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An Efficient Design for Coplanar Ripple Carry Adder in Quantum-dot Cellular Automata Technology

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The new nanotechnology, the Quantum-dot Cellular Automata (QCA) technology, is a promising technology for replacing the conventional CMOS technology at nanoscale. This new technology provides high-speed and extremely dense structures in digital circuits. This study presents new low complexity one-bit QCA Full Adder (FA) structure as a building block. Then, a new high-speed four-bit QCA Ripple Carry Adder (RCA) is proposed using this building block. The QCADesigner tool version 2.0.3 is utilized for verifying circuit functioning. The proposed one-bit QCA FA structure and proposed four-bit QCA RCA structure utilize 47 and 233 cells, respectively. The implementation results show that the proposed structures provide an improvement compared to other structures in terms of latency, area, cell count, and cost.

Keywords: Nanoelectronics, Nanotechnology, Ripple carry adder, Full adder, Quantum-dot cellular automata.

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1. INTRODUCTION

The conventional CMOS technology has faced with limitations such as short channel effects at nanoscale [1, 2]. So, several technologies such as CNTFETs [3, 4, 5], and Quantum-dot Cellular Automata (QCA) [1, 6, 7] are investigated as replaced technologies. The QCA technology has significant interest for researchers. The QCA devices and systems are designed by using QCA cell that is composed of two electrons [1]. The information in this technology is encoded by using the place of electrons in the QCA cell [1, 6, 7]. In addition, this technology has characteristics such as small dimensions and high-speed operation [1, 8].

On the other hand, Full Adder (FA) circuits play an important role in computational circuits, which are used to design digital circuits. The one-bit QCA FA is the main structure in n-bit QCA FA design [2].

In this study, a novel one-bit QCA FA with five-input Majority Gate (MG) is presented. Then, a novel four-bit QCA Ripple Carry Adder (RCA) is constructed using this building block. These structures are implemented using QCADesigner. The implementation results confirm that these new structures have an advantage compared with other QCA structures.

The rest of this paper is arranged as follows. In section 2, an overview of the QCA technology and previously offered descriptions for FA are presented [9-12]. The proposed structures are presented in section 3. Section 4 presents the implementation results and compares the proposed structures with other structures. Finally, section 5 concludes the paper.

2. BACKGROUND

2.1 The QCA Cells

The building block in the QCA technology is QCA cell, which consists of 2 electrons and 4 dots. When the potential barrier is low, the electrons are able to tunnel between quantum dots. As a result, they are arranged in two stable states. These two configurations for the cells are shown in Fig. 1 [6-9]. The polarizations – 1 and 1 can be utilized to show binary values of zero and one, respectively.

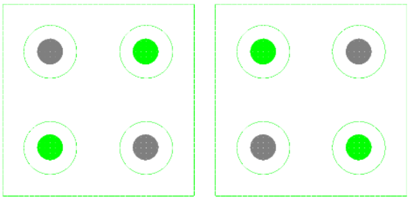

Fig. 1 – The possible polarizations for the QCA cell [9]

2.2 QCA Fundamental Structures

The MG and inverter are two important gates in this technology, as shown in Fig. 2 and Fig. 3 [6-9].

The MG has a significant role in the QCA digital circuits. Three-input MG is defined as follows:

$$MAJ3(A,B,C) = CA + AB + CB. \tag{1}$$

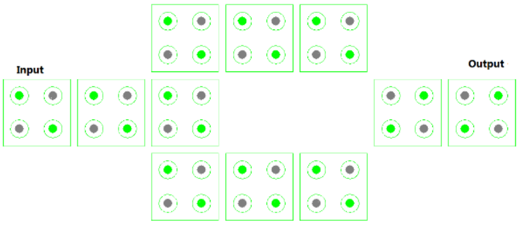

Fig. 2 – Layout of the QCA inverter [6-9]

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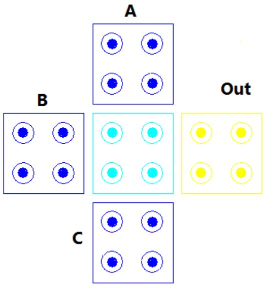


Fig. 3 – Layout of the three-input MG [6-9]

Moreover, the equation of five-input MG is as follows:

$$MAJ5(A,B,C,D,E) = DAB+CAB+DAC+EAB+EAC+EAD+EBC+DBC+EBD+ECD. \quad (2)$$

2.3 The QCA Clocking

QCA circuits' clocks are utilized to control the circuits. The QCA circuits have 4 clock zones. These clock zones are called hold, switch, relax, and release.

