A new 5-input majority gate without adjacent inputs crosstalk effect in QCA technology

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ABSTRACT

Transistor based CMOS technology has many drawbacks such as power consumption and cannot continue in following the scaling of Moore's law and system-on-a-chip in near future. These drawbacks lead the researchers to think about an alternative technology. Quantum-dot Cellular Automata (QCA) is a new nanoscale technology can implement the logical functionality by controlling the position of the electron. The basic building blocks for QCA circuit are majority gate and inverter, where AND and OR gate can be implemented using Majority gate by setting one of the inputs to "0" and "1" respectively. A lot of papers was introduced to propose a new gates construction such as XOR and 5- input majority gate in last few years. The complexity of the gate leads to the complexity of the whole circuit so whenever the proposed gate has a lower number of cells, that's mean it's a better. In this paper, we introduce a new construction of a novel 5- input majority gate. QCADesigner tool will be used to show the simulation result of the proposed gate. Then we will compare the proposed gate with the most important previous counterpart gates.

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1. INTRODUCTION

QCA cell consists of four quantum dots with free two electrons injected inside it. This cell has a square shape and the two electrons localized diagonally due to columbic interaction [1]. Selecting the side depending on the minimum energy required [2]. These electrons can tunneling between dots and cannot tunneling between cells [3]. Unlike CMOS technology, which used a voltage level for binary computation, QCA uses the position of electrons [4]. QCA does not need long interconnection lines because the connection is done with the nearest adjacent cell without current flow [3], [5]. QCA provides less than 100 w/cm2 as power dissipation, higher than 1012 device/cm2 device density and operates in terahertz frequency range [6]. The flow of information in QCA is done by using the clock signal which consists of four clock zones [7]. Furthermore clock signal give the energy to the QCA cells [8]. Although many logical gates have been proposed, including the majority gate, researchers are still looking at reducing the number of cells needed for gate construction.

2. PREVIOUS MAJ-5 GATE

A lot of structures are introduced in literature represented Majority gate with 5 inputs, some of them designed in a single layer while other need multi-layer for implementing. The previous layouts of Maj-5 gates are illustrated in Figure 1.

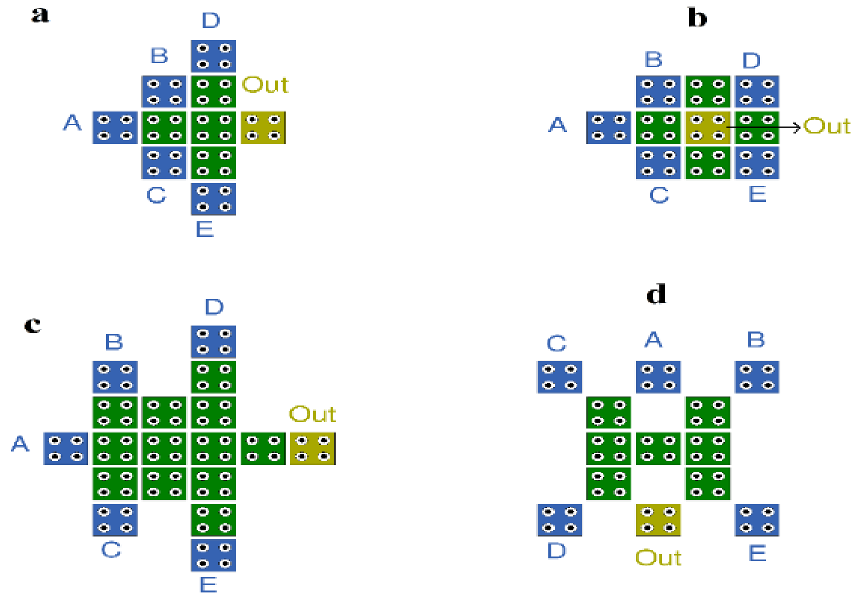

Figure 1. Maj-5 gates: (a) presented in [9], (b) in [10], (c) in [11] and (d) in [12]

3. PROPOSED GATE

Many researchers focus on introducing a new construction of 5-input majority gate, each of these has many features but the most important feature in designing any gate is the complexity or the number of cells required and the fault tolerant. In this paper, the proposed majority gate required only 10 cells and can be carried out in a single layer. Figure 2 Shows the proposed structure of the majority-5 gate.

