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All-Optical Reversible Hybrid New Gate using TOAD

Goutam Kumar Maity[1], Supriti Samanta[2], Ashis Kumar Mandal[3]

Abstract

Reversible logic is emerged as a promising computing paradigm with applications in low-power CMOS, quantum computing, optical computing and nanotechnology. Optical logic gates become potential component to work at macroscopic (light pulses carry information), or quantum (single photon carries information) levels with high efficiency. In this paper, we propose a novel scheme of Hybrid new gate realization in all-optical domain. Simulation results verify the functionality of the gate as well as reversibility. Approximate insertion power loss in dB is also reported for the Gaussian incident and control pulse.

Keywords

Reversible logic gates, Hybrid New Gate (HNG), Terahertz Optical Asymmetric Demultiplexer (TOAD).

1. Introduction

All-optical switching - the switching of one beam of light by another is an essential operation for transparent fiber optic networks and for all forms of optical information processing [1-6]. In order to overcome the electronic bottlenecks and fully exploit the advantages of optical fiber communication, it is necessary to move towards networks where the transmitted data would remain exclusively in the optical domain without optical-electrical-optical (OEO) conversions [7]. Two fold driving forces for this all-optical switching are the broadband photonic network environment that emerges due to rapid convergence of telecommunication and informatics.
The other one is the massive use of data applications such as internet and multimedia. All-optical gates avoid complex and speed-limited optoelectronic conversions.

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Goutam Kumar Maity, Electronics & Communication Engineering , MCKV Institute of Engineering , Howrah , India.

Supriti Samanta, Physics, Chaipat Girls' High School, Daspur, West Bengal, India.

Ashis Kumar Mandal, Physics, Chakur Haris Seminary High School, Howrah, India.

Among the proposed schemes, the terahertz optical asymmetric demultiplexer (TOAD) and semiconductor optical amplifier (SOA)-assisted Sagnac gate effectively offers fast switching time and a reasonable noise figure [8]. Moreover ease of integration and overall practicality enable it to compete with other similar optical time division multiplexing (OTDM) devices [9].

In conventional computers, majority of the computation operations are irreversible i.e. once a logic block generates the output bits based on certain input combinations, the later bits are lost. The classical set of gates such as AND, OR and X-OR are irreversible as they are all multiple-input single output logic gates. However, this is not the case for reversible logic circuits. A gate is reversible if the gate's inputs and outputs have a one-to-one correspondence, i.e. there is a distinct output assignment for each distinct input combination. Therefore, a reversible gate's inputs can be uniquely determined from its outputs. Reversible logic gates must have an equal number of inputs and outputs. Then the output rows of the truth table of a reversible gate can be obtained by permutation of the input rows. Reversible logic circuits have been emerged as a promising technology in the field of information processing, for example, military data processing to preserve intelligence or medical signal to prevent data loss or revert back data modification. Irreversible computation results in energy dissipation due to data loss [10]. On the other hand, the reversible logic circuits offer an alternative form that allows computation with arbitrary small energy dissipation [11]. There are number of existing reversible gates in literature like Fredkin gate. Experimental reversible chips and arithmetic circuits are developed.

The present work explores a circuit realization of Hybrid new gate (HNG) using SOA-based TOAD [12-16]. TOAD based switch satisfies the requirements for low switching energy and latency as well as stable and cascade ultrafast operations. Simulation is done with Mathcad-7. Simulation result confirms the functionality of forward and reverse logic operations.

The paper is organized as follows: In Section 2, principle and operation of TOAD-based optical switch is discussed. All-optical circuit realization for TOAD switch-based Hybrid New Gate is described in Section 3. Section 4 discusses simulation based performance analysis. Finally, conclusions are drawn in Section 5 along with scope of future works.

2. Operational principle of TOAD based optical switch and related works

The all-optical memories that are implemented with SOA-based TOAD switches are very promising candidates for use in all-optical packet switch (OPS) networks due to the fact that

- They are characterized by the attractive features of fast switching time, high repetition rate, low power consumption, low latency, noise and jitter tolerance, compactness, thermal stability and high nonlinear properties. All these properties enable their efficient exploitation in a real ultra-high speed optical communications environment [16].
- They have the potential of being integrated, which in turn means that they can be repeatable and reliably be manufactured leading to massive production. This highlights their commercial values and they can favorably compete with other buffering solutions [17-20].
- They are operationally versatile, i.e. they can be exploited in more complex all-optical signal processing applications without significantly changing their fundamental architecture [21].
- Their storage/buffering time can be altered on demand by simply adding or removing fiber without significant cost in power dissipation or energy loss.

In recent years, TOAD based gate has taken an important role in optical communication and information processing [17-24]. Sokoloff et al. [17] demonstrated a TOAD capable of demultiplexing data at 50 Gb/s. TOAD exploits the strong, slow optical nonlinearities present in semiconductor. It distinguished control and signal pulses using polarization or wavelength. It requires less than 1 pJ switching energy. The same authors group has also reported that by reducing the SOA length to 100 µm and increasing its dc bias current, its propagation delay can be reduce to 1 ps without impacting its performance as a nonlinear element. Then TOAD can perform demultiplexing at Tb/s [24].

The TOAD consists of a loop mirror with an additional intraloop 2×2 (ideally 50:50) coupler. The loop contains a control pulse (CP) and a nonlinear element (NLE) that is offset from the loop's midpoint by a distance Δx as shown in Fig. 1.

