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Add/drop applications in fiber ring networks based on a reconfigurable optical add/drop multiplexer in a re-circulating loop

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Abstract

A periodic add/drop system in a fiber ring network was investigated using a reconfigurable optical add/drop multiplexer (ROADM) in a re-circulating fiber loop. After seven cascaded add/drop nodes at every 150 km along the transmission, at bit error ratio (BER) equals to 10^{-9} and data rate of 10 Gbps, we observed a 2.5 dB power penalty for the passing through channels with 1050 km transmission distance, and 0.3 dB sensitivity penalty variation for the periodic add/drop channels at every 150 km, respectively.

Keywords: Optical fiber communication; Optical fiber device; Re-circulating loop, ROADM

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1. Introduction

As the Internet traffic is increasing rapidly and dense wavelength division multiplexing (DWDM) technologies in current optical communication systems is getting matured, the functionalities and configurations of DWDM networks must be rapidly evolving accordingly [1]. As a result, optical add drop node will play an important role in high bite rate networks [2–5]. The ultimate goal of such networks is to have a large traffic bandwidth capacity and a flexible and dynamic reconfigurability to provide diversified bandwidth management in the optical layers of future all optical networks. One of the key enabling elements is the reconfigurable optical add/drop multiplexer (ROADM) which can insert (add) and extract (drop) channels at specific wavelengths and provide various supervisions and reconfigurations that are required at the nodes of future DWDM networks [6]. Recently, different technologies have been utilized to ensure the functionality of ROADM, such as planar waveguide switches [7–9], MEMS switches [11], and liquid crystal switches [12]. It is highly desirable to have the flexibility of directing the dropped and added optical channel to any specific port in an ROADM to achieve a real dynamically reconfigurable network. Hence, a monolithic integrated silica-on-silicon planer lightwave circuit (PLCs) with a cross-bar switch array is the most promising candidate as an ROADM [9,10]. Since the traffic pattern is highly diverse in metro optical networks, the wavelengths are frequently reconfigured. As a result, the cascadability and extinction ratios of add/drop functions of ROADMs are important limiting factors on the applications of ROADMs.

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In this investigation, it is the first time to use a re-circulating optical fiber loop setup as an periodical add-drop WDM test bed to test the add/drop and cascading feasibility of such an system-on-a-chip ROADM, based on thermo-optic (TO) cross-bar switches design [9]. In addition, this ROADM is the first time to use a large-scale PLC device, 85.3 mm × 119 mm, made as an optical networking element. In contrast with [5], the ROADM, which used a liquid-crystal-based spatial light modulator to act as an optical switch, experiences more insertion loss as well as bulkier size than our total PLC-based SOC solution. In our transmission experiment, after seven cascaded add/drop nodes, we observed a 2.5 dB power penalty for the passing through channels (without add/drops) after seven circulations, corresponding to a transmission distance of 1050 km at 10 Gbps with bit error ratio (BER) level at 10^{-9}. Additionally, a 0.3 dB power penalty variation between one and seven circulations at the periodic add/drop channel with a period of 150 km transmission distance was obtained. Furthermore, due to the short round-trip time of the fiber loop and long thermal equilibrium time of the thermo-optic switch, we were unable to test the dynamic reconfigurability of the ROADMs in this setup. Nevertheless, it is still a cost-effective solution to test the cascade-ability and periodical add/drop functions of ROADMs by using re-circulating WDM test bed.

2. Device characteristics

The ROADM used in this experiment is based on the cross-bar switch design to add/drop arbitrarily four out of 32 input wavelengths. Fig. 1(a) schematically depicts the function of this ROADM. The 32 input WDM wavelengths, with a channel spacing of 200 GHz, are first demultiplexed by an array waveguide grating (AWG), and then sent to a 32 × 4 switching fabric for add/drop operations. Such a 32 × 4 switching fabric is scaled up by as many 2 × 2 cross-bar dilated thermo-optic switches, and is built in the ROADM. All the reconfigured output channels are subsequently optically multiplexed using a second AWG. The detailed design rules, the operation principles, the architectures and the device characteristics of this ROADM can be found in [9]. Fig. 1(b) displays the optical spectrum when one of the 32 input wavelengths is dropped. The extinction ratio of the dropped channel is more than 40 dB and the adjacent channel isolation exceeds 25 dB. Nevertheless, the high extinction ratio and isolation of the ROADM provide the feasibility for fiber network.

