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Comparison of A Single Layer Crossbar Switch using Quantum-Dot Cellular Automata For Nano Communication

Siddhi Narayan Naik
ECE Department
Usha Mittal Institute of Technology
Mumbai, India

Sankit Ramkrishna Kassa
ECE Department
Usha Mittal Institute of Technology
Mumbai, India

***Abstract*— Quantum-dot Cellular Automata (QCA) is a digital, arising, optimistic, and future generation nano communication technology that provides a low device area, high switching speed, minimum latency, high integrity, transistorless designs, etc. compared to the CMOS technology. In this paper, comparison of a various designs of a (2×2) crossbar switch which can be used as a base of any banyan network for future nano communication is done. The proposed circuit's design and its implementation are accomplished on a single layer. The simulation results show considerable improvement in terms of cell count, device area, and latency. All the proposed circuits have been designed and verified by QCA Designer 2.0.3 tool. The simulation results confirm that all the proposed designs are work well.**

***Keywords*—QCA, single layer, crossbar switch**

I. INTRODUCTION

For the last many years, CMOS technology has been used for designing low-powered, high-performance, high-speed integrated, transistor-based systems, etc. but, it is not supported very well in nanoscale designing. Also, the CMOS Technology is working beyond 10nm and has more current leakage problems [3]. Currently, we are using CMOS technology which is slowly outreaching its physical margin and has several deep-down problems. Though, new technology is imperative that can work as an alternative to CMOS technology. To overcome these problems the innumerable researchers work on this and found a solution which is called a Quantum-dot cellular automata (QCA) technology. [2].

QCA technology was established in 1993 which gives a low device area, minimum latency, minimum cell count, high switching speed, low power consumption for the nano communication [10]. It is one of the most optimistic, arising, and future generation nanotechnology for designing all types of digital circuits. QCA is a transistor less technology in that the electrons play a crucial role to perform the various logical as well as the transmitting of binary information. There is no current source that is essential in a QCA technology because it can work based on electronic charge. It decreases the information processing delay by increasing the frequency and operating speed. QCA can be allowed to the operating frequency in the range of THz [2].

QCA technology consists of an array or series of cells [9]. Each cell contains several quantum dots, each dot is a nanoparticle or a crystal particle A QCA cell particularly contains four quantum dots at the corner of a square [11]. But due to the Coulombic interaction, electrons may occupy two 'diagonally' opposite quantum dots. Because coulombs law says that the opposite electrons attract to each other and adjacent electrons ripple to each other that's why the electrons are in a diagonal position. Quantum dots are arranged in a 1 to 4 order, it shows that the electrons can occupy the dots either 1and 3 or 2 and 4. The physical interaction between the neighboring cells is used to perform numerous logic operations [2].

QCA Designer 2.0.3 is a software tool used for digital circuit designing layouts and performing simulations for QCA based circuits. QCA Designer tool allows to classifying different components of a digital design and also, permits the defining of clock zones for a circuit design. Every single circuit in the QCA is clocked [4]. A clocking system serves as a means of synchronization. There are four clocking zones in a QCA which are represented by four different colors in the QCA Designer tool such as green, magenta, blue, white. In particular, clock zone 0 is in green, clock zone 1 is in magenta, clock zone 2 is in blue, and clock zone 3 is in white [8]. For applying a different clock to a cell or an array of cells, it is necessary to select the cells and define the clock zone. Further, every logic element in the QCA circuit will be clocked [3].

II. QCA BASICS

In this section, the basics of QCA technology have been explained.

A. QCA Cell

QCA cell is the basic and most important element of QCA technology. A cell structure involves the four quantum dots which are arranged in a square as shown in fig.1

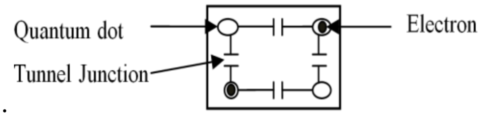

Fig. 1. QCA Cell

These electrons are conjoined by using the tunnelling barriers. The Information is transferred based on Coulombic interactions between the cells. Hence, the electrons occupy the opposite corner of a dot [10]. Therefore, the cell has two ground states which are also known as the polarization of a

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QCA cell, and it is denoted as, P = +1 and P = -1 respectively. Hence, the logic 1 and logic 0 are encoded in the polarization P= +1 and P = -1 respectively. Fig.2 shows the polarization of the cell [9].

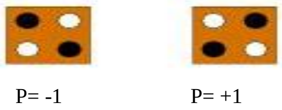

Fig. 2. Polarization of a QCA cell

B. *QCA Wire*

In a QCA wire, signals are transmitting (routing) the same information from an input port to the output port because of electrostatic interaction between the cells. Fig.3 shows that the QCA wire [9].

