Novel Design of High Polarized Inverter Using Minimum Number of Rotated Cells and Related Kink Energy Calculation in Quantum dot Cellular Automata

Angshuman Khan, Ratna Chakrabarty

Abstract— ***Quantum Dot Cellular Automata (QCA) has been emerged as a cut-in nano-technology in the field of digital logic architecture. It is the most emerging technology in nanoscience. QCA designed circuits require lesser power & it has high switching speed and high packaging density with respect to current CMOS technology. One of the basic building blocks of QCA circuits is QCA inverter. The conventional QCA inverters require more normal cells and it has less polarization. In this paper, we have designed high polarized inverters using minimum number of rotated (45˚) QCA cells. Till now, the conventional inverters which have large polarization, they require three to five normal cells. We have designed the novel inverter using three rotated cells whose polarization is more than the conventional three normal cells inverter. We increasing the polarization i.e. make the three rotated cells inverter circuit more fault- free by adding extra rotated cells at the output section. In each case, the designed rotated cells inverters have more polarization (i.e. more fault free) than conventional inverters though it has same number of cells. Our finally designed high polarized rotated cells inverter has five cells and its polarization is greater than any type of conventional inverters designed till now. Also, here we calculate the kink energy of each rotated cells inverters.***

Keywords— ***Kink energy, Majority gate, Polarization, QCA.***

I. INTRODUCTION

Quantum dot Cellular Automata (QCA) is an emerging technology in nano-science which offers a revolutionary approach at nano level computations [1]. It is a very important innovative technology at nano-scale. QCA has been discovered as one of the top six emanating technology [2]-[7]. QCA technology is famous to design general purpose computational circuits and memory circuits as well as all important digital circuits [8]-[11]. In 1993, Lent et al., first proposed the concept of QCA and it is experimentally verified in 1997. With respect to the most popular CMOS technology, QCA technology has high packaging density, high switching speed and low power requirements.

The majority gate, inverter and wire, this three are the fundamental building blocks of QCA circuits [14]-[18]. There are many designs of QCA inverter using standard QCA cells (90˚). The disadvantages of these circuits are that sometimes it requires more cells or sometimes it has less polarization. There is a popular design of high polarized QCA inverter using three to five standard cells [12]. In this paper, we design an inverter circuit using three rotated (45˚) QCA cells; whose polarization exceeds all the pre developed three standard cells QCA inverters. To make the implemented rotated cells QCA inverter circuit more fault free i.e. to increase the polarization much more, we manually insert cells at the output section of QCA inverter and find out their corresponding kink energy. Our final inverter circuit has five rotated cells and its polarization is greater than any types of inverters designed till now. To perform the defect characterization of QCA circuits and to study their behavior at logic level, a simulation tool is important. To study the change of polarization of the inverter circuits, here we have used QCA Designer tool [13].

This paper organized as follows. In section II, we provide a little background of QCA technology. Our proposed QCA inverter design using rotated cells is described in section III. Section IV reflects the fault free QCA inverter design process. In section III and section IV, we also provide the values of calculated kink energies of the inverters. Finally, we conclude this paper in section V.

Manuscript received on March, 2013.

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II. BACKGROUND MATERIAL

A. QCA Physics

The QCA technology is standing on the QCA cells which has four quantum dots. This four quantum dots of a QCA cell, located at corner position with two extra mobile electrons. An individual QCA cell has three states: a null state and two polarized state. A null state, as shown in Fig. 1(a), occurs when the potential barriers become lowered with the two mobile electrons are free to localize on any dot in the cell. The other two states are polarization states which occur when the barrier is raised, and provide the minimum the energy state of the cell. These two arrangements of polarizations are denoted as cell polarization P = +1 (binary '1') and P = -1(binary '0'). Again each QCA cell has two possible orientations: 90˚ and 45˚, as shown in Fig. 1(b). In each polarization state, electrons tend to capture the opposite locations for their mutual electrostatic repulsion [3].

