applied sciences

MDPI

Article

A Deeply Saturated Differentially-Biased SOA-MZI for 20 Gb/s Burst-Mode NRZ Traffic

Apostolos Tsakyridis *, Miltiadis Moralis-Pegios, Christos Vagionas, Eugenio Ruggeri, George Kalfas, Amalia Miliou and Nikos Pleros

Department of Informatics—Center for Interdisciplinary Research and Innovation, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

* Correspondence: atsakyrid@csd.auth.gr

Received: 24 June 2019; Accepted: 22 July 2019; Published: 25 July 2019

Featured Application: optical packet switching, passive optical networks.

Abstract: We experimentally demonstrate an optical Burst-Mode Wavelength Converter (BMWC) that simultaneously provides power equalization and wavelength conversion of Non-Return to Zero-On/Off Keying (NRZ-OOK) data and operates up to 20 Gb/s. It employs a balanced, differentially-biased, Semiconductor Optical Amplifier-Mach Zehnder Interferometer (SOA-MZI) operating in deeply saturated regime and its performance is evaluated at 10 Gb/s and 20 Gb/s with loud/soft peak–power ratios up to 9 dB and 5 dB, respectively. Bit Error Rate (BER) measurements reveal error free operation with up to 6.1 dB BER improvement at 10 Gb/s and 3.51 dB at 20 Gb/s, while the use of a single SOA-MZI yields 50% reduction in the number of active components against state-of-the-art BMWCs. Finally, the proposed BMWC is evaluated in non-dispersion compensated 25 km fiber transmission experiment, providing error-free operation with 1.43 dB BER improvement, validating its capabilities for potential employment in Passive Optical Networks (PON) and 5G fronthaul networks.

Keywords: burst-mode switches; optical wavelength conversion; passive optical networks; semiconductor optical amplifier-Mach-Zehnder Interferometer; 5G digital fronthaul; wavelength division multiplexing

1. Introduction

All-optical Wavelength Conversion (WC) and regeneration modules have been widely studied in the past two decades, having produced a large variety of principles, techniques and devices [1–7]. Semiconductor Optical Amplifier (SOA)-based devices have been a major class of widely used high-performance WC and regeneration modules, offering high-speed WC in different alternative configurations [8–11] and often deployed as highly compact integrated circuits. With SOA gain recovery time having been identified as the main line-rate limiting factor, the SOA gain dynamics have favored the use of Return to Zero (RZ) pulse formats in higher data-rate applications, reporting remarkable achievements in WC and regeneration layouts for RZ formatted data traffic with up to 320 Gb/s operational speed [12–17]. Nonetheless, with Non-Return to Zero (NRZ) data formats appearing as the clearly preferred modulation format choice over RZ pulses, research shifted towards SOA-based WC elements that could offer the necessary functionality even with NRZ data pulses at high data-rates [18–21]. Within this context, the differentially-biased SOA-Mach Zehnder Interferometer (MZI) scheme has probably prevailed as the highest-speed performing SOA-based WC for NRZ data, offering the best quality WC and regeneration characteristics up to 40 Gb/s, [21] and the highest possible cascadability potential [22].

However, when burst-mode traffic operation is targeted where data packets might have propagated through different fiber segments experiencing different losses and as such arriving with intense power fluctuations at the WC stage, wavelength conversion has to be preferably accompanied with power equalization capabilities on a per packet basis in order to ensure successful propagation of the wavelength converted signal into the next network segment. Although a large variety of burst-mode, regenerative, SOA-based WC schemes have already been proposed [23–29], most of them have been able to yield successful operation only with RZ data formats when linerates higher than 10 Gb/s are targeted [23–25]. When NRZ burst-mode operation is required, typically being the case in reach extender applications for Passive Optical Network (PON) uplink transmission or 5G digital fronthaul architectures [30], SOA-based WC schemes have been restricted to 10 Gb/s operational data-rates [26–29].

In this paper, we experimentally demonstrate a new SOA-MZI WC scheme that can provide burst-mode WC operation at up to 20 Gb/s linerates even for NRZ data packets, using a single SOA-MZI device in a modified, differentially-biased, architectural layout where both SOAs are forced to operate in their deeply saturated regime [21,31]. Combining the high-quality WC characteristics of the differentially-biased SOA-MZI scheme with the clipping properties of the SOA-MZI non-linear transfer function emerging in the deeply saturated semiconductor region, wavelength conversion can be accompanied with strong power equalization capabilities in a single device, decreasing the number of required active elements by 50% compared to state-of-the-art NRZ Burst-Mode Wavelength Converters (BMWCs) [29]. Extending our recent work on the proof-of-principle experimental demonstration at 10 Gb/s [32], the burst-mode WC credentials of the proposed deeply saturated, differentially-biased, SOA-MZI are experimentally validated both with 10 Gb/s and 20 Gb/s NRZ burst-mode packets as well as with burst-mode traffic originating after having been transmitted in 25 km dispersion uncompensated fiber links. Successful burst-mode WC operation has been obtained both at 10 Gb/s and 20 Gb/s for a loud/soft ratio of up to 9 dB and 5 dB, respectively, revealing negative power penalties of 6.1 dB and 3.51 dB at a 10^{-9} error-rate, respectively. Finally, its performance has been evaluated with 10 Gb/s NRZ traffic transmitted through non-dispersion compensated 25 km Standard Single Mode Fiber (SSMF), achieving error free operation with a 1.43 dB negative power penalty, validating its potential to perform successfully in realistic burst-mode traffic conditions where both propagation losses and dispersion accumulation vary on a per packet level.