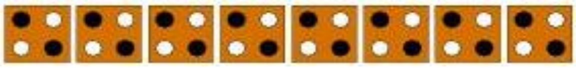

Fig. 3. QCA Wire

III. IMPLEMENTATION OF (2×2) CROSSBAR SWITCH

A (2×2) switch is also known as a crossbar switch. It is a logical switch that consists of a cross-like pattern between the input and output of the digital circuit [2]. In this crossbar switch, any input can be connected or communicate to any output. It consists of many inputs and many outputs. The crossbar switch can be used as a base of any banyan network. In a crossbar switch, communication is done only with the help of a selection input or control inputs. [5].

Fig.4 a, b shows that the (2×2) crossbar switch [2]. Fig.4a shows the block diagram of the (2×2) crossbar switch. In that, there are two inputs X_1, X_2, two outputs Y_1, Y_2, and have one selection input S_0. It shows that X_1 and X_2 are communicating with both the outputs (Y_1 and Y_2). Fig.4b shows that the circuit design of a (2×2) crossbar switch. In that (2×2) crossbar switch is designed by using the 2:1 multiplexer. It required two 2:1 multiplexers to design this crossbar switch [6].

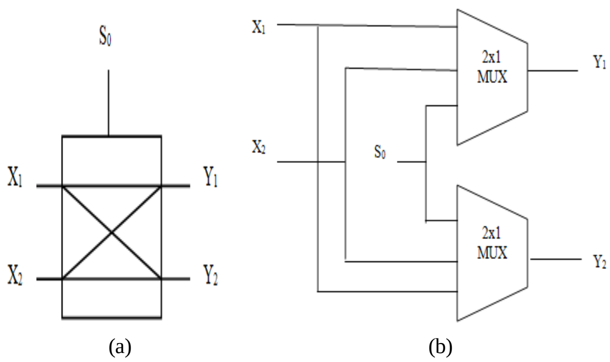

Fig. 4. Crossbar switch a) block diagram b) Circuit design

In the (2x2) crossbar switch, communication is done by using the control input i.e. S_0 which is illustrated through the conditions such as [7]

$$X_1 = Y_1, \text{ if } S_0 = 0 \quad (1)$$

$$X_2 = Y_2, \text{ if } S_0 = 0 \quad (2)$$

$$X_1 = Y_2, \text{ if } S_0 = 1 \quad (3)$$

$$X_2 = Y_1, \text{ if } S_0 = 1 \quad (4)$$

The truth table of this crossbar switch is shown in table I [2].

TABLE I. TRUTH TABLE OF 2×2 CROSSBAR SWITCH

inputs			outputs	
Control input S_0	X_1	X_2	Y_1	Y_2
0	0	0	0	0
0	0	1	0	1
0	1	0	1	0
0	1	1	1	1
1	0	0	0	0
1	0	1	1	0
1	1	0	0	1
1	1	1	1	1

According to Table I, there are two output equations such as

$$Y_1 = X_1\overline{S_0} + X_2S_0 \quad (5)$$

$$Y_2 = X_2\overline{S_0} + X_1S_0. \quad (6)$$

Each equation of this crossbar switch is equal to the 2:1MUX. Equation (5) is equal to the first output Y_1 and equation (6) is equal to the second output Y_2 [2].

IV. PROPOSED DESIGNS

In this section, the various proposed designs of a 2x2 crossbar switch have been explained. These proposed designs are comparing with already existing designs [1], [2].

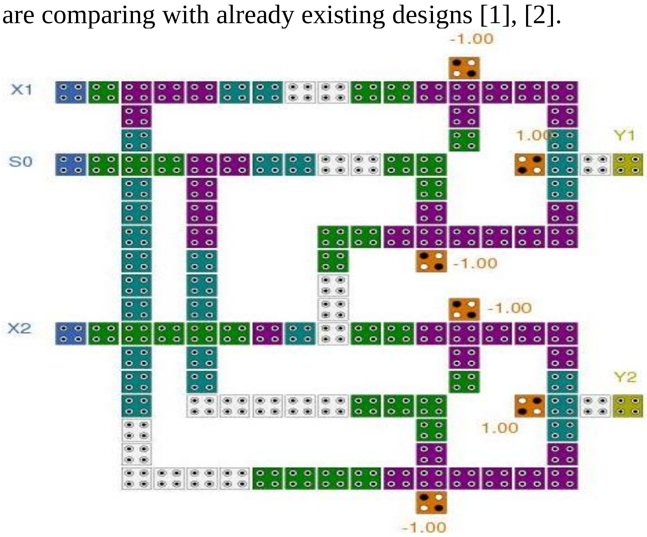

Fig. 5. (2×2) crossbar switch as shown in [1]

The fig.5. Shows the QCA layout design of a (2×2) crossbar switch which is taken from [1]. The design comprised 6 majority and 2 inverter gates. A total of 123 cells are used to make this design. Simulated results of the above design shown in table II.

