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1.28 Tb/s Wavelength Conversion for Polarisation Multiplexed RZ-DPSK Signals

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Abstract: All-optical wavelength conversion for single wavelength channel 1.28-Tb/s polarisation multiplexed RZ-DPSK signals was demonstrated using a 100-m polarisation-maintaining highly nonlinear fibre (PM-HNLF). Error free performance for the converted signal was achieved.

OCIS codes: (060.2330) Fiber optics communications; (230.7405) Wavelength conversion devices

1. Introduction

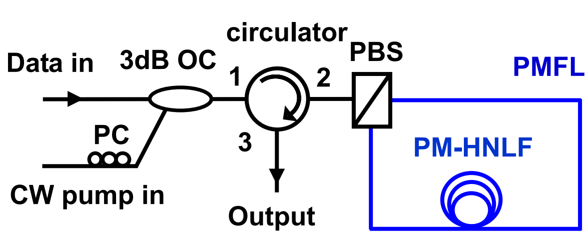
The concept of 1 Tb/s Ethernet envisioned to carry the future Internet traffic was born last year [1], spurred on by the continuous growth of the Internet. With the introduction of the 1 Tbit/s Ethernet, all the network techniques such as switching and routing on such high bit rates become quite challenging, and the electronic signal processing technique cannot carry the burden in the near future. On the other hand, all-optical signal processing techniques have shown the potential for high-speed signal processing on 640 Gb/s or beyond [2-3].

Wavelength conversion is a key network functionality in future wavelength division multiplexing (WDM) networks [4]. All-optical wavelength conversion (AOWC) has been obtained up to 640 Gb/s [5-6] and offers advantages over optical-electrical-optical (O/E/O) schemes such as potential low power consumption, simultaneous conversion of several WDM channels as well as transparency to data rate and modulation format [7].

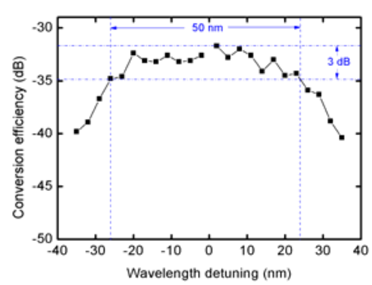
In this paper, polarisation insensitive AOWC based on the four-wave mixing (FWM) in a polarisation diversity loop configuration is demonstrated for single wavelength 1.28-Tb/s polarisation multiplexed (Pol-Mux) return-to-zero differential-phase-shift-keying (RZ-DPSK) signals. To the best of our knowledge, this is the highest operation speed of a wavelength converter reported to date.

2. Operation principle

A polarisation-maintaining fibre loop (PMFL) with bi-directional operation is used for the polarisation insensitive wavelength conversion, as shown in Fig. 1 (a). It provides a polarisation diversity scheme with an intrinsic equalization of the differential group delay in the two arms [3], which consists of a PM-HNLF, a polarisation beam splitter (PBS), a circulator and a coupler. A data signal and a continuous wave (CW) pump are coupled together and launched into the PBS through a 3-dB optical coupler (OC) and a circulator. In the PMFL, the data signal is split into two components that counter-propagate through the fibre loop and together with the wavelength converted signal are recombined by the PBS and sent out at port 3 of the circulator. The pump polarisation state is adjusted and launched into the PBS with 45˚ linear polarisation, acquiring equal intensity in both directions of the loop; therefore, the FWM conversion efficiencies (proportional to the square of the pump intensity) of both directions will be kept consistent. When the pump wavelength is set at 1545 nm, the FWM conversion efficiencies (defined as the ratio of the FWM product power and the power of the original data signal after the FWM, see Fig. 3 (a)) with CW characterization show a 50-nm conversion bandwidth (Fig. 1 (b)), covering the entire C-band.



(a)



(b)

Fig. 1. a) Polarisation-maintaining fibre loop (blue lines indicate the PMF), b) FWM conversion efficiency dependence on wavelength detuning

3. Experimental setup

The experimental setup for the AOWC of 1.28-Tb/s Pol-Mux RZ-DPSK signals is shown in Fig. 2. It mainly includes a 1.28-Tb/s Pol-Mux RZ-DPSK transmitter, an all-optical wavelength converter, a non-linear optical loop mirror

