# 1x2 optical packet switch using all-optical header processing

*Citation for published version (APA):*
Hill, M. T., Srivatsa, A., Calabretta, N., Liu, Y., Waardt, de, H., Khoe, G. D., & Dorren, H. J. S. (2001). 1x2 optical packet switch using all-optical header processing. *Electronics Letters*, *37*(12), 774-775. https://doi.org/10.1049/el:20010503

*DOI:*
10.1049/el:20010503

*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

*General rights*
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

*Take down policy*
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

© IEE 2001 *7 December 2000*
*Electronics Letters Online No: 20010498*
*DOI: 10.1049/el:20010498*

Xiaoling Huang and Nam Phamdo (*Department of Electrical and Computer Engineering, State University of New York at Stony Brook, USA*)

Li Ping (*Department of Electronic Engineering, City University of Hong Kong, Hong Kong*)

E-mail: eeliping@cityu.edu.hk

## References

1 BENEDETTO, S., and MONTORSI, G.: 'Unveiling turbo codes: some results on parallel concatenated coding schemes', *IEEE Trans. Inf. Theory*, 1996, **42**, pp. 409–428
2 BENEDETTO, S., DIVSALAR, D., MONTORSI, G., and POLLARA, F.: 'Analysis, design and iterative decoding of double serially concatenated codes with interleavers', *IEEE J. Sel. Areas Commun.*, 1998, **16**, pp. 231–245
3 LIN S., and COSTELLO D.J., JR.: 'Error control coding: fundamentals and applications' (Prentice Hall Series in Computer Application in Electrical Engineering)
4 BAHL, L.R., CULLUM, C.D., FRAZER, W.D., and JELINEK, F.: 'An efficient algorithm for computing the free distance', *IEEE Trans. Inf. Theory*, 1972, **18**, pp. 437–439
5 CEDERVALL, M., and JOHANNESSON, R.: 'A fast algorithm for computing distance spectrum of convolutional codes', *IEEE Trans. Inf. Theory*, 1989, **35**, pp. 1146–1159
6 PING, L.: 'Simple method for generating distance spectrum and multiplicities of convolutional codes', *IEE Proc. Commun.*, 1996, **143**, pp. 247–249

---

# 1×2 optical packet switch using all-optical header processing

M.T. Hill, A. Srivatsa, N. Calabretta, Y. Liu,
H. d.Waardt, G.D. Khoe and H.J.S. Dorren

A 1×2 all-optical packet switch is presented. The header processing is implemented by using a SLALOM structure and an optical flip-flop memory is used to store the processed header bits. The packets are switched in wavelength by using cross-gain modulation. Experimental results are presented.

*Introduction:* The need to produce an optical packet switch has been well documented [1, 2]. Approaches to all-optical header processing have been described in the literature [3]. We present (on a proof of concept basis) a 1×2 all-optical packet switch. All the processing steps related to both the header and the payload are executed in the optical domain. In our approach, the data-packets consist of non-return-to-zero amplitude-modulated data bits. The header information is implemented at an effectively lower bit rate than the payload. The payload is Manchester encoded. This data format ensures that header processing can be implemented by using a SLALOM configuration [4]. The processed header information can be stored in an optical flip-flop memory that drives a wavelength converter to switch the packet's wavelength.

*Operating principle:* The all-packet switch is implemented using the structure shown in Fig. 1. The optical power of an optical packet arriving at the packet switch is split into two equal parts. Half of the optical power of the packet is delayed and injected into a wavelength converter. The other half of the optical power is fed into the header processor.

The packet structure is shown in Fig. 1. We distinguish packets with two kinds of headers. The first header (header 1) consists of a repeated hexadecimal FF0FF00 pattern. The second header (header 2) consists of a repeated hexadecimal 0000000 pattern. Packets with alternating headers were used throughout the experiments. The packet's payload is Manchester encoded to avoid repetition of the header in the payload.

