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Towards Transparent All-Optical Label-Swapped Networks: 40 Gbit/s Ultra-Fast Dynamic Wavelength Routing Using Integrated Devices


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Abstract All-optical routing of 40 Gbit’s 1.6 ns packets is demonstrated employing integrated devices based on SOA-MZIs. The scheme allows wavelength transparent operation and sub-nanosecond dynamic wavelength selection for future packet/label switched networks.

Introduction
In order to increase data processing speed, all-optical label swapping (AOLS) technology has been recently proposed to, directly in the optical domain, contend with multiprotocol label swapping (MPLS) requirements [1,2]. However, AOLS can only be fully exploited if data routing is performed on a packet-by-packet basis. In this paper, we propose an all-optical flip-flop prototype based on SOA-MZI structures to achieve dynamic 40 Gbit’s wavelength routing with potential for sub-nanosecond operation.

All-optical flip-flop memory and routing
Fig. 1(a) shows the block diagram of the wavelength router, while Fig. 1(b) depicts the schematic layout of the SOA-MZI flip-flop prototype. The device behaves as a bistable switch between two continuous wave lasers (CW), $\lambda_1$ and $\lambda_2$, based on the interaction of two coupled SOA-MZIs [3]. The principle of operation can be briefly explained as follows. The phase shifter $\phi_1$ is tuned such that maximum power transfer of $\lambda_1$ is redirected to MZI 2 through the lower arm of the balanced coupler in MZI 1. This light modifies the gain and phase shift that $\lambda_2$ experiences in SOA 2. If $\phi_2$ is chosen properly, the amplified $\lambda_2$ at SOA 2 output can be redirected to the upper arm of the MZI 2, thereby leaving SOA 1 unperturbed. The flip-flop will maintain this $\lambda_1$ state indefinitely as MZI 1 suppresses MZI 2. Since the device is symmetrical, the states $\lambda_2$ can be dominant in an identical manner. The states can be toggled by injecting a suitable light pulse into the dominant MZI via Reset 1 or Set 2. The injection of this pulse perturbs the gain and phase of the SOA of the dominant MZI such that the suppression of the second MZI is inhibited. Toggling between states is achieved by injecting a light pulse and its delayed version into the set and reset ports respectively. The temporal delay between pulses determines the flip-flop set time, which is closely related to the packet length in an AOLS scenario.

This specific implementation yields several advantages. Firstly, the switch speed of the device is determined by its physical size, which can be minimised due to its fully integrated nature, leading to switching speeds less than 200 ps. Additionally, the requirements imposed on the set and reset pulses are greatly relaxed, as the pulse width required to toggle states is similar to the switching speed of the device. Experimentally, states were successfully changed employing 75 ps pulses, and switching with 50 ps pulses is expected after further prototype optimisation. This feature will substantially alleviate interconnection issues in AOLS networks as described in [4]. This speed comes at the expense of a reduced contrast ratio between stages, whose optimised static value was ~13 dB. Most importantly, this scheme is fully transparent in the wavelength operation band of the SOA without the need for customised designs, which enhances its versatility and sets this device as a strong candidate for future all-optical applications where fast switching is essential. Finally, all-optical routing is achieved connecting the output of the flip-flop to a SOA-MZI wavelength converter. The 40 Gbit/s data are applied in a differential scheme...
configuration to improve the response of the SOAs. Wavelength conversion over the entire C band was achieved using constant driving current for the SOAs by adjusting the CW power, thereby assuring wavelength transparency is preserved (Fig. 2).

**Experimental set-up and results**

The two bistable wavelengths powering the optical flip-flop (λ1 & λ2) were chosen at 1559 and 1562 nm. The 40 Gb/s data signal was encoded on a pulse train generated by a short pulse laser emitting at 1545 nm. Power and polarisation control were accessible at different points of the system. Initially, the performance of the system was characterised statically. The state of the flip-flop was set manually, either to 1559 or 1562 nm, to assess the quality of CW light generated by the flip-flop. A PRBS of length 2^31−1 was used. BER measurements were obtained and can be compared with results from an external tuneable laser source in Fig. 3. The power penalty is less than 1.5 dB, and can be ascribed to a reduced signal-to-noise ratio at the flip-flop output.

![Fig. 3: BER measurements for static flip-flop operation](image)

**Conclusions**

As all-optical processing concepts are being developed to circumvent the limitations currently imposed by electronics and substantially increase the throughput of optical communication systems, the need for devices able to cope with these new speed requirements is accentuated. Dynamic ultra-fast all-optical wavelength conversion based on a novel integrated flip-flop prototype has been presented. The design ensures wavelength transparency is achieved over the entire SOA gain band. All-optical 40 Gb/s wavelength routing of 1.6 ns packets is shown, with an ultimate switching speed under 200 ps. This allows optimised bandwidth exploitation due to reduced guard-bands requirements in packet switched networks. Considering the latest SOA-based wavelength conversion [5], the flip-flop design can be used for specific wavelength routing at rates beyond 160 Gbit/s.

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