AS/AC Network with Holographic Optical Switches

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Abstract — The holographic optical switches are three-dimensional devices, having the characteristics of flexibility and compactness. The procedure to realize a 4×4 active splitter and active combiner network with holographic optical switches is discussed in detail. After optimum design, the unique features of compactness and flexibility of holographic optical switches not only significantly saves space of system and efficiently eliminates all interconnection lines and crossovers, but also reduces the number of switches.

Index Items — holographic optical switch, optical switch, polarization beam splitter (PBS), optical interconnection network.

I. INTRODUCTION

There are some advantages for active splitter and active combiner (AS/AC) networks, like strictly nonblocking, simpler routing-algorithm, lower system-insertion-loss, zero differential loss, fewer drivers, and the best signal-to-noise ratio characteristics. However, they require a large number of switches, interconnection lines, and crossovers.

An N×N active splitter and active combiner network as shown in Fig. 1 consists of 1×N active splitters and N×1 active combiners. The numbers of 1×N active splitters and N×1 active combiners are both N. The basic optical switching elements of 1×N active splitter and N×1 active combiner are 1×2 and 2×1 optical switches, respectively, as shown in Fig. 2. Both of 1×N active splitter and N×1 active combiner are formed with N-1 switches arranged in a log2N-stage binary tree structure [1]-[2], and only one optical beam passes through each 1×N active splitter or N×1 active combiner.

Fig. 1 The structure of an N×N AS/AC network.

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

The 1×4 active splitter and a 4×1 active combiner, which are subnetworks to build a 4×4 AS/AC network, with ordered numbers of stages, channels, and switches are shown in Fig. 3(a) and 3(b), respectively. Both of them have two stages.
In Fig. 3(a), $S_{i,j}$ represents the $j_{th}$ switch in stage $i$, $I_0$ represents input channel, and $O_n$ represents output channel $n$. If input $I_0$ is connected to $O_1$, the connection path consists of two switches: $S_{1,1}$ and $S_{2,1}$. The switching state of $S_{1,1}$ is in the “straight” state and $S_{2,1}$ is in the “turn” state. In this subnetwork, Stage 2 has two $1 \times 2$ optical switches: $S_{2,1}$ and $S_{2,2}$. Because only one optical beam passes through this $1 \times 4$ active splitter, no optical beam passes through $S_{2,2}$. The switching state of $S_{2,2}$ can be set the same as $S_{2,1}$; therefore, these two $1 \times 2$ optical switches can be controlled by one driver. In other words, each $1 \times N$ active splitter only needs $\log_2 N$ drivers. Because $N \times 1$ active combiner has the same situation as $1 \times N$ active splitter, each $N \times 1$ active combiner requires $\log_2 N$ drivers, too. Therefore, the total number of drivers of an $N \times N$ AS/AC network is $2^N \log_2 N$.

II. HOLOGRAPHIC OPTICAL SWITCHES

Fig. 4(a) and 4(b) show two states of a $1 \times 2$ HOS. A $1 \times 2$ HOS consists of a holographic PBS and two electro-optic halfwave plates [7]. The halfwave plates 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 electro-optic halfwave plates are active, the polarization of the optical beam is not altered, so its direction will not be altered by the holographic gratings. In this case, the $1 \times 2$ HOS provides “straight” connection as shown in Fig. 4(a). Similarly, the optical signal from output channel will follow the same path backward with corresponding polarization and finally reach input channel.

Fig. 4 The $1 \times 2$ 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 electro-optic halfwave plates 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 (HGg). In this case, the 1×2 HOS provides “turn” connection as shown in Fig. 4(b). Also, the optical signal from output channel can follow the same path backward with corresponding polarization and finally reach input channel. Obviously, this 1×2 HOS provides bi-directional switching function. Therefore, a 1×2 HOS can act as a 2×1 HOS.

In this 1×2 HOS, the distance between two output channels is \( d_c \) and the corresponding thickness of the dielectric substrate is \( t_{sub} \). The relation between these two parameters is

\[
\frac{d_c}{t_{sub}} = \cot \theta_D.
\]

(1)

where \( \theta_D \) is the diffraction angle. In other words, when the distance between these two output channels in the 1×2 HOS is changed to \( 2d_c \), the corresponding thickness of the dielectric substrate needs to expand to \( 2t_{sub} \).

