Performance Investigation of an IQ Wavelength Converter

Runxiang Yu, Xingwen Yi, Junya Kurumida, S. J. B. Yoo

Department of Electrical and Computer Engineering, University of California, Davis, Davis, CA, 95616, USA

Abstract: We recently proposed an IQ wavelength converter supporting multiple modulation formats. This paper presents wavelength conversion results for 20 Gb/s RZ-DPSK and 5 Gb/s NRZ-DQPSK and investigates the input dynamic range of the IQ wavelength converter

Keywords: wavelength conversion, modulation format, optical signal processing

1. Introduction

Wavelength conversion is a key technology to realize scalable dynamic wavelength division multiplexing (WDM) networks. Modern optical networks adopting advanced modulation formats, such as differential phase-shift keying (DPSK) and differential quadrature phase-shift keying (DQPSK) will benefit from modulation format transparent all-optical wavelength conversion and signal regeneration technique in terms of interoperability and upgradability. While four-wave mixing (FWM) and difference–frequency generation (DFG) support the format transparency, they failed to provide signal regeneration for advanced modulation formats [1]. Recently, we proposed a multi-format wavelength conversion technique with potential signal regeneration capability, based on the optical cross modulation in semiconductor optical amplifiers in interferometric configuration [2]. In our proposal, two identical Mach-Zehnder type wavelength converters in a nested structure with a 90° optical hybrid allow independent wavelength conversion of in-phase (I) and quadrature (Q) components before IQ combination. Experimental results show wavelength conversion for 20 Gb/s RZ-DPSK and 5 Gb/s NRZ-DQPSK signals. We also investigate the dynamic range of the input power and wavelength.

2. Principle of IQ wavelength conversion

Fig. 1 shows the generalized schematics of the proposed technique for single polarization. It consists of two main devices: a 90° optical hybrid and an IQ wavelength converter. Without loss of generality, a single polarization can be written as

$$S_i(t) = (I_i + jQ)\cdot\exp(j\omega_i t) \qquad (1)$$

where the subscript *i* stands for input, and ω_i is the angular frequency of the optical carrier. The phase noise term is dropped for simplicity. I and Q carry the transmitted information and can represent any modulation format. A local laser input to the optical hybrid can be simplified as

$$l(t) = \exp(j\omega_i t + j\varphi_l) \qquad (2)$$

where φ_l is the random laser phase and is a function of t. The polarization states of the incoming signal and the local laser are aligned by a polarization controller. The IQ wavelength

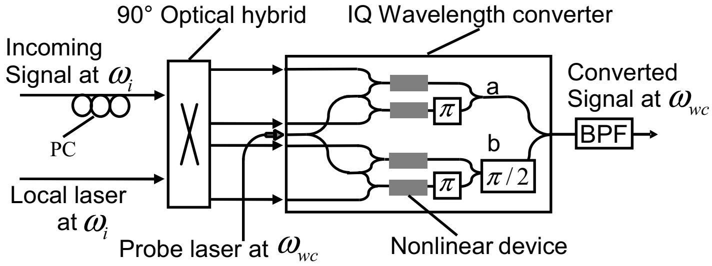

Figure 1 : Schematics of single polarization IQ wavelength conversion by using an optical hybrid and IQ wavelength converter. (BPF:band pass filter. PC: polarization controller)

converter is composed of a pair of nested Mach-Zehnder interferometers (MZI) with non-linear devices and an outside MZI. The two inner MZIs are biased at the null point and the outside one biased at π/2. In Fig. 1, each nonlinear optical device provides optical cross modulation and is assumed to only respond to the intensity of the input optical signal and have a proper low-pass function to filter out the unwanted high-frequency components after the optical hybrid. The probe laser is

$$l_{wc}(t) = \exp(j\omega_{wc}t + j\varphi_{wc}) \qquad (3)$$

After combining arm (a) and arm (b), the converted signal can be derived and written as

$$S_{wc}(t) = (I_i + jQ_i)\cdot\exp(j\varphi_l)\cdot l_{wc}(t) \qquad (4)$$

Thus the incoming optical signal is successfully converted to another wavelength with the phase noise term that can be considered as a wider linewidth laser source at either the transmitter or receiver.

