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320 Gb/s Single-polarization OTDM Transmission over 80 km Standard Transmission Fiber

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Abstract: 320 Gb/s single-channel and single-polarization error-free transmission over continuous spans of either 80 km SMF or 77 km NZDSF are realized.

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1. Introduction

Optical time-division multiplexing (OTDM) is an attractive technique for increasing the capacity of optical transmission systems [1]. Transmission of single-polarization optical time-division multiplexed (OTDM) intensity modulated data signals at single-channel bit rates of 320 Gb/s and higher has already been demonstrated [2-5], with the record single-channel rate being 640 Gb/s [2]. To increase the capacity even further, the use of several wavelength channels, each at a high OTDM bit rate, has been suggested and demonstrated with the impressive transmission of 10×320 Gb/s WDM/OTDM data channels [3]. Systems as these impose strict requirements on the optical data pulses used, on the switching techniques employed, as well as on the transmission fibers. Data pulses should generally have a FWHM of about 40-50 % of the OTDM time slot [6]. As for demultiplexing from 320 Gb/s and higher, various optical switching techniques have been implemented, including non-linear optical loop mirrors (NOLMs) [2,4], four-wave mixing in non-linear fibers [5] and Mach-Zehnder interferometers with semiconductor optical amplifiers [3]. Regarding transmission, various orders of dispersion and PMD strongly limits the transmission reach, and the lengths of continuous fiber segments used for transmission of 320 Gb/s (or higher) has not yet exceeded 40 km [2-5]. Recently, results of 320 Gb/s transmission through longer fiber segments (more than 80 km) have been reported [7,8], where electroabsorption modulators were used for demultiplexing. However, the signals in [7,8] were polarization-multiplexed from 160 to 320 Gb/s, thus easing the constraints on the transmission.

In the present paper, error-free transmission of a 320 Gb/s single-polarized OTDM signal through 80 km of continuous fiber is demonstrated for the first time. Two transmission experiments with either a continuous length of 80 km of standard single-mode fiber (SMF) or a continuous length of 77 km of non-zero dispersion shifted fiber (NZDSF) are realized. A NOLM with a single piece of commercial highly non-linear fiber (HNLF) is used for demultiplexing.

2. Experimental set-up

The experimental set-up, shown in Fig.1a, includes a transmitter (Tx), a transmission span and a receiver (Rx) with a NOLM-based demultiplexer. The Tx includes a 10 GHz erbium-glass oscillator pulse-generating laser (ERGO-PGL) as a source of 1.5 ps short pulses at 1557 nm. The pulse train is modulated by a Mach-Zehnder (MZ) modulator with a PRBS word length of 2^7-1 to 2^{31}-1. The 10 Gb/s modulated signal is multiplexed to 320 Gb/s by a fiber-delay OTDM multiplexer, which maintains the optical polarization and the 2^7-1 PRBS properties. A 10 GHz clock is coupled to the data signal at the input of the transmission span and extracted by optical filtering after transmission. The clock is a continuous-wave (CW) light at 1549 nm, sinusoidally modulated by an MZ-modulator. The power levels of the data and clock signals at the input of the transmission span are 8 dBm and –3 dBm, respectively.

The transmission span is a continuous 80 km SMF, compensated by 13 km of dispersion compensating fiber (DCF). Fine compensation by short pieces of SMFs and DCFs is employed to reduce the total accumulated dispersion to zero. The magnitude of the accumulated dispersion slope of the 80 km SMF with 13 km DCF is less than 0.5 ps/nm^2. An erbium-doped pre-amplifier is placed just after the 80 km SMF. A second transmission span consisting of a link of continuous 77 km of NZDSF, compensated by 3 km of DCF is also investigated. The residual dispersion slope of the 77 km NZDSF with 3 km DCF has a magnitude less than 0.2 ps/nm^2.

