Optical Demultiplexing with Extinction Ratio Enhancement Based on Higher Order Parametric Interaction

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Abstract *We present the experimental demonstration of an all-optical demultiplexer for high speed OTDM data with optical regeneration capability. It is shown that higher order parametric interactions provide optical sampling with high extinction ratio.*

Introduction

Optical time division multiplexing (OTDM) and optical demultiplexing are important technologies required to address the growing capacity demand of communication networks. All-optical demultiplexing has been demonstrated using several platforms, such as semiconductor devices, crystals, chalcogenide waveguides or optical fibres [1-3]. Four wave mixing (FWM) in highly non linear fibre (HNLF) is particularly of interest due to its inherent ultrafast response and efficiency, and fibre optic parametric amplifiers (FOPAs) have proven to be very valuable for ultrafast all-optical processing [4]. However, the degradation of signal quality due to noise accumulation and crosstalk cannot be effectively suppressed by traditional demultiplexing methods. On the other hand, single and double pump FOPAs have been investigated for their regenerative properties showing that higher order light can potentially offer the benefit of level fluctuation suppression without extinction ratio degradation [5]. The two aforementioned functionalities, (i.e. demultiplexing and regeneration) can be efficiently combined in a single parametric device. In this paper we present the experimental demonstration of simultaneous demultiplexing and extinction ratio enhancement of 320 Gb/s OTDM data based on higher order FWM in HNLF.

Experimental Procedure

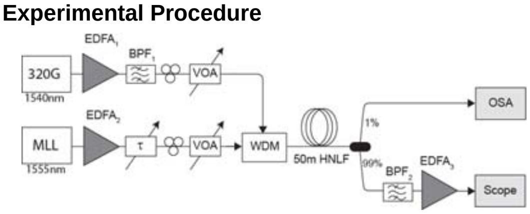

Fig. 1: Experimental setup. MLL: modelocked laser. BPF: band pass filter. VOA: variable optical attenuator. τ: tunable delay line

All-optical demultiplexing from 320 Gb/s to 40 Gb/s was performed in a single pump FOPA as shown in Fig. 1. The sampling pump was a 40 GHz modelocked laser (MLL) positioned at λ_p=1555 nm and amplified by an Erbium doped fibre amplifier ($EDFA_2$). A 320 Gb/s OTDM data signal at λ_s=1540 nm was generated compressing of a radio frequency 40 GHz sine wave to T_{FWHM}=1.6 ps pulses [6], followed by 40 Gb/s modulation and OTD multiplexing to 320 Gb/s. The modulated signal channel was amplified by $EDFA_1$ and filtered with a 5 nm bandpass filter (BPF_1). A WDM coupler combined the MLL pump and the 320 Gb/s data signal which were then launched into a 50 m long segment of HNLF. The HNLF had a zero dispersion wavelength (ZDW) at 1550 nm and a slope of 0.028 ps/nm^2-km. The length of the HNLF was kept short to avoid walk off between the pump and the signal. The walk off is given by ΔT_{WO}= $1/2SL(\lambda_s - \lambda_p)^2$ where S is the dispersion slope and L the length of the HNLF. For our parameters, ΔT_{WO}=0.1125 ps $\ll$ T_{FWHM}. After propagation, the output was monitored on an optical spectrum analyzer (OSA) through a 1% tap. The demultiplexed channel of interest was selected by a 2 nm tunable band pass filter before amplification ($EDFA_3$) and monitoring on a 500 GHz bandwidth optical sampling scope. The pump and signal powers launched inside the HNLF were controlled by variable optical attenuators (VOAs) while the time alignment between sampling pulses and data was adjusted with a manual tunable delay line (τ). The input 320 Gb/s data channel had a Q-factor of 18 dB and an extinction ratio of 13 dB (Fig 4.a).

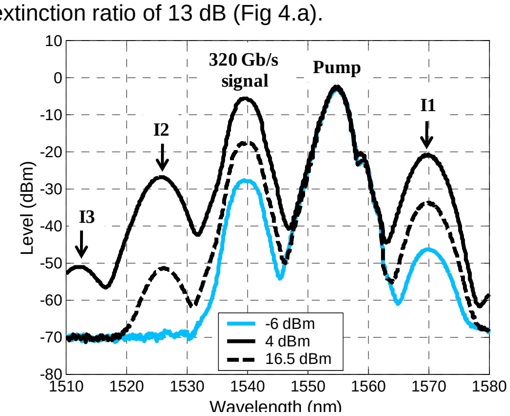

Fig. 2: Spectra at the output of the HNLF for an average pump power of 20 dBm and an average input signal power of -6 dBm (grey trace), 4 dBm (dash trace) and 16.5 dBm.

