

# PHYSICAL AND INFORMATION PARAMETERS OF NANOSCALE ELECTRONIC ELEMENTS AS A PART OF COMPUTING SYSTEMS WITH NEURAL NETWORK ARCHITECTURE

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**Abstract.** Problem of ensuring specified reliability indices when designing computation components of the telecommunication systems built via use of a nanoscale electronic element base is considered. Computer models of the computation components with neural network architecture and integrated nanoscale titanium oxide-based memristors and nanoscale graphene-based field-effect transistors are studied. Correlation between the physical and information parameters, integrated into the system of nanoscale electronic elements, as well as an impact of parameter variation on the system reliability, has been investigated.

**Keywords:** computing system, graphene, nanoscale, neural network, transistor

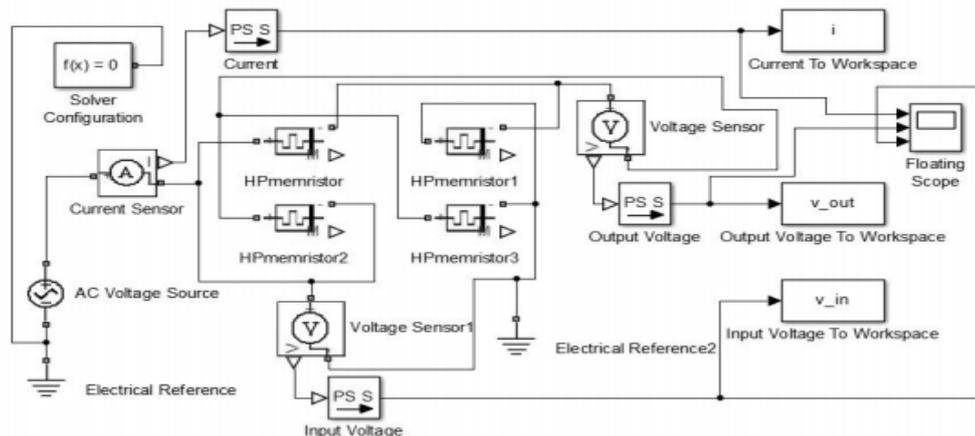
## 1. Introduction

Nowadays conceptually new opportunities for building high-performance computing systems appear at the confluence of nanoscale technologies and neural network technologies [1]. The reason for this is that the system acquires some extra opportunities due to a combination of parallel information processing and nanoscale electronic element base [2,3]. However, as a rule, the application of nanoscale electronic elements reduces system reliability indices which should be established at the design engineering stage and which are not achieved automatically [4]. The reliability indices of such systems are characterized by their operation accuracy. As for the elements of computing systems, they should be studied as uniform physical and information objects. Consequently, the operation accuracy of the systems under study represents the degree of conformity of the real physical and information parameters in question to the theoretical (nominal) parameters of the system electronic elements.

The aim of this study is to define a correlation between the physical and information parameters of the nanoscale electronic elements integrated into a computing system and to define the impact of parameter variation on the system reliability indices.

## 2. Methods

A computer model of the artificial neural network (ANN), built in the MATLAB environment, has been investigated. The model has been trained to make an approximation of a differential equation with maximum precision. Using nanoscale electronic elements as the research object is an essential part of the experiment. In particular, the research involves models of the nanoscale titanium oxide-based memristors as synaptic connections (synapses) between the layers of neurons and the nanoscale field-effect graphene-based transistors which control signals inside the system [5,6]. The structure of nanoscale titanium oxide-based memristor being modeled is shown in Figure 1.