B. Elementary Logic Primitives of QCA

The basic three building blocks of QCA logic devices include a QCA wire, QCA inverter, and QCA majority gate [14]-[18]. *QCA Wire:* A QCA wire is an arrangement of QCA cells on a line. The wire is driven at the input cell by a fixed (held) polarized cell [19].The two types of QCA wire: 90˚ QCA wire and 45˚ QCA wire are shown in Fig. 2(a) and Fig. 2(b), respectively.

QCA Inverter: The diagram of a conventional QCA inverter circuit and a high polarized QCA inverter circuit according to [12] is shown in Fig. 3(a) and Fig. 3(b), respectively. Fig. 3(c) shows the fault free inverter using normal cells, where 'a' is input and 'b' is the output, according to [12].

QCA Majority Gate: The logic function of a majority gate is

M (A, B, C) = AB + BC + CA (1)

Where, A, B, and C are arbitrary inputs. Generally, majority gate is a three inputs logic function as shown in Fig.4. By keeping the polarization of any input of the majority gate as logic '1' or logic '0', an AND gate or OR gate will be obtained like:

M (A, B, 0) = AB (2a)

M (A, B, 1) = A+B (2b)

Not only three inputs, it is also possible to design 'n' inputs majority gate [20]-[21] using threshold logic.

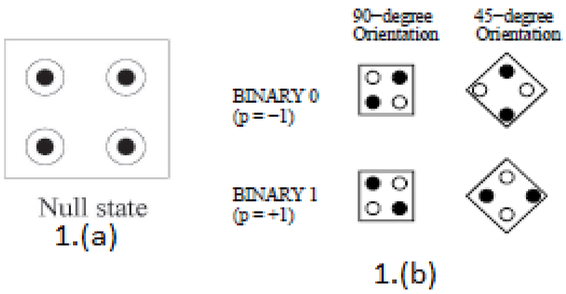

Figure 1. (a) Null state of cell, (b) Polarized state of cell

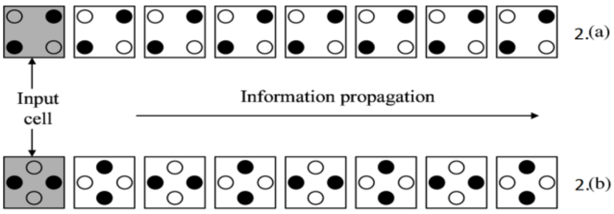

Figure 2. (a) 90˚ wire, (b) 45˚ wire

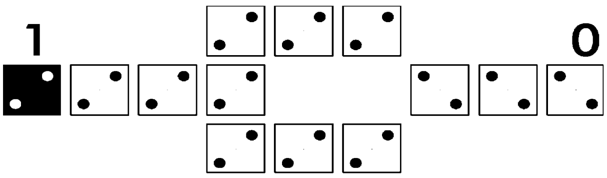

Figure 3. (a) Conventional QCA inverter

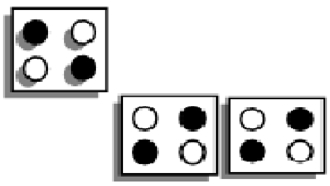

Figure 3. (b) High polarized QCA inverter according to [12]

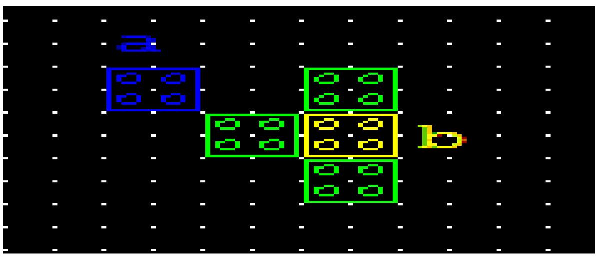

Figure 3. (c) Fault free inverter according to [12]

