Pulsewidth-tunable CSRZ-DQPSK signal generation using DPMZMs

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This letter proposes and experimentally demonstrates a simple scheme for generating 40-GBaud carrier-suppressed return-to-zero differential quadrature phase shift keying (CSRZ-DQPSK) modulation signals with tunable pulsewidths using two dual-parallel Mach–Zehnder modulators (DPMZMs). The duty cycle of the generated 40-GHz CSRZ-DQPSK pulse train is continuously tuned from 31% to 62%, with the full-width at half-maximum tuned from 7.8 to 15.5 ps, by electrically tuning the delay between the two sine-clock signals in one of the DPMZMs. Error-free performance is achieved after 320-km transmission.

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The carrier-suppressed return-to-zero (RZ) (CSRZ) format has recently attracted significant attention in the research and development of optical-fiber transmission systems. It has been proven to have better tolerance to group velocity dispersion (GVD)[1] and nonlinearity than the RZ format[2]. The robustness of RZ pulses with different pulsewidths to various fiber-based degradations, such as nonlinearity and polarization-mode dispersion, can be observed in many scenarios. Previous works have shown that the performance of a transmission link can vary significantly depending on the pulsewidth[3−5]. For example, when a pulsewidth is changed from 50 to 35 ps in a 10-Gb/s system, the achievable transmission distance could increase from 600 to 2 000 km[5]. A conventional CSRZ signal with a duty cycle of 66%, which is relatively larger than that of the conventional RZ (33%–50%), is generated by driving a $LiNbO_3$ Mach–Zehnder modulator (MZM) with an electrical clock signal. On the other hand, a CSRZ signal with a duty cycle of 50% can be generated using a dual-parallel MZM (DPMZM), but its amplitude fluctuation can be significantly large[6]. Reference [7] shows that a CSRZ signal with a shorter pulsewidth is more tolerant to dispersion and nonlinearity than its conventional counterpart. Therefore, CSRZ signals with tunable pulsewidths are necessary in optimizing system performance.

Several ways of generating CSRZ signals with tunable pulsewidths have been proposed[7,8]. Two cascaded MZMs driven by square wave signals were used[7] to generate a pulsewidth-tunable CSRZ signal by adjusting the delay between the two radio frequency (RF) signals. However, this scheme hardly works at higher speeds. An all-optical time-delay interference scheme using a Sagnac birefringence fiber loop was proposed to generate chirp-free CSRZ signals with tunable pulsewidths, but the scheme did not work stably due to the loop structure[8]. In this letter, one DPMZM is used to generate pulsewidth-tunable CSRZ signals and another is used to perform differential quadrature phase shift keying (DQPSK) modulation. Thus, pulsewidth-tunable CSRZ-DQPSK signals can be generated.

Figure 1 shows the scheme and principle of DPMZM-based optical pulsewidth-tunable CSRZ pulse generation. Two child MZMs (MZM-a and MZM-b) were biased at null point and driven by a 20-GHz sine RF clock signal at 20-dBm power. Then, two conventional CSRZ pulse trains with fixed duty cycles of 66% at 40 GHz were generated. An electric phase shifter (PS) was used to adjust the delay between the two RF clocks on the two child MZMs. The parent MZM-c was biased at null point, and the CSRZ pulses with tunable pulsewidths were generated only when the two original CSRZ pulse trains with opposite phases overlaped in the time domain. The pulsewidth was also tuned continuously, depending on the overlap of the two original CSRZ pulses, by continuously adjusting the PS. Basically, the maximum 16.5-ps pulsewidth is limited by the duty cycles of the original CSRZ pulses. Then, another DPMZM was used to modulate the CSRZ pulse train with a 2^7–1 pseudorandom binary sequence (PRBS) generated by the pulse pattern generator, and CSRZ-DQPSK signals were created.

