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# 168-Gb/s OTDM WAVELENGTH CONVERSION USING AN SMZ-TYPE ALL-OPTICAL SWITCH

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*Abstract:Wavelength conversion at an OTDM bit rate (168 Gb/s) using an SMZ-type all-optical switch is reported. The pattern effect was suppressed to within ±0.6 dB. The output pulse width was 1.5 ps. Extremely-low-power input pulses were used.*

## Introduction

Recently, semiconductor-based symmetric-Mach-Zehnder (SMZ)-type all-optical switches (Fig. 1, /1-3/) have been examined for possible use in optical-time-division-multiplexed (OTDM) communication systems because of their femtosecond-class ultrafast response times /4/. This response is caused by an ultrafast carrier-induced nonlinear refractive-index change in the semiconductor. Any effects associated with slow carrier recovery (around 100 ps) are masked by the time-differential interference of a phase-shifted lightwave. The time of light pulse propagation through the semiconductor waveguide (2-10 ps) does not limit the response, either. One application of SMZ-type switches is an all-optical demultiplexer. Error-free demultiplexing from 168-Gb/s pseudo-random signals to 10.5-Gb/s signals has already been achieved /5/ (where the switch worked at a repetition rate of 10.5 GHz).

SMZ switches have potentials to play a broad range of roles, such as wavelength conversion, 2R regeneration, 3R regeneration, and logic gates, in OTDM systems. To make these applications usable for 160-Gb/s systems, however, the switches must operate at 160 Gb/s because the switches for these applications are controlled by input signal pulses, not divided-clock pulses (Table 1). Moreover, the signal-pattern effect must be suppressed at that ultrahigh frequency, by increasing either the input clock-pulse intensity or the input continuous-wave (CW) light intensity.

Another important factor in the switch function design is synchronization. One design for wavelength conversion and regeneration is to gate each λ2 input clock pulse, being controlled by each λ1 input signal pulse. The gate width should be narrow enough (4-5 ps for 160 Gb/s) to distinguish each clock pulse. The other design is to gate a λ2 input CW light, controlled by each λ1 input signal. The second way has the advantage of not requiring synchronization. The gate width, however, needs to be narrower (< 2 ps) to form 160-Gb/s output pulses from the CW component. This gate width is comparable to the second slowest relaxation time of the semiconductor carriers (carrier cooling time, 2-3 ps).

Previously-reported repetition frequencies of SMZ-type switches are summarized in Table 1. The highest frequency was 100 Gb/s, where the gate width was reported to be 5 ps /9/. While the original SMZ switch (/1/, Fig. 1(a)) was used in /5, 6/, a polarization-descriminating SMZ switch (/2/, sometimes called as a UNI) was used in /8, 9/. A delayed-interference signal-wavelength converter (DISC /3/, Fig. 1(b)) was used in /7/. These switches share the same switch mechanism.

This study demonstrates wavelength conversion at 168 Gb/s with using an SMZ-type switch, where 168-Gb/s, 1.1-ps, 1-fJ quasi-random pulses control the switch. Controlled by these pulses, the switch gates co-propagating CW light and generates 1.5-ps pulses.

**Table 1**

| | Switch gates CW | Switch gates pulses |
|---|---|---|
| controlled by signal pulses | Wavelength conv. (168G, this work) (40G /6, 7/) 2R (not reported yet) | Wavelength conv. 3R (80G /8/) Logic gates (100G /9/) |
| controlled by clock pulses | | Demultiplexer (168G-10.5G /5/) |

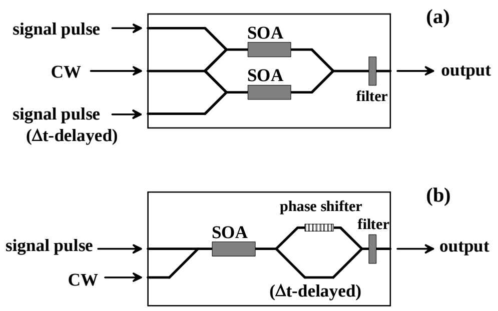


**Figure 1: SMZ-type all-optical switches**

(a): SMZ switch (configured for wavelength conversion)
(b): delayed-interference signal-wavelength converter (DISC)

## The switch structure and the experimental setup

The DISC structure in Fig. 1(b) was used for wavelength conversion in this study. Two cascaded polarization-insensitive SOA modules were used for the SOA part of the converter. To concentrate on the high-repetition all-optical performance of the SOA, we built a passive Mach-Zehnder interferometer (MZI) using spatial-beam optics (i.e. a birefringent calcite crystal, a Babinet-Soleil phase shifter, beam splitters, and a polarizer /10/). It should be noted that the DISC can be made polarization-insensitive by using a planar-lightwave-circuit MZI, in a manner similar to an integrated SMZ /5/. The MZI delay time that determines the all-optical gate width was set to 1.2 ps. The MZI phase bias was optimized with a phase shifter /10/.

