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Published in:
European Conference on Optical Communications, 2006. ECOC 2006.

Link to article, DOI:
10.1109/ECOC.2006.4801299

Publication date:
2006

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Galili, M., Oxenløwe, L. K., Mulvad, H. C. H., Clausen, A., & Jeppesen, P. (2006). Raman-assisted XPM wavelength conversion at 320 Gb/s. In *European Conference on Optical Communications, 2006. ECOC 2006.* (Vol. 3, pp. 333-334). IEEE. https://doi.org/10.1109/ECOC.2006.4801299

Raman-Assisted XPM Wavelength Conversion at 320 Gb/s

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Abstract *We report on the first demonstration of cross-phase modulation-based wavelength conversion at 320 Gb/s assisted by Raman gain and a notch filtering scheme. Error free operation of the wavelength converter is demonstrated.*

Introduction

The single channel bit rate has continuously increased in deployed optical transmission systems and networks, reaching 10 – 40 Gb/s in today's commercially available systems. With the appearance of new technologies for optical transmitters and receivers operating near 100 Gb/s [1], ultra fast signal processing becomes increasingly relevant. At such high bit rates optical signal processing must be considered as a useful supplement to electronic processing. Several signal processing tasks must be addressed in high speed communication systems and networks, including the indispensable wavelength conversion of data signals. Several approaches based on non-linear effects in optical fibres have been investigated and a few wavelength conversion set-ups have been demonstrated up to 160 Gb/s, including [2] and [3]. Optical wavelength conversion at 320 Gb/s based on semiconductor devices has also been demonstrated very recently [4].

In this paper, a wavelength converter based on notch-filtered cross-phase modulation (XPM) assisted by Raman gain is demonstrated at 320 Gb/s for the first time. Error free conversion is performed with a penalty in receiver sensitivity of only 3.5 dB compared to a back-to-back measurement on the original 320 Gb/s data signal.

Experimental procedure

The experimental set-up is shown in Figure 1.

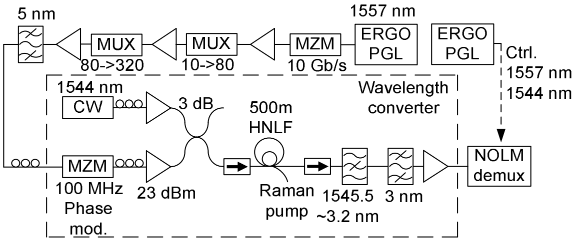

Figure 1. XPM wavelength conversion set-up.

The optical signal is generated by an erbium glass oscillator pulse generating laser (ERGO-PGL) at 10 GHz and 1557 nm having a pulse width of 1.7 ps. A data sequence (2^7-1 PRBS) is encoded on the pulse train using a Mach-Zender modulator (MZM). The 10 Gb/s data pulse train is multiplexed to 320 Gb/s in a passive fibre delay PRBS maintaining multiplexer (MUX). Phase modulation is performed by a symmetrically driven MZM at 100 MHz to suppress Stimulated Brillouin Scattering (SBS) from the narrow spectral components of the multiplexed high-speed signal [5]. The signal is amplified by an EDFA to ~23 dBm and combined with a ~17 dBm CW at 1544 nm (with ~ 500 MHz linewidth) before injection into 500 m of highly non-linear fibre (HNLF). The HNLF has a non-linear coefficient of γ ~ 10 $W^{-1}km^{-1}$, zero dispersion at 1550.4 nm and a flat dispersion profile (slope: 0.018 ps/nm^2km). In the HNLF, a counter-propagating 1400 mW Raman pump enhances the wavelength conversion by amplifying the spectral sidebands on the CW, generated through XPM by the high powered data signal. As sidebands on either side of the carrier are out of phase, it is imperative to select only one sideband to form the wavelength converted signal [6]. This is done using a Fibre Bragg Grating (FBG) as a notch filter to suppress the CW and one XPM sideband, and a band pass filter to suppress the original data signal. The FBG has its centre wavelength at 1545.5 nm and a bandwidth of 3.2 nm. The wavelength converted signal is demultiplexed to the 10 Gb/s base rate in a non-linear optical loop mirror (NOLM) using 1.5 ps control pulses from the second 10 GHz pulse source. This is tuned to either 1557 nm or 1544 nm for demultiplexing the converted signal or the back-to-back signal, respectively. Bit error rate (BER) measurements are performed to evaluate system performance.

Properties of wavelength conversion

Figure 2 shows the spectra of the original data signal and the filtered XPM wavelength converted data signal. The 320 GHz spectral components from the pulsed nature of the signal are not clearly visible in the original data, as the multiplexed signal is not phase stabilised. The 320 GHz peaks are clearly

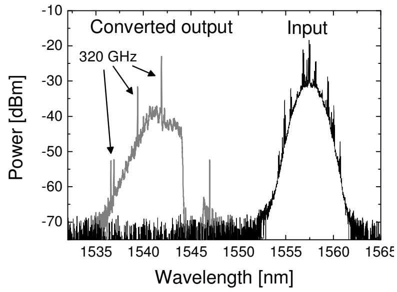

Figure 2. Input spectrum and XPM wavelength converted spectrum after filtering.

visible in the converted signal as this signal, though, has adopted the phase of the CW probe so no phase mismatch occurs between pulses [7].

