Switching Characteristics of All-Optical Wavelength-Selective Switch Controlled by a Single Light

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Abstract—**We reports operating condition of a modified architecture of all-optical wavelength-selective switch controlled by a single light. Switching characteristics in a proposed circuit are analyzed with regard to their phase dependence.**

Keywords- optical switch; asymmetric X-junction coupler; Raman amplifier; wavelength-selective; Integrated optics; Optical waveguide; Wide wavelength range

I. INTRODUCTION

Wavelength-selective processing in switching, routing systems will become key technologies in order to efficiently handle signals of multiple wavelengths in network nodes. Integrated-optic switches are essential devices in such processing systems, in particular, high-speed wavelength-selective switches are required for processing wavelength-division multiplexed (WDM) packets. The authors have proposed all-optical wavelength-selective switches controlled by light intensity in cascaded optical couplers [1-5]. They consist of waveguide-type Raman amplifiers and attenuators as light intensity control elements, and 3-dB directional couplers or asymmetric X-junction couplers as optical couplers. Our latest study [5] has investigated the operation principle and characteristics of the switch employing asymmetric X-junction couplers, that have shown broadening its operating wavelength range. In this paper, we make clear another architecture of the switch, condition for switching, and additional characteristics affecting the operation of the switch, namely, dependence of signal phase variation.

II. PRINCIPLE OF SWITCHING

The architecture of the broadband wavelength-selective switch reported in [5] and the architecture reported here are shown in Fig.1 and Fig.2, respectively. They consist of cascade connection of two interferometers, which formed with three asymmetric X-junction couplers. In addition, there are two waveguide-type Raman amplifiers and an optical attenuator in Fig.1, and a Raman amplifier and two attenuators in Fig.2. Multiple WDM signals can be simultaneously and wavelength-selectively switched with the single switch because the Raman amplifiers made of crystalline waveguides can wavelength-selectively amplify optical signals with narrow gain bandwidth.

In order to explain the switching condition of these switches, we focus on an X-junction coupler and signal with a certain wavelength. Optical electric fields of input and output waves in this coupler can be written as [6-8]

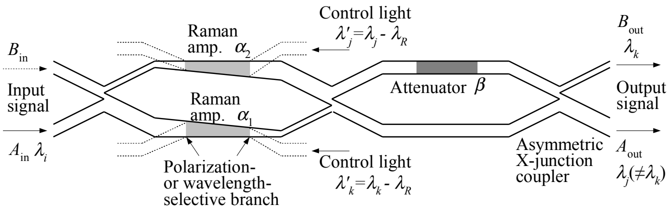


Figure 1 Schematic diagram of the previously reported switch.

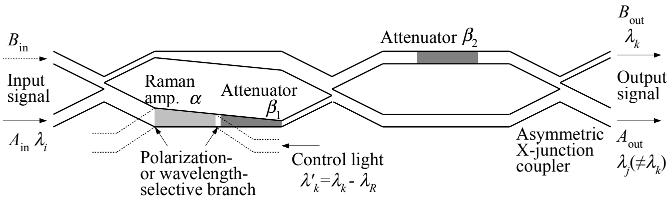


Figure 2 Schematic diagram of the modified switch.

$$\begin{pmatrix} A_{\rm out} \\ B_{\rm out} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} \begin{pmatrix} A_{\rm in} \\ B_{\rm in} \end{pmatrix} \qquad (1)$$

where phase terms due to the propagation along the waveguides are eliminated for simplicity. The output fields through the switch shown in Fig.1 are related to the input fields as reported in [5]. As a similar manner, the output fields of the architecture in Fig.2 are calculated as

$$\begin{pmatrix} A_{\rm out} \\ B_{\rm out} \end{pmatrix} = \begin{pmatrix} \dfrac{-E_{\rm in}}{(1+\sqrt{2})} \\ 0 \end{pmatrix} \quad \text{when} \quad \alpha = 1,\ \beta_i = \frac{1}{1+\sqrt{2}} \qquad (2)$$

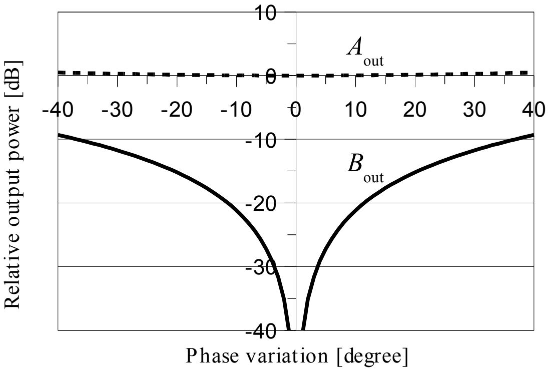
$$\begin{pmatrix} A_{\rm out} \\ B_{\rm out} \end{pmatrix} = \begin{pmatrix} 0 \\ -E_{\rm in} \end{pmatrix} \quad \text{when} \quad \alpha = (1+\sqrt{2})^2,\ \beta_i = \frac{1}{1+\sqrt{2}} \qquad (3)$$

where α is amplification coefficient, β_i (i=1,2) is attenuation coefficient. From these equations, it is found that incident wave is switched into each port when proper amplification and attenuation are maintained.

