Fibre-Based Parametric Wavelength Conversion of 86 Gb/s RZ-DQPSK Signals With 15 dB Gain Using a Dual-Pump Configuration

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Abstract *We show error-free wavelength conversion of 86 Gb/s RZ-DQPSK signals with 15 dB gain in a highly non-linear fibre using a dual-pump configuration with precisely counterphased pump-phase modulations.*

Introduction

Wavelength converters are key components for flexible all-optical network approaches using optical burst and packet switching.[1] All-optical fibre-based converters relying on four-wave mixing (FWM) with continuous-wave (CW) pump signals are promising candidates to provide bitrate and modulation format transparency needed to outperform optoelectronic solutions. However, stimulated Brillouin scattering (SBS) limits the conversion efficiency of fibre-based devices to below 0 dB unless the pumps are phase-modulated to increase the SBS threshold. In a single-pump configuration, the phase modulation itself introduces phase distortions at the converted signal that are critical for phase-modulated signals like differential binary phase-shift keying or differential quadrature phase-shift keying (DQPSK).[2] In a dual-pump configuration, the phase distortions can be suppressed by counterphasing of the pumps.[3] Since small deviations from the ideal counterphasing can lead to similar optical signal-to-noise (OSNR) penalties as in the single-pump case, a careful alignment of the pump modulation is necessary.[4] Note that the phase distortions are deterministic. Therefore, they can be removed by post-processing after coherent detection at the expense of the more complex receiver architecture compared to direct detection.

We show here wavelength conversion of 86 Gb/s RZ-DQPSK signals with 15 dB gain using a dual-pump configuration in highly non-linear fibre. The impact of the pump-phase modulation on the idler bit-error ratio (BER) is completely suppressed due to the precisely counterphased pump-phase modulations.

Experimental Set-up

A schematic depiction of the set-up is shown in Fig. 1. It included a 86 Gb/s RZ-DQPSK transmitter, the all-optical wavelength converter (AOWC) and a 86 Gb/s DQPSK receiver. The transmitter consisted of a tunable CW external cavity laser (ECL) at 1560 nm followed by an EAM-based pulse carver (PC) producing 43 GHz pulses (26 % duty cycle). This pulse train was modulated by a two stage modulator setup to encode the DQPSK signal. A dual-drive Mach-Zehnder $LiNbO_3$ modulator (MZM) in the first stage was driven in push-pull mode by a 43 Gb/s PRBS signal from a bit pattern generator (BPG) to encode the π-phase shift. A subsequent $LiNbO_3$ phase modulator (PM) in the second stage was used to encode the additional π/2-phase shift and was driven by the same electrical signal with sufficient delay for data de-correlation.

In the AOWC we used two CW ECL as pumps at 1540 nm and 1568 nm. Both of them were phase modulated by $LiNbO_3$ phase modulators driven by an electrical signal consisting of three sinusoidal tones (69 MHz, 253 MHz, 805 MHz) to suppress SBS.[5] The electrical driving signals were generated by a two channel arbitrary waveform generator (AWG). An additional electrical amplifier for each channel was used to assure a phase shift of 1.4 rad for each sinusoidal tone in the optical domain. Owing to the AWG, the separate adjustment of the pump-phase modulation signals in terms of modulation index and phase for each pump-wavelength and modulation frequency could be easily realised.

The pumps were each amplified by high-power erbium doped fibre amplifiers (EDFA), then filtered

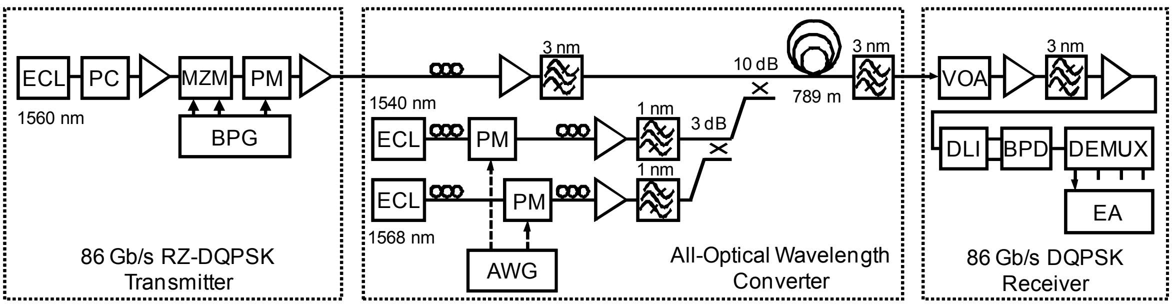

Fig. 1: Experimental set-up

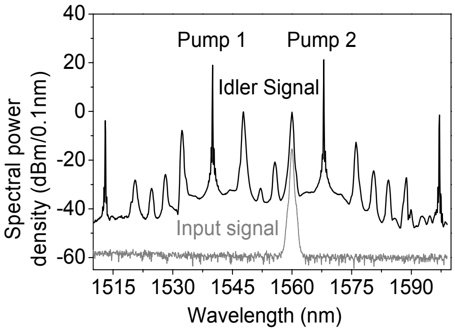

Fig. 2: Measured optical spectra after the HNLF and before the HNLF (with deactivated pumps)

