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REVIEW ON MZI BASED ALL-OPTICAL REVERSIBLE COMBINATIONAL CIRCUITS

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ABSTRACT

In present scenario, users have great requirement of high data transfer rate for different applications. As a result, the demand for systems which can keep a real link with a high rate of increase in data traffic is also gearing up. The only way for such upgradation is shifting to the optical domain from the conventional electric domain. Researchers are more focused on the optical logic of the optical network. The reversible logic gate has emerged as one of the most important option. It gives high power optimization and is used in high-speed power aware circuits. All-optical reversible logic gates are the key components in the all optical processing of the signal with the advantage of low power dissipation and input signal is not lost in reversible logic circuits. Mach-Zehnder Interferometer (MZI) based reversible logic gates has many advantages. Reversible logic gate can be easily fabric and has high speed, low power dissipation and fast switching time. By using MZI-based switch and all-optical reversible logic gates many high level circuits can be realized such as Half Adder, Full Adder, Half Subtractor, Full Subtractor and can be useful in many applications such as all-optical switching, cryptography, etc. Although many designs exist in present but some designs lacks in simplicity, cost, delay and high bit rate etc. Using only Mach-Zehnder Interferometer or combination of MZI along with Feynman gate helps in realizing optical reversible adders and optical reversible subtractors with simplicity at the minimized cost and overcomes the flaws present in the earlier designs of optical reversible adders and subtractors implemented by the various researchers. In this paper, all-optical reversible circuits have been discussed and analyzed for different parameters i.e. optical cost, delay, number of gates used, etc.

KEYWORDS- *Reversible Logic Circuits, Optical Computing, Mach-Zehnder Interferometer (MZI)*

I. INTRODUCTION

Optical communication systems transmit information from the source node to the destination node in the form of modulated optical signals. A typical optical communication system consists of a network of nodes interconnected through optical fibers. Fiber optic telecommunication lines are being widely used to provide much higher bandwidth and greater reliability as compared to copper wire lines, microwave relay stations or satellites. Optical fiber has the high immunity to electromagnetic interference.

A. *Reversible Logic-a Review*

There are two factors considered while designing any component; low power consumption and high performance. So Researchers are looking for alternate circuit design approach to reduce power dissipation due to leakage currents.

Landauer states that every lost information bit generates heat and produces heat equivalent to kTln2, where k is the Boltmann's constant and T is the temperature [16]. While designing of low power device, the amount of heat generated at room temperature cannot be neglected either dissipated heat is small. The amount of energy dissipated in a system is directly proportional to the number of bits erased during computation. Bennett used reversible circuit for low energy dissipation. These reversible circuits do not lose information [4]. Reversible circuits do not use the classical gates such as AND, OR and EX-OR because these gates use multi-input multi- output while in the case of reversible logic circuit, input can be generated back from the output and there is a one-one mapping between input and output.

At recent time researchers are more focused on micro- resonator and semiconductor optical amplifier based on Mach-Zehnder interferometer (MZI).

Semiconductor optical amplifier (SOA) is used not only for signal amplification but also for other optical signal processing applications, such as wavelength converting, switching and optical time domain demultiplexing. Semiconductor optical amplifiers (SOAs) are a type of laser diodes, which have fibers attached to both ends and there are no end mirrors. At the end, there is an anti-reflection coating. It reduces the optical reflection from the surface within a certain wavelength range. SOAs amplify any optical signal enters into the fiber and also sent amplified signal to the second fiber. SOAs work for 1310 and 1550 nm systems and transmit signals bi-directionally. Because of this size of the device reduces. This is big advantage over regenerators of EDFAs. Figure1. illustrates the basics of a semiconductor optical amplifier.

