THE ALL-OPTICAL REVERSIBLE NEW UNIVERSAL GATE USING MACH-ZEHNDER INTERFEROMETER

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ABSTRACT

At present time, reversible logic, one of the vital issue, has originated as a promising computing paradigm having application in low-power CMOS, quantum computing, nanotechnology and optical computing, DNA computing, etc. With much efficiency optical logic gates have the potential to perform at macroscopic (light pulses carry information), or quantum (single photons carry information) levels. Now, we propose and configure a great scheme of TAND gate in all-optical domain. We have explained their principle of operations and used a theoretical model to fulfill this task, finally confirming through numerical simulations In the field of ultra-fast all-optical signal processing Mach–Zehnder interferometer (MZI), semiconductor optical amplifier (SOA)-based, has an important function. The different logical (realization of Boolean function) operations can be executed by designed circuits in the domain of reversible logic-based information processing. The logic blocks in our traditional computer are irreversible because after generating the output bits the blocks lose the input bits permanently. The classical gates like AND, OR, NAND, etc. are such type of gates because they have multiple-input but single output. The reversible gates have inputs and outputs which are one-to-one correspondence. The inputs of such gates can be determined from its outputs. So, this type of gates has same number of inputs and outputs. In conventional irreversible hardware computation does in energy dissipation due to information loss [1]. But, the reversible logic circuits give us the computation with arbitrary small energy dissipation [2]. For the field of information processing a promising technology has been developed by reversible logic circuits. Many optical logic gates have been suggested to perform irreversible logic function [3-14]. A gate is universal if any logical reversible circuit can be designed using these gates. This paper
presents a circuit for realization of universal TAND gate in all-optical domain. This paper is built as follows. In Section 1 the principle and operation Mach–Zehnder interferometer (MZI)-based optical switch is explained. All-optical circuit of MZI-based universal TAND gate is discussed in Section 2. Designing of various gates in all-optical domain are reported in Section 3 by universal TAND gate. Corresponding simulation (by Matlab-7.0) results confirm gate’s properties are also attached in this paper.

**INDEX TERMS:** Reversible logic gates, Mach–Zehnder interferometer (MZI), and TAND gate.

1. MZI-BASED ALL-OPTICAL SWITCH

When the incoming signal is to be switched into the interferometer, it is split between the arms of the interferometer. The incoming signal emerges from crossbar port in the absence of a control signal. The presence of control pulse changes the refractive index of the medium given by $\Delta n = n_2 I$, here, $\Delta n$ is the change in the refractive index of the medium, $n_2$ the nonlinear refractive coefficient and $I$ the intensity of the light incident on the medium. The incoming signal is switched over to bar port due to a change in the index adds a phase shift between the two arms of the interferometer.

![Figure 1(a)](image1)

This switching process is based on cross phase modulation (XPM). The XPM used SOA-Mach–Zehnder interferometer is the great important interferometric structure due to
its low-energy requirement, simplicity, compactness and stability [15-25]. Symmetric MZI-SOA all-optical switch is shown in Fig. 1(a) and (b).

![Figure 1(c)](image)

Two semiconductor optical amplifiers (SOA-1 and SOA-2) are inserted in each arm of a MZ interferometer [15-18]. It has two input ports (port-1 and port-2) and two output ports (port-3 or Bar-port and port-4 or Cross-port). The incoming signal pulse of wavelength \( \lambda_2 \) enters through port-1, is divided equally by the coupler C1 (50:50) and propagates simultaneously in the two arms and port-2 is kept open. At that time, through coupler C2 a pulsed signal of wavelength \( \lambda_1 \) enters to the upper arm in such a way that most power goes through upper arm. This pulsed signal saturates the SOA-1 and changes its refractive index, while the SOA-2 remains the unsaturated gain state. As a consequence, a differential phase shift can be gained between the data signal of two arms. So, light is present in the port-3 (bar port), as shown in Fig. 1(a) and no light is present in the port-4 (cross port). This is known as ‘switched state’. Both SOA (SOA-1 and SOA-2) get the same unsaturated gain when control signal is absent. Then no light is present in the port-3 (bar port) but light is present in the port-4 (cross port). This is called ‘no-switched state’.

![Figure 1(d)](image)
Optical filters (F) are inserted in front of the output ports for blocking the signal (control signal). The MZ scheme is desirable for cross-gain saturation as it does not reverse the bit pattern and results in a higher on-off contrast because nothing exits from bar port during 0 bits. Schematic block diagram of MZI is shown in Fig. 1(b). Truth table of Fig. 1(a) is given in Table 1.

