Generation and Transmission of 10.709-Gbaud RZ-DQPSK using a Chirp Managed Laser

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Abstract

We demonstrate the generation of 10.709-Gbaud RZ-DQPSK using a directly modulated chirp managed laser, without differential encoder or external modulator. 40 km SSMF transmission at BER of 10^{-9} was realized without any dispersion compensation.

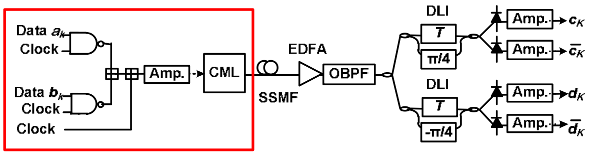
I. Introduction

Return-to-zero differential quadrature phase-shift-keying (RZ-DQPSK) is a promising modulation format for optical fiber transmission, owing to its increased spectral efficiency and high robustness towards fiber nonlinearities [1]. However, the conventional RZ-DQPSK transmitter requires a complex differential encoder and bulky external modulators. The directly modulated chirp managed laser (CML) [2], comprising a distributed feedback (DFB) laser and an optical filter, has been used to generate 10-Gbaud RZ-DQPSK [3], without differential encoder or phase modulator. However, an intensity modulator based pulse carver was needed and no transmission performance was yet investigated.

Here we demonstrate the generation of 10.709-Gbaud RZ-DQPSK using a directly modulated CML without differential encoder, external modulator or pulse carver. 40-km standard single mode fiber (SSMF) transmission at bit error rate (BER) of 10^{-9} was realized without any optical or electronic dispersion compensation.

II. Operation Principle

Fig. 1 shows the schematic of our proposed RZ-DQPSK signal transmitter, which comprises a CML driven by a simple designated electronic logic circuit. The relations among the input data, phase shift, demodulated data, and output data after decoding are also stated. Fig. 2 shows the operation principle of CML based RZ-DQPSK signal generation through the intensity, chirp and phase characteristics of the output signals from the inverse return-to-zero (IRZ) drivers, electrical combiner, DFB laser and filter in CML. Two IRZ-shaped data sequences a_k=01001101 and b_k=10101001 with duty cycles of 50% generated by two NAND logic gates were combined together with a clock to drive the DFB laser. The driving voltages of data a_k, data b_k and clock are V_π, 0.5 V_π and V_π, respectively. The laser is biased high above the laser threshold with the benefits of high output power, wide modulation bandwidth and suppression of the transient chirp [2]. The driving voltage of V_π is adjusted to induce adiabatic chirp Δf =1/T, where T is the symbol



Input Data $a_k b_k$	Phase Shift $\Delta\phi$	Demodulated Data c_k d_k	Decoding Operation	Output Data $p_k q_k$
0 0	π	0 0	$p_k = d_k$	0 0
0 1	1.5 π	1 0		0 1
1 0	2 π	1 1	$q_k = c_k \oplus d_k$	1 0
1 1	2.5 π	0 1		1 1

Fig. 1. A typical RZ-DQPSK optical transmission system using our proposed CML based RZ-DQPSK signal transmitter (denoted in red box). The inset table shows the relations among input data, phase shift, demodulated data, and output data.

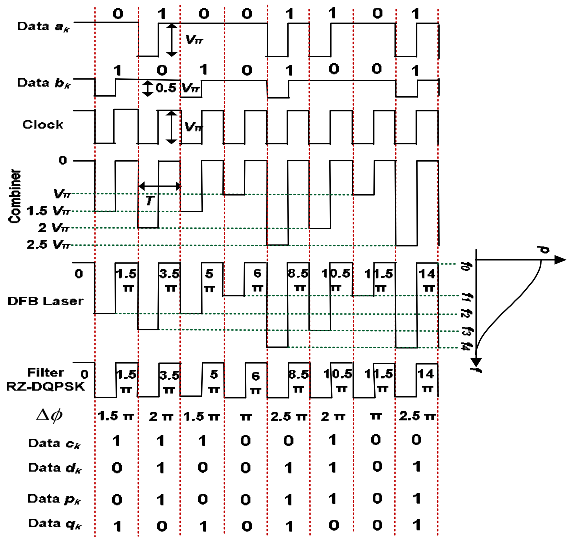


Fig. 2. Operation principle of CML based RZ-DQPSK signal generation.

