Generation and Transmission of 10-Gb/s RZ-DPSK Signals Using a Directly Modulated Chirp-Managed Laser

Wei Jia, Jing Xu, Zhixin Liu, Kam-Hon Tse, and Chun-Kit Chan

Abstract—We propose and experimentally demonstrate the generation of a 10-Gb/s return-to-zero differential phase-shift keying (RZ-DPSK) signal based on a directly modulated chirp-managed laser (CML), without requiring any differential encoder and optical phase modulator (PM). It shows better fiber chromatic dispersion tolerance and comparable nonlinearity tolerance, compared with a LiNbO₃ PM-based RZ-DPSK signal using $2^{31} - 1$ pseudorandom bit sequence data.

Index Terms—Chirp-managed laser (CML), direct modulation, return-to-zero differential phase-shift keying (RZ-DPSK).

I. INTRODUCTION

R ETURN-TO-ZERO differential phase shift keying (RZ-DPSK) is a promising modulation format in long-haul wavelength division multiplexed (WDM) transmission system due to the advantages of \sim 3-dB higher receiver sensitivity than on-off keying (OOK) when using balanced detection and its robustness against fiber nonlinearities [1]. In [2], 2.67-Gb/s RZ-DPSK signal was obtained using a directly modulated chirp managed laser (CML), which comprised a distributed feedback laser (DFB) and a passive optical filter [3]. The CML showed comparable back-to-back (BtB) receiver sensitivity to a LiNbO₃ transmitter with separate phase coding using $2^7 - 1$ pseudorandom bit sequence (PRBS) data.

In this letter, we demonstrate a new approach to generate RZ-DPSK signal using CML at higher date rate (10 Gb/s) and with longer PRBS data $(2^{31} - 1)$. We employed a commercially available 10-Gb/s CML (Finisar DM80-01), which is the same as the one used in [2]. No differential encoder and optical phase modulator (PM) are required. The driving signal to the CML is in two-level Inverse-Return-to-Zero (IRZ) format, instead of three-level RZ format [2]. After 70-km transmission on standard single mode fiber (SSMF) without chromatic dispersion compensation, the proposed CML based 10-Gb/s RZ-DPSK signal shows ~3-dB higher receiver sensitivity and comparable non-linear tolerance performance, compared with that generated by a conventional LiNbO₃ PM.

The authors are with the Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR, China (e-mail: jw009@ie.cuhk.edu.hk; ckchan@ie.cuhk.edu.hk).

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.2010.2092761

10-Gb/s Clock 10-Gb/s 10-Gb/s Data IRZ Clock Data IRZ Clock Clock Clock Clock Clock DI Clock Clock

Fig. 1. Proposed scheme of 10-Gb/s RZ-DPSK transmission system based on CML.



Fig. 2. Operation principle of RZ-DPSK generation based on CML.

II. 10-Gb/s RZ-DPSK SIGNAL GENERATION USING CML

Fig. 1 depicts the proposed scheme of 10-Gb/s RZ-DPSK transmission system based on CML. The transmitter consists of an IRZ driver, a CML, and a pulse carver. Fig. 2 illustrates the operation principle through intensity, frequency and phase characteristics of output signals of the driver, DFB laser (inside CML), filter (inside CML) and pulse carver. The IRZshaped data sequence 10111001 with a duty cycle of 50% is generated, via a commercial logic NAND gate, before being used to directly modulate the CML. The laser is biased high above the threshold with the benefits of high output power, wide modulation bandwidth and suppression of transient chirp [3]. The driving voltage V_{pp} is adjusted to induce adiabatic chirp of $\Delta f = 1/T$. The adiabatic chirp generates phase shift $\Delta \phi =$ $2\pi \int_0^{T/2} \Delta f(t) dt = 2\pi \times 1/T \times T/2 = \pi$ during low level period. Here, the chirp value required for 10-Gb/s RZ-DPSK is 10 GHz while 20 GHz was necessary in [2]. The relative spectral locations of the laser and filter are detuned to pass the high level frequency f_1 and suppress the low level frequency f_0 to increase the extinction ratio (ER) of the optical signal. The output of the filter is an IRZ-DPSK signal, in which both the

Manuscript received September 30, 2010; revised November 02, 2010; accepted November 06, 2010. Date of publication November 15, 2010; date of current version January 14, 2011. This work was supported in part by a research grant from the Hong Kong Research Grants Council (Project CUHK 410511).

intensity and differentially encoded phase carry the same information. The pulse carver, with a duty cycle of 50%, carves the second half-bit of the phase-modulated signal, thus generating an RZ-DPSK signal. The phase modulation is intrinsically differentially encoded, similar to [2]. No differential encoder and PM are needed. This scheme could be generalized to generate RZ-DQPSK, where the two input data streams are in IRZ format with different V_{pp} and are combined by a passive RF combiner to drive the CML.