<table>
<thead>
<tr>
<th>Input signal</th>
<th>Output signal</th>
<th>Port-3 (cross port)</th>
<th>Port-4 (bar port)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
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</tbody>
</table>

1.1 THEORETICAL MODEL

Mach-Zehnder interferometer (MZI) switch (fig. 1a & 1b) is a very powerful optical device to realize ultra fast all-optical switching. This switch has a semiconductor amplifier (SOA) in each arm of a MZ interferometer [15-16, 18]. The pulsed signal at the wavelength $\lambda_1$ enters to the upper arm through coupler C2 such that most power passes through upper arm. At the same time, the incoming signal pulse at the wavelength $\lambda_2$ enters port-1, is split equally by this coupler C1 and propagates simultaneously in the two arms.
At port-3 and port-4 the intensity transmission characteristics can be expressed as [26]

\[ T_3(t) = \frac{1}{4} G_1 \left[ k_1 k_2 + (1-k_1)(1-k_2)R_G - 2 \sqrt{k_1 k_2 (1-k_1)(1-k_2) R_G} \cos(\Delta \Phi) \right] \] (1)

\[ T_4(t) = \frac{1}{4} G_1 \left[ k_1 (1-k_2) + (1-k_1) k_2 R_G - 2 \sqrt{k_1 k_2 (1-k_1)(1-k_2) R_G} \cos(\Delta \Phi) \right] \] (2)

Where \( R_G = G_2 / G_1 \), \( G_1 \) and \( G_2 \) are the time dependent gain, \( \Delta \Phi(t) = -\frac{\alpha}{2} \ln \left( \frac{G_1}{G_1} \right) \), \( \alpha \) is the line width enhancement factor (taken 7.5 here), \( k_1 \) and \( k_2 \) are the ratios of the couplers C1 and C2 respectively. For simplicity we take \( k_1 = k_2 = 1/2 \). The output signal power at port-3 and port-4 are,

\[ P_j(t) = P_{ip}(t) \cdot T_j(t), \quad j = 3, 4. \] (3)

Where \( P_{ip}(t) \) is the power of the incoming signal pulse. When both beams are present simultaneously, the control pulse saturates SOA-1 on change in carrier density inside SOA. The gain of the SOA during this period is [27-29],

\[ G(t) = \frac{1}{1 - \left( 1 - \frac{1}{G_0} \right) \exp \left( - \frac{U_{in}(t)}{U_{sat}} \right) } \] (4)

Where \( U_{sat} \) is the saturation energy of the SOA and \( U_{in}(t) = \int_{-\infty}^{t} P_{in}(t') dt' \). Here we consider a Gaussian Pulse \( P_{in}(t) = \frac{E_{in}}{\sigma \sqrt{\pi}} \exp \left( -\frac{t^2}{\sigma^2} \right) \) as control signal, where \( E_{in} \) is the input pulse energy, \( \sigma \) is the full width at half maximum (taken 2.8 here). Now the gain recovery is happened in SOA-1 with time constant \( \tau_e \). The momentarily gain during this time is [30]

\[ G(t) = G_0 \left[ \frac{G(t_s)}{G_0} \right] \exp \left[ -\frac{(t-t_s)}{\tau_e} \right], \quad t > t_s \] (5)

Where, \( G(t_s) \) is the gain after saturation of SOA-1. We show the gain change for SOA-1 in the Figure3. (c) (All the simulation and calculation is done with Mathcad-7). Physically the pulse is so short that the gain has no time to recover [10].

Here we take \( G_0 \) = unsaturated amplifier gain =29.6 dB, \( \tau_e = 95 \) ps, \( E_{in}/U_{sat} = 0.1 \). From the graph in the Figure1(c) we find \( t_s = 5.5 \) ps and \( G(t_s) = 7.969 \) dB. The beam in the
lower arm experiences the unsaturated amplifier gain $G_i$ (as there is no strong optical pulse to saturate the SOA-2) i.e. $G_i \neq G_i$, recombine at the coupler C3. So that $\Delta\Phi \approx \pi$.

