Multiple-output all-optical header processing technique based on two-pulse correlation principle

Citation for published version (APA):

DOI:
10.1049/el:20010857

Document status and date:
Published: 01/01/2001

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication
25ps, respectively. We modulated them with a four-bit pulse pattern by using an electro-optic modulator, and injected into the D/A converter. The output pulses from the D/A converter were gated with an EA modulator at 2.5Gbit/s, and fed into the optical power monitor. The gate width was ~100ps. Figs. 3a and b show an input pulse pattern (0110) and an output waveform from the D/A converter, respectively, which we observed on a sampling oscilloscope. The height of the peak marked by the solid square in Fig. 3b corresponds to the digital-to-analogue converted 0110 pattern, that we gated with the EA modulator. The inset in Fig. 3b shows the theoretical output waveform, which agrees well with the measured waveform.

Fig. 3 Input and output waveform of D/A converter
a) Input pulse pattern (0110)
b) Output waveform
Inset: theoretical waveform

Fig. 4 Relationship between input pulse patterns and D/A output
● experimental data
― theoretical curve

Fig. 4 shows the measured relationship between incoming pulse patterns and D/A output. The dots show the measured data, which agree well with the theoretical curve. A slight discrepancy between them is due to the adjustment error in coefficients of the D/A converter and the measurement error.

Conclusion: We have demonstrated a novel pulse pattern recognition circuit based on a PLC D/A converter. Four-bit pulse sequences at 10Gbit/s were successfully recognised in the optical networks.

Acknowledgment: The authors wish to thank T. Kurihara, Y. Hibiino and T. Maruno for their encouragement.

References

Multiple-output all-optical header processing technique based on two-pulse correlation principle


A serial all-optical header processing technique based on a two-pulse correlation principle in a semiconductor laser amplifier in a loop mirror (SLALOM) configuration that can have a large number of output ports is presented. The operation is demonstrated experimentally at a 10Gbit/s Manchester encoded data stream. Experimental evidence is provided in the case of two different output ports.

Introduction: Recently, an all-optical header processing method, based on a two-pulse correlation principle in a semiconductor laser amplifier in a loop mirror (SLALOM) configuration, was experimentally demonstrated [1]. It was shown in [1] that if the packet header is chosen well, a correlation pulse can be generated at the output of the SLALOM (state 1). Alternatively, a suppressed payload with much smaller amplitude arrives at the output of the SLALOM (state 2). Later, this header processing method was successfully employed in a 1 x 2 all-optical packet switch [2]. The two states of the packet switch correspond to the two output states of the header processor.

In principle, the concept of the 1 x 2 all-optical packet switch presented in [2] can be generalised to a 1 x N all-optical packet. It is therefore crucial to extend the header processing technique of [1]. Whereas the header processor in [1] has only one output port (that could have two different states), we show in this Letter how the concepts presented in [1] can be extended to form all-optical header processing units (HPUs) that have a large number of output ports. The method that we present has all the advantages of the header processor presented in [1]. The serial processing nature avoids complicated serial-to-parallel conversion and our method does not impose a fixed packet length.

Principle of operation: To obtain two-pulse correlation in a SLALOM configuration, three time scales play an important role. First, there is the time $T$ between the two pulses. Moreover, there is the time $\tau$ that represents the displacement of the semiconductor optical amplifier (SOA) with respect to the centre of the loop. The third time scale is the recovery time $\tau_r$ of the SOA. If we choose $2\tau$ and $T$ large so that $\tau_r < \tau$, we can distinguish three important cases. The first case $T = 2\tau$ where $\tau_r > \tau$. This implies that the first pulse of the counter-clockwise propagating pulse arrives at the SOA between the two pulses of the clock-wise propagating signal. As a result, all the pulses in the packet header receive full gain and no correlation pulse is formed at the output port. The second case is $\tau < \tau_r < 2\tau$. This is the case in which a correlation pulse is formed, since the first pulse of the counter-clockwise propagating pulse experiences a saturated SOA owing to the second pulse of
the clockwise propagating signal [3]. The third case is 2τ2 - T > τ2. This implies that the first pulse of the counter-clockwise propagating signal arrives at the SOA after the second pulse of the clockwise propagating signal has left the SOA. Hence, all the involved pulses receive full gain and no correlation pulse is formed at the output port.

