All-Optical Phase-Regenerative Multicasting of 40 Gbit/s DPSK Signal in a Degenerate Phase Sensitive Amplifier

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Abstract *We demonstrate all-optical 1-to-5 differential phase-shift keyed (DPSK) wavelength multicasting at 40 Gbit/s using a degenerate four-wave mixing (FWM) based phase sensitive amplifier (PSA). Phase regenerative properties are reported with a sensitivity improvement of more that 10 dB.*

Introduction

All-optical wavelength conversion and multicasting, where a single data wavelength is simultaneously replicated onto multiple output wavelengths, are essential functions in applications where the information is broadcast to a large number of destinations and users (high-definition television, video-conferencing, etc.). Although at the optical level multicasting can be performed passively, e.g., by splitters that deliver the information to multiple users at a single wavelength[1], this passive approach is inherently lossy and does not offer regenerative properties. Thus, it is limited in scalability and functionality. A preferred approach is thus wavelength-division-multiplexed (WDM) multi-casting which allows for simultaneous wavelength conversion, offers network functionalities inherent to WDM networks (such as routing and monitoring), and which has the potential for signal regeneration[2].

Most of the existing multicasting approaches presented up to date are suited for amplitude modulated signals, such as on-off keyed (OOK) and the optical phase (which does not carry any information in OOK) is not necessarily preserved during the multicasting process[3,4]. Thus, many published schemes that perform simultaneous regeneration and multicasting are limited to the OOK modulation format[5,6]. However, DPSK modulation formats are recently emerging as preferred solutions over OOK, especially for long-haul transmission, thanks to the improved receiver sensitivity and nonlinear tolerance they offer. As DPSK may be widely employed in the near future, it is highly desirable to explore wavelength multicasting schemes for such signals[7].

Here, we demonstrate a scheme based on a FWM-based phase sensitive amplifier (PSA) in a dual pump configuration operating on an initial DPSK signal at 40 Gbit/s and that is capable of simultaneously multicasting and regenerating the output signals when a significant amount of phase noise is present at the input to the system. Five 40 Gbit/s multicast channels are obtained and properly regenerated at 400 GHz spacing.

Principle of Operation and Set-up

The operating principle of the proposed DPSK wavelength multicasting and phase regenerator scheme is shown in Fig.1. It is based on a dual pump degenerate FWM process in a fibre-based PSA. As sketched in Fig.1, two processes occur: (i) the PSA regenerates the phase of the data signal through properly optimizing the energy exchange with the two phase-locked pumps[8,9]; (ii) new (secondary) pumps as well as new copies of the data signals are generated via phase insensitive amplifier (PIA) interactions[3].

The corresponding experimental set-up is shown in Fig. 2. The data signal is a 40 Gbit/s non-return-to-zero (NRZ)-DPSK, 2^{31}-1 pseudo-random bit sequence (PRBS). In order to study the robustness of the multicasting scheme to phase noise, the signal phase was modulated in

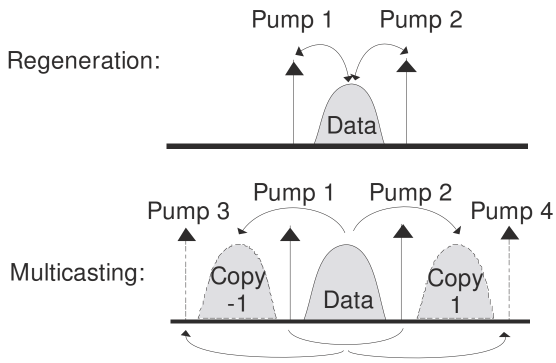

Fig. 1: Operation principle of the multicasting and regeneration scheme.

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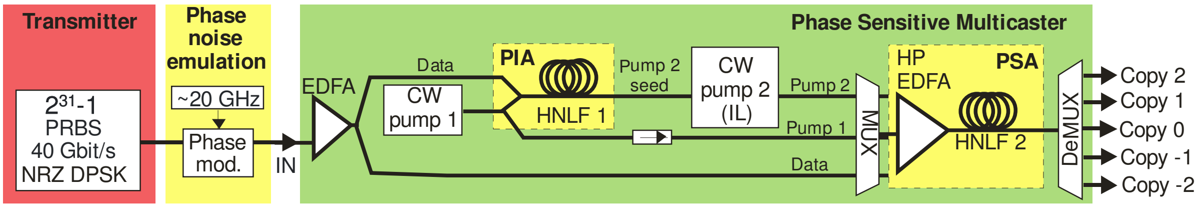


Fig. 2: Experimental set-up of the 40 Gbit/s multicasting and phase regenerator scheme.

a deterministic fashion using an additional phase modulator, driven at a single-frequency close to 20 GHz. The core of the multicasting and regenerating scheme consists of three main blocks: (i) a phase insensitive amplifier (PIA) to generate an idler that is automatically phase-locked to the data signal and a locally generated pump (Pump 1); (ii) a continuous wave (CW) laser that is injection-locked[10] by the PIA generated idler to produce the second phase locked pump (Pump 2); and (iii) a dual pump degenerate FWM-based PSA that performs the multicasting as well as the regeneration[8,9].

