# All-optical header pre-processor based on self-phase modulation in a semiconductor optical amplifier

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*We present an all-optical header pre-processor based on self-phase modulation in a semiconductor optical amplifier. The operation principle is discussed and demonstrated on packets with a NRZ header at a data-rate of 2.5 Gbit/s and a Manchester encoded payload at a data-rate of 10 Gbit/s. We also demonstrate that the header pre-processor improves the performance of an all-optical header processor based on two-pulse correlation in a SLALOM configuration.*

## Introduction

An all-optical header processor is a fundamental function to speed up hybrid optical packet switched networks [1]. An all-optical header processing technique based on two-pulse correlation principle in a SLALOM configuration was demonstrated [2,3]. The header of the data packets that were used in the experiments was at lower bit-rate (2.5 Gbit/s) than the packet payload (10 Gbit/s). Moreover, the payload was Manchester encoded so that the header pattern is not repeated in the packet payload. The packets had a guard-time between the header and the payload. The guard-time had a length equal to the length of the header section. Moreover the packets had a tail section. The guard-time and the tail sections were necessary to adequately suppress the correlated packet payload. This header processing system was successfully employed to demonstrate all-optical packet switching [4].

In this paper, an all-optical header-payload separator is presented. In the optical packet switch that is presented in [4], an optical threshold function is used to compensate for an insufficient contrast between the correlated header pulses and the suppressed packet payload. A pre-processing step that discriminates the header and payload is useful for two reasons. Firstly, it improves the performance of the header processor so that the optical threshold function becomes redundant. Secondly, the packet structure could be simplified. We will show that by using the all-optical header-payload separator, the guard-time and the tail section become redundant so that the packet overhead is reduced.

## Operating principle

The operation of the optical header-payload separator is based on Self-Phase Modulation (SPM) in a Semiconductor Optical Amplifier (SOA). As shown in Figure 1, the system is made out of an SOA in combination with a narrow bandwidth Fiber Bragg Grating (FBG). The packet format is also presented in Figure 1. The header section consists of NRZ data-bits that are at a lower bit-rate than the packet payload. The packet payload is Manchester encoded. In a Manchester encoded data stream a binary "1" and a binary "0" is represented by the rising or falling transitions respectively. Therefore, the average signal power of the payload is constant, regardless of the specific bit pattern. In our concept, using Manchester encoded payload is essential to guarantee that the SOA remains in saturation when the packet payload passes by.

