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A study on energy optimized 4 dot 2 electron two dimensional quantum dot cellular automata logical reversible flip-flops

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ABSTRACT

In the present scope, new design methodologies for reversible flip flops are proposed and the results are analyzed by the QCADesigner tool. To the best of our knowledge such methodologies are reported for the first time in the literature. In this paper, we provide few formalisms also. The first one is for the system energy derived using Hamiltonian paradigm and provides internal energy of cell electrons. The second formalism provides the minimum energy requirement for execution of a QCA architecture. This procedure reduces wastage of clock energy. Two very interesting parameters are identified playing crucial role in this context: (i) The electron quantum number n which indicates quantum energy level and (ii) intermediate quantum number for an electron lying between 1 and $(n-1)$. It is established that the incident energy frequency is directly proportional to the number of cells and quadratic function of electron quantum number and intermediate quantum number. The dissipated energy frequency is also directly proportional to the product of number of cells and quadratic function of electron quantum number. This paper, reports some remarkable results. The relaxation time is observed being inversely proportional to the product of number of cells in the architecture and quadratic function of quantum number as well as intermediate quantum number. Apart from these, differential frequency is found directly proportional to the number of cells in the architecture and quadratic function of intermediate quantum number. Few major observations are also indicated: (i) There is always a probability of reflection even if the system energy exceeds barrier energy. (ii) On the contrary, there is always a probability of transmission even though system energy is dominated by the barrier energy.

1. Introduction

CMOS technology has consistently ruled the VLSI technological field, because it works at high speed and consumes low power. The International Technology Road map for Semiconductor (ITRS) [1] had a prediction about some of the limitations of CMOS technology while to be integrated at nano level. It has also been predicted that, because of these limitations this technology is about to saturate within next few years. Naturally, there is an all pervading effort to achieve an efficient alternative to CMOS. Quantum Dot Cellular Automata (QCA) has all the technical ingredients to replace CMOS technology in days to come. QCA deals with binary information. The information is coded according to the antipodal arrangement of electrons within square cells [2–4]. QCA has the potential that any digital model can be converted into its QCA counterpart. There is no movement of electrons between the cells and is confined within cells instead. As a result, no electron flow and hence no power dissipation due to electron flow takes place. Accordingly, this paradigm has the advantage of very low power generation and consumption. In this paper, logical reversibility of various flip flops (*S*–*R*, *J*–*K*, *D* and T) is thoroughly studied and analyzed. To the best of our knowledge, there is hardly any reporting on reversible 2D 4 Dot 2 electron QCA circuit for flip flops. Accordingly, there is practically no scope of comparison with existing works in this respect. One study [5] focuses on the dynamism of confined electrons within cell channels. This paper presents the general derivation of system energy electrons within cells. In fact, our main interest here is to determine the exact clock energy required to function a reversible flip flop architecture unit consisting of N number of cells. This results in reduction of wastage of clock energy. To the best of our knowledge this effort happens to be unique in this respect. There are few existing works on the analysis of energy and power of QCA architecture. Blair et al. [5] presented heuristic model based on cell–cell interactions. Timler et al. [6] offered theoretical approach for the analysis of QCA power and energy based on density matrix formalism. It has discussed the approach to analyze the energy flow within QCA

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architecture and also discussed about the energy relaxation time. However, it is devoid of any derivation and analysis. In this paper, we start with developing a formalism regarding the system energy. It is the internal energy of electrons within channels. If the system energy is high enough to surpass the channel barrier, then the electron should have a flow as per the classical formulation. But quantum mechanically, even if the system energy exceeds the barrier energy, there is a probability of reflection. On the other hand, if system energy is less than the barrier energy, there is a probability of transmission. Basically, this paper proposes a methodology of regulating the clock signal to achieve minimum wastage of energy. The rest of this paper is organized as follows, Section 2 offers preliminary description of QCA. Section 3 presents discussions on reversible computing along with analysis of various reversible flip flops as case study. Section 4 presents formalisms for energy requirement for flow of electron through a channel within a cell. Further ratio of output to input power and its analysis are discussed in Section 4. These derivations are for the minimum energy required for running an architecture comprising N cells. Conclusion is drawn in Section 5.