![Figure 1.1(b)](image)

Hence, all one bits are directed toward the bar port (upper port-3 in the figure). In the presence of control pulse, the output pulse at port-3 and port-4 is shown in the Figure1.1(b) and the transmitted intensity for both port are also shown in Figure1.1(a). However, in the absence of the $\lambda_1$ beam, the both the incoming signal beam in two arms experiences the same unsaturated amplifier gain $G_0$ in both SOA (i.e. $G_i = G_z$), recombine at the coupler C3. So $\Delta\Phi = 0$. From equation (3), we can say $P_1(t) = 0$ and the pulse only exits at the cross port (lower port-4 in the figure). In the absences of control pulse, the output pulse at port-3 and port-4 is shown in the Figure1.1(c).

![Figure 1.1(c)](image)

Optical filters are placed in front of the output ports for blocking the $\lambda_1$ signal. The MZ scheme is preferable over cross-gain saturation as it does not reverse the bit pattern.
and results in a higher on-off contrast simply because nothing exits from bar port during 0 bits. Now, it is clear that in the absence of control signal ($\lambda_1$), the incoming signal ($\lambda_2$) exits through cross-port (lower channel) of MZI as shown in Fig. 3. (a). In this case no light is present in the bar-port (upper channel). But in the presence of control signal, the incoming signal exits through bar port of MZI as shown in Fig. 1.1(b). In this case no light is present in the cross port. In the absence of incoming signal, bar-port and cross-port receives no light as the filter blocks the control signal. Schematic block diagram of MZI is shown in Fig.-1 (b).

2. MZI-BASED NEW GATE: TAND GATE

TAND gate is also a (2*2) conservative reversible gate. It has two inputs (A, B) and two outputs (P, Q) satisfy the relation as follows:

$$\begin{align*}
P &= A \\
Q &= AB
\end{align*}$$

(6)

Table-2: Truth table of TAND gate

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>1</td>
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<tr>
<td>1</td>
<td>0</td>
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<td>1</td>
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</tbody>
</table>

2.1 PRINCIPLE AND DESIGN

Schematic diagram is given in Fig. 2(b). The MZI-based circuit for all-optical reversible TAND gate is given in Fig. 2(a). Here input ‘A’ is connected with MZI as incoming signal. The control signal of the corresponding gate comes from the input ‘B’. The output ‘P’ is taken by combining the light through a beam combiner (BC) from the bar port (B) and from the cross port (C) of MZI by splitting it by BS. The output ‘Q’ is taken from the cross port (C) of MZI. The operational principle of this gate is discussed below in details.

(1) When A=B=0, i.e. input A and B do not receive any light, the final output P and Q receives no light from the MZI. So P=Q=0, which satisfy the first row of the truth table 2
(2) When $A = 0$ and $B = 1$, then only the control signal is present at MZI. No incoming signal is present at MZI. According to the working principle of MZI described in the Section 1, all the ports do not receive any light. So the final output is $P=0$ and $Q=0$, which satisfy the second row of the truth table 2.

(3) When $A=1$ and $B=0$, then only the incoming signal is present at MZI and no control signal is present at MZI. According to the working principle of MZI described in the Section 1, only the cross port of MZI(C) receives light. Other port does not receive light. So $P=1$ and $Q=1$, which satisfy the third row of the truth table 2.

(4) When $A=1$ and $B=1$, then bar port of MZI(B) receives light (as both incoming and control signal of MZI receive light) and cross port does not receive light. So $P=1$ and $Q=0$, which satisfy the fourth row of the truth table 2.

![Figure 2(a)](image)

**Figure 2(a)**

- Beam Combiner, / BS: Beam Splitter, □ EDFA: Erbium Doped Fiber Amplifier,
- WC: Wavelength Converter

![Figure 2(b)](image)

**Figure 2(b)**
3. TAND GATE CAN BE USED TO PERFORM AS UNIVERSAL LOGIC GATE

Proposed arrangements to perform various gate operations are as follow-

3.1 NOT OPERATION

![Figure 3.1(a)](image1)

**Figure 3.1(a)**

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

![Figure 3.1(b)](image2)

**Figure 3.1(b)**

Schematic diagram is given in Fig. 3.1(b). The MZI-based circuit for NOT gate by all-optical reversible TAND gate is given in Fig. 3.1(a). Here input ‘B’ (=1) is connected with MZI as incoming signal. The control signal of the corresponding gate comes from the input ‘A’. The output ‘P’ is taken by combining the light through a beam combiner (BC) from the bar port (B) and from the cross port (C) of MZI by splitting it by BS. The output ‘Q’ is taken from the cross port (C) of MZI. The operational principle of this gate is discussed below in details.