A header processor based on this principle is implemented as shown in Fig. 1. The optical power of a packet arriving at the header processor is split into two equal parts by the optical splitter. Half of the optical power is fed into the SLALOM structure of HPU1. The other half of the optical power is fed into the SLALOM structure of HPU2. The SLALOM structure in HPU1 differs from the SLALOM structure in HPU2 by the displacement of the SOAs with respect to the centre of the loop. The data format is also shown in Fig. 1. The packet has a header section of 20 bits and a payload section of 74 bytes. Header and payload are separated by a guard band of 16 bits. The payload is followed by a tail section of five bytes. The optical packet header consists of non-return to zero (NRZ) data at effectively a lower bit rate than the payload. Manchester coding of the payload is necessary to avoid repeated header patterns in the payload [1].

We assume that we have packets with two different header patterns. The first packet has a header section consisting of a hexadecimal ‘FOOFO’ pattern corresponding to the time T1 (see Fig. 1). The second packet has a header section consisting of a hexadecimal ‘FOOOF’ pattern corresponding to the time T. We choose the displacement times τ1 and τ2 of the two HPUs in such a way that T1 = 2τ1 < τ and T2 = 2τ2 < τ.

Suppose that a packet with a header FOOF0 enters HPU1. Since T1 = 2τ1 < τ, a correlation pulse is formed at the output of the header processor. However, if the same packet enters HPU2, no correlation pulse is formed since 2τ2 > T and 2τ2 < τ. Conversely, if a packet with a header FOOFOF arrives at HPU2, a correlation pulse is formed at output port 2. However, no correlation pulse is formed at output port 1 since T2 = 2τ2 < τ.

The high bit rate optical payload is suppressed because it drives the SOA in saturation. To obtain efficient suppression of the payload, a tail section is necessary to guarantee that the SOA remains in saturation when the payload passes through. A tail section is useful in applications where the packet size is variable, and packet length information is needed.

**Experiment:** The concepts described in the previous Section are demonstrated experimentally by using the setup in Fig. 1. The wavelength division multiplexing (WDM) source at λ = 1550.9 nm was modulated by a 10Gbit/s Mach-Zehnder modulator, which is driven by an electronic packet generator. The packet consists of a header, a tail section at a 2.5 Gbit/s NRZ data format, and the payload format consists of a 10Gbit/s Manchester encoded pseudorandom bit stream (PRBS) data stream (information rate of 5 Gbit/s). The average optical power was -1.73 dBm at the input of the optical header processing system. The SOA was manufactured by JDS Uniphase and employs an 800 μm strained bulk active region. The displacements of the SOAs in the SLALOM configuration are set to 2τ1 = 4.5 ns for the HPU1 and 2τ2 = 6.4 ns for HPU2. The frequency of the signal generator was 9.5132 GHz to match with the τ of the displacement time.

First, data packets with a hexadecimal ‘FOOFOF’ header pattern enter the header processor. The photocurrents at output port 1 of HPU1 and output port 2 of HPU2 are presented in Fig. 2. It can be observed from this Figure that a correlation pulse is formed only at output port 1. The header processor produces a 1.8 ns-wide header correlation pulse and 4 ns correlation pulse for the tail. The suppression between the average power of the payload and the header correlation pulse was 14.39 dB.

**Fig. 1 Experimental setup showing SLALOM-based serial all-optical header processor and packet structure**

HPU: header processor unit; MZ: Mach-Zehnder modulator; PC: polarisation controller; PG: pattern generator; T1: delay line.

**Experiment:** The concepts described in the previous Section are demonstrated experimentally by using the setup in Fig. 1. The wavelength division multiplexing (WDM) source at λ = 1550.9 nm was modulated by a 10Gbit/s Mach-Zehnder modulator, which is driven by an electronic packet generator. The packet consists of a header, a tail section at a 2.5 Gbit/s NRZ data format, and the payload format consists of a 10Gbit/s Manchester encoded pseudorandom bit stream (PRBS) data stream (information rate of 5 Gbit/s). The average optical power was -1.73 dBm at the input of the optical header processing system. The SOA was manufactured by JDS Uniphase and employs an 800 μm strained bulk active region. The displacements of the SOAs in the SLALOM configuration are set to 2τ1 = 4.5 ns for the HPU1 and 2τ2 = 6.4 ns for HPU2. The frequency of the signal generator was 9.5132 GHz to match with the τ of the displacement time.

