INTERNATIONAL JOURNAL OF RESEARCH
In Advanced Engineering Technologies

Volume 6, Issue 2 NOV 2017

A NEW GATE FOR LOW COST DESIGN OF ALL-OPTICAL REVERSIBLE LOGIC CIRCUIT

K. NagaSiva Reddy[1] **R.Prabhakar**[2]
naga4258@gmail.com[1] rpr612@gmail.com[2]
[1]PG Scholar, Dept of ECE, Dr. K.V. SUBBA REDDY INSTITUTE 0F TECHNOLOGY,
DUPADU,KALLUR,KURNOOL,AP.
[2] Professor &HOD, Dept of ECE, , Dr. K.V. SUBBA REDDY INSTITUTE 0F TECHNOLOGY,
DUPADU,KALLUR,KURNOOL,AP.

Abstract- Reversible logic design has been one of the promising technologies gaining greater interest due to less dissipation of heat and low power consumption. The optical implementation of reversible logic gate based on Semiconductor Optical Amplifier is based on Mach-Zehnder Interferometer. Optical reversible designs have used ad-hoc approaches and require high cost in terms of MZI switches, Beam Splitters (BS), and Beam Combiners (BC) as well as optical delay. In this work, an optical reversible MNOT gate and all-optical realization of 4×4 Toffoli Gate have been proposed which is used in all-optical realization of optimized reversible combinational circuits. A general design approach to realize all-optical reversible circuits based on MZI switches has been proposed first time in the literature. Optimized all optical reversible 2×1 multiplexer and full adder circuits have been designed using these proposed gates and design approach. All-optical reversible designs of 4×1 multiplexer, 1×4 Demultiplexer and 3to8 Decoder circuits have also been presented in this work first time in the literature. Our results have shown significant improvements over existing designs in terms of MZI switches, BS, BC and optical delay.

Keywords—Optical Reversible computing; Mach Zehnder Interferometer(MZI); Full Adder; Multiplexer; Decoder; optical cost.

I.INTRODUCTION

In conventional computers, the computation carrying out is irreversible i.e. as the system generates the output bits, the input bits are lost. But it is not in the case of reversible logic circuits. A gate is reversible if the gate's inputs can be generated back from the output and have a one-to-one mapping between inputs and outputs, i.e. there is a distinct output assignment for each distinct input . Reversible logic has emerged as a potential alternative to low-power dissipating circuit design. Optical implementation of reversible gates can be a promising alternative to overcome the power dissipation problem in conventional computing. In recent times all-optical implementation of various reversible logic gates is gaining the attention of researchers. For all optical implementation researchers are using micro resonator and semiconductor optical amplifier (SOA) based Mach Zehnder interferometer (MZI) switch. Also MZI-based implementation of reversible logic gates offer significant advantages such as high speed, low power, ease of fabrication and fast switching time. The interferometer consist of bidirectional couplers and semiconductor optical amplifier in its arms. Interferometer acts as a very high speed switch since it does not require any optical to electronic conversation and vice versa.

Optical Computing is computation with photon as opposed to conventional electron based computation. Unmatched high speed and zero mass of photon have attracted the researchers towards the optical realization of reversible logic gates using Semiconductor Optical Amplifier (SOA) based Mach Zehnder Interferometer (MZI) switches. MZI Switches are preferred because of its high speed, fast switching, low power and ease in fabrication [4], [5], [6]. The authors have presented the optical realization of popular reversible logic gates such as Feynman and Toffoli Gates [4], Fredkin Gate [5], and Peres Gate [6] etc. All-optical reversible combinational circuits for instance 2×1 Multiplexer [7], Binary Ripple Carry Adder [8], NOR Gate [9], New Gate [10], Hybrid New Gate (HNG) [11] and Modified Fredkin Gate [15] etc. are proposed by the authors in the literature.

