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Low-penalty Raman-Assisted XPM Wavelength Conversion at 320 Gb/s

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Abstract: We report on an experimental demonstration and optimization of cross-phase modulation-based wavelength conversion at 320 Gb/s assisted by Raman gain. Error free operation is demonstrated with low penalty.

OCIS codes: (060.4510) Optical Communications (060.2360); Fiber optics links and subsystems

1. Introduction

The single channel bit rate has continuously increased in optical transmission systems and networks, reaching 10 – 40 Gb/s in deployed systems. To promote the increase in single channel bit rates, schemes for appropriate signal processing need to be developed. At very high bit rates all-optical signal processing has great potential for low penalty operation combined with increased transparency in the optical network compared with current technologies. Wavelength conversion of data signals is one of the key signal processing tasks to be addressed in any optical network. Only two schemes have been demonstrated for wavelength conversion of 320 Gbit/s data. One scheme is based on conversion in a semiconductor optical amplifier (SOA) [1] and the other scheme applies cross-phase modulation (XPM) in a highly nonlinear fibre (HNLF) [2].

In this paper, wavelength conversion based on Raman assisted XPM is investigated at 320 Gb/s. Error free conversion is performed and optimisation of the fibre set-up enables near penalty-free (0.2 dB)conversion compared to the original 320 Gb/s data signal. This is the lowest sensitivity penalty ever reported for a 320 Gb/s wavelength converter.

2. Experimental procedure

The experimental set-up is shown in Fig. 1. The erbium glass oscillator pulse generating laser (ERGO-PGL) supplies a 10 GHz optical pulse train at 1557 nm having a pulse width of 1.3 ps. A Mach-Zender modulator (MZM) is used to encode a data sequence (2^7-1 PRBS) on the pulse train. The 10 Gb/s modulated pulse train is multiplexed to 320 Gb/s in a passive fibre delay PRBS maintaining multiplexer (MUX) and amplified in a high power EDFA. A CW probe signal at 1544 nm is phase modulated at 100 MHz to reduce stimulated Brillouin scattering (SBS), increasing the linewidth above 500 MHz, and amplified before it is combined with the signal and injected into a highly non-linear fibre (HNLF). Two different lengths of HNLF were investigated, 500 m and 200 m. For 500 m HNLF the signal was amplified to ~ 23 dBm and the CW to ~ 17 dBm.

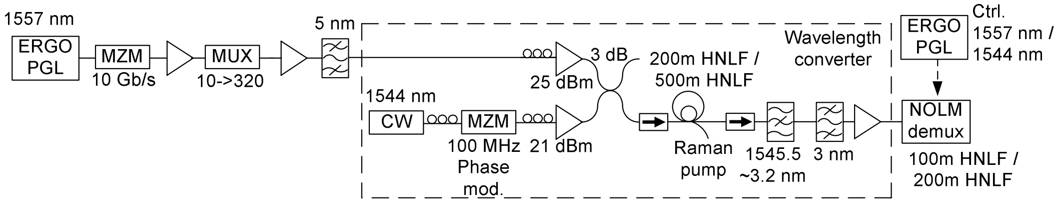

Figure 1. Set-up for XPM wavelength conversion.

For 200 m of HNLF the respective power levels were ~25 dBm and ~21 dBm. The two HNLFs have a non-linear coefficient of $\gamma \sim 10\ W^{-1}km^{-1}$, zero dispersion wavelength at 1550.4 nm and a flat dispersion profile (slope: 0.018 ps/nm^2km). In the HNLF, a counter-propagating 800 mW Raman pump enhances the wavelength conversion by amplifying the spectral sidebands on the CW, generated through XPM by the high powered data pulses. The sidebands on either side of the carrier are out of phase, and it is imperative to select only one sideband to form the wavelength converted signal [3]. 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 1.3 ps control pulses from the second 10 GHz pulse source and either 100 m or 200 m HNLF.

