COMPUTER-AIDED DESIGN SYSTEMS

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NANODEVICES WITH PROGRAMMABLE LOGIC

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Abstract*—The paper describes the computer-aided design of nanoelectronic circuits with programmable logic on quantum majority components is implemented. The single-electronic component base has the greatest influence on such basic parameters of modern computer systems as performance exceeding 10 THz, power consumption less than 1 nW and submicron dimensions. Methods of constructing arithmeticological computing devices of combinational and sequential types, which realize almost complete system of logical functions both in majority and in Boolean bases, are offered. The design of reliable nanoelectronic circuits with programmable logic based on the technology of quantum automata has been described. While constructing majority circuits the interaction of Colomb forces using. The order of syntesis and programming of various types of arithmetic-logic nanodevices has been analyzed.*

Index Terms—Quantum cellular automata; majority logic; computer-aided design.

I. INTRODUCTION

It is possible to eliminate the contradiction between the versatility and the specificity of functions by developing nanodevices with programmable logic (NDPL), the algorithms of which can be changed at the request of the developer of specific computing equipment [1]. One programmable nanocircuit replaces from 30 to 150 middle-scale integrated circuits.

The proposed article discusses the practical principles of building reliable computer nanosystems using the developments of Kharkiv scientists [1], who were among the first to introduce a majority methodology for designing electronic circuits and circuits. These previous advances make it possible to use computer-aided design of multifaceted nano-devices at the current level.

The volume of research and computer-aided design (CAD) are very energy-efficient (< 1 nW) and ultra-fast (up to 1 ps) nanosized devices based on modern quantum cellular automata (QCA) technology. The task of creating nanodevices with programmable logic is solved, which has significant advantages over binary CMOS components in the sense of energy efficiency, examples of the expansion of the frequency range up to 10 THz and increased noise immunity. However, the present disadvantage of QCA is the narrow, practically cryogenic range (10 mK) of operating temperatures on the nanodevices are widely used in the aerospace industry.

II. PROBLEM STATEMENT

For the implementation of adaptive systems, it is necessary to be able to programmatically change their technical characteristics in the process or before starting work. In order to reduce the cost of manufacturing nanodevices systems and increase the reliability of their operation, it is advisable to perform them on the same cell type with the same configuration of connections between cells.

As such a cell, NDPL consisting of three universal majority elements (UME), respectively, interconnected (Fig. 1) can be used to construct majoritarian adaptive systems. Information (x_3, x_2, x_1, x_0) and programmable (r_2, r_1, r_0) signals are fed to the inputs of NDPL [2].

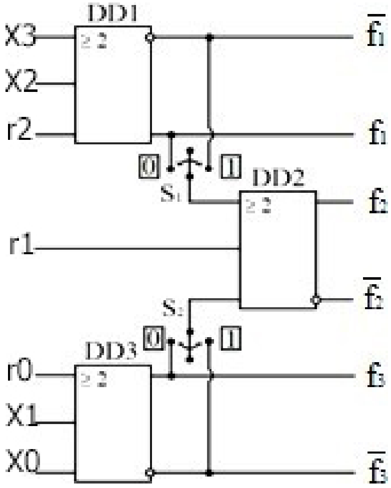


Fig. 1. Structural diagram of the universal NDPL

With NDPL of this type, all $2^{2^2}=16$ and $2^{2^3}=256$ functions of two and three arguments can be implemented, including the functions of sum, difference, product, transfer and borrow, functions of one, two and three elements of memory, as well as most functions of four and five of arguments. A peculiarity of NDPL is that it can be modified by the program its logical capabilities and connections, which allows it to be used to build majority adaptive systems.

Table I shows the most important functions in the majority basis, which are implemented on the basis of NDPL.

Nanodevices with programmable logic is a functionally complete device, as its composition includes functionally complete UME. Synthesis of majority systems based on NCPL is recommended to be performed in the following ordery [1]:

- given or received boolean functions are represented in the majority basis;
- minimize the obtained majority function;
- in the Table I a line is found equivalent to the minimum form of the majority function;
- draw up a block diagram of a given adaptive system, taking into account NDPL capabilities.