**Table-3.1: Truth table of Figure3.1(a)**

<table>
<thead>
<tr>
<th>A</th>
<th>Q</th>
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<tbody>
<tr>
<td>0</td>
<td>1</td>
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<tr>
<td>1</td>
<td>0</td>
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</tbody>
</table>
(1) When \( B=1 \) and \( A=0 \), then only the incoming signal is present at MZI and no control signal is present at MZI. According to the working principle of MZI described in the Section 1, only the cross port of MZI(C) receives light. Other port does not receive light. So \( P=1 \) and \( Q=1 \), which satisfy the first row of the truth table 3.1.

(2) When \( A=1 \) and \( B=1 \), then bar port of MZI (B) receives light (as both incoming and control signal of MZI receive light) and cross port does not receive light. So \( P=1 \) and \( Q=0 \), which satisfy the second row of the truth table 3.1.

### 3.2 AND OPERATION

![Figure 3.2(a)](image)

**Figure 3.2(a)**

[BC]: Beam Combiner, / BS: Beam Splitter, \( \square \) EDFA: Erbium Doped Fiber Amplifier, WC: Wavelength Converter

![Figure 3.2(b)](image)

**Figure 3.2(b)**

Schematic diagram is given in Fig. 3.2(b). The MZI-based circuit for AND gate by all-optical reversible TAND gate is given in Fig. 3.2(a). Here input ‘A’ is connected with MZI-based TAND gate as incoming signal. The control signal of another gate (TAND gate based NOT gate) comes from the input ‘B’ and the output (C) of this gate is connected as
a control signal of other gate. The final output 'Q' is taken from the cross port (C1) of MZI. The operational principle of this gate is discussed below in details.

Table-3.2: Truth table of Figure3.2(a)

<p>| | | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
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<td>Q</td>
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</tr>
</tbody>
</table>

(1) When A=B=0, i.e. input A and B do not receive any light, the final output P and Q receives no light from the MZI. So P=Q=0, which satisfy the first row of the truth table 3.2.

(2) When A = 0 and B = 1, then only the control signal is present at MZI. No incoming signal is present at MZI. According to the working principle of MZI described in the Section 1. So the final output is P=0 and Q=0, which satisfy the second row of the truth table 3.2.

(3) When A=1 and B=0, then only the incoming signal is present at MZI and no control signal is present at MZI. According to the working principle of MZI described in the Section 2, P=1 and Q=0, which satisfy the third row of the truth table 3.2.

(4) When A=1 and B=1, then both incoming and control signal of MZI receive light and according to the working principle of MZI described in the Section 1 and TAND gate, P=1 and Q=1, which satisfy the fourth row of the truth table 3.2.

3.3 OR OPERATION

![Figure 3.3(a)](image-url)
Schematic diagram is given in Fig. 3.3(b). The MZI-based circuit for OR gate by all-optical reversible TAND gate is given in Fig. 3.3(a). Here input ‘A’ is connected with MZI-based TAND gate as control signal. The control signal of the TAND based NOT gate comes from the input ‘B’ and its cross port (C) is connected as an input signal of above TAND gate. And cross port (C1) of this gate is connected as a control signal of another TAND based NOT gate. The output ‘P’ is taken form bar port (B1) and output ‘Q’ is taken form cross port (C2). The operational principle of this gate is discussed below in details.

**Table-3.3: Truth table of Figure 3.3(a)**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</tr>
</tbody>
</table>

(1) When \( A=B=0 \), i.e. input \( A \) and \( B \) do not receive any light, the final output \( P \) and \( Q \) accordingly is \( P=1 \) and \( Q=0 \), which satisfy the first row of the truth table 3.3.

(2) When \( A = 0 \) and \( B = 1 \), then only the control signal is present at MZI-based TAND gate. No incoming signal is present at TAND based NOT gate. According to the working principle of MZI and TAND gate described in the Section 1 Section 2, all the final output is \( P=0 \) and \( Q=1 \), which satisfy the second row of the truth table 3.3.

(3) When \( A=1 \) and \( B=0 \), then only the incoming signal is present at MZI-based TAND gate and no control signal is present at TAND based NOT gate. According to the working
principle of MZI and TAND gate described in the Section 1 Section 2, the cross port (C2) receives light. Other port also receives light. So P=1 and Q=1, which satisfy the third row of the truth table 3.3.

(4) When A=1 and B=1, then as both control signal of corresponding gates receive light and cross port (C2) receive light. So P=0 and Q=1, which satisfy the fourth row of the truth table 3.3.