TABLE II. SIMULATED RESULT OF [1]

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Ref [1]	123	0.137	2

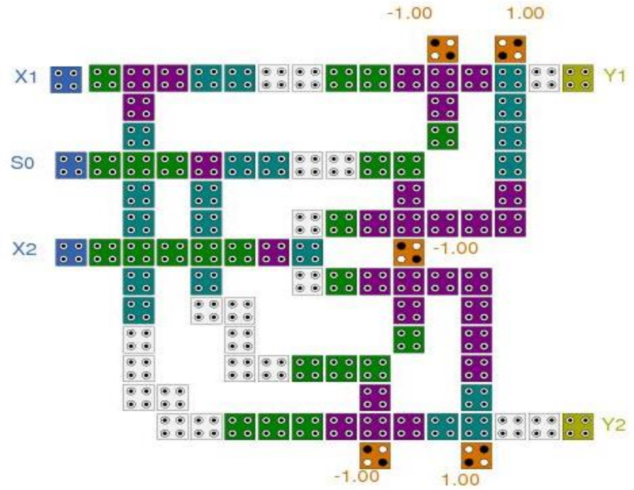

Fig. 6. (2×2) crossbar switch as shown in [2]

Fig. 6 shows the QCA layout design of a 2×2 crossbar switch which is taken from [2]. The design comprised 6 majority and 2 inverter gates. A total of 101 cells are used to make this design. Simulated results of the above design show in table III.

TABLE III. SIMULATED RESULT OF [2]

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Ref [2]	101	0.096	2

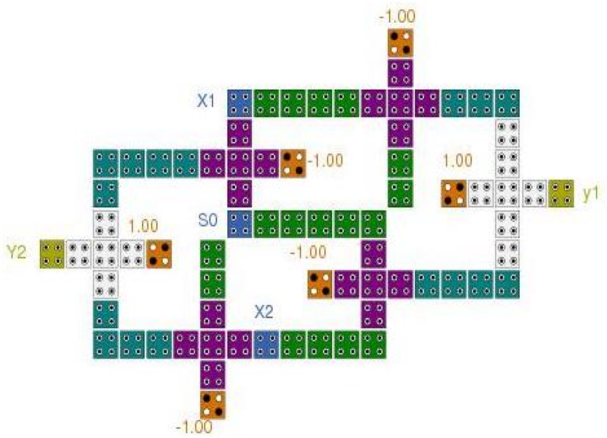

Fig. 7. proposed design 1

Fig.7 shows the proposed design no.1 of a 2×2 crossbar switch. The design comprised 6 majority and 2 inverter gates. A total of 76 cells are used to make this design. Simulated results of the above design show in table IV.

TABLE IV. SIMULATED RESULT OF DESIGN 1

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Design 1	76	0.13	1

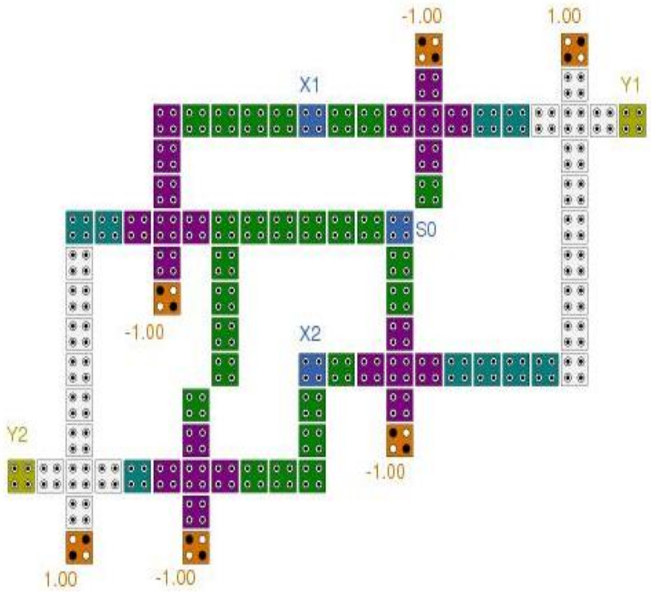

Fig. 8. proposed design 2

Fig.8 shows the proposed design no.2 of a 2×2 crossbar switch. The design comprises 6 majority and 2 inverter gates. A total of 89 cells are used to make this design. Simulated results of the above design show in table V.