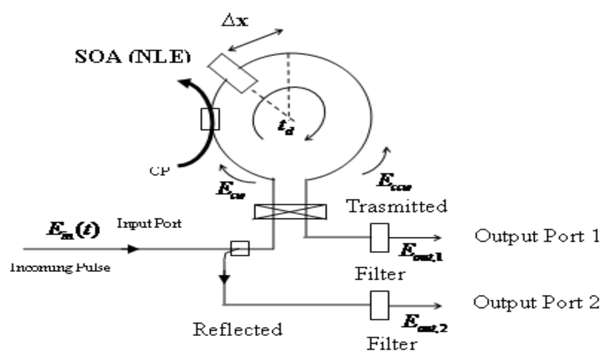


Fig. 1: TOAD-based optical switch

A signal with field $E_{in}(t)$ at angular frequency ω is split in coupler. It travels in clockwise (cw) and counter clockwise (ccw) direction through the loop. The electrical field at port-1 and port-2, can be expressed as follows:

$$\underline{E}_{out,1}(t)=\underline{E}_{in}(t-t_d)\cdot e^{-j\omega t_d}\cdot\left[d^2\cdot\underline{g}_{cw}(t-t_d)-k^2\cdot\underline{g}_{ccw}(t-t_d)\right] \quad (1)$$

$$\underline{E}_{out,2}(t)=jdk\underline{E}_{in}(t-t_d)\cdot e^{-j\omega t_d}\cdot\left[\underline{g}_{cw}(t-t_d)+\underline{g}_{ccw}(t-t_d)\right] \quad (2)$$

Where t_d is pulse round trip time within the loop as shown in the Fig- 1. Coupling ratios *k* and *d* indicate the cross and through coupling, respectively. The cw signal be amplified by the complex field gain. $\underline{g}_{cw}(t)$, while ccw by $\underline{g}_{ccw}(t)$. The output power at port-1 can be expressed as,

$$\begin{aligned}P_{out,1}(t)&=\frac{P_{in}(t-t_d)}{4}\cdot\left\{G_{cw}(t)+G_{ccw}(t)-2\sqrt{G_{cw}(t)\cdot G_{ccw}(t)}\cdot\cos(\Delta\varphi)\right\}\\&=\frac{P_{in}(t-t_d)}{4}\cdot SW(t)\end{aligned} \quad (3)$$

Where, $SW(t)$ is the transfer function. 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. Power gain is related with the field gain as $G=g^2$ and $\Delta\varphi=-\frac{\alpha}{2}\cdot\ln\left(\frac{G_{cw}}{G_{ccw}}\right)$.

Now we will calculate the power at port-2

$$P_{out,2}(t)=\frac{1}{2}\underline{E}_{out,2}(t)\cdot\underline{E}^{*}_{out,2}(t)$$

$$=d^2k^2\cdot P_{in}(t-t_d)\cdot g_{cw}^{2}(t-t_d)$$

$$\cdot\left\{1+\frac{g_{ccw}^{2}(t-t_d)}{g_{cw}^{2}(t-t_d)}+2\cdot\frac{g_{ccw}(t-t_d)}{g_{cw}(t-t_d)}\cdot\cos\left[\varphi_{cw}(t-t_d)-\varphi_{ccw}(t-t_d)\right]\right\}$$

$$=d^2k^2\cdot P_{in}(t-t_d)\cdot G_{cw}\cdot\left\{1+\frac{G_{ccw}}{G_{cw}}+2\cdot\sqrt{\frac{G_{ccw}}{G_{cw}}}\cdot\cos\left[\Delta\varphi\right]\right\}$$

$$=d^2k^2\cdot P_{in}(t-t_d)\cdot\left\{G_{cw}+G_{ccw}+2\cdot\sqrt{G_{ccw}\cdot G_{cw}}\cdot\cos\left[\Delta\varphi\right]\right\} \quad (4)$$

For ideal 50:50 coupler, $d^2=k^2=\frac{1}{2}$. In the absence of a control signal, data signal (incoming signal) enters the fiber loop, pass through the SOA at different times as they counter-propagate around the loop, and experience the same unsaturated amplifier gain G_0, recombine at the input coupler i.e. $G_{ccw}=G_{cw}$. This leads to $\Delta\varphi=0$. So expression for $P_{out,1}(t)=0$ and $P_{out,2}(t)=G_0\cdot P_{in}$. It shows that data is reflected back toward the source. When a control pulse is injected into the loop, it saturates the SOA and changes its index of refraction. As a result, the two counter-propagated data signals will experience a differential gain saturation profiles i.e. $G_{ccw}\neq G_{cw}$. Therefore, when they recombine at the input coupler, the data will exit from the output port-1. For this case, the mathematical forms of two output powers can be expressed as, $P_{out,1}(t)=\frac{P_{in}(t-t_d)}{4}\cdot SW(t)$ and $P_{out,2}(t)\approx 0$.

Result of numerical simulation with Matlab7.0 has been shown in Fig. 2. In this simulation line-width enhancement factor of SOA (α) was taken 9.5 and the ratio G_{ccw}/G_{cw} was taken 0.52.

A polarization or wavelength filter may be used at the output to reject the control and pass the input pulse. Now it is clear that in the absence of control signal, the incoming pulse exits through input port of TOAD and reaches the output port-2 as shown in Fig. 2. In this case no light is present in the output port-1. But in the presence of control signal, the incoming signal exits through output port of TOAD and reaches the output port-1 as shown in Fig. 1. In this case no light is present in the output port-2.

