All-Optical Design of Switching Network using TOAD based Cross-bar Switch

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***Abstract*— Recently operationally versatile semiconductor optical amplifier (SOA) based high speed optical switches in interferometric form are enormously important because of its own fast switching time, high repetition rate, low power consumption. This switch has contributed the revolution in all-optical information processing systems. Using this interferometric (2×2) all-optical Terahertz Optical Asymmetric Demultiplexer based switch; the switching network is designed to have four switching actions by the proposed circuit. Numerical simulation has been done to achieve the performance of the targeted design.**

Keywords - Terahertz optical asymmetric demultiplexer; optical cross-bar switch; switching network.

I. INTRODUCTION

The optical–optical–optical systems are established on optical switching frameworks. The dense wavelength division multiplexing of networks requires the all-optical switches [1]. These optical cross connect are significant system for their high bandwidth, lower power consumption, high connection density and low crosstalk [2]. For their speed and independence of data format, this optical switch has wide range of application in communication system [3, 4]. In the field of optical information processing systems the optical interferometric SOA-based switches are really good for fast switching time, and other factors. [5].

The complex combinatorial circuits and systems can be formed using TOADs and the sequential circuits concerning the crucial issues of versatility, measurability and spatial property of circuits may be designed [6]. Due to so many advantages, the network of switch using all-optical cross-bar switch based on interferometric TOAD has been designed in this paper.

II. ALL-OPTICAL (2×2) CROSS-BAR SWITCH

The TOAD has capacity of demultiplexing data at 50 Gbits/s [7]. Also, the same group has reported that, by the decreasing the SOA length to 100 μm and increasing of its dc bias current, its generation delay can be change up to 1 ps without impinging on its performance as a nonlinear element (NLE) then TOAD can perform Tb/s demultiplexing. The TOAD are made of a loop mirror with an additional intra-loop 2×2 coupler and this loop contains a control pulse (CP) of different wavelengths than 7that of incoming pulse and a se7miconductor optical amplifier (SOA) which is offset from the loop's midpoint by a distance Δx [8].

To design 2×2 optical cross-bar switch the circuit has been changed slightly. 'A' and 'B' are two inputs and 'P' and 'Q' are two outputs as displayed in Fig. 1. The input signals 'A' and 'B' are of different wavelength than CP that is introduced through a loop of 3-dB coupler. The output transmitted (Tr) and reflected (Re) transfer functions are [6, 9]:

['CW' means clockwise and 'CCW' means counter clockwise]

$$Tr(t) = 1/4\{G_{cw}(t) + G_{ccw}(t) - 2\sqrt{G_{cw}(t)\,G_{ccw}(t)}.\cos(\Delta\varphi)\} \quad (1)$$

$$Re(t) = 1/4\{G_{cw}(t) + G_{ccw}(t) + 2\sqrt{G_{cw}(t)\,G_{ccw}(t)}.\cos(\Delta\varphi)\} \quad (2)$$

The phase difference between cw and ccw pulse is defined by $\Delta\varphi = (\varphi_{cw} - \varphi_{ccw})$. The symbols $G_{cw}(t), G_{ccw}(t)$ indicate the respective power gains and $\Delta\varphi = -\frac{\alpha}{2}\cdot\ln\left(\frac{G_{cw}}{G_{ccw}}\right)$, where α is line-width factor of enhancement.

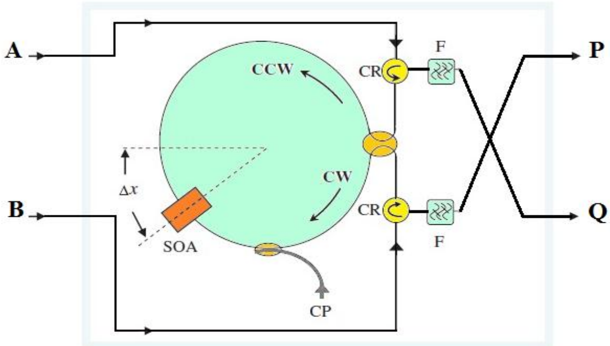

Fig. 1. TOAD based 2×2 cross-bar switch [F→Filter and CR→Optical circulator]

