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Design and Implementation of Feynman Gate in Quantum-dot Cellular Automata (QCA)

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Abstract

Quantum cellular automata (QCA) have been used widely to digital circuits and systems. QCA technology is a promising alternative to CMOS technology. It is attractive due to its fast speed, small area and low power consumption, higher scale integration, higher switching frequency than transistor based technology. Various QCA circuits, Multivalve Reversible Logic (MVL) Circuit as well as Feynman gate have been proposed in this paper. The QCA offers a novel electronics paradigm for information processing and communication. In this paper, a Feynman gate circuit is proposed based on QCA logic gates: the Maj3, Maj AND gate, Maj OR based on QCA logic gates. The proposed circuit is a remising future in constructing of nano-scale low power consumption information processing system and can stimulate higher digital applications in QCA.

Keywords: *Quantum Cellular Automata, QCA Logic Gates, Feynman gate in QCA.*

1. Introduction

QCA is a novel emerging technology in which logic states are not stored as voltage levels, but rather the position of individual electrons. Conceptually, QCA represents binary information by utilizing a bitable charge configuration rather than a current switch. A QCA cell can be viewed as a set of four “dots” that are positioned at the corners of a square. A quantum dot is a site in a cell in which a charge can be localized. The cell contains two extra mobile electrons that can quantum mechanically tunnel between dots, but not cells. In the ground state and in the absence of external electrostatic perturbation [1], the electrons are forced to the corner positions to maximize their separation due to Coulomb repulsion. As shown in Figure 1, the two possible charge configurations are used to represent binary “0” and “1”. Note that in the case of an isolated cell, the two polarization states are energetically degenerate. However the presence of other charges (neighbor cells) breaks the degeneracy and one polarization state becomes the cell ground state [1]. Polarization P measures the extent to which the charge distribution is aligned along one of the diagonal axes. If the charge density on dot i is ρ_i, then the polarization is defined as [2, 3],

$$P = \frac{(\rho_1 + \rho_3) - (\rho_2 + \rho_4)}{\rho_1 + \rho_2 + \rho_3 + \rho_4} \qquad (1)$$

The tunneling between dots implies that ρ_i may not be integers as polarization values.

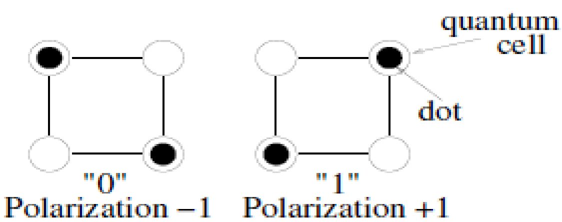

Fig. 1 QCA Cell

The QCA cells themselves comprise the interconnecting wires as described in [4]. An example of a QCA wire is shown in Figure 2. In this example, a value of 1 is transmitted along the wire. Only a slight polarization in a cell is required to fully polarize its neighbor. The direction for the flow of information through a gate or a wire is controlled by a four stage clocking system described in [5] which raises and lowers barriers between the cells.

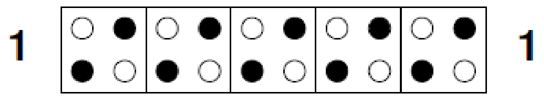

Fig. 2 QCA Wire.

Described in [3] were other logic gates formed by restricting the polarity of one input to the 3-input majority gate to be a constant value. Figure 3 illustrates a 2-input AND gate and a 2-input OR gate formed in this manner. By replacing input C with a cell having a fixed polarity of 0, the 3-input majority gate functions as an AND gate. By replacing input C with a cell having a fixed polarity of 1, the 3-input majority gate functions as an OR gate. In this case C is a control input. In the example, OR gate on the left side of Figure 3, Out = A+B. Similarly, replacing input C with a cell having a fixed polarity of 1 creates a 2-input OR gate. In the example AND gate on the right side of Figure 3, Out = AB.