For the first stage of the optical header processing, the packet is fed into a SLALOM structure. Suppose that a packet with header 1 enters the SLALOM. It is shown in [4] that the two-pulse correlation principle of SLALOM causes a correlation pulse to appear at the SLALOM's output. The high bit rate payload is suppressed because the SOA is driven in saturation [4]. The SLALOM's output is then passed through an optical threshold function to differentiate more strongly between the correlation pulse and the suppressed payload. The threshold function operation principle is similar to that of the optical flip-flop memory that is described later. The threshold function increases the contrast between the correlation pulse and the suppressed payload from 3dB at the output of the SLALOM to over 25dB. The output of the threshold function is then amplified by an EDFA and filtered. If a packet with header 2 enters the SLALOM structure, then no correlation pulse is formed and consequently no pulse is generated by the header-processing block [3].

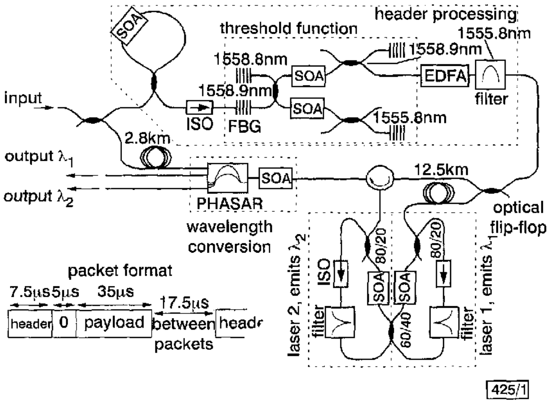

**Fig. 1** *Experimental setup to demonstrate 1×2 all-optical packet switch*

Traffic from network is coupled in packet switch at input. The packet format is given.

The output of the header processor produces an optical pulse when there is a packet containing header 1, indicating that the packet should be routed to wavelength $\lambda_1$. The optical power of the pulse is split into two. One half of the pulse is sent directly to the set input of the optical flip-flop. This pulse sets the output wavelength of the flip-flop to wavelength $\lambda_1$. The other half is delayed and resets the flip-flop output back to wavelength $\lambda_2$, after a delay equal to the packet length. The all-optical flip-flop memory that we used is based on two coupled laser diodes with separate laser cavities. The system can have two possible states. In state one, light from laser 1 suppresses lasing in laser 2. Conversely, in state 2, light from laser 2 suppresses lasing in laser 1. To change states, lasing in the dominant laser is stopped by injecting light, not at the dominant laser's lasing wavelength, into the dominant laser. The optical flip-flop memory is described in detail in [5, 6]. The particular implementation used here employed coupled ring lasers with Fabry-Perot filters in their cavities. This implementation provided a low noise light source suitable for wavelength conversion. For specific injection currents, the system of coupled lasers can form a threshold function rather than a flip-flop function. The threshold function was implemented using two coupled lasers made from SOAs and fibre Bragg gratings, as was shown in [6].

Finally, the flip-flop output was then fed into a SOA where the packets were converted to the flip-flop output wavelength via cross-gain modulation [2]. The output of the wavelength converter SOA was then passed through a phased array demultiplexer to spatially separate the two output wavelengths.