TABLE V. SIMULATED RESULT OF DESIGN 2

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Design 2	89	0.14	1

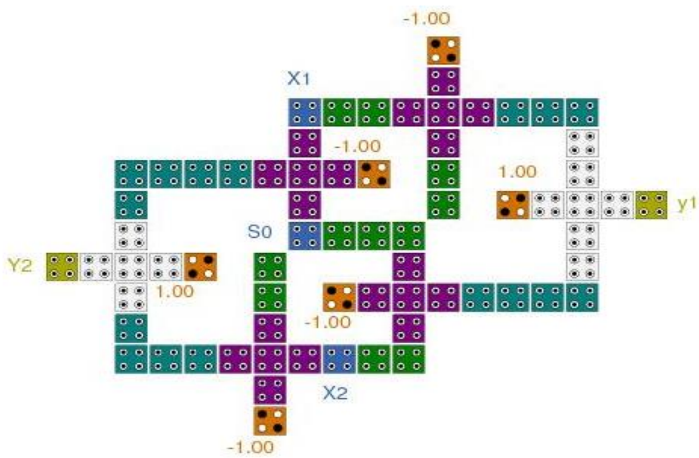

Fig. 9. proposed design 3

Fig.9 shows the proposed design no.3 of a 2×2 crossbar switch. The design comprises 6 majority and 2 inverter gates. A total of 70 cells are used to make this design. Simulated results of the above design show in table VI.

TABLE VI. SIMULATED RESULT OF DESIGN 3

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Design 3	70	0.12	1

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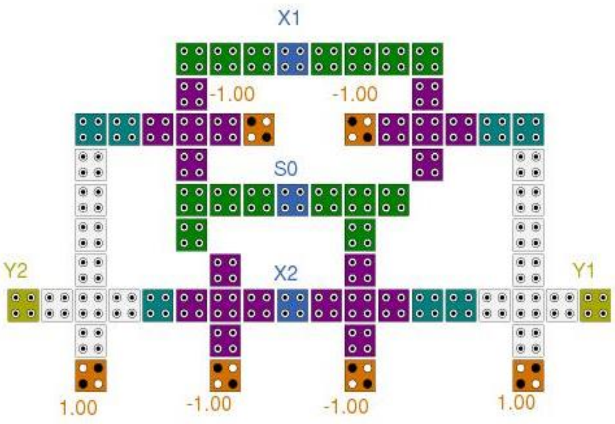

Fig. 10. proposed design 4

Fig.10 shows the proposed design no.4 of a 2×2 crossbar switch. The design comprises 6 majority and 2 inverter gates. A total of 69 cells are used to make this design. Simulated results of the above design show in table VII.

TABLE VII. SIMULATED RESULT OF DESIGN 4

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Design 4	69	0.09	1

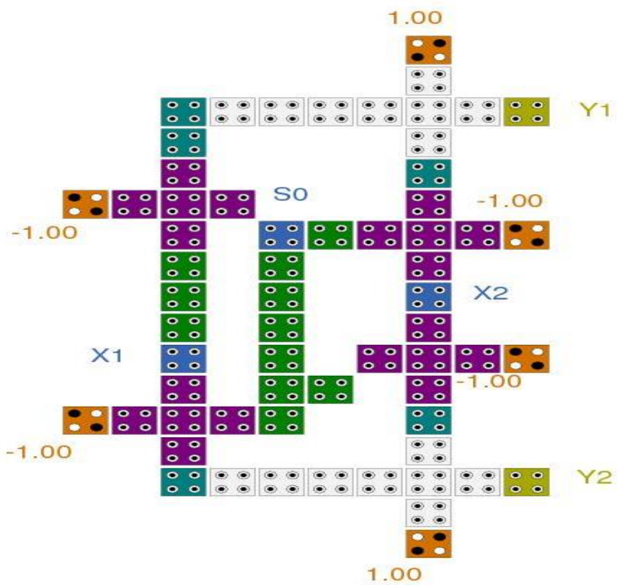

Fig. 11. proposed design 5

Fig.11 shows the proposed design no.5 of a 2×2 crossbar switch. The design comprises 6 majority and 2 inverter gates. A total of 63 cells are used to make this design. Simulated results of the above design show in table VIII.

