

UDC 620.3.049.77(045)
DOI:10.18372/1990-5548.88.20977

Oleksandr Melnyk

NANODEVICES WITH MAJORITY STRUCTURES

Department of Electronics, Robotics, Monitoring & IoT Technologies
State University "Kyiv Aviation Institute", Kyiv, Ukraine
E-mail: oleksandr.melnyk@npp.kai.edu.ua ORCID 0000-0003-1072-5526

Abstract—The article is devoted to the analysis of topical antagonistic issues regarding the implementation of new computer programming methods that can be used to reproduce heterogeneous binary functions of several arguments based on micro- and nanoelectronic multiplexer modules. The growth of specialization of modern large integrated circuits comes into conflict with their universality, which increases the cost of design work and reduces the production volumes of typonominal devices. The trade-off between specialization and versatility should be minimized by computer-aided design of micro- and nano-sized modules with programmable logic. Programming is not performed to create algorithms for processing discrete information, as implemented by a microprocessor, but by logical settings of multiplexer micro- and nanodevices. The results of the combined simulations obtained in the work confirm the equivalence of their functioning, as well as the advantages of cell-based Coulomb nanomultiplexers in reliability, technological scalability, energy efficiency, speed, and disadvantages in exclusively cryogenic ultra-low temperature applications. Obviously, the evolution of microelectronics will continue only in the context of the widespread introduction of nanoscale modules with new functional principles of operation.

Keywords—Micro- and nanomodules, programmable logic devices, majority logic, computer-aided design, multiplexers.

I. INTRODUCTION

Programming of micro- and nanoelectronic multiplexer devices does not involve creating algorithms for processing input multi-argument functions by changing the working programs, as is usually implemented by microprocessors. It concerns technological changes in the internal structure of nanoelectronic circuits in such a way as to ensure the implementation of the necessary functions at the structural-logical level.

II. ANALYSIS OF RECENT RESEARCH

Experiments in the field of programmable micro- and nanomodules are actively developing, and a significant part of the attention of scientists is focused on the computer design of such systems. The first significant developments in this field occurred as a result of the creation of multi-structure systems built on the basis of universal, functionally complete modules. Such modules turned out to be one of the promising trends in the development of modern microelectronics [1]. These studies demonstrated the possibility of automated design of micro- and nanocircuits capable of implementing 16 two-argument and 256 three-argument functions based on multiplexers [2]. However, there are significant difficulties in simplifying these circuits, which leads to excessive complexity in implementation and their universal application. An important aspect of the research was the improvement of micro- and nanocircuit

programming methods for reproducing various functions of Boolean algebra and majority logic [3], [4]. The scientists proposed effective algorithms for automated programming of microcircuits with a high level of integration, which became the basis for the further development of nanodevices with programmable logic [6]. Despite significant progress in this area, the task of effective automated design still remains open, and today the problem of simplifying algorithms and their adequate reproduction is the subject of active discussions.

Special attention is paid to the issue of the influence of temperature conditions on the performance of nanocircuits, in particular, operation at cryogenic temperatures. Studies have shown that such conditions can significantly affect the operation of nanodevices, stimulating the search for new approaches to improve their quality and stability of temperatures [8], [9].

III. PROGRAMMING UNIVERSAL LOGIC NANODEVICES

To use universal logic nanomodules, signals of various arguments of the function being reproduced are fed to the address inputs, and the information inputs act as programmable. For a digital device with two input arguments x_1 , x_0 , four discrete combinations are possible: 00, 01, 10, 11, and this allows us to synthesize 16 different output functions.

Figure 1a shows the graphic designation of a two-input multiplexer ($2 \rightarrow 1$).

