Loss Reduction of AS/AC Networks with Holographic Optical Switches

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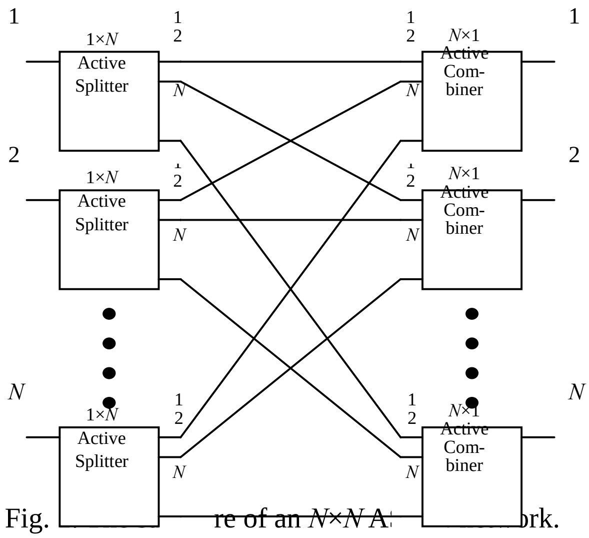
Abstract: - Using holographic optical switches to implement active splitter/active combiner networks not only significantly save the space of the whole system and efficiently eliminates all interconnection lines and crossovers, but also reduces the number of switches from $2N^2$-$2N$ to $2N\log_2N$. The system insertion loss can also be significantly minimized by combining the unique features of the active splitter/active combiner network and holographic optical switches.

Key-words: holographic optical switch, optical switch, polarization beam splitter, optical interconnection network, system insertion loss, polarization selective element.

1 Introduction

Active splitter/active combiner (AS/AC) networks [1, 2] have some advantages such as strictly nonblocking, simple routing-algorithm, low system-insertion-loss, zero differential loss, fewer drivers, and the best signal-to-noise ratio characteristics. However, it requires a large number of switches, interconnection lines, and crossovers to construct an AS/AC network. In recent researches, these drawbacks can be solved by using polarization selective elements, like holographic and prism polarization selective elements (PBSs) [3 - 6].

An $N\times N$ AS/AC network as shown in Fig. 1 consists of $1\times N$ active splitters and $N\times 1$ active combiners. The numbers of $1\times N$ active splitters and $N\times 1$ active combiners are both N. The basic optical switching elements of $1\times N$ active splitter and $N\times 1$ active combiner are 1×2 and 2×1 optical switches, respectively, as shown in Fig. 2. Both of $1\times N$ active splitter and $N\times 1$ active combiner are formed by N-1 switches arranged in a $\log_2N$-stage binary tree structure [1, 2], and only one optical beam can pass through each $1\times N$ active splitter or $N\times 1$ active combiner.



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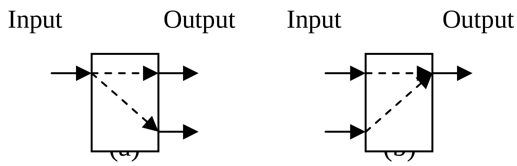

Fig. 2. The basic optical switches in AS/AC networks: (a) 1×2 optical switch. (b) 2×1 optical switch.

2 Holographic Optical Switches

Figs. 3(a) and 3(b) show the two states of a 1×2 holographic optical switch (HOS). A 1×2 HOS consists of a holographic PBS and two electro-optic halfwave plates (EOHWP) [7]. The EOHWPs are used to keep the polarization of output beam the same as that of input, and can be controlled by single driver.

The initial input and final output optical beams are *s*-polarized as shown in these figures. When EOHWPs are inactive, the polarization of the optical beam is not altered, so its direction will not be altered by the holographic gratings. In this case, the 1×2 HOS provides “**straight**” function as shown in Fig. 3(a). Similarly, the optical signal from the output channel will follow the same path backward with corresponding polarization and finally reach the input channel.

