OTDM to WDM Format Conversion Based on Cascaded SHG/DFG in a Single PPLN Waveguide

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Abstract: We propose and experimentally demonstrate error-free OTDM to WDM format conversion based on cSHG/DFG within a 30mm-long PPLN waveguide and a time-to-frequency domain conversion approach, which relies upon switching a linearly chirped pulse.

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1. Introduction

Future high-speed optical networks will require enhanced functionality in the optical layer in order to exploit the full potential of the bandwidth of the optical fiber and reduce the latency associated with optical to electrical (O/E) conversion and electronic processing [1]. Optical networks are based on time division multiplexing (TDM) or wavelength division multiplexing (WDM) which are already quite mature techniques. However, in order to meet the demand for new services and the next generation Internet, capabilities such as the conversion of TDM signals to mixed TDM-WDM will be required in order to combine WDM network topologies with ultra-high speed optical TDM (OTDM) networks and facilitate signal grooming at the networks' edge [2]. The conversion of TDM to mixed TDM-WDM format has also been proposed for other applications such as packet compression/expansion [3] and OTDM add-drop multiplexing [2, 4]. To date the conversion of TDM to a mixed TDM-WDM format has been reported using either cross gain compression in a semiconductor optical amplifier (SOA) [5], cross phase modulation (XPM) in a nonlinear optical loop mirror (NOLM) [4, 6, 7], self-phase modulation (SPM) followed by optical time gating [8] or four-wave mixing (FWM) [9] in highly nonlinear fibers.

Here, we propose a novel scheme to convert TDM to mixed TDM-WDM format using the cascaded interaction of second harmonic and difference frequency generation (cSHG/DFG) in a periodically poled lithium niobate (PPLN) waveguide. PPLN devices can operate at ultra-high bit-rates, are far more compact and less prone to either external environmental perturbations or parasitic nonlinear effects than nonlinear fiber devices, and do not suffer from the patterning and chirping effects frequently associated with SOAs [6]. As illustrated in Fig.1, in our scheme the second harmonic of the high bit rate TDM data signal (four tributary channels) is generated in the PPLN waveguide, and this process is accompanied by DFG interaction between the second harmonic and linearly chirped pulses which are synchronously launched into the PPLN device. Each tributary channel interacts with a different portion of the linearly chirped signal spectrum via cSHG/DFG, thus acquiring a different frequency offset. As a result, OTDM channels are mapped into the wavelength domain on a straight one-to-one basis.

2. Experimental results

Our setup is illustrated in Fig. 2(a). The OTDM to WDM format conversion was based on a 30 mm long pigtailed PPLN waveguide (HC Photonics Corp.) with an SHG phase matching wavelength of 1546 nm at 50^{o}C. The source used in the experiment was a 10GHz, ~1.5-ps pulsed erbium glass (ERGO) mode locked laser operating at the phase matching wavelength of the PPLN device. The laser signal was first split into two separate paths using a 3-dB coupler which were used to generate the data signal and the linearly-chirped rectangular pulses respectively. The pulses in the data path were modulated by a $2^{31} - 1$ pseudorandom bit sequence using a lithium niobate modulator, filtered by a 0.5 nm bandpass filter (yielding a temporal width of 7 ps) to match the PPLN bandwidth and multiplexed up to 40Gbit/s, thereby forming a ~30% duty cycle return-to-zero on-off-keying (RZ-OOK) signal (see Fig. 2(b)). To generate the 10 GHz linearly chirped rectangular-like pulses the initial pulses were amplified to 21 dBm and fed into a 490-m long highly nonlinear fiber (HNLF) with a nonlinear coefficient of ~20 /W/km, a dispersion slope of +0.030 ps/ nm^2/km, and a dispersion of -0.64 ps/nm/km at 1550 nm. The nonlinearly generated

