High – Speed OTDM Demultiplexer

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Abstract:-

Two types of semiconductor optical amplifier (SOA)– based optical gate are investigated the Mach-Zender Interferometer(MZI),Ultrafast nonlinear interferometer (UNI). The gate are characterized by switch window calculation.Using the ICR ,the switch are compared as demultiplexer at line data rate 100,320 and 560 Gb/s. the effect of SOA injection current ,control pulse energy and SOA length also presented.

I. INTRODUCTION

High-Speed Optical telecommunication Network with terabit transmission capabilities can be achieved if the data remain in the optical format and bottlenecks due to the optical to electrical conversion are avoided. These systems required ultrafast signal processing like optical multiplier, add/drop functions ,optical demultiplexer and wavelength conversion [1]. Due to the high data rate, only all-optical switching method can be employed [2] . All-Optical switching involves the use of an optical control signal to switch data in the optical domain by taking advantage of the nonlinear effect that are presented in semiconductor devices. Since these nonlinear effect occur in time scale in the order of a few femto- seconds (10^{-15}) [3]. they can be used for high speed switching . Starting from SOA-based nonlinear interferometric structure and using optical nonlinearities in semiconductor material, various approach have been proposed and used for all-optical signal processing.Using several interferometric configuration (e.g MZI,UNI, sagnac, etc) [4], all-optical demultiplexer for TDM data signal with line bit rate of up to 160Gb/s has been demonstrated [5]. In this work

,all-optical interferometric gate based on SOA are investigated as OTDM demultiplexer.

II .Switching Types

A. MZI

One of an interferometer gate is shown schematically in Figure 1. It consists of a nonlinear medium incorporated in an interferometer setup in this case MZI.

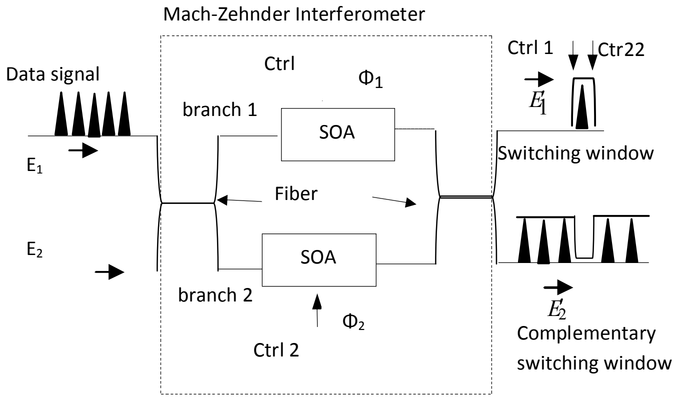

Figure1Schematicofmach-zehnderinterferometer switch based on SOAs as nonlinear medium.

In the Jones formulism [6] an optical systems, such as an interferometer, can be described by a transfer matrix M (Jones matrix) . That relates the output E' field to the input field E

$$E' = ME \qquad \text{--- (1)}$$

Where

$E = \begin{pmatrix} E_x \\ E_y \end{pmatrix}$ and $E' = \begin{pmatrix} E'_x \\ E'_y \end{pmatrix}$ are four-dimensional vectors

$$\begin{pmatrix} E'_1 \\ E'_2 \end{pmatrix} = \underbrace{\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}}_{M_{MZI}} \begin{pmatrix} E_1 \\ E_2 \end{pmatrix} \qquad \text{----(2)}$$

Equation (2) is written in a compact form. The Jones matrix of the MZI is denoted by MMZI whose elements M_{pq} (p,q $\in$ 1,2) are given by

$$M_{11} = J^{bar}_{(2)} J^{(1)} J^{bar}_{(1)} + J^{cross}_{(2)} J^{(2)} J^{cross}_{(1)} \quad \text{-- (3)}$$

$$M_{12} = J^{cross}_{(2)} J^{(1)} J^{bar}_{(1)} + J^{bar}_{(2)} J^{(2)} J^{cross}_{(1)}$$