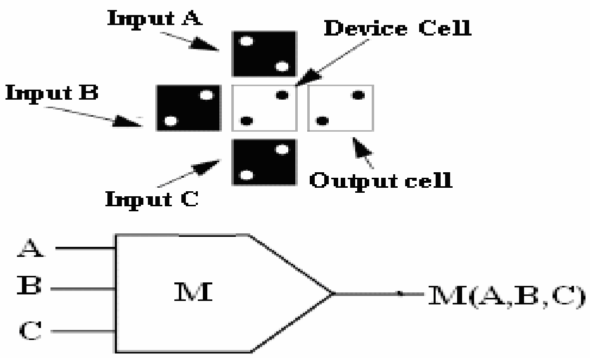

Figure 4.QCA majority gate

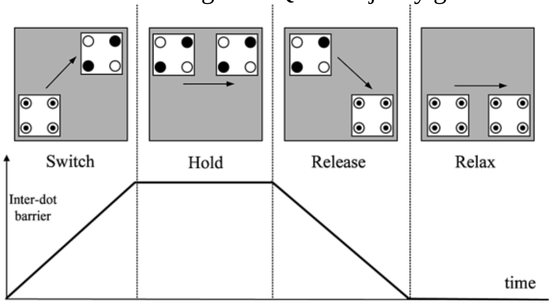

Figure 5. QCA clocking

C. *QCA Clocking scheme*

Multi phased clocking mechanism is used in the QCA circuit for information flow. The signal flows in a QCA circuit is completely controlled by clocks. So a clock plays an important role in the QCA circuit.QCA circuit areas are divided into four clocking zones, named Switch, Hold ,Release and Relax [3],[22] as shown in Fig. 5. In switch phase the actual computation occurs according to the given input. During the Switch phase, the inter-dot barriers are slowly raised and the QCA cells become polarized according to the state of their drivers (that is, their input cells).The output of this state can be used as the inputs to the next state. During the Hold phase, the inter-dot barriers are kept high and the QCA cells retain their present states. In the Release phase, the barriers are lowered and the cells are allowed to relax to an un-polarized state. Lastly, in the Relax phase, the barriers are kept low and the cells remain un-polarized. As shown in Fig. 5, always there is a 90 phase shift from one clock zone to the next. In each clock zone, the clock signal has four states, named: high-to-low, low, low-to-high, and high.

D. *Kink Energy*

The electrostatic interaction occurs between two QCA cells [12],[23] and it is given by

$$E = \frac{1}{4\pi\epsilon_0\epsilon_r}\cdot\frac{Q_1Q_2}{r} = k.\frac{Q_1Q_2}{r} \quad (3)$$

Where, the value of 'k' is 9×10^{-9}. As Q_1 and Q_2 are charges of electron. So, the figure of 'E' becomes,

$$E = \frac{23.04\times10^{-29}}{r} J \quad (4)$$

This electrostatic interaction determines the Kink energy between two cells. Thus, Kink energy is defined as,

$$E_{kink} = E_{opp.polarization} - E_{same\ polarization} \quad (5)$$

A point to be remember, the kink energy between two QCA cells only depends on the dimensions of the QCA cells and the spacing between the cells but it does not depend upon the temperature [24], [25].

III. QCA INVERTER DESIGN USING ROTATED CELLS

The conventional QCA inverters are designed using common or standard QCA cells (90˚).It has less polarization, as well as it takes large number of cells. Though it is possible to design an inverter using two cells but its polarization becomes very low. There is another QCA inverter using three to five common cells whose polarizations are higher than other conventional inverters [12], but it is not up to the mark. So, we have to design an inverter using less number of cells, as well as the polarization will be much high. For this purpose, we choose the rotated QCA cells. In this paper, we design a high polarized inverter using three rotated cells and make it faults free by adding extra cells up to five.

This paper represents the design of a high polarized QCA inverter using three rotated (45˚) QCA cells as shown in Fig. 6(a). Fig. 6(a) shows the inverter circuit in QCADesigner tool, where 'A' is the input and 'B' is the output of the inverter, and all cells are rotated cells. Fig. 6(b) shows the simulated output of the inverter for an arbitrary input in QCADesigner tool. The polarization from the simulation is found to be ± 9.76e^{-001} ,which is greater than the any conventional three normal cells inverters.

The calculated kink energy for the inverter circuit shown in Fig. 6(a) is 6.866 x10^{-20} J.