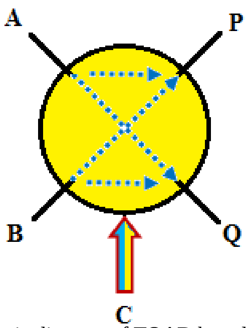

Fig. 2. Schematic diagram of TOAD based 2×2 cross-bar switch

TABLE I. TRUTH TABLE OF CROSS-BAR SWITCH

A	B	CP	P		Q		Remarks
0	0	0	0	B	0	A	Cross-state (×)
0	1	0	1		0		
1	0	0	0		1		
1	1	0	1		1		
0	0	1	0	A	0	B	Bar-state (=)
0	1	1	0		1		
1	0	1	1		0		
1	1	1	1		1		

As a consequence, the two counter-propagation data signal will get a differential gain, i.e. Gccw ≠ Gcw. Hence they recombine at the input coupler, and the data pulse will come out from the transmitted port and Re (t) ≈ 0.

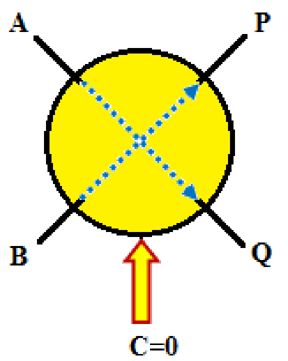

Fig. 3. Schematic diagram of TOAD based 2×2 cross-bar switch when CP=0, i.e. Cross-state operation

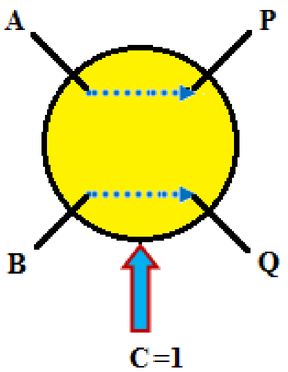

Fig. 4. 2×2 cross-bar switch when CP=1, i.e. Bar-state operation

When the control signal is absent (i.e., CP = off), the incoming signal passes through the SOA at different times around the loop, and experience the same unsaturated amplifier gain G_0 of SOA. The diagram of 2×2 cross-bar switch is shown in Fig. 2. The truth table of the switch is in Table I. From this table it is very easy to write [if CP → 'C']

$$P = B\overline{C} + AC$$
$$Q = A\overline{C} + BC \tag{3}$$

Hence, it is very easy to write, if C = 0 then P = B and Q = A → 'cross-state' (Fig. 3.) but, if C = 1 then P = A and Q = B → 'bar-state' (Fig. 4.).

III. PROPOSED SWITCHING NETWORK

The all-optical submitted switching network is formed by four cross-bar switches as shown in Fig. 5. There are four separate switching actions which are needed two control inputs. Here, the two control inputs are C_1 and C_2. For the four switching actions it is presumed the following:

$C_1 C_2$ = 00 for the 1st switching actions (Fig. 6)

$C_1 C_2$ = 01 for the 2nd switching actions (Fig. 7)

$C_1 C_2$ = 10 for the 3rd switching actions (Fig. 8)

$C_1 C_2$ = 11 for the 4th switching actions (Fig. 9)

Now, X_1, X_2, X_3 and X_4 are inputs and Y_1, Y_2, Y_3 and Y_4 are outputs of the switching network. The following four equations for the above four switching actions are shown below.

$$Y_1 = \overline{C}_2\overline{C}_1X_4 + \overline{C}_2C_1X_2 + C_2\overline{C}_1X_3 + C_2C_1X_1$$
$$Y_2 = \overline{C}_2\overline{C}_1X_3 + \overline{C}_2C_1X_1 + C_2\overline{C}_1X_4 + C_2C_1X_2$$
$$Y_3 = \overline{C}_2\overline{C}_1X_2 + \overline{C}_2C_1X_4 + C_2\overline{C}_1X_1 + C_2C_1X_3$$
$$Y_4 = \overline{C}_2\overline{C}_1X_1 + \overline{C}_2C_1X_3 + C_2\overline{C}_1X_2 + C_2C_1X_4 \tag{4}$$

The above equations can be realized using the proposed design in fig. 5.