The CSRZ-DQPSK signals with different pulsewidths were launched into a 320-km G.657 fiber with 5-dBm power, as shown in Fig. 2. The transmission link consisted of four spans of 80-km G.657 fibers and 10-km dispersion-compensating fibers (DCFs). Moreover, each span had two erbium-doped fiber amplifiers (EDFAs) to compensate the loss of the G.657 fiber and DCF. The G.657 fibers adopted in the link had a loss of 0.2 dB/km, with a chromatic dispersion (CD) coefficient of 17 ps/(nm·km). Meanwhile, the DCFs had a loss of 0.4 dB/km, with a CD coefficient of –138 ps/(nm·km). The average losses of the G.657 fiber and DCF in each span were 17 and 6 dB, respectively. Tunable attenuators (ATT) were employed in conjunction with EDFAs to set the input power launched into each span at 5 dBm. After transmission, the signal was amplified using an EDFA and then filtered using a 3-nm filter to suppress the amplified spontaneous emission (ASE) noise before feeding

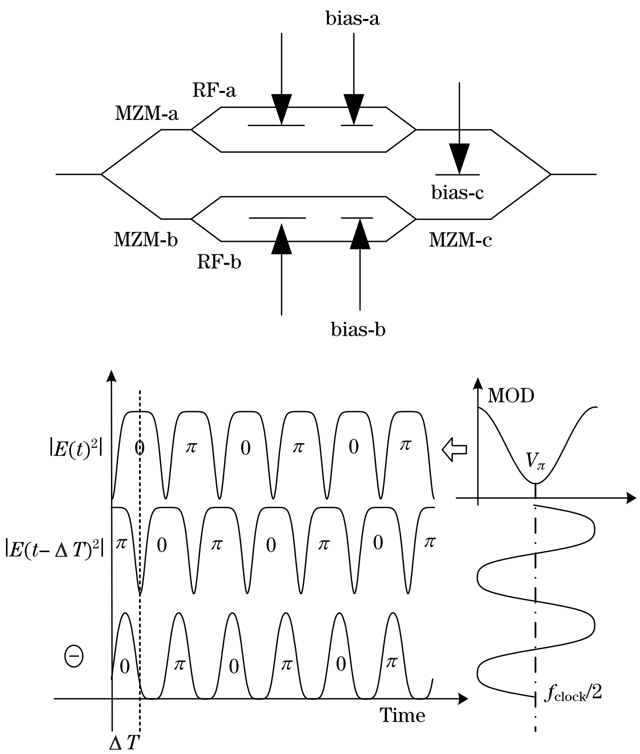

Fig. 1. Scheme and principle of DPMZM-based optical pulsewidth-tunable CSRZ generation.

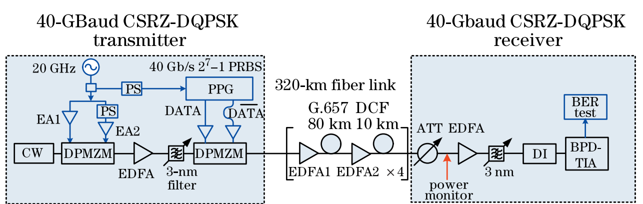

Fig. 2. Experimental setup of pulsewidth-tunable 40-GHz CSRZ-DQPSK generation and its transmission over a 320-km fiber link.

the signal into a b delay interferometer (DI) biased at $+\pi/4$ or $-\pi/4$ for the demodulation of the I and Q tributaries. Then, a 43-Gb/s balanced receiver composed of a balanced detector and a limiting amplifier was used to detect the demodulated signal before measuring the bit-error-rate (BER). The BER test was programmed with the expected differentially demodulated bit patterns.

