Simultaneous Multi-format Regeneration in a Large-Scale Photonic Integrated Circuit

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Abstract: Simultaneous dual-channel OOK and DPSK regeneration at 21.328Gb/s using a single monolithic quad-SOA array hybridly integrated on a silica-on-silicon PLC is demonstrated. The transmission performance of the regenerated signals was evaluated up to 950 km.

OCIS codes: (130.3120) Integrated optics devices; (070.4340) Nonlinear optical signal processing

1. Introduction

The latest advances and standardization efforts in ultra-high bandwidth optical WDM transmission technology, consider the use of advanced modulation formats for increasing channel capacity and transmission reach [1]. Furthermore, the co-existence of advanced phase encoding schemes with legacy intensity modulation formats in the network, imposes extra requirements to future transparent switching sub-systems which are called to support complex signal processing functionalities like wavelength conversion and regeneration on a per wavelength basis.

The most popular regeneration schemes so far rely on Semiconductor Optical Amplifier-based Mach-Zehnder Interferometric (SOA-MZI) structures due to the high operational speed of the SOAs and their integration potential. However, demonstrations have been so far limited on discrete devices and bulk fibers for their interconnection while only single format operation has been shown [2-3]. A multi-format wavelength converter relying on an optical hybrid frontend and two parallel SOA-MZIs was reported in [4], also using separate photonic elements. Recently, we presented single-channel OOK and DPSK regeneration using a single multi-format processing chip (MFPC) comprising more than 50 passive and active elements based on the hybrid integration of a monolithic quad SOA-array on a planar silica-on-silicon circuit [5].

In this paper, we demonstrate for the first time, dual-channel regeneration of OOK and DPSK formats simultaneously on the MFPC and we evaluate their transmission performance at 21.328 Gb/s using a 190 km recirculating loop setup. The obtained results showed improved transmission performance when compared to the initially degraded signal for distances up to 700 km and in excess of 1000 km for the cases of OOK and DPSK formats respectively, at the BER level of 10^{-9}. For BER values close to the FEC limit, transmission performance improvement was observed after regeneration for both OOK and DPSK signals and for all the measured distances.

2. Experimental setup

Fig. 1 shows the experimental setup used for the performance evaluation of the MFPC. The setup consists of: a) the OOK and DPSK data transmitters, each operating at 21.328 Gb/s, b) the MFPC used for all-optical regeneration, c) a 190km re-circulating loop transmission setup and d) the receiver. At the transmitter, two continuous wave (cw) signals at 1554.94 nm (λ1) and 1556.55 nm (λ2) were coupled and fed into an electro-absorption modulator (EAM) for pulse carving at 21.328 GHz with 6 ps pulse width. The two pulse streams were demultiplexed using a 200GHz channel spacing AWG and they were subsequently introduced into the two Mach-Zehnder modulators (MZMs) that were driven by 2^{31}-1 pseudo-random bit sequence (PRBS) for generating the DPSK and OOK signals at λ1 and λ2, respectively. The optical signal-to-noise-ratio (OSNR) of the data signals was degraded by the use of a variable optical attenuator (VOA) followed by an erbium-doped-fiber-amplifier (EDFA) for evaluating the regenerative capabilities of the MFPC under dual-channel operation. The DPSK signal at λ1 was introduced to the MFPC (point B) together with a copy of the clock signal at λ2 (point D) for realizing wavelength-conversion and regeneration using the upper 22 GHz DI and the upper SOA-MZI of the chip. In the same way, the OOK signal at λ2 entered the lower SOA-MZI (point C) together with a copy of the clock signal at λ1 (point A). The input signals are driven to the integrated chip elements independently by means of the complex network of waveguides, as shown in the MFPC layout in the top right of Fig. 1. The operation principle for OOK and DPSK regeneration is described in [5].

At the output of the MFPC, the data signals were multiplexed (point E) and fed into a 190 km optical transmission loop. The re-circulating loop consisted of two spans of 55 km and one span of 80 km SMF fibers each