We know, the fault free inverter circuit has the polarization ± 10.00e^{-001}. So, the inverter circuit shown in Fig. 6(a) is faulty one. We have to increase the polarization to make the inverter fault free.

IV. FAULT FREE QCA INVERTER DESIGN

To minimize the fault of the inverter i.e. to increase the polarization of the inverter shown in Fig. 6(a), one extra rotated cell is added with the output cell to make the inverter more fault free. Fig. 7(a) shows this inverter circuit with four rotated cells and corresponding simulated output is shown in Fig. 7(b). It is seen that the polarization becomes ± 9.94e^{-001} , which proves that the inverter is almost fault free.

The kink energy for the inverter circuit shown in Fig. 7(a), is 11.626x10^{-20} J.

Though, the inverter circuit shown in Fig. 7(a) is almost fault free, but we can try to make the inverter more faults free, i.e., try increase the polarization furthermore. Fig. 8 (a) shows the inverter, after addition of two extra cells with the output cell of the faulty inverter shown in Fig. 6(a). The polarization in the simulated output shown in Fig.8 (b) becomes ± 9.97e^{-001} .

The calculated kink energy for the inverter circuit shown in Fig.8 (a) is 16.386x10^{-20} J.

So, the inverter shown in Fig.8 (a) is more faults free than other designed inverters.

To increase the polarization i.e. to make the inverter circuit shown in Fig.8 (a), faults free furthermore, we have added three extra cells at the output of the faulty inverter shown in Fig. 6(a). But the polarization remains same as the polarization of inverter circuit shown in Fig. 8(a), and the calculated kink energy is 18.982x10^{-20} J.

So, the inverter circuit shown in Fig.8 (a) is the final, almost fault free circuit.

The kink energy & the polarization of the above discussed inverter circuits are shown in tabular form in the TABLE I. Here the kink energy as well as the polarization is increases with the number of rotated cells, where the initial inverter circuit consist of three rotated cells. However the polarization is not further increased with addition of more number of rotated cells. So, the inverter shown in Fig.8 (a) is our final desired design.

The plot of kink energy vs. number of rotated cells and Maximum polarization vs. number of rotated cells are shown in Fig. 10 and Fig. 11 respectively.

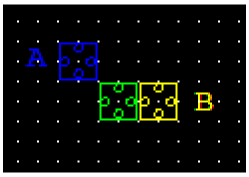

Figure 6. (a) Implemented high polarized inverter

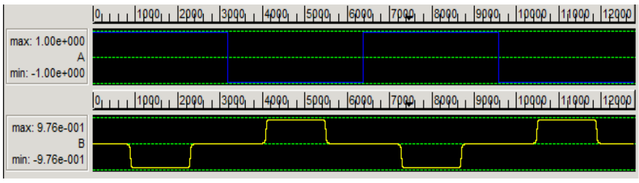

Figure 6. (b) Simulated output of the inverter shown in Fig.6(a)

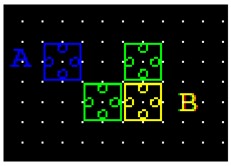

Figure 7. (a) Less faulty inverter using four rotated cells

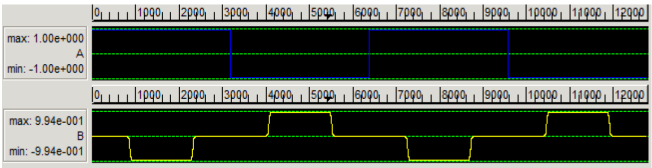

Figure 7. (b) Simulated output of the inverter shown in Fig. 7(a)

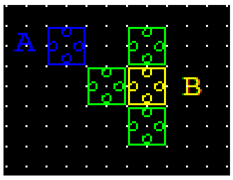

Figure 8. (a) Less faulty inverter using four rotated cells

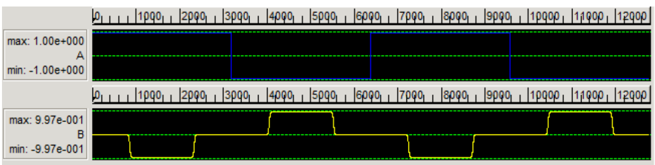

Figure 8. (b) Simulated output of the inverter shown in Fig. 8(a)