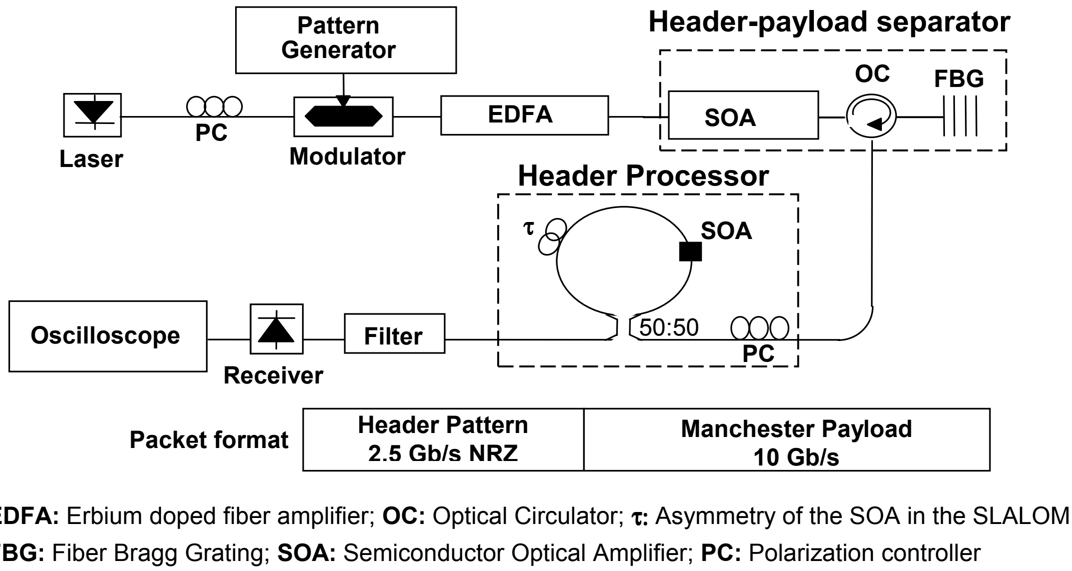


**Figure 1** Experimental set-up of the all-optical header-payload separator as pre-processor of an optical header processor.

When an optical bit at wavelength $\lambda$ with sufficient optical power arrives at the SOA, an overshoot in the amplification at the leading edge of the bit is generated due to the change of the gain in the SOA. Also the wavelength at the leading edge of the bit is red chirped ($\lambda \rightarrow \lambda + \Delta\lambda$) as a result of the overshoot [5]. The change in wavelength at the leading edge is caused by SPM driven by nonlinear gain saturation in the SOA [6]. By using a FBG centred around $\lambda + \Delta\lambda$, the red chirped leading edge of the pulse can be filtered out. The amplitude of the filtered leading edge of the bit depends on the gain of the amplifier.

When an optical data packet is fed into the all-optical header-payload separator, a red shift is generated at the leading edge of all the data bits. The time between the pulses in the header has been chosen larger than the recovery time of the SOA. This results in a strong red shift at the leading edges of the header bits. The constant averaged optical power of the Manchester encoded payload ensures that the SOA remains in deep saturation when the payload passes by. Hence, the red shift that is introduced at the leading edge of the payload bits is small compared to the red shift introduced at the leading edge of the header bits.

## Experiment

The concepts of the optical header-payload separator were demonstrated by using the set-up shown in Figure 1. The laser source at λ=1558.34 nm was modulated by a 10 Gbit/s Mach-Zehnder modulator, which was driven by a pulse-pattern generator. The

SOA in the optical header-payload separator was pumped with 204 *mA* of current, corresponding to a saturation gain of 10 dB with CW light. The FBG, centred at $\lambda$=1558.93 nm, has a bandwidth equal to 0.43 nm. Sequential optical packets with two different header patterns are used in the experiments. The packets are presented in Figure 2a. The packets have a header section consisting of NRZ data at a bit-rate of 2.5 Gbit/s, and a payload section consisting of Manchester encoded PRBS data at a bit-rate of 10 Gbit/s. In contrast to the results presented in [3], the packets used in this experiment have no guard-time and no tail sections. The first header (Header 1) has a '1100 0000 1100' bit pattern. The time between the leading edges of the two header pulses is equal to $T_1$=3.2 ns. The second header (Header 2) has a '1100 0000 0011' bit pattern, In this case is the time between the leading edges of the two header pulses equal to $T_2$=4 ns. In Figure 2a packets with Header 1 and Header 2 are shown.
The average optical power of the optical packets at the input of the header-payload separator was 4 dBm. The measured red shift at the leading edge of the data bit was 0.42 nm. The oscilloscope trace of the signal at the output of the all-optical header-payload separator is presented in Figure 2b. It is clearly visible in Figure 2b that the header-payload separator generates a pulse at the leading edges of the header bits. The averaged suppression of the packet payload is 11.4 dB. It is also visible in Figure 2b that the time between the header pulses of the first and second header pattern remains equal to $T_1$ and $T_2$, respectively.