In this paper, we have proposed an optical reversible MNOT gate using one MZI switch. All-optical realization of 4×4 Toffoli Gate has been presented which is used in alloptical realization of optimized reversible combinational circuits. A general design approach to realize all-optical reversible circuits based on MZI switches has been proposed first time in the literature. Optimized all-optical reversible 2×1 multiplexer and full adder circuits have been designed using these proposed gates and design approach. Alloptical reversible designs of 4×1 multiplexer, 1×4 D emultiplexer and 3to8 Decoder circuits have also been presented in this work first time in the literature. Our results have shown significant improvements over existing designs in terms of MZI switches, BS, BC and optical delay.

II. BASICS OF ALL OPTICAL REVERSIBLE LOGIC

A.SOA Based MZI Switch

MZI switch, as shown in fig. 1(a) and fig. 1(b) is a very useful optical device to realize ultra-fast all optical switching. A MZI based all optical switch can be designed using 2 Semiconductor optical amplifier (SOA-1, SOA-2) and two beam couplers (C-1, C-2). The operating principle of MZI based all optical switch can be explained as follows: In a MZI switch there are two input ports called as incoming signal port and control signal port respectively and two output ports called as bar port and cross port respectively. Absence of light at the input port is consider as logic 0. When there is an incoming signal at port A and control signal at port B then there is a light present at the output bar port and there is no light at the output cross port. When there is an incoming signal at input port A but no signal is present at the input of control port B then there is a light present at the output cross port and there is no light at the bar port. In the absence of incoming signal at the input port A no light is present at both the output ports. The above behavior of MZI can be expressed in terms of following Boolean equations: (A, B) → (A.B, A.B’).

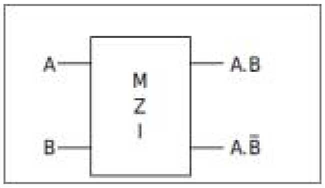


Fig. 1(a). Block diagram of Mach-Zehnder Interferometer switch

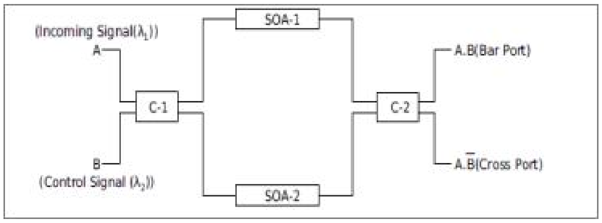


Fig. 1(b). SOA based Mach-Zehnder Interferometer switch

B. All-optical Feynman gate

Feynman gate is a 2*2 reversible logic gate having A, B as input vector and X, Y as output vector, where X=A, Y=A⨁B, given in table I. The Feynman is also referred as the copying gate or controlled- NOT gate (CNOT) as when the input A=1 then the output generated at Q will be complement of input B that is Y=B’.

Table I

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**

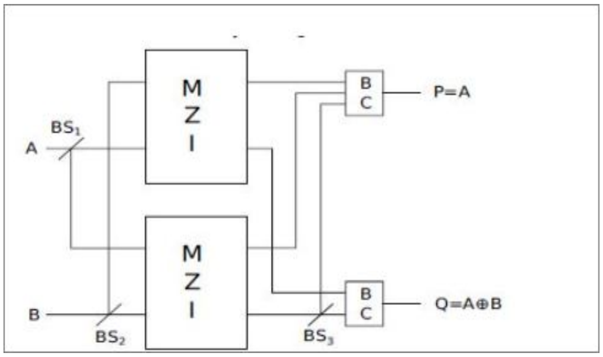


Fig. 2. Feynman gate and its all-optical implementation

A Feynman gate can be implemented using 2 MZI based all optical switch, 2 beam coupler (BC) and 2 beam splitter (BS) in all optical reversible computing. The circuit is shown in fig. 2. As in the implementation of Feynman gate 2 MZI based optical switches are required thus the optical cost of Feynman gate is considered as 2. In the all optical implementation of the Feynman gate, two MZIs switches works in parallel thus the delay of the optical Feynman gate is considered as 1∆.

