Synchronization Monitoring of I/Q Data and Pulse Carving Misalignment for a Parallel-Type RZ-DQPSK Transmitter by Measuring RF Clock Tone/Low Frequency Power

Xiaoxia Wu, *Student Member, IEEE*, Louis Christen, Bo Zhang, Wei-Ren Peng, Jeng-Yuan Yang, Lin Zhang, Scott R. Nuccio, Loukas Paraschis, *Senior Member, IEEE*, Jeffrey A. Jargon, *Senior Member, IEEE*, and Alan Willner, *Fellow, IEEE*

***Abstract*—We experimentally demonstrate a technique for monitoring the time misalignment of in-phase/quadrature (I/Q) data streams and pulse carver/data in a 20-Gb/s return-to-zero differential quadrature phase-shift-keying (RZ-DQPSK) transmitter. By measuring the radio-frequency clock-tone power at 10 GHz and low frequency power at 600 MHz, a monitoring power dynamic range of 18 dB is obtained for I/Q data misalignment and 6 dB is shown for carver/data misalignment. With the monitor information, a simple feedback loop is proposed to automatically align the RZ-DQPSK transmitter.**

***Index Terms*—Fiber-optics communications, return-to-zero differential quadrature phase-shift-keying (RZ-DQPSK).**

I. Introduction

ADVANCED modulation formats are attracting much attention in the field of optical fiber transmission systems due to the potential for high-spectral efficiency and robustness to chromatic dispersion [1]. Multilevel formats, such as differential quadrature phase-shift-keying (DQPSK), in which in-phase (I) and quadrature-phase (Q) are simultaneously transmitted in a single symbol time, have advantages similar to that of binary DPSK, which does not require coherent detection, is tolerant to nonlinearities, and exhibits high receiver sensitivity [2]. Moreover, return-to-zero (RZ) formats can provide better sensitivity than nonreturn-to-zero (NRZ). It is important to note that some of the most dramatic transmission results use RZ-DQPSK [3].

Due to unavoidable optical/electronic device aging and temperature variation induced drift, maintaining the correct timing within the transmitter becomes critical, and can be quite challenging considering the relative complexity of RZ-DQPSK transmitter modules, in which 1) I and Q data must be temporally aligned and 2) the RZ pulse carver must be synchronized to the data. It is shown that a severe system penalty is induced by the time misalignment between I/Q data and between data and carver [4]. 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/Q data streams, as well as misalignment between the carver and the bit transitions, can be readily corrected.

There have been several reports of time misalignment monitoring of the RZ carver in a simpler RZ-DPSK transmitter, including 1) a polarimetric filtering method [5], 2) an off-center optical filtering method [6], and 3) an optical frequency discriminator method [7]. However, there has been little reported effort towards monitoring of RZ-DQPSK transmitters.

In this letter, we analyze and demonstrate a monitoring technique for I/Q data and carver/data misalignment for 20-Gb/s RZ-DQPSK data generation, the main idea of which has been shown in [4]. The radio-frequency (RF) clock tone power at 10 GHz is measured using a simple photodiode and an RF spectrum analyzer to monitor the misalignment between the I and Q data streams. The RF power at 600 MHz is measured to monitor the misalignment between the pulse carver and data. With the monitor information, a simple feedback loop is proposed to automatically align the RZ-DQPSK transmitter. The application of this technique can be extended to higher bit-rate RZ-DQPSK systems, such as 100-Gb/s RZ-DQPSK.

II. Concept and Simulations Results

The concept of misalignments in the parallel-type RZ-DQPSK transmitter is shown in Fig. 1. The RZ-DQPSK signal is generated by use of a parallel Mach–Zehnder modulator (MZM) configuration followed by another MZM to pulse carve the signal to 50% RZ. When the I/Q data streams are misaligned, the locations of intensity dips caused by the phase transitions change accordingly. Therefore, the change in RF clock-tone power can be used to monitor I/Q data misalignment after direct detection of the DQPSK signal. We note that the clock-tone power in the RF spectrum at the symbol rate decreases significantly with the increasing misalignment. When the two data streams are aligned and we consider data/pulse carving misalignment, the RF power at low frequencies increases due to misalignment. This is caused by the removal of

Manuscript received June 17, 2008; revised October 01, 2008. First published October 31, 2008; current version published December 12, 2008. This work was supported by the Department of Commerce, National Institute of Standards and Technology (NIST), and Cisco Systems.

X. Wu, L. Christen, B. Zhang, J.-Y. Yang, L. Zhang, S. R. Nuccio, and A. Willner are with the Department of Electrical Engineering, University of Southern California, Los Angeles, CA 90089 USA (e-mail: xiaoxia@usc.edu).