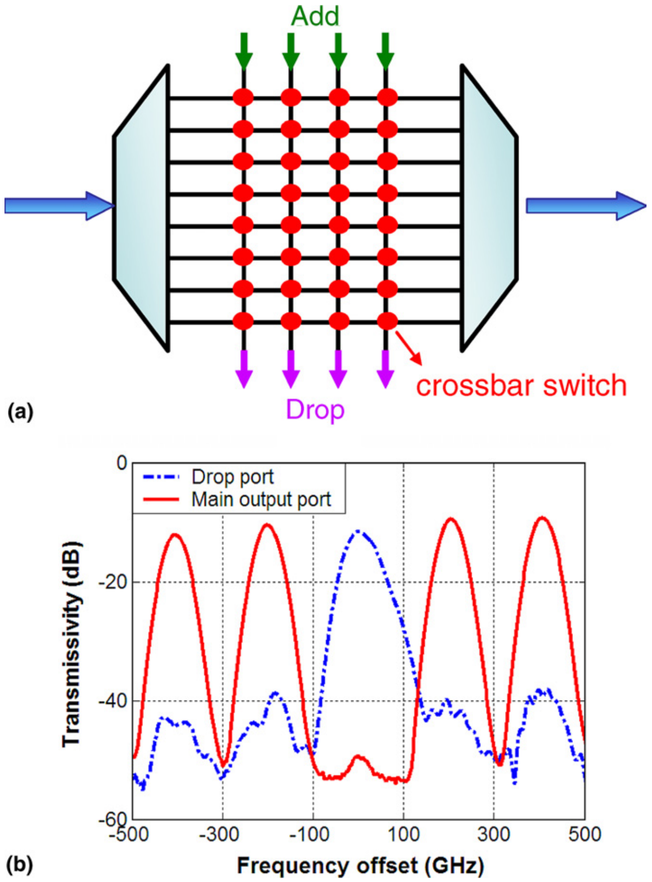

Fig. 1. (a) Schematic diagram of the ROADM and (b) optical spectra obtained at drop port and main output port when one channel is dropped.

Due to the limitation of laser sources, we used eight DFB lasers to demonstrate the features of this 32 × 4-channel ROADM for the passing through, adding and dropping channels that exhibited in Fig. 2. Fig. 2(a) and (c) schematically depict the measurements that yielded Fig. 2(b) and (d), respectively. As shown in Fig. 2(a), the odd channels of the eight output wavelengths were added from the add ports, and the even channels passed through the ROADM directly from the input port to output port. These eight channels were multiplexed by a second AWG and the corresponding adding and passing spectra are displayed in Fig. 2(b). Owing to the heating characteristics of the thermo-optic switches, the center wavelengths of the passing and adding channels are not accurately matched. The wavelength deviation from the ITU grid, caused by the thermal effect, is approximately 8 GHz. Such a frequency deviation will degrade the BER performance as many of such ROADMS are cascaded. As a result, to investigate this degradation, we also performed the measurement to demonstrate the effects of passband frequency deviation on power penalty performance in Fig. 4. To compensate this thermal drifting effect, a simultaneous temperature compensation in thermal equilibrium to match the precise ITU grids is required in operating the add/drop functions of this ROADM. Moreover, the BER performance of the ROADM was measured under different operation conditions. Fig. 2(c) schematically depicts the experimental setup and Fig. 2(d) plots the corresponding BER curves. The dropped (diamond-symbol), added (triangle-symbol) and passing (circular-symbol) channels were measured from the “input” port to the “drop” port, from the “add” port to the “output” port and from the “input” port to the “output” port, respectively. This figure indicates a sensitiv-