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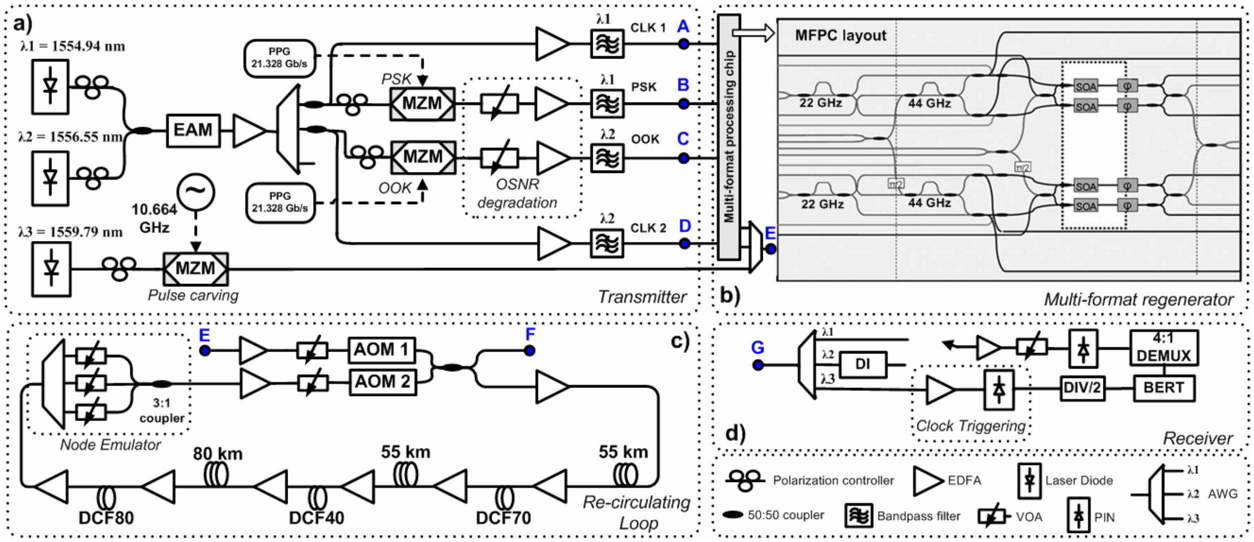

Fig. 1: Experimental setup.

followed by an EDFA and the appropriate dispersion compensating fiber (DCF) (1190 ps/nm, 680 ps/nm and 1360 ps/nm) to compensate for power losses and chromatic dispersion. The total input average power in the three SMF spans and DCFs were +8.4 dBm and +0.5 dBm, respectively. Moreover, an AWG demultiplexing stage followed by per-channel VOAs was used as a node emulator simulating the effect of filter concatenation in the transmission link. The output of the optical loop (point F) was then driven to the receiver (point G) for BER evaluation after 4:1 electrical demultiplexing. In the case of the DPSK signal a 22 GHz delay interferometer was used after the AWG for phase demodulation. In order for the BER measurements to be performed, a 1559.79 nm clock signal at 10.664 GHz was generated and transmitted through the re-circulating loop along with the regenerated data signals. This clock signal was filtered at the receiver and used as a trigger clock for all the diagnostic instruments that were used in the performance evaluation process. The power levels of the input degraded OOK and DPSK signals were 0 dBm and 10.6 dBm while the respective power levels of the input clock signals were -2.1 dBm and 3.2 dBm. The large DPSK input power is required to compensate for the losses introduced by the integrated DI before the upper SOA-MZI wavelength-converter [5]. Finally, all SOAs were operated at ~300 mA.

3. Results and discussion

The first study on the performance evaluation of the MFPC considered the identification of its operational limits as single chip multi-format regenerator for both the OOK and DPSK data signals at 21.328 Gb/s. Fig. 2a depicts the BER versus input OSNR for the degraded OOK signal with and without the use of the regenerator at the presence of the DPSK signal. In this case, regeneration is achieved for input OSNR values larger than 20 dB and smaller than 29 dB, showing a maximum benefit when the input OSNR is approximately 23 dB. Fig. 3a depicts the respective results for the DPSK signal at the presence of OOK signal. In this case, regeneration is achieved for DPSK signals bearing an input OSNR larger than 19 dB and smaller than 28 dB, showing a maximum improvement of an input OSNR value around 22 dB. The received power for both OOK and DPSK operational ranges was -17.8dBm.

Next, the WDM transmission performance of the regenerated signals from the MFPC was evaluated with the use of the 190 km recirculating loop set-up. For this purpose, degraded OOK and DPSK data signals of OSNR equal to 23.4 dB and 21.4 dB respectively, were used as inputs to the MFPC regenerator. Fig. 2b and Fig 3b illustrate the transmission performance over various distances of the OOK and DPSK signals when they are degraded in terms of OSNR (i.e. without the use of the regeneration stage), while Fig. 2c and Fig. 3c illustrate the transmission performance of the respective degraded signals after passing through the MFPC regenerator, for the same number of recirculations. In both cases, dual-channel transmission is considered. Comparing the quality of the regenerated and the originally degraded signals after transmission, it is evident that transmission performance improvement is achieved after regeneration for distances in excess of 570km for both formats (OOK and DPSK). Moreover, for the case of DPSK regenerated signal this improvement is evident even for distances close to 1000km. However, for the case of OOK regeneration a strong noise floor is evident at longer transmission distances (> 700km) that degrades the signal quality with respect to the case without regeneration. The regenerated OOK signal (Fig.2c) shows an improvement of 1dB in terms of received power at a BER of 10^{-9} in the back-to-back case (i.e. without transmission) and with respect to the degraded signal. This improvement reduces to 0.5dB after 570km of transmission and converts to an OSNR penalty for longer distances. On contrary, the regenerated DPSK signal (Fig.3c) shows an initial improvement of 2dB in terms of received power at the same BER level and drops to 1dB improvement in relation to the degraded non-regenerated signal at long transmission distances up to 760km. Moreover, for BER values close to the FEC limit (BER $4 \cdot 10^{-4}$), transmission performance improvement of about 0.6dB and 1dB is observed after regeneration for the cases of OOK and DPSK signals respectively and for all the measured distances. Finally it is noted that dual-channel operation using the MFPC was independent by the simultaneous processing of the two formats, yielding the same performance when either of the two input data signals (OOK or DPSK) in the MFPC was removed.