First, data packets with a hexadecimal ‘FOOFOF’ header pattern enter the header processor. The photocurrents at output port 1 of HPU1 and output port 2 of HPU2 are presented in Fig. 2. It can be observed from this Figure that a correlation pulse is formed only at output port 1. The header processor produces a 1.8 ns-wide header correlation pulse and 4 ns correlation pulse for the tail. The suppression between the average power of the payload and the header correlation pulse was 14.39 dB.

**Fig. 2 Output at ports 1 and 2 when packet 1 is processed**

**Fig. 3 Output at ports 1 and 2 when packet 2 is processed**

Fig. 3 shows the photocurrents at output port 1 and output port 2 should a packet with a hexadecimal ‘FOOFOF’ pattern enter the header processor. It follows from Fig. 3 that a header correlation pulse is formed only at output port 2. The header processor produces a 1.8 ns-wide header correlation pulse and 4 ns correlation pulse for the tail. The suppression between the average power of the payload and the header correlation pulse was 14.44 dB.

This experiment indicates that the setup presented in Fig. 1 is indeed capable of processing two different headers. By matching the displacement time 2τ2 and the time T between two header pulses in the correct way, a larger number of packet headers can be recognised. If we take a 32 bit IP destination address at 2.5 Gbit/s as a reference, at least 30 different addresses could be recognised per wavelength.
Conclusion: We have demonstrated an all-optical serial header processor that can recognise two different packet headers and form a correlation pulse at two distinct output ports. We believe that this principle can be extended to recognise more header patterns. Our demonstration showed the header processor working with payload data rates of 10 Gbit/s, however we believe that it is possible to process payloads at higher bit rates.

The design of the HPU provides several key advantages over alternate techniques. The serial nature of the HPU removes the additional complexity of the separation of payload and header sections of the packet and does not impose a fixed packet length. In addition, the HPU is a low-power device; the amount of input power required can be adjusted when the current into the SOA.

Acknowledgments: The authors wish to thank F.M. Huijskens for providing the optical delay lines that made the experiments possible. This research was supported by the Netherlands Organisation for Scientific Research (NWO) through the 'NRC Photonics' grant.

© IEE 2001
Electronics Letters Online No: 20010857
DOI: 10.1049/el:20010857
E-mail: n.calabretta@tue.nl

References

Fig. 1 Basic principle of proposed all-optical method

Operating principles: Fig. 1 shows the basic principle of the proposed method that separates the SCM header and the baseband data payload using an optical building block consisting of an FBG filter and an optical circulator. The input optical signal, generated by a standard DSB-SCM modulator, is a combination of a baseband data payload and a DSB-SCM header. Therefore, the setup allows the FBG filter to reflect the baseband payload and to transmit the DSB-SCM header, while the optical circulator separates the reflected data payload from the transmitted header. The data payload and the header can each be demodulated by an information-bandwidth-limited photoreceiver at each port since no cross-mixing terms of the two components will be present. Here, for the SCM header, because the original baseband data payload is removed by the FBG, the new baseband header appears as a dispersion-independent signal that can be demodulated using a standard square-law photoreceiver. The SCM fading phenomenon manifested by a relative phase delay between the two transmitted sidebands of an DSB-SCM signal [5] disappears due to elimination of the centre optical carrier using the FBG.

Fig. 2 Experimental setup for all-optical header extraction and fibre transmission

PPG: pulse pattern generator, BERT: bit error rate tester

Fig. 2 Experimental setup for all-optical header extraction and fibre transmission

PPG: pulse pattern generator, BERT: bit error rate tester

Experiments and results: Fig. 2 shows an experimental setup which included the DSB-SCM header at 622 Mbit/s 2\textsuperscript{nd}-1 PRBS NRZ data ASK-modulated at a 12.06 GHz subcarrier frequency and the data payload at 2.488 Gbit/s 2\textsuperscript{nd}-1 FRBS NRZ data. The 12.06 GHz subcarrier frequency is chosen to enhance RF fading effects at 20 and 60 km fibre lengths where part of the measure-