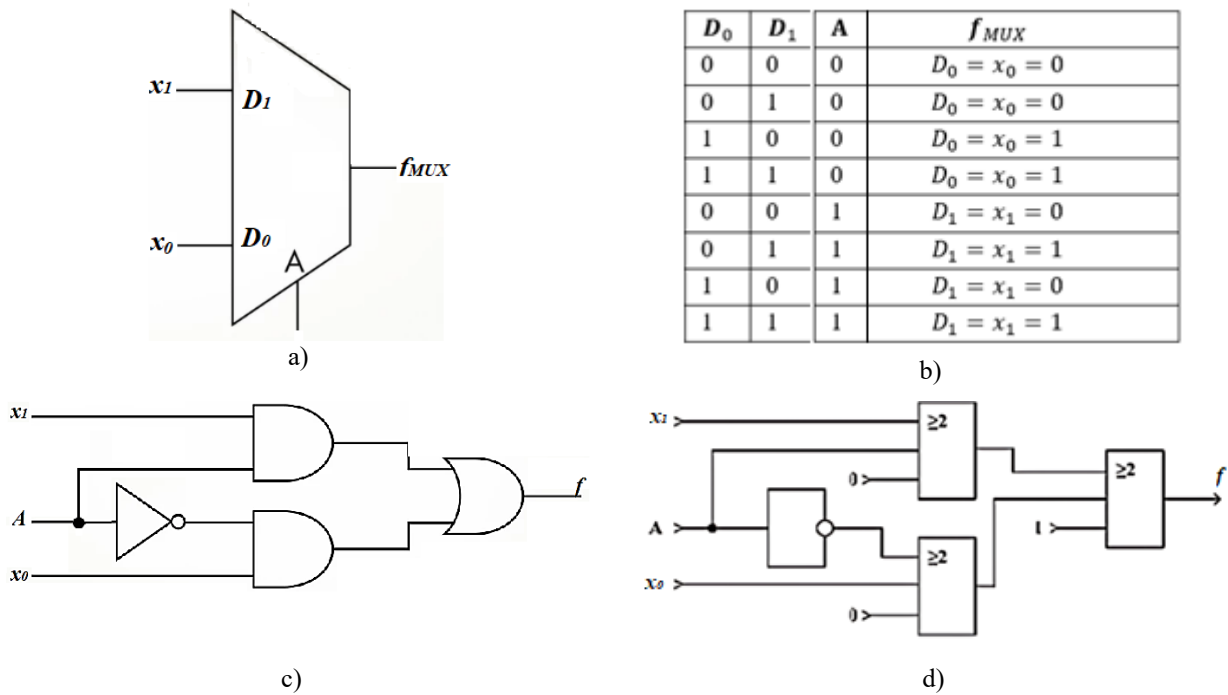


Fig. 1. One-input multiplexer (a), its truth table (b) and equivalent micro- (c) and nanocircuits (d)

According to the truth table (Fig. 1b) and the equivalent microcircuit of the (Fig. 1c), after algebraic transformations, the disjunctive normal form (DNF) of its logical Boolean function f_B is obtained in the form:

$$f_B = \bar{A}x_1\bar{x}_0 \vee \bar{A}x_1x_0 \vee A\bar{x}_1x_0 \vee Ax_1x_0. \quad (1)$$

To implement Boolean functions of several arguments, it is necessary, first, to obtain their DNF, and, second, to create a micromodule programming algorithm for their synthesis. For example, using the de Morgan duality law [4] for the logical function of

the inversion of the disjunction $f_1 = \overline{x_1 \vee x_0}$ we obtain the DNF $f_1 = \bar{x}_1\bar{x}_0$, and implement the programming algorithm by comparing the DNF of the function f_1 with the function (1).

Thus, to program one address input A , variations of signals x_1 and x_0 should be applied to two information inputs D_1 and D_0 of the itself micromodule. Table I illustrates the results of the formation of programming functions f_{pr} for it and, in fact, the reproduction of the NOR function by the multiplexer itself $f_{MUX} = f_1$.

TABLE I. PROGRAMMING A MICROELECTRONIC MULTIPLEXER MODULE

A	D_1	D_0	f_{pr}	f_{MUX}
x_1	\bar{x}_1 or 0	\bar{x}_0	$D_1x_1(0) \vee D_0\bar{x}_1$	$\bar{x}_1\bar{x}_0 = f_1 = \overline{x_1 \vee x_0}$
x_0	\bar{x}_0 or 0	\bar{x}_1	$D_1x_0(0) \vee D_0\bar{x}_0$	
\bar{x}_1	\bar{x}_0	\bar{x}_1 or 0	$D_1\bar{x}_1 \vee D_0\bar{x}_1(0)$	
\bar{x}_0	\bar{x}_1	\bar{x}_0 or 0	$D_1\bar{x}_0 \vee D_0x_0(0)$	

In a similar way, for the equivalent nanocircuit of a two-input multiplexer (Fig. 1c), created on the basis of majority elements (ME), its majority function f_M is obtained in the form:

$$f_M = maj[maj(A, x_1, 0), maj(A, x_0, 0), 1], \quad (2)$$

where the marking maj is a majority operation of

selecting the majority of binary values from an odd number (in this case three) of input arguments [5].

The majority choice function (2 out of 3) in canonical or decimal forms has the form $f_M = \sum(011, 101, 110, 111) = \sum(3, 5, 6, 7)$. Table II lists four options for programming a nanoelectronic single-bit assembled from three MEs and one inverter (Fig. 1d).

