# Fast 40 Gb/s Optical Packet Switching Using an All-Optical Flip-Flop based on a single Distributed Feedback Laser

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**Abstract**: Fast all-optical switching of 40 Gb/s packets is demonstrated using a single off-the-shelf DFB laser as all-optical flip-flop, thus offering a fast (150 ps) and economically viable method to implement a transparent network node.

**OCIS-codes**: (060.6719) Packet switching; (140.3490) Distributed-feedback lasers; (250.4745) Optical processing devices

## 1. Introduction

The demand for network traffic is rising further since new internet-based services (such as P2P, VoD, HDTV,…) are gaining more and more public attention. The opto-electric and electro-optic (OEO) conversions needed for routing these data through the network, impose a technological bottleneck because they are extremely power consuming and require fast electronic circuits. Most electro-optical switches are also rather slow, requiring more than 1 ns for switching. Transparent networks based on all-optical packet switching, offer a solution for these issues since all signal processing is done completely in the optical domain.

All-optical flip-flops (AOFF's) are one of the main building blocks for the implementation of all-optical packet switching, as they can temporarily store the header information while the payload is routed to the right output port [1,2]. Here we demonstrate a packet router design where the all-optical flip-flops are based on single distributed feedback (DFB) laser diodes [3]. Since DFB laser diodes are already widely used in today's telecommunication industry, the added functionality as an optical memory element offers an economically viable way to achieve all-optical packet switching. In addition, the flip-flop operation obtained for these DFB-lasers can be very fast (switching times as low as 45 ps can be achieved).

## 2. Concept

In electronic router configurations, the optical packets are wavelength multiplexed on different optical carriers and transmitted through a fiber. When the packets arrive at the router, the WDM signal is demultiplexed and converted to electrical signals by an array of photodiodes. After processing in the electric layer the signals are converted back to one of the optical carriers. These can be created by an array of DFB laser diodes, each emitting light at one channel of the WDM system.

Recently it has been demonstrated that a single DFB laser diode can act as a broadband all-optical flip-flop under the injection of CW light. We can thus switch a laser in the array of DFB's on and off by using an optical pulse. Such an optical pulse can originate from an all-optical header processor unit which compares the header with a pre-defined bit-sequence [4] (Fig.1). Using a wavelength converter, the packet can then be converted to the wavelength of the DFB AOFF. An AWG can subsequently switch the packets to different output ports according to their new wavelength. This technique allows very fast switching: in a separate experiment we could obtain even for non-optimized devices switching times as low as 45 ps when using higher pulse energies (2.2 pJ) than used in this system experiment. Even more important is the fact that it can also profit from the advantages of DFB laser technology: the array of lasers can be easily matched with the WDM system, the small linewidth offered by the DFB lasers allow a very dense spacing and the technology of DFB lasers is already mature. For the operation as AOFF, the DFB's require a holding beam. However, one single holding beam can in principle be distributed over all the lasers of a DFB array.

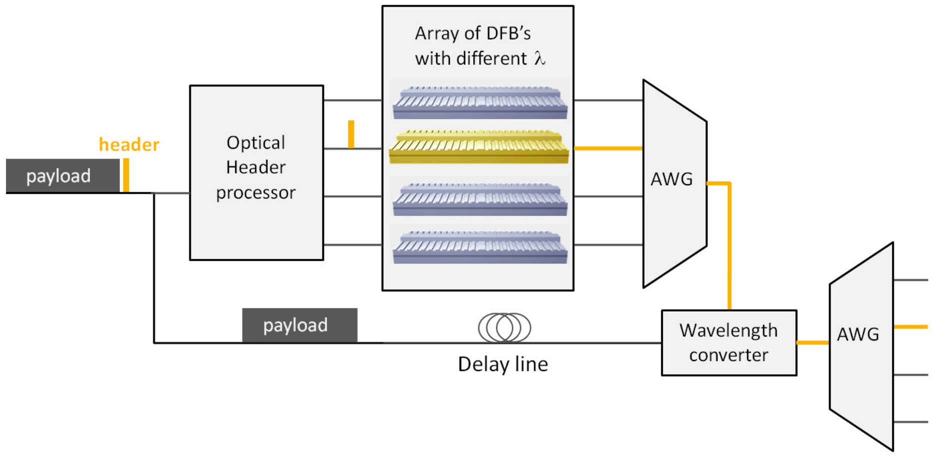


Fig. 1: Concept for all-optical packet switching based on an array of DFB lasers with different wavelengths