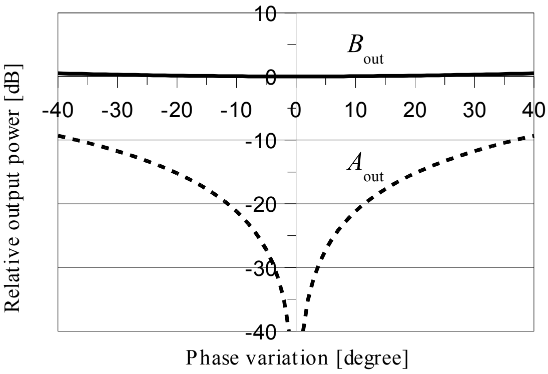
III. SWHITCHING CHARACTERISTICS

The wavelength range of switching is expected to be as wide as 400 nm as reported in [5]. Here we mention about the dependence on phase. When input waves are separated into their amplitude and phase factors, $A_{\rm in} = |A_{\rm in}| \exp(j\phi_{\rm Ain})$ and $B_{\rm in} = |B_{\rm in}| \exp(j\phi_{\rm Bin})$ where j is imaginary unit, (1) is calculated to

$$A_{\rm out} = |A_{\rm out}| \exp(j\phi_{\rm Aout}) \qquad (4)$$

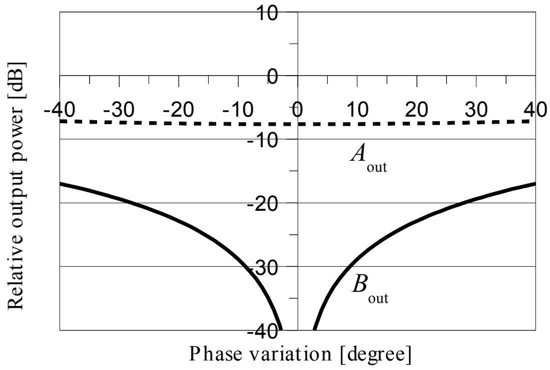


(a) At the condition when incident wave is routed to A_{out}

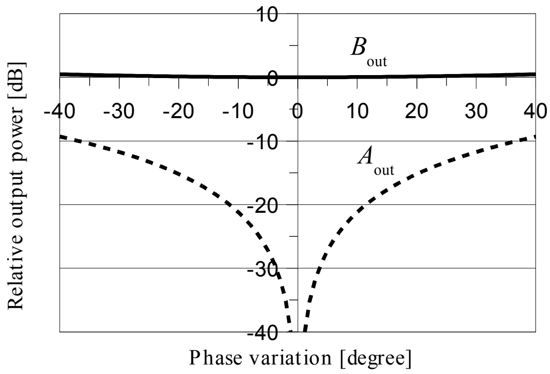


(b) At the condition when incident wave is routed to B_{out}

Figure 3 Phase dependence of the switch shown in Fig.1.



(a) At the condition when incident wave is routed to A_{out}



(b) At the condition when incident wave is routed to B_{out}

Figure 4 Phase dependence of the switch shown in Fig.2.

$$B_{out} = |B_{out}| \exp(j\phi_{Bout}) \quad (5)$$

where

$$|A_{out}| = \frac{1}{\sqrt{2}} \{|A_{in}|^2 + |B_{in}|^2 + 2|A_{in}||B_{in}| \cos(\phi_{Ain} - \phi_{Bin})\}^{1/2} \quad (6)$$

$$|B_{out}| = \frac{1}{\sqrt{2}} \{|A_{in}|^2 + |B_{in}|^2 - 2|A_{in}||B_{in}| \cos(\phi_{Ain} - \phi_{Bin})\}^{1/2} \quad (7)$$

$$\phi_{Aout} = \arctan \frac{A_{in} \sin\phi_{Ain} + B_{in} \sin\phi_{Bin}}{A_{in} \cos\phi_{Ain} + B_{in} \cos\phi_{Bin}} \quad (8)$$

$$\phi_{Bout} = \arctan \frac{-A_{in} \sin\phi_{Ain} + B_{in} \sin\phi_{Bin}}{-A_{in} \cos\phi_{Ain} + B_{in} \cos\phi_{Bin}} \ . \quad (9)$$

Fig.3 shows phase dependence of the switch shown in Fig.1. Phase change will occur between the upper and lower arms in front of the second coupler because the signal amplified in either amplifier may cause a nonlinear refractive index change. The phase change taking place in front of the third coupler can be neglected on installing phase shifting components such as optical delay lines or thermooptic devices. This is because the distribution of amplitudes of the signal in the waveguides between the second and the third couplers is the same whether the light wave is routed to one port or the other. Therefore, in this calculation, a virtual variation of phase is generated in front of the second coupler using (6)-(9).

Fig.4 shows phase dependence of the switch shown in Fig.2. There is slightly difference between Fig.4 and Fig.3, i.e. relative output power in Fig.4(a) is smaller than that of Fig.3(a) as expressed in (2).

It is found from Fig.3 and Fig.4, the extinction ratio over 20 dB is achieved within approximately ±12 degrees of phase variation. Moreover, this phase range is similar to our previously reported architecture employing 3-dB directional couplers [4].

IV. Conclusion

This paper reports operating condition and switching characteristics of a modified architecture for all-optical wavelength-selective switch. In future, we will investigate numerical simulation using a precise model and experimental verification with integrated-optic waveguides.

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