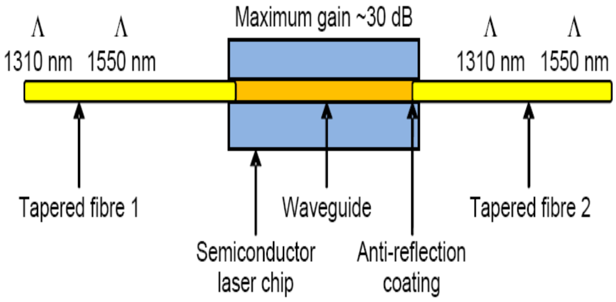

Fig. 1 Semiconductor optical amplifier

II. PRINCIPLE OF MZI and MZI-BASED ALL-OPTICAL SWITCH

Mach-Zehnder Interferometer (MZI) is shown in fig. 2(a) and fig. 2(b). It has highly optical computing capability and ultrafast all-optical switching. An all-optical MZI has two SOAs and two couplers. A semiconductor optical amplifier is inserted in each arm of MZI. The incoming signal splits by the interferometer and the incoming signal emerges from one output port. To get output, interferometer is nicely balanced. MZI consists of two input ports A, B and two output ports. The optical signal at port A is called the incoming signal (λ1) and the optical signal at port B is called as the control signal (λ2) respectively. The output ports are called bar port and cross port respectively. When the incoming signal at A and control signal at B present then there will be output at barport only and no output at crossport. On the other side, if the incoming signal present at A and no control signal at B then output will be present only at crossport not at bar barport. In Boolean function, if presence of light is represented as 1 and absence of light as 0, the output of MZI switch can be expressed in terms of the following Boolean equations as

(A, B) → (A.B, A.$\overline{B}$). Table I shows the truth table for MZI.

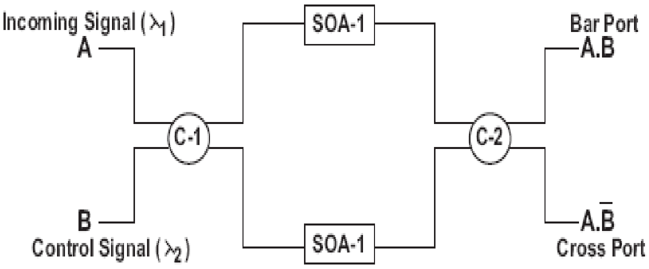

Fig 2(a) Semiconductor Optical Amplifier based MZI

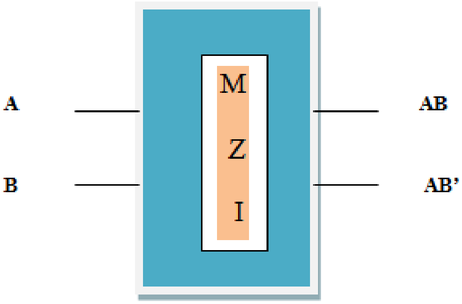

Fig 2 (b) Functional behavior of MZI switch

Table I. Truth table of MZI based switch

Input		Output	
Incoming Signal	Control Signal	Bar Port	Cross Port
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	0

III.REVERSIBILITY PRINCIPLE AND NEED OF REVERSIBILITY

Reversibility allows computing of logic state at any time. It means there is no loss of information and can be recovered any past stage by computing backward. This is known as logical reversibility.

Reversibility has many advantages. It has low power design, high performance, reliability and fast processing. In reversibility, there is minimum power dissipation. This improves the computational efficiency of the system. Minimum numbers of elements are used in designing of reversibility circuit and size of element is of atomic size. So, the reversible circuit is very simple and because of this portability of the device increases. On increasing of input and output, the cost of reversibility hardware increases but performance dominant over cost.

IV.REVERSIBLE LOGIC GATES

Mainly four types of reversible gates used in optical communication. Those are Fredkin gate, Feynman gate, Toffoli and Peres gate.

A. Feynman Gate

Feynman gate is a 2×2 reversible logic gate [16] It has two input vectors as A, B and two output vectors X, Y. The output is given as X=A, Y=A⊕B. Truth table is shown in table II. When the input A=1 then the output generated at Y will be complement of input B that is Y=B' that why this is also called copying gate or controlled- NOT gate (CNOT) as

Table II. Truth table for Feynman gate

Input		Output	
A	**B**	**X**	**Y**
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

A Feynman gate uses two MZI based all optical switch. It has 2 beam combiner (BC) and 2 beam splitter (BS). The circuit is shown in fig 3. Since the Feynman gate uses 2 MZI based optical switches. So, the cost of Feynman gate is considered as 2. In the Feynman gate, two MZIs switches are connected in parallel. So total delay of the optical Feynman gate is considered as 1Δ.