**Fig. 1.** Nanoscale titanium oxide-based memristor Simscape/MATLAB model of a memristor

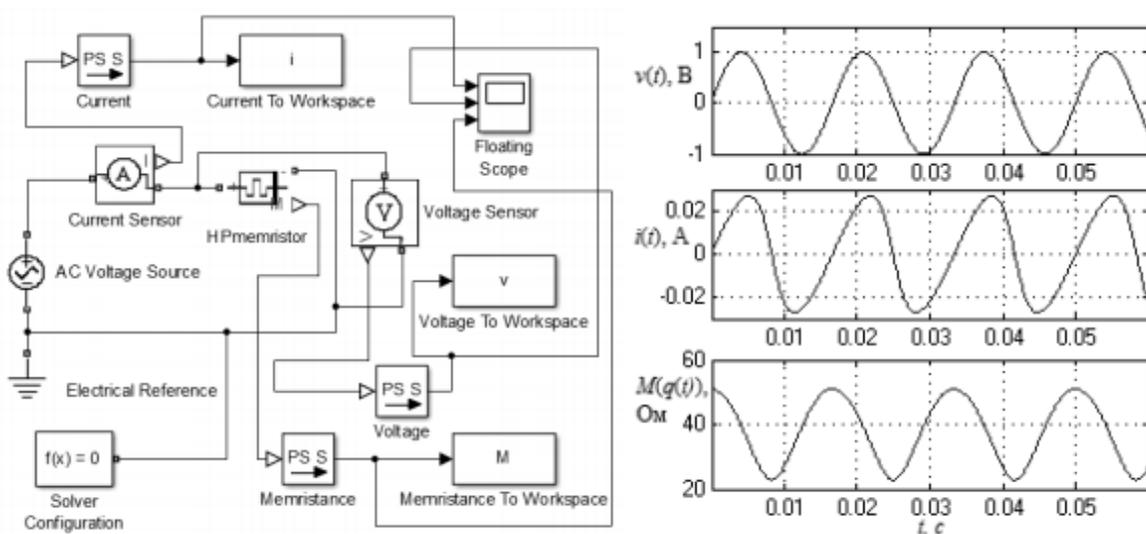
Several models of nanoscale titanium oxide-based memristors have been developed on the basis of the stated-above mathematical model in the Simscape environment, which is used to simulate physical systems integrated into the MATLAB mathematical computation toolkit. An example of such a model is shown in Figure 2.

Figure 3 demonstrates a neuron synapse model based on memristor in Simscape/MATLAB. A synapse is an element that performs a weighed signal transfer (1) from the neuron of one layer to the neuron of the next layer within an ANN.

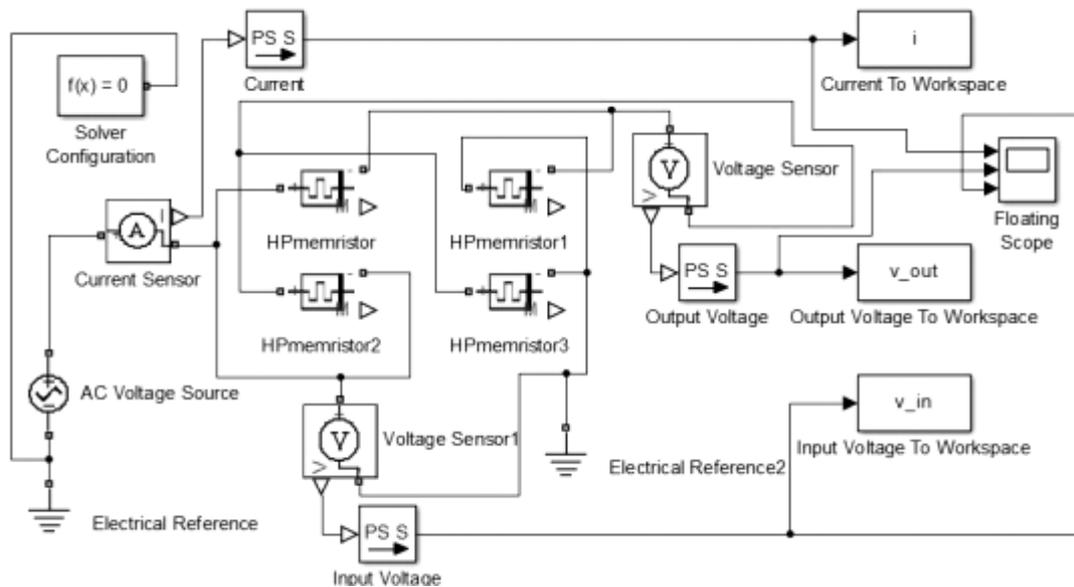
$$f(x) = w \cdot x, \quad (1)$$

where  $f(x)$  is the neuron input,  $w$  is the synapse weight,  $x$  is the output of a previous neuron.