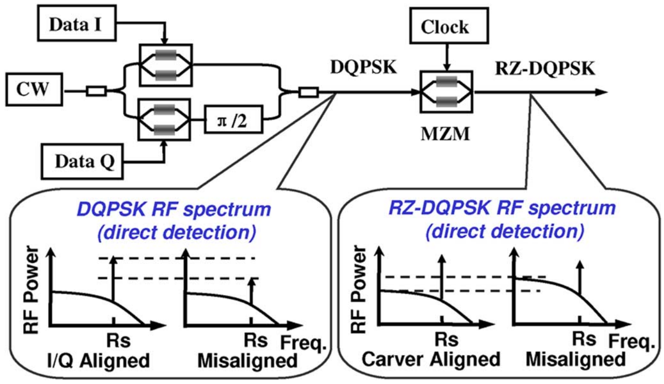
W.-R. Peng is with the Department of Electrical Engineering, University of Southern California, Los Angeles, CA 90089 USA, and also with the Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan.

L. Paraschis is with Cisco Systems, San Jose, CA 95134 USA.

J. A. Jargon is with NIST, Boulder, CO 80305 USA.

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LPT.2008.2007503



(a) (b)

Fig. 1. Conceptual diagram of misalignment monitoring for RZ-DQPSK transmitters. (a) Misalignment between I/Q data. Clock tone power at symbol rate decreases with I/Q misalignment. (b) Misalignment between carver and data. RF power at low frequencies increases with carver/data misalignment.

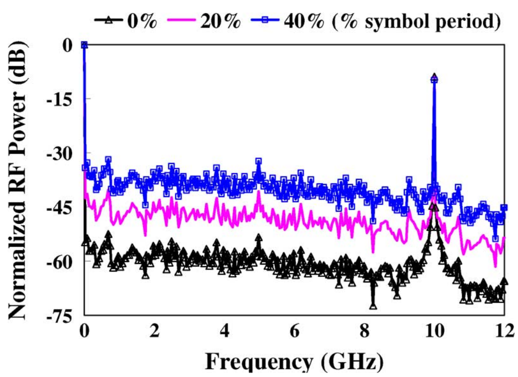


Fig. 2. Simulated RF spectra in the presence of carver/data misalignment.

less low frequency components with carver/data misalignment. Fig. 2 shows the simulated RF spectra with data/pulse carving misalignment. Note that the low frequency components can be chosen from hundreds of megahertz up to several gigahertz. In the following analysis and experiment, we measure RF power at 600 MHz for the carver/data misalignment monitoring.

We also analyze, via simulation, the proposed approach of monitoring RF power to identify the misalignments. The 20-Gb/s RZ-DQPSK is generated by a 20-Gb/s parallel-type modulator driven by 2 Vpi, where Vpi is the half-wave voltage of the modulator. The RF power is measured after being filtered by an RF bandpass filter (BPF) with a bandwidth of 200 MHz, and is centered at 10 GHz for I/Q data misalignment and 600 MHz for carver/data misalignment. Fig. 3(a) and (b) show the simulated RF power change versus time misalignment for the I/Q data misalignment and carve/data misalignment, respectively. We also measure the RF power at 600 MHz in the presence of both I/Q data misalignment and carver/data misalignment. We observe that the carver/data misalignment curve is shifted in the presence of I/Q data misalignment. The shift is about half of the percentage of the data misalignment. For example, the minimum point of the curve shifts from 0% to 10% of the symbol period in the presence of 20% I/Q data misalignment. The dynamic range decreases correspondingly with I/Q data misalignment, which could be attributed to the effect of data misalignment on the directly detected RZ-DQPSK RF spectrum. The RF power levels are normalized to the zero misalignment case, which is also true in the following figures.

