OTDM Demultiplexing using HNLF in a NOLM at 160 Gb/s

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We report all-optical demultiplexing using a Highly Nonlinear Fiber (HNLF) in a Nonlinear Optical Loop Mirror (NOLM). The NOLM uses Cross Phase-Modulation (XPM) between co-propagating control and signal pulses to switch the signal pulse from one output arm to the other. Simulations in combination with experiments show that this is a promising method for demultiplexing a single channel at a base rate of 10 or 40 Gb/s out of the 160 Gb/s Optical Time Division Multiplexed (OTDM) signal. A switching window of about 2.2 ps is measured with a control pulse of about 1.5 ps Full Width Half Maximum (FWHM).

Introduction

A Nonlinear Optical Loop Mirror (NOLM) has been studied extensively and is one of the most promising methods for fast all-optical switching. Tbit/s switching speeds are possible due to the ultrafast nonlinearities in the fiber [1]. Demultiplexing from 320 [2] and 640 Gb/s [3] to a 10 Gb/s base rate has already been reported. Several experiments have been reported that use orthogonally polarized signal and control pulse streams in a fiber with randomly varying birefringence. The advantage of this type of NOLM is the simple design and lower loss than a NOLM based on spliced polarization maintaining fibers [4]. In this paper we present demultiplexing from 160 Gb/s to a 10 and 40 Gb/s base rate with a commercially available Highly Nonlinear Fiber (HNLF).

Operation Principle

The schematic of the NOLM is depicted in figure 1. In the NOLM a single 160 Gb/s OTDM signal input is split into two counter-propagating signals. One part travels clockwise (CW) and the other part travels counter clockwise (CCW) through the loop. The optical path length is exactly the same for CW and CCW, since they follow the same path but in opposite direction. In CCW direction a 40 GHz clock signal is coupled into the loop through the first Polarization Beam Splitter (PBS1), and leaves the loop through PBS2. The CCW signal acquires an extra nonlinear phase shift, due to cross phase modulation (XPM) between the CCW signal and the clock, when the data coincides with the clock. Thus, when the CW and CCW signal interfere at the coupler the signal pulse can be switched to the drop port.

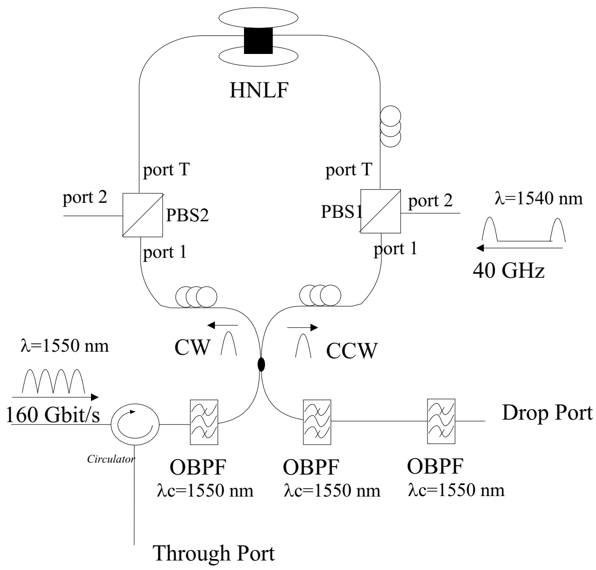

Figure 1: *Schematic of the Nonlinear Optical Loop Mirror (NOLM); OBPF: Optical Band-pass Filter*

Simulations

In the simulations we used a 40 GHz, 2 ps, 1540 nm clock pulse. The average power of the clock signal is $P_{clock} = +14.5$ dBm, corresponding to 350 mW peak power. The OTDM signal wavelength is 1550 nm with an average power of 0 dBm, and a pulse width of 1.9 ps. The zero-dispersion wavelength λ_0 of the 0.5 km HNLF is 1545 nm. The dispersion slope is 0.03 ps/nm^2/km. As the wavelengths of the signal and clock are arranged symmetrically around λ_0, there is no walk-off between the clock and signal. The results of the simulations are shown in figure 2 and 3. In figure 2 the dropped channel output of the NOLM is visualized, and in figure 3 the through channel output is shown. In the through channel a residual part of the dropped channel is clearly visible. This is partly because the data pulse (CCW) that overlaps in time with the clock pulse will experience pulse compression. Pulse compression appears because the data signal is in the anomalous ($\beta_2 < 0$) dispersion region. The combining of the CW and CCW pulses at the coupler leads to a certain output in the through channel, see figure 3. Another reason is that only part of the energy is switched due to the narrow switching window.

