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FOUR-BIT NANOADDER CONTROLLED BY FIVE-INPUTS MAJORITY ELEMENTS

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***Abstract*—*This paper presents a nano circuit of a full one-bit adder on the proposed five-input majority element. This innovative full adder design is used to development of a four-bit adder based on it. We offer a new single-bit full adder and a four-bit adder nano circuit in quantum-dot cellular automata technology. The proposed design four-bit adder utilizes only 231 quantum cells in a 0.49 μm2 area. It has a reduction in the number of cells, delay and energy dissipation at 1 K compared to the existing works. The QCADdesigner version 2.0.3 tool implements the developed quantum-dot cellular automata full adder and four-bit adder circuits. The implementation results show that the developed quantum-dot cellular automata full adder and four-bit adder circuits have an improvement over other quantum-dot cellular automata full adder circuits.*

Index Terms—quantum-dot cellular automata; majority element; full adder; computer-aided design systems; high performance design.

I. INTRODUCTION

Computer arithmetic plays an important role in the information and communication applications such as a arithmetic logic unit (ALU) and cryptography. Full adders have an important role in computer arithmetic. So, the efficiency of many computer arithmetic applications is primarily determined by the efficiency of the full adder implementation [1] – [3].

Quantum-dot cellular automata (QCA) technology is a promising technology, which can continue the Moore's law development. This technology uses charge formation to information transition instead of current. As a result, circuit design in the QCA technology has advantages in comparison with conventional technologies such as CMOS technology in terms of small dimension, fast operation and low power consumption [4], [5].

Comparing the results of previous years' work to improve the efficiency of the implementation of a full adder in QCA technology [6] – [15]. In article [6] present a QCA full adder that requires 102 QCA cells and 0.1 μm^2 area. The scientists [7] designed a QCA full adder that consists of 52 QCA cells and 0.038 μm^2 area. The authors [8] designed a QCA full adder that requires 59 QCA cells and 0.043 μm^2 area. In article [9] have offered a QCA full adder that requires 71 cells and 0.06 μm^2 area. The authors [10] presented a QCA full adder that requires 38 QCA cells and 0.02 μm^2 area. The scientists [11] constructed a QCA full adder that consists of 41 QCA cells and 0.04 μm^2 area. In article [12] have presented a QCA full adder that requires 63 QCA cells and 0.05 μm^2 area. The scientists [13] designed a QCA full adder that requires 29 QCA cells and 0.02 μm^2 area. However, these full adder circuits have advantages, but the complexity and required area of full adder circuit in the QCA technology can be reduced with a described new technique in this paper.

II. BACKGROUND

Quantum-dot cellular automata technology is an emerging technology that can be utilised for developing digital circuits based on Moore's law. This new technology uses charge formation instead current for information transition. The basic element in this technology is a four dots square, which has two free electrons. Figure 1 shows the basic cell of the QCA, two methods of its placement in space and the polarization of electrons [6].

Logical majority element and inverter. Placing the cells in sequence one after another and causing them to interact with each other, it is possible to ensure the flow of information along such a conductor. Theoretically, there are two methods of constructing a conductor depending on the 45-degree or 90-degree orientation of the cells, but it is technologically difficult to produce nanocells with different orientations. With the help of QCA, various elements can be constructed to perform logical and arithmetic operations. The basic logical

nanocomponents in the theory of cellular automata are the majority element (ME) and the inverter (Fig. 2) [6].

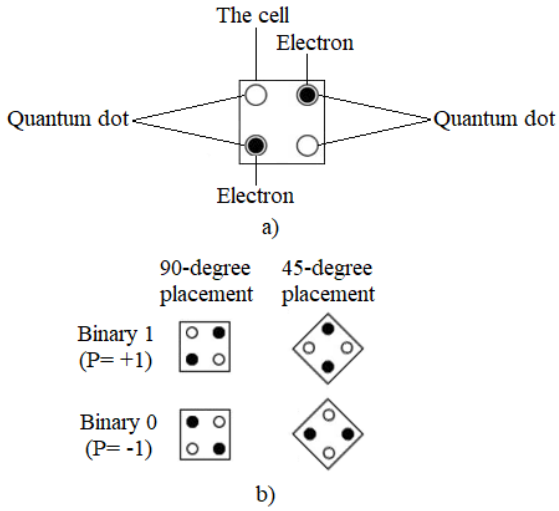
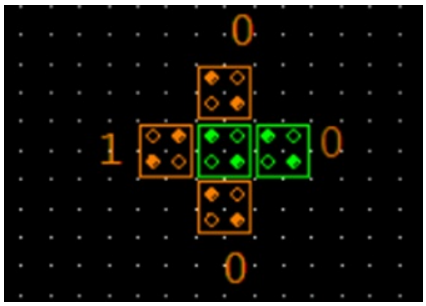
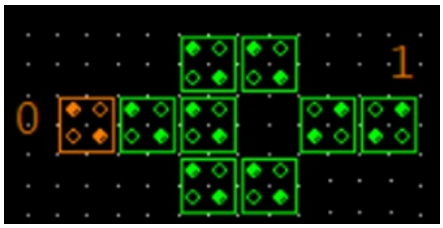


Fig. 1. Basic cell of the QSA, two methods of its placement in space and the polarization of electrons



a)



b)

Fig. 2. Three-input majority element (a) and inverter (b) based on cellular automata.