2. Experimental Setup and Principle of Operation

The architecture of the proposed BMWC and the experimental setup used for the evaluation of its operation are illustrated in Figure 1. The BMWC utilizes a differentially-biased SOA-MZI, where the two SOAs are operated in a deeply gain saturation regime, to realize a non-linear transfer function with clipping properties [21,31]. More specifically, at the steady state conditions, one of the two SOAs is deeply saturated in the transparency region, i.e., allowing all of the signal to simply pass through its waveguide structure without any amplification, while the second SOA is operated in a slightly less saturated condition with some small gain-amplification and before the transparency region. This saturated differential biasing condition allows setting the steady-state gain levels of two SOAs in an asymmetrically biased condition that corresponds to a constant differential phase shift close to π between its two branches, when no other control data signal is present. When a control signal is injected into the device, it leads both SOAs performing close to their gain transparency region, as such the SOAs' carrier fluctuation and intensity modulation are greatly reduced, supporting clipping properties and strongly power equalized output pulses. On the other hand, when SOAs are operated in a symmetrically biased condition, as in simple WC or push-pull schemes [33], they are generating amplitude fluctuations, jitter and transient phenomena as described in more details in [34].

In order to achieve these operational conditions, the two SOAs of the BMWC are each powered by a Continuous Wave (CW), gain-clamping, assist-light beam at $\lambda as_1 = \lambda as_2 = 1548$ nm and a power level of 7.13 dBm and −11.93 dBm, through SOA-MZI ports D and E, respectively. The present optical power levels enable gain clamping of the two SOAs in the saturated regime, where faster SOA gain dynamics are observed, while also setting a differential biasing with a constant π differential phase shift. In order to perform the wavelength conversion, a data signal on a λ_1 wavelength of 1550.4 nm was injected into two cascaded $LiNbO_3$ modulators, that were driven by Programmable Pattern Generators (PPGs). The first PPG was used to produce two sequential 10 Gb/s or 20 Gb/s 2^7-1 Pseudo Random Bit Sequences (PRBS) packets, while the second modulator was used to apply different optical power levels to the packets by changing its driver's gain. The present transmission setup allows emulating the bursty packet traffic generated through two different users with arbitrarily varying power levels, stemming from various near or far distant locations of the converged access-network.

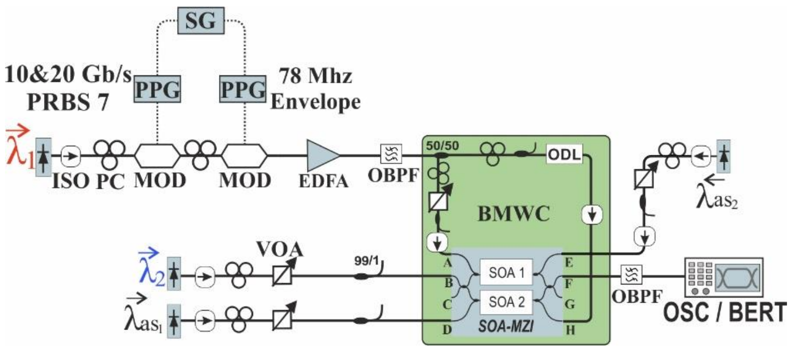

Figure 1. Experimental setup for testing the proof of concept of the Burst-Mode Wavelength Converter (BMWC). EDFA: Erbium Doped Fiber Amplifier; ISO: Isolators; MZI: Mach Zehnder Interferometer; OBPF: Optical Bandpass Filter; PC: Polarization Controllers; PPG: Programmable Pattern Generators; PRBS: Pseudo Random Bit Sequences; SOA: Semiconductor Optical Amplifier; VOA: Variable Optical Attenuators.