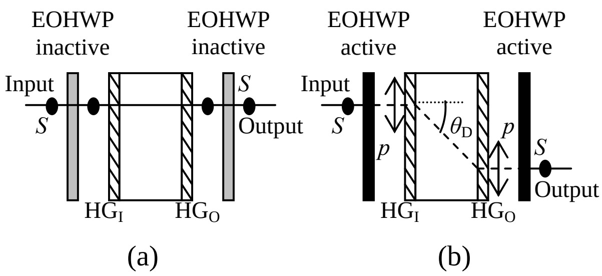

Fig. 3. The 1×2 HOS with holographic PBS; (a) straight state and (b) turn state, where EOHWP is the electro-optic halfwave plate and the HG is the holographic grating.

When EOHWPs are active, the polarization of the optical beam is rotated by 90° and is *p*-polarized. This optical beam is diffracted by the input coupling holographic grating (HG_I) and normally coupled out with a conjugate diffraction by the output coupling holographic grating (HG_O). In this case, the 1×2 HOS provides "**turn**" function as shown in Fig. 3(b). Also, the optical signal from the output channel can follow the same path backward with corresponding polarization and finally reach the input channel. Obviously, this 1×2 HOS provides bi-directional switching function. Therefore, a 1×2 HOS can act as a 2×1 HOS.

By the unique features of the AS/AC network, the structure of HOS can be simplified as shown in Fig. 4. A simplified 1×2 HOS consists of a holographic PBS and an electro-optic halfwave plate (EOHWP) [4, 5]. All of the switching situations are shown in Fig. 4. In Figs. 4(a) and (b), the input optical beams are *s*-polarized and in Figs. 4(c) and (d), the input optical beams are *p*-polarized. In Fig. 4(a), an *s*-polarized input optical beam passes directly through the inactive EOHWP and the dielectric substrate. In Fig. 4(c), the input optical beam is *p*-polarized and the EOHWP is active. After passing through the EOHWP, the polarization of the optical beam is rotated by 90° and is *s*-polarized. In this situation, this optical beam can directly pass through the dielectric substrate. Therefore, both of Fig. 4(a) and (c) provide the "**straight**" state and the output optical beams are *s*-polarized.

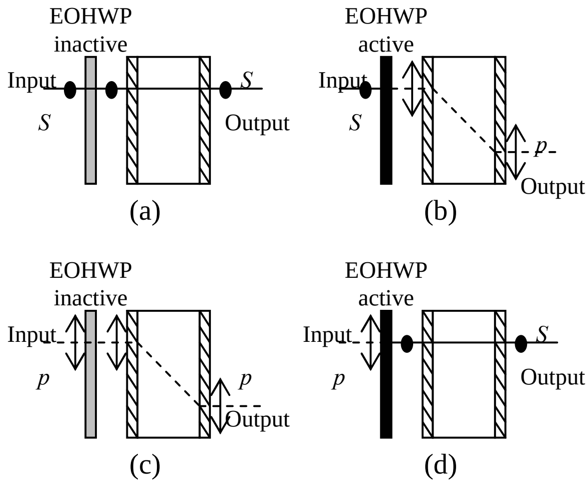

Fig. 4. A simplified 1×2 HOS consists of a holographic PBS and an electro-optic halfwave plate; (a) "straight" state, (b) "turn" state, (c) "turn" state, and (d) "straight" state, where EOHWP is the electro-optic halfwave plate.

In Fig. 4(b), the EOHWP is active. While the input optical beam passing through the EOHWP, the polarization of the optical beam is rotated by 90° and is *p*-polarized. This input optical beam is diffracted by the input coupling holographic grating (HG_I) and normally coupled out with a conjugate diffraction by the output coupling holographic grating (HG_O). In Fig. 4(d), the input optical beam is *p*-polarized and the EOHWP is inactive. In the dielectric substrate, this input optical beam will follow the same path as Fig. 4(b) to output. Hence, both of Fig. 4(b) and (d) provide the "**turn**" state and the output optical beams are *p*-polarized. Obviously, this 1×2 HOS provides bi-directional switching function. Therefore, a 1×2 HOS can act as a 2×1 HOS. The optical beam from the output channel can follow the same path backward with corresponding polarization and finally reach the input channel.

3 AS/AC Network with Holographic Optical Switches

A 4×4 AS/AC network with ordered stages number is shown in Fig. 5, which consists of 1×4 active splitters and 4×1 active combiners. The numbers of 1×4 active splitters and 4×1 active combiners are both four. A 1×4 active splitter with HOSs consists of three 1×2 HOSs as shown in Fig.