As the injection locking is a much slower process than FWM, any high frequency fluctuations (e.g., bit-to-bit phase variations) present on the original data signal are not transferred onto the output of the injection locked laser, allowing phase regeneration in the subsequent PSA[8,9].

More details of the customised components used are as follows. The highly non-linear fibre (HNLF) used in the PIA was 500 m long with a dispersion of 0.09 ps/nm/km, nonlinear coefficient of 11.5 $W^{-1}km^{-1}$, and an attenuation of 0.8 dB/km. The HNLF used in the PSA was an alumino-silicate fibre with an applied strain gradient to increase the Stimulated Brillouin Scattering (SBS) threshold to > 28 dBm thereby avoiding the need for any active SBS suppression scheme. This HNLF was 177 m long with a dispersion of 0.13 ps/nm/km, nonlinear coefficient of 7.1 $W^{-1}km^{-1}$, and an attenuation of 15 dB/km. The very low dispersion and dispersion slope values facilitate the generation of multiple copies of the signal and pumps. The injection locked laser was a discrete-mode semiconductor laser from Eblana Inc., Ireland with a natural linewidth of 300 kHz[11].The laser used to generate the input DPSK signal had a natural linewidth below 10 kHz.

As may be appreciated from Fig. 2, the data and two phase locked pumps propagate in different paths before being combined together in the PSA. Thus, their relative phase difference is subject to phase noise pick up due to acoustic and thermal effects. This relatively slow drift (kHz-range) is compensated for by an electrical phase-locked loop that controls a piezoelectric-based fibre stretcher in the pump path (to simplify the schematic, this feedback system is not shown in Fig.2).

Fig.3 shows the PSA output spectrum for the optimal total input power of 34 dBm. We see that it consists of many pumps (generated from the input Pumps 1 and 2 via FWM) and many copies of the signal. Here, we consider five copies only, which have similar power levels: Copy 0 (at the original wavelength), Copies ±1 with about the same powers as Copy 0, and Copies ±2 with powers about 2 dB below that of Copy 0.

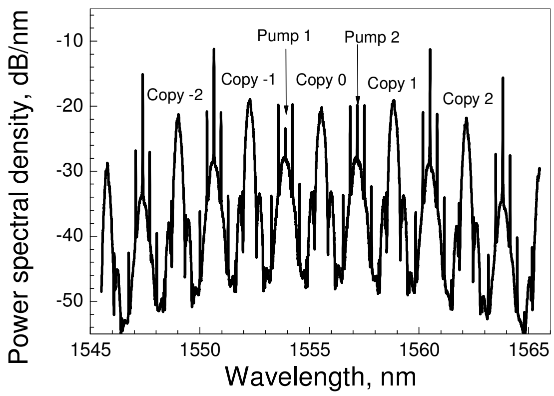


Fig. 3: Output PSA spectral characteristics. Signal at the input signal wavelength (Copy 0) and four copies with power difference of less than 2 dB are considered.

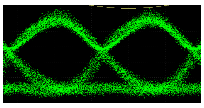
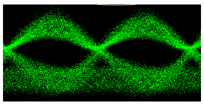
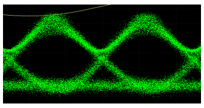
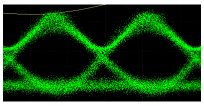
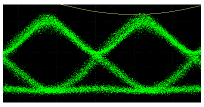
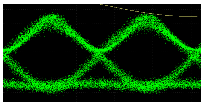
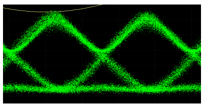
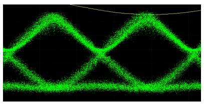
Results

For the sake of simplicity and due to the lack of a suitable filter at the corresponding wavelengths, we characterized only Copies 0, -1, and -2, respectively. However, results similar to that for Copy -1 and -2 are also expected for Copies 1 and 2, respectively.. To evaluate the performance of the system, we measured the bit error ratios (BERs) and the eye diagrams.