period, during the first half-symbol period of 00 symbol. The induced adiabatic chirp, in turn, causes a phase shift $\Delta\phi$ of π, given by $\Delta\phi = 2\pi\int_0^{T/2}\Delta f(t)dt = 2\pi\times 1/T\times T/2$. Thus the induced phase shifts of symbols of 00, 01, 10, and 11 for input $a_k b_k$ are π, 1.5π, 2π, and 2.5π, respectively. Then, the spectral position of the filter integrated in the CML is tuned to suppress the first half-symbol signal with frequencies of f_1, f_2, f_3 and f_4 and pass through the second half-symbol signal with frequency of f_0, generating RZ-DQPSK. At the receiver, the symbols of 00, 01, 10, and 11 for input $a_k b_k$ are demodulated into $c_k d_k$ of 00, 10, 11, and 01 by a 1-bit optical delay interferometer (DLI). Finally, the decoding operations of

$p_k = d_k$ and $q_k = c_k \oplus d_k$ are used to recover the input $a_k b_k$. The decoding operation could be replaced by pre-coding operation at the transmitter [3].

III. Experiment And Results

We have experimentally demonstrated the system for generation and transmission of CML based RZ-DQPSK, using the similar setup, as shown Fig. 1. We employed a standard CML module (Finisar DM200-01) with input impedance of 50 ohms, threshold current of 25 mA and FM efficiency of 0.24 GHz/mA. The filter in CML had a 3-dB bandwidth of 7 GHz and an average slope of 2.4 dB/GHz. Two 10.709-Gb/s IRZ data streams using 2^7-1 pseudo-random bit sequence (PRBS) with driving voltages of 20 mV and 10 mV were combined with a 20-mV clock. The peak-to-peak voltage V_{pp} of the driving signal was amplified to 4.2 V. The DFB laser was biased at 110 mA. The central wavelength and the optical power of the generated optical RZ-DQPSK signal were 1555.69 nm and 1.4 dBm, respectively. The generated optical RZ-DQPSK signal was then transmitted over a piece of SSMF and was received after being amplified, via an Erbium-doped fiber amplifier (EDFA), and filtered, via a 1.0-nm optical band pass filter (OBPF). The receiver was composed of DLIs with free spectral range (FSR) of 10.664 GHz, photo-detectors (PD) and 10-GHz electrical amplifiers (Amp.). We tuned the phase difference between the two arms of each DLI to $\pi/4$ or $-\pi/4$, so as to demodulate the received RZ-DQPSK signal.

Fig.3 shows the measured waveforms of the data $a_k b_k$ after NAND gates, the input clock signal, the driving signal of the CML, the demodulated data $c_k d_k$ at the two output ports of the DLIs. They verify that data a_k was recovered from data d_k and data b_k would be retrieved from exclusive-or (XOR) operation of data c_k and data d_k.

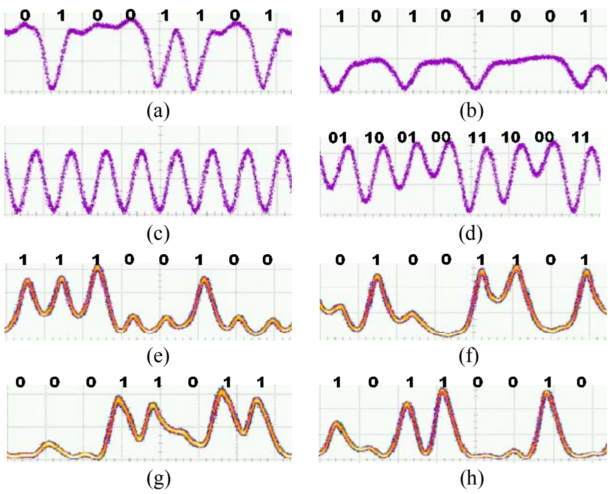


Fig. 3. Waveforms of (a) data a_k, (b) data b_k, (c) clock, (d) driving signal, (e) data c_k, (f) data d_k, (g) inverting data c_k, and (h) inverting data d_k. Time scale: 100 ps/div.