3. Experimental Setup

Fig. 2 shows the experimental setup of wavelength conversion for multiple modulation formats. The inset of Fig. 2 shows the structure of the IQ wavelength converter, including an integrated SOA-MZI pair and two external fused fiber couplers as an external interferometer. The transmitter includes a laser source at 1545 nm and three modulators, which are configured to generate different modulation formats. PRBS 2^7 is used for the BER measurement of DQPSK format. The local laser is tuned to the same wavelength as the transmitter and its polarization is aligned with the transmitted signal by a polarization controller. After the optical hybrid, the optical power levels of the local laser and the transmitted signals are -6 dBm and -11 dBm for RZ formats, and -9 dBm and -14 dBm for NRZ formats, respectively. The narrow linewidth (100 kHz) of the local laser helps to reduce the phase noise in the converted signal as illustrated by Eq. (4). We drive the four SOAs at 425, 450, 470 and 492 mA during the experiments for optimal performance. The optical power (5 dBm) of the probe laser at 1540 nm saturates the SOAs thus provides a wide linear range for the optical cross modulation. The converted signal has relatively low power level (-8 dBm), mainly because we bias the inner SOA-MZIs at their null points with OSNRs around 35 dB. One more SOA and filter are used to suppress the intensity noise generated by the wavelength converter, which is not necessary if we can find a better way to stabilize the device. For testing the input signal dynamic range and wavelength range, we use 10 Gb/s RZ-DPSK format and take the BER measurements at different input wavelengths and different input power levels (measured right after the BPF following the EDFA).

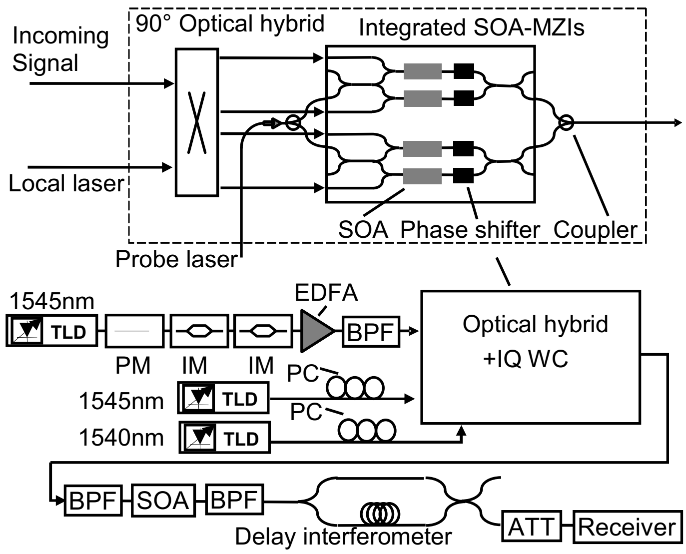

Figure 2 : Experimental setup of wavelength conversion for multiple modulation formats (ATT: Attenuator)

4 Experimental Results

Fig. 3(a) and (b) shows the wavelength conversion results of 5 Gb/s NRZ-DQPSK and 20 Gb/s RZ-DPSK. The RZ-DPSK detected from the destructive port of the delay interferometer has about 2 dB power penalty at 10^{-9} BER for the different lengths of PRBS pattern. The constructive port has a slightly worse eye-diagram. The RZ-DQPSK has a BER floor around 10^{-8} and the main reason is that it is more susceptible to the distortion caused by the IQ wavelength converter. This scheme shows at least a 6 dB input dynamic range (Fig. 4 (a)) partially due to the presence of the local laser. And it supports input signals over a wavelength range of 6 nm for 10 Gb/s RZ-DPSK (Fig. 4 (b)). We believe that the proposed scheme can perform much better with faster SOAs of more uniform response and more uniform insertion loss, and with a more stable MZI for IQ combination, probably by means of monolithic integration.