After generating the data packets, the data signal was amplified by an Erbium Doped Fiber Amplifier (EDFA) and filtered by a 3 nm Optical Bandpass Filter (OBPF), and then split into two identical signals through a 50:50 coupler before reaching the BMWC device. The two signals were then bit-level synchronized through an Optical Delay Line (ODL), so as to be simultaneously injected at the two available control ports A and H of the SOA-MZI and act as control signals of an optical push-pull configuration. This allows performing Cross-Phase Modulation (XPM) switching phenomena simultaneously at both branches of the SOA-MZI, facilitating fast response and gain recovery dynamics with almost constant differential phase shift between the two branches during the transient gain recovery immediately after a control pulse is extinct. A CW beam at λ_2 = 1549.3 nm was injected as input into the BMWC through port B, with its power level measured at 6.96 dBm. The two control signals featured power levels of 9.8 dBm and −1.5 dBm respectively, while the SOAs were driven at 268 mA and 330 mA, respectively.

3. Experimental Results

In order to demonstrate the power-equalization and wavelength switching capabilities of the proposed BMWC and evaluate the maximum supported bit rate and loud/soft ratio of the input packets, the BMWC was characterized at both 10 Gb/s and 20 Gb/s. The experimental results for 10 Gb/s operation are illustrated in Figure 2. The input traces of the incoming packets at λ_1 = 1550.4 nm are shown in Figure 2a–c featuring two loud and three soft packets interleaved, while for comparison purposes Figure 2d–f depict that the respective output traces exhibit flat and equalized peak power levels for all bits, demonstrating both power-equalization and wavelength conversion, while the respective output eye diagrams are illustrated in Figure 2g–i.

The 10 Gb/s operation of the BMWC was also evaluated with the aid of Bit Error Rate (BER) measurements for loud/soft ratios ranging from 4 dB up to 9 dB and the obtained BER curves are plotted in Figure 2j with the solid lines representing the output data signals and the dashed lines used for the respective input data signals. As can be seen for the solid-line curves of the output signals, error free operation at 10^{-9} was achieved for all loud/soft ratio values up to 9 dB. On the contrary, error free operation for the input signal was obtained only for loud/soft ratios up to 7 dB at the 10^{-9} condition, up to 8 dB for the 10^{-4} condition and could not be achieved for the 9 dB ratio. A better representation of this quantitative improvement of the BER curves between the input and output is shown in Figure 2k, where the required peak power for 10^{-9} BER operation is plotted versus the loud/soft ratios, showing that error free operation could not be achieved for the input at high loud/soft power ratios. The latter reveals that the BER measurements were heavily degraded by the requirement for a low threshold value in the BER-tester to detect the pattern of the soft packets.