*Experiment:* The data rate of the packet payload was 2.5Gbit/s and the wavelength was 1550.92nm. The header pattern was repeated for a duration of 7.5µs. The payload consists of a data stream of 35µs of Manchester encoded pseudo-randomly generated bits. Header and payload were separated by a guard band of 5µs. The time between two packets was 17.5µs. Repetition of the header pattern was necessary to make the optical flip-flop change states [6]. This was due to the large laser cavities, which had long round-trip times. Integration of the flip-flop memory into an optical chip would overcome this problem. All the couplers used in the experiment were 50/50 couplers except those couplers used in the flip-flop. Their coupling ratios are given in Fig. 1. The fibre Bragg gratings in the threshold function formed wavelength-selective mirrors at 1555.8 and 1558.43 nm. The optical flip-flop memory was implemented using Fabry-Perot filters as wavelength-selective elements operating at 1549.26 and 1552.52 nm, corresponding to wavelengths $\lambda_2$ and $\lambda_1$, respectively. The SOAs were manufactured by JDS Uniphase and employ a strained bulk active region. The wavelength outputs 1 and 2 were converted to electrical signals via photodiodes and observed on an oscilloscope. We sent subsequently packets with header 1 and header 2 through the packet switch. The resulting waveforms are shown in Fig. 2. The switching of packets between the two wavelengths can be clearly observed. Also shown in Fig. 3 is an eye diagram of the converted output data when the flip-flop was set to wavelength 2. The eye is open, indicating that the data packets can be transmitted error free through the packet switch.

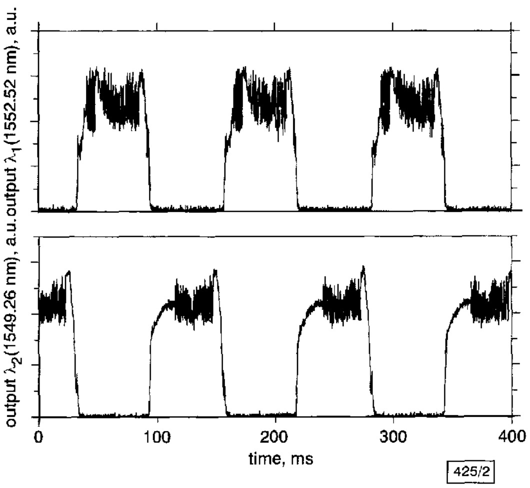

**Fig. 2** *Oscilloscope traces of optical power at two switch outputs*

Two different packets are directed to outputs at wavelength $\lambda_1$ and $\lambda_2$. If a packet with specific header arrives at packet switch, designated output wavelength is switched-on, and packet information is modulated on that specific wavelength.

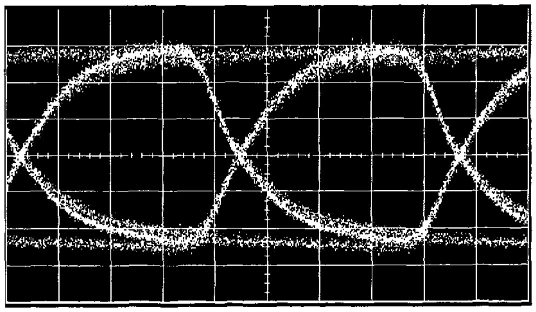

**Fig. 3** *Eye diagram of converted output data when flip-flop set to* $\lambda_2$

Timescale is 100 ps/div and voltage scale is 50 mV/div

*Discussion:* The packet payload data rate of the switch was 2.5 Gbit/s, which was only limited by the wavelength converter, and could potentially reach 100 Gbit/s [7]. The header data rate was much slower, with the header length needing to be of the order of microseconds. This was due to the particular implementation of the optical threshold function and flip-flop used in the experiment. The lasers used to form these functions were constructed from standard commercially available fibre pigtailed components having cavity lengths of many metres. Thus the component lasers had low intrinsic modulation bandwidths, which limited the speed of the threshold function and the flip-flop. However integrated versions of these functions using lasers with cavity lengths of less than a millimetre could attain speeds in the GHz range, allowing high header data rates and short packet lengths. In principle, this concept can be extended to a 1×$N$ switch since a SLALOM structure can be used to recognise more complicated header patterns [4].

*Acknowledgments:* This research was supported by the Netherlands Organisation for Scientific Research (NWO) through the 'NRC Photonics' grant. The authors wish to thank Lucent Technologies in Huizen in The Netherlands for providing equipment that made the experiments possible.