2. Preliminaries

In Quantum-Dot Cellular Automata paradigm, the logic states are represented by position of individual electron. The beauty of the paradigm is the absence of any current flow through the architecture. Hence, power consumption is very less as compared to existing VLSI counterparts [7]. QCA architecture encompasses the use of the primitives such as QCA cell, QCA wire, and clocking in their realization. This section considers the description of these primitives.

2.1. QCA cell

QCA paradigm is established on the Coulomb interactions between four quantum dots [7] of a bi-stable cell. Two electrons should be able to tunnel between the four dots establishing themselves to two antipodal dots, where the electrons are finding lowest energy level due to electrostatic repulsion between the two electrons. These two antipodal arrangements of electrons can be termed as polarization $P=+1$ which can be interpreted also as information 1 and polarization $P=-1$, which is considered as information 0 as indicated in Fig. 1.

This is how binary information can be encoded as charge configurations in the QCA cells. In conventional logic, the information is transferred by means of electron flow. In QCA logic, the information is transferred by means of Coulomb interaction between a cell and its neighboring cell(s).

2.2. QCA wire

It is like a contiguous array of QCA cells in physical sense. The effect of applied input signal on the first cell moves to the second and it is polarized by the induced polarity of the first cell, from second cell the effect moves to the third and the polarization moves forward accordingly. This process of inducing the neighboring cell and accordingly changing the polarization continues down the length of the QCA wire as shown in Fig. 2.

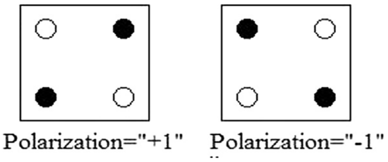

Fig. 1. QCA cells.

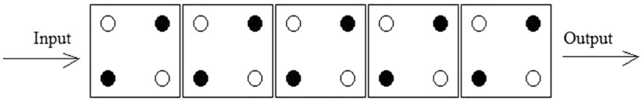

Fig. 2. QCA wire.

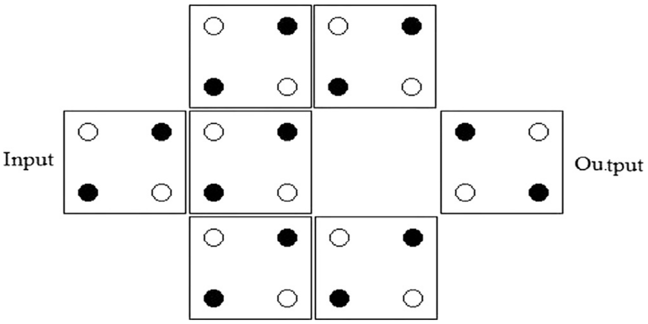

Fig. 3. QCA inverter gate.

2.3. QCA gate

QCA Inverter gate and majority voter gate have been considered here in this section.

2.3.1. QCA inverter

In QCA paradigm, inverter can be designed in different ways. In the design, as in Fig. 3, the applied signal disturbs the arrangement of the electrons of the input cell. The orientation of electrons of the input cell may vary with respect to time and create an electrostatic effect on its neighboring cell and the neighboring cell has in turn the same effect on its neighboring cell and so on. The effect is divided into two parallel wires and inverted at the point of convergence.

2.3.2. Majority voter gate

The basic gate in QCA circuit is 3 input majority voter gates. The three separate input signals are applied to the three input cells. The electron arrangements vary due to the variation of the applied input signals. The combined effect comes to the device cell. This effect is taken as output in an output cell as in Fig. 4. If we assume the three inputs labeled A, B and C, the logical function OUT of a majority gate can be expressed by the expression as

$$OUT=AB+BC+CA$$

If the input polarization is fixed to '1', in any one cell, the device will show the property of an OR gate and can be expressed, if $A=$'1', $OUT=B+C$.

If the input polarization is fixed to '0', in any one cell, the device will show the property of an AND gate and can be expressed like, if $A=$'0', $OUT=BC$.

2.4. QCA clocking

Four clocks are applied that are 90° out of phase. They are clock '0', clock '1', clock '2' and clock '3'. Each clock signal consists of four phases as apparent in Fig. 5. The four phases are high to low, low, low to high and high [8]. At high to low phase actual computation occurs. During low phase, cells hold the polarity. During low to high phase, cells release the polarity and during high phase, cells remain in inactive or maintain NULL state.