$$M_{21} = J^{bar}_{(2)} J^{(1)} J^{cross}_{(1)} + J^{cross}_{(2)} J^{(2)} J^{bar}_{(1)}$$

$$M_{22} = J^{cross}_{(2)} J^{(1)} J^{cross}_{(1)} + J^{bar}_{(2)} J^{(2)} J^{bar}_{(1)}$$

and $J^{bar}_{(1)}$, $J^{bar}_{(2)}$, $J^{cross}_{(1)}$ $J^{cross}_{(2)}$

are the Jones matrices for bar and cross coupling in the fiber couplers, and are given by [7]

$$J^{bar} = \sqrt{1-k}\begin{pmatrix} \sqrt{1-k_x} & 0 \\ 0 & \sqrt{1-k_y} \end{pmatrix} \qquad J^{cross} = \sqrt{1-k}\begin{pmatrix} j\sqrt{k_x} & 0 \\ 0 & j\sqrt{k_y} \end{pmatrix} \quad \text{----(4)}$$

$J^{(1)}$ $J^{(2)}$ and optical paths characterization The power transmission coefficient (p, q $\in \{1, 2\}$)

$$T_{pq}\left|E_p\right|^2 = \left|M_{pq} E_p\right|^2 \qquad \text{------(5)}$$

The Jones matrices J(1) and J(2) for propagation through polarization sensitive SOAs in the upper and lower interferometer branches are given by

$$J^{(1)} = \begin{pmatrix} \sqrt{G_1(\Delta t)}e^{j\Phi_1(\Delta t)} & 0 \\ 0 & \sqrt{G_1(\Delta t)}e^{j\Phi_1(\Delta t)} \end{pmatrix} \qquad J^{(2)} = \begin{pmatrix} \sqrt{G_2(\Delta t-\Delta\tau)}e^{j\Phi_2(\Delta t-\Delta\tau)} & 0 \\ 0 & \sqrt{G_2(\Delta t-\Delta\tau)}e^{j\Phi_2(\Delta t-\Delta\tau)} \end{pmatrix} \text{--(6)}$$

where ($\sqrt{G_2(\Delta t - \Delta\tau)}$) and $\Phi_2(\Delta t - \Delta\tau)$ are the gain and phase for the data signal propagating through the SOA in the upper (lower) branch the transmission coefficient for the upper MZI output port (‘demux port’) is calculated by substituting equations (6) into (3) and using the transfer matrix M_{MZI} then equation (5)

$$T_{11}\,(E_{in}{}^{*}E_{in}) = (M_{11}E_{in})^{*}(M_{11}E_{in}) \qquad \text{----(7)}$$

$$\Rightarrow T_{11} = k^{(1)}k^{(2)}G(\Delta t - \Delta\tau) + (1-k^{(1)})(1-k^{(2)})G(\Delta t)$$
$$-2\sqrt{k^{(1)}k^{(2)}(1-k^{(1)})(1-k^{(2)})\sqrt{G(\Delta t-\Delta\tau)G(\Delta t)}}\;\cos(\Delta\Phi\,(\Delta t)$$

The interferometer output power can be related to the nonlinear phase shift through the following relationship

$$P_{out}(\Delta t) = T_{11}(\Delta t)P_{in}$$

$$P_{out}(\Delta t) = k^{(1)}k^{(2)}G(\Delta t-\Delta\tau)P_{in} + (1-k^{(1)})(1-k^{(2)})G(\Delta t)P_{in} - 2\sqrt{k^{(1)}k^{(2)}(1-k^{(1)})(1-k^{(2)})\sqrt{G(\Delta t-\Delta\tau)G(\Delta t)}} \qquad \text{-----(8)}$$
$$\cos(\Delta\Phi(\Delta t)P_{in}$$