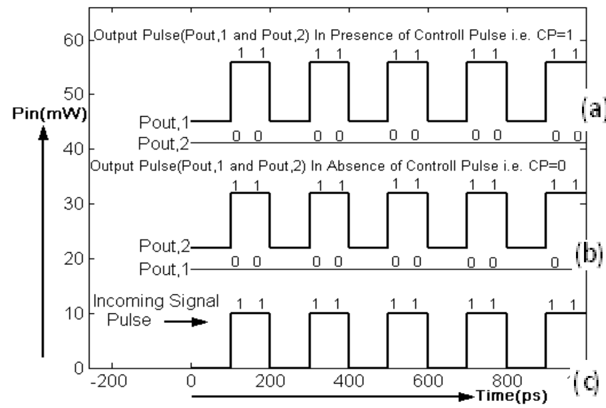


Fig. 2: Simulation result: (a) output pulse (Pout,1 and Pout,2) in presence of control pulse i.e. CP=1 (b) output pulse (Pout,1 and Pout,2) in absence of control pulse i.e. CP=0 (c) incoming signal pulse.

In the absence of incoming signal, Port-1 and Port-2 receive no light signal as the filter blocks the control signal. Schematic block diagram is shown in Fig. 3 and truth table of the operation is given in Table-1.

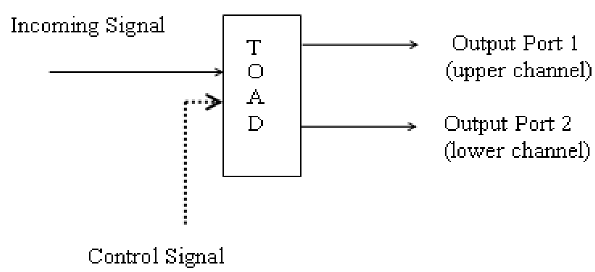


Fig. 3: Schematic diagram of TOAD-based optical switch:

Table-1: Truth table of TOAD based optical switch as shown in Fig. 3

Incoming Signal	Control Signal	Output Port-1	Output Port-2
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	0

3. TOAD based Gate Realization

This section presents the TOAD based realization of Hybrid New Gate.

TOAD-based Hybrid new gate: Principle and Design

HNG is a 4:4 one-through reversible logic gate. It has four inputs (A, B, C, D) and four outputs (P, Q, R, S) satisfy the relation as follows:

$P = A$
$Q = B$
$R = A \oplus B \oplus C$ (5)
$S = (A \oplus B).C \oplus AB \oplus D$

Schematic diagram is given in Fig. 4. The truth table is given in Table 2. HNG gate can be used for implementing arbitrary functions and is useful for implement in all Boolean functions. The OR and the X-NOR functions can be simultaneously implemented using HNG as show in Fig. 5 (a). The X-OR functions and the NAND function can be implemented as depicted in Fig. 5 (b). The NOR function can be obtained as shown in Fig. 5 (c), while the AND function can be implemented as in Fig. 5 (d). The implementation of the HNG gate as NOT function is shown in Fig. 5 (e).

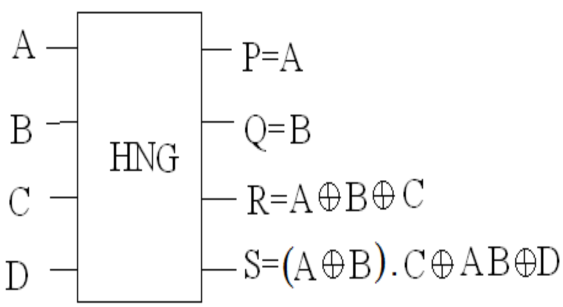
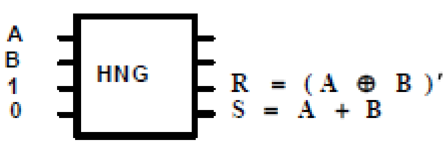
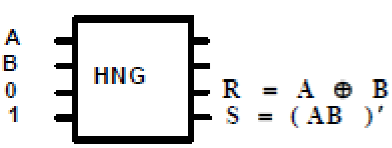


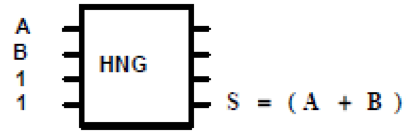
Fig. 4: Schematic diagram of HNG



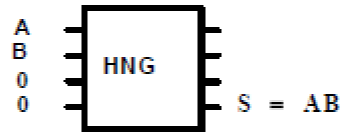
(a)



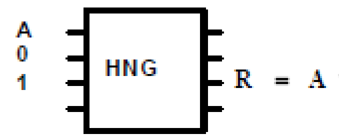
(b)



(c)



(d)



(e)

Fig. 5: (a) XNOR and OR gates; (b) XOR and NAND gates; (c) NOR gates; (d) AND gates; (e) NOT gates

The TOAD based circuit for all optical reversible HNG is given in Fig. 6. Light from input A is incident on beam splitter (BS) and is split into two parts. One part is directly connected with TOAD -2 and acts as incoming signal for TOAD -2. Another part is connected with TOAD -1 through wavelength converter (WC) and erbium doped fibre amplifier (EDFA) so that they can act as control signal to TOAD -1. In a similar way Light from input B is incident on beam splitter (BS) and is split in two parts. One part is used as output Q and another part again incident on beam splitter is connected with TOAD -1 and TOAD -2 as shown in Fig.6. The bar port of TOAD -1 (B_1) and cross port of TOAD -2 (C_2) are combined by a beam combiner BC-1 to get the output P. Light from cross port of TOAD -1 (C_1) and TOAD -2(C_2) are combined by BC-2 to get the control signal of TOAD -3 and input signal of TOAD -4 and TOAD -5. Light from input C is incident on beam splitter (BS) and is split into two parts. One part is directly connected with TOAD -5 as control signal and another part is again incident on beam splitter (BS). It divided in two parts. One part is directly connected with TOAD -3 and act as input signal for TOAD -3. Another part connected with TOAD -4 acts as control signal through WC and EDFA.