### 3. Measurement set-up

To demonstrate the concept, we use a single DFB AOFF to switch 40 Gb/s packets using color coded labels (figure 2). The 40-Gbps non-return-to-zero (NRZ) payload (1540 nm) is combined with label-encoded pulses (1543 nm) having a duration of 150 ps. After amplification through an EDFA, the set-pulses are extracted by an optical filter. To work in the bistable regime, the DFB AOFF needs a CW-light injection of about 3 dBm with a wavelength outside the stopband of the DFB grating (here 1546 nm). To switch the laser on, a set-pulse is injected from the opposite side. The reset-pulses are obtained by delaying the set-pulses over a fiber delay line for the duration of the packet. The output of the DFB AOFF is sent to a MZI-SOA which converts the optical packet to the wavelength of the optical flip-flop (1553 nm). The MZI-SOA consists of an optimized active-layer structure to reduce the carrier lifetime, enabling 40-Gbps NRZ wavelength conversion without push-pull operation [5].

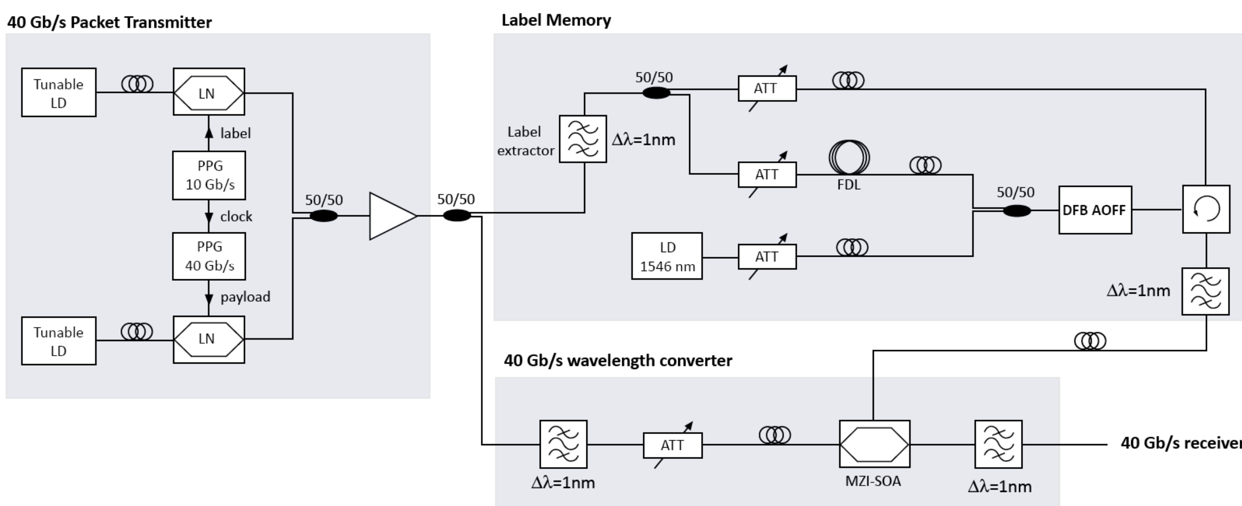


Fig. 2: Schematic of the measurement set-up to achieve routing with DFB AOFF.

### 4. Results

In Figure 3a-c, the 40 Gb/s optical packets with the label-encoded pulses are depicted together with the output of the AOFF and the switched packets. The packets have a length of 180 ns and the pulse energies needed for switching can be as low as 200 fJ. With pulse energies of 500 fJ, a guard time of only 150 ps should be taken into account as shown in the transient behavior of Figure 3e. Error free operation can be obtained with a power penalty of 2.4 dB as illustrated in the BER-curve of Figure 3d.

