Experimental demonstration of all-optical 2R regeneration at 10 Gb/s in a MZI-configuration with a single SOA

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10Gb/s all-optical 2R-regeneration is demonstrated using a Mach-Zehnder Interferometer with only one semiconductor optical amplifier, leaving the other arm transparent, rendering better noise and dynamic properties. Simulations in combination with literature prove the potential of this configuration for higher bit-rates.

Introduction

As signals propagating through an optical network suffer from degradations due to accumulation of noise introduced by the amplifiers, jitter and dispersion, regeneration is needed at intermediate distances. Because of cost and transparency considerations it is advisable implementing this in an all-optical configuration, thereby avoiding the O-E-O conversion.

In this paper we propose a novel 2R (Re-amplification – Re-shaping) regenerator scheme based on a so-called pass-through scheme. This implies that the regenerated signal is a cleaned version of the original signal, so no wavelength conversion is done. This simplifies the regenerator significantly, since no CW laser and optical filter at the output are needed [1,2]. Moreover it maintains the wavelength transparency of the device.

Ideally a regenerator should also fulfill the Re-timing task, then being extended to a 3R-regenerator. But simulations [3] as well as experiments [4] have shown that even by the use of only 2R regeneration the maximal achievable propagation distances of WDM-signals can significantly be increased.

Several pass-through schemes have already been proposed in literature [5, 6, 7], but most were limited in maximum speed, in particular for NRZ signals. Our scheme is a modified version of an MZI with two active arms, as proposed in [5]. The advantage is a better dynamic performance of the configuration for equal SOA properties, thereby better exploiting the high-speed properties of the amplifiers.

Principle of operation

The proposed regenerator scheme is a pass-through scheme, based on a Mach-Zehnder configuration with one transparent arm and one arm containing an SOA. An attenuator is added to the active arm, enabling a more or less equal gain in both the active and the passive arm, in order to obtain efficient interference. Figure 2 gives a schematic view of the regenerator scheme. A similar configuration was proposed in [8] for the purpose of wavelength conversion, but was not further exploited because it didn't result in the same benefits for the wavelength converter as it does when used in a pass-through scheme.

This configuration has several advantages as compared to the regenerator scheme proposed in [5]. The fact that one arm is transparent, allows obtaining higher speeds. Indeed, if both arms of the interferometer are active, the input power levels for zero and one must be in the neighborhood of the input saturation power levels of both SOAs. It is then not possible to increase the speed because one of the SOAs can not be operated in deep saturation. An increase in applied currents could only partially solve the problem, because this results in an increased amount of ASE, which then starts to control the dynamics. This makes it possible to enhance the speed at moderate input power [9], but also increases the amount of added noise to the regenerated signal, which is of course undesirable.

With only one SOA one can increase the input power, which is no longer restricted to a certain power interval once the current is set, rendering higher speeds with the same type of SOAs.

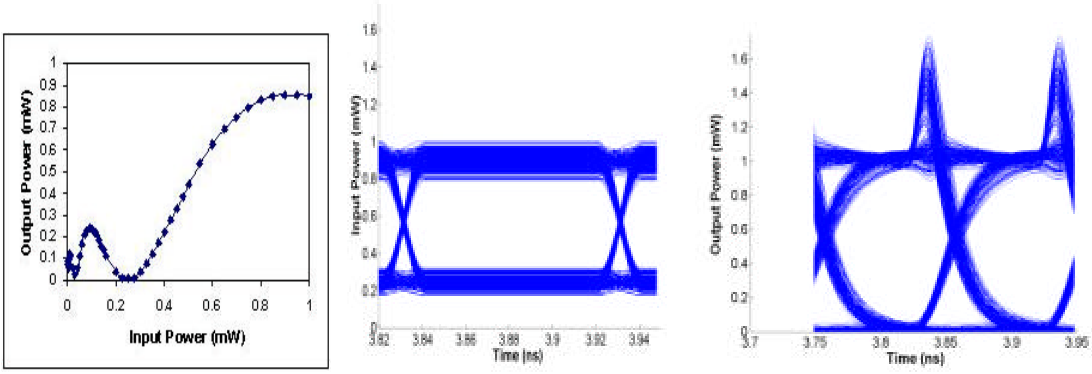


Figure 1. (a) Simulated static regeneration curve, (b) Simulated in- and output eye diagrams at 10 Gb/s

Simulation results

To check the feasibility of the proposed approach, simulations were carried out using a multi-section 1D single mode SOA-model, including forward and backward propagating ASE. Gain suppression was included in the model because it significantly influences the dynamics of the component. A device with a length of 1 mm and an optical confinement factor of 0.45 was used. For the material parameters typical values were used.

