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80 GB/S TRANSMISSION OVER 80 KM AND DEMULTIPLEXING USING A HIGHLY NON-LINEAR PHOTONIC CRYSTAL FIBRE

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Abstract *We report on, transmission of an 80 Gb/s signal over 80 km of standard single mode fibre with subsequent demultiplexing to 10 Gb/s in a NOLM containing a novel photonic crystal fibre.*

Introduction

A promising candidate for all-optical demultiplexing of future high bit rate optical time division multiplexing (OTDM) signals is the Non-linear Optical Loop Mirror (NOLM) switch. Switching capabilities in the order of Terabit/s is possible as the NOLM is based on the ultra fast Kerr effect in optical fibre /1/. Relatively low non-linear coefficients of existing standard technology fibres make fibre lengths of several hundred meters necessary. Unfortunately this makes the NOLM very sensitive to environmental disturbances such as e.g. acoustic waves /1/ /2/. Consequently, shorter fibre lengths would be preferable to make the NOLM a more stable and compact device.

In this paper, we report to the best of our knowledge the first demultiplexing of 40 and 80 Gb/s OTDM signals in a NOLM based on only 50 m of newly developed highly non-linear photonic crystal fibre (PCF) manufactured by Crystal Fibre A/S. Moreover, we characterise the demultiplexer in an 80 Gb/s transmission experiment over 80 km of standard single mode fibre (SMF).

NOLM Switching

The NOLM consists of a non-linear element and two couplers implemented in a fibre loop (See Fig. 1). The operation is based on cross phase modulation (XPM) in the non-linear element between a control signal and a data signal.

An injected data signal is split in two in the 3 dB coupler, and co- or counter-propagates with the control pulses through the loop (co and cnt). In the absence of a control signal the same phase shift is accumulated in both arms and the data signal is reflected back to the input port. Injection of a control pulse in the loop produces a phase shift between the co- and counter-propagating data signals due to XPM. Switching of the entire input data signal to the output occurs for a π phase difference. Choosing the proper power and timing of the control pulse will hence switch an OTDM base rate channel to the output.

Experimental setup

Fig. 1 shows the schematic setup for the experimental work. A 10 GHz mode locked fiber ring laser (MLFRL) operating at a wavelength of 1558 nm serves as the pulse source. An external Mach-Zender (MZ) modulator is used to modulate the pulse train at 10 Gb/s with a Pseudo random bit sequence (PRBS) of 2^7-1. Fibre based time delay multiplexers are used to multiplex the 10 Gb/s base rate channels to either a 40 Gb/s or 80 Gb/s OTDM data signal. In the transmission experiment 80 km of standard single mode fibre (SMF) and an 11 km dispersion compensating fibre (DCF) are used. The zero dispersion wavelength of the entire span including the DCF is measured to be 1557 nm and the accumulated dispersion at 1558 nm is -0.9 ps/nm.

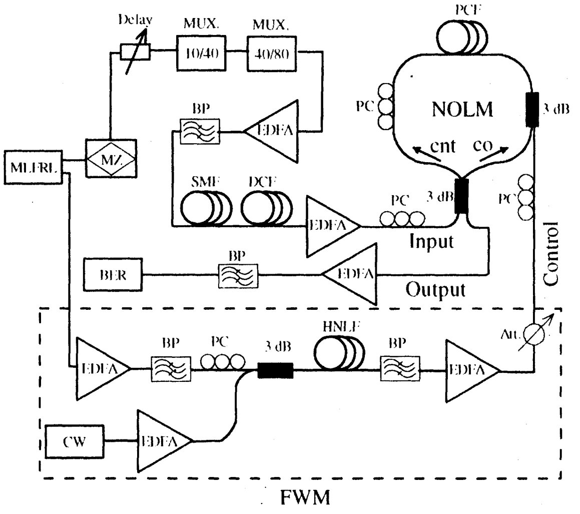


Figure 1: Schematic setup of the 80 Gbit/s transmission experiment.

