A New Scheme for Regenerative 40 Gb/s NRZ Wavelength Conversion using a Hybrid Integrated SOA-MZI

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Abstract: We present a new NRZ wavelength conversion scheme based on SOA-MZI. Experimental verification of its superior 2R regenerative capabilities are demonstrated for 40 Gb/s NRZ data signals.

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1. Introduction

Wavelength Conversion (WC) with Return-to-Zero (RZ) data signals using Semiconductor Optical Amplifier-Mach Zehnder Interferometers (SOA-MZI) has been recorded even for data rates that exceed 160 Gb/s [1]. Unfortunately, such achievements have not been matched with the NRZ format due to the continuous carrier depletion in the SOAs. At 40 Gb/s two main successful approaches of WC with NRZ signals have been reported. The differential scheme uses a sub-bit period relative time delay between two, identical data control signals [2] and the bidirectional scheme uses a counter-propagating arrangement of these identical control signals [3]. More recently, we have proposed and demonstrated at 10 Gb/s, a differentially biased SOA-MZI scheme that provides NRZ wavelength conversion with enhanced 2R regenerative characteristics [4].

In this letter, we extend this concept to 40 Gb/s NRZ signal wavelength conversion and show improved 2R regenerative properties. We developed a simulation model of a SOA-MZI capable of accurately simulating the performance of the device in a bi-directional configuration. Taking into account the simulation results, we optimized our proposed scheme by using two external CW signals in order to differentially bias the SOAs in the MZI, one for each of the SOAs. In this way, we achieved good balance both in the gain and phase imparted to the signals in the two arms of the MZI. The scheme was experimentally evaluated with 27-1 NRZ PRBS data sequence at 40 Gb/s, showing improved regenerative properties compared to the bidirectional scheme and the standard WC configuration, yielding a negative power penalty of 1.7 dB with respect to the degraded data input signal.

2. Simulation Model Development and Analysis

In order to study and optimize the performance of the proposed scheme at the demanding rate of 40 Gb/s, we developed a SOA model capable of providing accurate results when operated in a bi-directional way. This model considered the SOA as a multi-quantum well InGaAsP active waveguide with \( \lambda_g = 1.55 \) μm and it based on the position dependent carrier density rate equation and the field propagation equation. Moreover, the refractive index change due to the carrier density change was introduced through the alpha factor which is dependent on the carrier density and hence the longitudinal position in the SOA. This approach was necessary in order to include the asymmetric gain/phase induced effects generated in the case of counter-propagating fields.

The curves depicted in Figure 1 correspond to transfer functions of gain and phase experienced by \( \lambda_2 \) wavelength as a function of \( \lambda_1 \) power at SOA input assuming co- and counter-propagating \( \lambda_1, \lambda_2 \) waves. The gain and phase evolution can be utilized in order to envisage the performance of the three main SOA-MZI based WC schemes, the standard scheme, the bidirectional scheme [3] and the proposed differentially biased configuration [4]. All schemes are based on the principle that \( \lambda_2 \) light signals from both SOAs interfere destructively or constructively by adjusting the differential phase shift between the two arms of the MZI, which results in logic-maintaining or logic-inverting wavelength conversion. Concerning the standard scheme, the interference output will be a result of...
both phase and intensity unbalance among the two outputs and due to the latter significant pattern effects are expected [4].

On the other hand, the bidirectional input scheme exploits the dependence of the ratio of XPM to XGM on the injection direction of the data pulse, as shown in Figure 1, resulting in efficient cancelation of the XGM-induced intensity unbalance. The MZI is set such that the probe signal (\(\lambda_2\)) passing through the upper arm and that passing through the lower arm interfere constructively with each other when no data pulse (i.e., space level of the NRZ signal) is set as input, thus providing an inverted replica of \(\lambda_1\) to \(\lambda_2\). The counter-propagating data (lower arm) pulse at \(\lambda_1\) yields larger phase shift than the co-propagating data pulse (upper arm) with the same gain suppression (see Figure 1). The difference in phase shift turns the interferometer destructive with good intensity balance.

