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بررسی مشخصات خودسوییچ ماخزندری مبتنی بر تقویت کننده نوری نیمرسانا

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چکیده – در این مقاله مکانیزم خود سوییچ ماخزندری مبتنی بر تقویت کننده نوری نیمرسانا (*SOA*) با استفاده از پاسخ دینامیک بهره *SOA* ارائه شده است. پارامترهای کلیدی ساختاری و پالس ورودی خود سوییچ تعیین و تاثیر آنها بر عملکرد خود سوییچ بررسی شده است. برای دستیابی به بهترین شرایط عملکرد خود سوییچ، باید مقادیر بهینه پارامترهای خود سوییچ تعیین و انتخاب شوند. نتایج شبیه‌سازی شرایط بهینه اصلاح پارامترهای کلیدی، برای کاربردهای مختلف خود سوییچ نوری را نشان می‌دهد.

کلید واژه- تداخل‌سنج ماخزندری، تغییرات پارامترهای کاربردی، تقویت‌کننده نوری نیمرسانا، خود سوییچ تمام نوری.

Investigation of SOA-Based MZI Self-Switch Characteristics

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Abstract- In this paper, we present self-switching mechanism using Semiconductor Optical Amplifier (SOA)-assisted Mach-Zehnder interferometer (MZI) considering dynamic gain response of the SOA. The effect of key structural and input pulse parameters of an all-optical MZI self-switches is identified and their role in the operation of self-switch is analyzed. The optimum values of these parameters must be correctly selected and adapted so as to ensure the satisfaction of the best operating conditions. Simulation results demonstrate that key parameters must be suitably must be modified to the specific all-optical self-switching application.

Keywords: Mach-Zehnder interferometer, performance parameters variation, Semiconductor Optical Amplifier, All-optical self-switch.

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1 Introduction

Semiconductor optical amplifier (SOA) is a promising element in All-optical communication networks. The switching attractive features of SOA are the fast switching time, low power consumption, high repetition rate, compactness, and high non-linear properties [1]. These features caused to SOA-assisted Mach-Zehnder interferometer (MZI) all-optical switches have been of large attention in research. These switches will perform a set of critical network processing functions such as shift register with inverter, address recognition, full adder and multi/ demultiplexing [2].

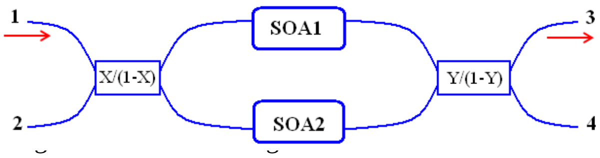
Self-switching (or asymmetric switching) is a technique that input signal can be switched to desire output port where the input signal is split unequally over the MZI arms without using high power extra switching signals. SOA–MZI self-switch has been used to perform various tasks such as pulse shaping [3], pattern effect compensator, all-optical time-domain label recognition, and low-loss optical combiner.

By using rate equation model (REM) we can describe the nonlinear gain and phase dynamics of SOA in a phenomenological way. The cross-phase modulation (XPM) and self-phase modulation (SPM) are common techniques to extract the SOA nonlinearities as switching nonlinear element [4]. Because of the unequally splitting input signal over the interferometer arms, two SOAs are operating in different gain regimes, obtaining a phase difference between the two signals which are propagated in each arm. Besides, due to the finite experiences a different phase shift relative to the lagging edge. SPM will change the pulse shape as well as its spectrum [5].

We propose here the effect of structural and input pulse parameters which have not been considered altogether comprehensively in previous MZI self-switches is considered.

2 Principle of Operation

The schematic diagram of the SOA-assisted MZI self-switch is shown in figure 1. When an input pulse launched at the input port 1, is split asymmetrically to each arm by the coupler. In the high optical power arm, the SOA experiences SPM, causing changes of both the gain and the refractive index as a function of entrance intensity. The phase shift of one of the SOA's is changed with respect to the other one by $\Delta\varphi$. As a result, due to SOA nonlinearities the phase difference occurs between these two pulses. If the phase difference between these pulses reaches adequate amount (π) the input pulse in Port 1 will be switched to switching port (Port 3 in figure 1) [5].



switch with unequal power distribution due to 2×2 coupler.

