All-Optical 2R Regeneration of BPSK and QPSK Data using a 90° Optical Hybrid and Integrated SOA-MZI Wavelength Converter Pairs

Kimchau N. Nguyen, Tomofumi Kise, John M. Garcia, Henrik N. Poulsen, and Daniel J. Blumenthal
Electrical and Computer Engineering Department, University of California, Santa Barbara, CA 93106
kim@ece.ucsb.edu

Abstract: We demonstrate all-optical 2R regeneration with a 90° optical hybrid and integrated MZI-SOA pairs for 10 Gb/s BPSK and 20 Gb/s QPSK with negative power penalty. Power penalty and OSNR improvements of 7 dB and 5 dB are shown with additive ASE noise.

OCIS codes: (060.1660) Coherent communications, (130.7405) Wavelength conversion devices

1. Introduction

Compared to on-off keying (OOK), quadrature phase shift keying (QPSK) and DQPSK (differential) modulation formats offers benefits such as increased spectral efficiency, tolerance to chromatic dispersion and polarization mode dispersion [1]. In efforts to increase reach and reduce cost, all-optical regeneration is a potential solution to greatly reducing the power consumed by OEO conversion and electronic regeneration. In this paper, we present a scheme to 2R regenerate (reshape and reamplify) 10 Gbps BPSK and 20 Gbps QPSK data using regenerators are based on a 90° optical hybrid and MZI-SOA wavelength converters.

2. BPSK and QPSK All-Optical Regeneration

Regeneration of phase keyed modulation formats has been achieved using fiber four-wave mixing (FWM) [2], however FWM is not efficient due to the high input signal power requirement. Semiconductor device based regeneration has been demonstrated for differential phase shift keying (DPSK) [3, 4] at up to 40 Gb/s using a delay-line interferometer (DI) to convert the DPSK signal into amplitude modulation and MZI-SOA wavelength converters to encode the phase information onto a new carrier. To regenerate QPSK signals all-optically, we use a 90° optical hybrid with homodyne detection to convert the phase information of the in-phase (I) and quadrature (Q) components into four OOK signals that are then used to gate two all-optical wavelength converters, which convert the phase information onto two phase aligned signals from a common local oscillator. Combining these two binary phase shift keyed (BPSK) signals in quadrature will generate a QPSK signal. On-chip integration is key, as maintaining a set phase difference in fiber is difficult due to phase fluctuations from temperature changes across long fiber lengths. Since the outputs of the wavelength converter pairs are not fabricated to be combined on-chip, we instead examine I and Q channels separately as two BPSK signals.

3. Experimental Setup

The experimental setup, consisting of an RZ-QPSK transmitter, all-optical 2R regenerator, and a DPSK receiver is shown in Fig. 1. In the transmitter, a pulse train is generated with light from a Brillouin fiber laser with a linewidth of 300 Hz (λ_1=1550 nm) modulated with a LiNbO3 Mach-Zehnder modulator (MZM) driven by a 10 GHz clock. This pulse train is amplified with an erbium-doped fiber amplifier (EDFA) and then split evenly into two branches. The first branch is modulated with a LiNbO3 double-nested MZM, the I and Q components of the modulator are driven by 10 Gbaud PRBS 2^7-1 electrical signals, generating an RZ-QPSK signal. Alternatively an RZ-BPSK signal can be generated if only the I or Q component is modulated. To impose noise based signal degradation, we use an amplified spontaneous emission (ASE) source with a variable optical attenuator (VOA) added to the transmitted signal with a 3-dB coupler. The second branch of the pulse train is used for homodyne mixing in the 90° optical hybrid. The LO branch is pulse and phase aligned with the transmitter branch with a tunable optical delay line and a phase shifter. The power of the LO and transmitted signals are matched using a VOA.

The transmitter branch and the LO branch are input to the regenerator and mixed using a dual polarization 90° optical hybrid to convert the QPSK signal into two sets of differential amplitude shift keyed (ASK) signals, I+/-, and Q+/-. One channel (I or Q) is regenerated using the corresponding set of differential signals as inputs to a MZI-SOA amplitude regenerator, biased at 180°. The differential gating signals transfer the phase information to a DPSK signal onto a new wavelength (λ_2=1560 nm) with a linewidth of ~100 kHz. The 1550 nm gating signals are filtered out with a 1.0 nm wide optical filter.