The 320 Gb/s data signal is demultiplexed to 10 Gb/s in a NOLM. A 10 GHz ERGO-PGL at 1542 nm, driven by the O/E-converted transmitted optical clock, is the source of control pulses. The NOLM includes 500 m of commercially available HNLF (non-linear coefficient $\gamma = 10.5$ W^{-1}km^{-1}) as the non-linear element. The HNLF has zero-dispersion wavelength at 1551 nm and a dispersion slope of 0.16 ps/(nm^{2}km). Since the zero-dispersion wavelength is placed between the control and data wavelengths, the walk-off between control and data is negligible

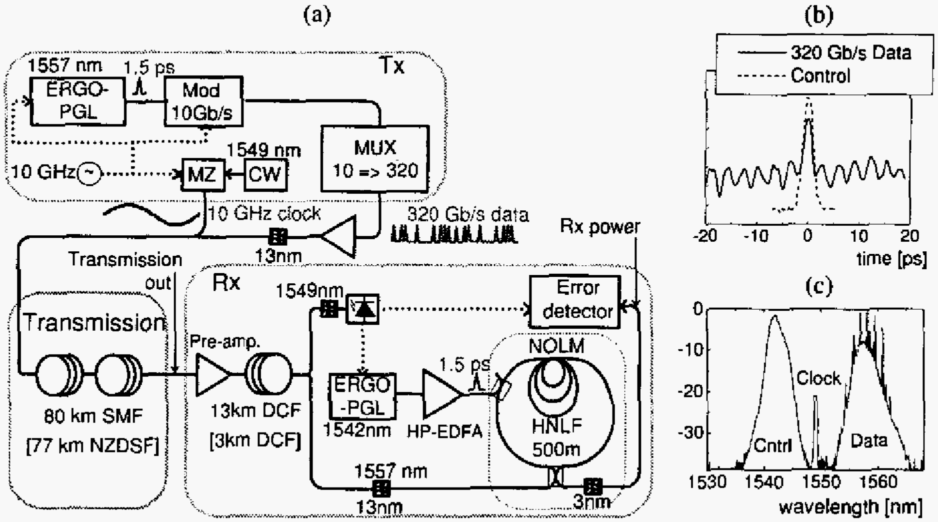

Fig. 1. a) Experimental set-up; b) The autocorrelation traces of the 320 Gb/s data signal and the control signal; c) The spectrum at the input to the HNLF in the NOLM

and the switching window width is equal to the width of the control pulses. The power levels of the control and data at the input to the HNLF are 6.7 and 7 dBm, respectively.

The autocorrelation traces of the 320 Gb/s data signal and the control signal are shown in Fig. 1b. The spectrum of the input to the HNLF in the NOLM is shown in Fig. 1c. Both ERGO-PGLs produce narrow pulses with a temporal full width of half maximum (FWHM) of 1.5 ps and a spectral FWHM of 2.5 nm. Further compression of the pulses is not required for successful demultiplexing. The SMF, NZDSF and HNLF are kindly provided by OFS Denmark.

3. Results and discussion

Fig. 2a shows the BER performance of the demultiplexed signal after transmission through 80 km SMF, 77 km NZ-DSF and without transmission. Demultiplexing 320:10 without transmission has a penalty of 2 dB at 10^{-9} with respect to the sensitivity of a single 10 Gb/s back-to-back signal (-37.5 dBm). Fig. 2b shows the sensitivity at 10^{-9} of all demultiplexed channels after transmission through 80 km of SMF, 77 km of NZDSF and without transmission. Fig. 2c and 2d show the eye-diagrams of the 320 Gb/s signal after transmission and after transmission and demultiplexing to 10 Gb/s. The eyes are measured on a 50 GHz sampling oscilloscope and show there is a small amplitude variation of the OTDM channels.