TABLE I. EXAMPLES OF THE MOST IMPORTANT FUNCTIONS THAT CAN BE IMPLEMENTED ON NANODEVICES WITH PROGRAMMABLE LOGIC

No	r_2	r_1	r_0	f_1	f_2	f_3	Number of output functions
1	0	0	0	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, x_1x_0, 0)$	$maj(x_1, x_0, 0)$	24
2	0	0	1	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, x_1 \vee x_0, 0)$	$maj(x_1, x_0, 1)$	24
3	0	1	0	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, x_1x_0, 1)$	$maj(x_1, x_0, 0)$	24
4	0	1	1	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, x_1 \vee x_0, 1)$	$maj(x_1, x_0, 1)$	24
5	1	0	0	$maj(x_3, x_2, 1)$	$maj(x_3 \vee x_2, x_1x_0, 0)$	$maj(x_1, x_0, 0)$	24
6	1	0	1	$maj(x_3, x_2, 1)$	$maj(x_3 \vee x_2, x_1 \vee x_0, 0)$	$maj(x_1, x_0, 1)$	24
7	1	1	0	$maj(x_3, x_2, 1)$	$maj(x_3 \vee x_2, x_1x_0, 1)$	$maj(x_1, x_0, 0)$	24
8	1	1	1	$maj(x_3, x_2, 1)$	$maj(x_3 \vee x_2, x_1 \vee x_0, 1)$	$maj(x_1, x_0, 1)$	24
9	0	0	x_4	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, maj(x_1, x_0, x_4), 0)$	$maj(x_1, x_0, x_4)$	44
10	0	x_4	0	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, x_1x_0, x_4)$	$maj(x_1, x_0, 0)$	40
11	0	x_4	x_5	$maj(x_3, x_2, 0)$	$maj(x_3 x_2, maj(x_1, x_0, x_5), x_4)$	$maj(x_1, x_0, x_5)$	76
12	x_4	0	0	$maj(x_3, x_2, x_4)$	$maj(maj(x_3, x_2, x_4), x_1x_0, 0)$	$maj(x_1, x_0, 0)$	44
13	x_4	0	x_5	$maj(x_3, x_2, x_4)$	$maj(maj(x_3, x_2, x_4), maj(x_1, x_0, x_5), 0)$	$maj(x_1, x_0, x5)$	48
14	x_4	x_5	0	$maj(x_3, x_2, x_4)$	$maj(maj(x_3, x_2, x_4), x_1x_0, x_5)$	$maj(x_1, x_0, 0)$	76
15	x_4	x_5	x_6	$maj(x_3, x_2, x_4)$	$maj(maj(x_3, x_2, x_4), maj(x_1, x_0, x_6), x_5)$	$maj(x_1, x_0, x_6)$	80
16	1	f_2	0	$maj(x_3, x_2, 1)$	$maj(x_3 \vee x_2, x_1x_0, f_2)$	$maj(x_1, x_0, 0)$	Trigger with control inputs
17	f_1	0	f_3	$maj(x_3, x_2, f_1)$	$maj(maj(x_3, x_2, f_1), maj(x_1, x_0, f_3), 0)$	$maj(x_1, x_0, f_3)$	Two triggers
18	f_1	f_2	f_3	$maj(x_3, x_2, f_1)$	$maj(maj(x_3, x_2, f_1), maj(x_1, x_0, f_3), f_2)$	$maj(x_1, x_0, f_3)$	Three triggers
19	f_2	f_2	$\overline{f}_2$	$maj(x_3, x_2, f_2)$	$maj(maj(x_3, x_2, f_2), maj(x_1, x_0, f_2), \overline{f}_2)$	$maj(x_1, x_0, \overline{f}_2)$	Cumul. adder

In the Table I x_6, x_5, x_4, x_3, x_2, x_1, x_0 are input information signals presented either in direct or inverse codes; r_2, r_1, r_0 are programmable signals; f_3, f_2, f_1 are the output functions.

III. PROBLEM SOLUTION

We synthesize, for example, using CAD QCADesigner [3] logic function:

$$f_2 = maj\left(x_3 \vee x_2,\ x_1 \vee x_0,\ 0\right), \qquad (1)$$

which corresponds to the majority equivalent in the sixth row of Table I. Two additional outputs of NDPL form the functions of logical addition in pairs of two of the four arguments:

$$f_1 = x_3 \vee x_2 = maj\left(x_3, x_2, 1\right), \qquad (2)$$

$$f_3 = x_1 \vee x_0 = maj\left(x_1, x_0, 1\right). \qquad (3)$$

In order to program the functions (1), (2) and (3), in the structural diagram of the NDPL (Fig. 1) the switches S_1 and S_2 should be switched to state 0, and at the programming inputs the polarizations $+P = 1$ should be set for the inputs $r_2 = r_0 = 1$, and $-P = -1$ for input $r_1 = 0$.