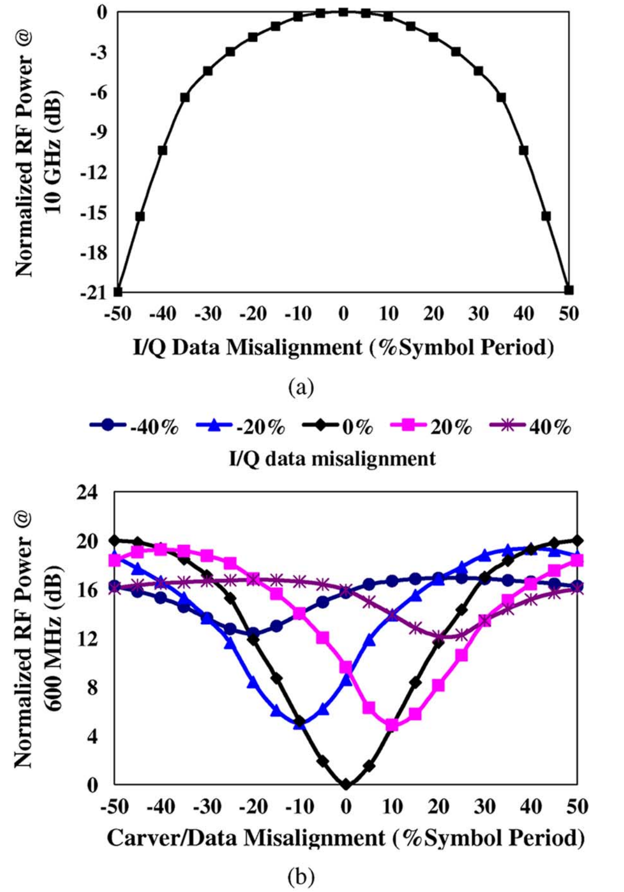


Fig. 3. Simulated RF power versus time misalignment. (a) I/Q data misalignment; (b) carver/data misalignment with and without I/Q data misalignment.

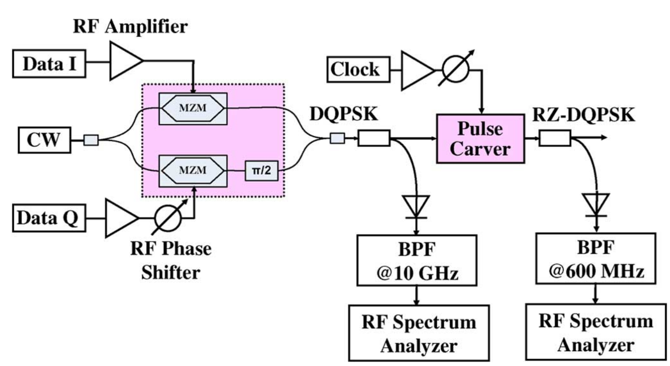


Fig. 4. Experimental setup for RZ-DQPSK misalignment monitoring.

III. Experimental Setup

Fig. 4 shows the proposed monitoring setup. The RZ-DQPSK transmitter consists of a continuous-wave (CW) laser operating at 1550 nm, a parallel-type DQPSK modulator, which is driven by two 10-Gb/s NRZ $2^{15}-1$ pseudorandom bit sequences, and an MZM for pulse carving. The pulse carver is driven by a 10-GHz sinusoidal clock signal to generate a 50% duty-cycle pulse train. An optical coupler is used after the DQPSK modulator to tap off a portion of the DQPSK signal, which is then detected by a 10-GHz photodiode. An RF spectrum analyzer is

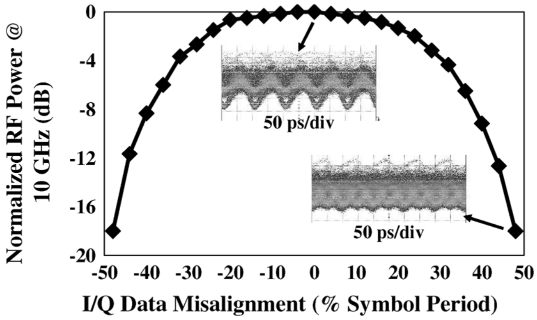


Fig. 5. Measured clock tone power of the 20-Gb/s DQPSK signal versus I/Q data misalignment. Clock tone power decreases with the misalignment.

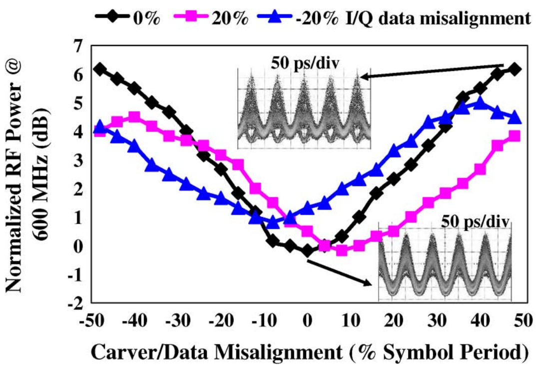


Fig. 6. Measured low-frequency power versus carver/data misalignment.

used to measure the clock tone peak power at 10 GHz. Another photodiode and RF spectrum analyzer are used after the pulse carver to measure the low-frequency RF power. The low frequency can be chosen between a few hundred megahertz and several gigahertz according to Fig. 2.

IV. Experimental Results and Discussion

Fig. 5 shows the measured clock tone power versus data misalignment in a 20-Gb/s parallel DQPSK transmitter. We can see from the curve that as the misalignment between the I/Q data increases, the clock tone power decreases accordingly. This can be understood by considering the situation in which the two data streams are misaligned by 50% of the symbol time. The period of the intensity dips of the misaligned DQPSK signal is reduced by half (equivalent to rate doubling), causing the clock tone at 10 GHz to decrease, while the clock tone at 20 GHz increases. By measuring the change of clock tone power at 10 or 20 GHz in the RF spectrum, the misalignment between the I/Q data can be measured. This method allows for a monitoring power dynamic measurement range of approximately 18 dB.

