

DPSK OVER INVERSE-RZ OPTICAL PULSES FOR 2-BIT PER SYMBOL TRANSMISSION

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Abstract: We successfully demonstrated superimposing DPSK over inverse-RZ optical pulses using SOA-XGM for 2-bit per symbol modulation/demodulation at 20-Gbit/s to simply double spectral efficiency. Error free operation less than 10^{-12} was achieved for both RZ and DPSK signals.

1. INTRODUCTION

Multi-state per symbol modulation format such as differential quadrature phase-shift keying (DQPSK) has been investigated to enhance spectral efficiency and tolerance to chromatic dispersion and polarization-mode-dispersion [1,2]. A combination of amplitude-shift keying (ASK) and differential phase-shift keying (DPSK) is another scheme without using complex encoder and decoder[3,4]. However precise adjustment of the extinction ratio has been required in the ASK-DPSK scheme. On the other hand inverse-RZ format with more than 100% spectral efficiency was proposed without using multi-state per symbol modulation scheme[5]. In this study, we demonstrated superimposing of DPSK over inverse-RZ as a simple solution for doubling the spectral efficiency.

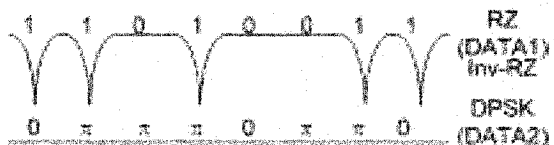


Figure 1 Timing chart of the overwriting of DPSK over inverse-RZ signal.

2. EXPERIMENTS AND RESULTS

Figure 1 shows the timing chart of the overwriting of DPSK over inverse-RZ signal. Inverting of RZ optical signal allows both “0” and “1” pulses to have finite pulse energy in the time slot without adjusting the extinction ratio.

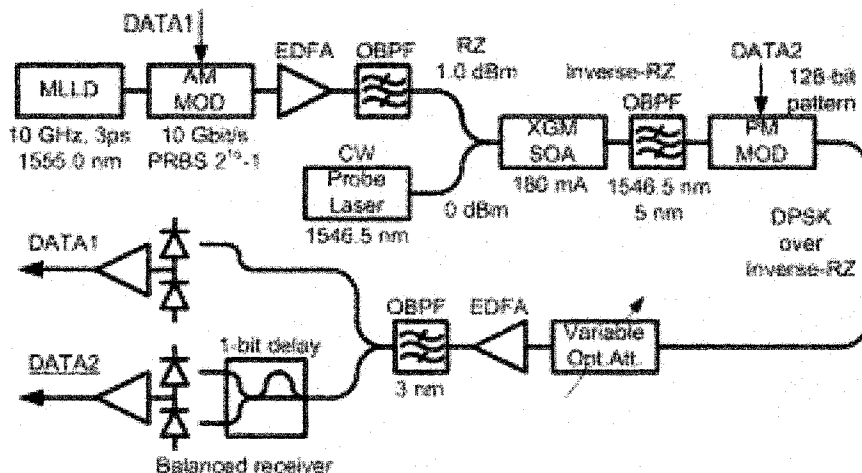
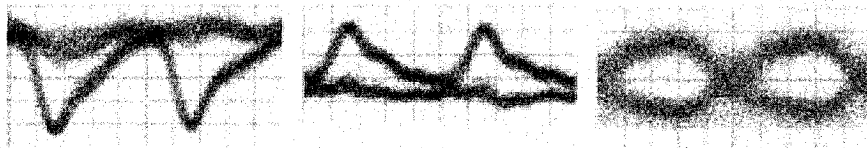


Figure 2 Experimental setup.

Figure 2 shows the setup. 10-GHz (9.95328 GHz), 3.0 ps optical pulses from a mode-locked laser diode (MLLD, 1555 nm) was modulated at 10 Gbit/s with a PRBS of $2^{15}-1$ (DATA1) by an intensity modulator for RZ modulation. For inverse-RZ generation, cross-gain modulation (XGM) in a semiconductor optical amplifier (SOA, biased at 180 mA) was adopted by injecting continuous wave (CW) probe (1546.5 nm, 4.0 dBm) and the RZ pulses (-1 dBm). Previously reported technique for inverse-RZ generation in electrical domain using push-pull type Mach-Zehnder modulator[5] is also applicable with an encoder to compensate alternative phase inversion. Optical band-pass filter (OBPF, 5nm) was employed to select converted inverse-RZ optical pulses. Then DPSK modulation with 128-bit pattern length (DATA2) was superimposed. In the receiver side, optical pre-amplifier (EDFA) followed by an OBPF (3 nm) and a balanced receiver was used for both RZ and DPSK detection. Single-end direct detection was used to convert polarity from inverse-RZ into RZ pulses. We set the expected differential data pattern to an error detector.

