Asynchronous, self-controlled, all-optical label and payload separator using nonlinear polarization rotation in a semiconductor optical amplifier

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Abstract: We demonstrate an all-optical label and payload separator based on nonlinear polarization rotation in a semiconductor optical amplifier (SOA). The proposed scheme uses a packet format composed of a label and payload information signal combined with a control signal by using polarization division multiplexing. The control signal is employed to separate the label from the payload signal by exploiting nonlinear polarization rotation in a SOA. Experimental results show a label from payload suppression factor of 22 dB. This scheme operates asynchronously and does not need external control signal. Clean and wide open eye diagrams are obtained for both the payload and the label signal operating at bit-rates of 10 Gbit/s and 625 Mbit/s, respectively.

OCIS codes: (060.2330) Fiber optics communications, (190.7110) Ultrafast nonlinear optics.

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1. Introduction

Optical label swapping (OLS) is a promising technique for implementing IP packet routing and forwarding functions over wavelength division multiplexed (WDM) optical networks [1]. OLS aims at reconciling the gap between the high line rate of data transmission over WDM links and the electronics processing bottleneck due to the high speed and complexity required to handle IP traffic at the core nodes of the network. All-optical label swapping techniques due to their potential ultra-fast operation are a promising solution for IP packet routing speeds matching the line rates; avoiding in this way any processing bottleneck [2-3]. At the ingress node of a OLS network, packets with a common destination or class of services will be aggregated and equipped with a short fixed label. Core nodes process this label and based on its information perform a forward decision. The routing and forwarding of IP packets can be done for example by adopting the rules of the multi-protocol label switching (MPLS) scheme. Therefore at the core nodes, the optical label is usually separated from the payload for the corresponding signal processing. Several schemes has been proposed to separate the label (header) and payload information by using all-optical signal processing techniques based on nonlinear polarization switches [4]. However, most of the proposed approaches use an external control pulse synchronized with the label bits [3]. Recently, [5] proposed a scheme without the need of a synchronized external control pulse, however it requires Manchester encoding of the payload data for its proper operation and thus it compromises the payload format.

In this letter we propose an all-optical label separation scheme with no need of external synchronized control signal and that allows for arbitrary payload data format. The proposed scheme uses polarization division multiplexing to simultaneously transmit the control signal together with the payload and label signal. In this way, the role of the control pulse is performed by one of the two polarization states. An advantageous feature of this technique is its simplicity and the freedom of payload data encoding format. Moreover, the proposed scheme has the potential for integration on a photonic circuit, including the SOA and the polarization diversity splitters [6].

We demonstrate experimentally the proposed scheme for a system operating at a payload bit rate of 10 Gbit/s and label signal at 625 Mbit/s. The measurements show that a label to payload suppression of 22 dB is achieved.

2. System concept

The experimental set-up of the proposed all-optical label and payload separator is depicted in Fig. 1. As shown in the dashed box of Fig. 1, the label and payload separator is composed of two SOAs, two polarization beam splitters (PBS) and one optical circulator (OC). Polarization controllers (PC) and optical band pass filters (BPF) are also necessary for adjusting the operating point of the separator. The packet format is composed of the payload data and its label, intensity modulated onto one of the principal state of polarization of the lightwave. A control signal is combined, simultaneously to the payload and label signal, by using polarization diversity multiplexing. The control signal is a high intensity pulse lasting the corresponding duration of the payload data. A guard time is inserted between the label and payload enough to allow possible misalignment between the packet and the control signal, and ensure polarization rotation effect in the SOA.

At the label separator block, the first polarization controller (PC_1) is used to adjust the incoming signal to the PBS_1 so that effective polarization splitting is achieved for the packet (payload and label) at one output port and the control signal in the complementary output port. The packet signal is injected into the SOA_1, and its polarization is adjusted by using the PC_2 to match the orientation of the second PBS_2. The control signal, obtained at the second port of the PBS_1, is amplified and used as a high-intensity pump signal for the SOA_1. The length of the optical delay ($Delay_1$) is adjusted so that the control and the payload signals coincide at the SOA_1. Note that due to the chosen packet format, once the delay is set, there is no need for additional synchronization. The injected pump signal, coinciding with the payload signal at

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the SOA_1, introduces additional birefringence in the SOA_1 and therefore the polarization mode of the signal experiences a different refractive index [7]. In the case where no control signal is present, the label is amplified by the SOA_1, exiting the system through the output of the PBS_2. Conversely, if the saturating pump control signal is present, the additional birefringence in the SOA leads to a phase difference between the propagation modes, causing the polarization of the payload signal to be rotated [8-9]. As a consequence, the polarization of the payload is rotated, exiting the system through the output of the PBS_3.

