National Technical University of Ukraine "Kyiv Polytechnic Institute" Faculty of Biomedical Engineering Department of Biomedical Engineering

Diploma Thesis for Bachelor's Degree
in the Specialty 163 "Biomedical Engineering"
on the topic:

NERVOUS SYSTEM BEHAVIOR SIMULATION UNDER ELECTROSTIMULATION

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Purpose and tasks

- The aim is to design and test a tDCS device that can be used to validate the accuracy of the equivalent model of the object under review.

Tasks:

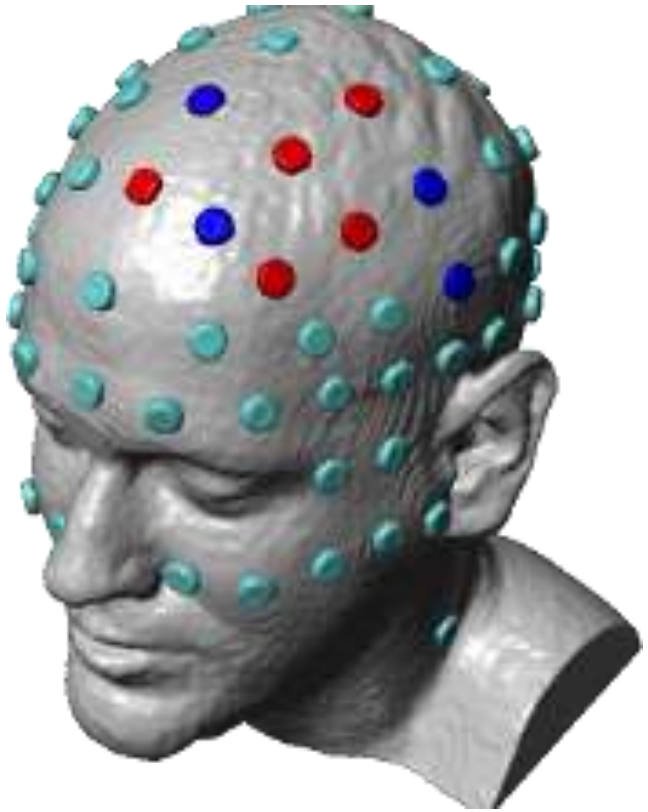
To achieve the goal the following tasks were established:

- To review the literature on the topic of work.
- To formulate medical and technical requirements.
- To develop a structural and electrical principle diagram of the device.
- To create an equivalent model of the object under study.

Introduction

Electrotherapeutic procedures based on the action of current are often used for the treatment and prevention of diseases.
According to recent scientific studies, Transcranial direct-current stimulation (tDCS) can improve cognitive abilities not only in the treatment of diseases, but also in completely healthy people.
We will discuss neurostimulation, which is a means of manipulating the neurological system via electrical signals. Some applications are the electrical stimulation of peripheral nerves, neurostimulation of the spinal cord, stimulation of deep structures or cerebral cortex.

Transcranial stimulation



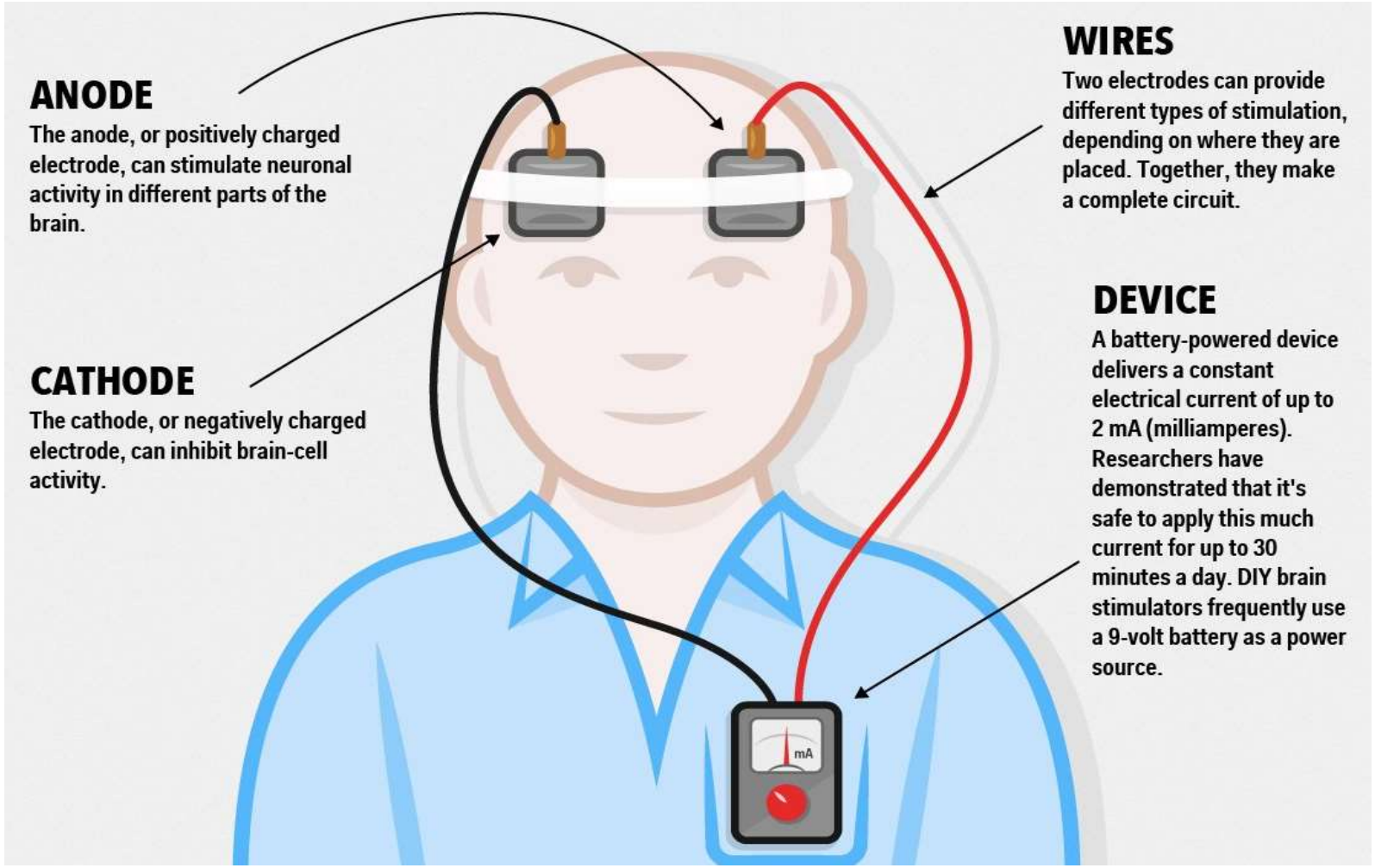
tDCS (tES) is a non-invasive effect of a weak current on the brain to change its functioning.

