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# 640 Gb/s OTDM Transmission and Demultiplexing using a NOLM with Commercially Available Highly Non-linear Fiber

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**Abstract:** Demultiplexing of a 640 Gb/s single-polarization OTDM signal and a 640 Gb/s signal with two alternating polarizations transmitted through 77 km of NZDSF are realized using a NOLM based on 500 m of HNLF.

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## 1. Introduction

The interest in ultra-high speed optical time-division multiplexed (OTDM) transmission systems has steadily increased over the last few years [1-9]. In OTDM systems fast switches are essential. Electrical driven Electroabsorption modulators (EAM) are convenient for demultiplexing from 160 to 40 Gb/s [2,3], but usually not at higher bit rates. Recently though, 320 Gb/s demultiplexing using semiconductor components were demonstrated [4,5] in the forms of a fast photodiode integrated with a traveling-wave EAM [4], and a Mach-Zehnder interferometer with semiconductor optical amplifiers [5]. However, all-optical switches based on Non-linear Optical Loop Mirrors (NOLM) remain the devices applicable for demultiplexing from 640 Gb/s [6,7].

The switching window in a NOLM-based demultiplexer is determined by the width of the control pulses and the walk-off between the control pulse and the data signal. To reduce walk-off, carefully matching fiber segments [6] or advanced fibers with increased non-linear coefficients [8] have been used in NOLMs.

In this paper we report on a 640 Gb/s experiments using a NOLM with a single piece of commercially available Highly Non-linear Fiber (HNLF) with careful optimized dispersion design. Successful demultiplexing of a 640 Gb/s Alternating Polarization OTDM (AP-OTDM) signal in complete transmission setup and a back-to-back demultiplexing of a 640 Gb/s Single Polarization OTDM (SP-OTDM) signal are realized. Recently we demonstrated demultiplexing of all OTDM channels after transmission of a 320 Gb/s single-polarization OTDM signal through spans containing continuous fiber of 80 km [9]. In this paper transmission of 640 Gb/s through continuous 77 km of non-zero dispersion shifted fiber (NZ-DSF) is realized for the first time.

## 2. Experimental set-up 640 Gb/s AP-OTDM

The experimental set-up for 640 Gb/s AP-OTDM is shown in Fig. 1,a. The pulse source in the transmitter (TX) is an Erbium Glass Oscillator Pulse Generating Laser (ERGO-PGL) emitting 1.5 ps pulses at the wavelength of 1557 nm at a 10 GHz repetition rate. The pulse stream is modulated with a  $2^7-1$  to  $2^{31}-1$  10 Gb/s Pseudo Random Bit Sequence using a Mach-Zehnder modulator (MZ). The 10 Gb/s data stream is multiplexed to 320 Gb/s using a  $2^7-1$  PRBS properties maintaining and polarization maintaining fiber-based multiplexer and to 640 Gb/s using two polarization-controllers, a polarization-coupler and a delay line.

Demultiplexing to 10 Gb/s in the receiver (RX) is based on a NOLM constructed with 500 meters of HNLF as the non-linear element. A polarizer and a polarization controller are situated in front of the NOLM to ensure polarization demultiplexing from AP-640 Gb/s to 320 Gb/s. The HNLF has a zero-dispersion wavelength of 1551 nm, a dispersion slope of 0.016 ps/(nm<sup>2</sup>km) and a non-linear coefficient of 10.5 W<sup>-1</sup>km<sup>-1</sup>. The short pulses with repetition of 10 GHz from the second ERGO-PGL at 1541 nm are applied to the NOLM as a control signal. Since the zero-dispersion wavelength is between the wavelengths of the data and control, the walk-off is minimized. The performance of the system is evaluated using a pre-amplified 10 Gb/s receiver including an error detector.

As the impact of interferometric crosstalk is reduced for AP-OTDM systems, no additional pulse compression for the data and the control signal is required, thus reducing the complexity of the set-up.