Table-2: Truth table of the proposed reversible HNG gate

Inputs				Outputs			
A	B	C	D	P	Q	R	S
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0
0	0	1	1	0	0	1	1
0	1	0	0	0	1	1	0
0	1	0	1	0	1	1	1
0	1	1	0	0	1	0	1
0	1	1	1	0	1	0	0
1	0	0	0	1	0	1	0
1	0	0	1	1	0	1	1
1	0	1	0	1	0	0	1
1	0	1	1	1	0	0	0
1	1	0	0	1	1	0	1
1	1	0	1	1	1	0	0
1	1	1	0	1	1	1	1
1	1	1	1	1	1	1	0

Light from cross port of TOAD -3 (C3) and TOAD -4 (C4) are combined by BC-3 to get the final output R. Bar port of TOAD -2 (B_2) in incident on BS and is split in two parts. These are input and control signal of TOAD-6 and TOAD-7, respectively. The cross port of TOAD -6 and TOAD -7 are combined by BC-4. Output of BC-4 is incident on BS and is split in two parts. These parts act as input of TOAD -8 and control of TOAD -9, respectively. The bar port of TOAD -5 is also split in two parts by BS and are used as input of TOAD -9 and control of TOAD -8. Light from cross port of TOAD -8 (C_8) and TOAD -9 (C_9) are combined by BC-5 to get the final output S.

Let us discuss the operation in details. Here, the presence of light is taken as 1 state and absence of light is taken as 0 state.

(1) When A=B=C=D=0 i.e. no light is present at input, the final outputs show no light condition i.e. P=Q=R=S=0.

(2) When A=B=C=0 and D=1, incoming signal is present only at TOAD -7 and TOAD -8 but control is absent. So light comes out through cross port of TOAD -7 and TOAD -8. Therefore, when A=B=C=0 and D=1, P=Q=R=0, and D=1. It satisfies the second row of the truth table-1.

(3) When A=B=0 and C=D=1, incoming signal is present only at TOAD -3 and TOAD -7 but control is absent. So light comes out through cross port of TOAD -3 and TOAD -7. Therefore, P=Q=0, C=D=1. It satisfies the third row of the truth Table 1.

(4) When A=B=D=0 and C=1, incoming signal is present only at TOAD -3 but control is absent. So light comes out through cross port of TOAD -3. Therefore, the conditions P=Q=S=0, and R=1 are satisfied.

(5) When A=C=D=0 and B=1, the TOAD -1 receive light as the incoming signal but control is absent at TOAD -1, so $B_1=B_2=C_2=0$, and subsequently $C_1=1$. Now for the TOAD -4 the incoming signal receives light but the control signal receives no light, hence, $C_4=1$. This indicates P=0, Q=R=1and S=0.

(6) When A=C=0 and B=D=1, the TOAD -1 receives light in the incoming signal but control is absent at TOAD -1, so $B_1=B_2=C_2=0$, and subsequently $C_1=1$. Now for the TOAD -4 the incoming signal receives light but the control signal receives no light. Again as the input D=1, the incoming signal of TOAD -7 is present but control is absent, so $C_7=1$ and subsequently $C_8=1$. P=0, Q=R=S=1 are satisfied.

(7) When A=0, B=C=1 and D=0, TOAD -1 receives light as incoming signal but does not receive control light signal. Again light from input C acts as incoming signal of TOAD -3. Hence P=0, Q=1, R=0 and S=1 are satisfied.

(8) When A=0, B=C=D=1, TOAD -1 receives light pulse as the incoming signals but does not receive control light signal. TOAD -3, TOAD -4, TOAD -5, TOAD -8, and TOAD -9 receive the incoming light and control light pulses, which means P=R=S=0 and Q=1.

(9) When A=1, B=C=D=0, TOAD -2 receives light pulse as the incoming signals but does not receive control light signal. The consequent results are $B_1=0$, $C_1=0$, $B_2=0$, $C_2=1$, so, at TOAD -4 the incoming signal receives light but the control signal receives no light, hence, $C_4=1$. This indicates P=R=1, Q=S=0.

(10) When A=D=1, B=C=0, then TOAD -2 receives light pulse as the incoming signals but does not receive control light signal. The consequent results are $B_1=0$, $C_1=0$, $B_2=0$, $C_2=1$, so, at TOAD -4 the incoming signal receives light but the control signal receives no light, hence, $C_4=1$. Again as the input D=1, the incoming signal of TOAD -7 is present but control is absent, so $C_7=1$ and subsequently $C_8=1$. This indicates P=R=S=1, and Q =0.