168-Gb/s quasi-random pulses were formed by manually multiplexing 10.5-GHz 1.1-ps 1545-nm pulses. The 10.5-GHz pulses were generated by a mode-locked fiber ring laser. The 1560-nm CW input light was generated by an external-cavity semiconductor laser. Each of the input lights was amplified by an Er-doped fiber amplifier (EDFA). The DISC output was also amplified by an EDFA and detected by a streak camera (resolution= 1.1-1.2 ps) and an auto-correlator. The output power level was carefully calibrated at the filter output. The total coupling loss from the SOA chip through the filter output was 12 dB.

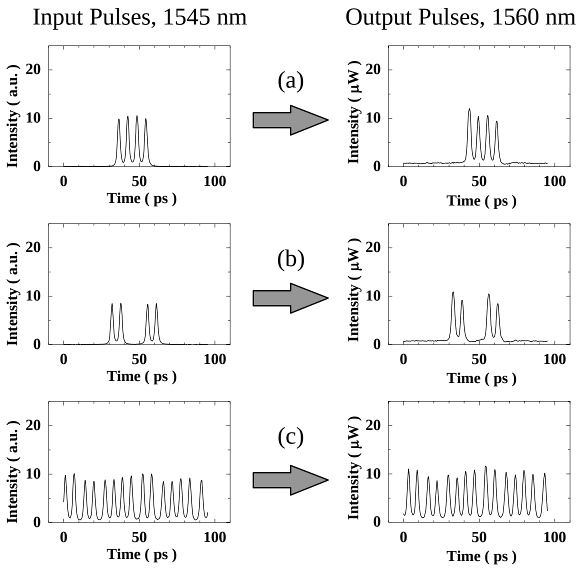


**Figure 2: 168-Gb/s wavelength conversion**

### Experimental results

Several patterns of 168-Gb/s pulses were input to the DISC, as shown in Fig. 2. The optimum input pulse energy was 1 fJ (100 times smaller than that reported in /9/), which corresponds to an average power of 84 μW at 168 Gb/s. The optimum input CW power to suppress the pattern effect was 300 μW. The optimum MZI phase bias was 1.017π /10/. These operating conditions were carefully kept unchanged throughout the measurements.

Figure 2 shows a typical set of results. When 168-Gb/s repeating ‘1111000000000000’ 1545-nm pulses controlled the DISC, the DISC gated the 1560-nm CW light and formed 168-Gb/s ‘1111000000000000’ 1560-nm pulses, as shown in Fig. 2(a). The wavelength was successfully converted from 1545 nm to 1560 nm. Similar 168-Gb/s ‘1100110000000000’ pulses were converted in a similar manner (Fig. 2(b)). The 168-Gb/s continuous pulses were converted as shown in Fig. 2(c). The peak height non-uniformity of the continuous input pulses was caused by our 1:8 multiplexer, used only for results in Fig. 2(c).

Among all the 16-bit-word patterns, the ‘11110000 00000000’ pattern in Fig. 2(a) should induce nearly the largest pattern effect. As shown in Fig. 2(a), the pattern effect was suppressed to within ±0.6 dB. (When the CW input was weak, we observed pattern effects of over ±3 dB). Futhermore, the output pulse heights in Figs. 2(a) and 2(b) matched that in Fig. 2(c).

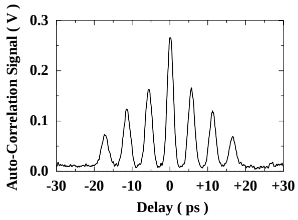


**Figure 3: Auto-correlation trace of output pulses**

Finally, we evaluated the output pulse width with an auto-correlator. The width of the three patterns of output pulses was 1.5 ps. A typical auto-correlation trace for the ‘1111000000000000’ output pulses is shown in Fig. 3.

In conclusion, we have demonstrated wavelength conversion using an SMZ-type all-optical switch at an OTDM bit rate (168-Gb/s), using quasi-random input pulses. The signal-pattern-induced effect was suppressed to within ±0.6 dB. The output pulse width determined by the all-optical gating width was measured to be 1.5 ps (comparable to the carrier cooling time). The input signal power was much lower (1 fJ/pulse, average= 84 μW) than that previously reported at 100 Gb/s. Part of this work was performed under the management of the Femtosecond Technology Association supported by the New Energy and Industrial Technology Development Organization.

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***Monday, September 4, 2000***

## Session 1.1 – OTDM-Systems

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## Session 1.2 – Space and Wireless Communications

Chairman: B. Schwaderer, Bosch Telecom, Germany