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(NOLM) demultiplexer and a 10 Gb/s DPSK receiver. The erbium glass oscillating pulse-generating laser (ERGO-PGL) produces 10 GHz pulses at 1542 nm with a 1.5-ps full-width at half-maximum (FWHM). The spectrum of the pulses is broadened in a 400-m dispersion-flattened highly nonlinear fibre DF-HNLF 1 (dispersion D = -0.45 ps/nm/km and dispersion slope S = 0.006 ps/nm^2/km at 1550 nm, nonlinear coefficient γ = 10.5 W^{-1}km^{-1}) due to self-phase modulation (SPM). The broadened spectrum is filtered at 1550 nm with a 5-nm optical bandpass filter (OBF) to generate the 10 GHz pulses for data signal and is also filtered at 1558 nm using another 5-nm OBF to obtain the 10 GHz control pulses for the NOLM demultiplexer. The 10 GHz pulses at 1550 nm are further compressed and regenerated in a 100-m DF-HNLF 2 (D = -1.07 ps/nm/km and S = 0.004 ps/nm^2/km at 1560 nm, γ = 10.5 W^{-1}km^{-1}) based on SPM [8], and subsequently filtered with a 14 nm BPF at 1556 nm. The compressed pulses are then encoded by DPSK with a 10 Gbit/s PRBS (2^7-1) signal in a Mach-Zehnder modulator. The modulated 10 Gbit/s DPSK signal was multiplexed in time to 640 Gbit/s using a passive fibre-delay multiplexer (MUX ×64). The FWHM of the data and control pulses are 560 fs and 920 fs, respectively. Finally, the 640 Gbit/s DPSK signals are polarisation-multiplexed (Pol. Mux) using a polarisation-maintaining 3-dB coupler and a polarisation beam combiner, resulting in 1.28 Tbit/s single wavelength data signals.

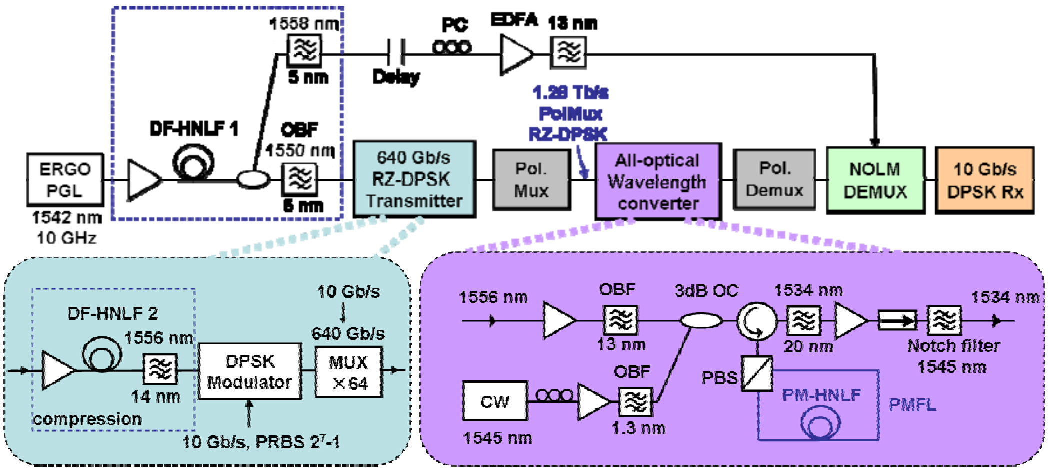


Fig. 2. Experimental setup for the all-optical wavelength conversion of 1.28-Tb/s Pol-Mux RZ-DPSK signals.

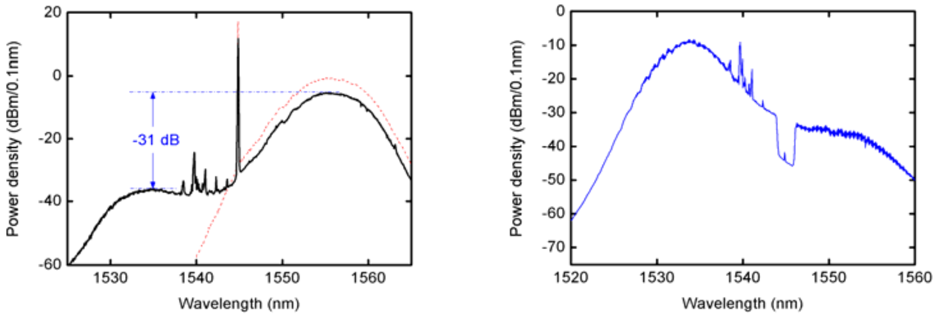
In the AOWC the generated 1.28-Tb/s Pol-Mux RZ-DPSK signals with random input polarisation were amplified by an EDFA, then filtered by a 13 nm OBF and finally launched into the PMFL through a 3 dB optical coupler (OC). The signal power was 22.9 dBm at the input of the circulator. The CW pump light at 1545 nm was amplified by an EDFA, filtered by a 1.3 nm OBF and launched into the PMFL through the second input of the 3 dB coupler. The pump power was 21.8 dBm at the input of circulator. The pump polarisation is adjusted for equal power in both directions of the loop; therefore, the pump power at the input of the PM-HNLF is only 18 dBm which is below the Stimulated Brillouin Scattering (SBS) threshold of 21 dBm. The wavelength converted signals together with the original signals and the CW pump were sent out at port 3 of the circulator and then launched into a filtering subsystem, which consisted of a 20-nm OBF, a fiber Bragg grating (FBG) based notch filter and an EDFA in between. The notch filter was used to block the pump light, and the OBF was used to separate the converted signal at 1534 nm from the original data signal.