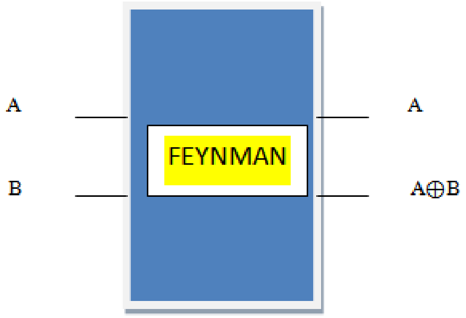

Fig.3 Schematic diagram of Feynman gate

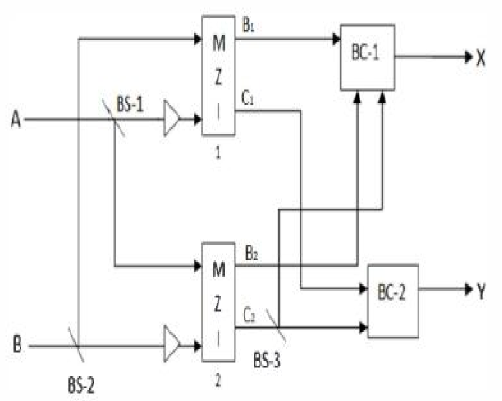

Fig.4 All-optical circuit of Feynman gate. BC: beam coupler, BS: beam splitter, ▶: EDFA

B. Fredkin Gate

Fredkin gate is a 3×3 reversible logic gate [19]. It has three input vectors A, B, C and three output vectors X, Y, Z. The output is given as $X=A$, $Y=\bar{A}B\oplus AC$, $Z=\bar{A}C\oplus AB$. The truth table is shown in Table III. The circuit of all-optical MZI based Fredkin gate is shown in fig.5. Since Fredkin gate uses two MZIs switches and connected in parallel. So the total delay of the optical Fredkin gate is considered as 1Δ and the optical cost is considered as 2.

Table III. Truth table of Fredkin gate

Input			Output		
A	**B**	**C**	**X**	**Y**	**Z**
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	1	1
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	1	0	1
1	1	1	1	1	1

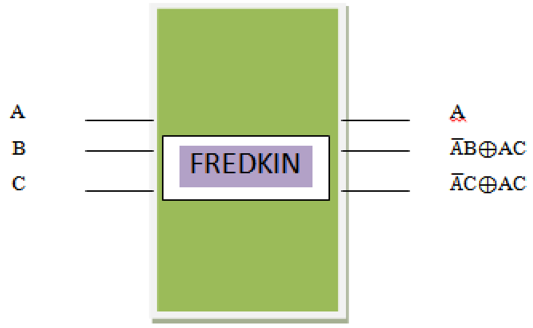

Fig.5 Schematic diagram of Fredkin gate

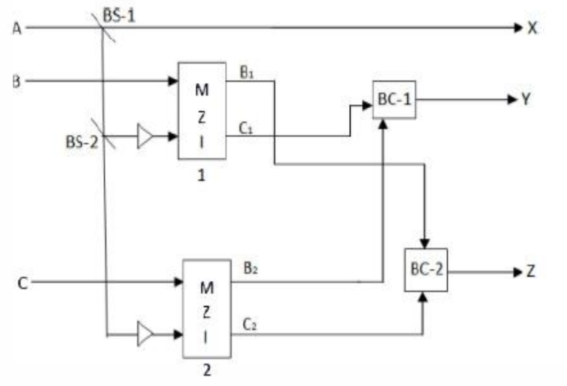

Fig.6. All-optical circuit of Fredkin gate

C. Toffoli Gate

The Toffoli gate is a 3×3 reversible logic gate [32]. It has three input vectors A, B, C and three output vectors P, Q, R. The output vectors are given as P=A, Q=B, R=A.B⊕C and truth table is shown in table IV.

Table IV. Truth Table of Toffoli gate

Input			Output		
A	**B**	**C**	**P**	**Q**	**R**
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	1	1
1	0	0	1	0	0
1	0	1	1	0	1
1	1	0	1	1	1
1	1	1	1	1	0

In the circuit diagram of MZI based Toffoli gate, it uses three MZI switches. So the total optical cost of Toffoli gate is considered as 3. Two MZIs switches connected in series. So the delay of the optical Toffoli gate is 2Δ. This is used as a universal gate and very popular reversible logic.

