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Novel 2×2 Multiwavelength Optical Cross Connects Based on Optical Add/Drop Multiplexers

Fenghai Liu, *Student Member, IEEE*, Rune J. S. Pedersen, and Palle Jeppesen

Abstract—A novel architecture of 2×2 multiwavelength optical cross connects based on optical add/drop multiplexers and optical switches is described. The structure is strictly nonblocking with a high degree of modularity. Its basic performance is experimentally demonstrated.

Index Terms—Optical cross-connect, optical add/drop multiplexer, strictly nonblocking, modularity.

I. INTRODUCTION

DENSE wavelength-division-multiplexing (DWDM) technology is well-known for its dramatic increase in transmission capacity, and its flexibility in optical networking [1]. A multiwavelength optical cross connect (OXC) is one of the key devices for developing cost efficient and reconfigurable DWDM networks, and different structures of OXCs have been proposed [2], [3]. Essential requirements to an OXC are strictly nonblocking nature and high modular-growth capability [4].

A novel 2×2 multiwavelength OXC architecture based on optical add/drop multiplexers (OADMs) and optical switches is presented in this letter. This structure is strictly nonblocking, which means that any channel interchange will not disturb other existing connections. It is highly modular, and each building block can be integrated as a planar device, which makes OXC nodes flexible and allows an easy upgrade to a larger number of wavelengths. It can be made to have low-loss, low-difference, between channel losses and low-crosstalk, using available technologies. An experimental demonstration is performed to verify the concept of the proposed 2×2 multiwavelength OXC.

II. MULTIWAVELENGTH OXC CONSTRUCTION

A. 2×2 Wavelength Switching Block

The basic unit in the new OXC is a 2×2 wavelength-switching block, shown in Fig. 1. It consists of two OADMs, with identical drop wavelength and an optical switch. When the switch is in "bar" state, as shown in Fig. 1(a), the drop ports are connected to the add ports of the same OADM, and all wavelength channels bypass the block without exchanging information. When the switch is in "cross" state, as shown in Fig. 1(b), each of the drop ports is connected to the add port of the other OADM. This results in the two drop channels being interchanged, while all other channels remain unchanged. Hence, a 2×2 wavelength switching block is capable of

switching one wavelength channel between 2 fibers, and is transparent for all other wavelength channels.

The loss for bypass channels is equal to the out-of-band loss of the OADM, and an OADM with out-of-band loss of 1.8 dB was reported in [5]. The loss for the switched channel is the sum of losses from in to drop and add to out in the OADM and the loss of an optical switch, which all amounts to 4.2 dB, using the same OADM and a mechanical optical switch with a typical loss of 0.6 dB. The crosstalk of the 2×2 wavelength switching block depends on the on–off ratio of the optical switch and the transfer functions of the OADMs. Mechanical optical switches with on-off ratio larger than 60 dB are commercially available, and the OADM mentioned above exhibits drop band rejection ratio of 45 dB and out-of-band reflection of -45 dB. This leads to a crosstalk less than -60 dB from the 2×2 wavelength switching block, according to the analysis in [6].

B. 2×2 Multiwavelength Optical Cross Connect

Constructing a 2×2 multiwavelength optical cross connect can be done simply by cascading a number of wavelength switching blocks each with a fixed wavelength, as shown in Fig. 2. Channels with the same wavelength from the two input ports can be interchanged via an independent wavelength switching block without disturbing the other existing connections, i.e., the cross connect is strictly nonblocking for all wavelength channels.

In a given OXC node, it is only necessary to use the 2×2 wavelength switching blocks corresponding to the wavelengths that are to be cross-connected rather than a full cross connection between two fibers. When more wavelengths need to be cross-connected, the corresponding wavelength switching blocks can be added to the already existing OXC. This is favorable in terms of initial investment.

The loss which a channel experiences through a 2×2 multiwavelength OXC is the sum of the losses in each 2×2 wavelength switching block. Different channels will experience the same loss in a fully cross-connected 2×2 multiwavelength OXC if the OADMs have uniform loss for bypassing channels. Since the 2×2 OXC is built by modules, loss can be compensated by optical amplifiers, when necessary.