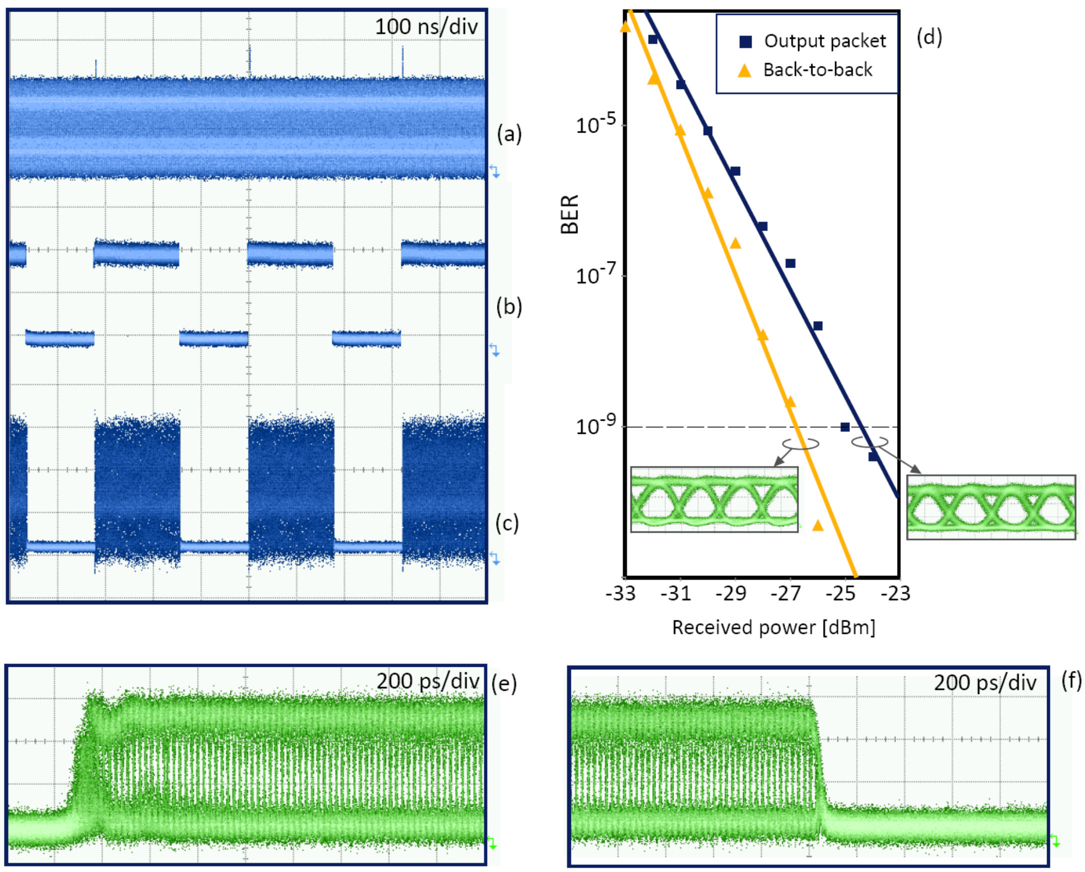


Fig. 3: Results for optical packet switching with a DFB AOFF; (a) 40Gb/s Optical Packets and label-encoded pulses; (b) Output of DFB AOFF; (c) Switched optical packets; (d) BER-curves for the output and back-to-back; (e-f) transient behaviour for switch-on and switch-off (200 ps/div).

## 5. Conclusion

We demonstrate a fast and practical method to switch 40 Gb/s all-optical packets using an off-the-shelf DFB laser as all-optical flip-flop. Switching is demonstrated with a guard time of 150 ps.


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## References


1. H. Dorren, M. Hill, Y. Liu, N. Calabretta, A. Srivatsa, F. M. Huijskens, H. de Waardt, and G.D.Khoe, "Optical packet switching and buffering by using all-optical signal processing methods," JLT 21, 2-12 (2003).
2. N. Calabretta, H.D. Jung, J. Herrera, E. Tangdiongga, A.M.J. Koonen, H. Dorren, “1x4 all-optical packet switch at 160 Gb/s employing optical processing of scalable in-band address labels” OFC 2008, PDP 33
3. K. Huybrechts, G. Morthier, R. Baets, “Fast all-optical flip-flop based on a single distributed feedback laser diode”, Optics Express, 16(15), p.11405-11410 (2008)
4. I. Kang, M. Rasras, M. Dinu, L. Buhl, S. Cabot, M. Cappuzzo, L.T. Gomez, Y.F. Chen, S.S. Patel, C.R. Giles, N.Dutta, A. Piccirilli, J. Jaques, “ Latency-free all-optical recognition of 32-bit optical bit patterns at 40 Gb/s using a passive optical Correlator”, ECOC 2008, Th.3.E.6
5. T. Hatta, et al., "Polarization-Insensitive Monolithic 40-Gbps SOA-MZI Wavelength Converter with Narrow Active Waveguides," IEEE J. Sel. Top. Quantum Electron., vol. 13, no. 1, pp. 32-39, Jan/Feb 2007