Design of Ring and Johnson Counter in a Single Reconfigurable Logic Circuit in Quantum Dot Cellular Automata

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Abstract
Quantum Dot Cellular Automata (QCA) is an emerging nanotechnology in the field of nanoscience for the low power consumption and high speed of operational phenomenon. Such type of circuit can be used in many digital applications in sequential and combinational mode of operation, where we are restricted to use different circuits for different digital logic and applications. Reconfigurable QCA mean one circuit can be used for different outputs. Reconfigurable hardware using FPGA are used by different technologist for some digital applications. But FPGA has some limitations in different type of applications such as it has limited size and least efficient use in wire connections. Using QCA a Reconfigurable counter is a new and a novel idea in the field of Nano electronics. In this paper the two most important counters Ring and Johnson counter are designed in the same circuit using QCA and the corresponding simulations are shown with the help of QCA Designer tool. The circuit acts as a Ring counter when the control logic is ‘1000’ and acts as a Johnson counter when the control logic is ‘0111’. So, a single QCA circuit have the twin digital logics with the help of a control signal.

Keywords
QCA, Majority Gate, Reconfigurable, Kink Energy

I. Introduction
Quantum dot Cellular Automata (QCA) is a nanotechnology which has been recognized as one of the top six emerging technologies [1]-[6]. Several researches have reported that QCA can be used to design general purpose digital circuits, computational circuits and memory circuits [7-10]. The concepts of QCA first proposed by Lent et al. in 1993, and it is experimentally verified in 1997. The QCA can achieve high device density, extremely low power requirements, and very high switching speed. The basic building blocks of QCA are the majority gate, inverter and wire. As two logic states are established in QCA, it is easy to implement many digital circuits in this technology. It is possible to implement the well known sequential counters named Ring and Johnson counter in QCA [23]. In many technological applications area, it is impossible to implement different circuits for different logics in a single chip due to area or other reasons. In that case it is very helpful to implement different logics in a single circuit. These circuits are well known as “Reconfigurable circuits”, which can reduce the consumption of extra hardware and decreases the expenses of designing. In this paper, we implement a reconfigurable Sequential Counter circuit, where a single circuit has been operated in two different modes of counter applications, first the Ring counter and second the Johnson counter, with the help of set or control input. We also calculate here the kink energies of the output portions of the circuit in two different modes separately for checking the stability of the operation. This paper is organized as follows. In section II, we provide a little background to QCA technology. The Section III is for motivation. Section IV is a short idea about digital reconfigurable counter. Section V is the brief idea of Reconfigurable Counter circuit in QCA. Section VI if for scalability of the reconfigurable circuit, Section VII, describes the calculation of the kink energy of the circuit. Section VIII is the Conclusion of the Reconfigurable Circuit.

II. Background of QCA

A. QCA Basics
QCA technology is based on the interaction of QCA cells, which has four quantum dots. The cells are charged with two free electrons, which are able to tunnel between adjacent dots and the electrons are tend to occupy the corner position of the cells due to mutual electrostatic repulsion established by Coulomb law. Thus, there exist two arrangements of QCA cells with minimal energies. These two arrangements are denoted as polarization P = +1 and polarization P = -1. The cell polarization P = +1 represents logic “1” and the cell polarization P = -1 represents logic “0”. Fig. 1 shows the diagram of QCA cells.

B. QCA Logic Primitives
The basic logic primitives of QCA include QCA wire, QCA inverter, and QCA majority gate [14]-[17], are described as below.

QCA Wire: QCA wire is formed by placing cells side by side, in QCA wire, the binary signal propagates from one cell to the next cell due to electrostatic interactions between the QCA cells, and hence polarization is enforced to each other. So by properly arranging the wire combination it is possible to implement any Combinational digital circuit by this new nanotechnology which is well known as QCA. Fig. 2 shows the diagram of a QCA wire.

QCA Inverter: The layout of a conventional inverter circuit is shown in Fig. 3(a), figure 3(b) shows the inverter designed by R. Chakrabarty et al [20], which requires less number of cells and area for QCA operation.