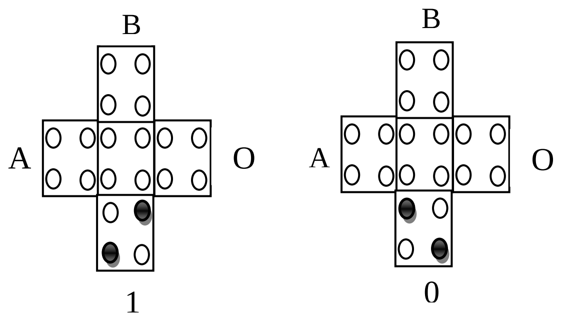

Fig. 3 2-input OR && 2-input AND gates.

Quantum arithmetic components need reversible logic circuits for their construction. Reversible logic circuits find wide application in low power digital design, quantum computing and nanotechnology. An optimized and low quantum cost one digit carry skip BCD adder, has been designed using new FHNG reversible logic gates [6]. It is an important logic gate in reversible logic. In this paper we have designed and simulated a Feynman gate in QCA technology.

2. QCA Implementation

There have been several proposals for physically implementing QCA: Micro-sized QCA devices have been fabricated with metal which operate at 50mK [7] [8] and an extensive literature has been reported on developing molecular implementations of QCA [9] [10].Magnetic QCA (MQCA) has been investigated and fabricated [11] [12] for room temperature operation. In this section, a brief background on Metal, Molecular, and Magnetic QCA is provided.

3. Proposed Circuit and Presentation

3.1 Feynman gate

Figure 4 shows a 2 x2 Feynman gate [13]. The input vector is I (A, B) and the output vector is O (P, Q) and the relation between input and output is given by P=A, Q = A ⊕ B. Since it is a 2 x 2 gate, it has a quantum cost of 1 [14]. It is used to copy the input without producing garbage bits.

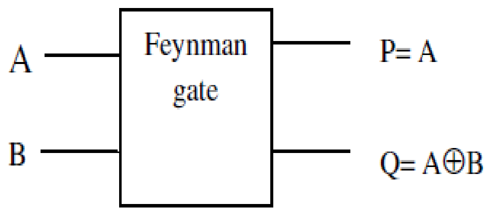

Fig. 4 Feynman gate.

3.2 Feynman gate in QCA

The block diagram of QCA is the Feynman gate shown in Figure 5 .The fundamental logic gate for QCA is the Feynman gate shown in Figure 6 that is composed of Sixty (60) cells. Two of these, representing the inputs to the cell, are labeled A and B. using the terminology of [3], the center cell is the “device cell” that performs the calculation. The remaining cell, labeled out, provides the output. The circuit shown in Figure 6 performs the Boolean function Out2 = A⊕B and out1 = A;

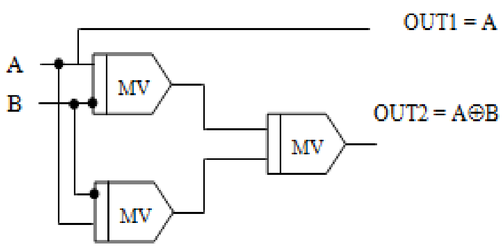

Fig. 5 Block Diagram of QCA is the Feynman gate.

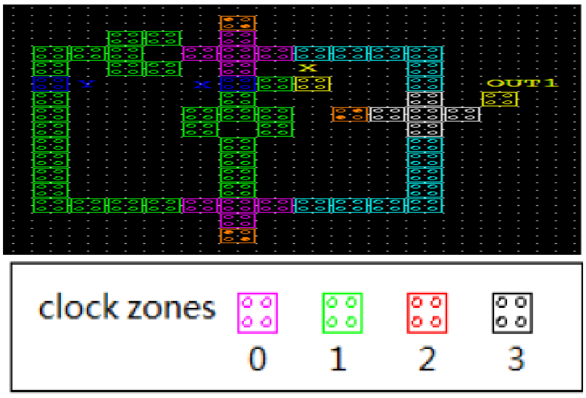

Fig. 6 Design QCA is the Feynman gate.