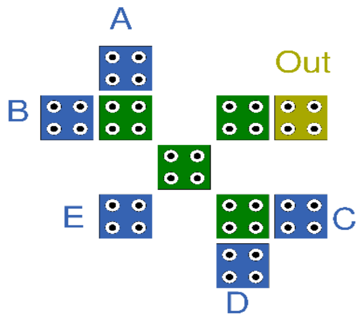

Figure 2. Proposed majority-5 gate

4. VALIDATION OF THE PROPOSED GATE

The validation of the proposed structure illustrated in Figure 3 and Table 1. The electrostatic energy or called Kink Energy, $E^{k}_{i,j}$, between two adjacent cells i and j can be calculated using 1.

$$E_{Total} = \sum_{i,j} \frac{q_i q_j}{4\pi\varepsilon_0\varepsilon_r |r_{i,j}|} \quad (1)$$

Where ε0 represent free space permittivity and εr is relative permittivity, qi and qj are represent the charge of the electron at i and j while the distance between the two dots is given by |ri - rj|. A configuration that contains the lower energy for certain input is the most stable orientation. Cell energy can be obtained by summing over the kink energy of all electrons in each cell. Kink energy E^{k} between two cells can be calculated by keeping one of them in its original state and the other in two different polarization states and then calculating the difference between these energies.

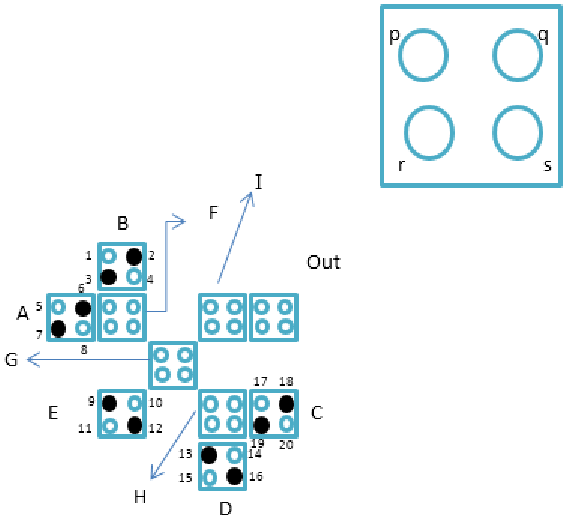

Figure 3. Sequence details to analysis the proposed gate

For Cell F

If input sequence (11100), The electrons inside cell 'A' occupy at positions 6 and 7, in cell 'B' at positions 2 and 3, in cell 'C' at positions 18 and 19, in cell 'D' at positions 13 and 16 and in cell 'E' at positions 9 and 12. The electrostatic energy at position p, Cell 'F', because of the electron inside cell "B" at position 2 is $\frac{Zeq}{L2}$, where L2 is the distance between 2 and p. In a similar way, the electrostatic energy at position p because of the electrons located at positions 3, 6, 7, 9, 12, 13, 16, 18, 19 are calculated. The calculation of the whole electrostatic energy at dot p (referred to as Up) for the input 11100 is as below.

$$\mathrm{Up} = \frac{Zeq}{L2} + \frac{Zeq}{L3} + \frac{Zeq}{L6} + \frac{Zeq}{L7} + \frac{Zeq}{L9} + \frac{Zeq}{L12} + \frac{Zeq}{L13} + \frac{Zeq}{L16} + \frac{Zeq}{L18} + \frac{Zeq}{L19}$$

$$= \frac{Zeq}{21.93} + \frac{Zeq}{11} + \frac{Zeq}{11} + \frac{Zeq}{21.93} + \frac{Zeq}{40} + \frac{Zeq}{49.82} + \frac{Zeq}{72.11} + \frac{Zeq}{84.63} + \frac{Zeq}{79.76} + \frac{Zeq}{77.47}$$
$$= 8.51 \text{ X } 10^{-20} \text{ j}$$