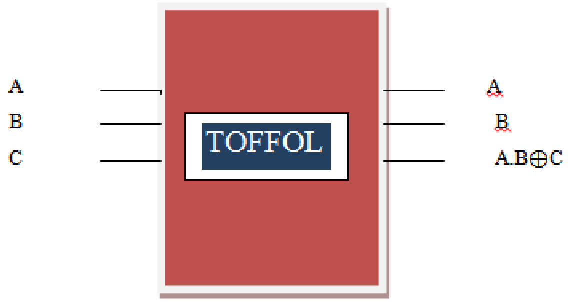

Fig.7 Schematic diagram of Toffoli gate

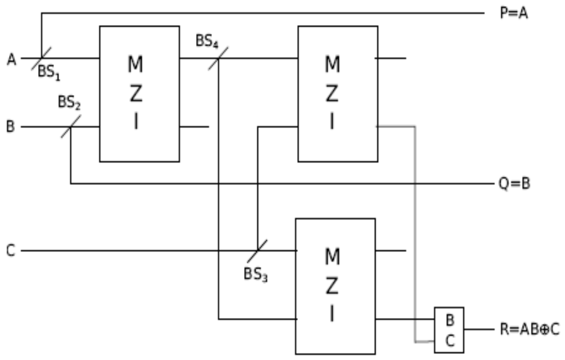

Fig.8 All-optical circuit of the Toffoli gate

D. Peres Gate

The Peres gate is a 3×3 reversible logic gate [20]. It has three input vectors A, B, C and three output vectors P, Q, R. The output vectors are given as P=A, Q=A⊕B, R=A.B⊕C. It is shown in table V.

Table V. Truth Table of Peres gate

Input			**Output**		
A	**B**	**C**	**P**	**Q**	**R**
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	1	1
1	0	0	1	1	0
1	0	1	1	1	1
1	1	0	1	0	1
1	1	1	1	0	0

The circuit of Peres gate is shown in fig. 10. It has four MZI switches thus the optical cost of Peres gate is 4. There are two MZIs switches connected in series. Hence the total delay for the optical Peres gate is 2Δ.

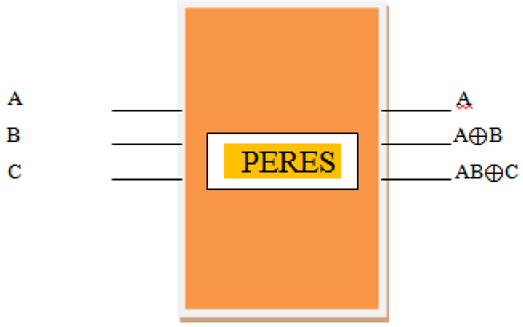

Fig.9. Schematic diagram of Peres gate

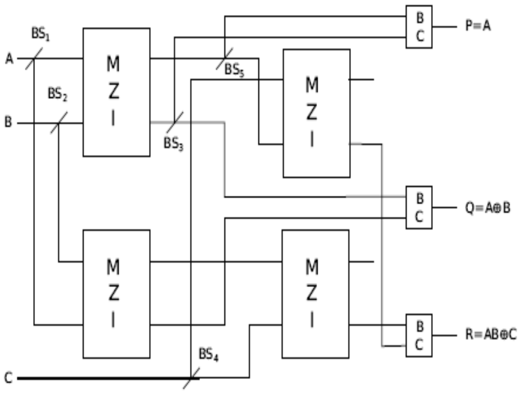

Fig.10. All-optical circuit of the Peres gate

V. CONCLUSION

Reversible logic gates have low power dissipation and high speed. They are designed for low input power and give high performance. It is used in many application areas as quantum computing, optical computing, quantum dot cellular automata, bio informatics, nanotechnology based systems, etc. Peres, Toffoli and Feynman gate show good performance and produce any Boolean output. Although the cost of circuit implementation increases with increase in input and output but the performance and power cost dominant over it.

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