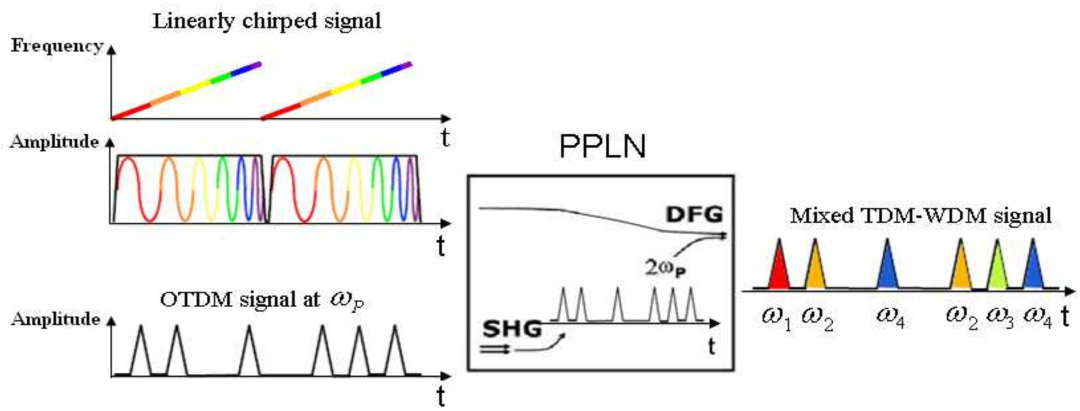

Fig.1. Illustration of the OTDM to mixed TDM-WDM conversion using cSHG/DFG in PPLN.

SPM spectrum extended over 25 nm and a portion of it between 1548 nm and 1554 nm was subsequently selected using a fiber Bragg grating (FBG) filter with a ~40dB extinction. The pulses were allowed to stretch in the time domain by propagation in 140 m of dispersion compensating fiber (DCF) and acquire a rectangular-like envelope of ~85 ps FWHM (see Fig. 2(c)). The pulses were seen to have sharp trailing and leading edges, a good flat-top section and their chirp rate parameter was +0.023 ps^{-2}. More crucially, they were sufficiently long to overlap with all four tributaries of the 40 Gbit/s signal and had a linear chirp which ensured that the mapped WDM channels would be equally spaced from each other. A variable delay line was used to adjust the relative delay between the OTDM pulses and the linearly-chirped rectangular pulses. The two signals were then combined with a 3-dB coupler and launched into the PPLN waveguide.

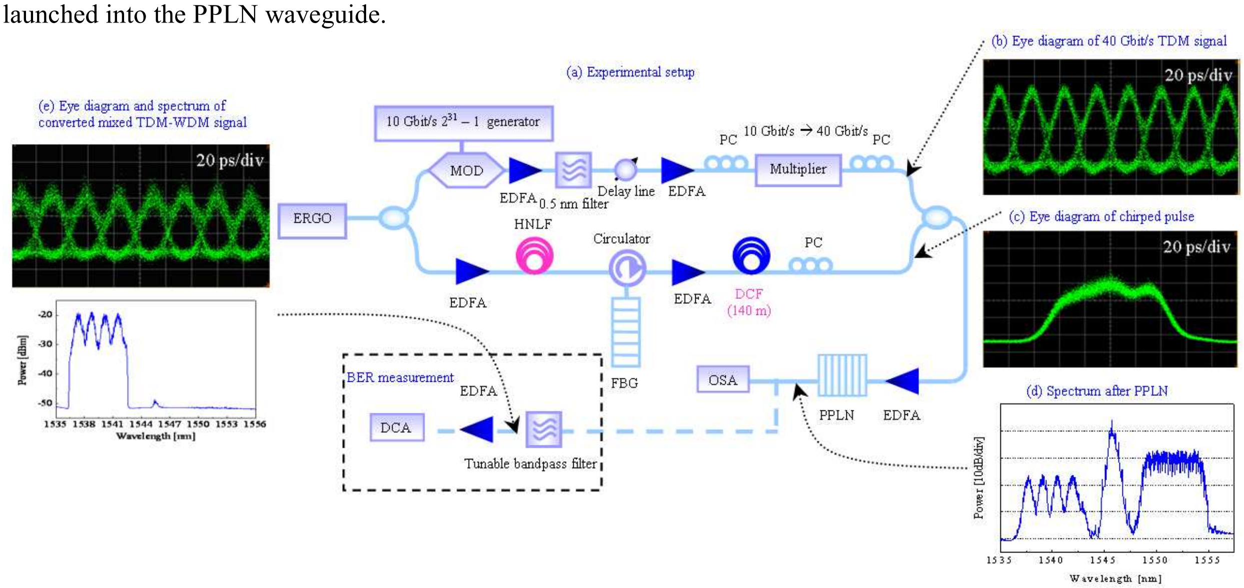

Fig.2. (a) Experimental setup of the OTDM to mixed TDM-WDM conversion. EDFA: erbium-doped fibre amplifier, PC: polarisation controller, DCA: Digital communication analyzer. (b) Eye diagram of the 40-Gbit/s data signal. (c) DCA trace of linearly-chirped rectangular pulse (for illustrative purposes, when taking this measurement the repetition rate was gated down to 5 GHz). (d) Spectral trace after PPLN. (e) Eye diagram and spectral trace of converted mixed TDM-WDM signal.