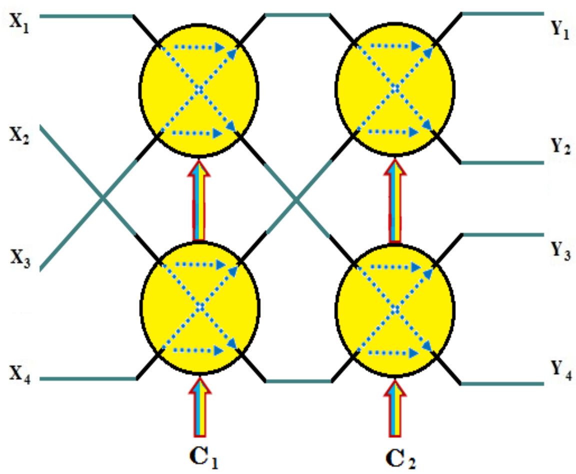

Fig. 5. Design of proposed switching network, Inputs: X_1, X_2, X_3 and X_4, Outputs: Y_1, Y_2, Y_3 and Y_4 and Control inputs: C_1 and C_2

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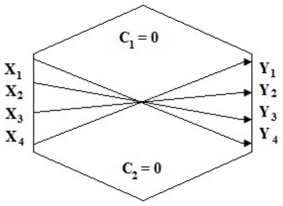

Fig. 6. 1st Switching action

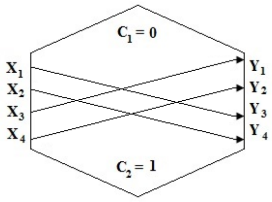

Fig. 7. 2nd Switching action

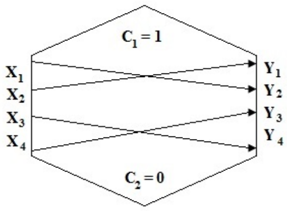

Fig. 8. 3rd Switching action

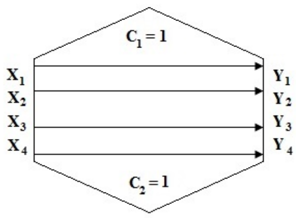

Fig. 9. 4th Switching action

IV. LOGIC UNIT OF CROSS-BAR NETWORK

The reconfigurable design by cross-bar switches is presented in Fig. 10. The switch-1 is connected to a constant signal. Signal ‘A’ is the control pulse of switch 1. The outputs of it are A and $\bar{A}$. They are inputs of switch 2 and switch 3 respectively [Fig. 10]. And ‘B’ is the control pulse of switch 2 and switch 3. Hence $A\bar{B}$, AB, $\bar{A}B$ and $\bar{A}\bar{B}$ are fed to the input of switch-4, 5 and 6 of 3 x 3 cross-bar systems as shown in Fig. 10. The controls pulses switch 5 and switch 9 are ‘0’. The control pulses of switch 4, 7, 8 and 6 are ‘C_4’, ‘C_3’, ‘C_2’ and ‘C_1’ respectively. We can change these control pulses to get different outputs as shown in Table II.

TABLE II. THE BOOLEAN LOGICAL OPERATION OF FIG. 10

Function	C_1	C_2	C_3	C_4	Output
f_1	0	0	0	0	$A \oplus B$
f_2	0	0	0	1	$\bar{A}B$
f_3	0	0	1	0	$A\bar{B}$
f_4	0	0	1	1	0
f_5	0	1	0	0	A + B
f_6	0	1	0	1	B
f_7	0	1	1	0	A
f_8	0	1	1	1	AB
f_9	1	0	0	0	$\bar{A} + \bar{B}$
f_{10}	1	0	0	1	$\bar{A}$
f_{11}	1	0	1	0	$\bar{B}$
f_{12}	1	0	1	1	$\bar{A}\bar{B}$