2.4 The QCA FA

The A, B, and C are inputs, which should be added and the outputs are C_{out} and Sum in the FA. The Sum output denotes the sum of these inputs and C_{out} denotes the carry output. The outputs of FA are defined as [11]:

$$C_{out} = AB + CA + CB, \quad (3)$$

$$Sum = A \oplus B \oplus C. \quad (4)$$

Using MG, the C_{out} is also written as follows [11]:

$$C_{out} = MAJ3(A, B, C). \quad (5)$$

Note that, equation (4) can be rewritten by using five-input MG [11]:

$$Sum = MAJ5(A, B, C, \overline{C_{out}}, \overline{C_{out}}). \quad (6)$$

The complexity of circuit design can be simplified by using five-input MG instead of three-input MG. Fig. 4 and Fig. 5 show the implantation of FA circuit by using five-input MG in the QCA technology [11, 12].

2.5 Related Works

Kassa and Nagaria [9] have proposed five-input MG, then they have designed one-bit FA structure based on this five-input MG. This structure has 48 cells and area of 0.05 μm^2. Hashemi and Navi [10] have proposed a QCA FA. They also proposed a QCA RCA structure. The one-bit QCA FA has 71 cells with area of 0.06 μm^2. The four-bit QCA RCA has 442 cells with area of 1 μm^2. Labrado and Thapliyal [11] have proposed a design for the one-bit QCA FA with five-input MG. They also have proposed a QCA RCA structure. The one-bit FA has 63 cells with area of 0.05 μm^2. The four-bit QCA RCA has 295 cells, and 0.30 μm^2 area. Another FA design has been proposed by Sasamal et al. [12] and uses five-input MG. This structure has 49 cells, and 0.04 μm^2 area. Kianpour et al. [13] have proposed another design that has 69 cells and 0.07 μm^2 area. Qanbari and Sabbaghi-Nadooshan [14] have proposed two designs for one-bit FA with 104 and 63 cells and 0.13 and 0.05 μm^2 area. Another FA design has been proposed by Mokhtari et al. [15]. This design has 46 cells and 0.04 μm^2 area. Rasouli Heikalabad et al. [16] have proposed a design for 1-bit FA with 41 cells and 0.03 μm^2 area.

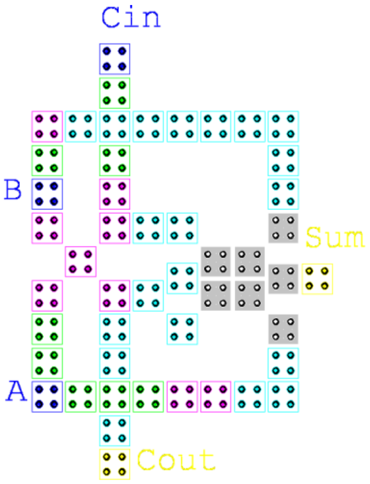


Fig. 4 – The layout of the QCA FA in [12]

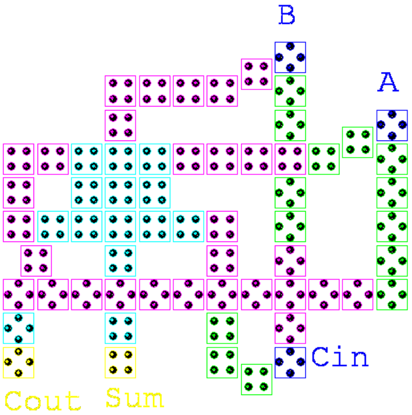


Fig. 5 – The layout of the QCA FA in [11]

