COMPUTER-AIDED DESIGN SYSTEMS

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MAJORITY NANO-DEVICES OF SEQUENTIAL TYPE

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Abstract**—***The paper describes the computer-aided design of reliable sequential nanoscale devices with majority structures. When constructing majority nanocircuits on the basis of technology of cellular quantum automates, the theory of finite automata is used. Basic principles of construction and peculiarities of trigger nanoelements functioning are considered. The developed mathematical models of high-speed one-electron nanocounters of addition and subtraction. Quantum cellular automata logic designers and circuits require a fast and accurate modeling and design tool to determine the functionality of quantum cellular automata circuits. The QCADesigner (software) gives the designer the ability to quickly develop and create quantum cellular automata by providing a wide range of computer-aided design tools. In addition, several simulation engines facilitate quick and accurate modeling. Sequential nanoscale devices were created using the QCADesigner.*

Index Terms—Majority element; sequential nanodevices; quantum automata; one-electronics; computer aided design.

I. INTRODUCTION

The volume of research and computer design are very energy-efficient (10 nW) and ultra-fast (up to 1 ps) nanosized single-electron memory circuits based on modern quantum cellular automata (QCA) technology. The task of creating complex trigger schemes with the use of new principles of majority choice logic is solved, which has significant advantages over binary complementary metal–oxide–semiconductor (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 of operating temperatures on the electronic devices are widely used in the aerospace industry. The feature of the sequential single-electron nanodevices is the dependence of the output signal not only on current inputs of logical variables, but also on those values of the variables that acted at the inputs at the previous moment of time. To use these conditions, the values of variables must be remembered by a logical nanodevice. The function of storing values of logical variables in digital nanocircuits is performed by triggers.

II. PROBLEM STATEMENT

Majority nanodevices with memory differ from majority nanodevices of a combinational type of presence of feedback circuits. Such nanodevices are called automata with memory. Figure 1 shows a generalized circuit of an automata with memory.

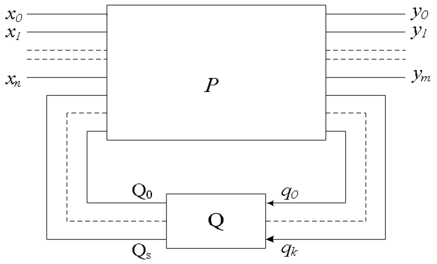


Fig. 1. General circuit automata with memory

Let introduce the designation: $X=(x_0,x_1,...x_n)$ is the set of input signals of the automaton with memory; $Y=(y_0,y_1,...y_m)$ is the set of output signals of the automaton with memory; $q=(q_0,q_1,...q_k)$ is the set of excitation signals; $Q=(Q_0,Q_1,...Q_s)$ is the set of internal states of an automaton with memory.

Majority nanodevice with memory is given by two functions: the function of transitions and the function of outputs [1].

The algorithm for synthesizing single-electron nanodevices with memory on the basis of majority elements (ME) is formed as follows: [2], [3]

1) determine the system of transitions and nanodevice outputs;
2) choose type of elementary automata;
3) compose a generalized table of transitions, outputs and excitation functions of a given nanodevice;

4) compose an equation for the outputs and excitation functions on the basis of a generalized table;

5) convert majority equations for their implementation;

6) compose a structural ciruit of a nanodevice on the basis of transformed equations.

Following the above algorithm, we will synthesize basic nanodevices with feedback.

III. BASIC IDEA

Let's take conditions: if, $Q=1$, $\bar{Q}=0$, then the trigger is in the state of the installation, if, $Q=0$, a $\bar{Q}=1$, then the trigger is in a reset state.

Existing types of triggers can be classified according to different features. Most often triggers are classified according to the type of information (setting) inputs used.

The trigger with the counting input (T-trigger) must change its state to the opposite with the arrival of each regular input signal. Based on the operating conditions of a given nanodevices and a transition matrix of a selected elementary automata, we compile a generalized table of transitions and the excitation function of the trigger with the counting input (Table I T-trigger transition).