Figure 3 shows optical waveform of DPSK with inverse-RZ measured at transmitter output (Fig. 3(a)), and detected eye diagrams of DATA 1 RZ signal

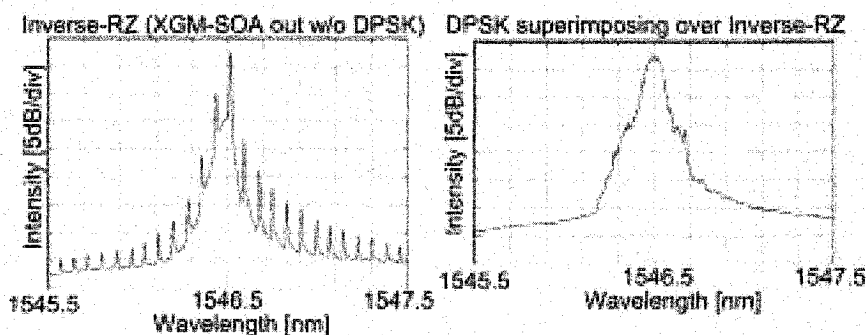
(Fig. 3(b)), and DATA 2 DPSK signal (Fig. 3(c)). Thanks to the pulse inversion, clear eye opening was obtained in detected DPSK signal (Fig.3 (C)). There was no prominent eye opening degradation in RZ detection by superimposing DPSK modulation (Fig.3 (b)).



(a)transmitter output (b) DATA 1 RZ signal (c) DATA 2 DPSK

Figure 3 Eye diagrams (50 ps/div.)

Figure 4 shows optical spectrum measured at the SOA output (a), at the transmitter output (b). A compact spectrum was obtained with 3-dB bandwidth of about 12 GHz was obtained in DPSK superimposing over inverse-RZ case (Fig. 2(b)).



(a) SOA output

(b) Transmitter output

Figure 4 Optical spectrum (Span 2 nm, resolution 0.01 nm)

Figure 5 shows the bit error rate (BER) characteristics for DPSK only (open circles), DATA 1: RZ (closed squares), DATA 2 : DPSK with inverse-RZ (closed circles). The received optical power was defined at the optical pre-amplifier input. It should be noted that there is only 2-dB receiver sensitivity penalty at 10⁻⁹ in DPSK with inverse-RZ from DPSK only. There was no error floor and error free less than 10⁻¹² was achieved for both DPSK with inverse-RZ and RZ with DPSK.

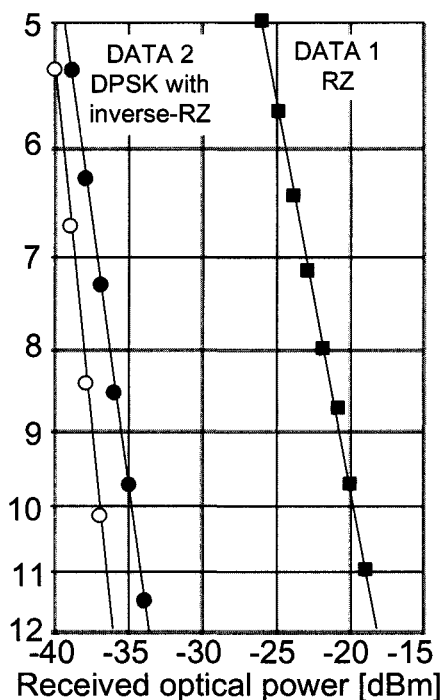


Figure 5 Bit error rate (BER) characteristics
 open circles : DPSK only, closed circles : DPSK with inverse-RZ,
 closed squares : RZ

3. CONCLUSION

We demonstrated DPSK over inverse-RZ format for 2-bit per symbol modulation/demodulation at 20 Gbit/s to simply double spectral efficiency. High sensitivity of DPSK data signal is preserved within 2-dB penalty from its original sensitivity by superimposing DPSK data onto inverse-RZ optical signal.

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