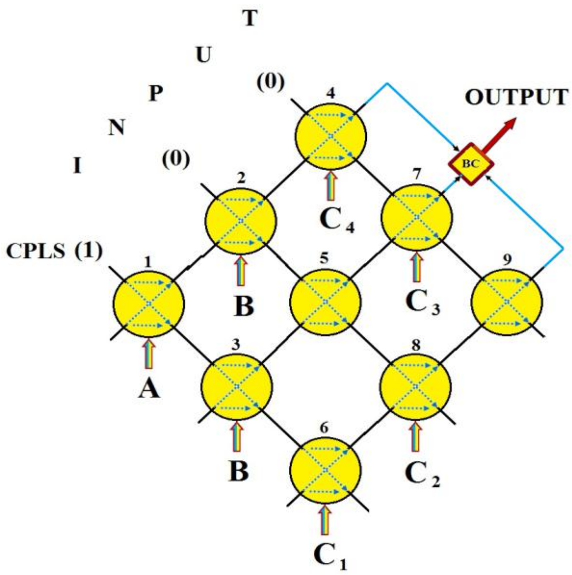

Fig. 10. Reconfigurable design. BC → Beam Combiner and CPLS → Constant Pulsed Light Source

V. SIMULATED RESULT

Computer simulation (in Optiwave.OptiSystem.v7.0) has been done using the parameter [10, 11] of SOA, which is shown in Table III. Fig. 12 shows that X_1, X_2, X_3 and X_4 are inputs and Y_1, Y_2, Y_3 and Y_4 are outputs of Fig. 10. Here logic states of inputs (X_1, X_2, X_3 and X_4) and outputs (Y_1, Y_2, Y_3 and Y_4) are ‘1111’, ‘1111’, ‘0000’, ‘1111’, ‘1101’, ‘1110’, ‘0111’, ‘1011’ respectively.

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TABLE III. PARAMETERS USED IN SIMULATION

Parameters	Symbol	Value
Injection current of SOA	I	250 mA
Confinement factor	Γ	0.5
Differential gain	a_N	3.3×10^{-20} m^2
Line-width enhancement factor of SOA	α	7
Carrier density at transparency	N_{tr}	1.0×10^{24} m^{-3}
Width of the active region of SOA	w	1.4 µm
Depth of the active region of SOA	d	300 nm
Active length of SOA	L	140 µm
Internal loss of the wave guide	α_D	2500 m^{-1}
Wave length of light	λ_0	1550 nm
Gain recovery time	τ_e	100 ps
Control pulse energy	E_c	400fJ
Full width at half maximum of control pulse	σ	2 ps
Incoming pulse energy	E_{in}	0.01 mW

Here, the section shows the simulation results that verify the all-optical proposed switching network. Fig. 12 is the simulation result of the proposed switching network.

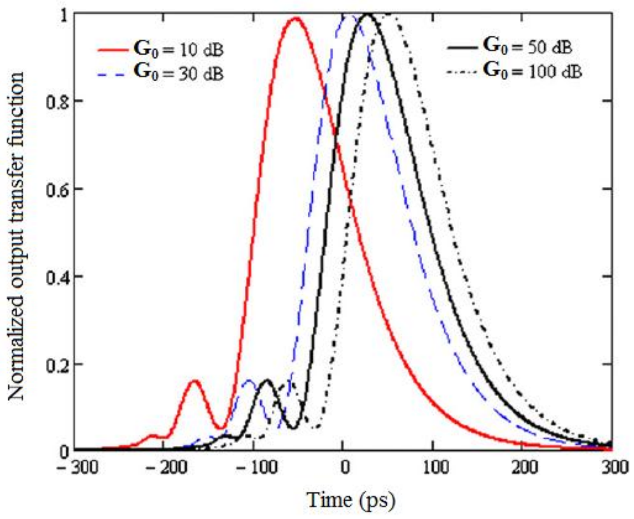
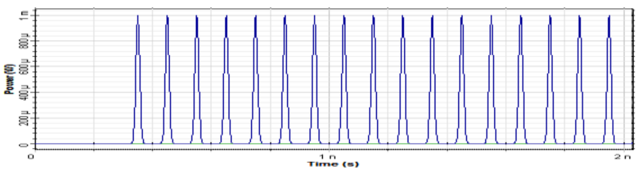
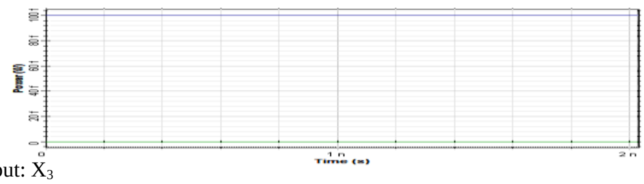


