Polarization-Independent OTDM Demultiplexer Based on a NOLM with a Polarization Diversity Loop

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Abstract: Polarization-independent all-optical time-division-demultiplexing is successfully demonstrated by incorporating a polarization diversity loop into the conventional NOLM. The polarization dependence is reduced from 6.3dB to 0.6dB in a 40 to 10-Gb/s OTDM experiment.

OCIS codes: (060.4510) Optical communications (060.4370) Nonlinear optics, fibers

1. Introduction

The nonlinear optical loop mirror (NOLM) [1,2] features a stable switching operation with fast response time (<1ps). Thus, when it is used as an all optical demultiplexer in high speed optical time-division-multiplexing (OTDM) systems, it can provide extremely narrow gating window for demultiplexing, which is beneficial to reduce the inter-channel crosstalk. However, the NOLM operation is in principle polarization dependent, which is a major obstacle to applying it in practical high speed systems, where the signal polarization is random.

Several methods have been proposed to realize polarization-independent demultiplexing operation [3-7]. In [3,4], the NOLM was constructed from some special components, such as polarization maintaining fiber (PMF) cross spliced at the mid point or twisted fibers, which were difficult to realize, in practice. In [5], a birefringent crystal was put into the loop to act as a full-wave plate for data wavelength and a half-wave plate for the control pulse wavelength, which limited the NOLM operation to narrow-band operation. In [6], the signal pulse was split into two orthogonal polarization components and fed into a conventional NOLM from different ports of the 3-dB coupler with suitable time delay. The walk-off between the control and signal pulses allowed the two orthogonally polarized signal components to be switched independently by the same control pulses and recombined after their polarization states were aligned. This relied on the walk-off between the control and signal wavelengths, posing more limitation on the switching speed and the choice of the control and signal wavelengths. In [7], a pair of short PMFwas put at the input and output ports of a conventional NOLM. The signal pulse width was required to be smaller than half of the bit duration to prevent overlapping between the fast axis component and slow axis component, leading to the limitation in switching speed.

In this paper, we propose and experimentally demonstrate a new scheme to achieve a polarization-independent NOLM (PI-NOLM) based OTDM demultiplexer by incorporating a polarization diversity loop into a conventional NOLM. Compared with previous schemes, it enables polarization-independent operation using conventional components without sacrificing operation speed, wavelength range or structural simplicity.

2. Operating Principles

The principle of the proposed scheme is shown in Fig.1. The main difference from a conventional NOLM is that a polarization beam splitter (PBS) is incorporated into the fiber loop to form one polarization diversity loop, which includes a span of dispersion-shifted fiber (DSF) as the nonlinear medium and one polarization controller (PC). The input signal pulse train is bi-directionally coupled into the NOLM via a 3-dB coupler and transmits in both clockwise (CW) and counter-clockwise (CCW) directions, as illustrated with thin solid arrows and thin dashed arrows in Fig.1, respectively. The signal in each direction is further split into two orthogonal polarization components by the PBS (namely TE and TM) with a corresponding amplitude ratio given by the input state of the polarization. A control pulse train is uni-directionally coupled into the NOLM (as illustrated with thick solid arrows in Fig.1) through a coupler with its polarization at 45° (through PC2) to the port A of the PBS such that the two orthogonally polarized components have equal amplitude to induce equal phase shift.

In the polarization diversity loop, the PC4 should be adjusted such that the recombined pulse trains will pass through the PBS instead of reflection (i.e. port A to port B or port B to port A). As both control pulses and CW signal pulses enter the polarization diversity loop from the same port of PBS, they will have the same polarization in this loop. Hence, the CW signal pulses will experience the maximum phase shift if it falls into the control pulse window. On the other hand, the CCW signal pulses will be injected into the polarization diversity loop from the other port of the PBS, thus its polarization in this loop is orthogonal to the control pulses. This means that the CCW signal will experience 1/3 of the maximum phase shift if it falls into the control pulse window or even zero phase shift if it does not fall into the window. The latter case is easy to achieve when the control pulse is much narrower than the bit duration. Consequently, the CW signal pulses will obtain the maximum phase shift (regardless of the input signal polarization but only depending on the control pulse power); while the CCW signal pulses will experience a much smaller phase shift. When they interfere at the 3-dB coupler of the NOLM, the polarization-independent demultiplexing of the input signal is achieved. An optical delay line should be incorporated into the NOLM to prevent the CCW signal pulses at those unwanted channels from being affected by the control pulses in the polarization diversity loop. This is not a stringent requirement, especially if the control pulse window is very narrow compared with the bit period, as in a lot of NOLMs.