Fig. 4 shows the respective eye diagrams of the driving signal after combiner, back-to-back (BtB) RZ-DQPSK after CML, demodulated data c_k and data d_k at one output port of DLI before and after the 40 km SSMF, using a 40-GHz PD.

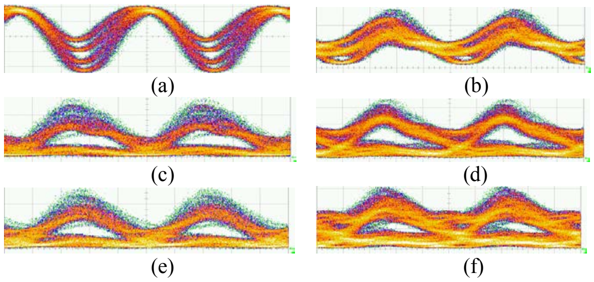


Fig. 4. Eye diagrams of (a) driving signal after combiner, (b) RZ-DQPSK signal after CML, (c) BtB data c_k, (d) BtB data d_k, (e) data c_k after 40 km SSMF, and (f) data d_k after 40 km SSMF. Time scale: 20 ps/div.

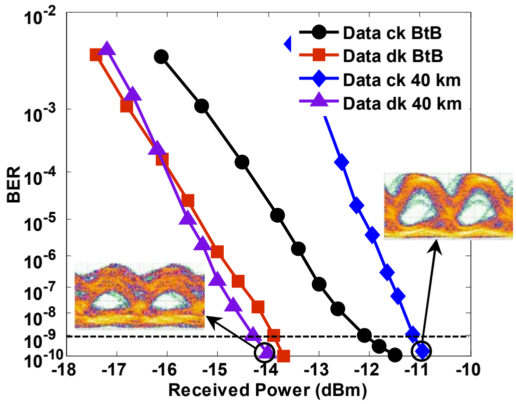


Fig. 5. Measured BER performance of RZ-DQPSK. Insets show the eye diagrams of detected signals fed into BER tester. Time scale: 20 ps/div.

Fig. 5 shows the measured BER performance of the generated optical RZ-DQPSK signal before and after 40 km SSMF transmission. Though the XOR decoding was not performed, we still could get the BER of data c_k to evaluate the signal quality, due to the pseudo-random property of PRBS. The power penalties at BER of 10^{-9} for data c_k and data d_k after 40 km SSMF were 0.95 dB and -0.41 dB, with reference to their BtB receiver sensitivities of -12.1 dBm and -13.9 dBm respectively. The difference might be attributed to the un-optimized phase shifts between symbols. The insets show the eye diagrams of the detected signals fed into the BER tester.

IV. Summary

We have demonstrated the generation of 10.709-Gbaud RZ-DQPSK signal using a directly modulated CML without differential encoder, external modulator, or pulse carver. Optical transmission performance over 40 km SSMF has been characterized. This work was supported by a CUHK Direct Grant 2050512.

References

[1] C. Wree, et al., "RZ-DQPSK format with high spectral efficiency and high robustness towards fiber nonlinearities," *Proc. ECOC*, Copenhagen, Denmark, 2002, pp. 9.6.6.

[2] Y. Matsui, et al., "Chirp-managed directly modulated laser (CML)," *IEEE Photon. Technol. Lett.*, vol. 18, no. 2, pp. 385-387, Jan. 2006.

[3] W. Jia, et al., "Generation of 20-Gb/s RZ-DQPSK signal using a directly modulated chirp managed laser," *Proc. OFC/NFOEC*, Los Angeles, CA USA, 2011, pp. OThE4.