III. EXPERIMENT AND RESULTS

We have experimentally demonstrated the proposed 10-Gb/s RZ-DPSK transmission system based on CML, as shown in Fig. 1. We used a standard CML module (Finisar DM80-01) in the experiment. The input impedance, threshold current and FM efficiency of the DFB laser were 50 ohms, 25 mA and \sim 0.24 GHz/mA, respectively. The filter in DM80-01 had a 3 dB bandwidth of ~ 11 GHz and an average slope of ~ 1.5 dB/GHz. The DFB laser was IRZ directly modulated with a 10-Gb/s 2^{31} – 1 PRBS. The driving voltage V_{pp} was ~2.0 V. The laser was biased at 80 mA. The central wavelength of signal after the filter was 1555.48 nm. A Mach-Zehnder intensity modulator (MZM) driven by 10-Gb/s clock was used as the pulse carver. The output power after the pulse carver was ~ 0.2 dBm. The linear transmission system was composed of SSMF and an erbium-doped fiber amplifier (EDFA) was inserted after fiber to boost up the optical power. A tunable optical filter with ~ 1.0 nm bandwidth was placed after the EDFA to eliminate the excessive amplified spontaneous emission (ASE) noise. At the receiver, the transmitted RZ-DPSK was demodulated by a 1-bit optical delay interferometer (DI) before being detected by the photo-detector.

Fig. 3 shows the back-to-back (BtB) eye diagrams of the IRZ driving signal after the driver, IRZ-DPSK signal after CML, RZ-DPSK signal after the pulse carver and demodulated RZ-DPSK signals at the two ports of the DI. The double line of RZ-DPSK signal, as shown in Fig. 3(c), was due to the wide bandwidth of the IRZ driving signal and the limited bandwidth of the DFB laser and the optical filter in the CML [4], denoted in Fig. 3(b). Demodulated RZ-DPSK signal at the destructive port of the DI, as shown in Fig. 3(d), had better performance than the one at the constructive port of DI, as shown in Fig. 3(e), mainly attributed to the asymmetric shape and noise of the driving signal as shown in Fig. 3(a) and the limited bandwidth of the DFB laser and the optical filter in the CML. CML based RZ-DPSK signal would have better performance using a CML with higher bandwidth and periodic delay line interferometer (DLI) filter [5].

Fig. 4(a) shows the waveform traces measured by a real-time oscilloscope. The 10111001 bit sequence was applied to the transmitter. Figs. 4(a) and (b) show the driver output and the detected outputs of the two ports of DI, without transmission, respectively. The subtraction of the top and bottom demodulated waveforms, shown in Fig. 4(b), would regenerate the input bit sequence correctly. It illustrated that no differential encoding of the original data was required.

We compared the BtB performance and tolerance in fiber chromatic dispersion and nonlinearity between the proposed CML based transmitter and the LiNbO₃ PM based transmitter, using $2^{31} - 1$ PRBS data. The PM based RZ-DPSK transmitter



Fig. 3. Eye diagrams of (a) IRZ driving signal, (b) IRZ-DPSK signal, (c) RZ-DPSK signal, (d) demodulated RZ-DPSK signal at the destructive port of DI, (e) Demodulated RZ-DPSK signal at the constructive port of DI. (a) 20 ps/div; (b) 20 ps/div; (c) 20 ps/div; (d) 20 ps/div; (e) 20 ps/div.



Fig. 4. (a) IRZ driving waveform for 10111001 bit sequence after the driver. (b) Demodulated waveforms for 10111001 bit sequence at the two ports of DI.

was composed of a wavelength tunable DFB laser, a $LiNbO_3$ PM and a pulse carver.

Fig. 5 shows the optical spectrum of the CML based RZ-DPSK signal. It exhibited relatively more compact spectrum, as compared to that of PM based RZ-DPSK signal. Thus it had better tolerance in fiber chromatic dispersion. Fig. 6 depicts the receiver sensitivities at bit-error-rate (BER) = 10^{-9} measured after various lengths of SSMF transmission. The insets of Fig. 6 show that CML based RZ-DPSK signal had much clearer eye diagram than PM based RZ-DPSK signal after 70-km SSMF transmission.