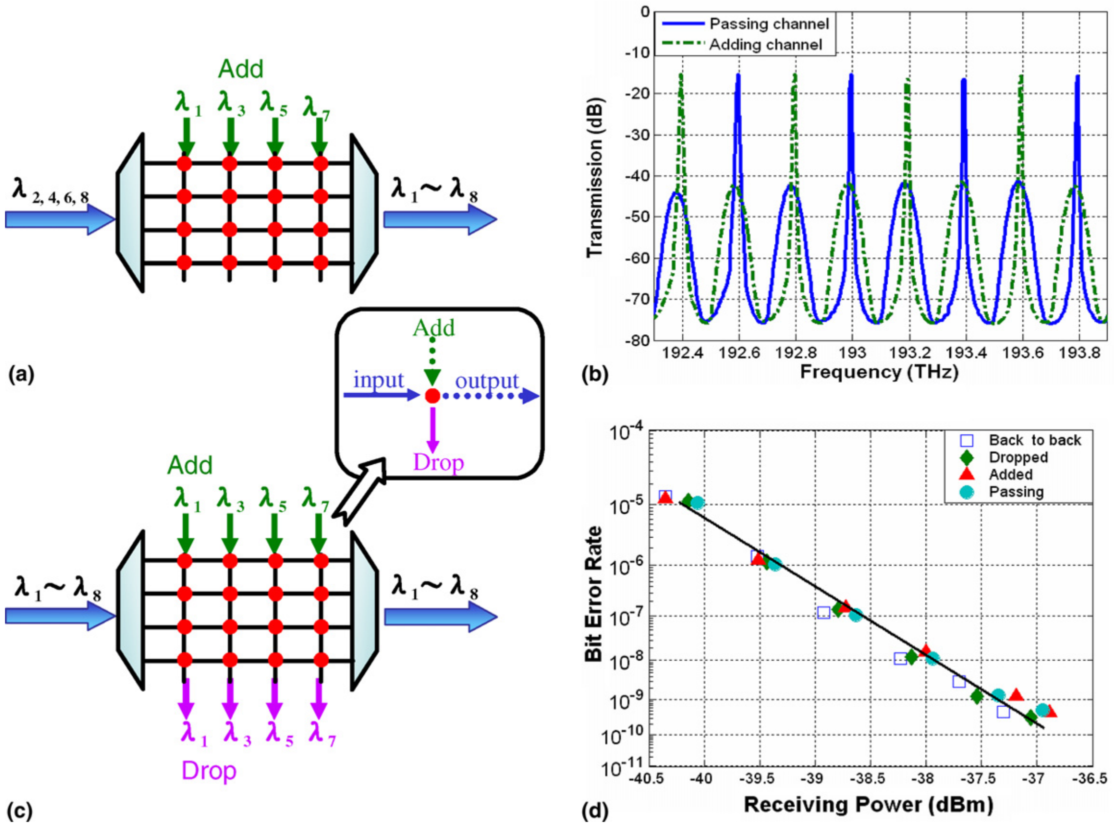

Fig. 2. (a) Schematic diagram of simultaneous addition of odd channels and passing through of even channels at the ROADM, (b) optical spectra for passing (even) and adding (odd) channels, (c) schematic diagram for eight passing and four adding/dropping channels and (d) the BER curves for these channels in (c).

ity variation of less than 0.3 dB under different operation modes in the ROADM. The variations were major due to different route paths in the cross-bar switching fabric under different operation conditions. The crosstalk-induced penalty was negligible, guaranteeing the strong performance of the ROADM device.

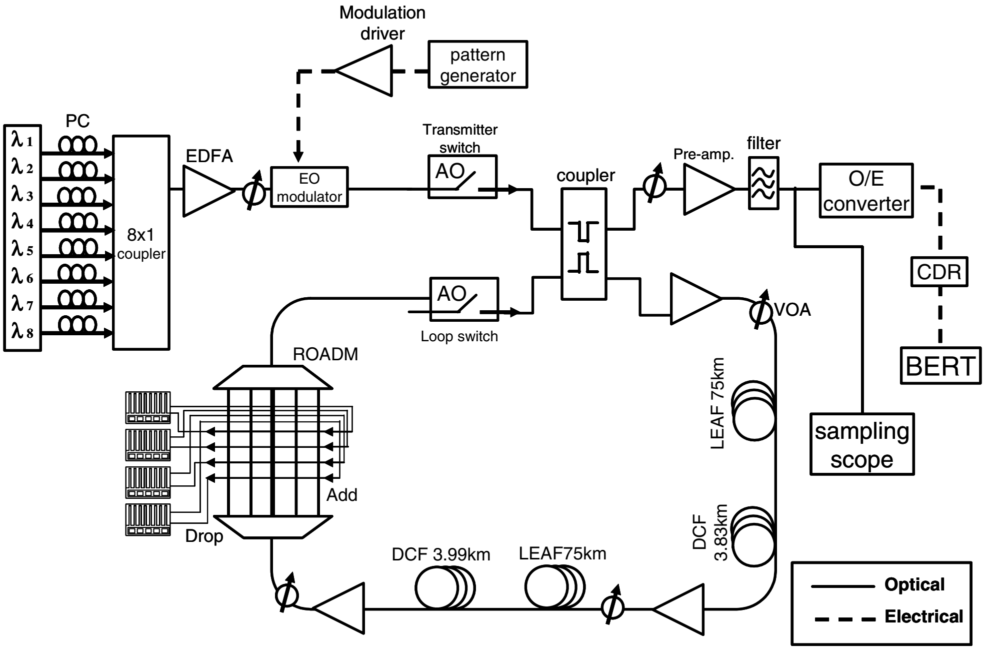

Fig. 3. Experimental setup of a re-circulating loop based periodic add/drop ring network.