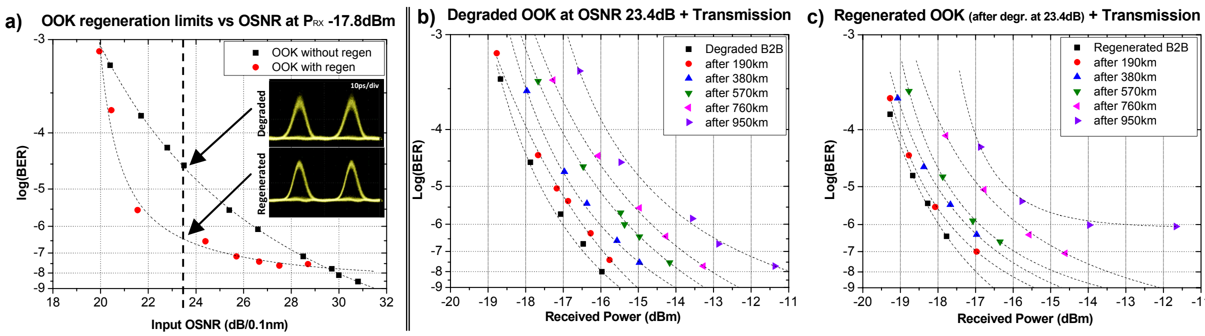

Fig. 2: a) MFPC operational limits vs. input OSNR at received power of -17.8 dBm for OOK signal and eye diagrams of degraded and regenerated OOK data for input OSNR 23.4 dB. Transmission performance of the b) degraded OOK signal for input OSNR 23.4 dB and c) regenerated OOK signal. The depicted results in a)-c) for the OOK channel consider that the DPSK channel is on. All OSNR values are measured at 0.1nm noise resolution.

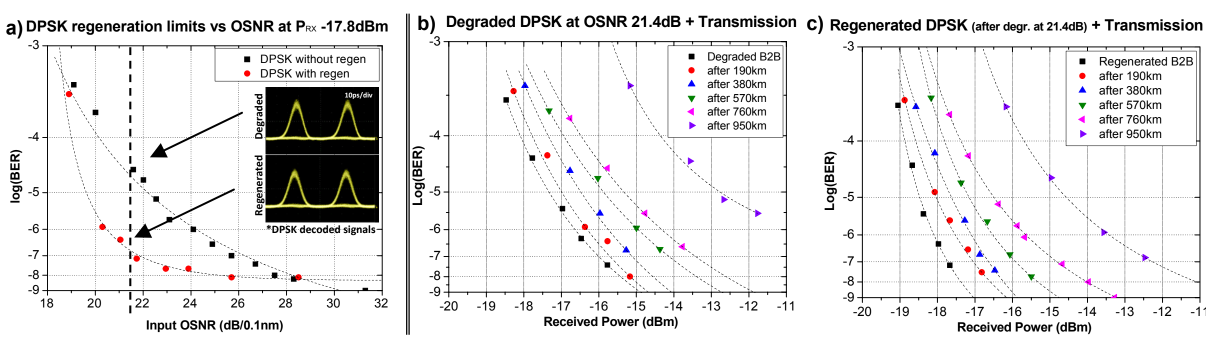

Fig. 3: a) MFPC operational limits vs. input OSNR at received power of -17.8 dBm for DPSK signal and eye diagrams of degraded and regenerated decoded DPSK stream for input OSNR 21.4 dB. Transmission performance of the b) degraded DPSK signal for input OSNR 21.4 dB and c) regenerated DPSK signal. The depicted results in a)-c) for the DPSK channel consider that the OOK channel is on. All OSNR values are measured at 0.1nm noise resolution.

4. Conclusions

We have experimentally demonstrated dual-channel all-optical regeneration of multi-format modulated signals in a single large-scale SOA-MZI based photonic integrated circuit at 21.328 Gb/s. The performance of the regenerated signals was evaluated after transmission over various distances showing improved transmission performance with respect to the initial degraded signal for distances up to 700km for the case of OOK format and up to 1000 km for the case of DPSK format.

Acknowledgments

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