Besides, the field-effect graphene-based transistor has been selected as one of the nanoscale electronic elements integrated into a computation system. Such field-effect transistors function as the control matrix elements inside a computation system under development. A mathematical model of the nanoscale graphene-based transistor has been formulated on the basis of the theory developed in Refs. [7,8]. The operating principal of such a device is based on the effect of electric field that changes the charge carrier concentration (carrier density) in graphene.



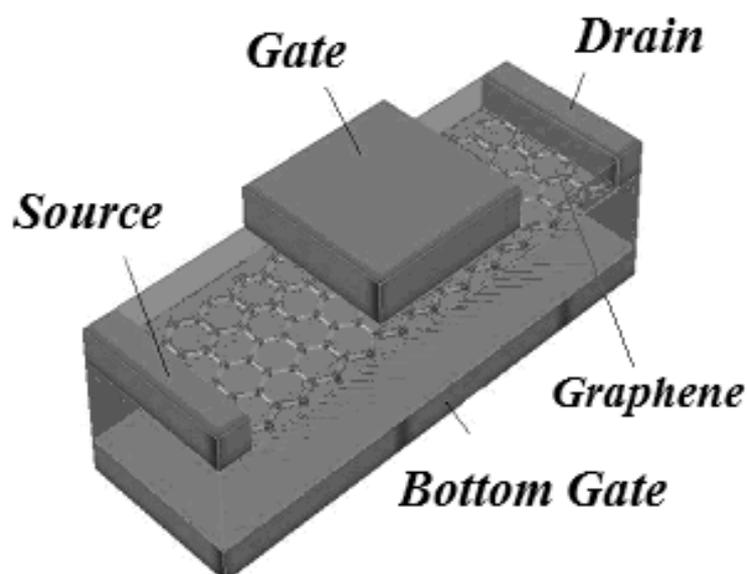
**Fig. 2.** Simscape/MATLAB model of memristor



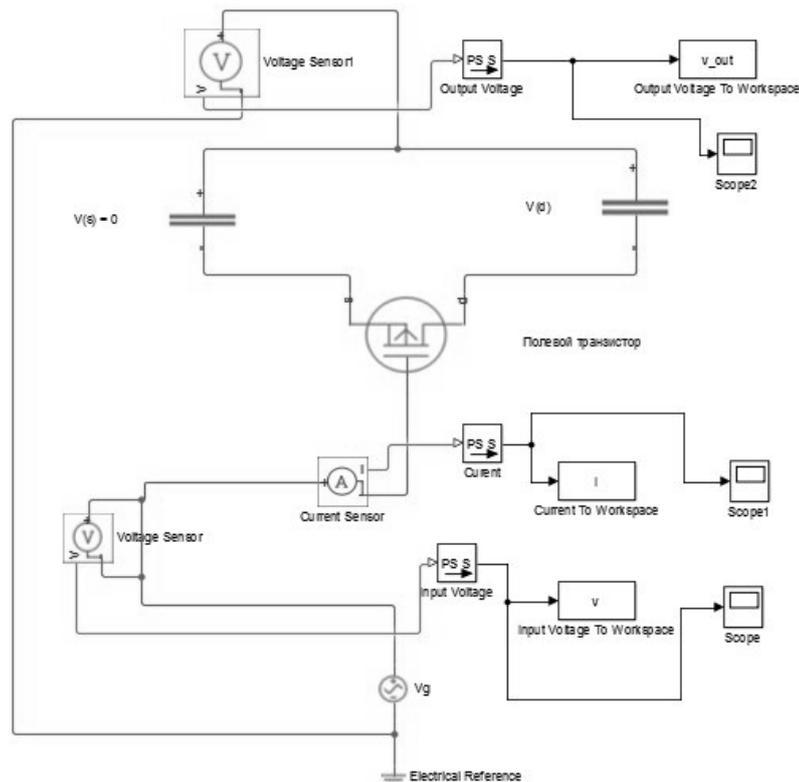
**Fig. 3.** Neuron synapse model based on memristor in Simscape/MATLAB