5. Conclusion

We have presented an SOA-MZI based IQ wavelength conversion technique. Wavelength conversion results of 5 Gb/s NRZ-DQPSK and 20 Gb/s RZ-DPSK have been presented. The input dynamic range and input wavelength range of the IQ converter have also been investigated.

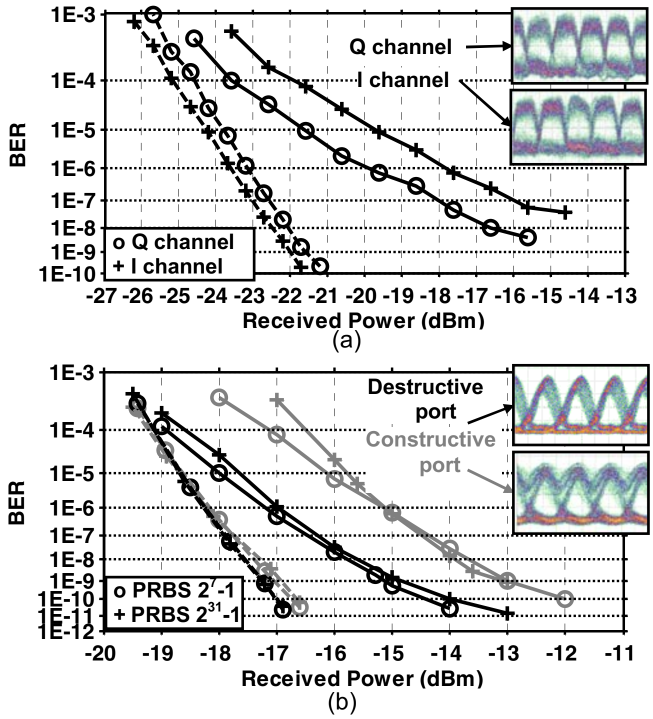

Figure 3 : BER curves before (dash lines) and after (solid lines) wavelength conversion (a) 5 Gb/s NRZ-DQPSK, (b) 20 Gb/s RZ-DPSK (black curve: destructive port of the delay interferometer, grey curve: constructive port of the delay interferometer). Eye diagrams are after wavelength conversion

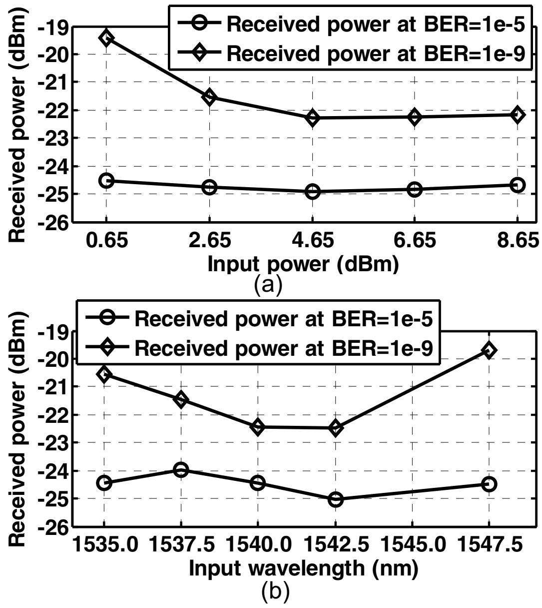

Fig 4: (a) input dynamic range, (b) input wavelength range for 10 Gb/s RZ-DPSK

6. References

[1] S. J. B. Yoo: "*Wavelength conversion technologies for WDM network applications*", JLT, Vol14, pp. 955-966 1996

[2] Xingwen Yi, Runxiang Yu, Junya Kurumida, S. J. B. Yoo: *"Modulation-Format-independent Wavelength conversion*", OFC, Dan Diego, CA, US, 2009, PDPC8.