3.4 NAND OPERATION
Schematic diagram is given in Fig. 3.4(b). The MZI-based circuit for NAND gate by all-optical reversible TAND gate is given in Fig. 3.4(a). Here input ‘A’ is connected with MZI-based TAND gate as incoming signal. The control signal of the TAND based NOT gate comes from the input ‘B’. The output of this gate, cross port (C), is connected to the control port of above gate. The out of this MZI-based TAND gate, cross port (C1), is connected to another TAND based NOT gate and its output, cross port (C2), is taken as final output ‘Q’. ‘P’ is taken from bar port (B1) of MZI-based TAND gate. The operational principle of this gate is discussed below in details.

**Figure 3.4(a)**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>MZI</td>
<td>MZI Beam Combiner</td>
</tr>
<tr>
<td>WC</td>
<td>Beam Combiner</td>
</tr>
<tr>
<td>BS</td>
<td>Beam Splitter</td>
</tr>
<tr>
<td>EDFA</td>
<td>EDFA: Erbium Doped Fiber Amplifier</td>
</tr>
<tr>
<td>WC</td>
<td>WC: Wavelength Converter</td>
</tr>
</tbody>
</table>

**Figure 3.4(b)**
Table-3.4: Truth table of Figure 3.4(a)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
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</table>

(1) When A=B=0, i.e. input A and B do not receive any light, the final output P receives no light and Q receives light from the MZI. So P=0 and Q=1, which satisfy the first row of the truth table 3.4.

(2) When A = 0 and B = 1, then only the control signal is present at TAND based NOT gate. No incoming signal is present at MZI-based TAND gate. According to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=0 and Q=1, which satisfy the second row of the truth table 3.4.

(3) When A=1 and B=0, then only the incoming signal is present at MZI-base TAND gate and no control signal is present at TAND based NOT gate. According to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=1 and Q=1, which satisfy the third row of the truth table 3.4.

(4) When A=1 and B=1, According to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=1 and Q=0, which satisfy the fourth row of the truth table 3.4.

3.5 NOR OPERATION

![Figure 3.5 (a)]
Beam Combiner, BS: Beam Splitter, EDFA: Erbium Doped Fiber Amplifier, WC: Wavelength Converter

Figure 3.5(b)

Schematic diagram is given in Fig. 3.5(b). The MZI-based circuit for NOR gate by all-optical reversible TAND gate is given in Fig. 3.5(a). Here input ‘A’ is connected with MZI-based TANT gate as control signal. The control signal of TAND based NOT gate comes from the input ‘B’. The output of this gate, cross port (C), is connected to the incoming signal of above gate, MZI-based TAND gate. The output ‘Q’ and ‘P’ are taken from the cross port (C1) and bar port (B1) of this MZI-based TAND gate. The operational principle of this gate is discussed below in details.

Table-3.5: Truth table of Figure3.5(a)

<table>
<thead>
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<th>A</th>
<th>B</th>
<th>P</th>
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</tbody>
</table>

(1) When A=B=0, i.e. input A and B do not receive any light, the final output P and Q receives light from the MZI-based TAND gate. So P=Q=1, which satisfy the first row of the truth table 3.5.

(2) When A = 0 and B = 1, then only the control signal is present at TAND based NOT gate. No control signal is present at MZI-based TAND gate. According to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=0 and Q=0, which satisfy the second row of the truth table 3.5.
(3) When \(A=1\) and \(B=0\), then only the control signal is present at MZI-based TAND gate and no control signal is present at TAND based NOT gate. According to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are \(P=1\) and \(Q=0\), which satisfy the third row of the truth table 3.5.

(4) When \(A=1\) and \(B=1\), then both control signals of MZI-based TAND gate and TAND based NOT gate receive light. So \(P=0\) and \(Q=0\), which satisfy the fourth row of the truth table 3.5.

### 3.6 XNOR OPERATION

Schematic diagram is given in Fig. 3.6(b). The MZI-based circuit for X-NOR gate by all-optical reversible TAND gate is given in Fig. 3.6(a). Here input ‘A’ and ‘B’ are connected with two MZI-based TAND gates as incoming and also control signal at the same time. The outputs of the cross port (C, C2) are connected to the control port of TAND based NOT gate and MZI-based TAND gate respectively. The output from cross port (C1) is connected to the input port of MZI-based TAND gate which gives final output ‘Q’ through cross port C3. And output ‘P’ is taken from bar port (B). The operational principle of this gate is discussed below in details.