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3. Properties and results of wavelength conversion

Fig. 2 (center) illustrates the wavelength conversion process showing the spectrum at the output of the HNLF before any filtering is performed. The XPM induced sidebands on the CW are clearly seen. 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 visible in the XPM generated CW sidebands, though. The sidebands have adopted the phase of the CW probe so no phase mismatch occurs between pulses [4]. The spectrum of the input signal is seen to have 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 induce significant noise in the converted signal

In Fig. 2 (left) the spectra of the original data signal and the filtered XPM wavelength converted data signal are shown. The steep right edge of the converted spectrum is caused by the sharp filtering of the FBG.

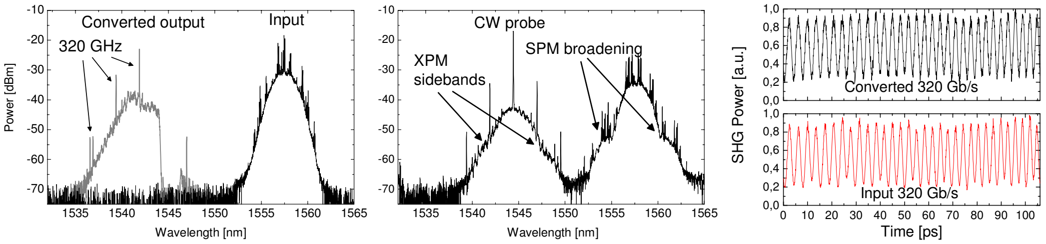

Figure 2. Left - Input spectrum and XPM wavelength converted spectrum after filtering. Center - Output from HNLF before filtering. Right - Cross correlations of 320Gb/s input (lower trace) and converted signal (upper trace)

Fig. 2 (right) shows cross-correlations of the 320 Gb/s input data signal and the wavelength converted signal. The cross correlations were performed using sampling pulses of ~0.8 ps FWHM. This gives a high temporal resolution and thus a good visible separation between pulses at 320 Gb/s. The peak pulse levels for the 32 channels are seen to be very even, both before and after conversion, indicating similar performance of all the multiplexed channels. The eye diagram in Fig. 3 also shows good equalisation of the channels.

Fig. 3 shows the BER performance of the wavelength converter using 200 m HNLF and 500 m HNLF. As previously reported the conversion using 500 m HNLF imposes a penalty in receiver sensitivity of ~ 3.5 dB when using 200 m HNLF in the demultiplexer [2]. Reducing the HNLF length in the demultiplexer to 100 m is seen to cause a mere ~0.3 dB penalty compared to the case for 200 m HNLF. Reducing the fibre length in the wavelength converter from 500 m to 200 m, however, reduces the penalty in receiver sensitivity dramatically. The sensitivity is improved by 3.3 dB giving an almost penalty-free wavelength conversion with a penalty of only 0.2 dB.

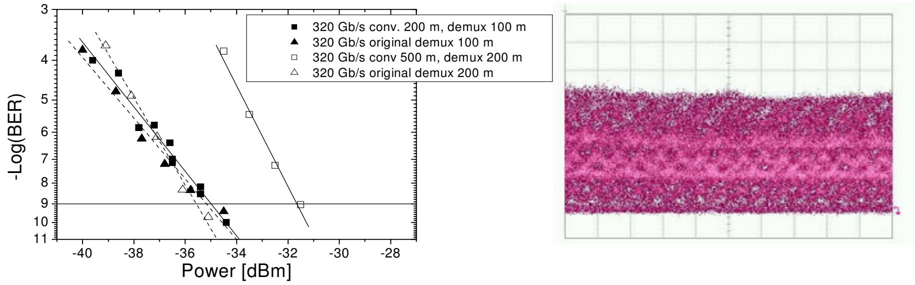

Figure 3.Left - BER measurements for the converted and original 320 Gb/s signals. Right - eye diagram for 320 Gb/s input signal.

4. Conclusion

We have demonstrated wavelength conversion of 320 Gb/s data signal using Raman-assisted XPM in 200 m HNLF with only 0.2 dB of power penalty. .

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