3. Periodic add/drop ring network system experiment

In the system experiment, a re-circulating loop was employed to simulate multiple adds/drops in an add/drop ring network system and to demonstrate the attainable cascadability of the ROADMs. Fig. 3 shows the experimental setup of a periodic add/drop ring network. The wavelengths of the eight-channel laser sources span from 192.4 to 193.8 THz with 200 GHz channel spacing. The optical channels were modulated by a LiNbO3 electro-optical (EO) modulator at 10 Gbps with a pseudo random binary sequence (PRBS) length of $2^{31} - 1$. Two types of fiber were used in this experiment. They were 150 km of Corning LEAF fiber, with −4 dBm launched power per channel into each fiber span, and 8 km of Corning DCF, which was set to compensate for the accumulated chromatic dispersion in LEAF fiber. A 3R receiver, combined with an optical preamplifier, of −37 dBm receiving sensitivity at BER of 10^{-9} was used to evaluate the signal's performance after transmission. At every 150 km of transmission, an ROADM was installed to simulate periodic add/drop nodes in this fiber ring network.

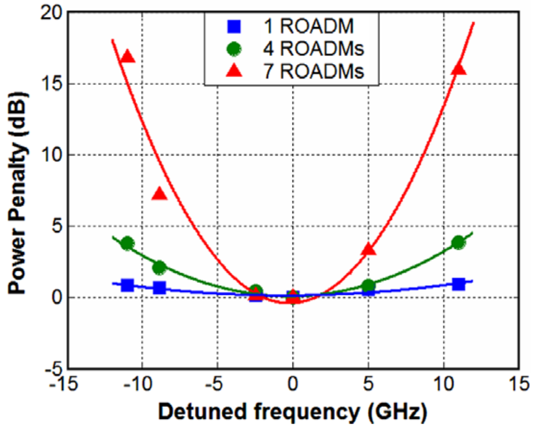

Fig. 4. Power penalty variation at BER = 10^{-9}, with ±11 GHz frequency detuning, for cascading the ROADM for one, four and seven times.

Since the pass bands of the ROAD are in Gaussian shapes, Fig. 4 plots the power penalty variations at BER equals to 10^{-9}, with ±11 GHz frequency detuning, after different numbers of cascaded ROADMs. This figure reveals power penalty variations of 1, 3.9 and 16 dB, which are normalized to the corresponding receiving sensitivities at the ITU grid, following one, four and seven cascaded ROADMs, which correspond to 150, 600, and 1050 km of transmission, respectively. Non-flattened pass-band of the ROADM is responsible for the high sensitivity penalties at the offset frequencies. Optical signals pass through

