Optically Controlled 2x2 Exchange/Bypass Switch with 0.8 m of Bismuth Oxide Nonlinear Fibre

O. Zouraraki (1), P. Bakopoulos (1), K. Vyrsokinos (1), H. Avramopoulos (1)
1: Photonics Communications Research Laboratory, National Technical University of Athens
Zographou, GR 15773, Athens, Greece, e-mail: ozour@mail.ntua.gr

Abstract *We demonstrate an all-optical 2x2 switch using 0.8 m of Bismuth Oxide fibre. Error-free operation is obtained with less than 1.06 dB BER power penalty at both output ports.*

Introduction

The aim for higher network capacity has pushed intelligent routing and processing functionalities to the optical layer. In this way efforts have been made to demonstrate by all-optical means, a 2x2 exchange-bypass switch which is one of the more basic switching units. Up to now these efforts have been limited to semiconductor-based devices [1], [2], as they offer compactness, low switching power and potential for larger scale integration. However the recent advance in highly nonlinear fibres (HNLF) has renewed interest in fibre-based devices, as they offer fs nonlinearity response and nearly penalty-free switching with their off-resonant Kerr nonlinearity [3]. The kilometre-length nonlinear fibre spans in all-optical switches of the past are now being replaced by meter-long HNLF types. This has dramatically enhanced compactness and polarization stability of fibre-based schemes which are now emerging as competitive candidates for realistic optical switching applications. One of the most promising HNLF types is represented by Bismuth Oxide based nonlinear fibre (Bi-NLF), that displays a nonlinear coefficient in excess of 1000 $W^{-1}km^{-1}$ [4].

In this letter we use for the first time to our knowledge 0.8 m of highly nonlinear Bi-NLF to implement an optically controlled 2x2 exchange/ bypass switch. A single-arm, Ultrafast Nonlinear Interferometer (UNI) scheme [5] is adopted for the 2x2 switch configuration, providing simplicity and immunity to fibre instability. The switching window is defined by the width of the control pulses and enables successful bitwise operation with 40 Gb/s signals, whereas the scheme could in principle operate at considerably higher rates due to the response time of the nonlinearity. Error-free operation is obtained in bar- and cross state at both output ports with less than 1.06 dB power penalty.

Experiment

Fig. 1 shows the experimental setup for the evaluation of the 2x2 exchange/bypass switch. In this demonstration a single 10 Gb/s data channel along with a 40 Gb/s time-division-multiplexed (TDM) signal enter the fibre UNI, from inputs IN 1 and IN 2. In the absence of the control signal, the input signals exit the switch from OUT 1 and OUT 2 unaltered. Injection of the control signal causes the exchange function: one 10 Gb/s channel of IN 2 is switched to OUT 1, whereas the input signal of IN 1 is switched to OUT2 to form the new 40 Gb/s output signal.

A 1553 nm DFB laser diode was gain switched at 10 GHz to provide 10 ps pulses, which were fibre compressed to 3 ps. This pulse train was modulated in a Ti:LiNbO$_3$ modulator (MOD1) to form a pseudorandom data pattern and was divided to two parts in a 3 dB coupler. The first part was wavelength converted in an integrated, semiconductor Mach Zehnder interferometer (MZI 1) to generate a 10 Gb/s input signal (IN 1) to the 2x2 switch at 1558 nm. The second part was rate quadrupled in a fibre bit interleaver, to produce a 40 Gb/s 2^7-1 PRBS data

