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Citation for published version (APA):
Calabretta, N., Liu, Y., Waardt, de, H., Khoe, G. D., & Dorren, H. J. S. (2002). Bragg grating assisted all-optical header pre-processor. *Electronics Letters*, *38*(24), 1560-1561. https://doi.org/10.1049/el:20021030

DOI:
10.1049/el:20021030

Document status and date:
Published: 01/01/2002

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:

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Bragg grating assisted all-optical header pre-processor

N. Calabretta, Y. Liu, H. de Waardt, G.D. Khoe and H.J.S. Dorren

A Bragg grating assisted all-optical header pre-processor based on self-phase modulation in a semiconductor optical amplifier is presented. The operation principle is discussed and demonstrated on packets with an NRZ header at a data rate of 2.5 Gbit/s and a Manchester encoded payload at a data rate of 10 Gbit/s. It is also demonstrated 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 processing technique based on the two-pulse correlation principle in a SLALOM configuration was recently demonstrated [1, 2]. 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 section and the tail section were necessary to adequately suppress the correlated packet payload. This header processing system was successfully employed to demonstrate all-optical packet switching [3].

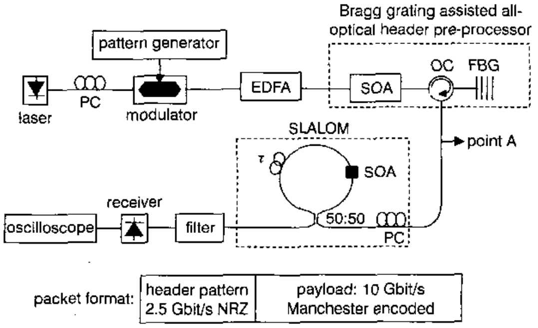

Fig. 1 *Experimental setup of Bragg grating assisted all-optical header pre-processor in combination with optical header processor based on two-pulse correlation in SLALOM configuration*

EDFA: erbium-doped fibre amplifier; PC: polarisation controller; SOA: semiconductor optical amplifier; OC: optical circulator; FBG: fibre Bragg grating; τ: time-displacement of SOA in SLALOM configuration

In this Letter, a Bragg grating assisted all-optical header pre-processor is presented. In the optical packet switch that is presented in [3], 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. First, 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 Bragg-grating assisted all-optical header pre-processor, the guard-time and the tail section become redundant so that the packet overhead is reduced.

Operating principle: The operation of the all-optical header pre-processor is based on self-phase modulation (SPM) in a semiconductor optical amplifier (SOA). As shown in Fig. 1, the system is made out of an SOA in combination with a narrow bandwidth fibre Bragg grating (FBG). The packet format is also shown in Fig. 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.

When an optical bit at wavelength λ 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 [4]. The change in wavelength at the leading edge is caused by SPM driven by nonlinear gain saturation in the SOA [5]. By using an 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 Bragg grating assisted optical header pre-processor, 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.

Experiments: The experimental setup used to demonstrate the concept of the Bragg grating assisted optical header pre-processor is shown in Fig. 1. The laser source had a wavelength of 1558.34 nm and was modulated by a 10 Gbit/s Mach-Zehnder modulator, which was driven by a pulse-pattern generator. The packet format is shown in Fig. 2*a*. 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. Note that in contrast to the results presented in [1, 2], the packets used in this experiment have no guard-time in between the header and the payload and no tail sections. The SOA in the header pre-processor was pumped with 204 mA of current, corresponding to a saturation gain of 10 dB with CW light. The FBG employed had a reflectivity of 99.9% at $\lambda = 1558.93$ nm with a bandwidth equal to 0.43 nm. The measured red shift at the leading edge of the data bit was 0.42 nm.

Sequential optical packets with two different header patterns are used in the experiments. The first header (header 1) has a '1100 0000 1100' bit pattern. The '11' symbol represents the header pulse. The sequence of '0s' represents the time in between the header pulses. 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 the time between the leading edges of the two header pulses is equal to $T_2 = 4$ ns. Fig. 2*a* shows packets with header 1 and header 2. The average optical power of the optical packets at the input of the header pre-processor is 4 dBm. The oscilloscope trace of the signal at the output of the Bragg grating assisted header pre-processor is shown in Fig. 2*b* (measured at point A in Fig. 1). It is clearly visible in Fig. 2*b* that the header pre-processor 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 Fig. 2*b* that the time between the header pulses of the first and second header pattern remains equal to T_1 and T_2, respectively.

