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# Fully reconfigurable $2 \times 2$ optical cross-connect using tunable wavelength switching modules

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**Abstract:** A modular tunable wavelength switching module is proposed and used to construct  $2 \times 2$  fully reconfigurable optical cross-connects. Large size optical switch is avoided in the OXC and it is easy to upgrade to more wavelength channels.

## Introduction:

Wavelength division multiplexing (WDM) not only increases fiber transmission capacity but also simplifies network operation by introducing the optical path layer concept [1]. Multi-wavelength optical cross-connects (OXC) are key elements in reconfigurable WDM networks.

A conventional way of building an optical cross-connect is shown in Fig. 1.  $M$  wavelength channels packed in each of two input fibers are separated by demultiplexers, and put into a  $2M \times 2M$  optical space switch. All channels are cross-connected by the switch and combined in two multiplexers after conversion to the proper wavelengths. As more and more wavelengths are packed into fibers (some transmission systems with more than 150 channels have been reported [2,3]), the conventional construction scheme is hard to implement due to the large dimension (e.g.,  $300 \times 300$ ) space switch that is required in the structure. The OXC constructed in the conventional way also has a low degree of modularity and it is hard to upgrade smoothly to more wavelengths once it has been installed.

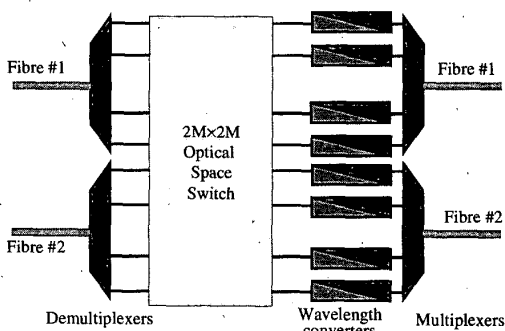


Fig. 1. Schematic diagram of a conventional  $2 \times 2$  fully reconfigurable OXC.

In this paper, a tunable wavelength switching block is proposed based on tunable optical add/drop multiplexers, a  $2 \times 2$  space switch and tunable wavelength converters. Each block can cross-connect two channels between two fibers, and a fully reconfigurable  $2 \times 2$  OXC can be built by cascading  $M$  such modules. Only  $2 \times 2$  space switches are used, so that the structure of the OXC is simplified by avoiding use of a large dimension optical space switch. In nodes where the full reconfiguration is not needed, a smaller number of the modules can be chosen. Upgrade to more wavelengths can be easily done by adding more modules.

## Structure of the proposed $2 \times 2$ OXC

The basic unit in the proposed  $2 \times 2$  OXC is a tunable wavelength switching module, as shown in Fig. 2(a). This unit consists of two tunable optical add/drop multiplexers (OADMs), two tunable wavelength converters and a  $2 \times 2$  optical space switch. Any two channels to be cross-connected between two fibers can be dropped by the two tunable OADMs tuned to the wavelengths of the corresponding channels. The two dropped channels are switched in the  $2 \times 2$  space switch operated in "cross" state, and then they each proceed to its tunable wavelength converter. Each wavelength converter tunes its output to the same wavelength as the add/drop wavelength of the OADM connected, and converts any input to this wavelength. The converted channels are added to the respective output fibers through the add ports of the OADMs. When the space switch is set to "bar" state, no channels will be cross-connected.

When each fiber hosts  $M$  wavelength channels, a fully reconfigurable  $2 \times 2$  OXC without wavelength swapping in the same fiber can be constructed by using a cascade of  $M$  such tunable wavelength switching modules. A schematic diagram of the  $2 \times 2$  OXC is shown in Fig. 2(b). Tunable OADMs can be

realized in different ways, e.g., acous-optic filters [4] or tunable polymer Bragg gratings [5]; Many types of wavelength converters reported can be made tunable by using tunable optical probe sources [6, 7]; 2x2 space switches are commercially available, e.g., mechanical optic switches or thermo-optic switches. In case full reconfiguration is not necessary in one OXC node, less than M modules are needed, and the node can always be upgraded smoothly when the need for cross-connection increases. The 2x2 OXC is re-arrangeably non-blocking.

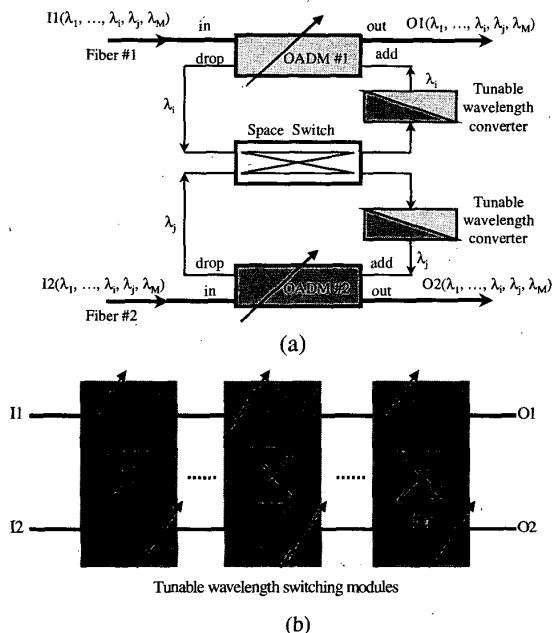


Fig.2. Schematic diagrams of the proposed tunable wavelength switching module (a) and a 2x2 fully reconfigurable OXC based on the modules (b)

**Experiment:**

In order to demonstrate the basic concept of the proposed 2x2 OXC, a wavelength switching module is constructed, as shown in Fig. 3. Two fiber Bragg grating based Mach-Zehnder interferometric OADMs with fixed instead of tunable add/drop wavelengths are used, since no tunable OADM is available for the experiment yet.

