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# COMPUTER-AIDED DESIGN OF NANOCELLULAR AUTOMATA

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*Quantum cellular automata is a promising nanotechnology that has been recognized as emerging technology with potential applications in future computers. In this paper the method of majority voting scheme is used to develop basic quantum cellular automata combinational and sequential circuits. We verified gates using simulation from QCADESINGER tool. These algorithms and simulations are useful for building complex quantum cellular automata circuits.*

**Key words:** quantum cellular automata, simulation, design.

**Introduction.** One nanostructure paradigm, proposed by Lent et al., is quantum-dot cellular automata [1; 2], which employs arrays of coupled quantum dots to implement Boolean logic functions [3].

The advantage of quantum cellular automata (QCA) lies in the extremely high packing densities possible due to the small size of the dots, the simplified interconnection, and the extremely low power-delay product. Using QCA cells with dots of 20 nm diameter, an entire full adder can be placed within 1 $mm^2$.

Quantum-dot cellular automata is a transistorless computation paradigm that addresses the issues of device density and interconnection. The basic building blocks of the QCA architecture, such as AND, OR, and NOT are presented. The experimental device is a four-dot QCA cell with two electrometers. The dots are metals or semiconductors islands, which are coupled by capacitors and tunnel junctions. An improved design of the cell is presented in which all four dots of the cell are coupled by tunnel junctions. The operation of this basic cell is confirmed by the externally controlled polarization change of the cell.

The fundamental QCA logic primitives are the three-input majority gate, wire, and inverter. Each of these can be considered as a separate QCA locally interconnected structure, where QCA digital architectures are combinations of these cellular automata structures. The basic Boolean primitive in quantum cellular automata is the majority gate [4; 5].

Quantum cellular automata technology is based on the interaction of bi-stable QCA cells constructed from four quantum dots. The cell is charged with two free electrons, which are able to tunnel between adjacent dots. These electrons tend to occupy antipodal sites as a result of their mutual electrostatic repulsion. Thus, there exists two equivalent energetically minimal arrangements of the two electrons in the QCA cell, as shown in fig. 1. These two arrangements are denoted as cell polarization $P = +1$ and $P = -1$. By using cell polarization $P = +1$ to represent logic “1” and $P = -1$ to represent logic “0,” binary information is encoded in the charge configuration of the QCA cell.

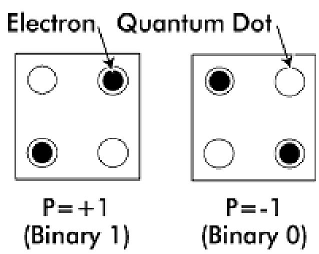



Fig. 1. Quantum cellular automata cells showing how binary information is encoded in the two full polarized diagonals of the cell

The fundamental QCA logic primitives include a QCA wire, QCA inverter, and QCA majority gate, as described below.

In a QCA wire, the binary signal propagates from input to output because of the electrostatic interactions between cells. The propagation in a 90° QCA wire is shown in fig. 2. Other than the

90° QCA wire, a 45° QCA wire can also be used. In this case, the propagation of the binary signal alternates between the two polarizations.

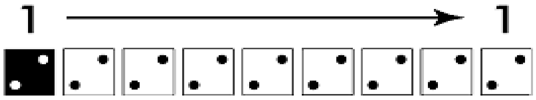



Fig. 2. Quantum cellular automata wire

A quantum cellular automata layout of an inverter circuit is shown in fig. 3. Cells oriented at 45° to each other take on opposing polarization. This orientation is exploited here to create the inverter shown in this figure.