by 1 nm optical bandpass filters (OBF) to remove out-of-band amplified spontaneous emission noise and coupled together using a 3 dB coupler. A 10 dB coupler was used to combine the pumps and the signal (weak arm) before launching them into a highly non-linear fibre (HNLF) with zero-dispersion wavelength of 1555 nm, a non-linear coefficient of 9 $(W\ km)^{-1}$ and a length of 789 m. The power at the input of the HNLF was 24.8 dBm in total for the pumps and -6.6 dBm for the signal. The polarization controllers used in the set-up were optimized for maximum FWM efficiency. A tunable OBF after the HNLF allowed to extract either the wavelenght converted signal (idler) at 1547.8 nm or the parametrically amplified signal at 1560 nm.

The extracted signal was then detected by an optically pre-amplified 86 Gb/s receiver. A variable optical attenuator (VOA) and a subsequent EDFA allowed to vary the OSNR. After an OBF (3 nm) and a second EDFA the signal was demodulated by a delay-line interferometer (DLI) with a free spectral range of 43 GHz and detected by a balanced photodetector. The selection of the in-phase and quadrature component was done by tuning the relative phase of the DLI to +/- π/4. The optical-to-electrical converted signal was then applied to an 1:4 electrical demultiplexer with subsequent error analyser (EA) for BER measurements. Since no precoder was used the EA was programmed with the expected bit pattern which limited the word length in the experiments to 2^7-1.

Experimental results

The optical spectrum after the HNLF is shown in Fig. 2, together with the input DQPSK signal directly before the HNLF with deactivated pumps. The conversion efficiency, defined as the ratio between the idler power at the fibre output and the signal power at the fibre input, was +15 dB. The pump and signal wavelengths were chosen for maximum conversion efficieny. The 3 dB conversion band-width was 6 nm, measured with unmodulated input signals. The OSNR of the parametrically amplified signal and the idler after the HNLF was 40.5 dB, measured with 0.1 nm resolution, which is 4.5 dB less than the signal OSNR at the input of the HNLF.

In Fig. 3, BER curves of one I/Q component for the back-to-back (b2b) measurement, for the wavelength converted 86 Gb/s DQPSK signal and for the parametrically amplified signal are shown. The b2b measurement was done at 1547.8 nm without the AOWC. The converted signal experienced no penalty compared to the parametrically amplified signal which indicated that the phase distortions due to the pump-phase modulation were negligible. The amount of residual phase modulation was determined by a heterodyne measurement shown in the inset of Fig. 3. It depicts the converted signal spectrum for an unmodulated input signal. A sideband suppression of more than 36 dB was achieved which corresponds to a residual phase modulation index of 0.03 rad.

Compared to the b2b measurement, the OSNR penalty for both the converted and the amplified signal at a BER of 10^{-9} was about 1.2 dB. This penalty was attributed to non-linear phase noise that is transferred to the signal and the idler due to cross-phase modulation by the high power pump signals.

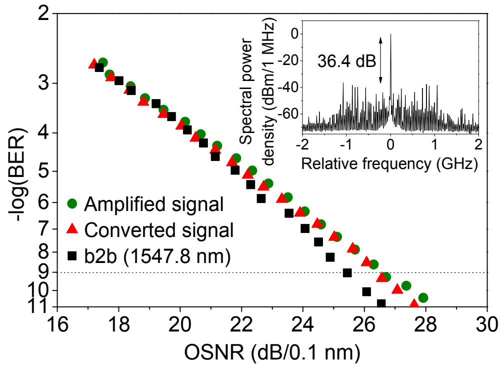

Fig. 3: BER measurements and idler heterodyne spectrum without data modulation as inset

Conclusions

We have demonstrated wavelength conversion of 86 Gb/s RZ-DQPSK signals with 15 dB gain in a HNLF using a dual-pump configuration. BER measurements showed that the careful adjustment of the modulation signals used for the counterphasing of the pumps allowed to completely suppress the impact of the pump-phase modulation on the converted signal. Heterodyne measurements of the idler proved a very low residual phase modulation that indicates that the conversion of higher-order phase modulated signals is also feasible.

This work was supported by the DFG (Schu 2058/2-1).

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