The 40 Gbit/s data signal generated the second harmonic (at 773 nm) via the SHG process in the PPLN, which in turn interacted with the linearly chirped pulses via the DFG process to produce the mixed TDM-WDM-format signal as a replica of the original data – see Fig. 2(d). The 3-dB bandwidth of each of the four converted WDM channels was ~0.57 nm, the spacing between them was 1.42 nm and their optical signal to noise ratio was more than 22 dB. A filter, tunable both in bandwidth and central wavelength, was used after the PPLN device to extract either the full converted mixed TDM-WDM signal or one of the four WDM channels separately, see the corresponding eye-diagrams and spectral traces in Fig. 2(e) and Fig. 3. All of the four converted channels show a clear open eye-diagram and are also equally spaced in time. Their waveform characteristics were also assessed using a linear frequency resolved optical gating technique. The envelope and pulse width (8-9 ps) of the individual pulses (not shown here) were similar to the original pulses, suggesting that the TDM–WDM conversion has not affected the quality of the signal (the slight increase in the signal pulse width is attributed to the choice of a tight filter bandwidth at the system output). We also assessed the performance of the conversion system through bit-error rate (BER) measurements, as shown in Fig. 3. Error-free performance was achieved for all four WDM channels. Compared to the back-to-back measurement (at 10 Gbit/s), the power penalty of the four channels varied between 1.5 and 2dB.

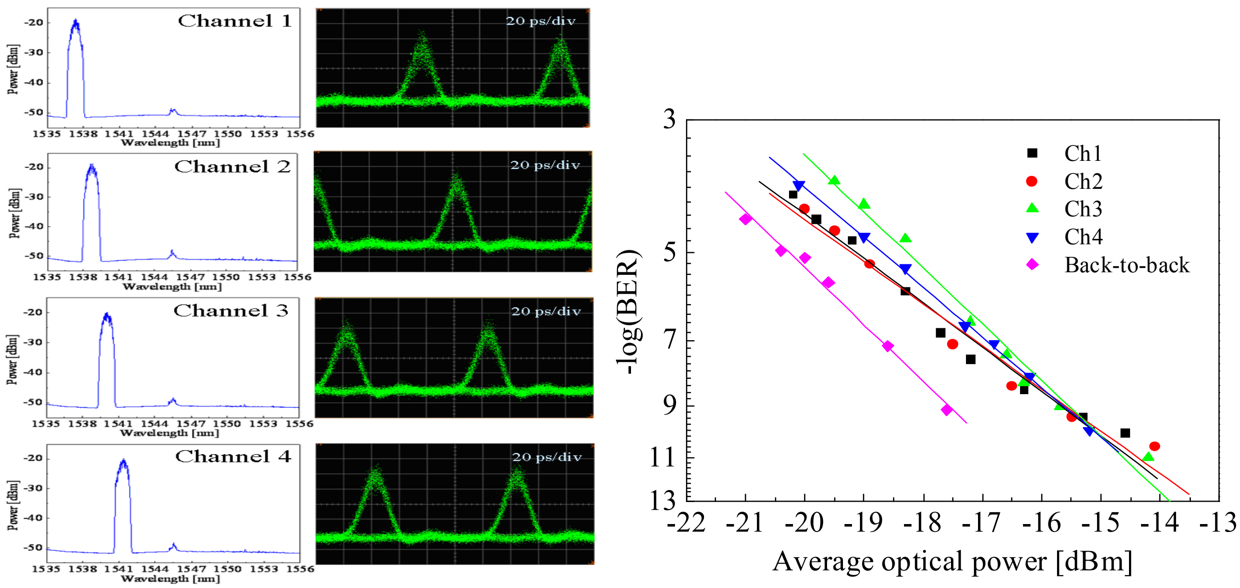

Fig.3. Left: Spectra and eye diagrams of each switched tributary channel. Right: BER curves for each tributary channel and the back-to-back signal.

3. Conclusion

We have successfully demonstrated the conversion of a 40 Gbit/s TDM signal to 4 × 10 Gbit/s WDM channels in a PPLN waveguide. The technique relies on the generation of spectrally (and temporally) flat linearly chirped pulses and their nonlinear switching with short data pulses using cSHG/DFG in a fully fiberized 30 mm long PPLN device. This process generates a spectral representation of data packets, which can then be further processed either temporally or spectrally. Error-free operation was obtained for all channels with a power penalty below 2 dB.

Acknowledgement

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