TABLE II. PROGRAMMING A NANO-ELECTRONIC MULTIPLEXER MODULE

A	D_1	D_0	f_{pr}	f_{MUX}
x_1	$maj(x_1, \bar{x}_1, 0)$	$maj(\bar{x}_1, \bar{x}_0, 0)$	$D_1 x_1(0) \vee D_0 \bar{x}_1$	Function (2), $f_1 = x_1 \vee x_0$
x_0	$maj(x_0, \bar{x}_0, 0)$	$maj(\bar{x}_1, \bar{x}_0, 0)$	$D_1 x_0(0) \vee D_0 \bar{x}_0$	
\bar{x}_1	$maj(\bar{x}_1, \bar{x}_0, 0)$	$maj(\bar{x}_1, x_0, 0)$	$D_1 \bar{x}_1 \vee D_0 x_1(0)$	
\bar{x}_0	$maj(\bar{x}_1, \bar{x}_0, 0)$	$maj(\bar{x}_1, x_0, 0)$	$D_1 \bar{x}_0 \vee D_0 x_0(0)$	

IV. DISCUSSION OF THE RESULTS OF PROGRAMMING MICRO- AND NANOMODULES

According to Fig. 1c, a two-input multiplexor was built on the Multi-Cap II CAD workspace [4]. Fig. 2 shows the microcircuits of the computer

implementation of the logical NOR function on four multiplexors (a), which are programmed according to the transformation (1) and Table 1, as well as the results of identical simulations of four corresponding timing diagrams (b).

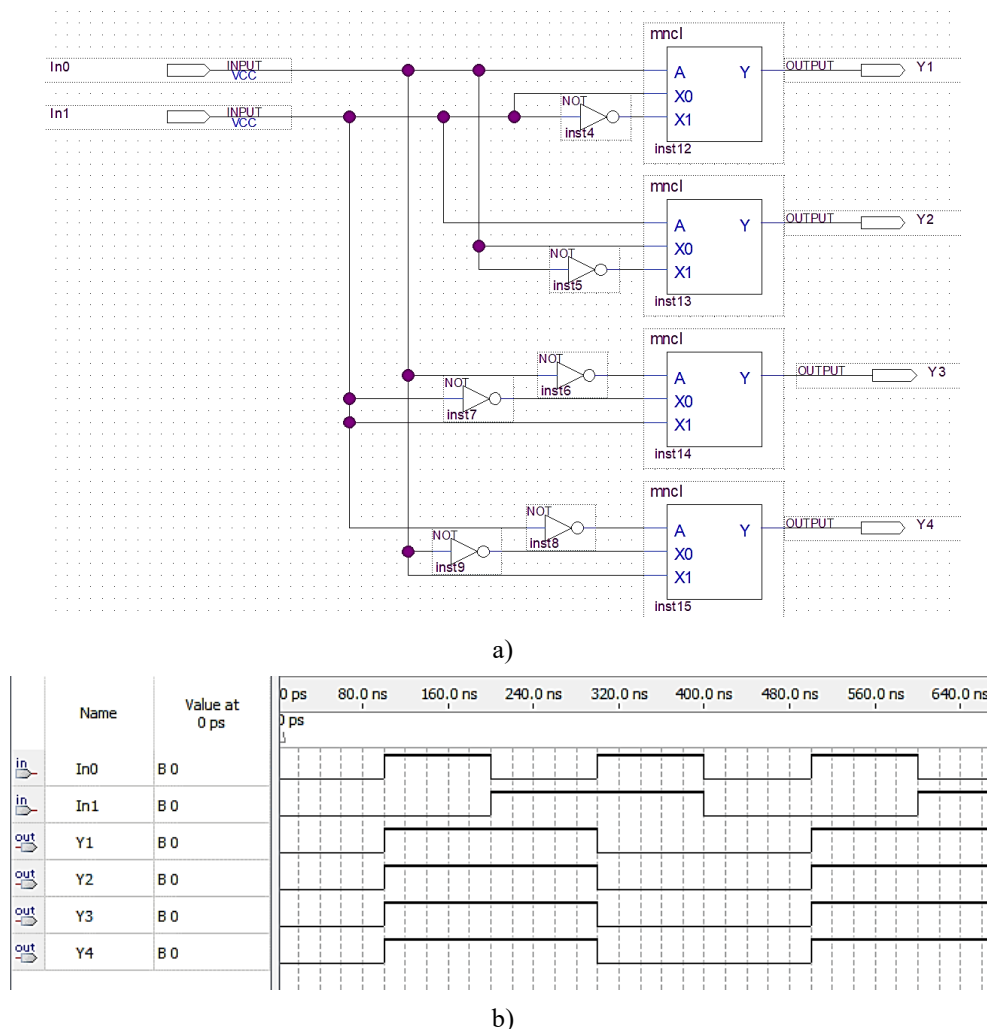


Fig. 2. Computer programming of the micromodules (a) and results of simulation their oscillograms (b)