3 Model Formulation

The optical input pulse injected in the input port 1, is distributed unequally as SOA1 and SOA2 input pulses. The power splitting ratios in input and output coupler are X and 1-Y, respectively. The SOA1 and SOA2 input pulse powers after passing through input coupler are $X \times P_{in}$ and $(1-X)\times P_{in}$ respectively, where P_{in} is input pulse power. As mentioned before, SOA induces a nonlinear phase shift ($\Delta\varphi$) to these optical pulses. When $\Delta\varphi = \pi$, maximum extinction ratio between switch outputs (Port 3 and Port 4) can be reached. The switching window of the proposed port (port 3) can be expressed as [5]

$$SW(t) = XYG_1(t) + (1-X)(1-Y)G_2(t) - 2\sqrt{XY(1-X)(1-Y)G_1(t)G_2(t)}\cos(\Delta\varphi) \quad (1)$$

The basic interferometric equations that describe the self-switch output (port 3 and port 4), can be written as [6]

$$P_3(t) = \frac{P_{in}}{2}[XYG_1(t) + (1-X)(1-Y)G_2(t) - 2\sqrt{XY(1-X)(1-Y)G_1(t)G_2(t)}\cos(\Delta\varphi)] \quad (2)$$

$$P_4(t) = \frac{P_{in}}{2}[X(1-Y)G_1(t) + (1-X)YG_2(t) + 2\sqrt{XY(1-X)(1-Y)G_1(t)G_2(t)}\cos(\Delta\varphi)] \quad (3)$$

respectively. Where $G_1(t)$ and $G_2(t)$ are the SOA1 and SOA2 gain seen by the data pulses. These two parameters are related to $\Delta\varphi$ by [1]

$$\Delta\varphi = -\frac{\alpha_N}{2} Ln\left(\frac{G_1(t)}{G_2(t)}\right) \quad (4)$$

3.1 SOA Modelling

To take into account the electrical fields propagation in the SOA for picosecond regime, a theoretical basic model is solved numerically. The electrical fields is written as [4]

$$E(z,t) = A(z,t)\exp\left[-i(\omega_0 t\mu\beta_0 z)\right] \qquad (5)$$

Here, A is slowly varying complex envelope function of a propagating optical pulse in the SOA length; $\omega_0/2\pi$ is carrier frequency, and β_0 is propagating constant in SOA at transparency. The envelop propagation is described by the well-known equation [6]

$$\frac{\partial A}{\partial z} + v_g^{-1}\frac{\partial A}{\partial t} = g(1 - i\alpha_N)A \qquad (6)$$

Where, v_g is group velocity, α_N is line width enhancement factor associated with the gain change due to carrier depletion. Due to relatively narrow spectral width of optical pulse, the field gain g is assumed to be frequency independent. Otherwise, g in Eq. (6) should be replaced by an operator including second order time derivative [7]. The interaction between pulses and SOA is described by the (7) ordinary differential rate equation [6]. Where τ is carrier lifetime, E_{sat} is saturation energy of SOA. The small-signal gain coefficient per unit SOA length (linear gain) g_0 is determined by current injection.

$$\frac{\partial g}{\partial t} = \frac{g_0 - g}{\tau} - \frac{g \times |A|^2}{E_{sat}} \qquad (7)$$

4 Results and Discussions

The critical role of the SOA in the operation of the self-switch caused to investigate and understand the SOA dynamical behaviour with respect to several key operational parameters, such as the input pulse energy, input and output couplers unequal power splitting, and the SOA unsaturated power gain. We set the parameters as mentioned [4].

Figure 2 shows the normalized output power ($P_3/P_{3,max}$) and extinction ratio (P_3/P_4), by replacing P_3 and P_4 from (2) and (3), versus input pulse energy (E_{in}). For the normalized output power, increasing E_{in} enhances the depletion of carriers, so that the data pulses experiences a higher gains. Increasing SOA1 and SOA2 gains cased to the normalized output power increasing. The larger is E_{in}, the deeper is the SOA2 saturation and the steeper gain transition from the initial small signal to the final saturation value. On the other hand, as mentioned in Eq. (4), the gain ratio (G1/G2) for the pulses must be reaches adequate amount to have reaches desired phase difference (π). The result reveals that to have switching operation the input pulse energy should be 0.65 pJ< E_{in} < 2.85 pJ. For E_{in} = 1.3 pJ the phase difference between two data pulses reaches π and biggest extinction ration is achieved.