We have described that a 2×2 wavelength switching block is capable of switching one wavelength between two fibers, and is transparent for all other wavelength channels. In a 2×2 OXC, channels with different wavelengths are treated independently, like using 2×2 optical space switches in parallel. This not only results in the strictly nonblocking feature of a 2×2 OXC, but also in possible constructions of strictly nonblocking $N \times N$ OXCs (N input ports and N output ports) using proper growth
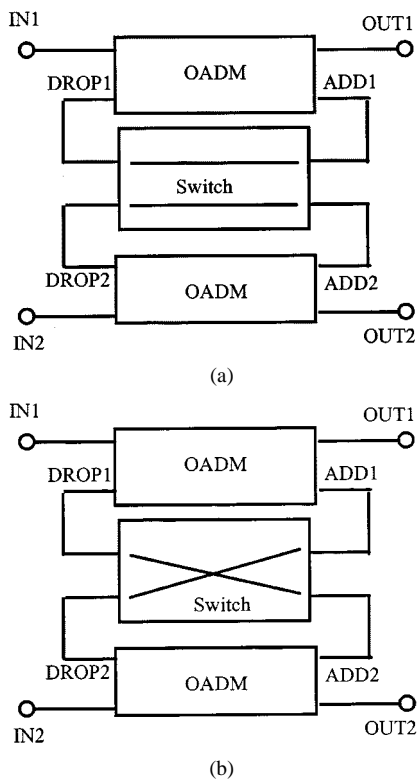
Fig. 1. Structure of 2×2 wavelength switching block. (a) in "bar" state. (b) in "cross" state.

paths. For example, if the 2×2 switch elements in [7] are replaced by the proposed 2×2 OXC, a strictly nonblocking $N \times N$ OXC can be built following the same growth path.

III. EXPERIMENTAL DEMONSTRATION

An experiment is made to demonstrate the concept and basic performance of the proposed 2×2 multiwavelength OXC, using fibergrating-based Mach–Zehnder interferometer (MZI) OADMs and a mechanical optical switch. Fig. 3 shows the experimental setup. Eight DFB lasers, with channel spacing of 1.6 nm, are combined through an arrayed-waveguide grating multiplexer, and modulated by a lithium niobate external modulator at 10 Gb/s. EDFAs are used to overcome the loss from all passive components. The extinction ratio of the modulated signals is 10 dB. The power of the eight channels is then divided into 2 parts, and decorrelated by a 5 km fiber delay line, in order to simulate the 2 inputs into a 2×2 multiwavelength OXC. The 2×2 multiwavelength OXC contains two wavelength switching blocks. One is working at 1555.7 nm, with a connection of two fiber grating based MZI-OADMs and a mechanical optical switch in "cross" state, and the other is working at 1559.0 nm and contains one MZI-OADM, with a connection from drop port to add port to simulate a block in "bar" state. From one output of the 2×2 multiwavelength OXC, all eight channels are demultiplexed and, in turn, put into a PIN receiver. Bit-error-rate (BER) curves are measured using a BER test-set, with optimal threshold setting. Polarization controllers are used to maximize the influence of the crosstalk in the BER measurement.
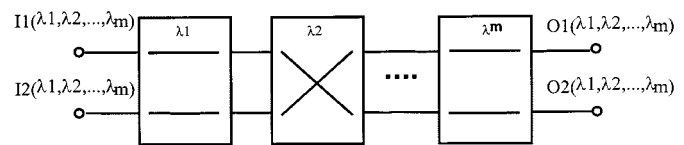

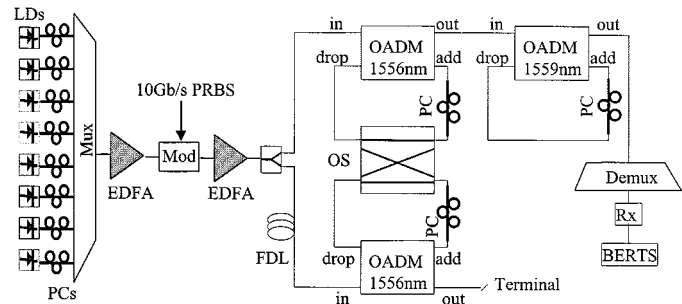Fig. 2. Structure of 2×2 multiwavelength optical cross-connect block.

Fig. 3. Experimental setup of a 2×2 multiwavelength OXC. PC: polarization controller. Mux: Multiplexer. Mod: Lithium Niobate external modulator. FDL: Fiber delay line. OS: Mechanical optical switch. Demux: Demultiplexer. Rx: PIN receiver. BERTS: Bit-error-rate test set.

Penalty of each channel is defined as the difference between receiver sensitivities with and without the 2×2 OXC, and is shown in Fig. 4 as open squares together with the calculated value shown in solid line in the same figure. Maximum measured penalty is 0.7 dB. The calculated penalties agree well with the measured values for all channels. The crosstalk-induced penalty is calculated based on the measured transfer functions of the OADMs, on-off ratio of the optical switch and losses in the optical paths, using a Gaussian crosstalk model, described in [8]. Detailed analysis of crosstalk in the proposed OXC can be found in [6]. The transfer function of the 1559-nm OADM is shown in Fig. 5. The calculation also shows that the 1555.7 nm switching block gives little influence on the penalties of all channels because of the transfer functions of the OADMs and the high on–off ratio of the space switch. Penalties of all channels, except the one at 1559.0 nm, are mainly due to the poor extinction ratio E in the 1559-nm OADM; the low penalty in 1559.0 nm channel benefits from the high drop band rejection ratio R in the same OADM.