Using Table I, lets get expressions for the excitation function q:

$$q=\overline{X_s}Q_t \vee X_s\overline{Q_t} \text{ (unit)},$$

$$q=(X_s \vee Q_t)(\overline{X_s} \vee \overline{Q_t})=\overline{X_sQ_t}(X_s \vee Q_t) \text{ (zero)}.$$

TABLE I. T-TRIGGER TRANSITION

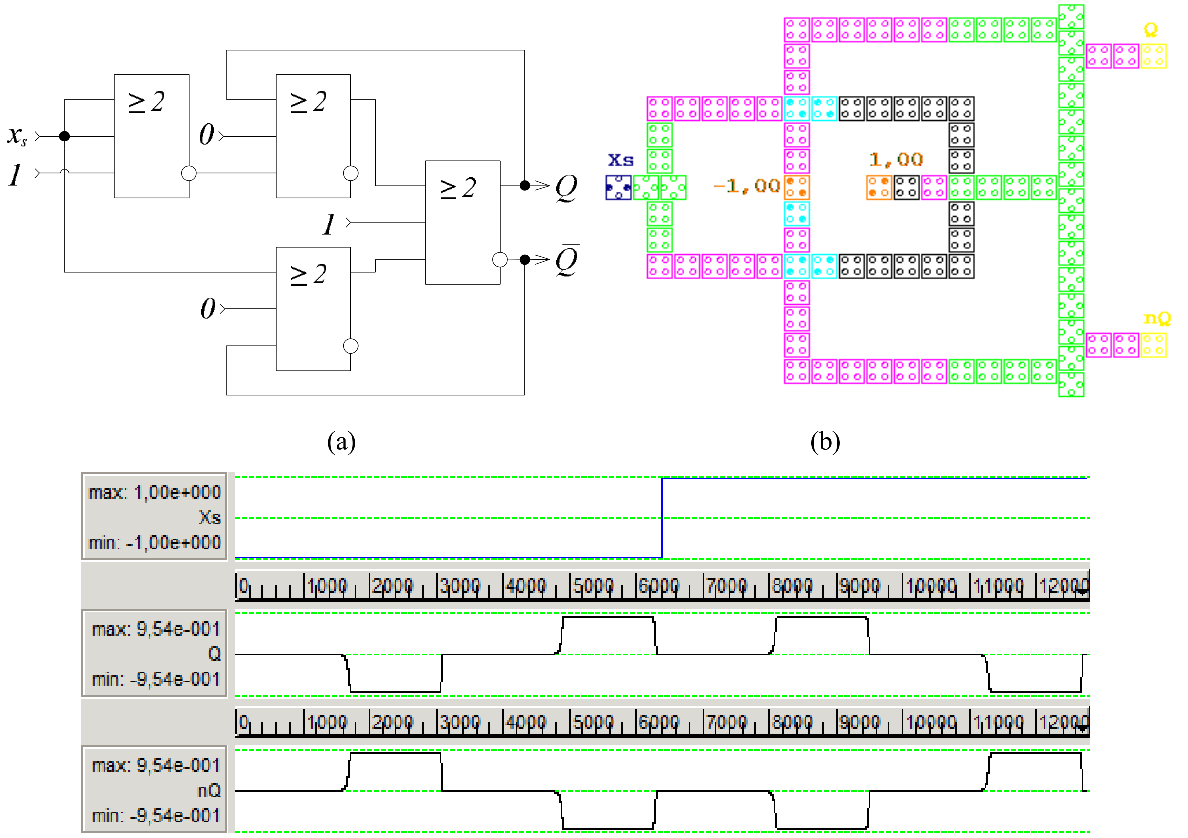
x_s	Q_t	Q_{t+1}	Q
0	0	0	0
0	1	1	1
1	0	1	1
1	1	0	0

Let convert the obtained relations for their realization using majority element (ME):

$$q=\mathrm{maj}\big(\mathrm{maj}(\bar{x}_s, Q_t, 0), \mathrm{maj}(x_s, \bar{Q}_t, 0), 1\big), \quad (1)$$

$$q=\mathrm{maj}\big(\mathrm{maj}(\overline{x_s, Q_t}, 0), \mathrm{maj}(x_s, Q_t, 1), 0\big). \quad (2)$$