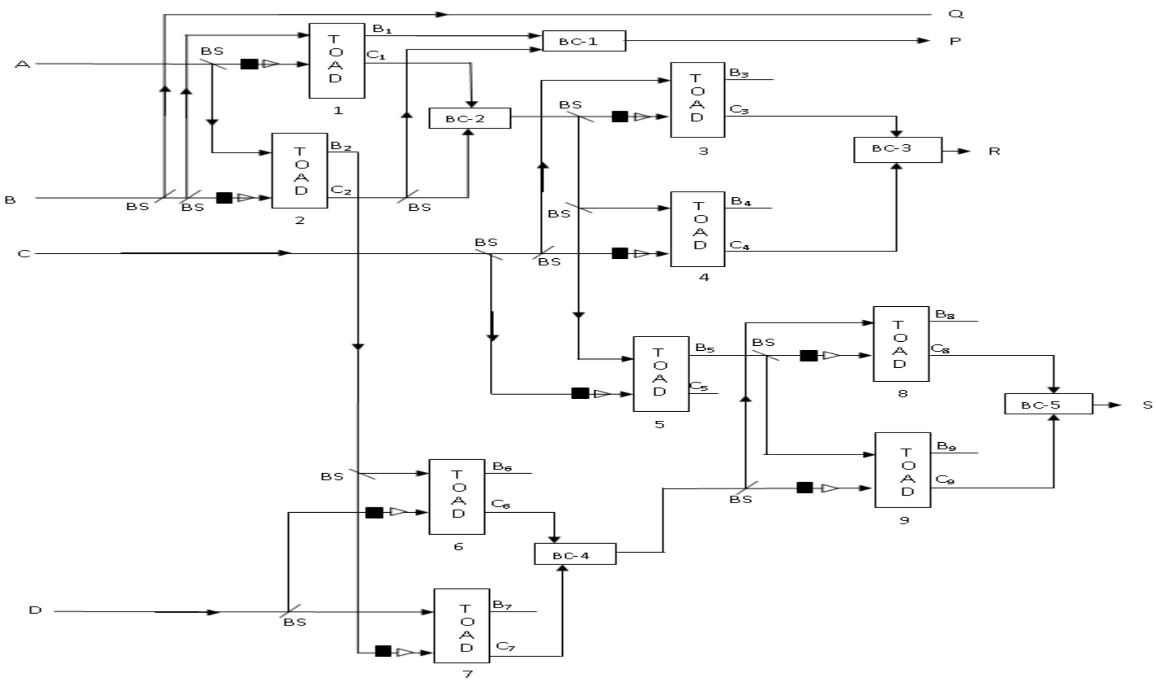


Fig. 6: Circuit for all-optical HNG

BC: Beam Combiner, BS: Beam Splitter, ▷ EDFA: Erbium Doped Fiber Amplifier, ■WC: Wavelength Converter

Implementation requires 9 TOAD switch, 5 BC, 12 BS, 9 EDFA and 9 WC.

(11)When A=C=1, B=D=0, TOAD -2 receives light pulse as the incoming signals but does not receive control light signal. Again as the input C=1, TOAD -3 and TOAD -4 receive both the incoming signal and the control signal. This indicates P=S=1, Q=R =0.

(12)When A=C=D=1, B=0, TOAD -2 receives light pulse as the incoming signals but does not receive control *light signal. Again as the input C=D=1, TOAD -3*, TOAD-4, TOAD -5, TOAD -6, TOAD -7, TOAD -8 and TOAD -9 receive both the incoming signal and the control signal. This indicates P=1, Q=R =S=0.

(13)When A=B=1, C=D=0, TOAD -1 and TOAD -2 receive both the light pulses as the incoming signal and the control light signal. So, B1=1, C1=0, B2=1 and C2=0. P= Q= S=1, R=0 are satisfied.

(14)When A=B=D=1, C=0, TOAD -1 and TOAD -2 receive both the light pulses as the incoming signal and the control light signal. So, B1=1, C1=0, B2=1 and C2=0. Again as the input D=1, so C6= C7=0. P= Q=1, R=S=0 are satisfied.

(15)When A=B=C=1, D=0, TOAD -1 and TOAD -2 receive both the light pulses as the incoming signal and the control light signal. So, B1=1, C1=0, B2=1 and C2=0. Again as the input C=1, at TOAD -3, the incoming signal receive light but the control signal receives no light. Hence, C3=1 and subsequently C6=1. This indicates C8= 1. This shows P=Q=R=S=1.

(16)When A=B=C=D=1, TOAD -1, TOAD -3, TOAD -6, TOAD -7 receive both the light pulses as the incoming signal and the control light signal. So, this indicates P=Q=R=1and S=0.

4. Simulation based performance and discussion

This section presents the simulation results that verify the Boolean functions of the gate.

Simulation result of Hybrid new gate

The simulated waveforms are shown in Fig. 7. Simulation is done in Mathcad-7. The power of the input pulse is taken A=1.13 dBm, B=2.26dBm and C=D=1.13 dBm. Here we use 50:50 beam splitters.