III. AS/AC NETWORK WITH HOLOGRAPHIC OPTICAL SWITCHES

This section describes how to build a 4×4 AS/AC network without interconnection line and crossover by using HOSs. After optimal design, the final configuration not only saves the space required for the whole system and eliminates all interconnection lines and crossovers, but also reduces the number of 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 both 1×4 active splitters and 4×1 active combiners are four.

Fig. 6(a) shows a 1×4 active splitter with HOSs, which consists of three 1×2 HOSs. 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 pair of EOHWPs. These two holographic PBSs can be combined together into one holographic PBS as shown in Fig. 6(b). Therefore, two 1×2 HOSs at Stage 2 are replaced by a single 1×2 HOS. This 1×4 active splitter only needs two HOSs and the number of switches is reduced. With the same method, both of the 1×N active splitter and N×1 active combiner only need \( \log_2 N \) HOSs.

Obviously, the number of switches is decreased by using HOSs to build these active splitters and active combiners. Therefore, an \( N\times N \) AS/AC network consists of 1×N active splitters and N×1 active combiners, and the numbers of these splitters and combiners are both \( N \). The number of switches of an \( N\times N \) AS/AC network has significantly been reduced from \( 2N^2-2N \) to \( 2N \log_2 N \).

As shown in Fig. 6(b), two interconnection lines connect the output channels of Stage 1 and the input channels of Stage 2. The distance between the output channels at Stage 1 is \( d_c \), and the distance between the input channels at Stage 2 is \( 2d_c \). For eliminating these two interconnection lines, they have to be arranged parallel and completely normal to HOSs. Therefore, the distance between the output channels at Stage 1 has to be adjusted to \( 2d_c \). According to Eq. (1), the corresponding thickness of the dielectric substrate must change to \( 2t_{sub} \) as shown in Fig. 6(c). Because both of interconnection lines are parallel and completely normal to HOSs, two HOSs can be directly packeted together as shown in Fig. 6(d), and no interconnection lines are required. Because HOSs are bi-directional devices, this 1×4 active splitter can also function as a 4×1 active combiner.
A 4×4 AS/AC network with HOSs is shown in Fig. 7. In this figure, 1×4 active splitters or 4×1 active combiners on each stage all have the same structure including the corresponding thicknesses of dielectric substrates. All of the HOSs at the same stage can be formed on the same holographic PBS as shown in Fig. 8. In this figure, four EOHWPs are formed on a holographic PBS at each side. The first pair of EOHWPs are (EOHWP01, EOHWP11), which construct the first 1×2 HOS. The second, third, and last pairs of EOHWPs are (EOHWP02, EOHWP12), (EOHWP03, EOHWP13), and (EOHWP04, EOHWP14), respectively. Four 1×2 HOSs are constructed by four pairs of EOHWPs and one holographic PBS. With the same method, \( N \) 1×2 HOSs can be constructed with \( N \) pairs of EOHWPs and one holographic PBS. Because there are \( 2\log_2 N \) stages in an \( N \times N \) AS/AC network [1, 2], this network needs \( 2\log_2 N \) holographic PBSs with different corresponding thicknesses of dielectric substrates to construct \( 2N\log_2 N \) HOSs.

After suitably adjusting the positions and orientations of all HOSs as shown in Fig. 9, all interconnection lines between HOSs can be arranged to become parallel and completely normal to HOSs. Therefore, all HOSs can be directly packeted together as shown in Fig. 10, and no interconnection line is required. Finally, a compact network is built by using HOSs without any interconnection line and crossover.
Fig. 8 Four HOSs constructed by four pairs of EOHWPs form on a holographic PBS.

Fig. 9 The AS/AC network after rearranging all HOS’s position and orientation. (All interconnection lines are parallel, and completely normal to the switches.)

IV. CONCLUSION

In summary, we demonstrate the active splitter and active combiner network which built by holographic optical switches. With the unique features of compactness and flexibility, holographic optical switches efficiently 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 and active combiner network decreased from $2N^2-2N$ to $2N\log_2N$.

Fig. 10. Three-dimensional compact configuration of an AS/AC network.

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REFERENCES