Carefully observing figure 1, we can see that it is not straightforward to locate one \(\lambda_1\) power value for both co- and counter-propagating branches for which gain experienced by \(\lambda_2\) is the same and the induced phase is different. To be precise, we observe the opposite: that is the same XPM result but different XGM at \(\lambda_2\) for the same \(\lambda_1\) power value. That implies that one should feed the two arms with different amounts of power in order to conserve the gain variations identical at the output of both branches (at \(\lambda_2\)) and to enhance their phase differences. This is actually the underlying mechanism of the third optimized differentially biased bi-directional scheme. Notice that \(\lambda_1\) with higher power is injected to the counter-propagating SOA in order to increase the XGM at this branch and make it equal to that experienced by \(\lambda_2\) at the upper co-propagating branch [4]. In this way, perfect intensity balance can be achieved and the data translation from \(\lambda_1\) to \(\lambda_2\) is largely attributed to phase to amplitude conversions at the output coupler.

3. Experiment and Results

Figure 2 illustrates the experimental setup that was used for the performance evaluation of the new wavelength conversion scheme at 40 Gb/s and its comparison with the other NRZ wavelength conversion solutions. The set-up consists of an optical signal generator, a commercially available, hybridly integrated, SOA-MZI regenerator fabricated by CIP Technologies and a 40 Gb/s receiver. The optical signal generator employs a CW signal at 1560 nm (CW1) that was injected into a Ti:LiNbO\(_3\) electro-optic modulator (MOD) driven by a 40 Gb/s NRZ pulse pattern generator, producing a 2\(^{11}\)-1 PRBS data pattern. This pulse train was then inserted into a variable optical attenuator (VOA) and an erbium doped fibre amplifier (EDFA) to degrade its quality in terms of optical signal to noise ratio (OSNR) prior being split into two identical streams that comprise the two MZI control signals, denoted as control 1 (CTR1) and control 2 (CTR2), respectively. The extinction ratio of these signals could also be reduced with the polarization controller prior to the electro-optic modulator. The NRZ data content was wavelength converted to 1553 nm and was finally filtered with a 2 nm bandwidth filter. In the standard WC scheme, only the degraded CTR1 was fed into the MZI as control signal. In the bidirectional scheme, both CTR1 and CTR2 signals were inserted in counter-propagating directions into the upper and lower SOAs, respectively, of the MZI [3]. In the differentially biased bidirectional push-pull scheme, two additional CW signals at 1564 nm (CW3 and CW4) counter-propagate SOA1 and SOA2. They allowed for full and independent adjustment of the gain saturation levels and associated phase shifts induced in the CW2 signal travelling in the two arms of the MZI. Both SOAs were driven at 300 mA. BER measurements were obtained for the wavelength converted signal after electrical de-multiplexing to 10 Gb/s. In the standard scheme, the power of the input CW and of the control signal was 7 dBm. In the bidirectional scheme the respective values were 5.6 dBm for the input CW, 4.7 for CTR1 and 4.3 dBm for CTR2. The injected power of the input CW was 4 dBm in the differentially biased scheme and the control signals power were 6.9 (CTR1) and 4.7 dBm (CTR2). The power of the external CW signals that were used in this scheme were -8.9 (CW3) and 3.2 dBm (CW4).
Figure 2: Experimental setup for the wavelength conversion.

Figure 3 shows the eye diagrams of the degraded input and the wavelength converted signal at the output of each scheme. An improvement in signal quality is observed for the differentially biased push-pull scheme compared to the standard and bidirectional schemes. The superiority of the differentially biased push-pull scheme is also observed in the Bit Error Rate (BER) measurements of Figure 4. For an input signal degraded by 2.5 dB with respect to the back-to-back signal, the bidirectional scheme provides 0.4 dB improvement and the differentially biased push-pull scheme provides improvement of 1.7 dB. With respect to the initial back-to-back signal, the schemes incur 2.1 and 0.8 dB power penalties and hence the superior performance of the differentially biased push-pull scheme. Finally it should also be noted that for the standard scheme an error floor at $10^{-3}$ was obtained even for maximum input power at the receiver.

Figure 3: Experimental results for all the wavelength conversion schemes. Eye diagram for the: (a) degraded input signal, (b) single control scheme, (c) bidirectional scheme and (d) differentially biased bidirectional scheme.

Figure 4: Bit Error Rate measurements.

4. Conclusion

We have presented a new all-optical wavelength conversion scheme for NRZ data signals at 40 Gb/s with improved 2R regeneration capabilities. Our technique utilizes a differentially biased SOA-MZI switch operating in a bidirectional configuration.

References


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