Using the gate voltage, one can control the graphene conductivity which is approximately proportional to the concentration. The structure of graphene-based nanoscale transistor being modeled is shown in Fig. 4. Such a transistor consists of a semiconducting channel separated from the metal gate by a graphene layer. The areas designated in Fig. 4 by "Source" and "Drain" are contact pads that have high conductivity. The channel resistance determines current  $I$  flowing from the source to the drain when voltage  $V_{Drain}$  is applied between them. Gate voltage  $V_{Gate}$  is used for controlling the electron density in the channel and consequently its conductivity. Typically, earthed source schemes are used, therefore  $V_{Source}=0$ .

Several models of nanoscale graphene-based transistors have been developed on the basis of the mathematical model [9] in the Simscape environment, which is used to simulate physical systems and which is part of the MATLAB mathematical computation toolkit. An example of such a model is shown in Fig. 5.



**Fig. 4.** View of field-effect graphene-based nanoscale transistor



**Fig. 5.** Control element model based on field-effect transistor in Simscape/MATLAB

The desired values of the major parameters of the modeled nanoscale elements have matched the values obtained in the developed models. Therefore, it can be concluded that the models have been built correctly. A two-phase methodology has been used within the scope of the experimental research into the physical parameters of memristors. In the first phase it is intended to formulate and apply some possible mechanisms for impacting various properties of the nanoscale objects under study, capable of triggering the system reaction in the form of parameter variation. The second phase is needed to define qualitative and quantitative dependences between the variation of the system-element parameters and its element properties predetermining such variation.

Analyzing the memristor physical parameters, based on the proposed approach, come down to a few procedures:

- Synthesizing computer models of the memristors meeting the specified requirements.
- Developing a computation system in the form of ANN to define the indices of information conversion accuracy when the information state of the system elements has been varied.
- Modeling various impacts on the geometrical parameters of the memristors functioning as synaptic connections in the ANN.
- Measuring the system technical indices and forming statistical data on the element parameter variations at different levels of the factor impacting the memristor geometrical parameters.
- Analytical estimation and defining the target dependence of the system operation variation and element-parameter variation caused by the impact on their properties.

A few geometrical parameters of the memristor have been brought out: top contact surface, lower contact surface and a dielectric-layer thickness. The memristors have been exposed to factor variation at different levels. Each time the memristor properties varied, the variations of information parameters were registered.

What is more, the ANN operation with the information parameter variations of the synapses was emulated. The overall research results are demonstrated in Tables 1 and 2 [10]. These dependences make it possible to obtain the tolerance limits of element parameter variation and to help define the mechanisms influencing the element physical properties with the purpose of optimizing the system technical indices. The methodology aimed to study the information parameters of memristors replicates the one used before [10, Table 3].

### 3. Conclusions

We investigated a correlation between the physical and information parameters integrated into a computation system of nanoscale electronic elements; the effect of parameter variation on the system reliability being defined. The results obtained demonstrate that the physical processes in the nanoscale elements, which carry information in a neural network computation system, define the reliability index of this system, since geometrical parameters impact information parameters and so define the system operation accuracy.

The undertaken study serves as a practical basis for solving the problem of tolerance limits for physical and information parameters of nanoscale electronic elements. It ensures the operation accuracy of designed neural network computation components of telecommunication systems.

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