Where $Zeq = \frac{q^2}{4\pi\epsilon_0\epsilon_r} = 23.04 \text{ X } 10^{-20}$

Table 1. The Proposed Gate Validation

Cell Name	Up	Uq	Ur	Us	Stable Position (minimum energy required)	Cell Polarization
	X 10^{-20} j					
Cell F	8.51	7	7.27	6.38	"q" + "r"	P=+1 (logic 1)
Cell H	6.42	6.92	7.49	8.13	"q" + "r"	P=+1(logic 1)
Cell G	5.22	5.10	5.81	5.22	"p" + "s"	P=-1(logic 0)
Cell I	6.31	5.33	6.71	6.31	"q" + "r"	P=+1(logic 1)
Cell Out	Same polarization of Cell I					P=+1(logic 1)

5. SIMULATION RESULT AND COMPARISON

QCADesigner software [13] is used to simulate the proposed gate and the simulation results shows error free operation for all the possibilities of inputs. The output waveforms of the proposed Maj-5 gate is illustrated in Figure 4.

Table 2 shows the comparison between the proposed gate from the complexity side with the most important previous works it's clear from the table that the proposed gate has the same complexity of the one presented in [8] with the crosstalk noise effect is eliminated for adjacent inputs.

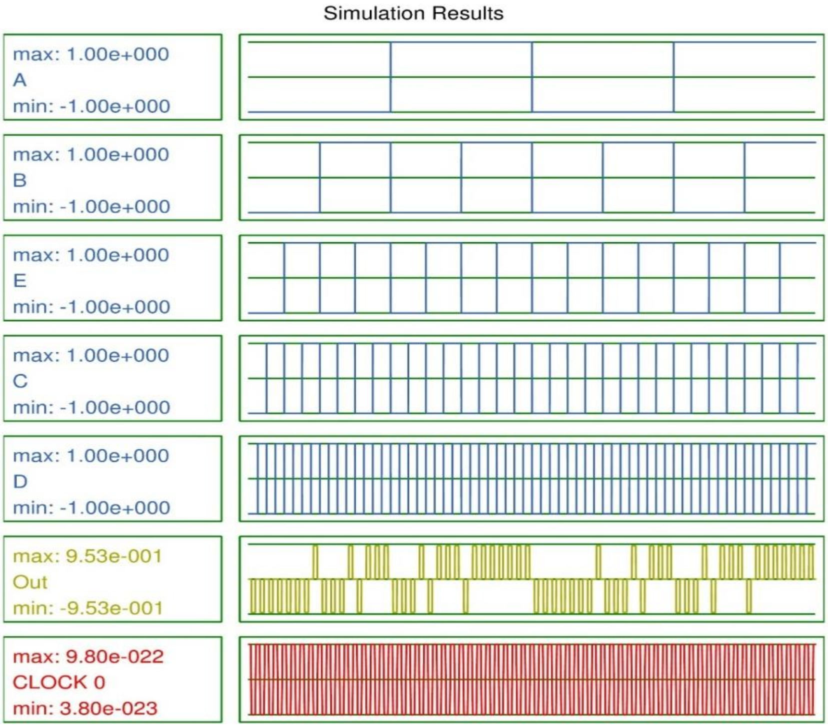

Figure 4. simulation result of the proposed 5-input gate

Table 2. The Characteristics of the Most Important 5-Input Majority Gates

5-input majority gate	Layer Type	Number of cells
[9]	Single	10
[14]	Multiple	10
[15]	Single	23
[16]	Single	42
[17]	Single	51
[18]	Single	17
[19]	Single	14
[12]	Single	13
[20]	Single	18
Proposed	Single	10

6. POWER DISSIPATION COMPARISON

The power dissipation is a very important factor in determining the performance of any circuit. Starting from the quasi-adiabatic switching model derived in [21]. QCAPro software [22] is used to calculate the dissipated power for the proposed design of the majority gate. Figure 5 shows the energy mapping of the proposed gate with Ek =0.5 meV at 2 K temperature. In Table 5 the dissipated power of the proposed gate is compared to previous designs of the 5-input Majority gates. It is clear from this table that the proposed design is superior to other designs. The Comparative Analysis of Dissipated Power at Different Maj-5 as shown in Table 3.