III. PROPOSED ALL-OPTICAL REVERSIBLE LOGIC GATE

We have proposed a new M NOT gate and presented an all-optical realization of 4×4 Toffoli Gate which are efficient to design optimized optical reversible circuits.

Proposed all-optical reversible MNOT Gate:

A new 2×2 all-optical reversible MNOT gate (1, A) → (P, Q) has been proposed, where P =A and Q = A . Figure 3 shows the Block diagram of M NOT gate. This gate generates logical NOT of the input logic A. Table I shows the truth table of MNOT gate.

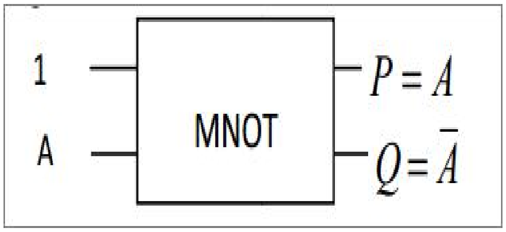


Fig. 3. Block diagram of Proposed 2×2 MNOT gate

Input		Output	
1	A	P = A	Q = $\bar{A}$
1	0	0	**1**
1	1	1	0

TABLE I TRUTH TABLE OF THE PROPOSED REVERSIBLE GATE

The all-optical reversible MNOT gate has been shown in figure 3. This gate is designed with single MZI switch. The incoming signal of MZI switch is set to 1 then output generated at cross port is inverse of the input at control signal. The optical cost of MNOT gate is one. NO Beam Splitter (BS) or Beam Combiner (BC) is used in this gate. As only one MZI switch is used, so the delay is 1∆.

The optical MNOT gate is a useful logic gate in all optical reversible circuit realization. Earlier the authors has used Feynman gate to generate inverse of logic with optical cost 2 MZI switches. Using this gate cost has been reduced to one MZI switch.

B .Optical Realization of 4×4 Toffoli Gate

The 4×4 Toffoli Gate (4×4 TG) is mapped from input vector (A, B, C, D) to output vector (P, Q, R, S), where P=A, Q=B, R=C, and S=D ⊕ABC, respectively. Basically, 4×4 Toffoli gate is Multiple Controlled Toffoli gate (MCT) with 3

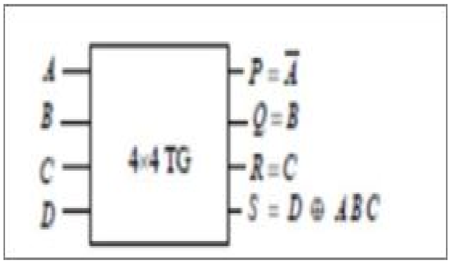


Fig. 4. Block diagram of 4×4 Toffoli gate

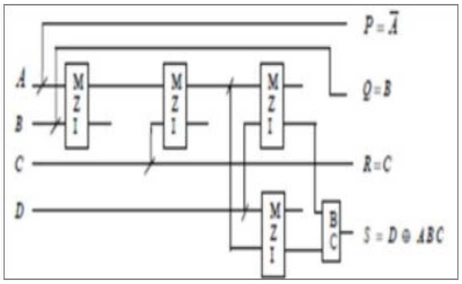


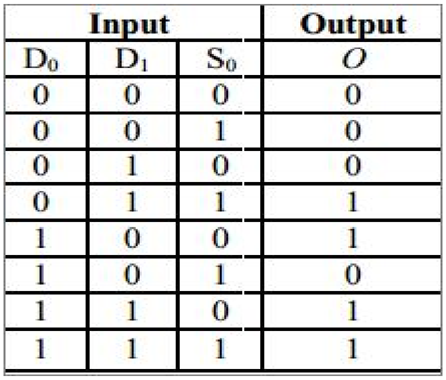
Fig. 5. All-optical Realization of 4×4 Toffoli gate control lines.