Output spectra are shown in Fig. 2 for an average pump power of 20 dBm and input signal powers of -6 dBm, 4 dB, and 16.5 dBm. At low input power, the 1st

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order idler wave (I1) was generated at 1570 nm. FWM efficiency of -4 dB was estimated from the spectra taking into consideration the 11 dB duty-cycle ratio of the sampling pump. As the signal power increased, 2nd order light (I2) was generated at 1525 nm. At high input power, higher order light (I3) was also generated at 1514 nm, albeit with low efficiency.

Experimental Results

The output average powers of signal, idler (I1) and 2nd order idler (I2) waves were monitored on the optical spectrum analyzer and are plotted as a function of average input signal power in Fig. 3. The signal and idler powers increased proportionally to the input signal power. As expected, the signal experienced 0 dB of conversion while the idler maintained a conversion of -4 dB over the entire input signal range. The transfer function of the device showed a steeper response with increasing FWM order: the 2nd order sampled light behaviour was characterized by a slope of 2 in the log-log. Using identical physical parameters, the parametric processes between all waves were simulated by solving the nonlinear Schrodinger equation in VPI. The results are plotted in Fig.3 (dash line) and are in good agreement with the experimental data. The onset of saturation is observed at 16.5 dBm of input signal power.

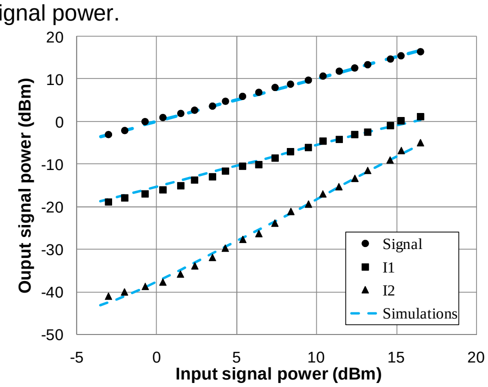

Fig. 3: Experimental power transfer characteristics of 320 Gb/s signal, I1 and I2. Dash line: simulations

Extinction ratio (ER) of the generated samples is an important figure of merit in practical applications. The improvement in output ER can be determined from the power transfer characteristics shown in Fig. 3. Assuming a 13 dB input ER, we find the expected output ER to be 13 dB and 25 dB for I1 and I2, respectively. The second order parametric processes resulted in a 12 dB ER improvement. The signal, pump, I1 and I2 waves were observed on an optical sampling scope. The input 320 Gb/s signal and 40 GHz sampling pump are shown in Fig.4 a and b, respectively. The measured pump pulse width was 2 ps, with a signal to noise ratio (SNR) in excess of 36 dB. The resulting demultiplexed outputs I1 and I2, for a 16 dBm input signal, are shown in Fig. 4.(c) and (d), respectively. The 40 Gb/s tributaries were selected with a 2 nm bandpass filter resulting in pulse broadening from 1.6 ps to 4 ps. Extinction ratio improvement was observed between I1 (Fig. 4c) and I2 (Fig. 4d): an ER of 13 dB was measured on I1 while more than 24 dB ER was measured on I2. The values retrieved from the time domain waveforms are in excellent agreement with the power transfer function predictions and experimentally confirmed the demultiplexing and ER improvement characteristics of higher order parametric interactions.

The Q-factors of the sampled streams were measured to be 17.3 dB for I1 and 16 dB for I2. The 1.3 dB penalty between the 1st and 2nd order idlers is a consequence of two contributions: the 1525 nm position of I2 which resulted in excess ASE from $EDFA_3$., as well as the inherent magnification of '1' level fluctuations, imposed by the power transfer function in Fig. 3. Note that suppression of '1' level fluctuations, and thus additional performance improvement by regeneration, requires that the peak power level be close to the saturated portion of the transfer curve, which was not reached in our experiments. Overall, the demultiplexing operation from 320 Gb/s to 40 Gb/s resulted in Q-factor penalties less than 0.7 dB on I1 and 2 dB on I2.

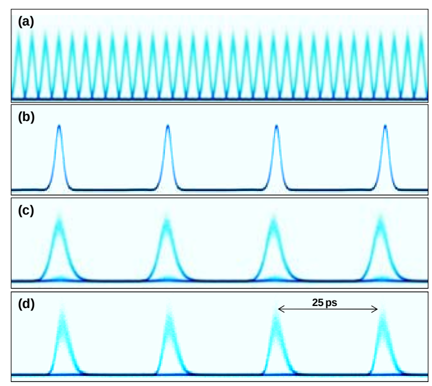

Fig. 4: Waveforms of: (a) Original input 320 Gb/s. (b) 40 GHz sampling pump. (c) Demultiplexed 40 Gb/s idler I1. (d) Demultiplexed 40 Gb/s idler I2.

Conclusions

We have presented the experimental demonstration of an all-optical regenerative demultiplexer for high speed OTDM data based on higher order parametric interaction. The device shows 12dB extinction ratio enhancement with respect to that of the input signal, owing to the steepness of the transfer function curve. Further performance improvement of the regenerative parametric demultiplexer can be obtained by operation in the saturation regime.

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