TABLE VIII. SIMULATED RESULT OF DESIGN 5

QCA Design	Cell count	Area (μm^2)	Delay (nS)
Design 5	69	0.08	1

V. GRAPHICAL RESULTS

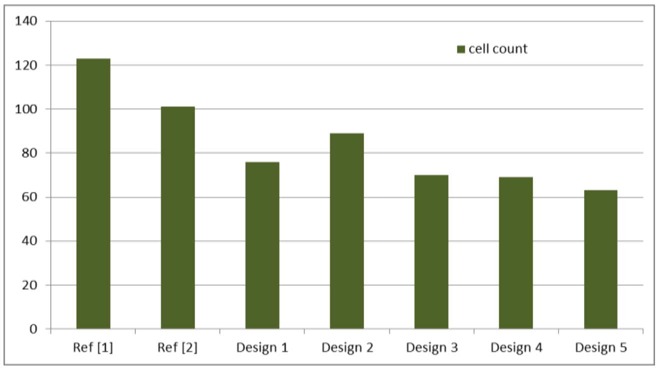

Fig. 12. Cell count of proposed designs

Fig.12 shows the graphical result of the proposed designs in terms of total cell count. It shows that design no.5 has comprised minimum cells compared to the other designs.

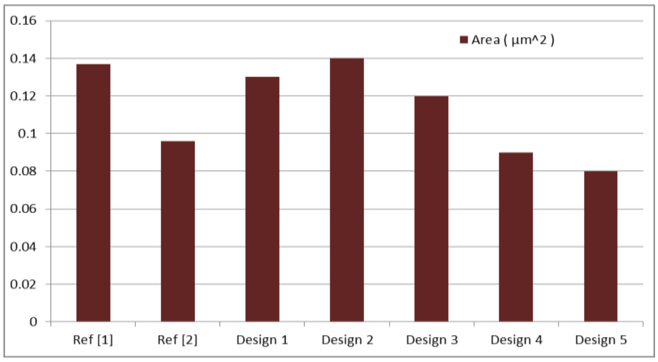

Fig. 13. Area of proposed designs

Fig.13 shows the graphical result of the proposed designs in terms of a total Area. It shows that design no.5 consumed very less area compared to the other designs.

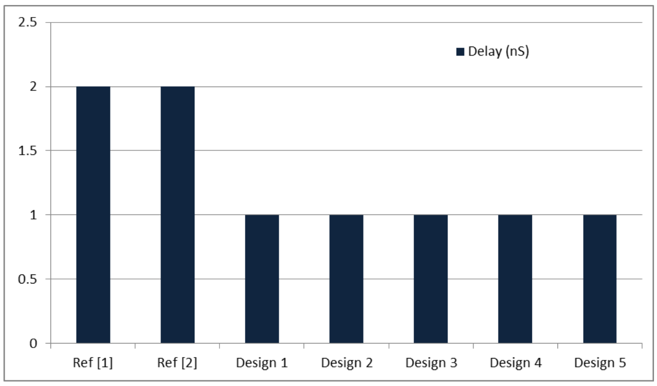

Fig. 14. Delay of proposed designs

Fig.14 shows the graphical results of the proposed designs in terms of the delay of the circuit. It shows that except for reference designs, all the proposed designs have the same delay. The overall analysis of all the designs has been illustrated in Table IX.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 04, April-2021

TABLE IX. ANALYSIS OF PROPOSED DESIGNS

Proposed Designs	Cell count	Area (μm^2)	Delay (nS)
Ref [1]	123	0.137	2
Ref [2]	101	0.096	2
Design 1	76	0.13	1
Design 2	89	0.14	1
Design 3	70	0.12	1
Design 4	69	0.09	1
Design 5	63	0.08	1

Table IX gives the overall analysis of all the proposed designs. It shows that Out of all the circuits, Design no. 5 has comprised minimum cells (63). It consumed less area (0.08 µm2) with only 1nS delay. Design no.5 has a 51.21% reduction in the cell count, 58.39% reduction in the area, and 50% delay other designs is reduced compared to the other designs. Therefore, the best results have been achieved in design no.5.

VI. CONCLUSION

In this paper, various designs of the (2x2) Crossbar switch are implemented, and their simulated results are proved that all designs have been work very well. All the proposed designs of a (2×2) crossbar switch can be used as a base of any banyan network. In this paper, the best results have been achieved in design no.5 compared to other designs, which can be used as a base design for future nano communication. The proposed designs have been tested and simulated using the QCA Designer version 2.0.3. The comparison result shows that design no.5 has a reduction in the number of QCA cells, area, and delays. Also, it has much scope in the research field.

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