B.UNI

TheUltrafast-Nonlinear Interferometer (UNI) is shown in Figure 2

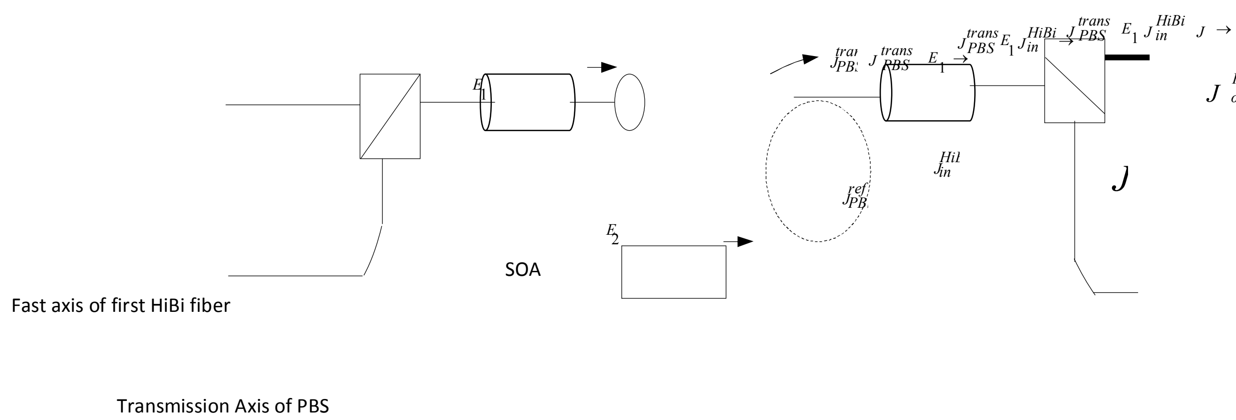

Figure 2 Schematic of ultrafast-nonlinear interferometer switch based on SOAs as nonlinear medium.

The waves at the UNI output can be written in the following compact form:

$$\begin{pmatrix} E'_1 \\ E'_2 \end{pmatrix} = \underbrace{\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}}_{M_{UNI}} \begin{pmatrix} E_1 \\ E_2 \end{pmatrix} \quad \text{----(9)}$$

where the components of the transfer matrix M_{UNI} are given by

$$M_{11} = J_{PBS}^{trans} J_{out}^{HiBi} J \; J_{in}^{HiBi} J_{PBS}^{trans} \qquad M_{12} = J_{PBS}^{ref} J_{out}^{HiBi} J \; J_{in}^{HiBi} J_{PBS}^{trans}$$

$$M_{21} = J_{PBS}^{trans} J_{out}^{HiBi} J \; J_{in}^{HiBi} J_{PBS}^{ref} \qquad M_{22} = J_{PBS}^{ref} J_{out}^{HiBi} J \; J_{in}^{HiBi} J_{PBS}^{ref}$$

and J_{PBS}^{trans} J_{PBS}^{ref} ---(10)

$$J_{in}^{HiBi} = R(-\theta)\sqrt{1-k_{HiBi}} \begin{pmatrix} e^{j\Phi_{DGD}} & 0 \\ 0 & 1 \end{pmatrix} R(\theta) \qquad J_{PBS}^{ref} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \qquad J_{PBS}^{trans} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \quad \text{----(11)}$$

$$= \sqrt{1-k_{hiBi}} \begin{pmatrix} e^{j\Phi_{DGD}} \cos^2(\theta) + \sin^2(\theta) & (e^{j\Phi_{DGD}})\cos(\theta)\sin(\theta) \\ (e^{j\Phi_{DGD}} - 1)\cos(\theta)\sin(\theta) & e^{j\Phi_{DGD}} \sin^2(\theta)\cos^2(\theta) \end{pmatrix} \quad \text{---(12)}$$

$$J_{in}^{HiBi} = J_{in}^{HiBi}(\theta + \frac{\pi}{2})$$

$$= \sqrt{1-k_{hiBi}} \begin{pmatrix} e^{j\Phi_{DGD}} \sin^2(\theta) + \cos^2(\theta) & -(e^{j\Phi_{DGD}})\sin(\theta)\cos(\theta) \\ -(e^{j\Phi_{DGD}} - 1)\sin(\theta)\cos(\theta) & e^{j\Phi_{DGD}} \cos^2(\theta)\sin^2(\theta) \end{pmatrix} \quad \text{----(13)}$$