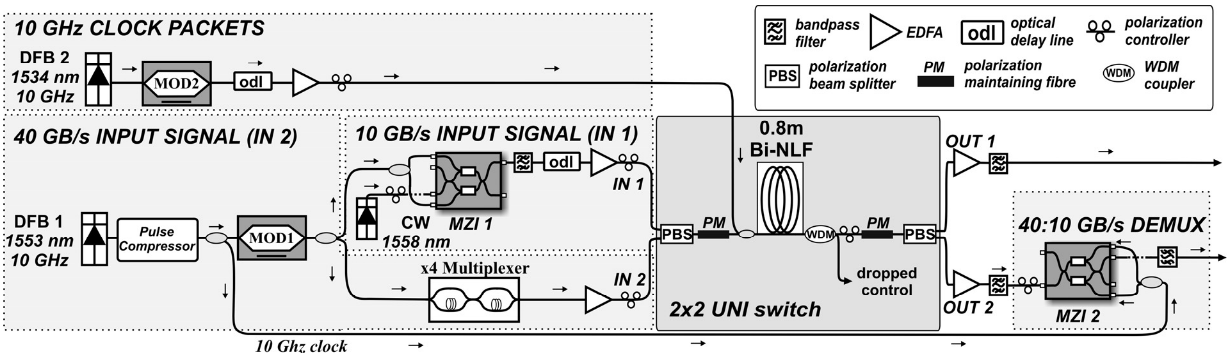

Figure 1: Experimental setup for the 2x2 exchange/bypass switch

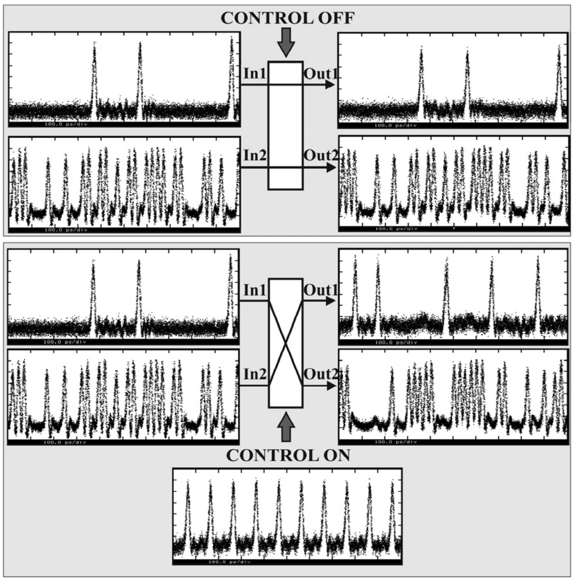

Figure 2: Pulse traces. First row: Bar state operation, second row: Cross state operation. (time scale: 100ps/div).

pattern (IN 2). The control signal was in the form of bursts of 10 GHz, 8.2 ps clock pulses. They were obtained from a gain-switched 1534 nm DFB diode whose pulse train was modulated in a Ti:LiNbO$_3$ modulator (MOD2) to form the bursts. This signal was then amplified in a high-power EDFA. These three signals were injected into the UNI 2x2 exchange/bypass switch, implemented as shown in Fig.1. The nonlinear element was a 0.8 m long, highly nonlinear (γ = 950 W^{-1}Km^{-1}) Bi-NLF fibre which was pigtailed with single-mode fibre (SMF). The Bi-NLF exhibited 1.3 dB/m propagation losses whereas the input pigtail splice caused an additional 2.1 dB loss. The polarization maintaining fibre sections before and after the Bi-NLF fibre provided 10 ps of birefringent delay. Precise bitwise synchronization between the three interacting signals in the UNI was achieved through variable optical delay lines. The control signal was removed after the nonlinear fibre with a 1550/1530 nm WDM demultiplexer. The signals at the output ports of the UNI were observed with a 50 GHz sampling oscilloscope and bit error rate measurements were performed. At output port OUT 2 a 40:10 SOA-MZI demultiplexer was used to demultiplex and evaluate the 10 Gb/s tributary channels.

Results

Fig. 2 shows typical results obtained at both output ports simultaneously. The first two rows depict bar state operation of the switch where the signals at IN 1 and IN 2 exit unaltered and the following two rows show the cross state.

The Bit-Error-Rate (BER) performance of the switch is shown in Fig. 3. BER curves are presented for the 10 Gb/s OUT 1 data along with the coinciding 10 Gb/s data channel of OUT 2 where the exchange/bypass operation occurs. Error-free operation was achieved at both output ports. In bar state operation a power penalty of 0.3 dB and 0.28 dB was measured at OUT 1 and OUT 2 ports respectively. Cross state operation caused an additional penalty of 0.5 dB and 0.78 dB at OUT 1 and OUT 2. For this performance the switch required 8.5 W of peak power corresponding to 69.7 pJ of control pulse energy and a complete π nonlinear phase change. Power levels refer to the Bi-NLF fibre input and take into account splice losses between it and the SMF pigtails. The shortness of the Bi-NLF ensured operational stability and no signal walk-off. The additional 2 dB power penalty in the input 10 Gb/s signal (IN 1) of Fig. 3 compared to the input 40 Gb/s (IN 2), is due to the wavelength conversion in MZI 1.

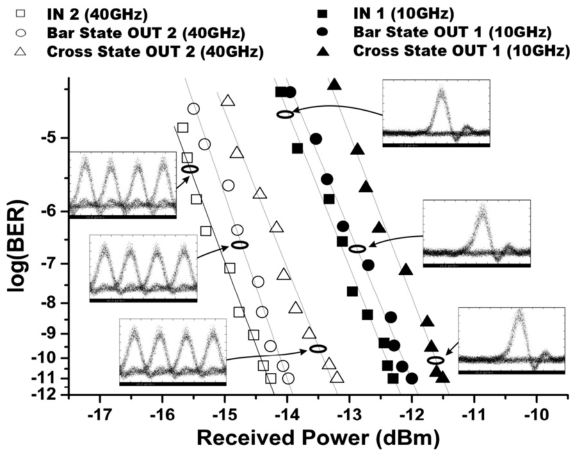

Figure 3: BER performance of the 2x2 exchange/bypass switch in bar and cross state.

Conclusions

We have demonstrated a 2x2 optically controlled exchange/bypass switch using 0.8 m of highly nonlinear Bi-NLF in a UNI configuration. Short fibre length provides compactness and operational stability to the switch. Error-free 2x2 operation was demonstrated with low power penalties, indicating the switch may be cascaded or used in feedback applications, without requiring regeneration.

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