Compact Integrated Tunable Filter Utilizing AWG Routing Function and Small Switches

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Abstract: The wavelength tunable filter will play a key role in realizing C/D/C add/drop functions in ROADMs. We fabricate a novel tunable filter for 192 optical channels on a PLC chip. Transmission experiments verify its optical characteristics.

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1. Introduction

Optical path networks using reconfigurable optical add/drop multiplexers (ROADMs) have been widely adopted all over the world to cope with the rapid Internet traffic increase. To support the envisaged dynamic wavelength services [1] which include ultra-/super-high definition video (72 Gbps per channel) distribution among TV broadcasting stations or headends [2], the dynamic allocation of wavelength paths is necessary, which requires ROADMs with colorless, directionless, and contentionless (C/D/C) add/drop capabilities. The realization of C/D/C services [1] which include ultra-/super-high definition video (72 Gbps per channel) distribution among TV broadcasting stations or headends [2], the dynamic allocation of wavelength paths is necessary, which requires ROADMs with colorless, directionless, and contentionless (C/D/C) add/drop capabilities. The realization of C/D/C needs large scale space switches [3] or tunable filters. To realize C/D/C using space switches, intensive switch hardware is necessary and various studies have been done to mitigate the requirement. They include C/D ROADMs (without contentionless capability) that use client-side cross-connects with [4] and without [5] utilizing intra-node contention aware RWA (Routing and Wavelength Assignment). Another architecture, using tunable filter, enables full C/D/C with simple drop-parts (Fig. 1); it does not need large scale optical switches nor complicated intra-node contention aware RWA. Moreover, it realizes the finest modular growth capability, one-by-one transponder addition is possible, and hence the number of unused transponders (in each transponder bank) is minimized. On the other hand, each drop channel requires one dedicated tunable filter, so the filter needs to be compact and cost-effective. Coherent detection can replace this tunable filter function, but its usage will be limited to high-speed channels and mostly to long-haul networks.

A simple way to realize a tunable filter is to utilize an AWG (arrayed-waveguide grating) followed by channel selecting switches, however, the switch scale becomes excessive when the number of wavelength channels becomes large. To reduce the tunable filter scale, in [6], we proposed a multi-stage optical channel selection scheme; in each stage, we use a cyclic AWG with one input and multiple outputs to divide a set of incoming wavelengths into wavelength groups and the desired wavelength is output at the last stage. We confirmed that this approach can extract a single arbitrary wavelength from 96 channels with 50 GHz spacing; a filter was compactly fabricated on a 15x70 mm² planar lightwave circuit (PLC) chip. Compared to a single stage tunable filter, the switch scale reduction was 81% [6]. To obtain a further switch scale reduction, in [7], we proposed an advanced architecture that utilizes the routing function of a multi-input/multi-output AWG and switches in combination, which substantially reduces the switch scale. The concept was successfully proved by utilizing off-the-shelf discrete devices (50GHz-spaced 90 channels). This paper reports a newly fabricated monolithic PLC tunable filter that can accommodate 192 wavelength channels with 25 GHz spacing. The size of the PLC chip is 15x74.5 mm². Transmission experiments confirm that any of the 192 channels can be extracted.
2. Proposed multi-stage wavelength selection method

In this paper, we evaluate switch scale as the necessary number of 1x2 switch elements; an nx1 switch has switch scale of \((n-1)\). A multi-stage wavelength selection scheme has been shown to be effective [6] in reducing switch scale of a tunable filter, whose concept is shown in Fig. 2. An incoming WDM signal is divided into wavelength groups, and a group that contains the desired wavelength is selected at the first stage. In the following stages, the group is repeatedly divided into smaller groups and finally a single arbitrary wavelength is selected. Each stage consists of a 1x(multi-output) cyclic AWG and an optical switch. The cyclic AWG is capable of de-multiplexing wavelengths in a cyclic manner into each output port, as determined by the free spectral range (FSR). Fig. 3 (a) shows an example of a stage that is composed of a 1x15 cyclic AWG and a 15x1 switch; the output wavelengths at each output port of the AWG are periodically configured. We used this selection method to fabricate a 2-stage tunable filter for 96 channels with 50 GHz grid spacing, where the first stage uses a 1x9 cyclic AWG and a 9x1 switch while the second stage has a 1x15 cyclic AWG and a 15x1 switch [6]. They are integrated on a 15x70 mm² PLC chip, however, the switch part occupies a relatively large portion (2/3 of the chip: AWG part (1/3).

To attain further switch scale and hence cost reduction, we have newly proposed a wavelength selection mechanism that exploits the wavelength routing function of multi-input/multi-output cyclic AWGs [7]. The AWG output wavelength configurations can be shifted by changing the input port position owing to the wavelength routing characteristics of the cyclic AWGs. In other words, by changing AWG input port, the selectable wavelengths can be changed. To change the input port, a small switch is placed at the input side of the AWG. Fig. 3 (b) depicts an example of the proposed wavelength selection scheme that has the same wavelength de-multiplexing capability as Fig. 3 (a). Please note that in Fig 3 (b), only 5 output ports of the AWG are used (in Fig 3(a), 15 output ports are utilized), although 3 input ports are utilized. A 1x3 switch is placed in front of the 15x15 cyclic AWG and a 5x1 switch is connected to the opposite side. Compared to Fig 3 (a), overall switch scale is reduced from 15-1=14 to (3-1)+(5-1)=6. This selection method is applied to each stage of a multi-stage tunable filter.

Fig. 4 compares the switch scale of proposed and conventional multi-stage tunable filters, where appropriate AWG sizes are selected to minimize switch scales depending on the number of channels. Increasing the number of wavelength selection stages reduces the switch scale, but the reduction gain falls. Please note using more stages...
increases the loss because optical signals must pass through more AWGs. Therefore, we adopt here the 2-stage filter architecture. The switch scale of the conventional 2-stage filter is 19 when the number of wavelengths is 100. On the other hand, the switch scale of the proposed 2-stage filter is only 12 even for 200 wavelengths. Its switch scale is smaller than that of a previous one [6] even though it can process twice the wavelengths.

3. Fabrication of tunable filter and transmission experiments
To confirm the feasibility, we fabricated a 2-stage filter for 192 channels with 25 GHz grid spacing; a 14x14 and a 15x15 cyclic AWGs whose FSRs are 350 GHz and 375 GHz, respectively, were utilized as shown in Fig. 5 (a). The AWGs and switches were integrated on a 15x74.5 mm$^2$ PLC chip as shown in Fig. 5 (b). Its size is almost the same as that of the 96 channel filter (15x70 mm$^2$) in our previous work [6] but processes twice as many wavelengths. Fig. 6 shows the measured optical characteristics: (a) the average and worst insertion loss on the ITU-T grid were 10.1 and 13.4 dB, respectively, (b) the adjacent crosstalk was less than -31 dB, (c) the offset of passband center wavelength from ITU-T grid was less than 0.027 nm, and (d) the polarization dependent loss (PDL) was less than 0.56 dB.

4. Conclusion
We demonstrated an ultra-compact tunable filter that can arbitrarily select one of 192 wavelengths (25GHz-spacing), using a newly developed architecture with multi-input/multi-output AWGs. The filter was fabricated on a 15x74.5 mm$^2$ PLC chip and its wavelength selection capability was verified in experiments. We may expect further footprint reduction in the future with silicon photonics technology [8].

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5. References