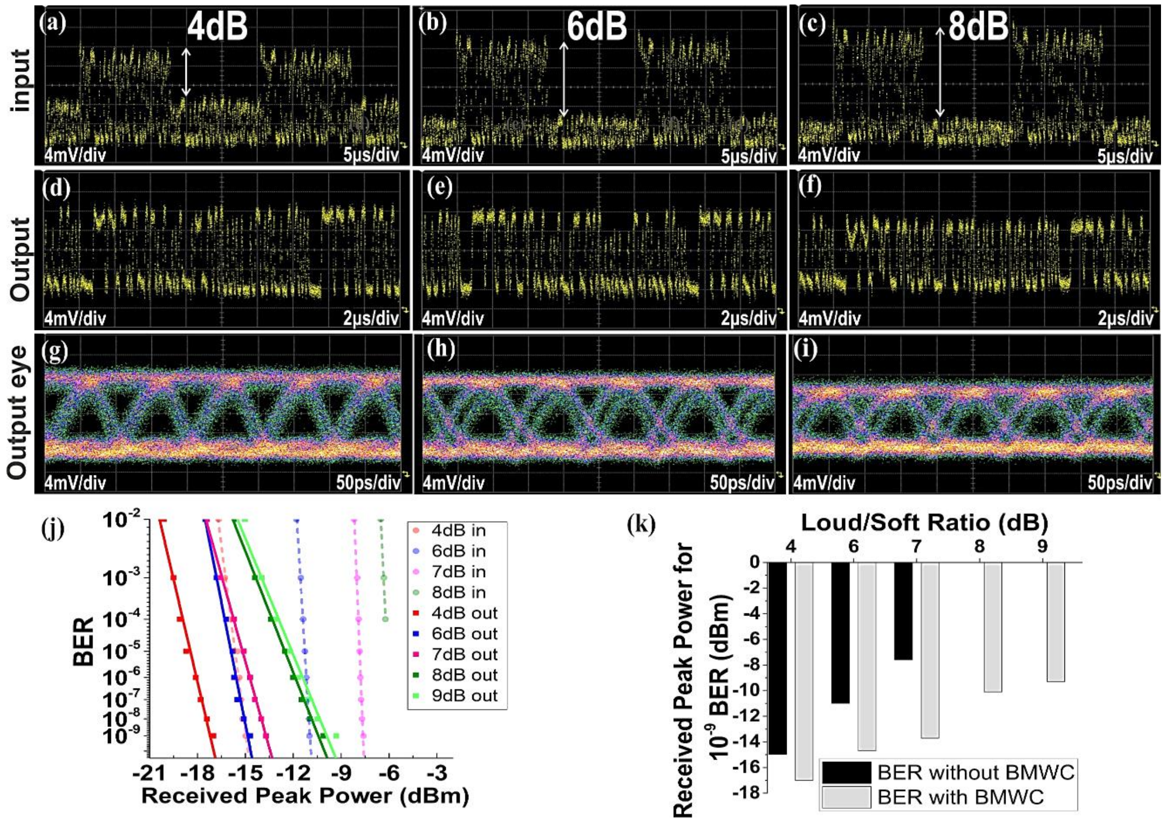

Figure 2. Experimental results for 10 Gb/s for 4 dB loud/soft ratio (**a**) input trace (5 µs/div), (**d**) output trace (2 µs/div), (**g**) output eye diagram (50 ps/div). For 6 dB (**b**) input trace, (**e**) output trace, (**h**) output eye diagram. For 8 dB (**c**) input trace, (**f**) output trace, (**i**) output eye diagram, (**j**) Bit Error Rate (BER) measurements for input and output signals and (**k**) BER improvement of input–output signals at different loud/soft ratios. All traces and eyes are in 4 mV/div.

Equivalently, the experimental results for 20 Gb/s operation are shown in Figure 3. The input traces of the incoming packets at λ_1 = 1550.4 nm are shown in Figure 3a–c with two loud and three soft packets interleaved, while Figure 3d–f depict the respective flat and equalized peak power output traces of two consecutive packets at λ_2 = 1549.3 nm. Figure 3g–i show the output eye diagrams with an extinction ratio (ER) of 6.2 dB and amplitude modulation (AM) of 1 dB, validating the credentials of the BMWC to operate at rates up to 20 Gb/s. Moreover, BER measurements were also performed for loud/soft ratios 3–5 dB, as plotted in Figure 3j, with solid lines used for the output signals and dashed lines for the input signals. The BER improvement between the input and output signals is depicted in Figure 3k showing up to 3.51 dB BER improvement for 5 dB loud/soft ratio when using the BMWC. The device characteristics (SOA lengths, saturation power levels, small signal gain etc.), as well as the operational conditions that allow SOA-MZI operating as BMWC are summarized in Table 1.