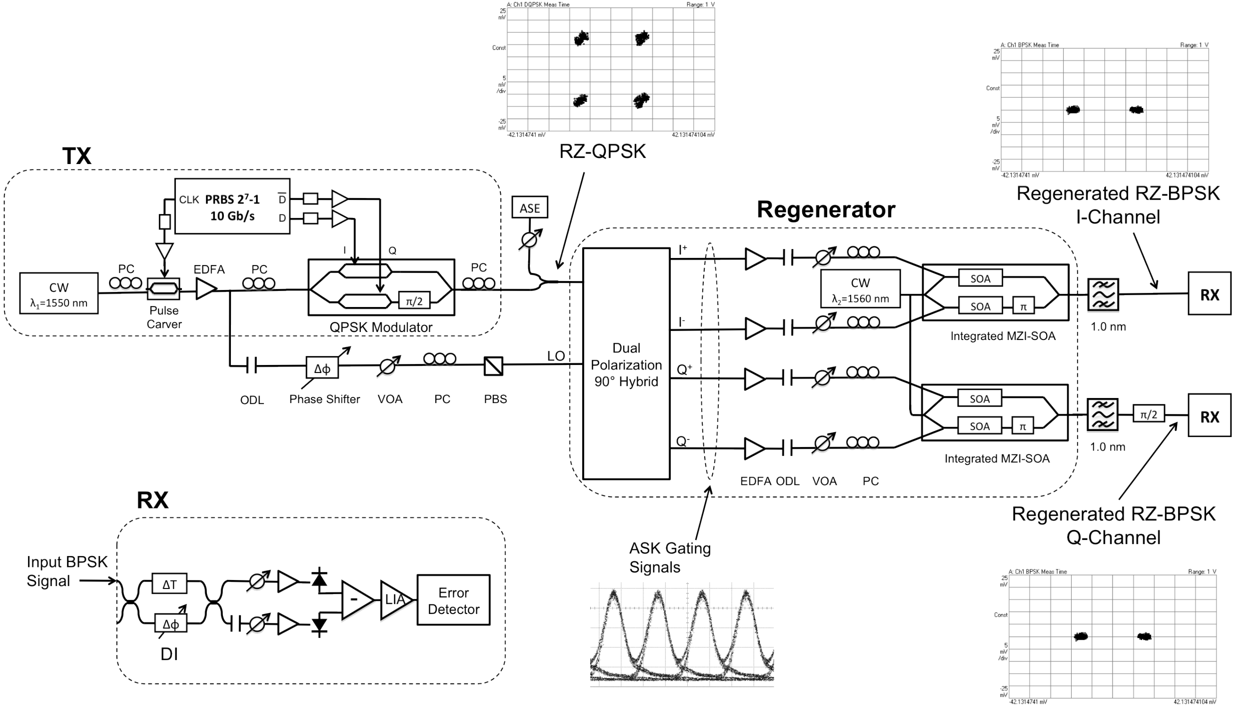


Fig. 1. Experimental setup. Constellation plots taken with Agilent N4391A Optical Modulation Analyzer

The receiver is a standard DPSK receiver design consisting of a phase tunable 100 ps DI, and can be used to receive both DPSK and BPSK. The received power of the differential signals from the DI is adjusted with a VOA and then amplified with EDFAs before the balanced photoreceiver. The skew between the photodiodes is compensated with a tunable optical delay. The electrical signal from the balanced photoreceiver is sent through a limiting amplifier (LIA) before the bit error detector. For BER measurements, received average power is measured before the EDFAs in the receiver. The Agilent N4391A Optical Modulation Analyzer is used to verity the transfer of phase information onto regenerated signals before BER measurements are taken with the receiver.

To evaluate regeneration, noise from an ASE source was added with a 3-dB coupler to degrade the signal. Power penalty at 10^{-9} BER and OSNR is measured as a function of added ASE power, shown in Fig. 3. The phase difference between the transmitted signal and the LO is optimized by observing a tap of an output ASK differential signal in an oscilloscope. The same data pattern is used to drive both I and Q signals, thus making it difficult to determine if the LO and signal are in-phase or in quadrature. To differentiate between I and Q channels, only the corresponding arm of the QPSK modulator was driven during BER measurements to generate a BPSK signal.