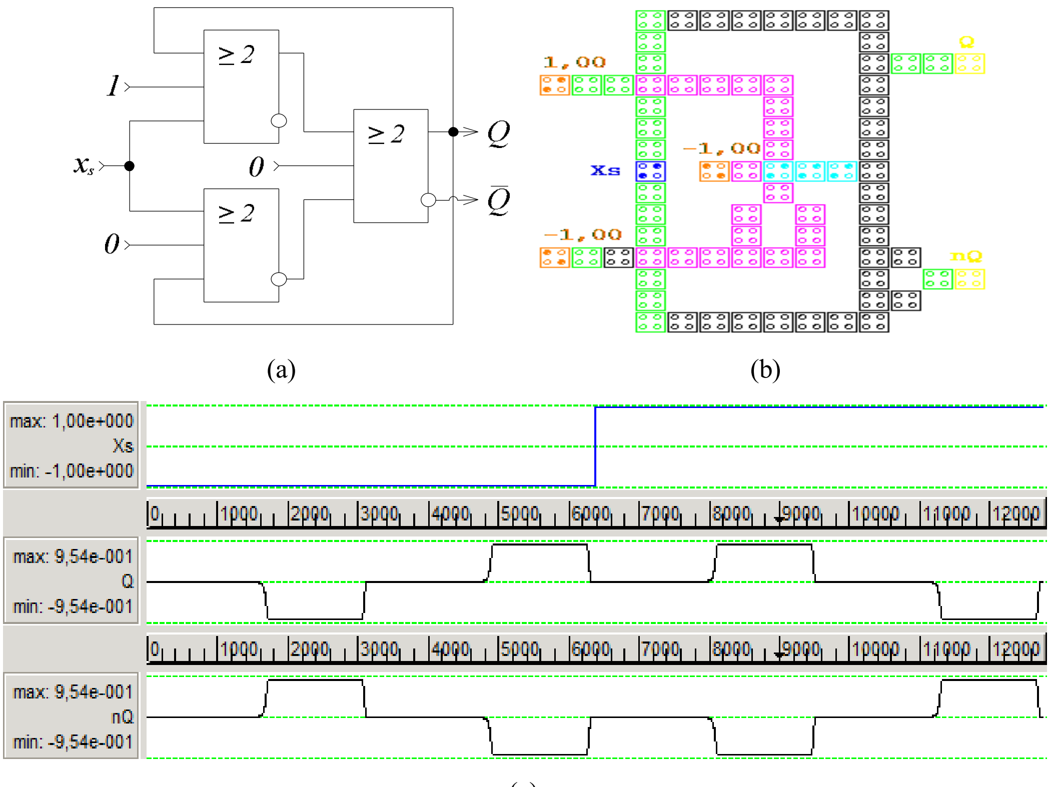
Structural circuits of triggers with logic inputs, constructed according to equations (1) and (2), are shown in Figures 2 and 3, respectively.



(a) (b)

(c)

Fig. 2. T-trigger (modification 1): circuit on majority elements (a); nanocircuit on quantum automata (b); and results of simulation of signals of logical states (c) in CAD QCADesignet [4]



(a) (b)

(c)

Fig. 3. T-trigger (modification 2): circuit on majority elements (a); nanocircuit on quantum automata (b); and results of simulation of signals of logical states (c) in CAD QCADesigner

IV. SYNTHESIS OF NANOCOUNTERS

A counter is called a sequencing device designed to count incoming pulses and fix their numbers in a binary code. The meters are constructed on the basis of *N* of the same type of interconnected bit circuits, each of which in general consists of a trigger and some combination scheme designed to generate trigger control signals.

The synthesized nanoscales on the basis of ME are much simpler microelectronic analogues, higher speed and energy efficiency. When synthesizing the counters as an elementary automaton we use the T-trigger (Figs 2a, and 3a).

A generalized table of transitions and functions of excitation of a nanocounter of addition is made according to the conditions of the counter and the matrix of transitions (6) of the T-trigger (Table II Nanocounter transition).

Based on Table II, the following equations can be written as:

$$q_s^0 = x\,, \tag{3}$$

$$q_s^1 = xQ_t^0,\ q_s^1 = \mathrm{maj}\left(x, Q_t^0, 0\right), \tag{4}$$

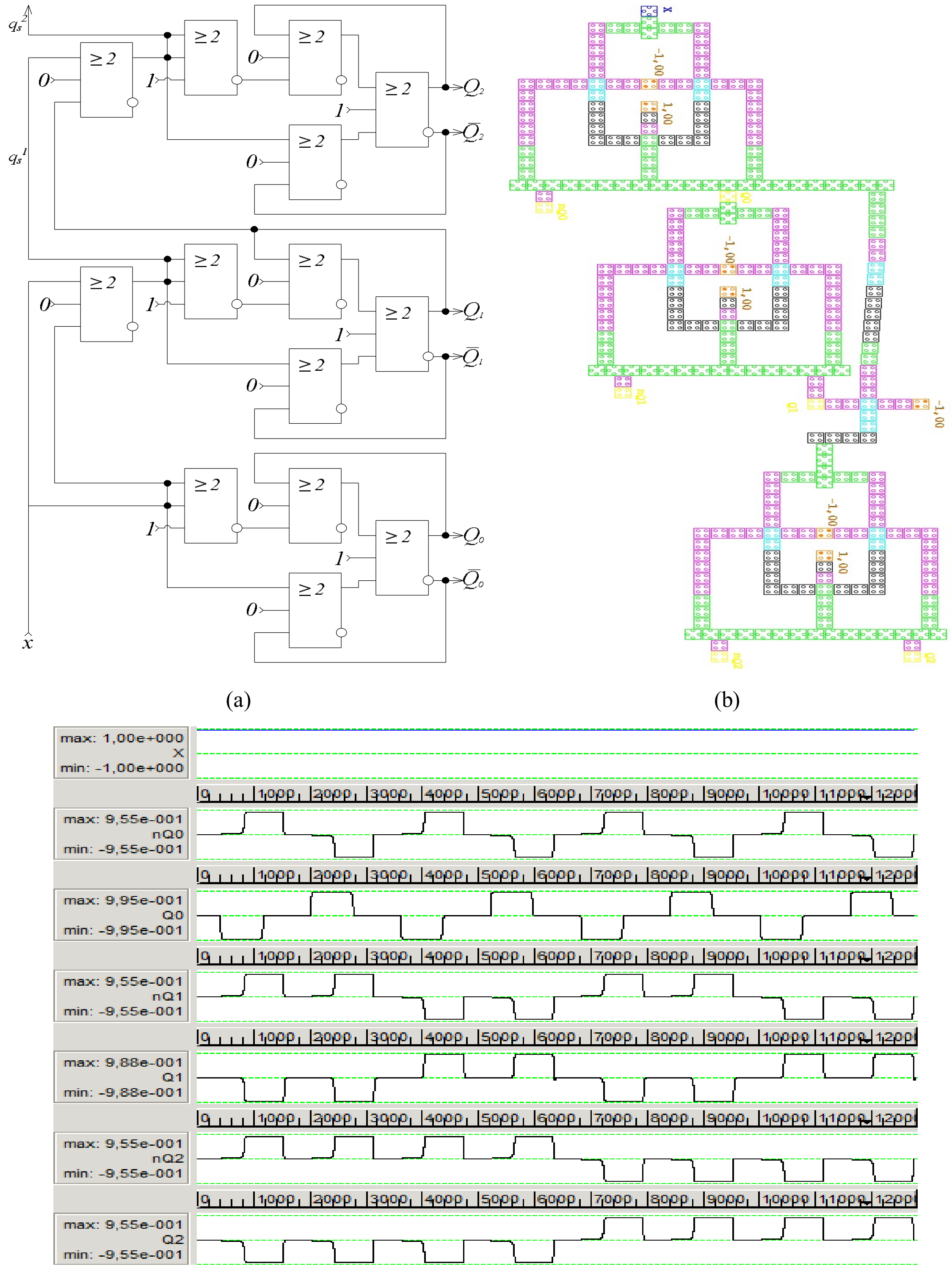
$$q_s^2 = x\overline{Q}_t^0\overline{Q}_t^1 = q_s^1 Q_t^1,\ q_s^2 = \mathrm{maj}(q_s^1, \overline{Q}_t^1, 0)\,. \tag{5}$$

TABLE II. NANOCOUNTER TRANSITION

x	Q_t^2	Q_t^1	Q_t^0	Q_{t+1}^2	Q_{t+1}^1	Q_{t+1}^0	q_s^0	q_s^1	q_s^2
1	0	0	0	0	0	1	1	0	0
1	0	0	1	0	1	0	1	1	0
1	0	1	0	0	1	1	1	0	0
1	0	1	1	1	0	0	1	1	1
1	1	0	0	1	0	1	1	0	0
1	1	0	1	1	1	0	1	1	0
1	1	1	0	1	1	1	1	0	0
1	1	1	1	0	0	0	1	1	1

On the basis of expressions (3) – (4) it is possible to construct counters with group or through transitions. A group-driven counter has a high-speed performance, but for its implementation, multi-entry elements are required. When used in a chain of ME transport on quantum automata [1], [3] can be constructed using the same formulas (3) – (4). The fast-acting nanoscale addition with a transverse transfer and the results of simulating its time characteristics are shown in Fig. 4.