The Feynman gate layout has been simulated using QCA Designer version 2.0.3; a layout and simulation tool for QCA. The simulation results for a Feynman gate are shown in Figure 7.

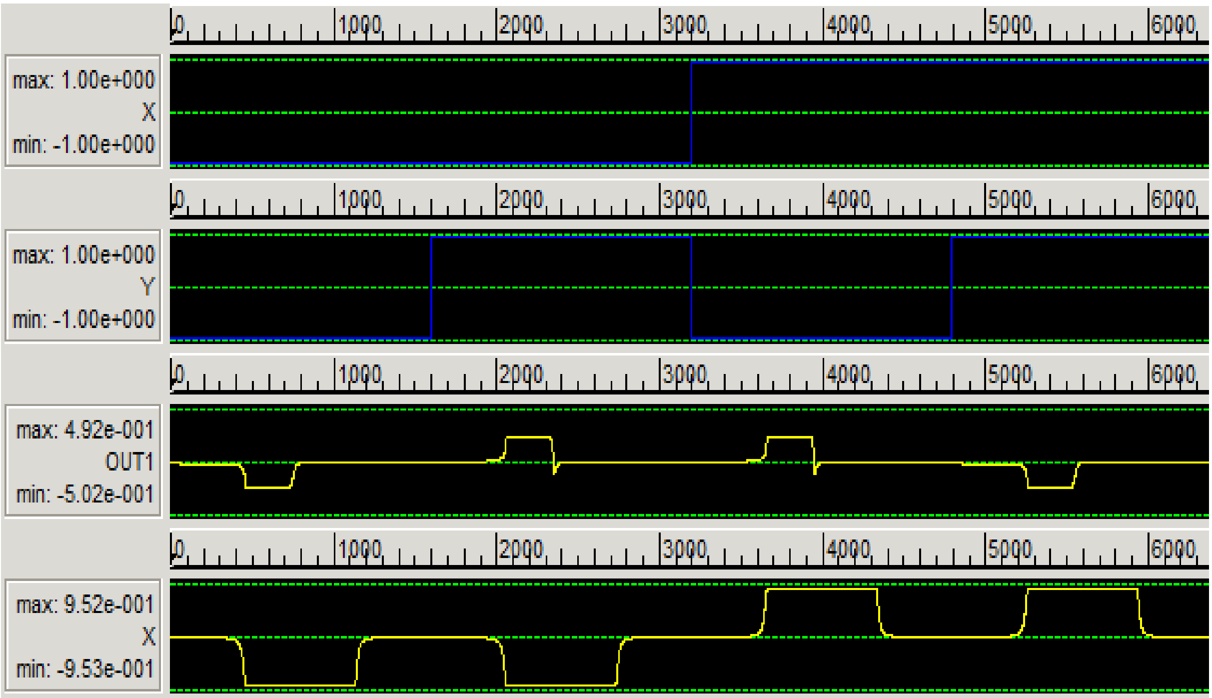

Fig.7 Simulated waveforms for Feynman gate circuit.

In this Simulation we have used the coherence vector computational engine and the following parameters: (10 nm × 10 nm) cell size, 2.5 nm cell-to-cell distances, and 2.5 nm dot size and 40 nm radius of influence.

4. Conclusion

This paper present a Feynman gate based on QCA does logic gates. The design is very useful for future computing techniques like ultra low power digital circuits and quantum computers. MVs provide a functionally complete logic set for QCA. This QCA circuit design provide a new functional paradigm for information encoding. In addition, QCA binary logic functions and the associated new nano-technology will provide high-speed computing, high-density applications. It is believed that QCA will become a more practical ways to create a faster and denser circuit.

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