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# Simultaneous 160 Gb/s Add-Drop Multiplexing in a Non-Linear Optical Loop Mirror

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**Abstract**— We report on a demonstration of error-free simultaneous add-drop multiplexing of 160 Gb/s data in a non-linear optical loop mirror composed of 100 m highly non-linear fibre.

## I. INTRODUCTION

Add-drop multiplexing (ADM) is an important functionality in Optical Time-Division Multiplexed (OTDM) systems, which are based on high bit-rate data signals obtained by multiplexing several low bit-rate data-channels of identical wavelength. ADM is the operation where one channel is extracted (dropped) from the aggregate signal and a new channel is added in the vacant time-slot (added channel). This functionality is a requirement for the realisation of network nodes in OTDM systems. ADM switches have been realised using both semiconductor components [1], [2] and Highly Non-Linear Fibre (HNLF) [3], [4], [5]. In [1-5], the drop-channel is extracted actively through a non-linear optical process, while the added channel is passively coupled to the aggregate data signal after the drop operation. Recently, we demonstrated that both the add- and drop-operations could be performed simultaneously in a Non-Linear Optical Loop Mirror (NOLM) [6]. Here, we improve this experiment by increasing the bit rate to 160 Gb/s while at the same time achieving lower penalties.

## II. PRINCIPLE

The principle of the Simultaneous Add-Drop Multiplexer (sADM) based on a NOLM is shown in Figure 1. The internal polarisation control is adjusted so that input signals (at wavelength  $\lambda_{data}$ ) at the 160G-in and add-in ports are reflected by the loop. Circulators redirect the reflected signals towards the 160G-out and drop ports, respectively. High-intensity control pulses at 10 GHz (at  $\lambda_{ctrl}$ ) are then coupled into the NOLM. Time-delays ensure synchronisation inside the HNLF between the drop-channel (black pulse in the 160 Gb/s input signal), the 10 Gb/s add-channel (dashed pulse) and the 10 GHz control pulses. The external polarisation controllers and the control pulse power are adjusted so that the add- and drop-channels experience a phase-shift through cross-phase modulation (XPM) by the control pulses. This causes them to be transmitted by the NOLM instead of being reflected. As a result, the drop-channel is switched out at the drop port, and the add-channel is switched into the 160 Gb/s signal at the original position of the drop-channel, both operations being

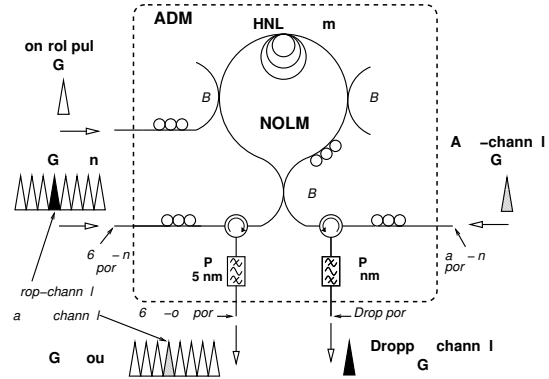


Fig. 1. Principle: simultaneous Add-Drop Multiplexing in a nonlinear optical loop mirror (sADM).

performed simultaneously. The control pulses are suppressed at the output ports by optical bandpass filters (BPF), centered at  $\lambda_{data}$ .

## III. EXPERIMENTAL SET-UP

The experimental set-up is shown in Figure 2.

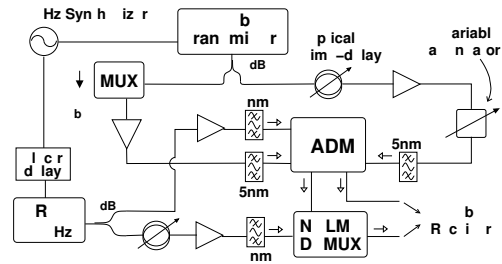


Fig. 2. The experimental set-up. The sADM is depicted in Figure 1.

The 10 Gb/s transmitter is composed of a 10 GHz Erbium Glass Oscillator Pulse Generating Laser (ERGO PGL,  $\lambda_{data} = 1557$  nm), followed by a Mach-Zender modulator which intensity-modulates the pulses with a  $2^7 - 1$  PRBS data pattern. A second 10 GHz ERGO PGL at  $\lambda_{ctrl} = 1544$  nm is used as a source for control pulses for both the sADM and DEMUX units. A 10 GHz synthesizer synchronises the transmitter, pulse sources and the 10 Gb/s receiver. The 10 Gb/s data is split in two by a 3 dB coupler. The first output is multiplexed up to 160 Gb/s by a passive PRBS-maintaining delay-line multiplexer