The wavelength converted 1.28-Tb/s Pol-Mux RZ-DPSK signals were detected by the receiver which consists of a polarisation demultiplexer (Pol. Demux), a NOLM demutiplexer and a 10 Gb/s DPSK receiver. Firstly, the PBS separates each 640 Gb/s polarisation component to TM mode and TE mode. The NOLM is then used to OTDM demultiplex the single polarisation 640 Gb/s data (TM or TE) down to a 10 Gb/s data signal. The NOLM operation is based on cross-phase modulation (XPM) in a 15 m HNLF. Finally, the demultiplexed 10 Gb/s RZ-DPSK signal was demodulated and detected using a delay interferometer and a balanced photodetector in the 10 Gb/s DPSK receiver.

4. Experimental results

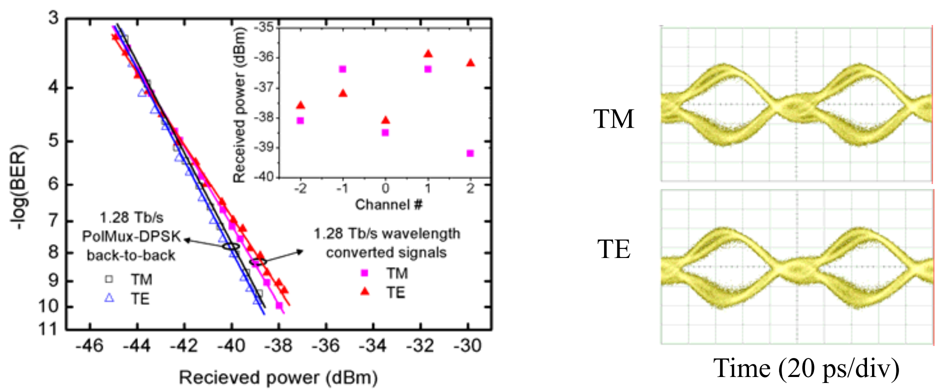
The spectrum at the input and the output of the PMFL is shown in Fig. 3 (a). The FWM conversion efficiency is –31 dB and it could be improved if using higher CW pump power. The spectrum of the wavelength converted 1.28-Tb/s Pol-Mux RZ-DPSK signals is shown in Fig.3 (b). The residual peaks are due to the XPM on the CW pump from the data signals. The BER measurements are shown in Fig. 4 (a) as a function of the received power. BER curves are plotted for the 10 Gb/s DPSK channels demultiplexed from the 1.28-Tb/s Pol-Mux RZ-DPSK signals back to back

(TM and TE), and the converted 1.28-Tb/s Pol-Mux RZ-DPSK signals (TM and TE). The wavelength conversion causes about 1 dB power penalty at the BER of 10^{-9} compared with the back to back case (unconverted signal). Inset shows the receiver sensitivity at BER of 10^{-9} for five adjacent channels. Error free operations were achieved for all these channels (TM and TE). The 10 Gb/s eye-diagrams of the converted, demultiplexed and demodulated signals in TM and TE polarisation are shown in Fig. 4 (b).



(a) (b)

Fig. 3. (a) Spectrum at the input (red dash) and the output (black solid) of the PMFL. (b) The spectrum of the wavelength converted 1.28-Tb/s Pol-Mux RZ-DPSK signals.



(a) (b)

Fig. 4. (a) BER measurements for the 10 Gb/s DPSK channels demultiplexed from the 1.28-Tb/s Pol-Mux RZ-DPSK signals back to back, and the wavelength converted 1.28-Tb/s Pol-Mux RZ-DPSK signals (TM and TE). (b) 10 Gb/s eye-diagrams of the converted, demultiplexed and demodulated signals in TM and TE polarisation.

5. Conclusion

We have demonstrated polarisation insensitive wavelength conversion for 1.28-Tb/s Pol-Mux RZ-DPSK signals using a 100-m PM-HNLF in a PMFL used as all-optical wavelength converter. Error free operation with only about 1 dB receiver penalty for the wavelength converted signal was achieved.

6. Acknowledgment

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