The diamond plot in Fig. 6 shows the measured RF power at 600 MHz versus pulse carver misalignment when I/Q data are perfectly aligned. We observe from both experiment and simulation that the clock tone peak power in this situation changes only slightly, while the RF power at lower frequencies can vary by about 6 dB. Fig. 6 shows the variation at 600 MHz for pulse carver/data misalignment. We also measure the change in RF power at 600 MHz in the presence of both carver/data misalignment and I/Q data misalignment. We observe that carver/data misalignment (diamond plot) is shifted only in the presence of I/Q data misalignment.

The experimental result of I/Q misalignment matches with the trend in our simulation. Due to the limited output voltage of our RF amplifiers, only Vpi is used to drive the parallel modulator instead of the standard 2 Vpi. RF noise at "1" level gets modulated linearly into the optical domain with relatively larger amplitude compared with that for the 2-Vpi case. Correspondingly, the low-frequency power changes less with the time misalignments, which is a possible reason why the monitoring power dynamic range for carver/data misalignment is relatively smaller compared to the simulation results.

The RF spectrum analyzers in the experiment can be replaced by two low-cost RF BPFs, one centered at 10 GHz and the other at 600 MHz. The BPF bandwidth can be hundreds of megahertz, e.g., 200 MHz. The measured clock and low-frequency RF power after the filters can be fed back into the control circuits to generate two control signals. These control signals can be used to drive voltage-controllable phase shifters to automatically adjust the delay between the I/Q data streams and between the carver and the data. Such a feedback loop could be applied to automatically align the RZ-DQPSK transmitter, as shown in [4].

V. Conclusion

We demonstrate a synchronization monitoring technique for I/Q time misalignment and carver/data misalignment in a 20-Gb/s parallel-type RZ-DQPSK transmitter by measuring RF clock tone and low-frequency power. A monitoring power dynamic range of 18 dB is obtained for I/Q data misalignment, and 6 dB is shown for carver/data misalignment. A simple feedback loop is proposed to automatically align the transmitter. This technique can be readily extended to higher bit-rate RZ-DQPSK systems, such as 100 Gb/s.

References

[1] A. H. Gnauck, P. J. Winzer, C. Dorrer, and S. Chandrasekhar, "Linear and nonlinear performance of 42.7-Gb/s single-polarization RZ-DQPSK format," *IEEE Photon. Technol. Lett.*, vol. 18, no. 7, pp. 883–885, Apr. 1, 2006.

[2] G. Charlet, P. Tran, H. Mardoyan, M. Lefrancois, T. Fauconnier, F. Jorge, and S. Bigo, "151 × 43 Gb/s transmission over 4080 km based on return-to-zero-differential quadrature phase-shift keying," in *Proc. ECOC 2005*, Glasgow, Scotland, Postdeadline paper Th4.1.3..

[3] A. H. Gnauck, G. Charlet, P. Tran, P. Winzer, C. Doerr, J. Centanni, E. Burrows, T. Kawanishi, T. Sakamoto, and K. Higuma, "25.6-Tb/s C+L-band transmission of polarization-multiplexed RZ-DQPSK signals," in *Proc. OFC 2007*, Anaheim, CA, Paper PDP19.

[4] X. Wu, L. Christen, B. Zhang, J.-Y. Yang, L. Zhang, S. R. Nuccio, A. E. Willner, and L. Paraschis, "Experimental synchronization monitoring of I/Q misalignment and pulse carving misalignment in 20-Gb/s RZ-DQPSK data generation," in *Proc. ECOC 2007*, Berlin, Germany, Paper 3.5.5..

[5] H. Kim, C. R. Doerr, R. Pafchek, L. W. Stulz, and P. Bernasconi, "Alignment monitoring of the pulse carver and data modulator for RZ-DPSK systems," *IEEE Photon. Technol. Lett.*, vol. 15, no. 11, pp. 1594–1596, Nov. 2003.

[6] G.-W. Lu, Y.-C. Ku, L.-K. Chen, and C.-K. Chan, "A novel technique for pulse-carver and data alignment monitoring in RZ-DPSK systems using off-center optical filtering," *IEEE Photon. Technol. Lett.*, vol. 17, no. 3, pp. 711–713, Mar. 2005.

[7] K. T. Tsai, G.-W. Lu, L.-K. Chen, and W. I. Way, "Alignment monitoring technique for pulse carver and data modulator in RZ-DPSK systems using an optical frequency discriminator," *IEEE Photon. Technol. Lett.*, vol. 18, no. 10, pp. 1119–1121, May 15, 2006.