The Jones matrix J, describing the propagation of the split signals through the SOA, which is polarization sensitive, is given by

$$J = R(-\theta) \begin{pmatrix} \sqrt{G(\Delta t)} e^{j\Phi(\Delta t)} & 0 \\ 0 & \sqrt{G(\Delta t - \Delta\tau)} e^{j\Phi(\Delta t - \Delta\tau)} \end{pmatrix} R(\theta)$$

$$\begin{pmatrix} \sqrt{G(\Delta t)} e^{j\Phi(\Delta t)} \sin^2(\theta) + \sqrt{G(\Delta t - \Delta\tau)} e^{j\Phi(\Delta t - \Delta\tau)} \cos^2(\theta) & \left[\sqrt{G(\Delta t)} e^{j\Phi(\Delta t)} - \sqrt{G(\Delta t - \Delta\tau)} e^{j\Phi(\Delta t - \Delta\tau)}\right] \cos(\theta)\sin(\theta) \\ \left[\sqrt{G(\Delta t)} e^{j\Phi(\Delta t)} - \sqrt{G(\Delta t - \Delta\tau)} e^{j\Phi(\Delta t - \Delta\tau)}\right] \cos(\theta)\sin(\theta) & \sqrt{G(\Delta t)} e^{j\Phi(\Delta t)} \cos^2(\theta) + \sqrt{G(\Delta t - \Delta\tau)} e^{j\Phi(\Delta t - \Delta\tau)} \sin^2(\theta) \end{pmatrix} \quad \text{----(14)}$$

where (θ) is the angle between the polarization of the leading data component in the SOA and the *x* axis[8].

III. Switching Window

The switching windows are analyzed to extract the switching parameters related to ultrafast all-optical demultiplexing

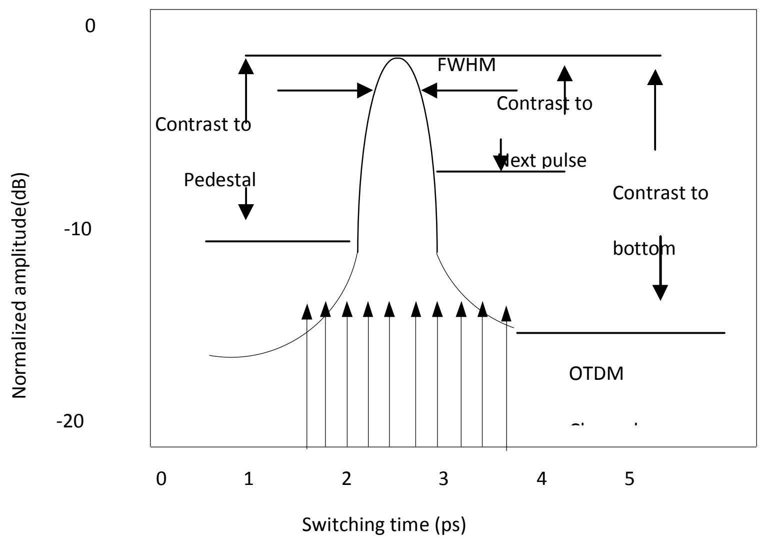

Figure 3 Parameters of the switching window.

To compare the performance of switching windows and to analyze the switching performance, some parameters have to be extracted. These parameters describe the width and the depth of the switching window. The width of the switching window can be expressed by the full width at half maximum (FWHM). Depending on the bit rate of the data stream, there is a maximum width which can be tolerated for a successful switching performance The maximum width is equal to the bit period of the data signal. If the FWHM is larger than this maximum, adjacent OTDM channels will be also switched. The minimum width of the switching window depends on the pulse width of data si the window width and the on-off contrast ratio. These quantities are not always sufficient to characterize gnal stream performance for different type switch. An integrative approach for the definition of the switching contrast is therefore reasonable The ICR is designed to evaluate the performance of the switch as demultiplexer in an OTDM system.