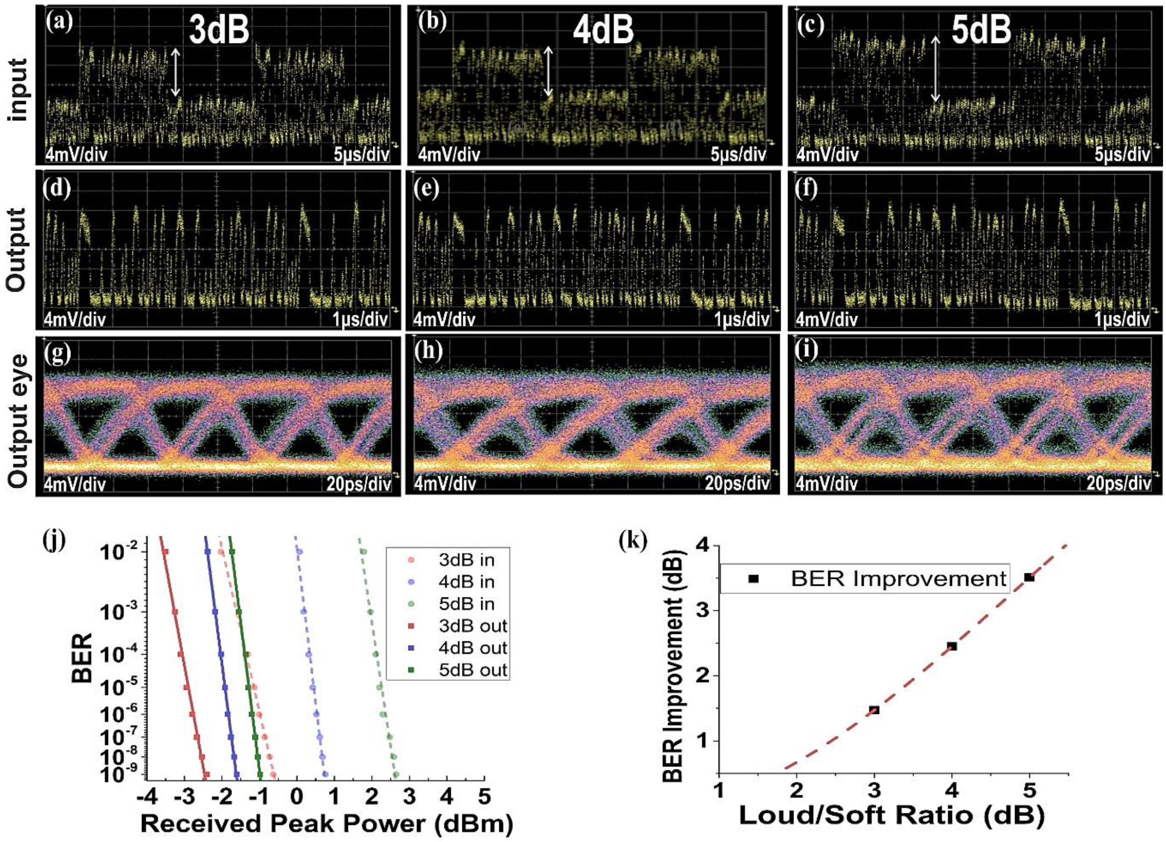

Figure 3. Experimental results for 20 Gb/s for 3 dB loud/soft ratio (**a**) input trace (2.5 µs/div), (**d**) output trace (1 µs/div), (**g**) output eye diagram (20 ps/div). For 4 dB (**b**) input trace, (**e**) output trace, (**h**) output eye diagram. For 5 dB (**c**) input trace, (**f**) output trace, (**i**) output eye diagram, (**j**) BER measurements for input and output signals and (**k**) BER improvement of input-output signals at different loud/soft ratios. All traces and eyes are in 4 mV/div.

Table 1. Operational conditions of the BMWC.

Parameter	Value
SOA length	1.7 mm
Output saturation power of SOA	18 dBm
Typical recovery time of the SOA	80 ps
Small signal gain of the SOA	30 dB
Current SOA1	268 mA
Current SOA2	330 mA
Power of λas1	7.13 dBm
Power of λas2	−11.93 dBm
Input power	6.96 dBm
Control 1 power (Port A)	−1.5 dBm
Control 2 power (Port H)	9.8 dBm

4. 25 km Fiber Transmission Experiment

The performance of the BMWC was finally evaluated in a 25 km fiber transmission experiment without employing any dispersion compensation. The experimental setup used is shown in Figure 4. Two separate signals at λ_1 = 1550.4 nm and λ_5 = 1551.1 nm were combined in a 50:50 coupler and injected into a PPG-driven $LiNbO_3$ modulator to produce a 284 bit pattern including one repetition of 10 Gb/s 2^7-1 PRBS. The two wavelength streams were then demultiplexed through an Arrayed Waveguide Grating (AWG), and transmitted through two different optical paths with 25 km difference, with one of the branches featuring an ODL for controlling the time synchronization of the data. The two optical wavelength streams were then combined through a 50:50 coupler into a single data stream comprising two sequential loud/soft PRBS7 packets of 127 bits, with an intermediate guardband of 15 bits, towards an overall 284 bit long multi-wavelength pattern that emulates the aggregated non-compensated traffic of two PON clients reaching the BMWC. At various stages of the setup, Isolators (ISO), Polarization Controllers (PC), Variable Optical Attenuators (VOA), ODLs and 99:1 monitoring couplers were used to control and optimize the operational settings of the experiment, while the BMWC was operated at the same conditions found at the loud/soft characterization experiments of the previous section.

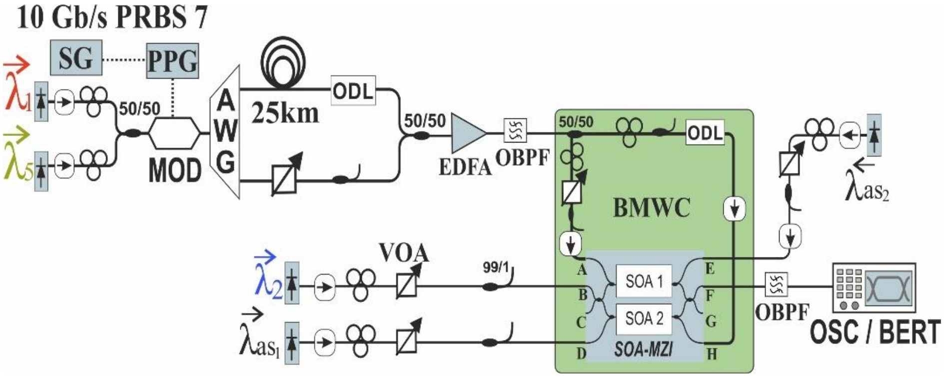

Figure 4. Experimental setup for testing the BMWC with 25 km fiber transmission. AWG: Arrayed Waveguide Grating.