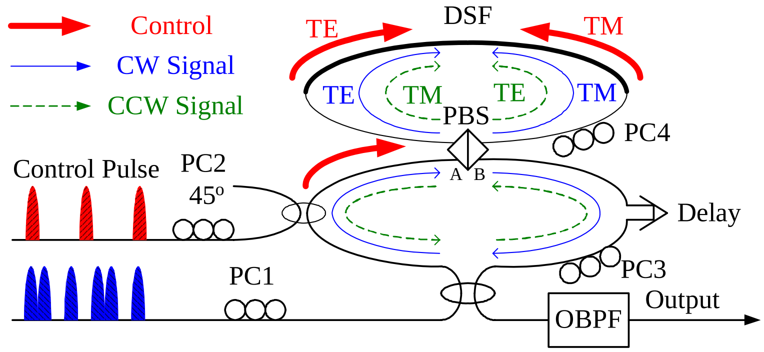

Fig. 1 Proposed schemes of PI-NOLM

3. Experimental Demonstration

Fig. 2 shows the experimental setup. The signal pulses (center wavelength: 1555nm) were generated from a mode-locked semiconductor laser (MLSL) at 10.61GHz with 1-ps pulse width, then externally modulated by a $LiNbO_3$ Mach-Zehnder modulator (MZM) with 2^{31}-1 pseudo-random bit sequence (PRBS) data, and optically multiplexed up to 42.44Gb/s. The PC1 is used to control the input signal polarization state. The control pulses (center wavelength: 1545nm) were generated from a mode-locked fiber ring laser (MLFL) at 10.61GHz (driven by the same radio frequency generator) with 3-ps pulse width. Its polarization could be adjusted via PC2 and the delay in this arm was used to adjust the relative position of the control and signal pulses. The NOLM consisted of a 3-dB coupler, a side port (3-dB coupler) for the input of control pulses, a PBS, 4-km DSF (zero dispersion wavelength: 1550nm), and two PCs (PC3 and PC4) for adjusting the system. The delay line described in Fig. 1 was replaced by using an optical patch cord of suitable length. An optical band-pass filter (OBPF) with 2-nm bandwidth was put at the NOLM output to block the control pulses and filter out the signals.

The adjustment of the system included three steps: Step 1-- only turn on the signal pulses and open the NOLM loop at the point between PBS and PC3. Then we adjust the PC4 to make sure the reflection is minimal. We can obtain the results by monitoring the power at the NOLM output to be minimal. Step 2-- close the NOLM loop and adjust PC3 to ensure the power at the NOLM output port is minimal. In this way, the NOLM is working in the mirror state. Step 3--turn on the control pulses and amplify them to 20 dBm. Then adjust the PC2 to realize the polarization independent operation. By tuning the delay on this arm, we could obtain different OTDM channels at the output.