A complete transmission system is realized for the 640 Gb/s AP-OTDM. The transmission span is 77 km NZDSF compensated by 3 km Dispersion Compensating Fiber (DCF). The accumulated dispersion of the span is less than 0.4 ps/nm in the magnitude at 1557±3 nm. The input power of the data signal to the transmission span is 8 dBm. For the transmitted optical clock, a light of a continuous-wave laser (CW) at 1548 nm was sinusoidally

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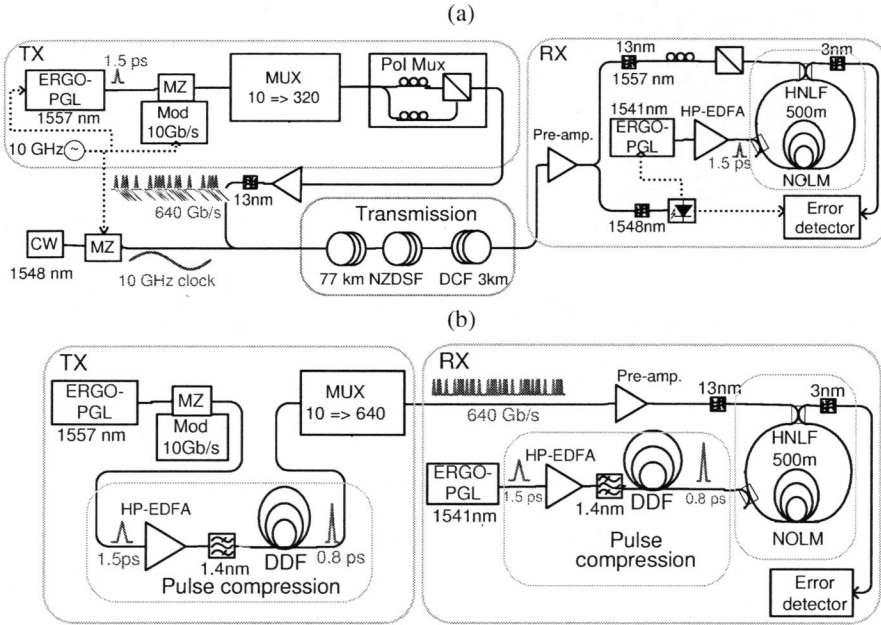


Fig. 1. a) 640 Gb/s system with two alternating polarizations (640 Gb/s AP-OTDM set-up); b) 640 Gb/s system with one polarization (640 Gb/s SP-OTDM set-up)

modulated by a MZ. The data and clock signals are combined before transmission and separated by filtering after transmission. The NZDSF and HNLf are kindly provided by OFS Denmark.

3. Experimental set-up 640 Gb/s SP-OTDM

In Fig. 1,b the set-up for SP-OTDM 640 Gb/s is shown. This is a modified version of the set-up shown in Fig. 1,a. As opposed to the AP-OTDM, the impact of interferometric crosstalk between the pulses increases and significantly narrower pulses are required for both data and control pulses. In the 640 Gb/s SP-OTDM set-up both data and control pulses are compressed in the following way: the 1.5 ps pulses are amplified by a high-power erbium-doped fiber amplifier (HP-EDFA), then broadened by 1.4 nm filters to 2.5 ps and injected into 1 km of dispersion decreasing fiber (DDF). The width of the compressed pulses of both data and control signals is 0.8 ps. For the 640 Gb/s SP-OTDM set-up the multiplexer is a PRBS and polarization maintaining fiber delay line structure. The RX is similar in the two set-ups, except that the polarization demultiplexer in front of the NOLM has been removed.