The results obtained for the 25 km long fiber transmission experiment are illustrated in Figure 5. More specifically, Figure 5a,b show the time traces and eye diagrams of the incoming packet bursts exhibiting 5.2 dB loud/soft ratio due to the propagation losses of the 25 km long fiber, and broadened pulses for the soft burst stemming from the chromatic dispersion effect. The BMWC's output signal is illustrated in Figure 5c,d, exhibiting equalized peak power levels and an eye diagram with an ER of 6.5 dB. Figure 5e depicts the BER measurements for the 25 km fiber transmission with and without the BMWC, revealing error free operation with 1.43 dB BER improvement for the case of the BMWC.

Finally, it is worth mentioning, that the BMWC could potentially support higher data rates up to 40 Gb/s and fiber spans up to 40 km, as the differentially-biased scheme has already been demonstrated at this speed [21], and the loud/soft ratio has been shown at up to 9 dB.

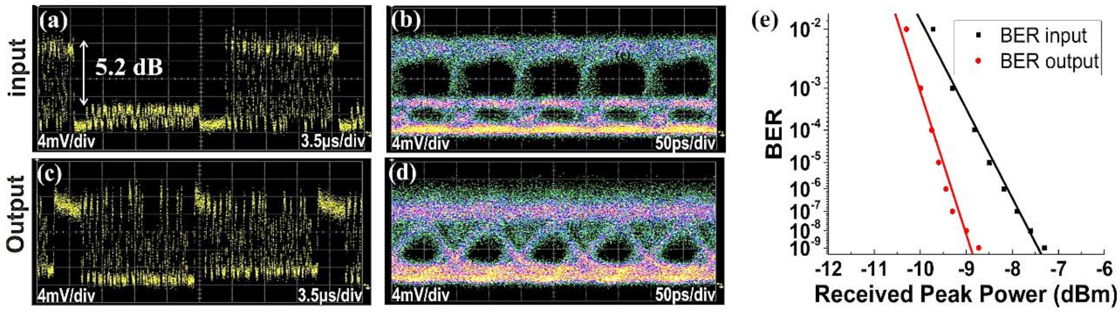

Figure 5. Experimental results for 10 Gb/s packets and 25 km fiber transmission (**a**) input trace (3.5 µs/div), (**b**) input eye diagram (50 ps/div) (**c**) BMWC output trace, (**d**) BMWC output eye diagram and (**e**) BER measurements without the BMWC (input) and with the BMWC (output). All traces and eyes are in 4 mV/div.

5. Conclusions

We experimentally demonstrated an all optical BMWC relying on a single differentially-biased SOA-MZI operating in the strongly saturated conditions. The device has been experimentally verified to support loud/soft ratios up to 9 dB and operational speeds up to 20 Gb/s which is the highest reported so far for burst-mode operation in NRZ format, while revealing error free operation with

6.1 dB BER improvement for 10 Gb/s and 3.51 dB for 20 Gb/s operation. A realistic non-dispersion compensated 25 km fiber transmission scenario was also demonstrated, achieving error free operation with 1.43 dB BER improvement, and successfully validating its credentials to act as reach extender for PON uplink transmission or 5G digital fronthaul applications.

Author Contributions: A.T., M.M.-P., E.R. performed the experiments and prepared the manuscript; C.V., G.K., A.M. and N.P. reviewed both the results and the manuscript.