Figure 4 shows the Block diagram and Figure 5 Shows all -optical realization of 4×4 Toffoli gate. This gate has been realized with 4 MZI Switches, Five Beam splitters (BS) and one Beam Combiners (BC). The optical delay of this gate is considered as 3∆.

IV.PROPOSED ALL-OPTICAL REVERSIBLE LOGIC CIRCUIT DESIGNS

Proposed All-optical Reversible 2×1 Multiplexer This section describes the design and realization of the reversible 2×1 Multiplexer in all-optical domain using the proposed MNOT gate and optical Toffoli Gate (TG) [4]. It has two data inputs (D0 and D 1), a single output O and a select line S0 to select one of the two input data lines. The output unction of 2×1 Multiplexer is given by O = S0D0+S0D1 .

TABLE II TRUTH TABLE OF 2×1 MULTIPLEXER



Input			Output
D_0	D_1	S_0	*O*
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

The truth table of 2×1 Multiplexer is shown in table II. The optical realization of 2×1 Reversible Multiplexer is shown in figure 6. It is designed with one MNOT and two TG gates. Here, MNOT gate behaves as NOT gate. When the third input line of TG is set to Constant 0 (Zero), the TG behaves as AND gate.

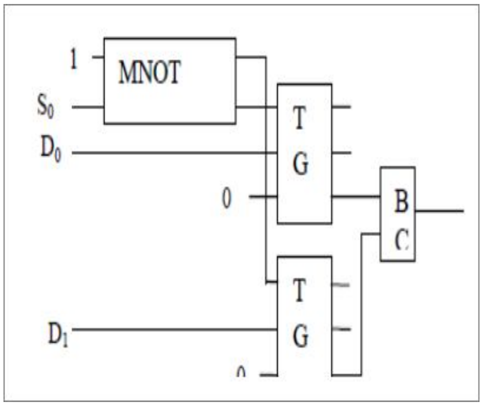


Fig. 6. Optical Realization of 2×1 Reversible Multiplexer

Proposed All-optical Reversible Full Adder Circuit

This section describes a design of all-Optical reversible full Adder circuit using two existing all Optical Reversible Logic gates with improved Optical cost.

The ORG-I gate is shown in the Figure 7. T he improved all-optical reversible full adder is shown in the figure 8. Input bit A, B and C are passed at three inputs of the ORG -I gate. The output P of ORG-I implements the output carry function of Full adder; Output Q of ORG-I and input C are passed to input lines of Feynman gate which produces output Sum Function of Full Adder.

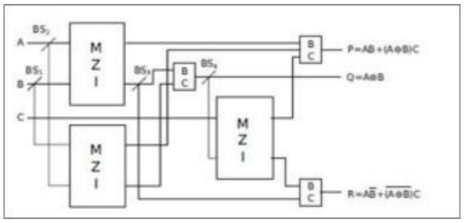


Fig. 7. Optical Reversible Gate (ORG)-I [8] The ORG-I has 3 MZI switches, 4 BS and 3 BC with optical delay as 2Δ. The Feyn man Gate is realized with 2MZI switches, 3 BS, 2 BC and optical delay is 1Δ . Thus, it can be observed from the figure that AllOptical Reversible Full Adder is realized with 5 MZI switches, 8 Beam Splitters and 5.

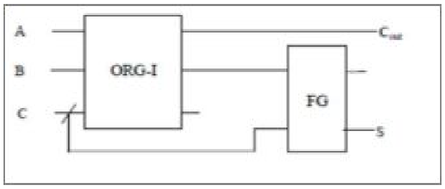


Fig. 8.The improved All- Optical Reversible Full Adder

4-bit Optical Reversible Full Adder Circuit

A 4 -bit optical reversible full adder circuit is designed using 4 ORFA (optical reversible full adder). The diagram of the 4-bit optical reversible full adder is shown in the Figure 9. The carry output of first ORFA is passed to carry input of second ORFA, carry output of second ORFA is passed to carry input of third ORFA and so on.