3. THE PROPOSED STRUCTURE

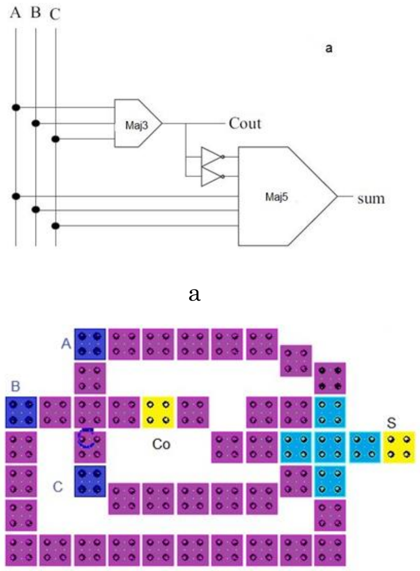
3.1 The Proposed One-Bit QCA FA Structure

Fig. 6 illustrates the developed structure for the one-bit FA in the QCA technology.

As illustrated in Fig. 6a, the utilized logical diagram for the implementation of QCA FA structure contains three main components: two inverter gates, a five-input MG, and a three-input MG. Fig. 6b presents the layout of the developed one-bit QCA FA. Note that, we use half space between our cells to area reduction. Our proposed design consists of 47 cells and area of 0.03 μm^2.

3.2 The Proposed Four-Bit QCA RCA Structure

Fig. 7 shows the designed four-bit QCA RCA structure. This structure is composed of 233 cells and 0.29 μm^2 area. In addition, the QCA cells are located in 7 clock phases or 1.75 clock cycles.



a

b

Fig. 6 – The developed one-bit FA structure in the QCA technology: (a) logical diagram, (b) implemented layout

4. SIMULATION RESULTS AND COMPARISON

We use QCADesigner simulation engine to certify the accurate functionality of the proposed structures.

4.1 The Proposed QCA FA Structure

Based on the achieved implementation results, the developed structure for the FA in the QCA technology works correctly. Table 1 summarizes the implementation results of the designed QCA FA compared to other QCA FA structures. It should be noted that the cost is determined in this section as follows:

$$\text{Cost} = \text{Area} \cdot \text{Latency}.$$

According to Table 1, in comparison with other structures, our developed structure has an improvement in all terms. For example, the area, cost and cell count of the designed QCA FA decreased by about 50 %, 70 %, and 33.8 %, respectively, compared to QCA FA in [10]. Despite similar delay to [11], our developed structure has improvements in terms of area, cost and cell count. Despite lesser cell count to that of structure presented in [15], our structure has improvements in terms of cost and delay. Our developed structure has 25 %, 25 %, and 43.75 % improvements in terms of area, delay and cost compared with [15].