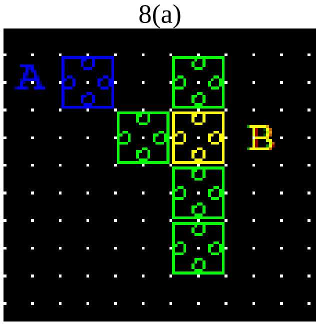

Figure 9. (a) Less faulty inverter using five rotated cells

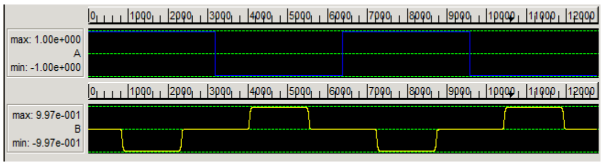

Figure 9. (b) Simulated output of the inverter shown in Fig. 9(a)

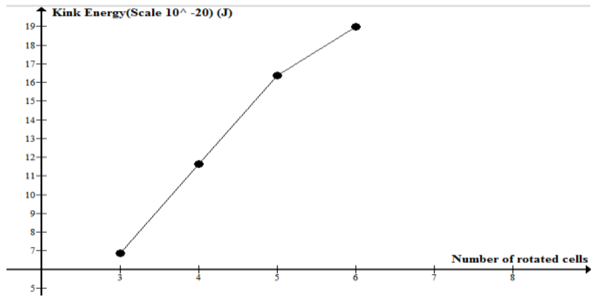

Figure 10. Plot of Kink energy vs. Number of rotated cells

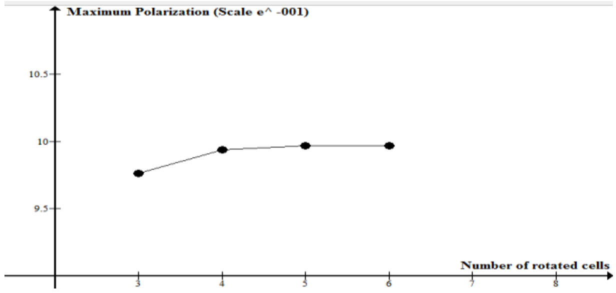

Figure 11. Plot of Maximum polarization vs. Number of rotated cells

TABLE I. Inverters at a glance

Sl.. No.	*No. of rotated cells*	*Kink energy(J)*	*Polarization*
1.	3	$6.866\ x10^{-20}$	$\pm 9.76e^{-001}$
2.	4	$11.626x10^{-20}$	$\pm 9.94e^{-001}$
3.	5	$16.386x10^{-20}$	$\pm 9.97e^{-001}$
4.	6	$18.982x10^{-20}$	$\pm 9.97e^{-001}$

V. CONCLUSION

From the above results it is concluded that, the QCA inverters can be constructed using rotated cells instead of normal cells. The polarization of a rotated cells inverter is always greater than that of a normal or standard cells inverter. Here, inverter is constructed using only three rotated cells which require less area than the conventional inverters consist of more normal cells. Again for the same number of cells, the rotated cells inverters have greater polarization than the normal cells inverters. It is possible to design an inverter using two rotated cells but polarization becomes very less for that kind of design, i.e. the two rotated cells inverter have much more faults. To make our designed three rotated cells inverter faults free, i.e. to increase the polarization, it is required to add cells at the output section of the circuit. Our final less faulty, high polarized inverter consists of five rotated cells. By adding more cells in the output of a five rotated cells inverter cannot change the polarization at all. So, the five rotated cells inverter is our desired less faulty inverter. The kink energy is increased with the increase of the number of cells in the inverter. The polarization is constant after five rotated cells. So, a QCA inverter can be made with five rotated cells with minimum fault.

In the applications of any QCA circuits, where it required to using inverters, we can use our designed high polarized inverter instead of conventional inverters to get better response and a strong output.

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