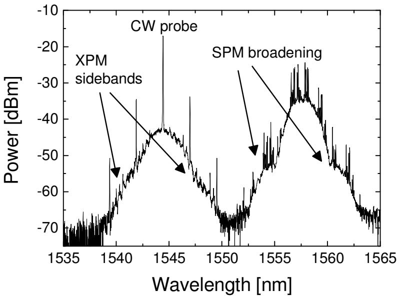

Figure 3. Output from HNLF before filtering.

Figure 3 shows the spectrum at the output of the HNLF before any filtering is performed. The XPM induced sidebands on the CW are clearly seen. The spectrum of the input signal has been broadened due to Self Phase Modulation (SPM). This limits the amount of optical power that can be launched into the HNLF, as spectral overlap between the SPM broadening and the XPM sideband to be filtered out will contribute significant noise to the converted signal.

Figure 4 (left) shows cross correlations of the 320 Gb/s input data signal (lower) and the wavelength converted signal (upper). The cross correlations were performed using sampling pulses of 1.7 ps FWHM. This limits the temporal resolution and thus the visible extinction between pulses at 320 Gb/s. However the pulse peaks are visible, both before and after conversion allowing for verification of the timing and channel equalisation in the signal. The cross correlation of the converted signal indicates a little more fluctuation in pulse position. This is expected to be due to slight pulse broadening from the filtering scheme, causing increased interference between neighbouring channels. The eye diagram in figure 4 (right) shows the multiplexed 320 Gb/s data signal on a 70 GHz oscilloscope. Though it is not possible in this eye to resolve the individual pulses, it does reveal that the channel power is reasonably equal.

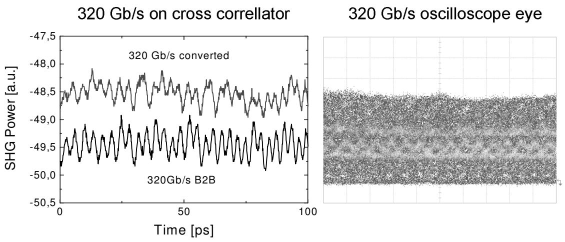

Figure 4. Left: Cross correlation of 320 Gb/s signal before and after wavelength conversion. Right: Eye diagram for the 320 Gb/s input signal.

Results

The BER results in figure 5 show an excellent performance of the 320 Gb/s wavelength conversion: it is clearly error free with no sign of an error floor. The BER measurements are for a typical demultiplexed channel after wavelength conversion at 320 Gb/s, and compared to a demultiplexed 320 Gb/s back-to-back measurement. The sensitivity penalty is only around 3.5 dB compared to the back-to-back, which has a sensitivity of -35.5 dBm. Receiver sensitivities at BER 10^{-9} are measured for six consecutive channels in the converted signal. In all cases, the eyes are clear and open (figure 5 right / bottom) with reasonable sensitivities, which varies about 3 dB.

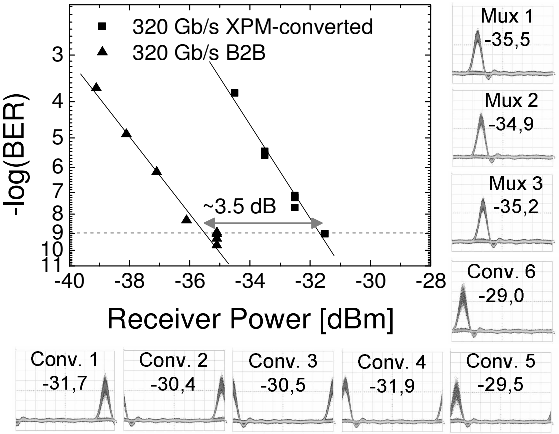

Figure 5. BER measurements for the converted and back-to-back 320 Gb/s signals with corresponding eye diagrams.

For the back-to-back measurement the three channels shown in figure 5 indicate a more constant receiver sensitivity, being separated by only 0.6 dB. This, together with the cross correlation and the 320 Gb/s eye, shows that the multiplexed 320 Gb/s data signal is of a good quality.

Conclusion

We have demonstrated the first Raman-assisted XPM wavelength conversion at the high bit rate of 320 Gb/s. The 320 Gb/s wavelength conversion performed very well with a low penalty of only 3.5 dB.

Acknowledgements

This work is partly funded within the Danish Research Strategy framework of NABIIT under project UltraNet. OFS Fitel Denmark I/S is acknowledged for providing the HNLF.

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