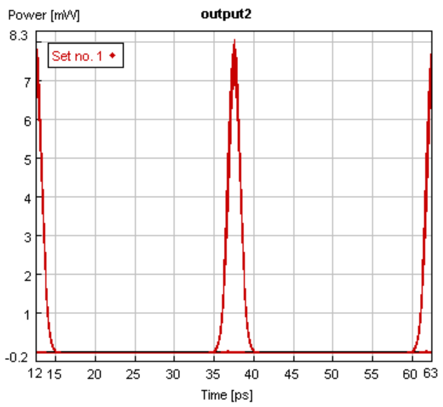

Figure 2: *Drop channel output of the NOLM*

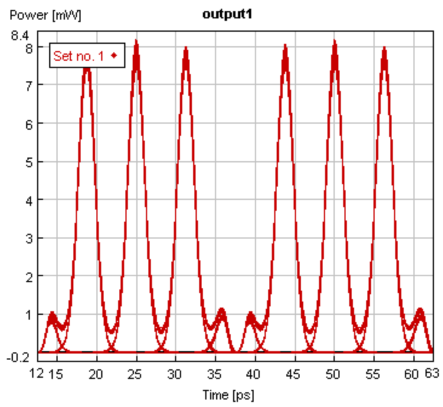

Figure 3: *Through channel output of the NOLM*

Experimental Results

Generation Clock signal

The clock signal and the OTDM signal are obtained from the same Mode Locked Laser (MLL) source operating at 1550 nm, but to avoid crosstalk the clock is converted to 1540 nm based on supercontinuum generation (SC) in a 2.25 km Dispersion Shifted Fiber

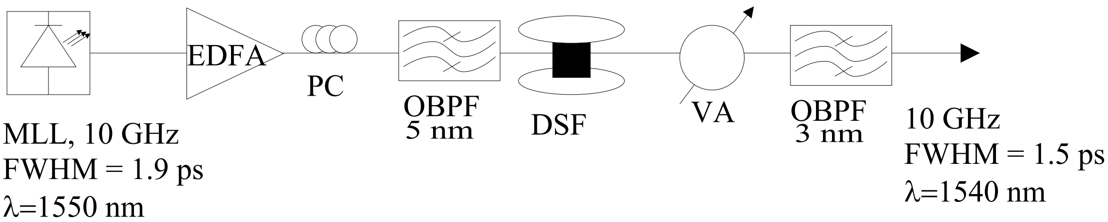

Figure 4: *Schematic of the experimental setup for wavelength conversion based on super continuum generation in 2.25 km DSF.*

(DSF). The schematic for the wavelength conversion is shown in figure 4. The MLL generates pulses of 1.9 ps duration with a repetition rate of 10 GHz. The 10GHz pulse stream is then amplified to a average power of +20 dBm for SC generation. The output of the DSF is filtered with a 3-nm bandpass filter with center frequency $\lambda_c = 1540$ nm. The time trace of the converted clock pulse is shown in figure 5. For the 40 Gb/s base rate we also need a 40 GHz clock signal. To get the the 40 GHz clock signal, the 10 GHz pulse from the MLL is multiplexed to 40 GHz first and then the above SC generation procedure is carried out to convert the clock to another wavelength. The pump signal average power for SC generation is +25 dBm. At this power level, a clean converted 40 GHz clock signal is found at 1560 nm.

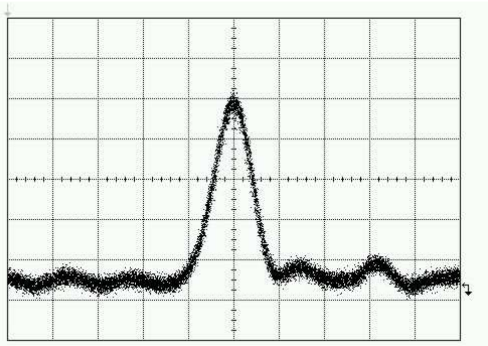

Figure 5: *Super continuum generated 1.5 ps clock pulse at 10 GHz and 1540 nm. X-scale: 10 ps/div, on a 50-GHz bandwidth oscilloscoop.*

Demultiplexing

The all-optical demultiplexer was first tested for the 10 Gb/s base rate and later for the 40 Gb/s base rate. For the 10 Gb/s base rate we used the wavelengths: $\lambda_{data} = 1551$ nm and $\lambda_{clock} = 1539$ nm. For the base rate of 10 Gb/s, the 10GHz pulse stream from the MLL is modulated by an MZI intensity modulator driven by a pattern generator producing PRBS $2^7 - 1$. Then the 10 Gb/s signal is multiplexed to a 80 Gb/s and 160Gb/s OTDM signal. For the 40 Gb/s base rate, the 40 GHz optical pulse is obtained by multiplexing the 10 GHz pulse from MLL first, and then the PRBS pattern is modulated onto the pulse streams by an EAM to produce the 40 Gb/s base signal. Then the 40 Gb/s signal is multiplexed to 80Gb/s and 160Gb/s. Pattern effect is observed in the multiplexed signal which is introduced by the EAM. The clock power injected into the HNLF is +10 dBm average, corresponding to 665 mW peak power. The clock pulse measured on the autocorrelator is 1.5 ps FWHM, shown in figure 6. The BER for demultiplexing from 80 Gb/s and 160 Gb/s to the 10 Gb/s base rate is measured and depicted in figure 8. The power penalty to obtain a BER of 10^{-9} is varying between 1.2 and 5 dB. The measurements were unstable because of wandering of the clock signal due to temperature fluctuations in the DSF. The