Funding: This research and APC was funded by the European Commission through H2020 projects 5GPPP Phase II 5GPHOS (contract 761989), and MSCA ITN 5G STEP-FWD (contract 722429).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Inoue, K.; Mukai, T. Experimental study on noise characteristics of a gain-saturated fiber optical parametric amplifier. *J. Light. Technol.* **2002**, *20*, 969–974. [CrossRef]
2. Rochette, M.; Fu, L.; Ta'eed, V.; Moss, D.J.; Eggleton, B.J. 2R optical regeneration: An all-optical solution for BER improvement. *IEEE J. Sel. Top. Quantum Electron.* **2006**, *12*, 736–744. [CrossRef]
3. Ong, J.R.; Kumar, R.; Mookherjea, S. Silicon microring-based wavelength converter with integrated pump and signal suppression. *Opt. Lett.* **2014**, *39*, 4439–4441. [CrossRef]
4. Suzuki, J. All-optical regeneration of 40-Gb/s low-Q signal using XPM-induced wavelength shift in highly-nonlinear fiber. In Proceedings of the 31st European Conference on Optical Communications (ECOC 2005) 2005, Glasgow, UK, 25–29 September 2005; pp. 199–200.
5. Terzenidis, N.; Moralis-Pegios, M.; Mourgias-Alexandris, G.; Vyrsokinos, K.; Pleros, N. High-port low-latency optical switch architecture with optical feed-forward buffering for 256-node disaggregated data centers. *Opt. Express* **2018**, *26*, 8756–8766. [CrossRef]
6. Moralis-Pegios, M.; Terzenidis, N.; Mourgias-Alexandris, G.; Cherchi, M.; Harjanne, M.; Aalto, T.; Miliou, A.; Vyrsokinos, K.; Pleros, N. Multicast-Enabling Optical Switch Design Employing Si Buffering and Routing Elements. *IEEE Photonics Technol. Lett.* **2018**, *30*, 712–715. [CrossRef]
7. Moralis-Pegios, M.; Terzenidis, N.; Mourgias-Alexandris, G.; Vyrsokinos, K.; Pleros, N. A 1024-Port Optical Uni- and Multicast Packet Switch Fabric. *J. Lightw. Technol.* **2019**, *37*, 1415–1423. [CrossRef]
8. Joergensen, C.; Danielsen, S.; Stubkjaer, K.; Pommerau, F.; Poulsen, H.; Kloch, A.; Vaa, M.; Mikkelsen, B.; Lach, E.; Laube, G.; et al. All-optical wavelength conversion at bit rates above 10 Gb/s using semiconductor optical amplifiers. *IEEE J. Sel. Top. Quantum Electron.* **1997**, *3*, 1168–1180. [CrossRef]
9. Mikkelsen, B.; Vaa, M.; Poulsen, H.; Danielsen, S.; Joergensen, C.; Kloch, A.; Hansen, P.; Stubkjaer, K.; Wünstel, K.; Daub, K.; et al. 40 Gbit/s all-optical wavelength converter and RZ-to-NRZ format adapter realised by monolithic integrated active Michelson interferometer. *Electron. Lett.* **1997**, *33*, 133–134. [CrossRef]
10. Apostolopoulos, D.; Vyrsokinos, K.; Zakynthinos, P.; Pleros, N.; Avramopoulos, H. An SOA-MZI NRZ Wavelength Conversion Scheme With Enhanced 2R Regeneration Characteristics. *IEEE Photonics Technol. Lett.* **2009**, *21*, 1363–1365. [CrossRef]
11. Menon, V.; Tong, W.; Li, C.; Xia, F.; Glesk, I.; Prucnal, P.; Forrest, S. All-optical wavelength conversion using a regrowth-free monolithically integrated Sagnac interferometer. *IEEE Photonics Technol. Lett.* **2003**, *15*, 254–256. [CrossRef]
12. Runge, P.; Bunge, C.A.; Petermann, K. All-Optical Wavelength Conversion with Extinction Ratio Improvement of 100 Gb/s RZ-Signals in Ultralong Bulk Semiconductor Optical Amplifiers. *IEEE J. Quantum Electron.* **2010**, *46*, 937–944. [CrossRef]
13. Contestabile, G.; Presi, M.; Ciaramella, E. Multiple wavelength conversion for WDM multicasting is a SOA. *IEEE Photonics Technol. Lett.* **2004**, *16*, 1775–1777. [CrossRef]
14. Contestabile, G.; Calabretta, N.; Presi, M.; Ciaramella, E. Single and multicast wavelength conversion at 40 Gb/s by means of fast nonlinear polarization switching in a SOA. *IEEE Photonics Technol. Lett.* **2005**, *17*, 2652–2654. [CrossRef]
15. Zhang, J.; Wu, J.; Xu, K.; Lin, J. 40 Gbit/s All-Optical Wavelength Conversion with Enhanced Performance Based on Nonlinear Polarization Rotation (NPR) in SOA with AWG Filtering. In Proceedings of the 2005 IEEE LEOS Annual Meeting Conference, Sydney, Australia, 22–28 October 2005; pp. 63–64.