4. Characterizations and results

The autocorrelation traces of the 320 Gb/s data signal based on 0.8 ps pulses, the 640 Gb/s signal based on 0.8 ps

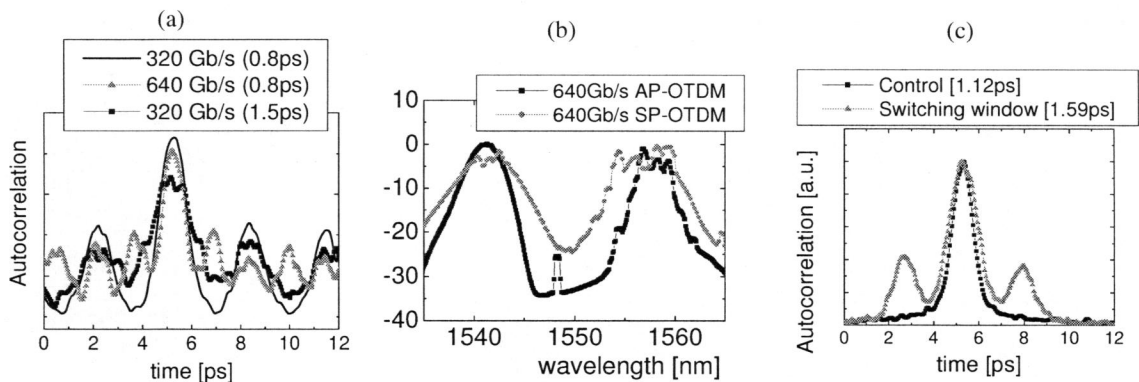


Fig. 2. a) Autocorrelation traces of the 320 Gb/s and 640 Gb/s data signals. b) The spectrum at the input to the HNLf in the NOLM for the 640 Gb/s AP and SP set-ups. c) Autocorrelation traces of the control signal and the switching window

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pulses and the 320 Gb/s signal based on 1.5 ps pulses are shown in Fig.2,a. The autocorrelation traces of the multiplexed data show that the time separation between the pulses is ample to resolve different OTDM channels. Fig.2,b shows the spectra of the control and data signals injected to the HNLf of the NOLM in the AP and SP 640 Gb/s set-ups. The spectra show a very small overlapping between control and data signals.

Fig.2,c shows the switching window of the NOLM in the 640×1 Gb/s set-up. To evaluate the switching window, CW light at data wavelength was injected in to the NOLM instead of the data. A control signal with a pulsewidth of 0.8 ps (1.12 ps on autocorrelator) results in the switching window of 1.15 ps (1.59 ps on autocorrelator) which is acceptable for demultiplexing from 640 to 10 Gb/s. The switching window is slightly broader than the control signal because of the walk-off between the control and data wavelengths in the NOLM.

Fig. 3 shows the BER performance of the 640 Gb/s AP- and SP- set-up as a function of the input power to the pre-amplified receiver. In the 640 Gb/s AP set-up without transmission (b-b) polarization demultiplexing gives only 1 dB penalty compared to 320 Gb/s with a single polarization. Transmission introduces a penalty of 5 dB. The different OTDM channels have similar performances and the difference between the sensitivity of the different OTDM channels does not exceed 3 dB. The demultiplexing from 640 to 10 Gb/s in 640 Gb/s SP system shows an error floor due to walk-off and the resultant relatively wide switching window and gives a penalty of 12.5 dB compared to the 10 Gb/s back-to-back. Demultiplexing of the 320 Gb/s signal based on 0.8 ps pulses has a penalty of 8 dB, emphasizing the challenge of using very narrow pulses.