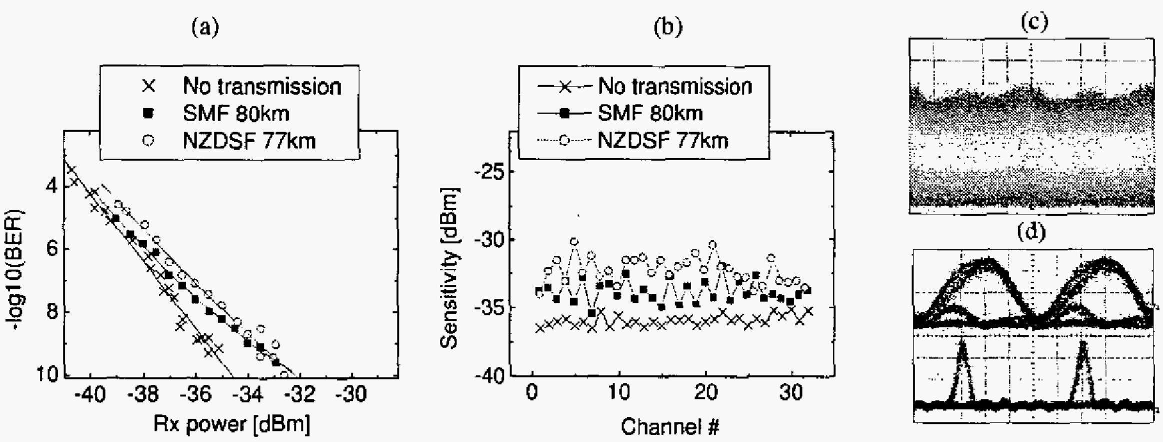

Fig. 2. a) BER performance of demultiplexing after transmission, b) sensitivity of all 32 OTDM channels, c) eye-diagram of the 320 Gb/s signal after transmission and d) electrical (top) and optical (bottom) eye-diagrams of the demultiplexed signal.

For both transmissions all 32 demultiplexed channels were error-free; the variation of sensitivity between the different channels is 4 dB. The penalties are 2 dB and 3.5 dB for transmission through 80 km of SMF and 77 km of NZDSF respectively. Here we define the penalty as the difference in average channel sensitivity between demultiplexing after transmission and without transmission. Since the transmission fibers have low polarization-mode dispersion (PMD) and the pulses of the data signal are not extremely short, the PMD does not strongly affect the transmission performance.

In order to investigate acceptable losses for 320 Gb/s transmission, we measured the sensitivity at 10^{-9} at different output powers after transmission (Fig.3, left). The minimum optical power at which error-free 320:10 demultiplexing is possible, is –21.5 dBm. Fig.3, right, shows the corresponding spectrum of the signal after pre-amplification at the end of transmission. The minimum optical signal to noise ratio (OSNR) at which error-free 320:10 demultiplexing can be obtained, is 16 dB. The sensitivity of demultiplexing does not depend on the power after transmission if this power is higher than –17 dBm (the OSNR after the pre-amplifier is 20 dB). Without transmission the minimum power at the input of the pre-amplifier for 320:10 demultiplexing is the same as with transmission (-21.5 dBm).

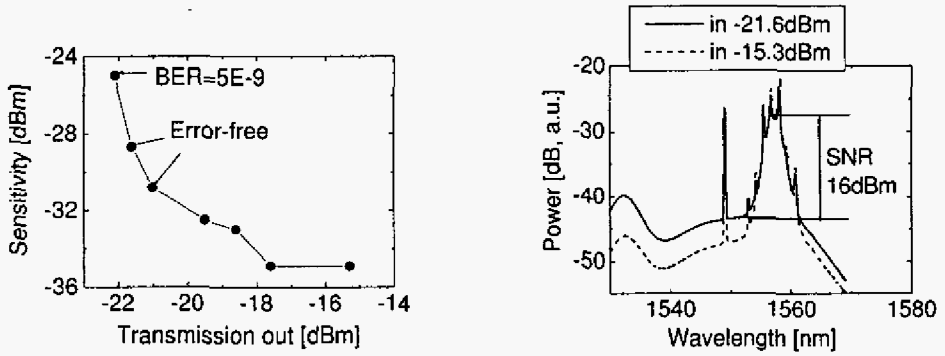

Fig. 3. Sensitivity at different output powers of the transmission span (left) and spectrum of the signal after the pre-amplifier at the end of transmission (right).

4. Conclusion

A complete transmission system with 320 Gb/s single-polarization OTDM transmission and NOLM-based demultiplexing from 320 to 10 Gb/s is realized. Transmissions through either continuous 80 km of standard SMF or 77 km of NZDSF are realized.

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