

A strictly nonblocking network based on nonblocking 4×4 optical switches

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ABSTRACT

Recently, the demand for communication has been growing rapidly. Hence, optical multistage network technologies are more appreciated nowadays. A double-layer network is a strictly nonblocking network, and it has the lowest system insertion loss of non-dilated networks. A Beneš network is a rearrangeably nonblocking network, and it has the same system insertion loss as a double-layer network. We have proposed the use of modified polarization selection elements (PSEs). The system insertion loss, number of drivers, and number of required components of a double-layer network could be reduced if it is constructed with modified PSEs. A nonblocking 4×4 optical switch with two stages of polarization selective elements has been presented in our previous study. Based on this nonblocking 4×4 optical switch, we propose a strictly nonblocking network structure which features even lower system insertion loss than those of a double-layer network and a Beneš network. The signal-to-noise ratio of the proposed network structure is a constant, and is higher than the constraint, although it is lower than that of the double-layer network. The number of major components of the proposed network is less than that of a double-layer network and larger than that of a Beneš network, since a Beneš network is rearrangeably nonblocking. We also offer a routing algorithm for the new proposed network; the time complexity of the routing algorithm is $O(1)$.

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1. Introduction

Recently, the demand for communication has increased greatly. High transmitting capacity is an important feature

of communication systems. Since the bit rate of optical communication systems is higher than that of electronic communication systems [1], optical multistage networks are receiving more and more attention nowadays. To support optical communication systems, several kinds of optical multistage network have been presented [1–17]. A double-layer network is a strictly nonblocking network, and it has the lowest system insertion loss among non-dilated networks. A Beneš network is a rearrangeably nonblocking network. It has the same system insertion loss but a smaller number of optical switching elements compared with a double-layer network.

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To implement these optical multistage networks, several optical switch structures have been proposed, such as integrated electro-optic devices on Ti : LiNbO₃ (titanium diffused lithium niobate) material [18], a prism PBS (polarization beam splitter), and a holographic PBS [19,20]. An optical multistage network constructed with LiNbO₃ features the allocation of all of the optical switching elements and interconnection lines on the same plane. This feature induces the crossover problem of interconnection lines. The crossovers not only increase the system insertion loss but also reduce the signal-to-noise ratio (SNR) [21]. Since the polarization selective elements (PSEs), such as the prism PBS and the holographic PBS, are three-dimensional (3D) switching elements, all interconnection lines between two adjacent stages are parallel if the locations of the PSEs are arranged accurately. We could delete all interconnection lines and eliminate the crossover problem by coupling the stages tightly [22–32].

PSEs are convenient for constructing optical multistage networks due to the above features. A nonblocking 4×4 optical switch has been presented in our research [32]. Based on this nonblocking 4×4 optical switch, we propose a strictly nonblocking network in this study. This paper is organized as follows. First, three types of optical switching element with PSEs are introduced in Section 2. In Section 3, the properties of blocking and crosstalk are discussed. In Section 4, a strictly nonblocking network structure is proposed. We then offer the routing algorithm for the strictly nonblocking network in Section 5. Finally, a brief conclusion is given.

2. Optical switching elements with PSEs

A 2×2 optical switching element with a PSE can have four possible switching states: “straight”, “swap”, “combine”, and “split”. The switching state is determined by the propagation direction of the PSE, which is determined by the polarization of the optical signal. These four states are shown in Fig. 1. In the figures in this paper, *s*-polarization and *p*-polarization are denoted by “•” and “↔”, respectively. In Fig. 1(a), two *s*-polarized optical signals pass directly through the PSE; it provides the “straight” state. In Fig. 1(b), two *p*-polarized optical signals enter the PSE, and the propagation directions of these two *p*-polarized optical signals will be swapped by the PSE, so it provides the “swap” state. In Fig. 1(c), two optical beams with different polarizations enter the PSE from two separate input channels and depart from the same output channel; therefore, it provides the “combine” state. Fig. 1(d) shows the opposite case. In this figure, two optical beams with different polarizations enter the PSE from the same input channel and depart from two separate output channels, so it provides the “split” state.

An electro-optic halfwave plate (EOHWP) is a component which can change the polarization of beam. An EOHWP has two states: “active” and “inactive”. An EOHWP is in the “active” state when a voltage is applied to the EOHWP. Otherwise, the EOHWP is in the “inactive” state. The beam through an EOHWP is changed from *s*-polarization to *p*-polarization or from *p*-polarization to *s*-polarization when the EOHWP is in the “active” state. In the other state,

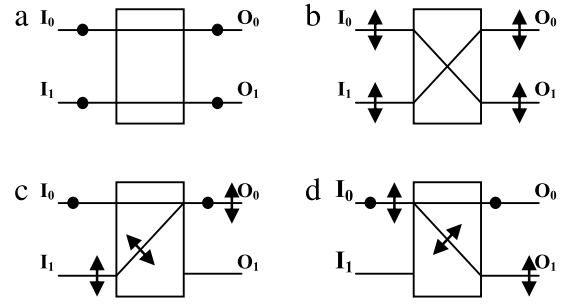


Fig. 1. Four switching states of a 2×2 optical switching element with a PSE: (a) the “straight” state, (b) the “swap” state, (c) the “combine” state, and (d) the “split” state.

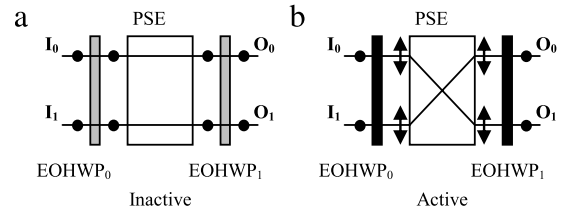


Fig. 2. The two switching states of a 2×2 optical switching element with one PSE and two EOHWPs: (a) the “straight” state, and (b) the “swap” state.

the EOHWP would not change the polarization of the passing beam [33].

Shown in Fig. 2 is a normal 2×2 optical switching element which is constructed by one PSE and two EOHWPs. The functions of the EOHWPs are twofold: to keep the polarization of the signals of the output channels the same as that of input channels, and to determine the switching state of the optical switching element. The switching element has two inputs (I_0 and I_1) and two outputs (O_0 and O_1), and provides two switching states: one is the “straight” state and the other is the “swap” state. Each input (output) channel is passed by one optical signal; therefore, each interconnection line is passed by only one optical signal. A normal 2×2 optical switching element does not provide the “combine” state and the “split” state. We propose a modified 2×2 optical switching element as shown in Fig. 3. It is constructed by one PSE and four EOHWPs, and can provide the full states.

A normal 1×2 optical switching element is constructed by one PSE and two EOHWPs, as shown in Fig. 4. The functions of the EOHWPs are the same as in a normal 2×2 optical switching element. The 1×2 switching element has one input (I) and two outputs (O_0 and O_1), and provides two switching states: a “straight” state and a “turn” state. We also propose a modified 1×2 optical switching element constructed by a PSE and an EOHWP; all of its possible switching states are shown in Fig. 5. Both Fig. 5(a) and (b) show the “straight” state, and the output optical beams are *s*-polarized. Both Fig. 5(c) and (d) show the “turn” state, and the output optical beams are *p*-polarized. Since the optical beam from the output channel could follow the same path backward with the corresponding polarization and finally reach the input channel, the 1×2 optical switching element provides a

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