To demonstrate that the use of the Bragg grating assisted header pre-processor improves the performance of a SLALOM-based header processor [1, 2], the output of the header pre-processor is fed into the

SLALOM-based optical header processor (see Fig. 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 suspect that a correlation pulse is formed at the output of the header processor only for optical packets with header 1. This is confirmed in Fig. 2*c* where it is clearly visible that only for the packet with header 1 is a correlation pulse 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 [1, 2].

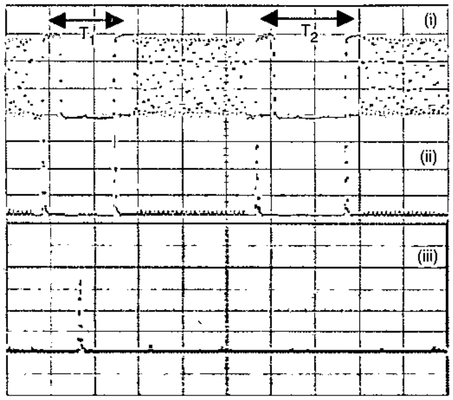

Fig. 2 *Measured oscilloscope traces*

Timescale, 2 ns/div; voltage scale, 100 mV/div
Trace (i), optical packets shown
Trace (ii), output of optical header pre-processor (measured at point A in Fig. 1) shown
Trace (iii), output of SLALOM.

Conclusion: A Bragg grating assisted all-optical header pre-processor 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 [6]. Moreover, the design of the optical header pre-processor 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 pre-processor improves the performance of the optical header processor that is presented in [1, 2]. 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 [1, 2].

Acknowledgments: This research was supported by the Netherlands Organisation for Scientific Research (NWO) through the 'NRC Photonics' grant. The authors wish to thank M. Hill for commenting on the manuscript.

21 May 2002
Electronics Letters Online No: 20021030
DOI: 10.1049/el:20021030

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FBG-based multi-channel low dispersion WDM filters

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Multi-channel FBGs for use as low dispersion WDM filters are reported. The filters are realised in a single section of optical fibre using superposition techniques and are designed for use in high-speed networks (10–40 Gbit/s) where they may be employed in OADM applications.

Introduction: Fibre Bragg gratings (FBGs) are an established technology for the fabrication of components for optical telecommunications applications such as wavelength-division-multiplexing (WDM) [1]. In simple terms a Bragg grating allows light propagating along an optical fibre to be reflected back when its wavelength is equal to $2n_{eff}\Lambda$ where Λ is the grating period and n_{eff} is the effective refractive index of the fibre core at the centre wavelength. This Letter describes the superposition of multiple Bragg gratings in a section of optical fibre resulting in a multi-channel low dispersion WDM filter. We demonstrate that these filters have attractive optical performance which renders them useful for many telecommunications applications such as low-loss optical add-drop multiplexing (OADM).

Motivation: Low dispersion WDM filters based on FBGs have attracted increased interest over the past few years [2] due not only to their flat top spectral response, steep spectral roll off and low insertion loss, but also because of their flattened in-band group delay profile which permits their use in high-speed networks (10 Gbit/s).

Low dispersion filters (LDF) exhibit up to a 10-fold reduction in group delay variation (GDV) across a reflected band when compared with standard FBG-based WDM filters. The in-band group delay profile for a standard WDM filter is typically a parabolic function with a variation of up to 100 ps; this compares poorly with the maximum variation of <15 ps typically observed for a LDF. Fig. 1*a* shows the difference in in-band group delay for an LDF and a standard 50 GHz WDM filter. The net effect of reducting in-band GDV is that for a given filter configuration a LDF has a wider usable bandwidth available for error-free data transport than a standard WDM filter (Fig. 1*b*). For demonstration purposes we choose a bit error rate (BER) of 10^{-9} as the maximum acceptable error rate.

An LDF is normally produced by writing a grating with a complex apodisation profile in an optical fibre. The apodisation profile serves not only to reduce the sidelobes observed in the reflection spectrum of the grating but also to equalise the in-band GDV by introducing a series of phase shifts along the length of the grating [2].

The superposition of multiple Bragg gratings has been previously reported [3] and may be achieved using a variety of techniques. The primary motivation behind the superposition of multiple gratings is that it eliminates the need for an individual package for each filter and allows for the packaging of multiple gratings in one package, thus ensuring that all channels experience identical thermal responses.

We propose merging LDF technology and superposition techniques to produce multi-channel LDFs for use in add-drop applications in high-speed optical networks.