4. Results

The BER measurements in Fig. 2 show close to 0 dB power penalty and negative power penalty for the regenerated I and Q channels, respectively. The negative power penalty shown for the regenerated Q channel can be explained by the nonlinear transfer function of the wavelength convertor operating on a non-ideal original signal generated at the transmitter input into the regenerator [5].

The measured power penalty as a function of added ASE power is shown in Fig. 3a. With increased ASE power, the regenerated signals have considerably lower power penalty, approximately 7 dB lower, at over 0.6 mW added ASE power. Similarly the OSNR for the regenerated signals is improved, approximately 5 dB at over 0.6 mW added ASE power. With no ASE added, the transmitted signals have very high OSNR, and wavelength conversion incurs a degradation in OSNR.

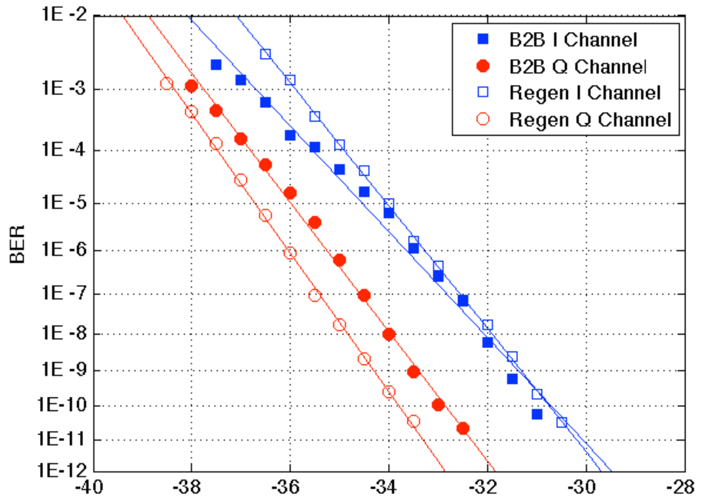
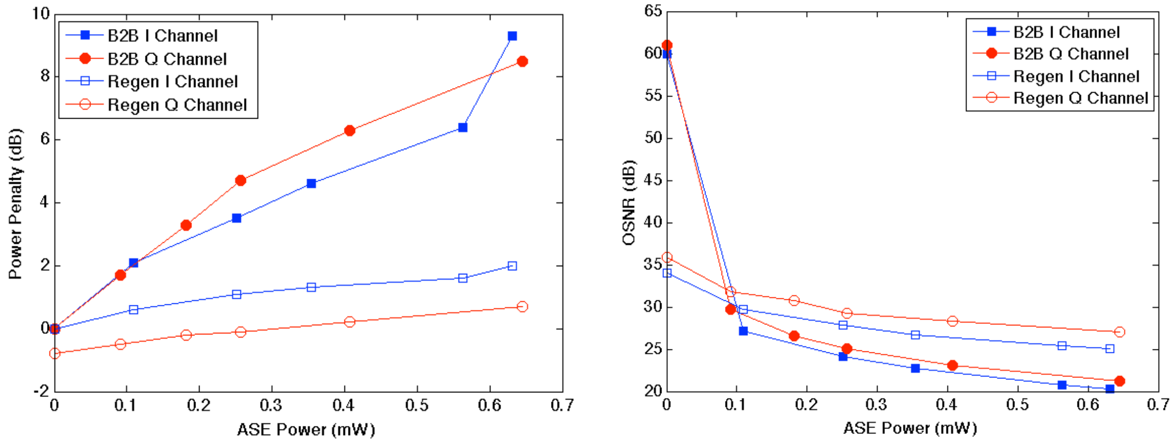


Fig. 2. I and Q channel back-to-back and regenerated BER



(a) (b)

Fig. 3. Improved regenerator performance demonstrated for added ASE on Power Penalty at 10^{-9} BER (a) and OSNR (b) for back-to-back and regenerated I and Q channels

5. Conclusion

We demonstrate 90° optical hybrid based all-optical regeneration of 10 Gb/s BPSK and 20 Gb/s QPSK signals with no power penalty. Regenerative properties of up to 7 dB decreased power penalty and 5 dB improvement OSNR are observed after the regeneration of signals with over 0.6 mW added ASE.

4. Acknowledgements

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5. References

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