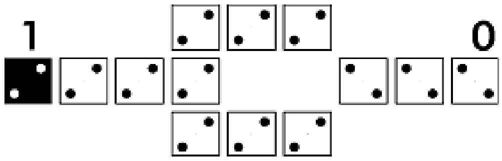


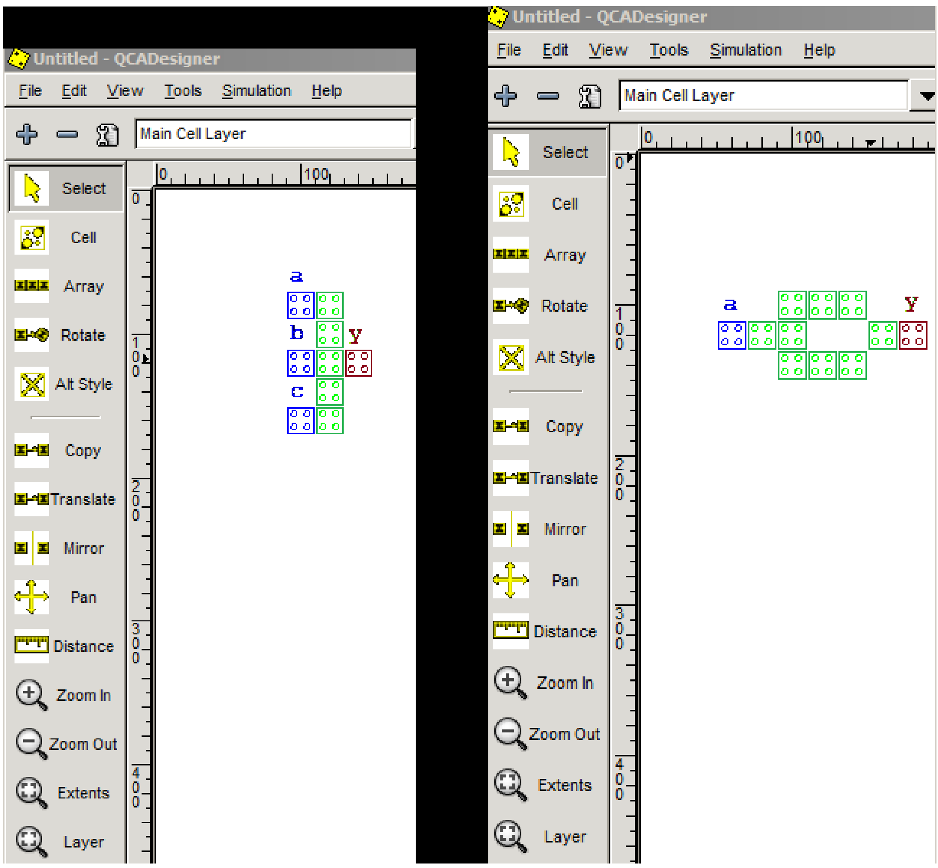

Fig. 3. Quantum cellular automata inverter

The QCA majority gate performs a three-input logic function. The majority gate produces an output that reflects the majority of the inputs.

**Experiment.** Any QCA circuit can be efficiently built using only majority gates and inverters. As shown in fig. 4, an ordinary QCA gate implementing the majority function is as follows.

Assuming the inputs are “*a*”,”*b*”,”*c*”, the logic function of a majority gate is shown:

$$f(a,b,c) = ab + ac + bc = maj(a,b,c) .$$




*a* *b*

Fig. 4: Primitive components: *a* – a QCA majority gate; *b* – a QCA inverter

The signal comes in from the left, splits into two parallel wires and is inverted at the point of convergence.

Beside, truth table of a three-input majority gate is shown in table 1. As illustrated in fig. 3 every QCA inverter gate can be implemented by 11 quantum cells.

An *n*-input majority gate produces a logic “1” output if he majority of its inputs are logic “1”; two out of three in the case of a three-input majority function. If n is even, *n*/2+1 inputs must be at logic “1” to produce an output of logic “1.” The three-input QCA majority gate is a special case of the *n*-input majority function. Currently, there is evidence from the latest fabrication technology that feed-forward networks, constructed with threshold gates, are becoming a promising solution for computer arithmetic.

*Table 1*

**Truth table of a three-input majority gate**

| Input | Majority voting |
|---|---|
| 000 | 0 |
| 001 | 0 |
| 010 | 0 |
| 011 | 1 |
| 100 | 0 |
| 101 | 1 |
| 110 | 1 |
| 111 | 1 |

A quantum cellular automata majority gate and a QCA inverter can be physically simulated by the well known QCADesigner tool [6].

Quantum cellular automata has a clocking mechanism that consists on four clock signals with equal frequencies.

One of the clock signals can be considered the reference (phase = 0) and the others are delayed one (phase = π/2), two (phase = π) and three (phase = 3π/2) quarters of a period (see fig. 5 and 6).

The clocking of QCA is accomplished by controlling the potential barriers between adjacent quantum-dots.