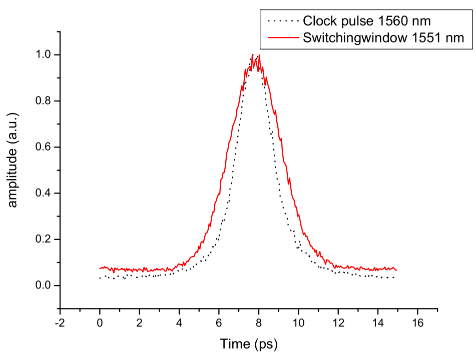

Figure 6: *Autocorrelation trace of the switching window and the converted clock.*

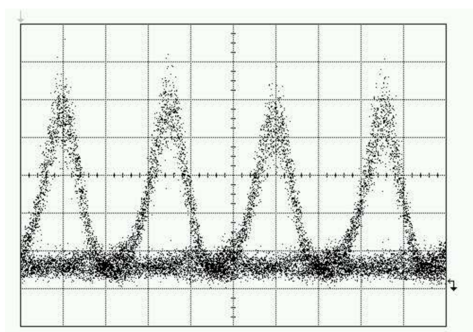

Figure 7: *Demultiplexed channel from 160 Gb/s OTDM data signal to a 40 Gb/s base rate.*

measured switching window profile is shown in figure 6. The FWHM is measured to be 2.2 ps. The BER measurements with a 40 Gb/s base rate are performed by connecting a 50 GHz photodiode (XPDV-2020R from U^2t) output directly to the input of the BER test-set. The sensitivity penalty for demultiplexing from 80 Gb/s to 40 Gb/s is 3.7 dB, which is shown in figure 9. Demultiplexing from 80 Gb/s to 40 Gb/s meets an error floor at BER=10^{-10}, while demultiplexing from 160 Gb/s to 40 Gb/s gave us already an error floor at BER=10^{-7}, see figure 7. The power of the clock signal injected in the HNLF is +16 dBm average. This corresponds to 665 mW peak power. The loss between the EDFA and the HNLF is 4 dB.

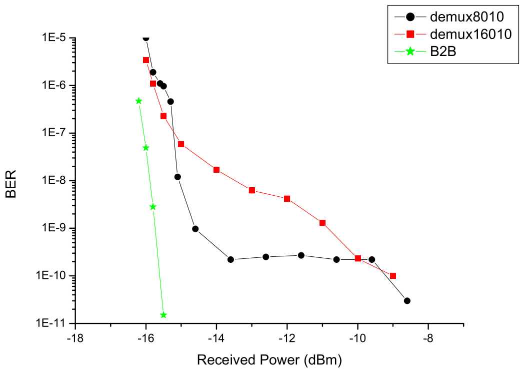

Figure 8: *BER of the demultiplexed channel at a 10 Gb/s base rate compared with a back-to-back measurement.*

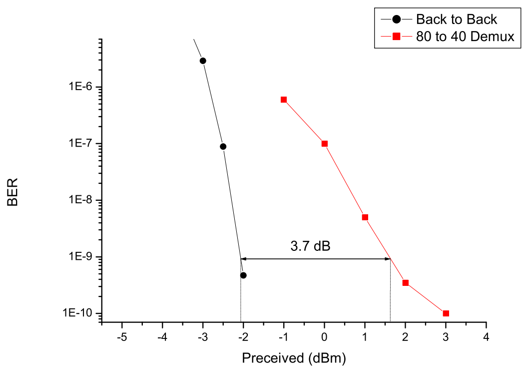

Figure 9: *BER of the demultiplexed channel at a 40 Gb/s base rate compared with a back-to-back measurement.*

Conclusions

Demultiplexing from 80 Gb/s to a 10 Gb/s or 40 Gb/s base rate, and 160 Gb/s to a 10 Gb/s base rate with a BER lower than 10^{-9} is demonstrated using a NOLM with a 500 m HNLF as nonlinear element. A better and more stable performance is expected using a better clock signal and good OTDM signal for the all-optical demultiplexing.

Acknowledgements

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References

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