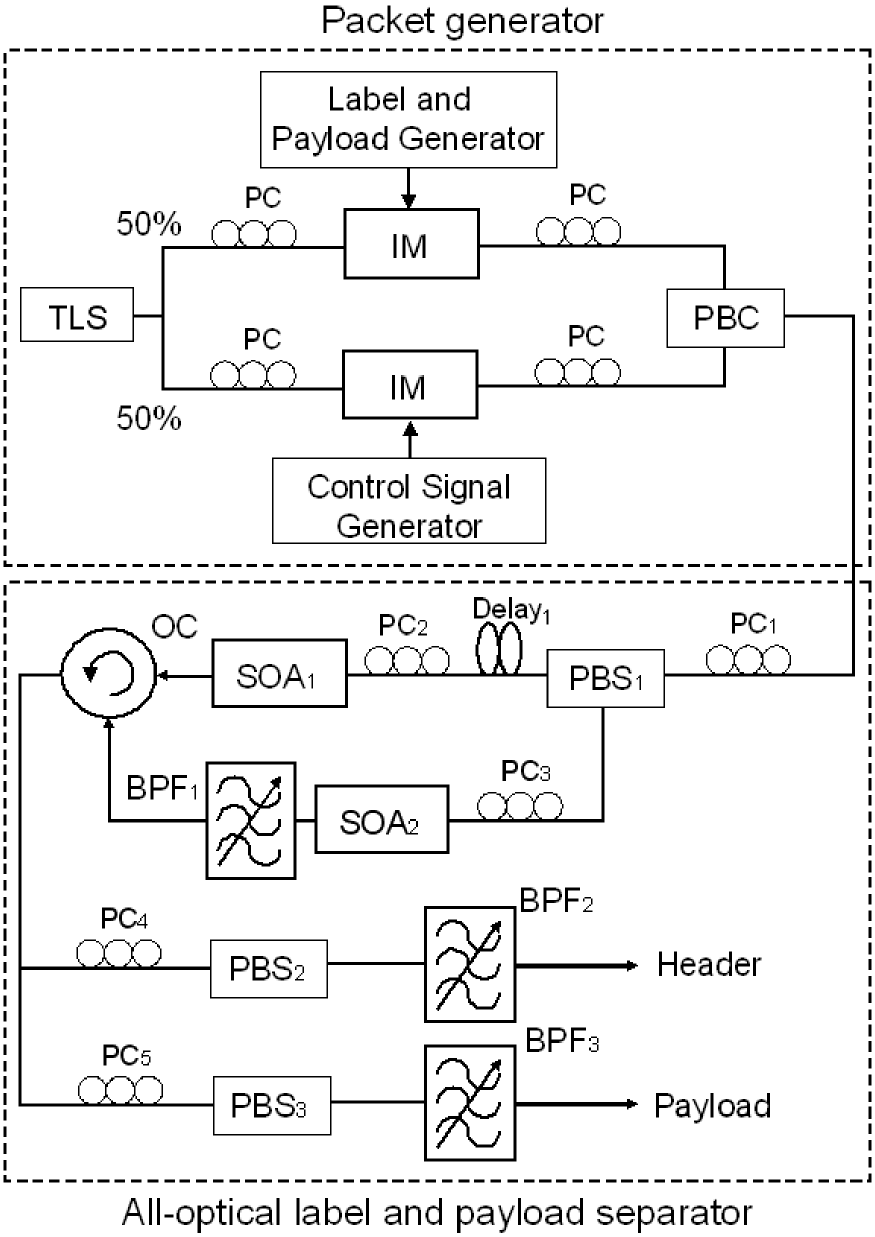

Fig. 1. The configuration of the all-optical label and payload separator based on nonlinear polarization rotation. TLS: tunable laser source. PC: polarization controller. IM: intensity modulator. PBC: polarization beam combiner. PBS: polarization beam splitter. BPF: optical band pass filter. DELAY: optical delay.

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3. Experiment and results

In the experimental setup shown in Fig. 1, the continuous wave (CW) probe light (1550.2 nm) generated by a tunable laser source (TLS) is split by using a 3 dB coupler and injected into two intensity modulators. The modulator of the upper branch is used to impose the payload and label modulation, driven by an electrical signal coming from a pulse pattern generator (PPG). The label was modulated at 625 Mbit/s and the payload at 10 Gbit/s. Although we selected a low bit-rate for the label, it can be increased up to 10 Gbit/s without noticeable changes in the results. The label is composed of a pattern consisting of a hexadecimal “AA” data stream, and the payload data is a 2^{31}-1 non-return-to-zero pseudorandom bit stream. The optical intensity modulator of the lower branch is used to introduce the control signal modulation. It is driven by an electrical signal derived form a second PPG, synchronized to the one in the upper branch in such a way that it generates a ‘1’ signal only during the payload duration.

The modulated signals were fed into a polarization beam combiner to assure that only one of the polarization axes of the label and the payload and, complementarily, the orthogonal polarization axis of the control signal are present at the output of the packet generator block. The resulting combined signal is shown in the inset (a) of the Fig. 2.