Figure 3 depicts the influence of the input and output couplers unequal power splitting on the switching characteristics. At X=Y=0.5 two data pulses have equal power pulses and hence equal gains (G_1=G_2). Therefore according to Eq. (4), $\Delta\varphi$ is equivalent to a zero and the full destructive interference at the Port 3 will occurred. By increasing amount of X(Y), the gain ratio of pulses

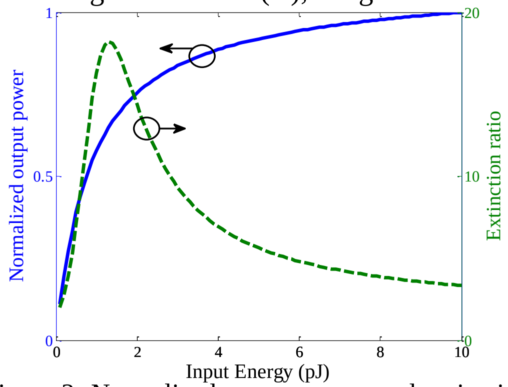


Figure 2: Normalized output power and extinction ratio from switched port 3 versus input pulse energy

and $\Delta\varphi$ increases. For X = Y = 1, the full constructive interference at the Port 3 will be occurred which in turn leads to the phase difference between two data pulses reaches π and hence biggest extinction ration is achieved. As shown in figure 3 for X(Y)< 0.125 and X(Y)> 0.875, the gain ratio of input pulses will be increased which in turn leads to input signal can be switched to desire output (port 3).

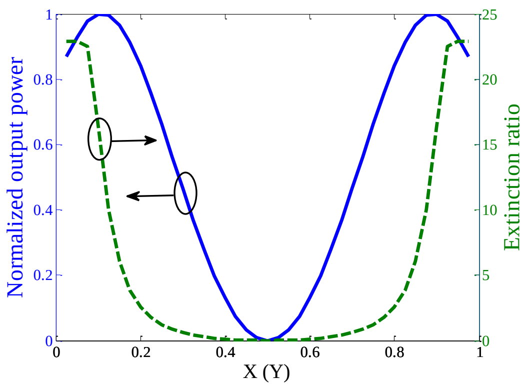


Figure 3: Normalized output power and extinction ratio from switched port 3 versus unequal power splitting coefficients

Figure 4 illustrates the unsaturated power gain (G_0) effect. An increased G_0 results in a gain variation far away from heavy saturation that cause to the gain seen by the pulses increases. The result shows that to have switching operation the unsaturated power gain should be 18 dB< G_0< 24 dB. For G_0 = 21 dB the phase difference between two data pulses reaches π and biggest extinction ration is achieved.

Figure 5 shows the input pulse is transmitted to port 3 (switching port) and the switching function will be achieved. Measured in FWHM, SOA1, SOA2, and port 3 output pulses are slightly expanded with an asymmetry shortening their leading edges, as is usually observed with SOA. These expansion and asymmetry shortening are more significant for port 3 output pulse.

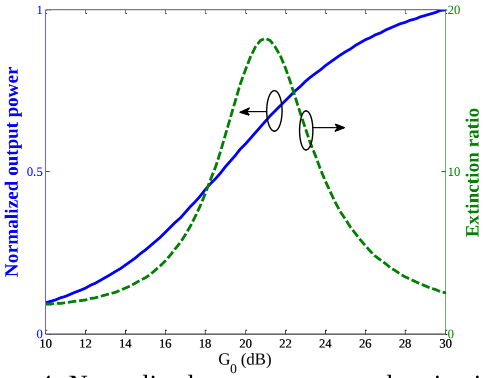


Figure 4: Normalized output power and extinction ratio from switching port 3, versus unsaturated power gain

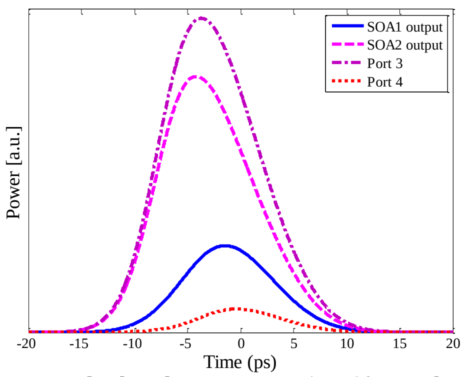


Figure 5: Calculated SOA's and self-switch output pulses temporal profile

5 Conclusion

We numerically analysed self-switching mechanism in SOA-based MZI interferometer by unequal distribution of input optical pulse. We showed that the switching characteristics can be accomplished by varying the input pulse energy, couplers unequal power splitting coefficient, and SOA's unsaturated gain.

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