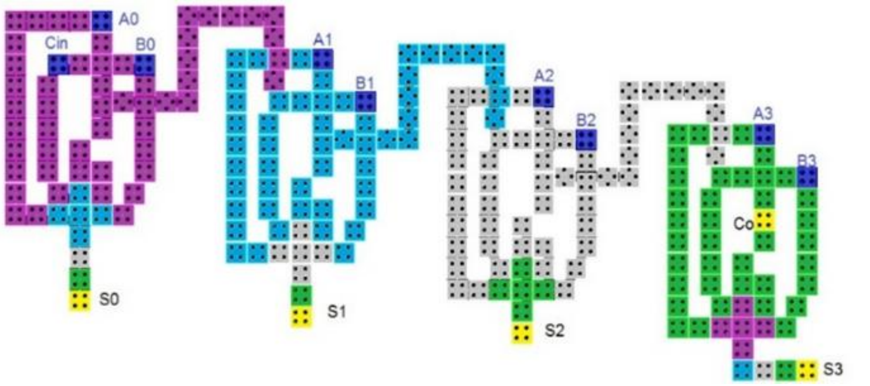


Fig. 7 – The layout of the designed four-bit QCA RCA

Table 1 – Comparison table for the on-bit QCA FA

References	No of cells	Area, μm²	Delay (clock cycle)	Cost	Crossover type
[14]	104	0.13	1	0.13	Coplanar
[14]	63	0.05	0.75	0.0375	Multilayer
[15]	46	0.040	1	0.04	Coplanar
[12]	49	0.04	1	0.04	Coplanar
[11]	63	0.05	0.75	0.0375	Coplanar
[9]	48	0.05	0.75	0.0375	Coplanar
[13]	69	0.07	1	0.07	Coplanar
[10]	71	0.06	1.25	0.075	Coplanar
[16]	41	0.03	1	0.03	Coplanar
This paper	47	0.03	0.75	0.0225	Coplanar

Table 2 – Comparison table for the four-bit QCA RCA

References	No of cells	Area, μm²	Delay(clock cycle)	Cost	Crossover Type
[11]	295	0.30	1.5	0.57	Coplanar
[10]	442	1	2	2	Coplanar
[15]	187	0.2	4	0.8	Coplanar
[18]	269	0.37	3.5	1.295	Coplanar
[17]	366	0.51	2.5	1.275	Coplanar
This paper	233	0.29	1.75	0.5075	Coplanar

4.2 The Proposed QCA RCA Structure

Based on the achieved implementation results, the designed structure for four-bit QCA RCA works correctly. Table 2 summarizes the implementation results of the four-bit QCA RCA structures.

Based on our implementation results that are displayed in Table 2, the designed structure has advantages in terms of latency and cost compared with other four-bit QCA RCA structures in [10, 11, 17, 18]. In particular, our developed structure has 60 %, 36 %, and 43 % improvements in terms of cost, cell count, and area, respectively, compared with [17]. Moreover, our design has 60 %, 50 % and 21 % improvements in terms of cost, delay and area, respectively compared with [18]. Despite lesser cell count to that of design presented in [15], our design has improvements in terms of cost and delay compared with [15].

5. CONCLUSIONS

The QCA is a new and developing technology that is looking forward for replacing CMOS technology at nanoscale [19]. It is because this technology is a novel one with greater potential to provide circuits with small size and high speed compared with CMOS technology [20].

In this study, a novel structure was presented for FA using five-input MG in this technology. Moreover, novel four-bit QCA RCA was designed. The developed structures were implemented using QCADesigner version 2.0.3. Our implementation results demonstrate that the designed structures have significant improvements compared to other structures. The proposed structure for the QCA FA has an improvement compared to other coplanar designs. For example, area, cost and cell count of the designed QCA FA are decreased by about 50 %, 70 % and 33.8 %, compared to QCA FA structure in [10]. The designed structure for four-bit QCA RCA has an improvement compared to other coplanar structures in [10, 11, 17, 18] in terms of cost and delay. In particular our design has 60 %, 50 % and 21 % improvements in terms of cost, delay and area, respectively in comparison with [18].

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Ефективний дизайн для копланарного суматора з нерівномірною точкою в технології клітинних автоматів

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Нова нанотехнологія – технологія клітинних автоматів на базі квантових точок (QCA) – є багатообіцяючою технологією для заміни традиційної технології CMOS на нанорівні. Ця нова технологія забезпечує високошвидкісні і надзвичайно щільні структури в цифрових ланцюгах. У цьому дослідженні представлена нова структура однобітного QCA повного суматора (FA) з низькою складністю як будівельного блоку. Потім з використанням цього стандартного блоку пропонується новий високошвидкісний двоканальний QCA суматор Ripple (RCA). Інструмент QCADesigner версії 2.0.3 використовується для перевірки функціонування схеми. Запропонована структура однобітного QCA FA і запропонована чотирибітна структура QCA RCA використовують 47 і 233 клітини відповідно. Результати реалізації показують, що запропоновані структури забезпечують поліпшення у порівнянні з іншими структурами з точки зору часу затримки, площі, кількості клітин та вартості.

Ключові слова: Наноелектроніка, Нанотехнології, Суматор Ripple, Повний суматор, Клітинні автомати на базі квантових точок.