First, we assessed the performance of our multicasting scheme using a clean (no noise) input data signal. The eye diagrams are shown in Table 1 (left part) and the BER curves in Fig. 4a. As also observed previously in Ref. 9, Copy 0 has a slightly negative power penalty as compared to the back-to-back (about 1 dB). Analysis of the corresponding eye diagrams in

Table 1 suggest that the shape of the demodulated pulse is different at the PSA input/output, which may explain this slight improvement in the receiver power sensitivity. BER measurements of the other copies show error free operation with power penalties of less than 1 dB as compared to the back-to-back (and less than 3 dB as compared to the Copy 0).

Table 1: Eye diagrams of Copy 0,-1 and -2 for noise off (left) and on (right), respectively.

Noise	**OFF**	**ON**
Input		
Copy 0		
Copy -1		
Copy -2		

Subsequently, we introduced phase distortion on the data at the input of the multicasting scheme, severely degrading the corresponding BER curve and eye diagram at the input of the multicasting scheme (Fig. 4b and Table 1) – a power penalty of 13 dB was obtained at the BER~10^{-7} level (Fig. 4a and 4b). The BER curves for all the characterized copies (Fig. 4b) have better BER sensitivity as compared to the input signal clearly demonstrating the regenerative property of the presented scheme. This regenerative property is also visible from the corresponding eye diagrams shown in the second column of the Tab. 1.

Conclusions

We have proposed and experimentally demonstrated phase regenerative multicasting of 40 Gbit/s DPSK signal using cascaded PIA-PSA processes in a dual pump configuration. The use of a high SBS-threshold HNLF with low dispersion and dispersion slope has enabled the generation of several copies of the input signal (as well as of the pumps). We note that the use of smaller wavelength spacing between the signal and the pumps should allow the generation of a larger number of high fidelity signal copies.

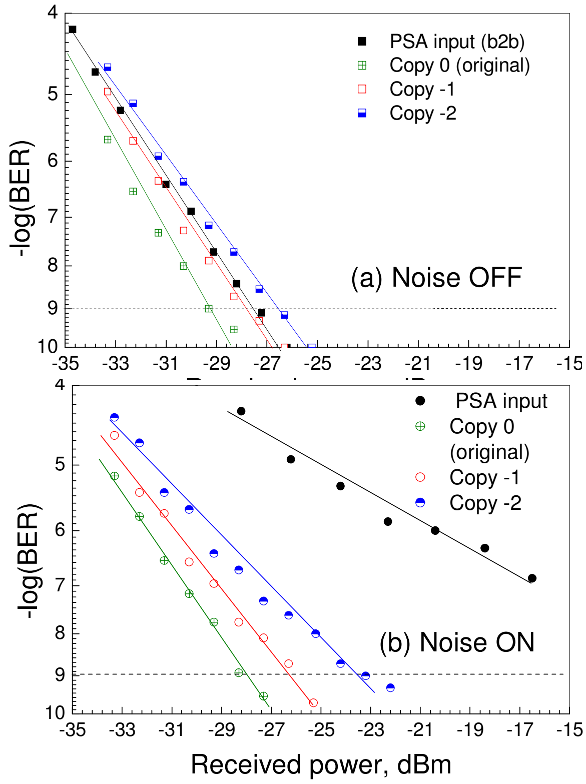


Fig. 4: BER curves of Copy 0,-1 and -2 for noise off (a) and on (b), respectively.

Acknowledgments

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References

1. B.M.N.K. Singhal, Proc. OFC'01, TuG8-1-TuG8-3 (2001).
2. K.K. Chow and C. Shu, Opt. Express **12**, 3050 (2004).
3. C.-S. Bres et al., J. Lightw. Technol. **27**(3), 356-363, (2009).
4. W. Wang et al., J. Lightw. Technol. **23**(1), 211-218, (2005).
5. M. Matsuura et al., IEEE Phot. Technol. Lett., **18** (24), 2659-2661, (2006).
6. K. K. Chow et al., J. Selec. Topic Quantum Electronics. **12**(4), 838-842, (2006).
7. M. P. Fok et al., J. Lightw. Technol. **27**(15), 2953-2957, (2009).
8. F. Parmigiani et al. Proc. OFC'10, PDPC3 (2010).
9. K. Croussore et al., IEEE Phot. Technol. Lett., **19** (11), 864-866, (2007).
10. R. Weerasuriya, et al., Proc. OFC'10, OWT6 (2010).
11. R. Phelan et al, Electron. Lett. **45**, 43 (2009).