The full-width at half-maximum (FWHM) of the generated 40-GHz pulse train at the output was continuously tuned from 15.5 to 7.8 ps by tuning the delay between the two child MZMs of the first DPMZM. As the time delay between the two applied RF signals decreased, the overlap between the opposite phases of the pulses generated from the two child MZMs lessened and therefore caused a decrease in the pulsewidth, extinction ratio (ER), and signal-to-noise ratio (SNR) of the pulses. However, the minimum pulsewidth was limited not only by the overlapping parts of the two original pulses but also by the ER and SNR of the pulses. Hence, in the experiment, the achievable minimum pulsewidth was 7.8 ps. Figure 3 shows the three sample waveforms and the spectra of the CSRZ signals generated from the first DPMZM, with FWHMs of 7.8, 12, and 15.5 ps. The spectra were measured using a 500-GHz-bandwidth optical sampling oscilloscope (EXFO PSO-102) and an optical spectrum analyzer with a resolution of 0.02 nm. The experimental results show that the generated signals have good-quality waveforms and that the optical spectra are carrier suppressed. Carrier suppression of more than 25 dB was observed in the spectra of the generated 40-GHz optical CSRZ pulses. However, the corresponding optical spectrum widths of the three different pulses at –3 dB were 0.3154 nm, whereas those at –20 dB were 0.99, 0.3825, and 0.98 nm for 7.8, 12, and 15.5 ps, respectively. The experimental results show that the –20-dB spectrum width of the 12-ps CSRZ signal is much narrower than the others. The SNRs and ERs for the three signals with varying pulsewidths are shown in Table 1. When the pulsewidth was modulated to approximately 8 ps, the overlapping area over the two original pulses decreased and hence resulted in the decreased peak power of the signal and further led to SNR degradation. The ER variations for the three signals with different pulsewidths were found to be insignificant.

The spectra after DQPSK modulation at pulsewidths of 7.8, 12, and 15.5 ps are shown in Fig. 4. The figure also shows that the –20-dB spectrum width of a 12-ps CSRZ-DQPSK signal is much narrower than the others.

The back-to-back (BTB) and after 320-km transmission BER results for both I and Q tributaries of 40-GBaud CSRZ-DQPSK signals with pulsewidths of 7.8, 12, and 15.5 ps are shown in Fig. 5. Given the above pulsewidths, the generated CSRZ-DQPSK signals suffered from 2.8 and 2.95, 2.6 and 2.7, and 3 and 3.1 dB

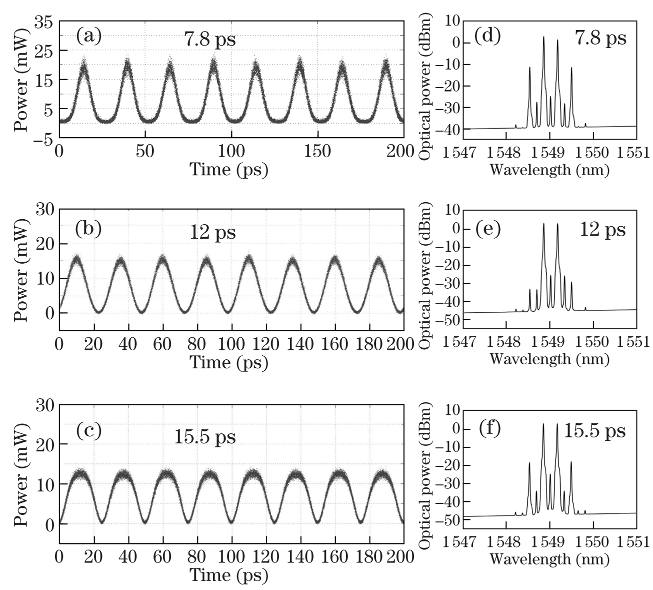

Fig. 3. (a)–(c) Optical waveforms and (d)–(f) optical spectra of signals with different pulsewidths.