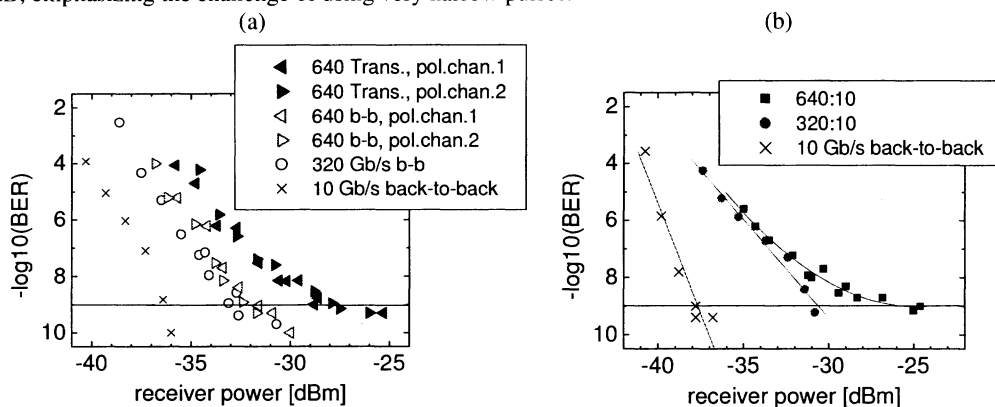


Fig. 3. a) BER performance of demultiplexing after transmission for 640 Gb/s AP set-up, b) BER performance of demultiplexing for 640x1 Gb/s SP set-up.

#### 4. Conclusion

Demultiplexing of a 640 Gb/s OTDM signal is performed using a NOLM with a 500 m HNLf with carefully managed dispersion as the non-linear element. Transmission through 77 km of NZDSF of a 640 Gb/s signal with two polarizations and back-to-back demultiplexing of 640 Gb/s signal with single polarization are realized. The demultiplexing is successful and error-free for both systems.

#### 5. References

- European IST project TOPRATE IST-2000-28657
- M. Schmidt, E. Lach, K. Schuh, M. Schilling, P. Sillard, G. Veith, "Unrepeated 320 Gbit/s (8x40 Gbit/s) OTDM transmission over 80 km TeraLight™ fiber link", ECOC'03 (2003), paper We4-P.117.
- B. Mikkelsen, G. Raybon, R.-J. Essiambre, A.J. Stentz, T.N. Nielsen, D.W. Peckham, L. Hsu, L. Gruner-Nielsen, K. Dreyer and J.E. Johnson, "320-Gb/s single-channel pseudolinear transmission over 200 km of nonzero-dispersion fiber", IEEE Photonics Technology Letters, **12**, 1400-1402 (2000).
- S. Kodama, T. Yoshimatsu, H. Ito, "320 Gbit/s error-free demultiplexing using ultrafast optical gate monolithically integrating a photodiode and electroabsorption modulator", Electronic Letters, **39**, 1269-1270 (2003).
- A. Suzuki, X. Wang, Y. Ogawa, S. Nakamura, "10x320Gb/s (3.2Tb/s) DWDM/OTDM Transmission in C-band by Semiconductor-Based Devices", ECOC'04 (2004), paper Th4.1.7.
- M. Nakazawa, T. Yamamoto, K.R. Tamura, "1.28 Tbit/s-70 km OTDM transmission using third- and fourth-order simultaneous dispersion compensation with a phase modulator", Electronic Letters, **36**, 2027-2029 (2000).
- V. Marembert, C. Schubert, S. Ferber, K. Schulze, C. Schmidt-Langhorst, C. Boerner, M. Kroh, R. Ludwig, S. Watanabe, F. Futami, R. Okabe, H.G. Weber, "Single-Channel 640 Gb/s DPSK transmission over a 160 km Fibre Link", ECOC'04 (2004), paper Th4.4.2.
- H. Sotobayashi, C. Sawaguchi, Y. Koyamada and W. Chujo, "Ultrafast walk-off-free nonlinear optical loop mirror by a simplified configuration for 320 Gb/s time-division multiplexing signal demultiplexing", Optics Lett., **27**, 1555-1557, (2002).
- A.I. Siahlo, J. Seoane, A.T. Clausen, L.K. Oxenløwe, P. Jeppesen, "320 Gb/s Single-polarization OTDM Transmission over 80 km Standard Transmission Fiber", OFC'05 (2005).