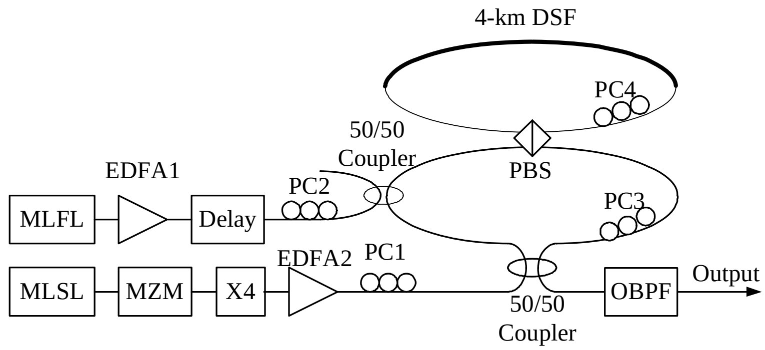

Fig. 2 Experimental setup

For purpose of comparison, a conventional NOLM was also built with similar setup (without the PBS and PC4). By tuning the input signal state, we obtained the best and the worst cases of the conventional NOLM switching operation, with the eye diagram (after pre-amplification before the oscilloscope) shown in Fig. 3 (a) and (b). The polarization dependence was 6.3 dB by measuring the switched signal power. When our proposed scheme was used, the polarization dependence was reduced to 0.6dB, with the eye diagram for the best case and worst case shown in Fig. 3 (c) and (d). We also measured the bit error rate (BER) performance of the conventional NOLM and our proposed PI-NOLM and compared them with the baseline, as shown in Fig.4. For the conventional NOLM, the best case exhibited 0.5-dB power penalty (at BER of 10^{-9}). However, for the worst case, it showed an error floor at BER=10^{-5} when the received power was -10dBm, so it was not shown in the figure. For our proposed scheme, the best case had 1.4-dB power penalty and the worst case had 1.8-dB power penalty when compared with the baseline. The reasons for the penalty include: (1) the self-phase-modulation (SPM) effect may cause the broadened spectrum of the control pulses to overlap with the signal wavelength, leading to crosstalk. This phenomenon is more serious in our PI-NOLM because the polarization diversity requires double control power or even more; (2) the polarization isolation of the PBS is not perfect (extinction ratio: 24-dB) so a small part of signals power is reflected to form the noise. In our experiment, we have measured all of the four OTDM channels and the results were quite similar to each other.

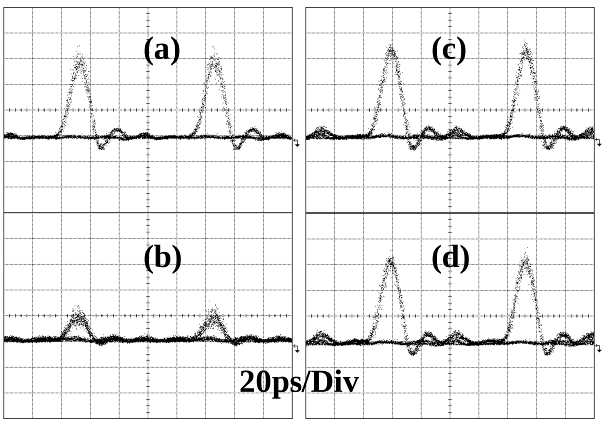

Fig.3 Eye diagrams of the switched signal pulses:
(a) and (b) the best and worst case of the conventional NOLM;
(c) and (d) the best and worst case of PI-NOLM

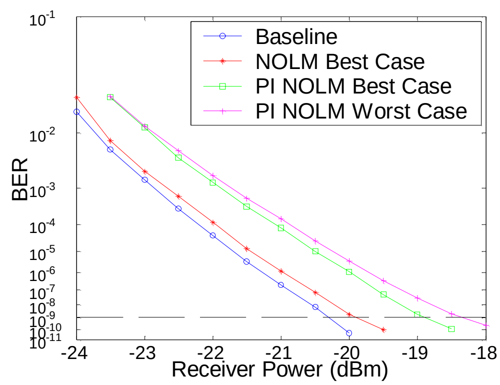

Fig.4 BER performance of the demultiplexed channels in various situations

4. Conclusion

In this paper, we have proposed and experimentally demonstrated a new polarization-independent OTDM demultiplexing scheme by incorporating a polarization-diversity loop into a conventional NOLM. 42.44-Gb/s to 10.61-Gb/s demultiplexing is successfully achieved with 0.6-dB polarization dependence. The power penalties are less than 2-dB in all cases. The proposed PI-NOLM offers stable operation using the conventional components without sacrificing the operation speed or structural simplicity. This scheme can be readily upgraded for 80-Gb/s demultiplexing applications. This project was partially supported by a research grant from Hong Kong RGC.

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