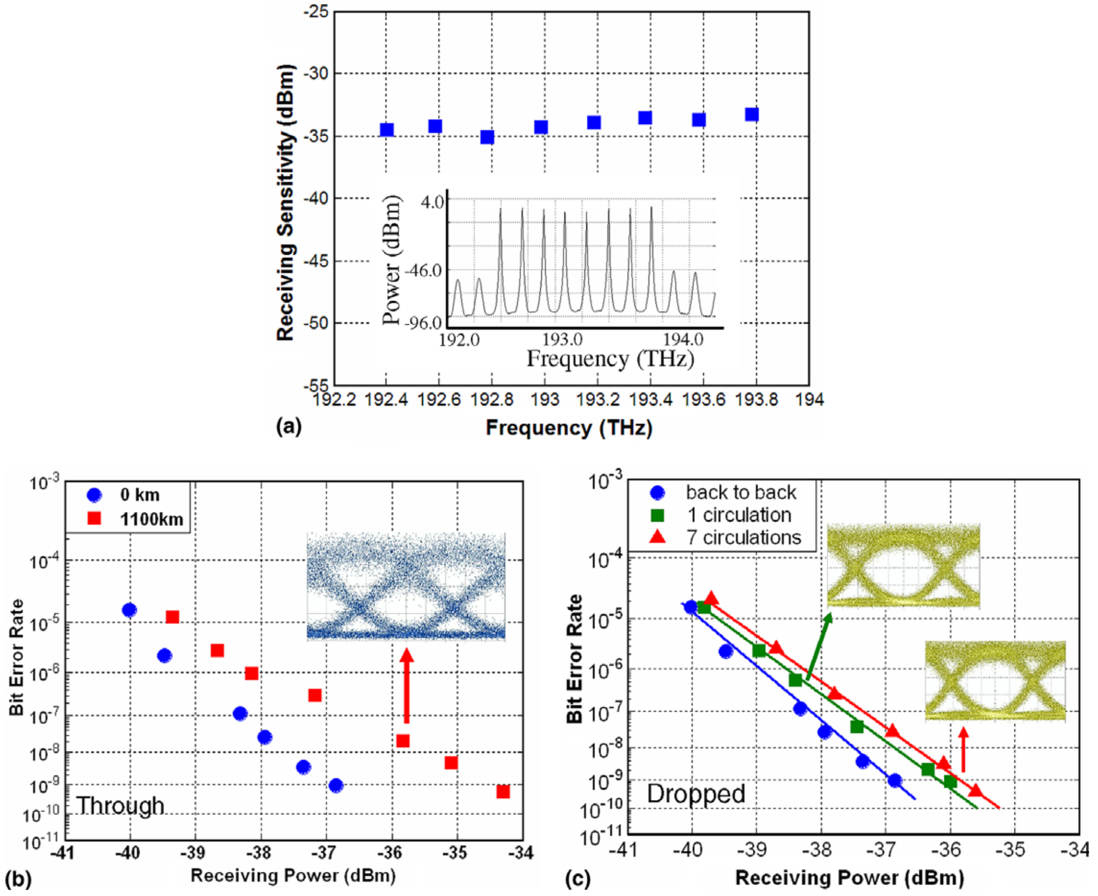

Fig. 5. (a) Optical spectrum and receiving sensitivity for eight channels, and BER curves and corresponding eye diagrams at channel three for (b) pass-through function after 1050 km of transmission and (c) periodically added/dropped signals at every 150 km.

two AWGs at each ROADM, so the cascading filter narrowing effect results in a large penalty if the optical channels are not precisely aligned to the ITU grids. Therefore, a flat-top AWG passband is desirable in future design. Fig. 5(a) presents the optical spectrum and the receiving sensitivity, measured at $\mathrm{BER} = 5 \times 10^{-9}$, for each of the eight channels after seven cascaded ROADMs and 1050 km of transmission. The sensitivity variations among all channels are less than 2 dB. Since the fully compensated channel was at 192.8 THz in the proposed re-circulating loop, the 2 dB sensitivity variation is caused mostly by the residual chromatic dispersion accumulation after 1050 km of transmission. Fig. 5(b) plots the BER curves and presents the corresponding eye diagrams at channel three (192.8 THz). BER curves obtained when all of the signals passed through the ROADM were measured. However, the add/drop function of the ROADM was turned off at this time. After seven cascaded ROADMs and 1050 km of transmission, a penalty of about 2.5 dB was observed. The chromatic dispersion is fully compensated for at this channel, so the accumulation of ASE noise from the EDFAs used in the loop are responsible for most of this penalty. The periodic add/drop function was demonstrated by dropping and adding channel three (192.8 THz), while the remaining seven channels just passed through, at the ROADM in this re-circulating loop, which is identical to a periodic add and drop of channel three at every 150 km in an add/drop ring network. Consequently, after seven circulations, channel three had been added and dropped seven times, whereas the other seven channels had transmitted about 1050 km. Fig. 5(c) shows the BER measurements and the corresponding eye diagrams at the “drop” port of the ROADM at every 150 km for back-to-back, after one circulation and seven circulations. The optical signal at channel three was refreshed every 150 km, so a very minor penalty, of less than 0.3 dB, between one circulation and seven circulations was observed. This minor penalty is attributable to the tiny wavelength deviation from the ITU grid due to the temperature effect of the optical thermo switches within the ROADM and the accumulation of the residual signals that had been dropped because of imperfect switching isolation. Because this ROADM is designed to cover the C band from 192 to 196 THz with 200 GHz channel spacing, this configuration can accommodate more optical channels within C band. The maximum number of channels is 32 with 4 adding and dropped functions simultaneously.

4. Conclusion

In this paper, a periodic add/drop fiber ring network based on a 32-wavelength ROADM, which is a system-on-a-chip network subsystem and offers low loss and crosstalk performance, with a channel spacing of 200 GHz in a re-circulating loop is proposed and experimentally demonstrated. The channel narrowing effect, caused by non-flat-top pass bands, is critical as the number of cascaded ROADM nodes increases. After seven cascaded nodes and transmission for 1050 km through all passing channels, a 2.5 dB sensitivity penalty was observed. Furthermore, less than 0.3 dB penalty variation was obtained between one and seven circulations when one of the eight channels was periodically added and dropped at every 150 km and the remaining seven channels were just passed through. Such results indicate the feasibility of add/drop functions in dynamic fiber ring networks by using this silica-on silicon ROADM.

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