In Figure 2a is an NDPC that is based on the QCA Designer CAD workspace [3]. It consists of 37 quantum cells 18×18 nm in size with 4 quantum dots with a diameter of 5 nm and a distance between centers of 20 nm. The total size of NDPL (198×218) nm^2. It has four information inputs x_3, x_2, x_1 and x_0, three programming inputs with polarizations $+P = 1$ and $-P = -1$, and three pairs of complementary outputs f_1, f_2 and f_3. The energy consumption of one clock period has only from 3.8×10^{-23} *J* to 9.8×10^{-22} *J*.

The results of computer simulation of the NDPL temporal characteristics are shown in Fig. 2b. Positive impulses correspond to positive polarizations $+P = 1$, and negative – negative polarizations $-P = -1$.

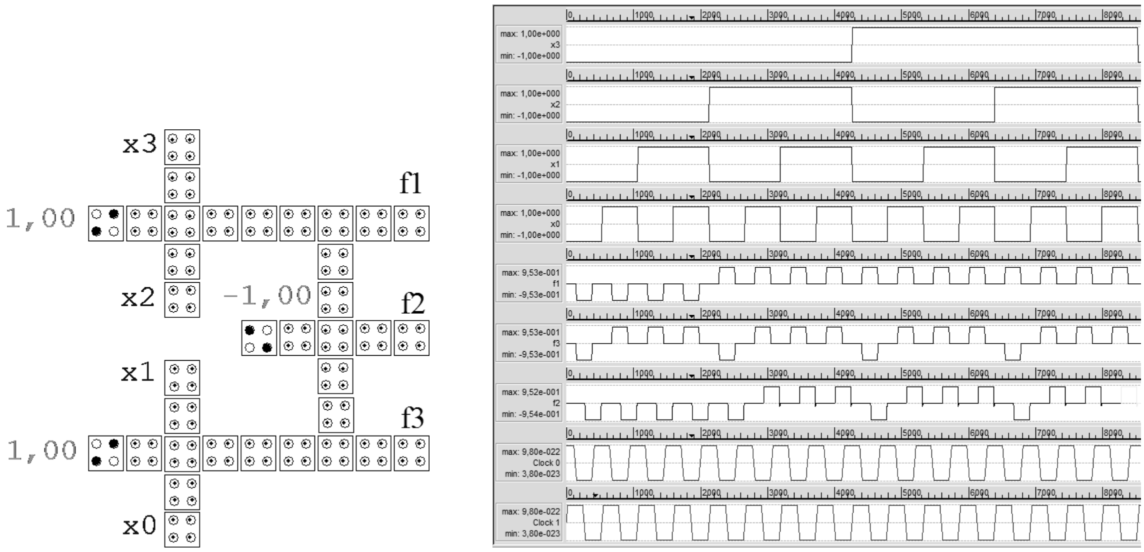
The corresponding truth table of NDPL for this programming mode is given in Table II.

By changing the polarization at the inputs r_2, r_1, r_0, and switching the keys S_1 and S_2, the seven-input NDPL (see Fig. 1) can be programmed to obtain 192 logical functions of two- and four-input combination circuits.

Next, we synthesize, for example, the sequential circuit of the 16th variant of Table I in the composition of two major elements with separate inputs x_3, x_2 and x_1, x_0. The direct outputs f_1 and f_3 of these majority elements are the inputs of the RS trigger, f_2 feedback.

In Figure 3a is constructed this sequential nanocircuit in the format of QCADesigner, and the results of modeling its time characteristics are shown in Fig. 3b. It has a size (350×240) nm^2 and consists of 48 quantum automata.

The verification table of the states of the single-trigger NDPL is presented in Table III.



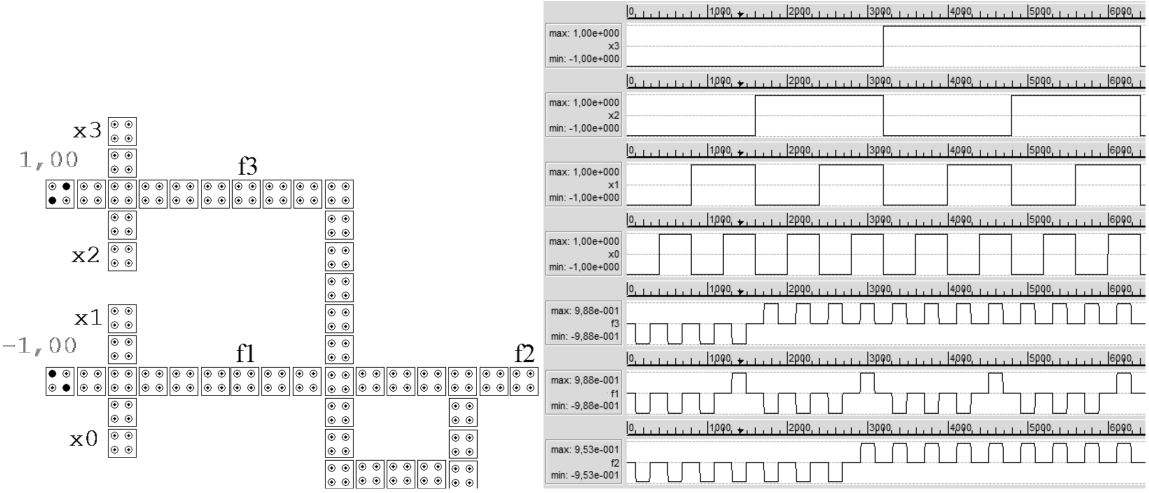
(a) (b)