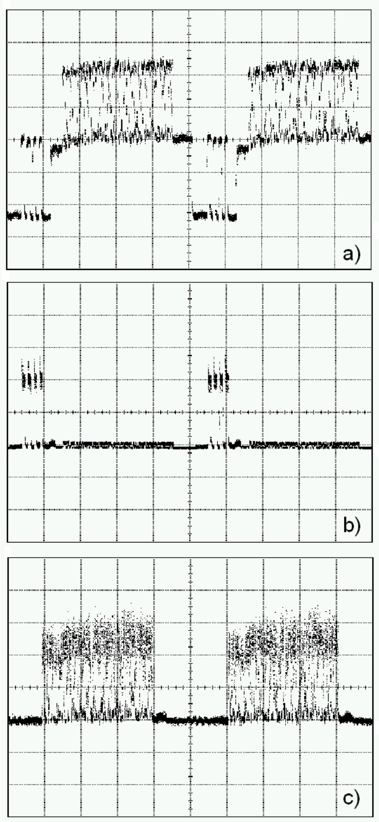

Fig. 2. Oscilloscope traces of the combined signal from the generator (a), the separated label (b) and the separated payload (c). The timescale is 20 ns/div and the voltage scale is 50 mV/div.

This signal was launched into the all-optical label and payload separator, where the first stage is the PC_1 and the PBS_1. By adjusting the setting of the PC_1, effective separation of the packet and the control signal is performed. At one output port of the PBS_1 is present the

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packet signal which is fed into the SOA_1 thought the PC_2. The bias current of the SOA_1 is set to 200 mA. The SOAs used at the present experiment have an active length of 800 μm, employing a strained bulk active region and are manufactured and commercially available by JDS Uniphase. The output signal of the SOA_1 was coupled into the OC, and then into the PBS_2 through the PC_4. The control signal, present at the other output port of the PBS_1, is fed into the SOA_2 thought the PC_3. The bias current of SOA_2 is set to 350 mA. The output signal of this SOA was filtered by using an optical band pass filter (BPF_1) (0.3 nm bandwidth) to suppress the spontaneous emission noise and then coupled into the OC. The signal at the output port of the OC is connected to the PBS_2 and the PBS_3, and filtered by using the optical filters BPF_2 and BPF_3 (1 nm bandwidth).

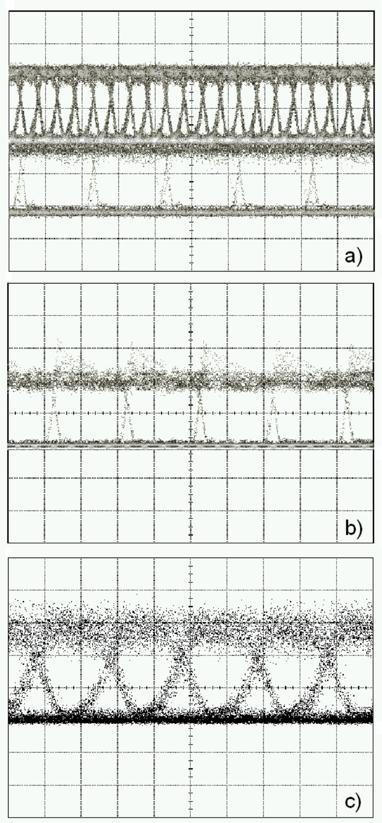

Fig. 3. Eye diagram of the combined signal from the generator (a), the separated label (b) and the separated payload (c). The timescale are 200 ps/div, 50 ps/div and 200ps/div, respectively. The voltage scale is 50 mV/div.

Figure 2 shows the oscilloscope traces of the separated label and payload. The recovered label shows an overshoot, due to the selected operating point of the SOAs, close to the saturation regime. The recovered payload shows a noisy ‘1’ level, mainly due to crosstalk between the orthogonal modes during the separation process performed at PBS_1. However, as it can be seen from Fig. 3, the corresponding eye diagrams are clean and wide open. The suppression factor between the label and the payload is measured to be 22 dB. Although we only present results with a 625 Mbit/s label, this bit-rate can be increased up to 10 Gbit/s obtaining the same results of suppression ratio. The ultimate speed of the scheme is limited by the recovery time of the carrier density. If operating bit-rates are below the main limitation given by the SOA recovery time, arbitrary bit-rate may be used for the payload and label signals.

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4. Conclusion

We have experimentally demonstrated a simple technique for all-optical label separation by using nonlinear polarization rotation in an SOA. We use a polarization multiplexing scheme to send together the packet and its corresponding control signal that is used to introduce additional birefringence in a SOA. The packet signal experiences different polarization rotation depending whether the control signal is present or not, yielding an effective separation of the payload and the label. The experimental results show that a 22 dB label to payload suppression factor is achieved for a 10 Gbit/s payload and a 625 Mbit/s label data rate. A WDM diversity scheme could be used as well for send the control signal. However, the present proposed polarization diversity scheme has the advantage of better bandwidth utilization.

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