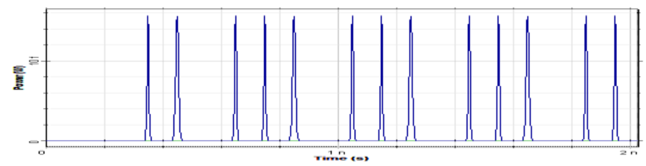
Fig. 11. Output transfer function versus time (ps)



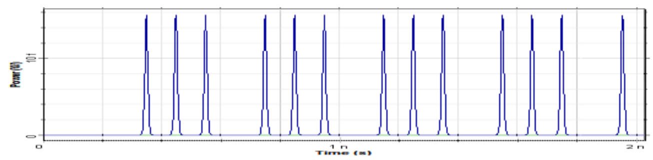
Inputs: X_1, X_2, and X_4



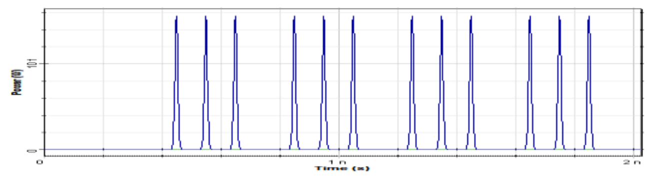
Input: X_3



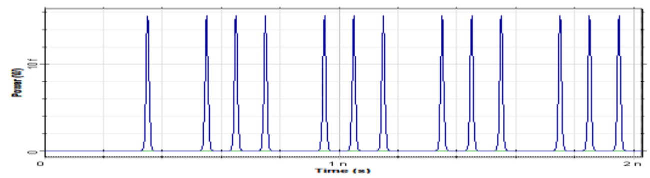
Output: Y_1



Output: Y_2



Output: Y_3



Output: Y_4

Fig. 12. Inputs of switching network: X_1, X_2, X_3 and X_4 and outputs of switching network: Y_1, Y_2, Y_3 and Y_4

In Fig. 11, when CP is ON with few sets of G_0 the output transfer function (Tr of equation 1) versus time (ps) is drawn.

And the expression of contrast ratio (C.R.) is given below [12].

$$C.R.(dB) = 10 \log\left(\frac{P_{Min}^{1}}{P_{Max}^{0}}\right) \quad (5)$$

By eq. (5) we get the output C.R. (dB) for reversible logic gates is found 18.03 dB.

Fig-13 shows give the variation of *C.R.* with control pulse energy with eccentricity of the loop is kept constant. The variation of C.R. with E_{cp} is shown in fig-13 and it confirms that C.R. is high when E_{cp} of the loop is 95.5 fJ.

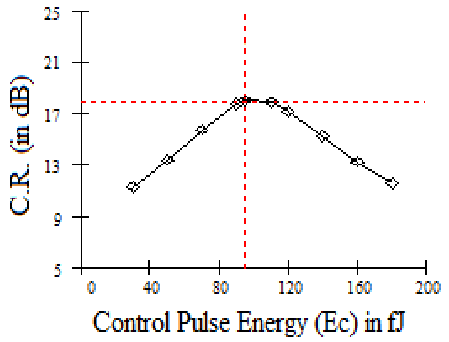


Fig. 13. Contrast ratio versus control pulse energy (E_c)

VI. CONCLUSION

In this paper, we have design of all-optical switching network using TOAD based cross-bar switches. The theoretical model is introduced in this paper and the simulation results also show that the proposed scheme achieves higher all-optical logic computing system. To get experimental result of this targeted design, some factors like, intensity losses due to beam splitters/fiber couplers, walk-of problem due to dispersion, optical circulator, etc are to be examined and the polarization controller may apply. We apply small length SOA and control pulse of very lower than 1 pJ to avoid the effect of amplified spontaneous emission. The future work would concentrate the realization of Digital Signal Processing.

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