Fig. 2. Computer-aided design of NDPL of combination type on quantum automatons: (a) is the nanocircuit; (b) is the waveforms

TABLE II. FUNCTION TRUTH TABLE $maj(x_3, x_2, 1)$, $maj(x_3 \vee x_2, x_1 \vee x_0, 0)$ AND $maj(x_1, x_0, 1)$

x_3	x_2	x_1	x_0	f_1	f_2	f_3
0	0	0	0	0	0	0
0	0	0	1	0	0	1
0	0	1	0	0	0	1
0	0	1	1	0	0	1
0	1	0	0	1	0	0
0	1	0	1	1	1	1
0	1	1	0	1	1	1
0	1	1	1	1	1	1
1	0	0	0	1	0	0
1	0	0	1	1	1	1
1	0	1	0	1	1	1

1	0	1	1	1	1	1
1	1	0	0	1	0	0
1	1	0	1	1	1	1
1	1	1	0	1	1	1
1	1	1	1	1	1	1



(a) (b)

Fig. 3. Computer-aided design of NDPL sequences on QCA: (a) is the circuit of nanodevice; (b) is the waveforms

TABLE III. FUNCTION TRUTH TABLE $maj(x_3 \vee x_2,\ x_1x_0,\ f_2)$

x_3	x_2	x_1	x_0	f_1	f_2	f_3
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	1	0	0	0	0
0	0	1	1	0	0	1
0	1	0	0	1	0	0
0	1	0	1	1	0	0
0	1	1	0	1	0	0
0	1	1	1	1	1	1
1	0	0	0	1	1	0
1	0	0	1	1	1	0
1	0	1	0	1	1	0
1	0	1	1	1	1	1
1	1	0	0	1	1	0
1	1	0	1	1	1	0
1	1	1	0	1	1	0
1	1	1	1	1	1	1

IV. CONCLUSIONS

In the next decade, semiconductor components of the large-scale integrated circuits will reach quantum-thermodynamic limits and will not be able to meet the increasing requirements of computational efficiency. Therefore new nanotechnologies are being actively developed to deliver significantly higher efficiency. One of these developments is quantum cellular automata and devices with programmable logic created on their basis. As stated above, it is these devices that will provide the implementation of a complete system of logical functions for both combinational and sequential logic arithmetic devices.

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О. С. Мельник, І. І. Юрчик. Нанопристрої з програмованими характеристиками

В роботі реалізовано автоматизоване проектування наноелектронних пристроїв з програмованою логікою на квантових мажоритарних компонентах. Запропоновано методи побудови арифметикологічних обчислювальних пристроїв комбінаційного та послідовностного типів, що реалізують майже повну систему логічних функцій як у мажоритарному, так і в булевому базизах. Описано проектування надійних наноелектронних схем з програмованою логікою, які базуються на технології квантових автоматів. Конструювання мажоритарних схем враховує кулонівські сили взаємодії. Проаналізовано синтез та програмування різних типів арифметико-логічних нанопристроїв.

Ключові слова: квантові автомати; мажоритарна логіка; автоматизоване проектування.

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А. С. Мельник, И. И. Юрчик. Наноустройства с программированой логикой

В работе реализовано автоматизированное проектирование наноэлектронных схем с программируемой логикой на квантовых мажоритарных компонентах. Предложены методы построения арифметико-логических вычислительных устройств комбинационного и последовательностного типов, реализующих почти полную систему логических функций как в мажоритарном, так и в булевом базах. Описано проектирование надёжных наноелектронных схем с программированой логикой, которые базируются на технологии квантовых автоматов. Конструирование мажоритарных схем учитывает кулоновские силы взаимодействия. Проанализированы синтез и программирование различных типов арифметико-логических наноустройств.

Ключевые слова: квантовые автоматы; мажоритарная логика; автоматизированное проектирование.

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