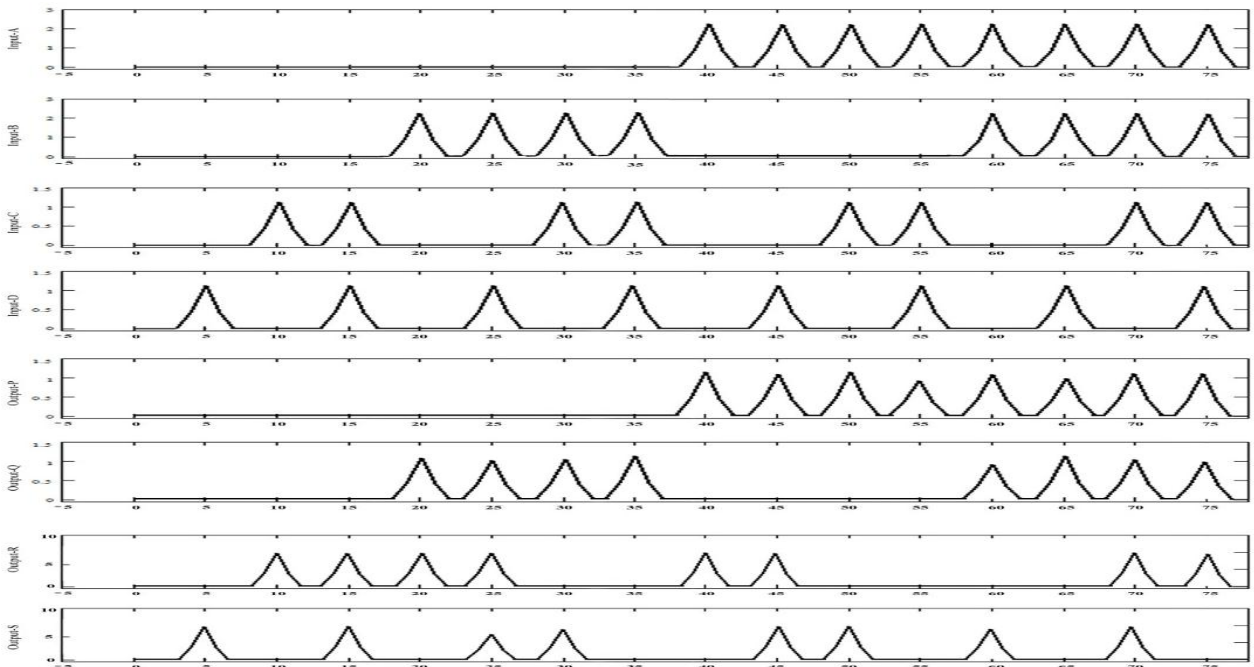


Fig-7: Simulation result of Fig.6
The vertical axis in Fig. 7 indicates power in dB, while horizontal axis represents time scale in ps.

The timing instant for the occurrence of bit pattern are at 0,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75 ps. Upper three set waveforms indicate the input bit sequences, 0000000011111111, 0000111100001111, 0011001100110011, 0101010101010101 for the input variables A, B, C, D, respectively. Similarly, the lower three waveforms indicate bit sequences 0000000011111111, 0000111100001111, 0011110011000011, 0101011001101010 bit pattern change of output variables P, Q, R, S, respectively.
From Fig-7, we get $I.L|_{X,A(\text{at } 35\text{ ps})}$= 3.01 dB= $I.L|_{Y,A(\text{at } 35\text{ ps})}$, =$I.L|_{Z,A(\text{at } 30\text{ ps})}$, $I.L|_{Y,B(\text{at } 25\text{ ps})}$ = 6.98 dB, $I.L|_{Z,B(\text{at } 30\text{ ps})}$= 6.98 dB, $I.L|_{Z,C(\text{at } 15\text{ ps})}$= 8.75dB. The power level clearly distinguishes logic state 1 and logic state 0.
Let us test the reversible operation from the simulation results with chosen arbitrary time at 10 ps. The output signals are P=0, Q=0, R=1, S=0. Using these specific outputs we gate from Equation 5, A=0, B=0, C=1 and D=0. Similarly, different output bit patterns give the different input bit combinations that satisfy the reversibility conditions.

Result of numerical simulation (with Mathcad-7) of the TOAD based Hybrid New gate verify the truth table of the gates.
The parameters used in this simulation (MQW SLA [16]) are shown in Table-3. Incoming and control pulse energy of every TOAD are Gaussian $\left[\frac{E_0}{\sigma\sqrt{\pi}}\exp\left\{-\left(\frac{t}{\sigma}\right)^2\right\}\right]$ in nature. The pulse width σ (full width at half maximum) takes value 2.05 ps here.
The BS used here is not polarizing. They reflect (and transmit) 50 % of the light incident, for all polarizations of the incident light. The insertion loss (*I.L.*) of this circuit can be calculated by the following equation:

$$\text{I.L(dB)} = 10 \log \left(\frac{P_{out}}{P_{in}}\right) \qquad (6)$$

The extinction ratio of the TOAD based switch can be calculated by the following equation (Leuthold et al. 1998) [44] :

$$Ex.R(dB)\Big|^{OFF} = 10\ log\left(\frac{P_{out,2}}{P_{out,1}}\right)\Bigg|_{Control=off} \qquad (7)$$

$$Ex.R(dB)\Big|^{ON} = 10\ log\left(\frac{P_{out,1}}{P_{out,2}}\right)\Bigg|_{Control=on}$$

With these formulae we obtain $Ex.R(dB)\big|^{OFF}$ = very high (because we get $P_{out,1}$ by theory is zero) and $Ex.R(dB)\big|^{ON}$ = 13.18 dB. We select the output contrast ratio (C.R.) as the optimization criteria. This indicates the opening of the eye diagram and define the output contrast ratio *(C.R.)* as the minimum peak power when the pulse of the payload is high (1) say (P^1_{Min}) and to the maximum when the pulse is low (0) say (P^0_{Max}) (Li et al. 2005) [20].