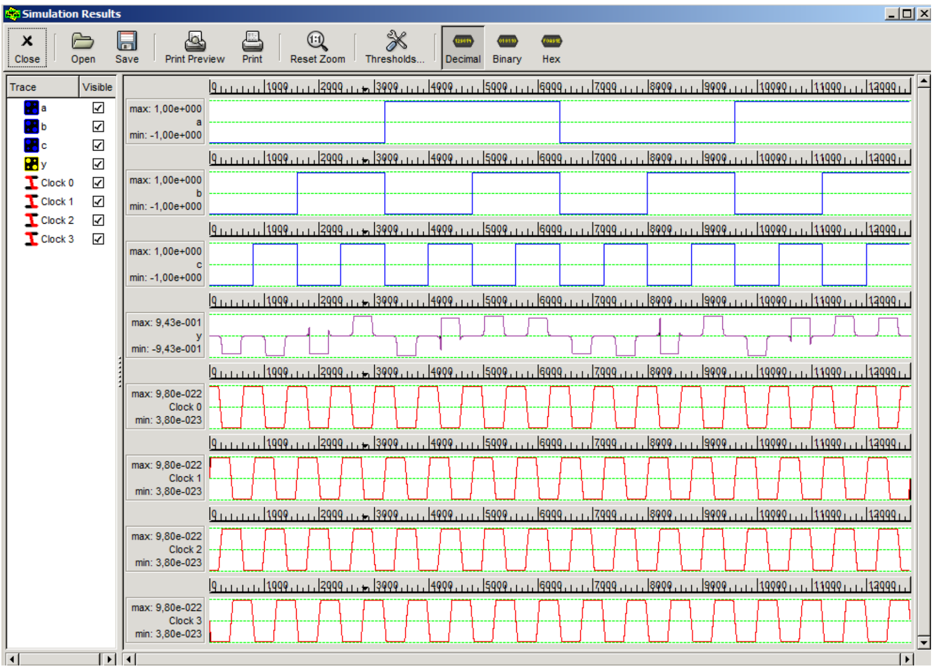



Fig. 5. Simulation results for a QCA majority gate

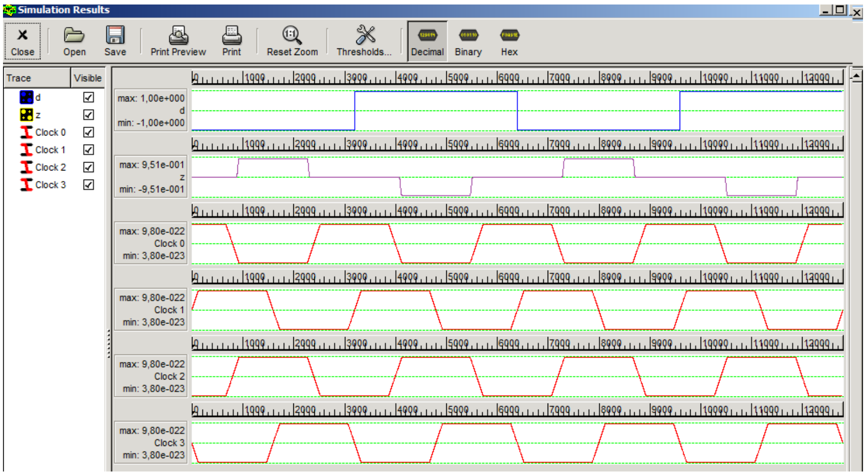



Fig. 6. Simulation results for a QCA inverter

**Conclusion.** Quantum-dot cellular automata (QCA) have been recognized as one of the revolutionary to nano-scale computing devices. The basic quantum-dot cell is charged with two excess electrons and performs computation on Coulomb interactions of electrons.

In this paper, we proposed the design of QCA logic gates: majority gate and inverter by the QCADesigner tool.

In addition, the QCA binary logic functions and the related new digital computational nanotechnology will provide high speed, and high density applications. It is believed that QCA will become a much more practical approach to create a faster and denser circuit.

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**Проектирование наноразмерных автоматов с помощью системы автоматизированного проектирования**

Выполнено и рассмотрено проектирование квантовых точечных автоматов на примере мажоритарного элемента и инвертора в среде проектирования QCA Designer tool. Представлены результаты моделирования наносхем инвертора и мажоритарного выбора.

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**Проектування нанорозмірних автоматів за допомогою системи автоматизованого проектування**

Виконано і розглянуто проектування квантових точкових автоматів на прикладі мажоритарного елемента та інвертора в середовищі проектування QCA Designer tool. Подано результати моделювання наносхем інвертора та мажоритарного вибору.