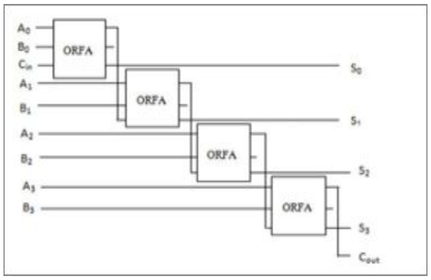


Fig.9.4-bit Optical Reversible Full Adder Circuit

Finally the carry output line of the fourth ORFA produces output carry of addition of two 4-bit numbers. The sum output line of all he ORFA collectively produces 4-bit sum of two 4-bit numbers. Optical cost of the circuit is 20 MZI switches as each ORFA is designed with 5 MZI switches, 8 Beam Splitters and 5 Beam Combiners. Thus, total 32 BS and 20 BC are used in the design of 4-bit optical reversible full adder. The optical delay of the circuit is 12Δ.

Design of Optical Reversible 4×1 Multiplexer

This is first attempt in the literature for designing all Optical Reversible 4×1 multiplexer circuit. The all optical Reversible 4×1 Multiplexer circuit has been realized with proposed Optical Reversible MNOT gate and Optical 4×4 Toffoli Gate (4×4 TG). It has four data input lines (D0-D3), two selection lines S0 and S1 to select one of the four inputs and a single output line O. the expression for data output O is given as

$$O = D_0\bar{S}_0\bar{S}_1 + D_1S_0\bar{S}_1 + D_2\bar{S}_0S_1 + D_3S_0S_1$$

The optical realization of the 4×1 Reversible Multiplexer is shown in the figure 12. It is designed using two MNOT gates and four optical 4×4 TG gates. The fourth input lines of all the 4×4 TG are set to constant 0, which results in Logical AND of the remaining three inputs at fourth output line of 4×4 TG. The fourth output lines of all the 4×4 TG are combined using Beam Combiner (BC) at the final output.

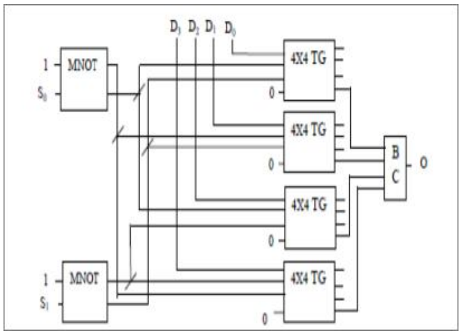


Fig. 10.Design of 4×1 Optical Reversible Multiplexer

Design of Optical Reversible 1×4 De-Multiplexer

Authors, in the literature, have not yet designed any single Reversible 1×4 De-Multiplexer in optical domain. This is first time, an All -optical Reversible 1×4 De-Multiplexer has been proposed. It has one input data line D, 2 select input lines (S0 and S1) and four output lines (O 0- O3). The expression for output lines are given as follows:

$$O_0 = D\overline{S}_1\overline{S}_0, O_1 = D\overline{S}_1 S_0, O_2 = DS_1\overline{S}_0 \text{ and } O_3 = DS_1 S_0$$

The logical NOT Gate and the logical AND are replaced with proposed optical reversible MNOT gate and 4×4 TG, respectively. Optical realization is shown in Figure 11.

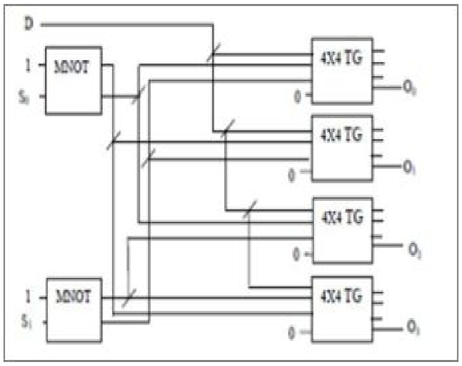


Fig. 11.Optical realization of reversible 1×4 DeMultiplexer

Design of Optical Reversible 3to8 Decoder

A Decoder circuit is similar to the De-Multiplexer circuit but there is no data input line. This is also first time attempt in the literature to design an all- Optical Reversible 3to8 Decoder circuit. A 3to8 Decoder has three input li nes (P, Q, R) and eight output lines (O0 - O7). The output function of the 3to8 Decoder is expressed as follows:

$$O_0 = \overline{\overline{P}\,\overline{Q}\,\overline{R}} \;;\; O_1 = \overline{P}\,\overline{Q}R \;;\; O_2 = \overline{P}Q\overline{R} \;;\; O_3 = \overline{P}QR$$
$$O_4 = PQ\overline{R} \;;\; O_5 = P\overline{Q}R \;;\; O_6 = PQ\overline{R} \;;\; O_7 = PQR$$

The circuit is designed with 35 MZI switches, 58 Beam Splitters and 8 Beam Combiners. Delay of the circuit is 4Δ.

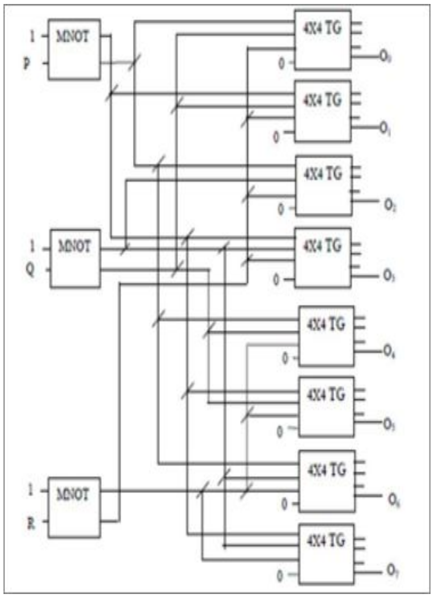


Fig. 12.All-Optical realization of the reversible 3to8 Decoder

EXTENSION.

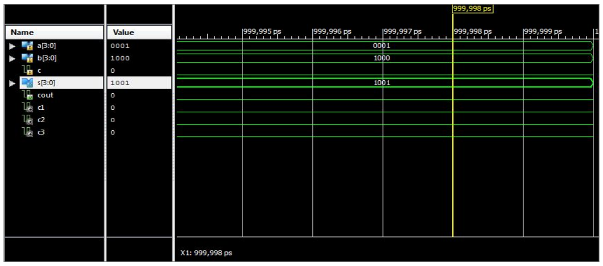
Reversible 32-bit Addition.

By cascading 4 bit ORFA, 32-bit can be realized.

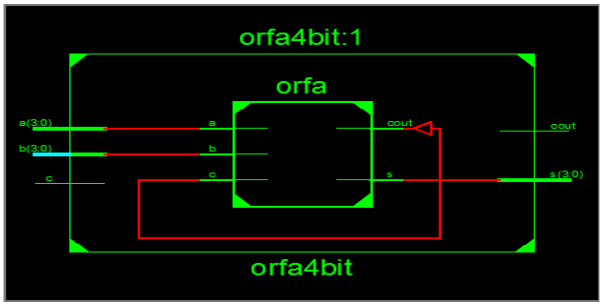
VI. SIMULATION RESULT

PROPOSED

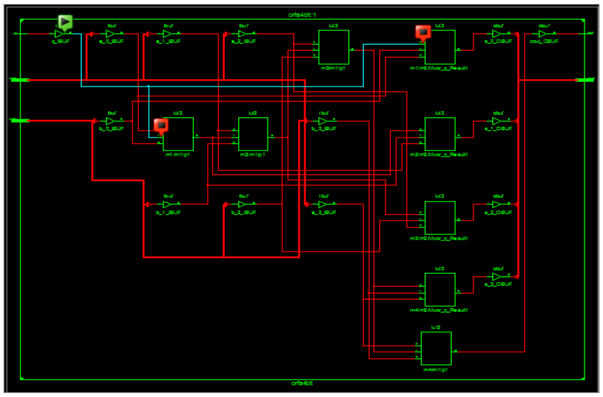
Simulation:



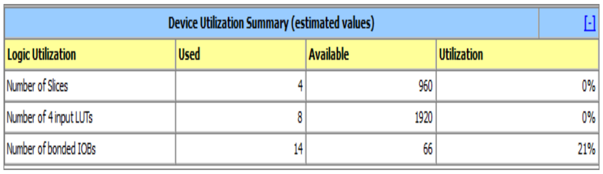
RTL Schematic:



Technology Schematic:



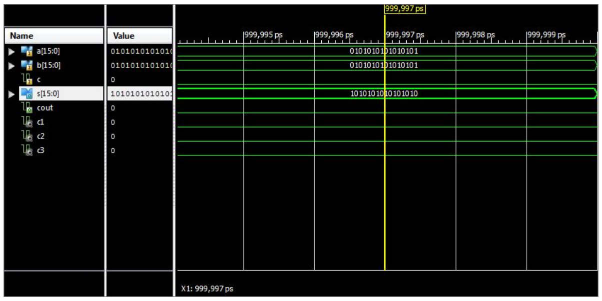
Design Summary:



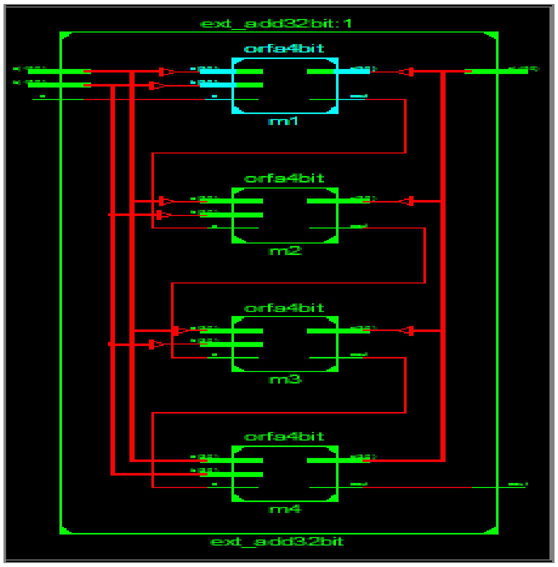
Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slices	4	960	0%
Number of 4 input LUTs	8	1920	0%
Number of bonded IOBs	14	66	21%

EXTENSION:

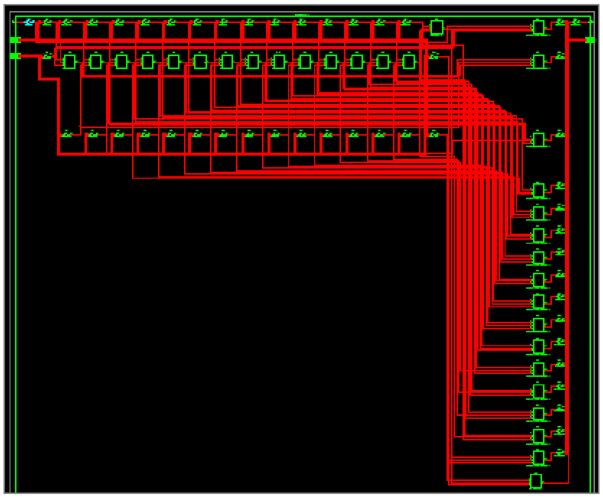
Simulation:



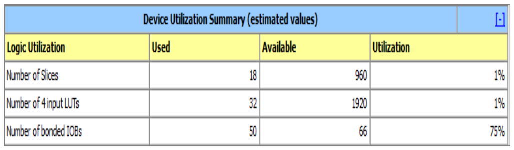
RTL Schematic:



Technology Schematic:



Design Summary:



Device Utilization Summary (estimated values)			[-]
Logic Utilization	Used	Available	Utilization
Number of Slices	18	960	1%
Number of 4 input LUTs	32	1920	1%
Number of bonded IOBs	50	66	75%

VI. CONCLUS ION

Optical computing is emerging as a feasible technology to implement reversible logic. We have proposed a new general design approach to realize alloptical reversible logic circuits using SOA based MZI switches. An all-optical reversible MNOT gate has been proposed. The optical costs of the all optical reversible 2×1 multiplexer and full adder circuits have been minimized in the proposed designs. A 4-bit full adder circuit has been also designed using this full adder circuit. New designs of All-optical reversible designs of 4×1 multiplexer, 1×4 Demultiplexer and 3to8 Decoder circuits are proposed first time.

REFERENCES

[1] Moore, Gordon. "The Future of Integrated Electronics."Fairchild Semiconductor internal publication, 1964.

[2] R. Landauer, “Irreversibility and heat generation in the computing process”, IBM Journal of Research and Development, pp. 183–191, July 1961

[3] C. H. Bennet, “Logical Reversibility of Computation”, IBM Journal of Research and Development, vol. 17, no. 6, pp. 525-532, 1973

[4] C. Taraphdara, T. Chattopadhyay, and J. Roy, “Mach-zehnder interferometer-based all-optical reversible logic gate”, Optics and Laser Technology, vol. 42, no. 2, pp. 249–259, 2010.

[5] G. K. Maity, S. P. Maity, T. Chattopadhyay and J. N. Roy, "MachZehnder Interferometer Based AllOptical Fredkin Gate", International Conference on Trends in Optics and Photonics March 1 - 4, 2009 Kolkata, India Department of Applied Optics and Photonics University of Calcutta, Kolkata, India.

[6] G. K. Maity, J. N. Roy, and S. P. Maity, “Machzehnder interferometer based all-optical peres gate”, in Advances in Computing and Communications, ser. Communications in Computer and InformationScience, A. Abraham, J. L. Mauri, J. F. Buford, J. Suzuki, and S. M. Thampi, Eds. Springer Berlin Heidelberg, 2011, vol. 192, pp. 249–258.

[7] G. K. Maity, T. Chattopadhyay, J. N. Roy, and S.P. Maity, "All-optical reversible multiplexer", Computers and Devices for Communication, 2009. CODEC 2009. 4th International Conference on , vol., no., pp.1,3, 14- 16 Dec. 2009

[8] S. Kotiyal, H. Thapliyal, and N. Ranganathan, “Mach-zehnder interferometer based design of all optical reversible binary adder”, in Design, Automation Test in Europe Conference Exhibition (DATE),2012, pp. 721 –726, March 2012.

[9] S. Kotiyal, H. Thapliyal, and N. Ranganathan, "Mach-Zehnder Interferometer Based All Optical Reversible NOR Gates", VLSI (ISVLSI), 2012 IEEE Computer Society Annual Symposium on , vol.,no., pp.207,212, 19-21 Aug. 2012 .

[10] G. K. Maity, J. N. Roy, and S.P. Maity, "Design of all-optical new gate using Mach-Zehnder interferometer", Devices, Circuits and Systems (ICDCS), 2012 International Conference on , vol., no., pp.474,478, 15- 16 March 2012

[11] G. K. Maity and S.P. Maity, "Implementation of HNG using MZI", Computing Communication & Networking Technologies (ICCCNT), 2012 Third International Conference on , vol., no., pp.1,6, 26-28 July2012.

[12] Mehdi Saeedi and Igor L. Markov, “Synthesis and Optimization of Reversible Circuits – A Survey”, arXiv: 1110.2574v2 [cs.ET], 20 Mar 2013, pp. 1-34.

[13] R. Feynman, “Quantum mechanical computers”, Optical News, vol. 11, pp. 11-20 1985.

[14] T. Toffoli, “Reversible computing”, In Automata, Languages and Programming, Springer Verlag, pp. 632-644, 1980.