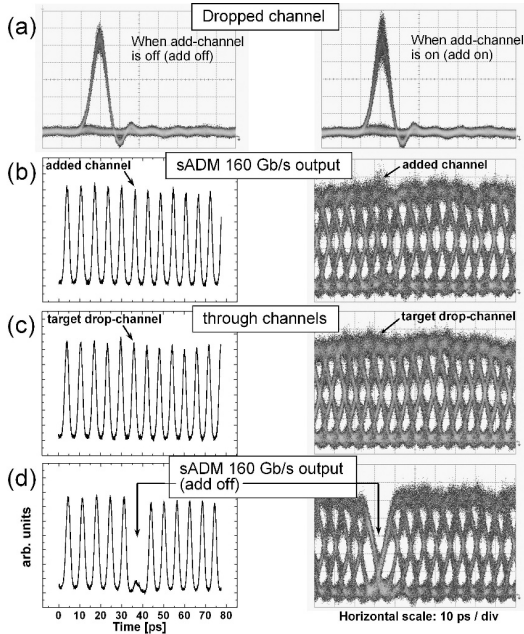


Fig. 3. Oscilloscope eye diagrams of: (a) the dropped channel, and of the sADM 160 Gb/s output in various cases: (b) with the added channel, (c) when the control pulses are off, resulting in reflection of the 160 Gb/s input signal by the sADM (then denoted through channels), (d) when the add-pulses are off. The corresponding cross-correlation traces have been included for (b), (c) and (d), on the left. The resolution on these is limited by the pulse width of the sampling pulse which is about 800 fs.

(MUX), amplified, filtered by a 5 nm BPF, and then directed to the 160G-in port of the sADM. The second output of the 3 dB coupler is directed to the add-in port, via a variable optical time-delay, an EDFA and a variable attenuator, used to adjust the synchronisation and amplitude of the add-channel. The HNL in the sADM is 100 m long, with a nonlinear coefficient  $\gamma = 10.5 \text{ W}^{-1}\text{km}^{-1}$ , a zero-dispersion wavelength  $1553.9 \pm 0.4 \text{ nm}$  and a dispersion slope  $0.018 \text{ ps}\cdot\text{nm}^{-2}\text{km}^{-1}$ . The average input powers and pulse widths (FWHM) at the sADM are: 6.9 dBm and 1.6 ps for the 160 Gb/s pulses, -5.7 dBm and 1.6 ps for the add pulses, and 26.0 dBm and 2.7 ps for the control pulses. The dropped channel is sent to the 10 Gb/s receiver. The 160 Gb/s sADM output signal is sent to an additional NOLM (DEMUX) for demultiplexing to 10 Gb/s, before detection in the receiver.

#### IV. RESULTS AND DISCUSSION

Cross-correlation traces and oscilloscope eye diagrams are shown in Figure 3. Bit error rate (BER) measurements and demultiplexed channel sensitivities are shown in Figure 4.

The sADM operation is successful with error-free performance. Figure 3 (a) shows a clear and open eye on the dropped channel, both with the add-channel on and off. Figure 3 (b) and (c) show that the added channel has the same amplitude and timing as the original channel (the target drop-channel). After demultiplexing, the sensitivity of the added channel is degraded by only 0.3 dB compared to the target drop-channel.

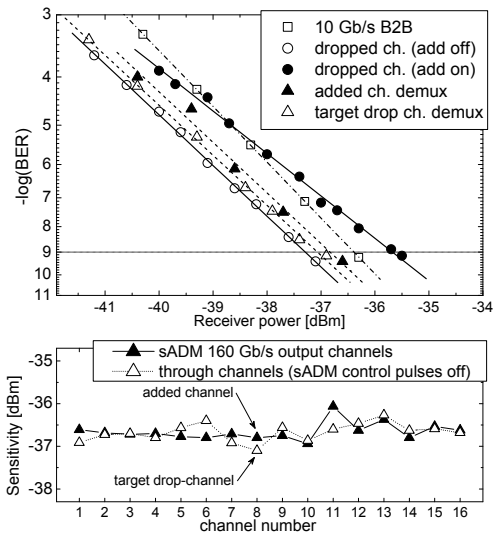


Fig. 4. BER curves (top), and demultiplexed channel sensitivities (bottom).

The sensitivity of the dropped channel is -35.7 dBm when the add-channel is turned on (add on), and -37.3 dBm when it is turned off (add off). This difference in sensitivity of 1.6 dB originates in the limited sADM switching extinction ratio (which is about 14 dB), resulting in interferometric cross talk between reflected (non-switched) and transmitted (switched) signals, which overlap temporally. For example, in Figure 3 (d), the add-channel has been turned off, which reveals non-switched drop-pulse light in the vacant time-slot. However, the total penalty is negligible owing to the regenerative properties of the NOLM demultiplexing. For the same reason, most of the demultiplexed channels have improved sensitivities compared to the 10 Gb/s B2B, which is -36.4 dBm. As shown in Figure 4, bottom, the sADM operation introduces no substantial penalty on any channel in the 160 Gb/s output. The maximum penalty is less than 0.6 dB, and all sensitivities lie within a 1 dB interval.

#### V. CONCLUSION

We have demonstrated error-free simultaneous add-drop multiplexing in a NOLM at 160 Gb/s, with practically no penalty on the added channel.

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