.4 Measured 40 G RF clock tone power versus carver misalignment after 80-Gbit/s RZ-DQPSK direct detection.

Fig. 5 shows the eye diagrams after 80-Gbit/s RZ-DQPSK balanced detection with and without time misalignments. The system performance distorts with increased time misalignments. It is shown that the correct timing in the transmitters is critically important for the system performance.



(a) (b) (c) (d) (e)

Fig.5 80-Gbit/s RZ-DQPSK balanced eye diagrams in presence of I/Q misalignment and carver misalignment. (a) aligned; (b) w/ 20% I/Q misalignment; (c) w/ 40% I/Q misalignment; (d) w/ 20% carver misalignment; (e) w/ 40% carver misalignment.

Using the converted RF power change from the monitored optical clock tone power change for I/Q misalignment and the RF clock tone power change for carve misalignment, a feedback loop could be applied to automatically align the RZ-DQPSK transmitter, which is similar to the configuration in [7]. Note that the optical delay lines between modulators could be replaced with voltage-controllable RF phase shifters in the path of one of the data steams and the RF clock. The measured RF powers could be fed back into control circuits to generate two control signals, which can be used to drive the phase shifters to automatically adjust the delay between the two data streams and between the data and the pulse carver.

5. References

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