6(a). Because only one optical beam passes through this 1×4 active splitter, two 1×2 HOSs at Stage 2 can be driven by one driver; therefore, only need one EOHWP. These two holographic PBSs can be combined together into one holographic PBS. After optimal design, both of interconnection lines can be eliminated as shown in Fig. 6(b) [4].

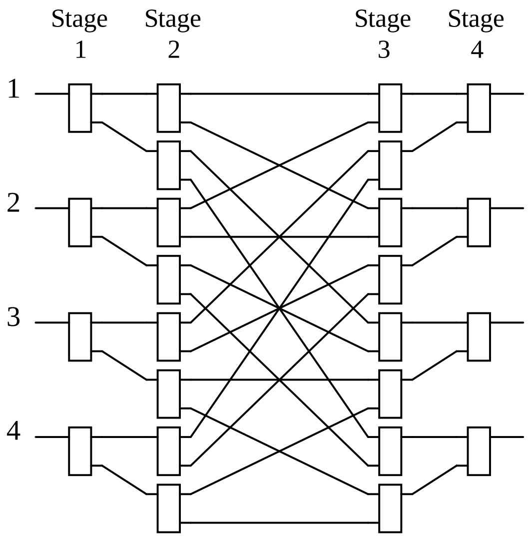

Fig. 5. 4×4 AS/AC network with ordered stages number.

Table 1 The switching states of HOSs of the 1×4 active splitters.

Output Cannel	HOS Switching State		Polarization of the Output Optical Beam
	Stage 1	Stage 2	
O_1	Straight	Straight	*s*-polarized
O_2	Straight	Turn	*p*-polarized
O_3	Turn	Straight	*s*-polarized
O_4	Turn	Turn	*p*-polarized

According to the switching states of these two HOSs, the connection path in the 1×4 active splitters can be determined as shown in Table 1. While these two stages of HOSs are in "**straight**" state, the input connects to O_1 and it is *s*-polarized at output channel. If Stage 1 is in "**straight**" state and Stage 2 is in "**turn**" state, the input is connected to O_2 and the output optical beam is *p*-polarized. In the opposite case, Stage 1 is in "**turn**" state and Stage 2 is in "**straight**" state, the input is connected to O_3 and the output optical beam is *s*-polarized. At the last case, the input connects to O_4 and the output optical beam is *p*-polarized. Both of these two stages of HOSs are in "**turn**" state.

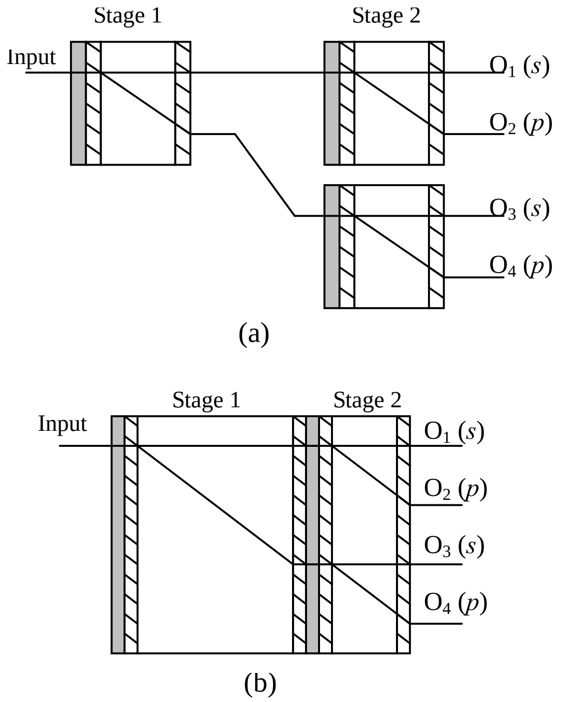

Fig. 6. (a) 1×4 active splitter with three simplified 1×2 HOSs; (b) a compact structure of 1×4 active splitter with two simplified 1×2 HOSs.