Tunable wavelength converters based on cross-gain modulation in semiconductor optical amplifiers (SOAs) are built. Each input optical signal from the space switch is coupled into an SOA via an optical circulator, and it subsequently modulates the gain of the SOA. CW light from a tunable external cavity laser tuned to the same wavelength as the add/drop channel of the OADM connected, is fed into the

SOA. When the CW light counter-propagates with the input signal in the SOA, it is subjected to the modulated gain, and hence becomes intensity modulated. The modulated signal is guided out through the circulator and put into the add port of the connected OADM. Each wavelength converter is capable of converting any input to the particular wavelength that is needed in the wavelength switching module. In our experiment the optical space switch is simply replaced by manual connections since the crosstalk from a mechanical optical switch is very low (<-70dB) and switching speed is not the issue studied here.

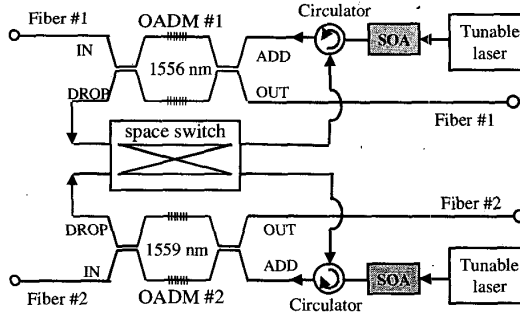


Fig.3. Experimental construction of the wavelength switching module.

8x10Gb/s WDM channels separated by 200GHz are hosted in each fiber. Fiber #1 is connected to OADM #1 with center wavelength 1556 nm, and the output of the wavelength converter connected to OADM #1 is tuned to 1556 nm. Fiber #2 is connected to OADM #2 with center wavelength 1559 nm and the output of the wavelength converter associated with OADM #2 is tuned to 1559 nm accordingly. The experiment focuses on the wavelength conversion part. With reference to Fig. 4, BER curves have been measured for channels at 1556 nm and 1559 nm after demultiplexing and detection by a PIN receiver. The following four situations are considered.

1. Channel at 1556 nm dropped from Fiber #1 is converted to 1559 nm and added to Fiber #2, referred to as 1556->1559.
2. Channel at 1559 nm dropped from Fiber #2 is converted to 1556 nm and added to Fiber #1, referred to as 1559->1556.
3. Channel at 1556 nm dropped from Fiber #1 is converted to the same wavelength and added back to Fiber #1, referred to as 1556->1556.
4. Channel at 1559 nm dropped from Fiber #2 is converted to the same wavelength and added back to Fiber #2, referred to as 1559->1559.

Among these four situations, the 1<sup>st</sup> and 2<sup>nd</sup> involves the optical switch in “cross” state, and the 3<sup>rd</sup> and 4<sup>th</sup>

in "bar" state. For comparison, a base-line BER curve is also measured for the receiver, which is referred to as Back-Back. From Fig.4 we can see the power penalty for the four cases varies from 1dB to 2.3dB, which mainly stems from the wavelength converters used in the block. Wavelength conversion from long to short wavelength (1559->1556) exhibits the smallest penalty while conversion from short to long wavelength (1559->1556) shows the highest penalty. That is because the gain peak of the SOA shifts to longer wavelength for higher input power, which leads to a poor signal extinction ratio for conversion from short to long wavelength [7]. The wavelength conversion scheme used in the present experiment is very simple and we should emphasize that wavelength conversion does not always introduce power penalty. On the contrary a wavelength converter can also provide power equalization between the cross-connected channels and the bypassing channels and some wavelength conversion schemes can even provide a regenerative function [8, 9].

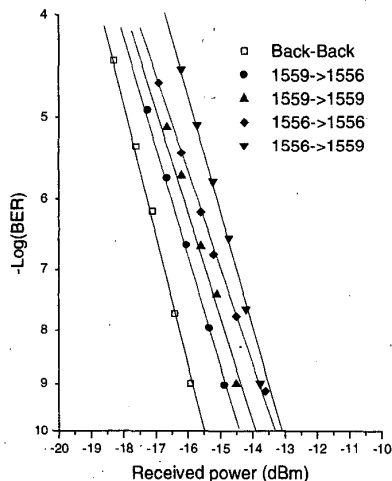


Fig.4 Bit-Error-Rate curves of back to back and after the wavelength switching module.

#### Conclusion:

We have proposed a new 2x2 fully reconfigurable OXC based on tunable wavelength switching modules. A large dimension of the optical space switch is avoided in the structure, and it has a high

degree of modularity that enables smooth upgrade to more wavelength channels. Our experiments have demonstrated the feasibility of the wavelength switching module. Tuning speed and cascability of the modules need to be further studied.

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