The time of account in this case depends on the time of propagation of signals in the chain through the transfer.



(a) (b)

(c)

Fig. 4. Block diagram of a high-speed nanocounter with a group transfer (a); a nanocircuit on quantum automata (b); and the results of simulation of signals (c) in CAD QCADesigner

The total number of quantum cellular nanocounters is 278. The sizes of quantum cellular automata (18 × 18) nm^2. The distance between the centers of quantum cellular automata is 20 nm. Diameters of quantum islands 5 nm.

The time of account in this case depends on the time of propagation of signals in the chain through the transfer.

The total number of quantum cellular nanocounters is 278. The sizes of quantum cellular automata (18 × 18) nm^2. The distance between the

centers of quantum cellular automata is 20 nm. Diameters of quantum islands 5 nm.

The total dimensions of the nanocounter add up (1120 × 540) nm.

The block diagram and nanocircuit of a subtracting counter with a transverse transfer are shown in Fig. 5a and b. The results of simulation of this circuit are shown in Fig. 5c.

Based on Table III, the following equations can be written as:

$$q_s^0 = x, \tag{5}$$

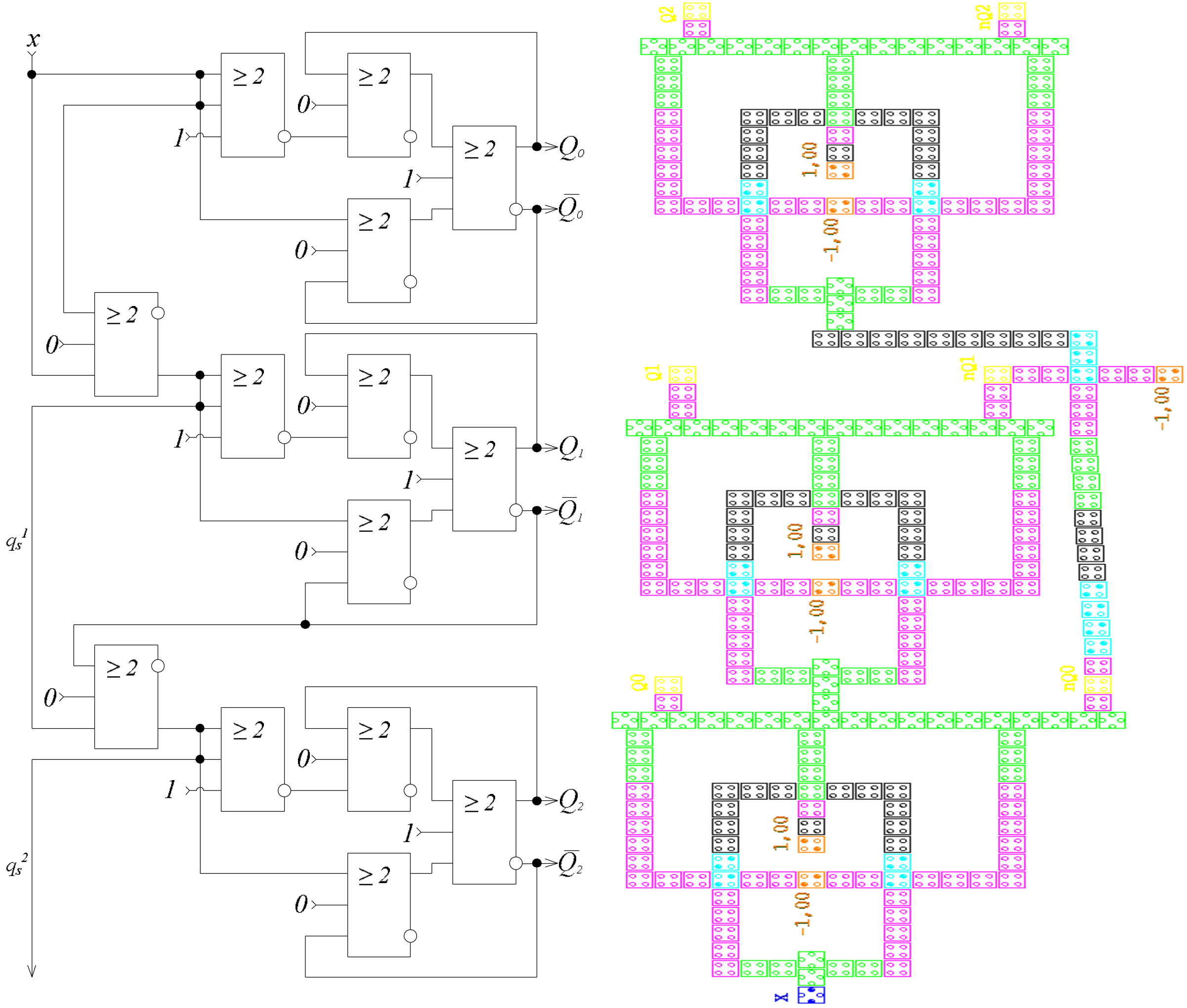
$$q_s^1 = x\overline{Q}_t^0, q_s^1 = \mathrm{maj}(x, Q_t^0, 0), \tag{6}$$