A 4×4 AS/AC network with HOSs is shown in Fig. 7. In this figure, there are some polarization states between the active splitters and the active combiners are unmatched, such as from I_1 to O_2. In this situation, the second output of the first active splitter is connected to the first input of the second active combiner. When the input and output optical beams are *s*-polarized, the polarization of the second output of the first active splitter and the first input of the second active combiner are *p*- and *s*-polarized, respectively. In this case, this connection path can not be built. By cascading a halfwave plate (HWP) between these two points as shown in Fig. 7, the problem can be solved. However, these halfwave plates increase the insertion loss and system cost. These problem can be solved by upside down the arrangement of the even number active splitters and active combiners as shown in Fig. 8. In this figure, all of the connection paths have the matched polarizations. Compared with the original design

[4], half of the number of EOHWPs will be reduced. Because each stage of HOS has been reduced one EOHWP, the system insertion loss will be decreased from $2\log_2 N(2L_{EOHWP}+L_{PBS})$ to $2\log_2 N(L_{EOHWP}+L_{PBS})$, where L_{EOHWP} and L_{PBS} are the insertion losses of the electro-optic halfwave plate and holographic PBS, respectively. Hence, the insertion loss and system cost can be efficiently reduced.

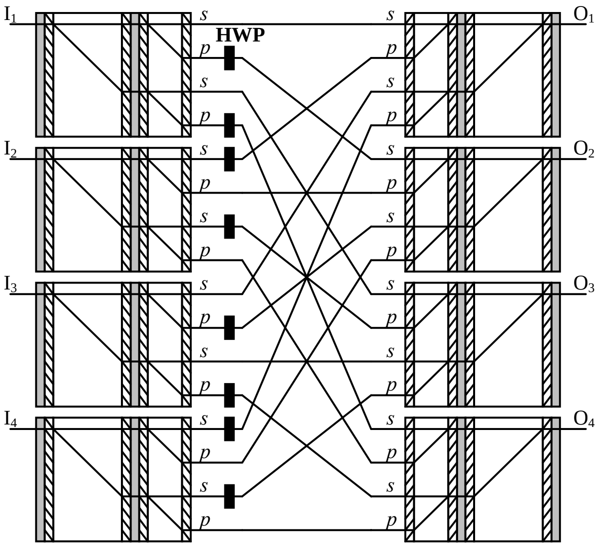

Fig. 7. A 4×4 AS/AC network with HOSs in which needs some halfwave plate (HWP) to solve the polarization unmatched problem.

4 Conclusions

In this study, using holographic optical switches to build the active splitter/active combiner network has been proposed. With the unique features of compactness and flexibility, holographic optical switches eliminate all interconnection lines between switches. Not only the volume of all system but also the number of required components are reduced significantly. Especially, the number of switches of an $N\times N$ active splitter/active combiner network decreased from $2N^2-2N$ to $2N\log_2 N$. In this presentation, according to the network characteristics, the structure of the holographic optical switch has been modified. Because each stage of HOS has been reduced one EOHWP, the system insertion loss will be decreased from $2\log_2 N(2L_{EOHWP}+L_{PBS})$ to $2\log_2 N(L_{EOHWP}+L_{PBS})$. This modification results that the insertion loss and system cost can be efficiently reduced.

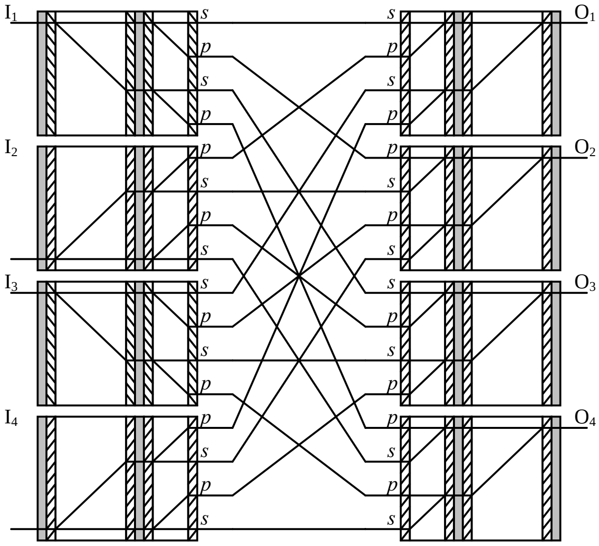

Fig. 8. A 4×4 AS/AC network with HOSs in which the arrangement of the even number active splitters and active combiners have been upside downed to solve the polarization unmatched problem.

Acknowledgement

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