Table-3: Parameters used in simulation

Parameters	Symbol	Value
Injection current of SOA	I	120 mA
Unsaturated single-pass amplifier gain	G_0	17.5 dB
Line-width enhancement factor of SOA	α	7.1
Gain recovery time	τ_e	270 ps
Saturation energy of the SOA	E_{sat}	1215 fJ
Eccentricity of the loop of TOAD	T	95 ps
Control pulse energy	E_{cp}	~200 fJ
Full width at half maximum of control pulse	σ	2.05 ps
Incoming pulse energy	E_{in}	~20 fJ

$$C.R.(dB) = 10\ \log\left(\frac{P^1_{Min}}{P^0_{Max}}\right) \qquad (8)$$

By equation (8) we can calculate the output *C.R.*(*dB*) for reversible logic gates is found 18.027 dB.

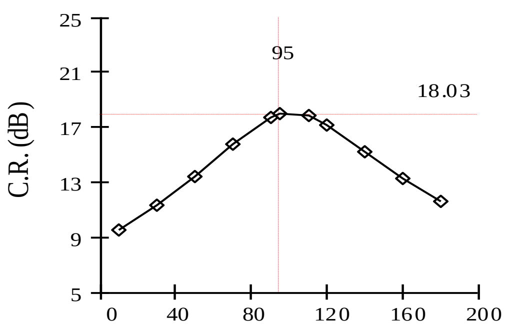


Fig.8: The variation of contrast ratio (C.R.) with control pulse energy (E_{cp})

Fig-8. gives the variation of *C.R.* with control pulse energy (E_{cp}) with eccentricity of the loop (T) is kept constant. It shows that maximum C.R. is obtained at 200fj control pulse energy. Fig-9. shows the variation of C.R. with T when, E_{cp} is fixed and it confirms that C.R. is high when eccentricity of the loop (T) is 95 ps.

The theoretical model developed and the results obtained numerically will be useful in future all-optical computing and information processing. If we use orthogonally polarized light as control signal then wavelength converter (WC) can be avoided in our proposed design. This alternative technological option will enhance the potentiality of this scheme for exploitation in sophisticated interconnection of enhanced combinational/ sequential functionality
To experimentally achieve result from the proposed scheme, some design issues have to be considered. For example, walk-of problem due to dispersion, polarization properties of fiber, predetermined values of the intensities / wavelength of laser light for control and incoming signals, introduction of filter ,intensity losses due to fiber couplers, etc. Because of the small size of TOAD, the walk-off between control and incoming signal may not be a great problem. Lasers of wavelength 1557 nm and 1549 nm can be used as incoming and control signal, respectively.

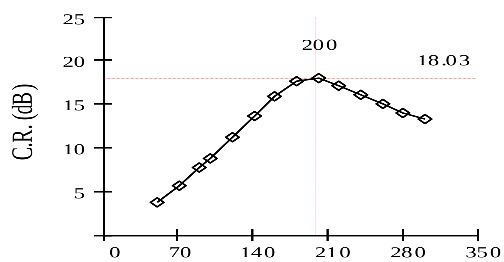


Fig. 9: Variation of contrast ratio (C.R.) with Eccentricity.

Here, control pulse (CPLS) can be a mode-locked Er^{3+} doped fiber pulsed laser (EDFL) source (unpolarized/partially polarized) of wavelength 1557 nm. The control signal is also an EDFL of 1549 nm wavelength. Optical circulator can be used to isolate the reflected pulse. Band pass filter (BPF) passes the signal of wavelength 1557 nm and blocks the signal of wavelength 1549 nm. Here, SOA used in TOAD loop may be of InGaAsP travelling wave semiconductor optical amplifier of length $\approx 500\ \mu m$ and of low polarizing sensitive (BT & D

SOA 3200). Intensity losses due to couplers in interconnecting stage may not create much trouble in producing the desired optical bits at the output as the whole system is digital one and the output depends only on the presence or absence of light.

5. Conclusion and Future Work

In conclusion, the design of all-optical reversible Fredkin gate by TOAD is theoretically addressed and demonstrated. Simulation results verify the functionality of the gate with verified reversibility. Approximate insertion loss (I.L.) and variation of contrast ratio (C.R.) with control pulse energy are also reported. The primary component of the design is the TOAD. The critical parameters designed from the simulation results highlight the important fact that implementation may be realized with more than adequate contrast ratio and in a practically feasible way. Future work would concentrate realization of various Boolean expressions and arithmetic operations.