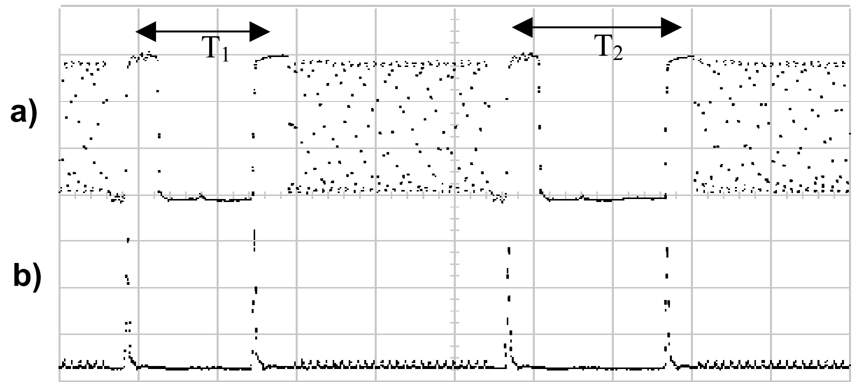


**Figure 2** Measured oscilloscope traces. In a) the optical packets are plotted; in trace b) the output of the optical header-payload separator is shown. The timescale was 2 ns/div and voltage scale 100 mV/div.

In order to demonstrate that the use of the all-optical header-payload separator improves the performance of a SLALOM based header processor [2, 3], the output of the header-payload separator is fed into the SLALOM based optical header processor (see Figure 1). The SOA in the SLALOM configuration was pumped with 119 *mA* of current. The displacement of the SOA with respect to the centre of the loop is $\tau$=1.6 ns. The displacement of the SOA matches with the time $T_1$ between the leading edges of pulses in Header 1. Thus, we aspect that a correlation pulses is formed at the output of the header processor only for optical packets with Header 1. This is confirmed in Figure 3 where it is clearly visible that only for the packet with Header 1 a correlation pulse is formed. The contrast ratio between the average optical power of the header correlation pulse and the suppressed payload is equal to 17.8 dB, resulting in an improvement of 3.3 dB compared to the results presented in [2, 3].

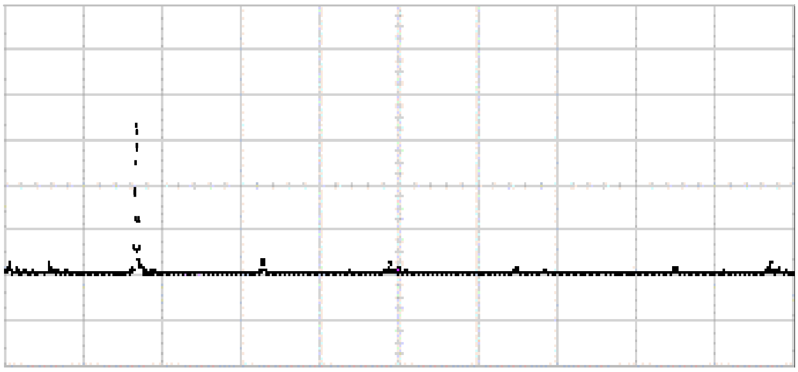

**Figure 3** Measured oscilloscope traces of the output of the header processing system. The timescale was 2 ns/div and voltage scale 100 mV/div.

## Conclusions

In this paper, an all-optical header-payload separator is demonstrated. The contrast ratio of the header pre-processor is equal to 11.4 dB. We have demonstrated the operation at a header bit-rate of 2.5 Gbit/s and a payload data rate of 10 Gbit/s. Operation at higher bit-rate may be possible by increasing the gain recovery time of the SOA [7]. Moreover, the design of the optical header-payload separator involves only a single SOA and an optical filter, thus the system could be integrated in a photonic integrated circuit.

We have also demonstrated that the header-payload separator improves the performance of the optical header processor that is presented in [2, 3]. The guard-time and the tail section of the optical packets become redundant so that the packet overhead is reduced. Moreover, the contrast ratio between the header correlation pulse and the suppressed payload is equal to 17.8 dB, which is an increase of 3.3 dB compared to the result obtained in [2, 3].

## Acknowledgements

This research was supported by the Netherlands Organisation for Scientific Research (NWO) through the “NRC Photonics” grant.

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