The MZI output signal was calculated as the interference of the input signal and the SOA output signal to which a constant phase difference and attenuation was added. The constant phase difference will in practice be realized by a slight change in applied current to the SOA.

Figure 1.a depicts a static regeneration curve obtained in this way. From the simulations it becomes clear that regeneration can only be achieved for modest input signal extinction ratios (ERs), because of the fast phase change of the signal propagating through the SOA with increasing input power.

For the dynamic simulations a 2^9-1 PRBS NRZ signal with Gaussian distribution on both zero and one level, and with rise and fall times of 1/10 of the bit period was applied to the MZI. Figure 1.b shows the resulting eye diagrams of input and corresponding output signal. From those it is clear that the signal has been regenerated. A clear suppression of the noise on the zero level was observed in combination with an increase in ER from 5.5 dB to 12 dB. Also the noise on the one level is slightly suppressed.

The simulation results prove the feasibility of the configuration for regeneration up to at least 10 Gb/s, when a component with given properties is used. If a component as described in [10], exhibiting a carrier recovery time < 14 ps, could be used in the same configuration, regeneration up till 40 Gb/s must be possible.

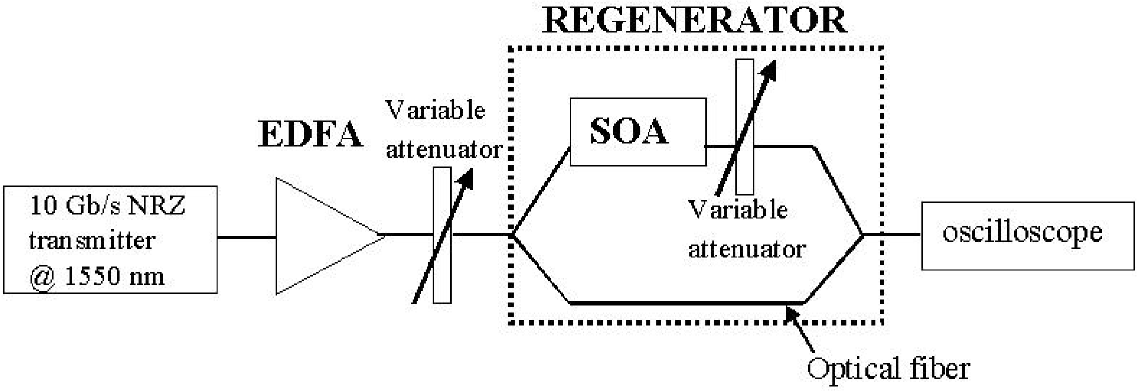
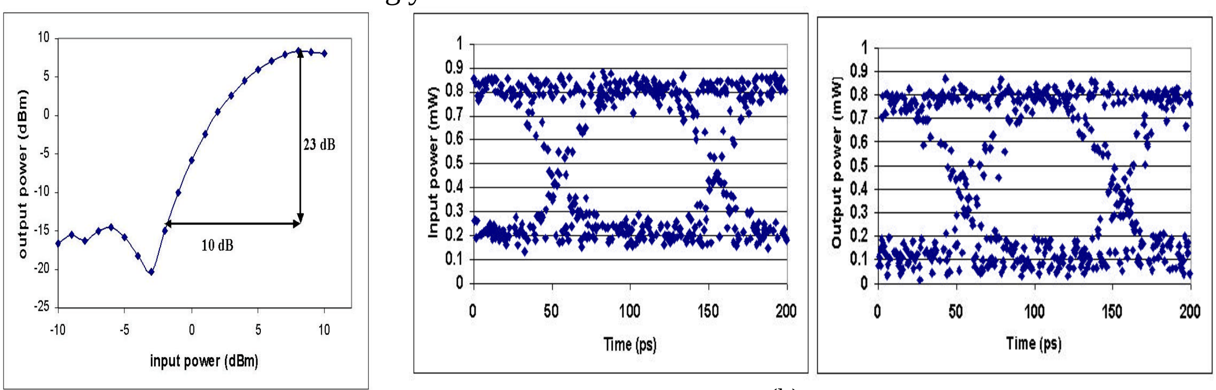


Figure 2. Experimental set-up for the 2R regeneration scheme. The dashed rectangle encloses the regenerator configuration.