References

[1] J.Hardy and J.Shamir, Optics inspired logic architecture, Optics Express, 15(1), 150-165, 2007.
[2] S. Dolev, T. Haist and M. Oltean, Optical Supercomputing: First International Workshop, Vienna, Austria, (Springer) P. 33-45 (2008).
[3] F. T. S. Yu, S. Jutamulia, S. Yin, Introduction to information optics. Academic Press, San Diego (2001).
[4] G. P. Agrwal Applications of nonlinear fibre optics (Academic press, India [an imprint of Elsevier, San Diego, USA,]) (2001).
[5] M. A. Karim, A. A. S. Awal, Optical Computing: an introduction (Wiley, New York) (1992).
[6] A.I. Zavalin, J. Shamir, C. S. Vikram, H. J. Caulfield, Achieving Stabilization in interferometric Logic Operations, Appl. Opt. 45, 360-365. 2006.
[7] T. Houbavlis, K. E. Zoiros, SOA-assisted Sagnac switch and investigation of its roadmap from 10 to 40 GHz, Optical and Quantum Electronics 35, 1175–1203, 2003.
[8] T. Houbavlis, K. E. Zoiros, Ultrafast pattern-operated all-optical Boolean XOR with semiconductor optical amplifier-assisted Sagnac switch, Opt. Eng. 42 (12), 3415–3416, 2003.
[9] K. E. Zoiros, T. Houbavlis, M. Kalyvas, Ultra-high speed all-optical shift registers and their applications in OTDM networks, Optical and Quantum Electronics 36, 1005–1053, 2004.
[10] R.Landauer, Irreversibility and heat generation in the computational process. IBM Journal of Research and Development, 5:183–91, 1961.
[11] CH. Bennett, Logical reversibility of computation. IBM Journal of Research and Development , 17:525–32, 1973.
[12] DP. Vasudavan, PK. Lala, J. Di, JP. Parkerson, Reversible-logic design with online testability. IEEE Transactions on Instrumentation and Measurement , 55(2):406–14, 2006.
[13] M. Mohammadi, M.Eshghi, M.Haghparast, Bahroloom A. Design and optimization of reversible BCD adder/subtractor circuit for quantum and nanotechnology based system. World Applied Sciences Journal, 4(6):787–92, 2008.
[14] M.Haghparasat, K.A. Navi, novel reversible BCD adder for nanotechnology based systems. American Journal of Applied Sciences, 5(3):282–8, 2008.
[15] J. Shamir, HJ.Caulfield, W.Micelli, RJ. Seymour, Optical computing and Fredkin gates. Applied Optics , 25(10):1604–7, 1986.
[16] N. A. Whitaker, Jr., M. C. Gabriel, H. Avramopoulos, A. Huang, All-optical, all-fiber circulating shift register with an inverter, Opt. Lett. , 16(24), 1991.
[17] J. P. Sokoloff, P. R. Prucnal, I. Glesk, M. Kane, A terahertz optical asymmetric demultiplexer (TOAD), IEEE Photon. Techno. Lett. 5 (7), 787-789, 1993.
[18] J. P. Sokoloff, I. Glesk, P. R. Prucnal, R. K. Boneck, Performance of a 50 Gbit/s Optical Time Domain Multiplexed System Using a Terahertz Optical Asymmetric Demultiplexer, IEEE Photon. Techno. Lett.6 (1), 98-100, 1994.
[19] Z.Y. Shen and L. L. Wu, Reconfigurable optical logic unit with a terahertz optical asymmetric demultiplexer and electro-optic switches, Appl. Opt. 47(21), 3737-3742, 2008.
[20] Y. J. Jung, S. Lee, N. Park, All-optical 4-bit gray code to binary coded decimal converter, Optical Components and Materials, Proceedings of the SPIE, Volume 6890, 68900S, 2008.
[21] B.C. Wang, V. Baby, W. Tong, L. Xu, M. Friedman, R.J. Runser, I. Glesk, P. R. Pruncnal, A novel fast optical switch based on two cascaded Terahertz Asymmetric Demultiplexers(TOAD), Optics Express 10(1), 15-23, 2002.
[22] Y.K.Huang, I.Glesk, R.Shankar, P.R.Prucnal, Simultaneous all-optical 3R regeneration scheme with improved scalability using TOAD, Optics Express, 14(22), 10339-10344, 2006.
[23] J.N.Roy, D.K.Gayen, Integrated all-optical logic and arithmetic operations with the help of TOAD based interferometer device – alternative approach, Appl. Opt. 46(22), 5304-5310, 2007.

[24] J. N. Roy, G. K. Maity, D. Gayen, T. Chattopadhyay, Terahertz Optical Asymmetric Demultiplexer based tree-net architecture for all-optical conversion scheme from binary to its other 2^n radix based form, Chinese Optics Letter 6(7), 536-540, 2008.

Goutam Kumar Maity had started his carrier with Lectureship at Panskura Banamali College, after completing his post graduation in Eletronics from Jadavpur University, Kolkata, West Bengal, India in 2000. He left Lectureship in 2005 & switched to reputed private engineering colleges since last ten years. He did M.Tech. from West Bengal University of Technology& Ph.D from Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India in Information Technology & Optical Communications respectively. He has teaching and research experience of more than 14 years. Presently he is working as Associate Professor in ECE Department at MCKV Institute of Engineering, Liluah, Howrah, West Bengal, India. His interests include embedded systems, optical information processing in communication Systems and optical cryptography.

Supriti Samanta was born in Purba-Medinipur, West Bengal on 28th July, 1978. She received BSc (Hons. in Physics) degree & MSc (Physics) degree from Vidyasagar University in 1999 & 2001 respectively. She is presently working as an Assitt. Teacher in Chaipat Girls' High School.. Her interests include Digital Electronics, Embedded systems and optical communication Systems.

Ashis Kumar Mandal was born in Howrah, West Bengal on 15th March, 1980. He received BSc (Hons. In Physics) degree from Calcutta University & MSc (in Pure Physics) degree from Madurai Kamaraj University. He is presently working as an Assistant Teacher in Chakur Haris Seminary High School. With nearly 8 years of teaching experience he passed CSIR-UGC NET-2012 (LS, Rank-70) in India. He is interested in Digital Electronics, optical information processing in communication system & organic solar cell.