IV. INTEGRATION

Since the MZI-OADMs and optical switches can be fabricated as planar lightwave circuits (PLCs) [9], [10], the 2×2 wavelength-switching block can be integrated on a PLC. Fig. 6 shows a schematic diagram of the 2×2 wavelength switching block. The basic structure is 8 Mach–Zehnder interferometers (MZIs). Gratings, with the central wavelength of the switching channel, are written in the arms of a cascaded MZI to form two-stage MZI-OADMs, in order to obtain a high rejection ratio of the drop channels [11]. Thermal films are put on top of the MZI to realize the thermo-optic (TO) switches, and switching is performed by changing the electrical current through the thermal films. A double-gate TO switch is employed in the block to provide a high on–off ratio [10]. Integration of the 2×2 wavelength-switching blocks will make the proposed 2×2 multiwavelength OXC, promising for mass production at low cost.
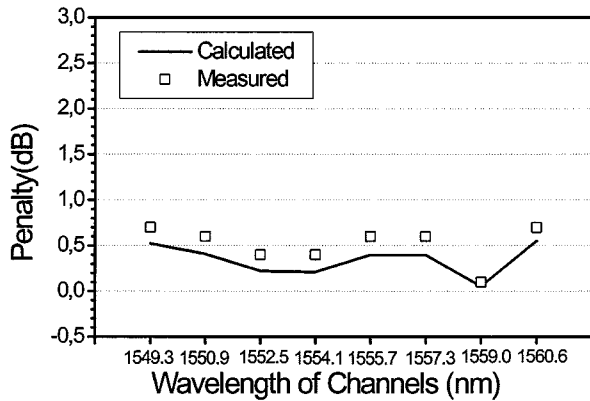
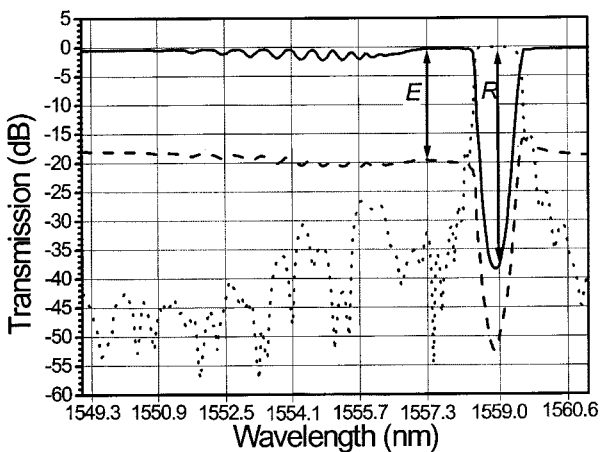Fig. 4. Penalty of each channel after the 2×2 OXC.

Fig. 5. Transfer functions of the OADM with drop wavelength at 1559.0 nm. ——— IN to OUT; . . . IN to DROP; ——— IN to ADD.

V. CONCLUSION

A new architecture of a 2×2 multiwavelength OXC has been presented. The proposed OXC is strictly nonblocking, has high degree of modularity, and can be constructed with low-loss differences between channels and low crosstalk. The transmission performance of the 2×2 multiwavelength OXC is experimentally demonstrated. A possible integration scheme of the 2×2 wavelength switching block is proposed, that enables low-cost mass production.
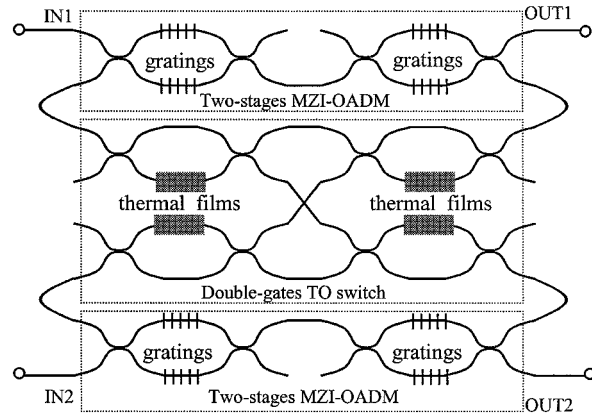

Fig. 6. Integration scheme of the 2×2 wavelength switching block using MZI-OADM's and TO switch.

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