Coulomb quantum cellular automata (QCA) are an example of majority modeling, according to which binary information is encoded by two diagonally arranged electrons in a QCA cell [8]. Single-electron nanodevices based on quantum

technology consist of nanoscale dielectric cells that have four semiconductor quantum Coulomb islands in the corners, and two free electrons that tunnel between them inertially. The previously created nanoelectronic circuit of the (Fig. 1d) is now

reproduced on the QCA (Fig. 3a) as an initial task for modeling on the QCADesigner CAD [5], [6]. It consists of an inverter of the address signal A at the inputs of the majority modules with programmable logic in the form of a negative polarization of -1.00 to perform the logical multiplication operation in equation (2). The output ME is programmed with a

positive polarization of 1.00 to perform logical addition in the function f_M (2). Fig. 3b shows the results of modeling the oscillograms of the nanoelectronic module, which exactly match the truth table (Fig. 1), which confirms the adequacy of the programming

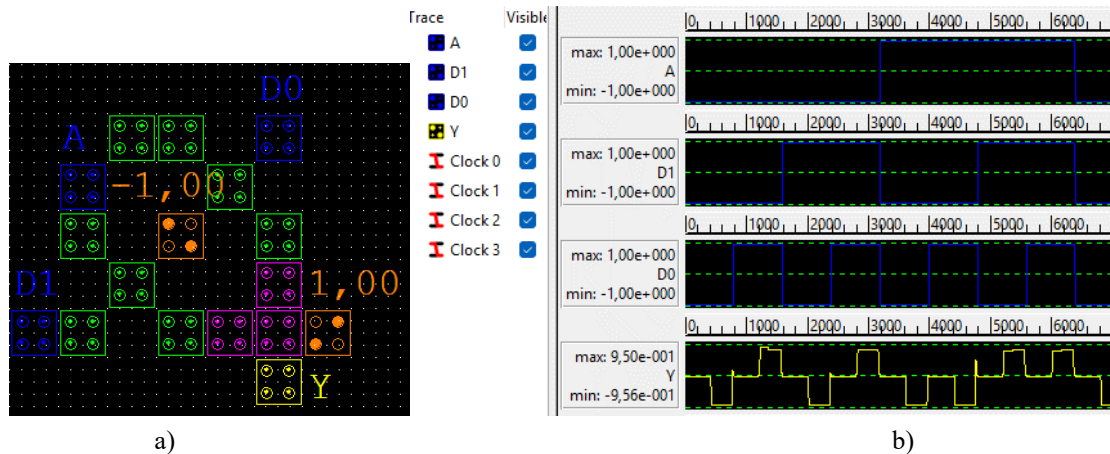


Fig. 3. Imulation for nanomodule NOR (a) and his time diagrams (b)

IV. RESEARCH PROSPECTS

The authors consider the development of new methods for programming nanomodules based on majority logic to be promising, since further miniaturization and increased performance are possible only with the introduction of single-electron nanodevices. In addition, research directions that contribute to the development of spintronics and biomolecular electronics nanomodules are promising [4].

V. CONCLUSION

Since the development of microelectronics based on complementary metal-oxide-semiconductor transistors is limited by small-scale and quantum-technological effects, the article gives priority to the use of nanomodules with programmable logic for the implementation of Boolean and majority functions. The developed algorithms (Tables I and II) of automated programming of micro- and nanomodule (Figs 2 and 3) confirmed the adequacy of the proposed models. However, a significant drawback of single-electronic nanomodules remains the exclusively cryogenic temperature range, which currently determines their reliable operation only in space conditions.

REFERENCES

[1] P. Tougaw, S. Lent, and W. Porod, "Bistable saturation in coupled quantum cellular automata",

Journal of Applied physics, vol. 74, no. 5, pp. 3558–3566, 1993. <https://doi.org/10.1063/1.354535>

[2] S. L. Kardigai, "Efficient design of logical structures and functions using nanotechnology based QCA, Intern," *Journal of Computer Application*, vol. 3, no. 3, pp. 0975–0988, 2010.