<table>
<thead>
<tr>
<th>(A)</th>
<th>(B)</th>
<th>(P)</th>
<th>(Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 3.6(b)**

Table-3.6: Truth table of Figure3.6(b)

\[\text{BE}: \text{Beam Combiner, BS: Beam Splitter, EDFA: Erbium Doped Fiber Amplifier, WC: Wavelength Converter}\]
(1) When A=B=0, i.e. input A and B do not receive any light, the final output P receives no light and Q receives light from the corresponding gate. So P=0 and Q=1, which satisfy the first row of the truth table 3.6.

(2) When A = 0 and B = 1, according to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=1 and Q=0, which satisfy the second row of the truth table 3.6.

(3) When A=1 and B=0, according to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=0 and Q=0, which satisfy the third row of the truth table 3.6.

(4) When A=1 and B=1, the final outputs are P=1 and Q=1, which satisfy the fourth row of the truth table 3.6.

3.7 XOR OPERATION

![Figure 3.7(a)](image)

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

![Figure 3.7(b)](image)
Schematic diagram is given in Fig. 3.7(b). The MZI-based circuit for X-OR gate by all-optical reversible TAND gate is given in Fig. 3.7(a). First, a circuit is done like X-NOR gate operation. Then outputs from cross port (C3) and bar port (B1) are connected to a MZI-based TAND gate as control signal and incoming signal respectively. The final outputs ‘Q’ and ‘P’ are taken from cross port (C4) and bar port (B). The operational principle of this gate is discussed below in details.

Table-3.7: Truth table of Figure3.7(a)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

1) When A=B=0, i.e. input A and B do not receive any light, the final output P and Q receives no light from the used MZI-based TAND gate. So P=Q=0, which satisfy the first row of the truth table 3.7.

2) When A = 0 and B = 1, according to the working principle of MZI and MZI-based TAND gate described in the Section 1 and Section 2, the final outputs are P=1 and Q=1, which satisfy the second row of the truth table 3.7.

3) When A=1 and B=0, according to the same working principle of the used gate, the final outputs are P=0 and Q=1, which satisfy the third row of the truth table 3.7.

4) When A=1 and B=1, the both incoming and control signal of MZI-based TAND gate receive light and cross port does not receive light. And then similar working principle we get the final outputs are P=1 and Q=0, which satisfy the fourth row of the truth table 3.7.

4. SIMULATION (BY MATLAB-7.0) RESULT OF ABOVE DESIGNED GATES

The vertical axis in Figure4(a) to 4(j) indicates power in dB, while horizontal axis represents time scale in ps. The timing instant for the occurrence of bit pattern is at 1,3,5,7 ps. Upper first two (Figure4(a) and Figure4(b)) set waveforms indicate the input bit sequences, **0011** and **0101** for the input variables A and B respectively.
Let us test the reversible operation from the simulation results with chosen arbitrary time at 5 ps for the Figure 4(a), 4(b) and 4(c) of TAND gate. The output signal P=1, Q=1. Using these specific outputs we get from equation-6, A=1, B=0. Similarly, from different output bit patterns gives the different input bit combinations which satisfies the reversibility condition.
Figure 4(e): Output of AND operation

Figure 4(f): Output of OR operation

Figure 4(g): Output of NAND operation

Figure 4(h): Output of NOR operation

Figure 4(i): Output of X-NOR operation
5. CONCLUSION

Here, in this paper, the all-optical scheme of reversible TAND gate is proposed and discussed. Simulation result verifies the functionality of those designed gates with verified reversibility. This is important that the above explanations are based on simple model. We have used Mach–Zehnder interferometer as it is often used in practice due to it can be easily integrated by using SiO2/Si or InGaAsP/InP waveguides, resulting in a compact device [31]. The theoretical models developed and the results obtained numerically are useful to future all-optical reversible logic computing system. Different logic operations in reversible system can easily be achieved with these gates. It is worth noting that the synthesis of reversible logic is different from irreversible logic synthesis. The major constraints in reversible logic are to minimize the number of reversible gates used and garbage outputs produced. The output, which is not used for further computations, is known as garbage output. Future work would concentrate realization of various Boolean expression and arithmetic operations using TAND gate.

REFERENCE


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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-Dec, 2012(LS, Rank-70) in India. Also, he has published some research papers in international journal. He is interested in Digital Electronics, optical information processing in communication system & organic solar cell.
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