Dynamic measurements at 10 Gb/s

Figure 2 shows the experimental set-up used in the measurements. A CW signal from a tunable laser is modulated with a PRBS sequence of word length 2^{31}-1 to generate the data signal. An EDFA is used to amplify the signal to the desired power level. The interferometer was constructed using fiber-based 3dB couplers, a fiber-pigtailed SOA and a variable attenuator. A 10 Gb/s receiver detected the signal.

To investigate the quality of the configuration, static input-output characteristics were measured. By controlling the applied current to the SOA and the attenuation, good static regeneration curves were achieved. An example is shown in figure 3.a. We see that, under static or low bit-rate operation, an ER improvement of 13 dB can be achieved. We also observe a larger Input Power Dynamic Range as compared to the simulation results, probably because the SOA is not as strongly saturated.



(a) (b)

Figure 3. (a) Experimentally obtained static regeneration curve. (b) Eye diagrams of in- and output signals at 10 Gb/s.

Input and output eye diagrams resulting from a 10Gb/s measurement are depicted in figure 3.b. An ER improvement of 3dB is achieved for an input ER of 6dB, in combination with a clear suppression of the noise on the one level. The slightly larger rise and fall times in the output signal are the result of the rather slow dynamics of the used component, which was an non-optimized prototype.

We were not able to perform BER measurements due to the rather low stability of the fiber-based interferometer. From the simulations and the measured static regeneration curve it is expected that with an integrated version of the regenerator, in combination with a faster SOA, regeneration up to higher bit-rates can be achieved.

Conclusion

We have experimentally demonstrated 2R regeneration of a 10 Gb/s data signal in a pass-through scheme consisting of an MZI with one transparent arm and an SOA in the other arm. The measurements show extinction ratio improvement as well as noise suppression. Simulations in combination with literature prove the potential of this configuration up to higher bit-rates when using a better SOA in an integrated interferometer.

References

[1] D. Wolfson et al.,"40 Gb/s all-optical wavelength conversion, regeneration, and demultiplexing in an SOA-based all-active Mach-Zehnder interferometer", Photonics Technology Letters, vol. 12, pp. 332-334, 2000.

[2] O.Brox et al.,"Q-switched laser module for regenerative wavelength conversion", in Proceedings of the Conference ECOC '00 , 2000, vol. 2, pp. 57-58.

[3] S. Boscolo et al.,"All-optical passive 2R regeneration of dispersion-managed RZ data at 40 and 80 Gbit/s using in-line NOLMs", in Proceedings of LEOS '01, 2001, vol 1, pp. 83-84.

[4] D. Rouvillain et al.,"Optical 2R regenerator based based on passive saturable absorber for 40 Gb/s for WDM long-haul transmissions", Electronics Letters, vol. 38, pp. 1113-1114, 2002.

[5] J. De Merlier et al.,"All-optical 2R regeneration based on an integrated asymmetric Mach-Zehnder interferometer incorporating an MMI-SOA", Electronics Letters, vol. 38, pp. 238-239, 2002.

[6] D. Wolfson et al.,"Experimental investigation at 10 Gb/s of the noise suppression capabilities in a pass-through configuration in SOA-based interferometric structures", Photonics Technology Letters, vol. 12, pp. 837-839, 2000.

[7] M.Zhao et al., "Experimental demonstration at 10 Gbps of 2R optical regeneration in a fiber-based MZI with SOAs", in Proceedings of the Conference ECOC '02, 2002, pp. 7.3.6.

[8] T.Durhuus et al., "Penalty free all-optical wavelength conversion by SOA's in Mach-Zehnder configuration", in Proceedings of the Conference ECOC '93, 1993, vol. 2, pp. 129-132.

[9] T. Liu et al., "Effect of saturation caused by amplified spontaneous emission on semiconductor optical amplifier performance", Electronics Letters, vol. 33, 2042-2043, 1997.

[10] M.L. Nielsen et al., "40 Gbit/s standard-mode wavelength conversion in all-active MZI with very fast response", Electronics Letters, vol. 39, pp. 385-386, 2003.