QCA Majority Gate: The QCA majority gate generally a three input logic function. For three inputs A, B, and C, the logic function of the majority gate is,

\[ M(A,B,C) = AB + BC + CA \]  

The layout of a majority gate is shown in fig. 4.

By fixing 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:

\[ M(A,B,0) = AB \]  

\[ M(A,B,1) = A + B \]  

Not only the three inputs majority gates, a study is going on the implementation of the ‘n’ inputs majority logic function [18-19] using threshold logic.

C. QCA Clocking
The information flows in a QCA circuit is controlled by the clock signal which is the main power supplied to the QCA circuit for the propagation of the logical signals. While designing a QCA circuit the areas are organized into four clocking zones, named Switch, Hold, Release and Relax phase [11-12] as shown in...
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). During the Hold phase, the inter-dot barriers are kept high and the QCA cells retain their 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, there is a 90 phase shift from one clock zone to the next. In each clock zone, the clock signal has four states: high-to-low, low, low-to-high, and high.

**Kink Energy**

Polarization in QCA is defined as

\[
P = \frac{(q_1+q_2)-(q_1+q_3)}{q_1+q_2+q_3+q_4}
\]

The electrostatic interaction between two QCA cells [20-21] is given by

\[
E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q_1 Q_2}{r} = k \cdot \frac{Q_1 Q_2}{r}
\]

(3)

The value of ‘k’ is \(9 \times 10^{-9}\). As Q1 and Q2 are electronic charges.

So, ‘E’ is defined as,

\[
E = \frac{2.04 \times 10^{-29}}{r}
\]

(4)

This interaction determines the Kink energy between two cells. Thus,

\[
E_{\text{Kink}} = E_{\text{opp polarization}} - E_{\text{same polarization}}
\]

(5)

Kink energy between two cells depends on the dimensions of the QCA cells and the spacing between the cells but it does not depend upon the temperature [13, 22].
where Fig. 8 is the results when the circuit is operated as a Ring counter mode and Fig. 9 is the results for Johnson or Shift counter mode of operation. The design consists of 170 QCA cells and covered area is 249724.00 nm2 or 0.25 um2 for four output operation. Figure. 12 show the flow chart of the reconfigurable counter Ring and Johnson counter.

VI. Scalability of the Reconfigurable Circuit

In this section we had checked that the Reconfigurable counter is also operable for more than four outputs or less than four outputs. Fig. 10(a) shows the five outputs of the Ring counter and figure 10(b) shows the five outputs of the Johnson counter. We can design n numbers of output as per application or requirement from this basic four output reconfigurable counter circuit. In every design only one more complete clock cycle is required to get the additional output which signifies that one more Flip Flop we are adding in the design and accordingly the set or control input is calculated, it will be always 100...00 for Ring counter mode of operation and 011...11 for Johnson or shift counter mode of operation. Every output is taken in clock four, only the first output for every design is taken in first clock cycle. There is no significant delay in the circuit operation. Figure 13 shows the n output Reconfigurable Counter circuit for the two mode of operation. The cell count of the design can be formulated as follows

Cell count = 150 + 20(n-4), where n is the number of output. So there is a linear relationship between the number of output and the cell count.

VII. Calculation Of Kink Energy

In this section we calculate the Kink energy of the output section of the Reconfigurable Counter shown in fig. 11. As the total effect of the circuit is reflected on the output section, so, we consider only the output portion for calculation of the energies. Here, QA=Q1, QB=Q2, QC=Q3 and QD=Q4. The energies are same for any mode of the circuit. For the any mode the calculated energy of the output section is 10.823×10⁻²⁰ J. Kink energy is calculated taking the neighboring cells considering the radius of effect of the cells towards the target cell.
Counter plays an important role in the design of any memory circuit. In this paper we have developed a novel Reconfigurable Ring and Johnson/Shift Counter in a single circuit by applying QCA technology. The circuit has very important role in the implementations where space is a critical point for designing purposes. The circuit can be used in n number of outputs by suitable adjustment of the clock signals. The circuit has higher reliability and lead to the architectural innovation. Calculation of the kink energy shows the stability of the circuit, the output energy remain same for every four or five or n number of outputs of the two mode of operation.

**References**


International Conference at Institute of Engineering & Management, IEMCON 2011.

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