Table 3. The Comparative Analysis of Dissipated Power at Different Maj-5

Parameter	Avg. leakage energy dissipation (meV)			Avg. switching energy dissipation (meV)			Total energy consumption (meV)		
	0.5 E_k	1 E_k	1.5 E_k	0.5 E_k	1 E_k	1.5 E_k	0.5 E_k	1 E_k	1.5 E_k
In [9]	1.28	4.14	7.69	11.53	10.37	9.16	12.81	14.51	16.85
In [10]	1.35	4.25	7.8	10.94	9.84	8.7	12.29	14.09	16.5
In [11]	3.44	10.67	19.52	32.66	29.89	27.01	36.1	40.56	46.53
In [12]	3.38	8.95	15.03	9.23	7.7	6.41	12.61	16.65	21.44
proposed	2.48	6.29	10.18	3.54	2.61	2	6.02	8.9	12.18

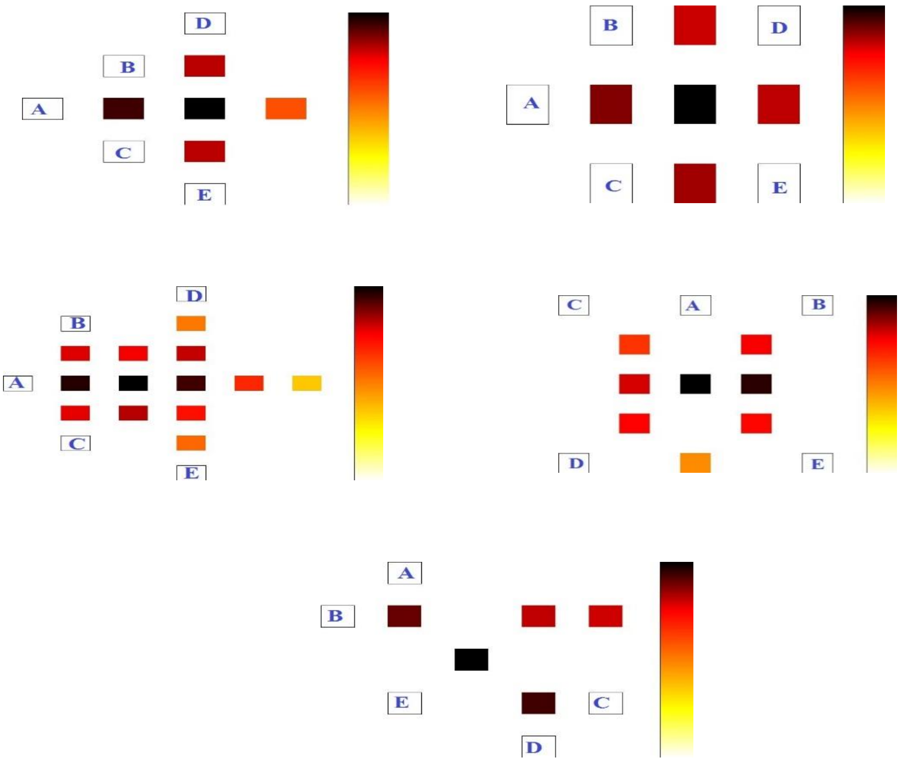

Figure 5. The power dissipation mapping for Maj-5 gates with 0.5 Ek at 2 K temperature presented in [9], (b) in [10], (c) in [11], (d) in [12] and (e) Proposed Maj-5

7. CONCLUSIONS

In this paper new structure of 5-inputs majority gate for QCA technology is introduced. The proposed gate is proved theoretically by calculating the electrostatic forces, and by simulation using QCAdesigner software. The power dissipation analysis is also done using QCA Pro software. The proposed gate complexity is equal to the best reported in the literature with the advantage that the crosstalk effect between adjacent inputs in the previous designs is not available and this will give powerful and flexible building block to the designers to design better circuits with less complexity.

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