The polarization of the ME output cell coincides with the polarizations of most input cells.

Boolean expression for the majority function:

$$\text{maj}(x_2, x_1, x_0) = x_2 x_1 \vee x_2 x_0 \vee x_1 x_0 ,$$

where x_2, x_1 and x_0 are input arguments. Fixing the polarization of one of the inputs of the majority of an element as a logical "0" or a logical "1" allows you to obtain AND or OR elements, respectively:

$$\text{maj}(x_2, x_1, 0) = x_2 \cdot x_1, \quad \text{maj}(x_2, x_1, 1) = x_2 \vee x_1.$$

Such cells can be created in the process industrial manufacturing, which eliminates the need to maintain direct current through scheme.

III. The Designed QCA Full Adder Circuit

When using five-way MEs, you can build the most rational and simple one-bit adder scheme. The structural diagram of a one-bit adder is built on one five-input ME and one three-input (Fig. 3).

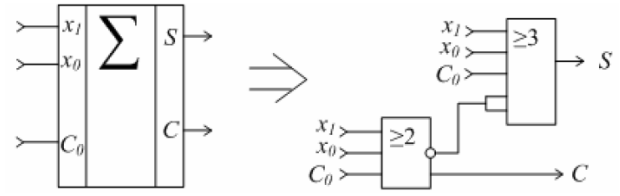


Fig. 3. Circuit of a one-bit adder based on a five-input ME

The results of the computer design of this nano circuit using CAD QCAD are shown in Figs 4 and 5.

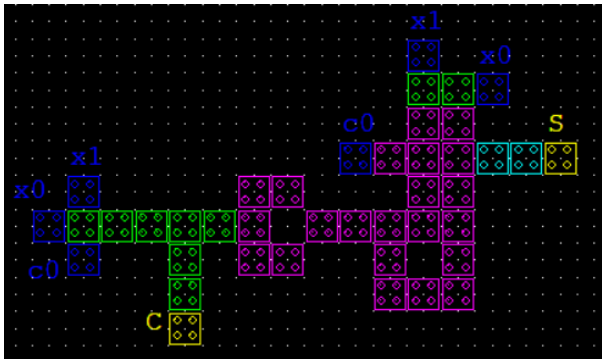


Fig. 4. The project of a full one-bit adder on a five-input ME

Fig. 5. Modeling the time characteristics of a full one-bit adder on a five-input ME

The implementation results of the designed circuit for the one-bit QCA full adder confirm the correctness of this circuit.

The functions of addition S and transfer C are determined by the rules of addition in the majority basis [7]:

$$S = \mathrm{maj}\left(x_1, x_0, C_0, \overline{C}\right) = \overline{C}\left(x_1 \vee x_0 \vee C_0\right) \vee x_1 x_0 C_0,$$
$$C = \mathrm{maj}\left(x_1, x_0, C_0\right) = x_1 \vee x_0 \vee x_1 C_0 \vee x_0 C_0.$$

The developed full-adder nano circuit is based on 41 KA, and its total size is (288×162) nm.

Three clocking zones are utilized in this circuit as follows: light blue indicates clock zone 2, violet indicates clock zone 1, and green indicates clock zone 0.

Table I summarizes the implementation results of the designed circuit for the one-bit QCA full adder compared to other one-bit QCA full adder circuits in [8] – [16].

TABLE I. THE COMPARATIVE TABLE FOR ONE-BIT QCA FULL ADDER CIRCUITS

Reference	Complexity (#cell)	Area (μm^2)	Delay (clock zone)
[8]	102	0.1	8
[9]	71	0.06	5
[10]	52	0.038	4
[11]	59	0.042	4
[12]	38	0.02	3
[13]	41	0.04	2
[14]	63	0.05	3
[15]	29	0.02	2
[16]	46	0.04	4
This paper	41	0.07	4

IV. COMPUTER ADDICT DESIGN OF A FOUR-BIT ADDER

On the basis of a one-bit full adder, a four-bit adder was built, the structural diagram of which is presented in Fig. 6.