*12 March 2001*
*Electronics Letters Online No: 20010503*
*DOI: 10.1049/el:20010503*

M.T. Hill, A. Srivatsa, N. Calabretta, Y. Liu, H.d.Waardt, G.D. Khoe and H.J.S. Dorren (*COBRA Research Institute, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands*)

A. Srivatsa: On leave from Optical Communications Research Laboratory, Stanford University, USA

## References

1 DANIELSEN, S.L., HANSEN, P.B., and STUBKJAER, K.E.: 'Wavelength conversion in optical packet switching', *J. Lightwave Technol.*, 1998, **16**, (12), pp. 2169–2180

2 BOYRAZ, O., LOU, J.W., AHN, K.H., LIANG, Y., XIA, T.J., KAO, Y.H., and ISLAM, M.N.: 'Demonstration and performance analysis for the off-ramp portion of an all-optical access node', *J. Lightwave Technol.*, **17**, (6), pp. 998–1010

3 TOLIVER, P., RUNSER, R.J., DENG, K.L., YU, B.Y., and PRUCNAL, P.R.: 'Routing of 100 Gb/s words in a packet-switched optical networking demonstration (POND) node', *J. Lightwave Technol.*, 1998, **16**, (12), pp. 2169–2180

4 SRIVATSA, A., D.WAARDT, H., HILL, M.T., KHOE, G.D., and DORREN, H.J.: 'All-optical serial header processing based on two-pulse correlation', *Electron Lett.*, 2001, **37**, (4), pp. 234–235

5 HILL, M.T.: 'All optical flip-flop based on coupled laser diodes', *Microw. Opt. Technol. Lett.*, 2000, **25**, (3), pp. 157–158

6 HILL, M.T., D.WAARDT, H., KHOE, G.D., and DORREN, H.J.S.: 'All-optical flip-flop based on coupled laser diodes', to appear in *J. Quantum Electron.*

7 ELLIS, A.D., KELLY, A.E., NESSET, D., PITCHER, D., MOODY, D.G., and KASHYAP, R.: 'Error-free 100 Gbit/s wavelength conversion using grating assisted cross-gain modulation in 2 mm long semiconductor amplifier', *Electron. Lett.*, 1998, **34**, (20), pp. 1958–1959

---

# 50 GHz spaced 40 Gbit/s × 25WDM transmission over 480 km using bandlimited RZ signals

K.Tanaka, I. Morita and N. Edagawa

50 GHz spaced 40 Gbit/s × 25WDM transmission over 480 km has been successfully demonstrated using bandlimited RZ signals and an SMF-based dispersion-flattened transmission line. What the authors believe is the longest distance transmission for a spectral efficiency of 0.8 bit/s/Hz was achieved without using polarisation demultiplexing.

*Introduction:* A higher channel bit rate, such as 40 Gbit/s, is preferable for terrestrial WDM transmission systems, since the number of terminals can be significantly reduced. In addition, to increase the aggregate capacity with a finite transmission bandwidth, a higher spectral efficiency is indispensable. So far, the highest spectral efficiency reported at a 40 Gbit/s channel bit rate has been 0.8 bit/s/Hz, which was demonstrated in 186 km NRZ transmission with polarisation demultiplexing of the adjacent WDM channels at the receiver [1]. In practical conditions, however, the use of such an automated polarisation-demultiplexer may introduce too much complexity and cost increase. Without using polarisation demultiplexing, the highest reported spectral efficiency in 40 Gbit/s-based WDM transmission has been 0.64 bit/s/Hz, demonstrated in 300 km NRZ transmission [2].

In this Letter, we present experimental results of 50 GHz spaced 40 Gbit/s × 25WDM transmission over 480 km using bandlimited RZ signals and an SMF-based dispersion-flattened transmission line without using polarisation demultiplexing. The achieved spectral efficiency was 0.8 bit/s/Hz with just passive optical components, and the transmission distance was more than double the length of that reported previously with polarisation multiplexing [1].