16. Leuthold, J.; Marom, D.M.; Cabot, S.; Jaques, J.J.; Ryf, R.; Giles, C.R. All-optical wavelength conversion using a pulse reformatting optical filter. *J. Lightw. Technol.* **2004**, *22*, 186–192. [CrossRef]
17. Liu, Y.; Tangdiongga, E.; Li, Z.; De Waardt, H.; Koonen, A.M.; Khoe, G.D.; Dorren, H.J.; Shu, X.; Bennion, I. Error-free 320 Fb/s SOA-Based Wavelength Conversion Using Optical Filtering. In Proceedings of the 2006 Optical Fiber Communication Conference and the National Fiber Optic Engineers Conference, Anaheim, CA, USA, 5–10 March 2006.
18. Patrick, D.; Manning, R. 20 Gbit/s wavelength conversion using semiconductor nonlinearity. *Electron. Lett.* **1994**, *30*, 252–253. [CrossRef]
19. Joergensen, C.; Danielsen, S.; Vaa, M.; Mikkelsen, B.; Stubkjaer, K.; Doussiere, P.; Pommerau, F.; Goldstein, L.; Goix, M. 40 Gbit/s all-optical wavelength conversion by semiconductor optical amplifiers. *Electron. Lett.* **1996**, *32*, 367. [CrossRef]
20. Miyazaki, Y.; Takagi, K.; Matsumoto, K.; Miyahara, T.; Nishikawa, S.; Hatta, T.; Aoyagi, T.; Motoshima, K. Polarization-Insensitive 40G-NRZ Wavelength Conversion Using SOA-MZI. In Proceedings of the Frontiers in Optics 2007/Laser Science XXIII/Organic Materials and Devices for Displays and Energy Conversion, San Jose, CA, USA, Septemble 2007. paper FEMI1.
21. Spyropoulou, M.; Pleros, N.; Vyrsokinos, K.; Apostolopoulos, D.; Bougioukos, M.; Petrantonakis, D.; Miliou, A.; Avramopoulos, H. 40 Gb/s NRZ Wavelength Conversion Using a Differentially-Biased SOA-MZI: Theory and Experiment. *J. Lightw. Technol.* **2011**, *29*, 1489–1499. [CrossRef]
22. Apostolopoulos, D.; Klonidis, D.; Zakynthinos, P.; Vyrsokinos, K.; Pleros, N.; Tomkos, I.; Avramopoulos, H. Cascadability Performance Evaluation of a New NRZ SOA-MZI Wavelength Converter. *IEEE Photon Technol. Lett.* **2009**, *21*, 1341–1343. [CrossRef]
23. Wessing, H.; Sorensen, B.; Lavigne, B.; Balmefrezol, E.; Leclerc, O. Combining Control Electronics with SOA to Equalize Packet-to-Packet Power Variations for Optical 3R Regeneration in Optical Networks at 10 Gb/s. In Proceedings of the Optical Fiber Communication Conference, OFC 2004, Los Angeles, CA, USA, 23–27 February 2004.
24. Sato, R.; Ito, T.; Shibata, Y.; Ohki, A.; Akatsu, Y. 40-gb/s burst-mode optical 2R regenerator. *IEEE Photonics Technol. Lett.* **2005**, *17*, 2194–2196. [CrossRef]
25. Leuthold, J.; Kauer, M. Power equalisation and signal regeneration with delay interferometer all-optical wavelength converters. *Electron. Lett.* **2002**, *38*, 1567. [CrossRef]
26. Pato, S.V.; Meleiro, R.; Fonseca, D.; Andre, P.; Monteiro, P.; Silva, H. All-Optical Burst-Mode Power Equalizer Based on Cascaded SOAs for 10-Gb/s EPONs. *IEEE Photonics Technol. Lett.* **2008**, *20*, 2078–2080. [CrossRef]
27. Liu, Y.; Chow, C.; Kwok, C.; Tsang, H.K.; Lin, C. Optical Burst and Transient Equalizer for 10Gb/s Amplified WDM-PON. In Proceedings of the OFC/NFOEC 2007—2007 Conference on Optical Fiber Communication and the National Fiber Optic Engineers Conference, Anaheim, CA, USA, 25–29 March 2007; pp. 1–3.
28. Mendinueta, J.M.; Cao, B.; Thomsen, B.C.; Mitchell, J.E. Performance of an optical equalizer in a 10 G wavelength converting optical access network. *Opt. Express* **2011**, *19*, B229–B234. [CrossRef] [PubMed]
29. Cao, B.; Mendinueta, J.M.D.; Thomsen, B.C.; Mitchell, J.E. Demonstration of a 10 Gbit/s Long Reach Wavelength Converting Optical Access Network. *J. Lightw. Technol.* **2013**, *31*, 328–333. [CrossRef]
30. International Telecommunications Union (ITU). *Recommendation ITU-T G.9807.2-Optical Line Systems for local and Access Networks*; ITU: Gevena, Switerland, 2017 August.
31. Mourgias-Alexandris, G.; Tsakyridis, A.; Passalis, N.; Tefas, A.; Vyrsokinos, K.; Pleros, N. An all-optical neuron with sigmoid activation function. *Opt. Express* **2019**, *27*, 9620–9630. [CrossRef] [PubMed]
32. Tsakyridis, A.; Moralis-Pegios, M.; Vagionas, C.; Vyrsokinos, K.; Pleros, N. Optical Burst-Mode Wavelength Conversion for 10Gb/s NRZ Optical Signals. In Proceedings of the SPIE Photonics West, Broadband Access Communication Technologies XIII, San Francisco, CA, USA, 1 February 2019.
33. Tsakyridis, A.; Alexoudi, T.; Miliou, A.; Pleros, N.; Vagionas, C. 10 Gb/s optical random access memory (RAM) cell. *Opt. Lett.* **2019**, *44*, 1821–1824. [CrossRef] [PubMed]
34. Agrawal, G. *Applications of Nonlinear Fiber Optics*; Elsevier Academic Press: Cambridge, MA, USA, 2008.