Fig. 7 shows the measured BER performances. The BtB receiver sensitivities for CML and PM based RZ-DSPK signals were -20.6 dBm and -21.5 dBm, respectively. The 0.9-dB penalty was due to the asymmetric shape and noise of the driving signal and the limited bandwidth of the DFB laser and the optical filter in the CML. 80-km error free SSMF transmission was achieved for CML based 10-Gb/s RZ-DPSK signal, while the



Fig. 5. Optical spectra of CML and PM based RZ-DPSK signals.



Fig. 6. Measured chromatic dispersion tolerance for CML and PM-based RZ-DPSK signals. Insets show the respective eye diagrams after 70-km SSMF transmission. Time scale: 20 ps/div.



Fig. 7. BER measurements for CML and PM-based 10-Gb/s RZ-DPSK signals.

PM based 10-Gb/s RZ-DPSK signal could only be transmitted up to 70 km with error-free performance. After 70-km SSMF transmission, their respective power penalties were 3.8 dB and 8.0 dB.

We have further measured and compared the nonlinearity tolerance of both CML and PM based RZ-DPSK signals. One span of 80 km SSMF was used in this study. The fiber chromatic dis-



Fig. 8. Measured nonlinearity tolerance for CML and PM-based RZ-DPSK signals. Insets show the respective eye diagrams at launch power of 16 dBm. Time scale: 20 ps/div.

persion of the SSMF was compensated with dispersion compensate module (DCM). The power launched into the SSMF was varied from 0 dBm to 16 dBm and the results were shown in Fig. 8. CML based RZ-DPSK signal demonstrated comparable tolerance to high launch powers, compared with PM based RZ-DPSK signal. With reference to their respective receiver sensitivities at 0-dBm launch power, the CML and PM based RZ-DPSK signal suffered from 1.1-dB and 1.3-dB power penalties, respectively, at launch power of 16 dBm. At launch power of 14 dBm, their respective power penalties were 0 and 0.6 dB. The insets of Fig. 8 show their corresponding eye diagrams at launch power of 16 dBm.

IV. SUMMARY

We propose and experimentally demonstrate the generation of 10-Gb/s RZ-DPSK signal based on CML, without requiring any differential encoder and PM. The transmission performance and its tolerance in fiber chromatic dispersion and fiber nonlinearity have been experimentally characterized and compared with that generated by LiNbO₃ PM.

REFERENCES

- A. H. Gnauck and P. J. Winzer, "Optical phase-shift-keyed transmission," J. Lightw. Technol., vol. 23, no. 1, pp. 115–130, Jan. 2005.
- [2] J. Franklin, L. Kil, D. Mooney, D. Mahgerefteh, X. Zheng, Y. Matsui, K. McCallion, Z. F. Fan, and Payebati, "Generation of RZ-DPSK using a chirp-managed laser (CML)," presented at the Optical Fiber Communication/National Fiber Optic Engineers Conf. (OFC/NFOEC), San Diego, CA, Feb. 2008, Paper JWA67.
- [3] Y. Matsui, D. Mahgerefteh, X. Zheng, C. Liao, Z. F. Fan, K. Mc-Callion, and P. Tayebati, "Chirp-managed directly modulated laser (CML)," *IEEE Photon. Technol. Lett.*, vol. 18, no. 2, pp. 385–387, Jan. 15, 2006.
- [4] R. S. Vodhanel, A. F. Elrefaie, R. E. Wagner, M. Z. Iqbal, J. L. Gimlett, and S. Tsuji, "Ten-to-twenty gigabit-per-second modulation performance of 1.5- μm distributed feedback lasers for frequency-shiftkeying systems," J. Lightw. Technol., vol. 7, no. 10, pp. 1454–1460, Oct. 1989.
- [5] X. Zheng, D. Mahgerefteh, Y. Matsui, X. Ye, V. Bu, K. McCallion, H. Xu, M. Deutsch, H. Ereifej, R. Lewén, J. Wesström, R. Schatz, and P. Rigole, "Generation of RZ-AMI using a widely tunable modulated grating Y-branch chirp managed laser," presented at the Optical Fiber Communication/National Fiber Optic Engineers Conf. (OFC/NFOEC), San Diego, CA, 2010, Paper OThE5.