$$q_s^2 = x\overline{Q}_t^0\overline{Q}_t^1 = q_s^1 Q_t^1, q_s^2 = \mathrm{maj}(q_s^1, \overline{Q}_t^1, 0). \tag{7}$$

Total number of nanocircuit quantum cellular automata the subtracting counter is 299. The sizes of quantum cellular automata (18 × 18) nm. The distance between the centers of quantum cellular automata is 20 nm. Diameters of quantum islands 5 nm. Overall dimensions of the subtractor nanocounter is (1130 × 430) nm.

TABLE III. TRANSITIONS OF A SUBTRACTING NANOCOUNTER

x	Q_t^2	Q_t^1	Q_t^0	Q_{t+1}^2	Q_{t+1}^1	Q_{t+1}^0	q_s^0	q_s^1	q_s^2
1	0	0	0	1	1	1	1	1	1
1	1	1	1	1	1	0	1	0	0
1	1	1	0	1	0	1	1	1	0
1	1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	1	1	1	1
1	0	1	1	0	1	0	1	0	0
1	0	1	0	0	0	1	1	1	0
1	0	0	1	0	0	0	1	0	0



(a) (b)

Fig. 5. Block diagram of a high-speed subtractive nanocounter with transverse transfer (a); a nanocircuit on quantum automata (b); and the results of signal simulation (c) in CAD QCADesigner

(c)

Fig. 5. Ending. (See also p. 27)

V. CONCLUSION

The difference between the proposed solutions for computer simulation of sequential nanoscale from existing methods of automated development of microcircuits consists in the use of universal majority elements, which have greater noise immunity and eliminate problems of synchronization of work. In addition, Majority logic provides more possibilities for multivariate synthesis of trigger circuit than the common Boolean logic. One of the most promising directions for increasing the reliability and noise immunity in the action of their inputs are the random fluctuations of signals of the work of computing systems are majoritarian elements of the nanoelectronic type. Was developed robust sequence nanodevice and combination types using QCADesigner's automated design system. The aim of designing a reliable stratification of nanocircuit and improving their operational efficiency has been achieved, but the presence of defects in the molecular technology of the manufacture of quantum cellular automata requires further work in the direction of automated design of nanodevices.

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О. С. Мельник, Д. Г. Мількe. Мажоритарні нанопристрої послідовностного типу

У роботі описується комп’ютерне проектування надійних послідовностних наноприладів з мажоритарними структурами. Для побудови мажоритарних наносхем на базі технологій коміркових квантових структур використовується теорія кінцевих автоматів. Розглянуто базові принципи побудови та особливості функціонування тригерних наноелементів. Розроблено математичні моделі швидкодіючих одноелектронних нанолічильників додавання і віднімання. Створено послідовностні нанопристрої із застосуванням системи автоматизованого проектування QCADesigner.

Ключові слова: мажоритарний елемент; послідовностні нанопристрої; квантові автомати; одноелектроніка; автоматизоване проектування.

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А. С. Мельник, Д. Г. Мильке. Мажоритарные наноприборы последовательностного типа

В работе описывается компьютерное проектирование надежных последовательностных наноприборов с мажоритарными структурами. При построении мажоритарных наносхем на базе технологий воротниковых квантовых структур используется теория конечных автоматов. Рассмотрены базовые принципы построения и особенности функционирования триггерных наноэлементов. Разработаны математические модели быстродействующих одноэлектронных наносчетчиков сложения и вычитания. Созданы последовательностные наноприборы с применением системы автоматизированного проектирования QCADesigner.

Ключевые слова: мажоритарный элемент; последовательностные наноприборы; квантовые автоматы; одноэлектроника; автоматизированное проектирование.

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