Table 1. SNRs and ERs for the Three Signals with Different Pulsewidths

Pulsewidth (ps)	SNR (dB)	ER (dB)
7.8	24.5	14.5
12	30.5	16.2
15.5	29.6	14.7

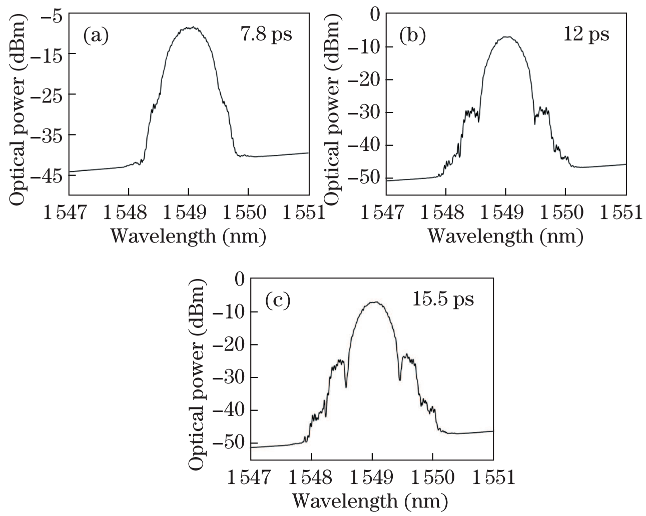

Fig. 4. Optical spectra of the CSRZ-DQPSK signals at (a) 7.8, (b) 12, and (c) 15.5 ps, respectively.

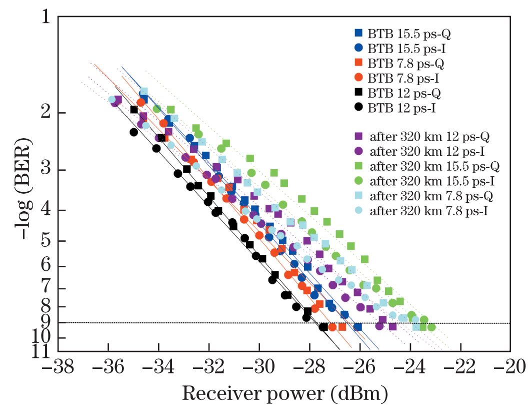

Fig. 5. BER performances of the CSRZ-DQPSK signals with different pulsewidths.

power penalties for the I and Q tributaries, respectively. The results show that the best transmission performance was achieved when the pulsewidth was 12-ps. In the experiment, the CD was well compensated, and the power transmitted into the fiber was small. Therefore, the CD tolerance and nonlinear effect were negligible. Moreover, the 12-ps CSRZ-DQPSK signals achieved the best performance according to the SNR and ER results.

In conclsion, a simple scheme for generating pulsewidth-tunable 40-GBaud CSRZ-DQPSK signals is proposed and experimentally demonstrated. The generated CSRZ-DQPSK signal is chirp free because the proposed technique does not involve any nonlinear processes. In addition, the duty cycle of the CSRZ-DQPSK signal can be easily changed by adjusting the delay time between the two sine clocks on the two child MZMs of the DPMZM. Error-free transmission is achieved after 320 km, and the 12-ps CSRZ-DQPSK pulses show optimal performance. These results show that the generated pulse train is suitable for high-speed transmission.

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References

1. Y. Miyamoto, A. Hirano, K. Yonenaga, A. Sano, H. Toba, K. Murata, and O. Mitomi, Electron. Lett. **30,** 2041 (1999).
2. A. Kanaev, G. G. Luther, and V. Kovanis, in *Proceedings of Lasers and Electro-Optics Society 2002* TuY3 (2002).
3. G. C. Gupta, K. Fukuchi, and T. Ogata, in *Proceedings of OFC 2000* TuJ7-1 (2000).
4. A. Sano, Y. Miyamoto, T. Kataoka, and K. Hagimoto, J. Lightwave Technol. **16,** 977 (1998).
5. L.-S. Yan, S. M. R. M. Nezam, A. B. Sahin, J. E. McGeehan, T. Luo, Q. Yu, and A. E. Willner, in *Proceedings of ECOC 2002* 10.6.2 (2002).
6. Y. Xing and C. Lou, Chin. Opt. Lett. **9,** 010602 (2011).
7. Y. Dong, Z. Li, J. Mo, Y. Wang, C. Lu, and T. Cheng, Photon. Technol. Lett. **16,** 1409 (2004).
8. X. Zhang, G. T. Zhou, K. Xu, J. Wu, and J. Lin, in *Proceedings of Lasers and Electro-Optics Society 2006* Wp3 (2006).