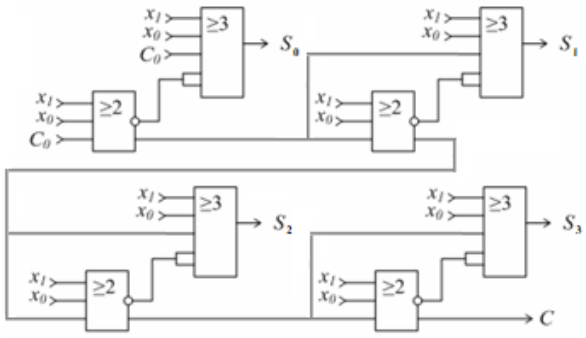


Fig. 6. Circuit of a four-bit adder based on a full one-bit adder

Computer addict design of nano circuit the four-bit adder is shown in Fig. 7.

Figure 8 shows the implementation results of the designed nano circuit for the four-bit adder.

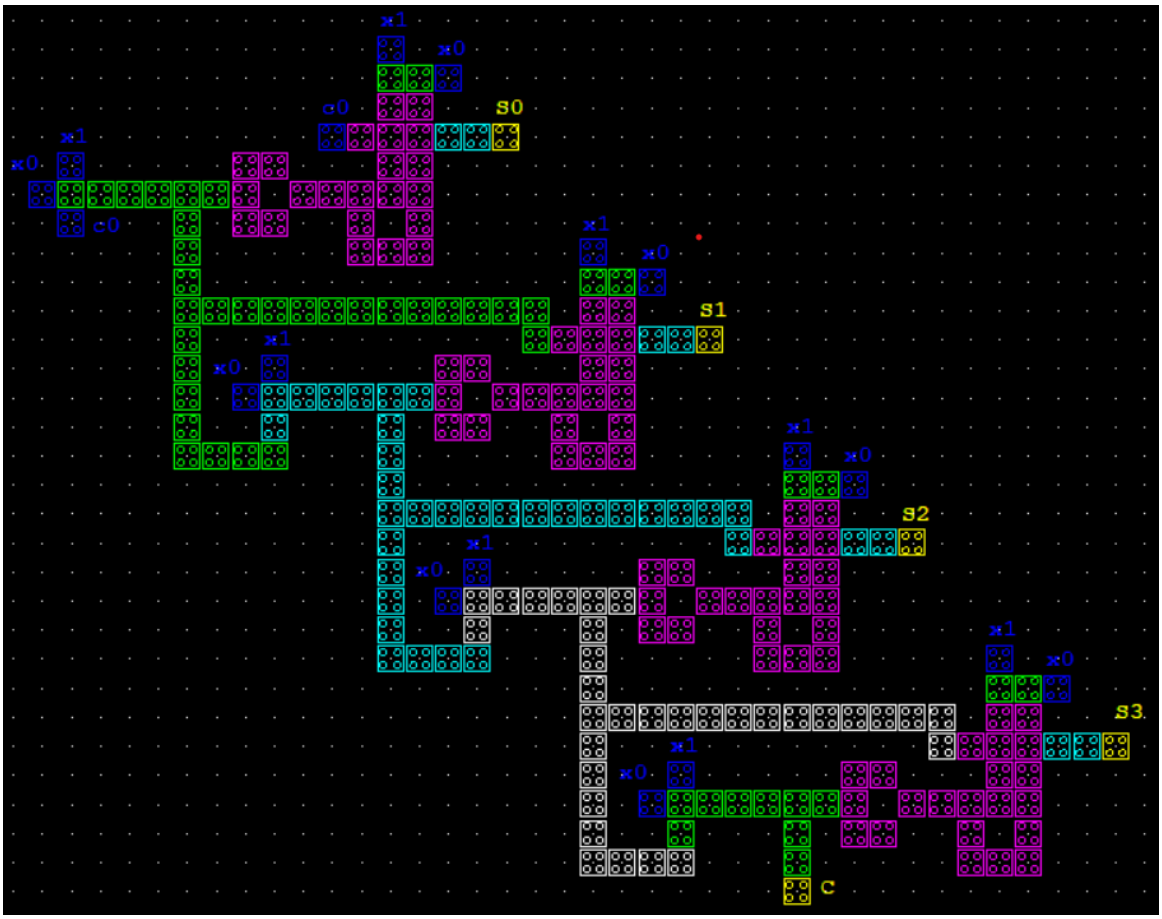


Fig. 7. The designed nano circuit of the four-bit adder

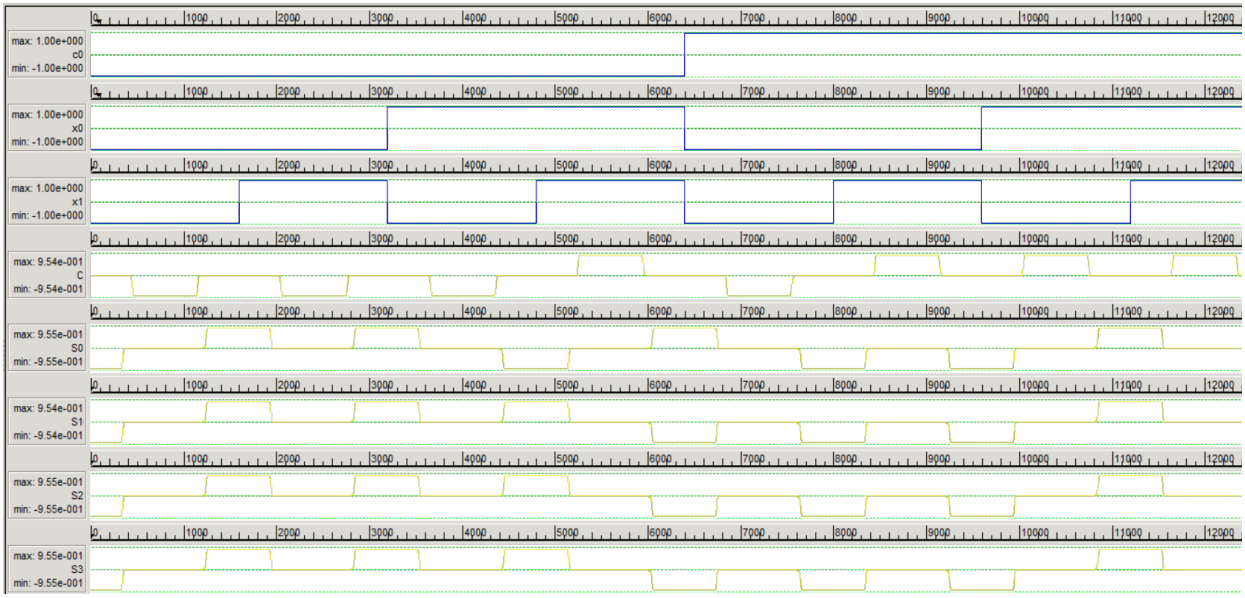


Fig. 8. The implementation results of the designed nano circuit for the four-bit adder

Table II summarizes the implementation results of the designed circuit for the four-bit QCA compared to other four-bit QCA nano circuits in [8] – [12], [14] – [17].

TABLE II. THE COMPARATIVE TABLE FOR FOUR-BIT QCA NANO CIRCUIT

Reference	Complexity (#cell)	Area (μm^2)	Delay (clock zone)
[8]	558	0.85	20
[11]	442	1	8
[9]	260	0.28	10
[10]	262	0.208	28
[12]	237	0.24	6
[14]	295	0.3	6
[15]	269	0.37	14
[17]	339	0.2542	7
[16]	187	0.2	16
This paper	231	0.49	15

V. CONCLUSION

Full adders play an important role in computer arithmetic fields. So, efficient implementation of full adders can increase the efficiency of the computer arithmetic circuits. This paper presented and evaluated an efficient full adder circuit in the QCA technology. In addition, we implemented a four-bit QCA nanocircuit based on this new one-bit QCA full adder. The designed circuits have been implemented using the QCADesigner tool version 2.0.3. The implementation results confirmed that the designed circuits outperform recent modified one-bit QCA full adder circuits and four-bit QCA circuits in [8] – [11], [14] in terms of complexity, and required area.

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О. С. Мельник, М. М. Кравець, В. М. Кравець. Чотирирозрядний наносуматор, керований п'ятивходовими мажоритарними елементами

У роботі представлено наносхему повного однорозрядного суматора на розроблених мажоритарних елементах з п'ятьма входами. Ця прогресивна конструкція повного суматора використовується для розробки нової наносхеми чотирирозрядного суматора. Запропоновано новий однорозрядний повний суматор і чотирирозрядну наносхему за технологією квантових автоматів. Створений чотирирозрядний суматор використовує лише 231 квантову комірку на площі 0,49 мкм^2. В результаті він має зменшену кількість комірок та зменшені затримки і розсіювання енергії при 1 К порівняно з відомими результатами. Реалізовано комп'ютерне проектування повної наносхеми чотирирозрядного суматора на базі чотирьох однорозрядних суматорів із застосуванням систе́ми автоматизо́ваного проєктува́ння QCAdesigner версії 2.0.3. Результати експерементальних досліджень вказують на його переважні характеристики, особливо із застосуванням п'ятивходових мажоритарних елементів.

Ключові слова—коміркові автомати з квантовими точками; мажоритарний елемент; повний суматор; системи автоматизованого проектування; висока продуктивність конструкції.

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