In order to generate the control pulses necessary for demultiplexing in the NOLM, a wavelength conversion of the MLFRL pulse train is performed by partly degenerate Four Wave Mixing (FWM) in 500 m of highly non-linear fibre (HNLF) (non-linear coefficient, γ = 10.6 $W^{-1}km^{-1}$) /3/. The pump is the MLFRL pulse train and a continuous wave (CW) laser operating at a wavelength of 1566 nm acts as the probe in the process. Subsequent filtering of the FWM spectrum using an optical band pass (BP) filter provides control pulses at a wavelength of 1550 nm. The described configuration not including the transmission span will provide the NOLM with a ~4 ps full width half maximum (FWHM) data pulse and a ~2 ps (FWHM) control pulse. The fibre used in the NOLM is a highly non-linear PCF with a non-linear coefficient (γ) of $18\ W^{-1}km^{-1}$ and zero dispersion wavelength at 1552 nm /4/. Temporal alignment of the data signal and the control pulse of the NOLM is obtained using a variable time delay.

Results

The bit error rate (BER) measurements evaluating the system in Fig. 1 are shown in Fig. 2.

The BER curve for the demultiplexed 40 Gb/s data signal show no sign of an error floor. The combined penalty for multiplexing and demultiplexing is ~1.7 dB for 40 Gb/s and ~5.1 dB for 80 Gb/s compared to the back to back. As these data signals are directly demultiplexed immediately after the multiplexing the most probable cause of the power penalties are due to channel cross talk. The channel cross talk is partly due to the width of the data pulses, and partly due to the improper width of the demultiplexing window introduced by walkoff /5/.

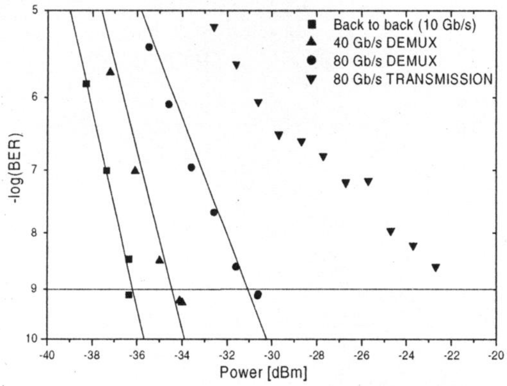
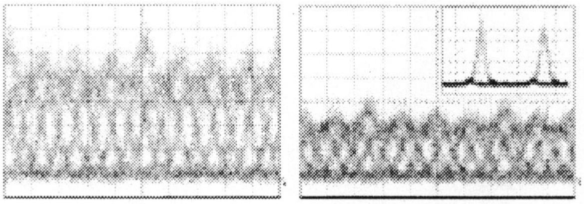


Figure 2: Results of BER measurements for 40 Gb/s demultiplexing, 80 Gb/s demultiplexing, and 80 Gb/s transmission through 80 km SMF

For the transmission experiment at 80 Gb/s over 80 km a minimum BER of $2.6\cdot10^{-9}$ is reached with quite high power penalties. Numerical results have shown that for a BER of 10^{-9}, a 20° misalignment of the state of polarisation between the data signal and control pulses is tolerable /1/. The polarisation is therefore probably not accountable for the power penalty observed. Most likely explanations are misplacement of the switching window and timing jitter which can lead to substantial increases in the power penalty /1/ /5/. The timing jitter is believed to stem from environmental disturbances of the transmission span. No clock recovery unit was used in these experiments, and the lack of synchronisation of the demultiplexer to the data signal resulted in a constant drift of the demultiplexed channel. Clock recovery will thus be necessary to obtain error free operation after transmission. A pulse broadening due to operation away from the zero dispersion wavelength will lead to an increase of the cross talk and additional power penalties.

Fig. 3 shows the 80 Gb/s multiplexed OTDM signal before and after the 80 km transmission span (measured on a 50 GHz oscilloscope using a 50 GHz photodiode). As an example of a clear and open demultiplexed 10 Gb/s eye after transmission see the inset of Fig. 3b



a) *b)*

Figure 3: Eye diagrams of the 80 Gb/s optical signal a) at the transmitter output b) after transmission through the span. The inset shows one of the demulitplexed 10 Gb/s channels.

Conclusion

Demultiplexing using a NOLM based on 50 m of highly non-linear photonic crystal fibre is shown for the first time to our knowledge. Error free demultiplexing of a 40 Gb/s and 80 Gb/s OTDM signal are presented with a ~1.7 dB and ~5.1 dB power penalty, respectively.

Transmission of a 80 Gb/s OTDM signal over 80 km with a minimum BER of $2.6\cdot10^{-9}$ is achieved. Power penalties due to the lack of synchronisation and timing jitter are the biggest problems encountered. A suitable clock recovery in connection with the NOLM demultiplexer would very likely improve the performance.

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