[3] E. Sicard and S. D. Bendhia, *Advanced CMOS Cell Design*, McGraw-Hill, 2007, 385 p.

[4] J. L. Hennessy and D. A. Patterson, *Computer Architecture: A Quantitative Approach*, Morgan Kaufmann, 2011, 856 p.

[5] K. Walus, T. Dusart, C. Budiman, "QCA Designer: A rapid design and simulation tool for QCA," *IEEE Transactions on Nanotechnology*, vol. 3, no. 4, pp. 26–39, 2004. <https://doi.org/10.1109/TNANO.2003.820815>

[6] QCADesigner, version 2.0.3. Available at www.atips.ca.

[7] B. Sen and S. Gosman, "Towards modular design of reliable QCA logic circuits using multiplexers," *Computer Electronics Eng*, vol. 45, no. 2, pp.42–54, 2015. <https://doi.org/10.1016/j.compeleceng.2015.05.001>

[8] O. S. Melnyk and V. O. Kozarevych, "Arithmetic Logic Single-electron," *Electronics and Control Systems*, vol. 2, no. 76, pp. 68–77, 2023. <https://doi.org/10.18372/1990-5548.76.17670>

[9] H. Cho and E. Swartzlander, "Adder and multiplier design in quantum-dots cellular automata," *IEEE Trans on Computers*, vol. 58, no. 1, pp. 721–729, 2009. <https://doi.org/10.1109/TC.2009.21>

[10]S. Shin and C. Jeon, "Design of wire-crossing technics based on difference of cell in quantum-dot cellular automata," *Int. Journal of control and automation*, vol. 7, no. 7, pp. 153–165, 2014.
<https://doi.org/10.14257/ijca.2014.7.4.14>

Received: March 11, 2026

Accepted: March 27, 2026

Published: April 19, 2026

Melnyk Oleksandr. ORCID 0000-0003-1072-5526. Candidate of Sciences (Engineering). Associated Professor. Department of Electronics, Robotics, Monitoring & IoT Technologies, State University "Kyiv Aviation Institute", Kyiv, Ukraine.

Education: Kyiv Polytechnic Institute, Kyiv, Ukraine, (1971).

Research interests: Modeling micro- and nanoelectronics devices, computer-aided design, solid-states electronics.

Publications: over 170 publications.

E-mail: oleksandr.melnyk@npp.kai.edu.ua

О. С. Мельник. Нанопристрої з мажоритарними структурами

Статтю присвячено аналізу актуальних антагоністичних питань щодо впровадження нових методів комп'ютерного програмування, які можуть бути використані для відтворення гетерогенних бінарних функцій кількох аргументів на основі мікро- та наноелектронних мультиплексорних модулів. Зростання спеціалізації сучасних великих інтегральних схем вступає в суперечність з їхньою універсальністю, що збільшує вартість проектних робіт та зменшує обсяги виробництва типомінальних пристроїв. Компроміс між спеціалізацією та універсальністю має бути мінімізований за допомогою автоматизованого проектування мікро- та нанорозмірних модулів з програмованою логікою. Програмування виконується не для створення алгоритмів обробки дискретної інформації, як це реалізовано мікропроцесором, а шляхом логічних налаштувань мультиплексорних мікро- та нанопристроїв. Результати комбінованого моделювання, отримані в роботі, підтверджують еквівалентність їх функціонування, а також переваги кулонівських наномультимплексорів на основі клітин у надійності, технологічній масштабованості, енергоефективності, швидкодії та недоліки у виключно криогенних наднизькотемпературних застосуваннях. Очевидно, що еволюція мікроелектроніки продовжиться лише в контексті широкого впровадження нанорозмірних модулів з новими функціональними принципами роботи.

Ключові слова: мікро- та наномодулі, програмовані логічні пристрої, мажоритарна логіка, системи автоматизованого проектування, мультиплексори.

Мельник Олександр Степанович. ORCID 0000-0003-1072-5526. Кандидат технічних наук. Доцент.

Кафедра електроніки, робототехніки, моніторингу та технологій Інтернету речей, Державний університет «Київський авіаційний інститут», Київ, Україна.

Освіта: Київський політехнічний інститут, Київ, Україна, (1971).

Напрямок наукової діяльності: моделювання пристроїв мікро- та наноелектроніки, автоматизоване проектування, твердотільна електроніка.

Кількість публікацій: більше 170 публікацій.

E-mail: oleksandr.melnyk@npp.kai.edu.ua