EOP is the most important system of the body that regulates the neuro-immune-endocrine function. tES selectively activates the EOP structures of the brain, producing β-endorphin

An increase of β-endorphin in the blood leads to increased immunity, accelerated healing processes in the body and slow the growth of tumors.

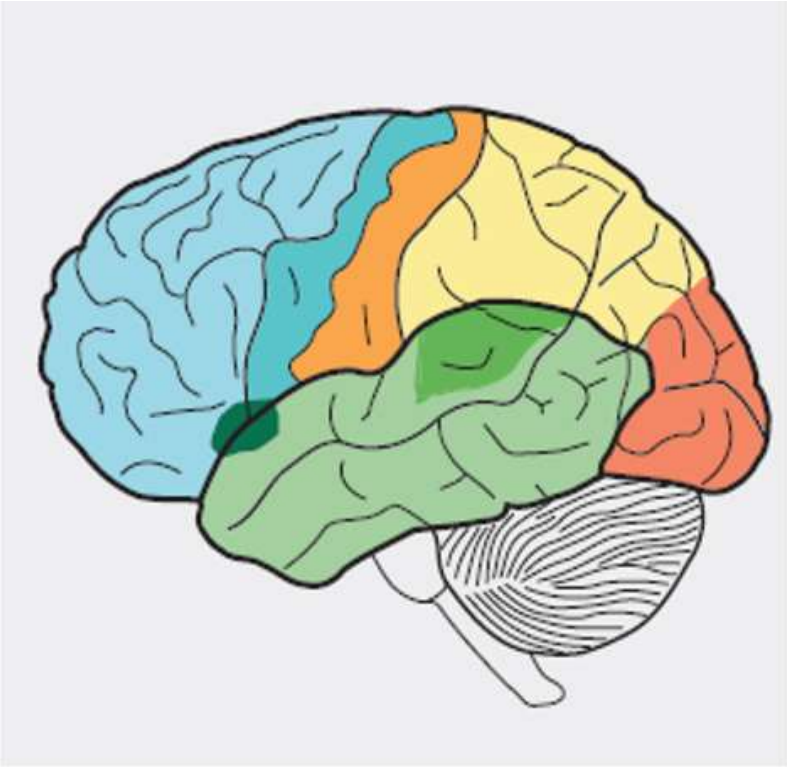
tES-therapy is based on long-term studies that revealed the relationship between the degree of activation of the image intensifier and the main characteristics of the applied pulse current.

tDCS operation principle



Functional areas of the cerebral cortex

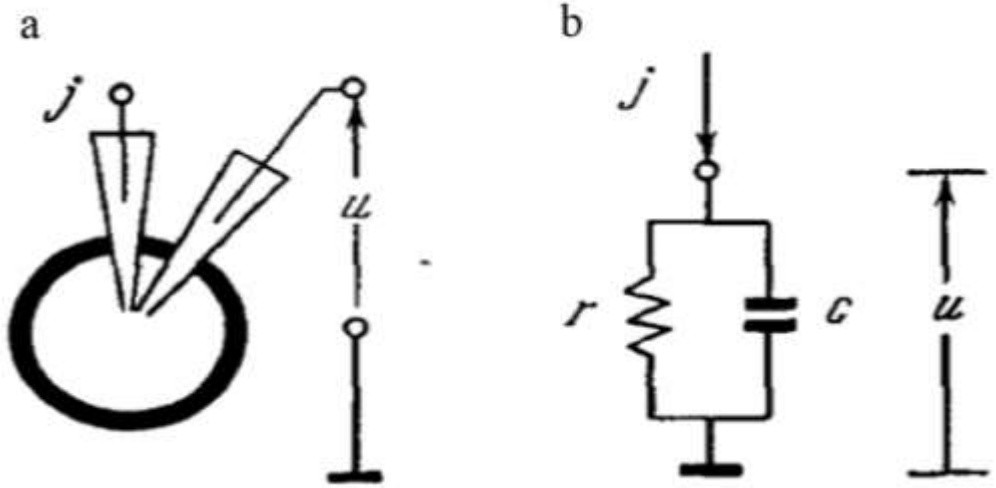
Prefrontal cortex	Attention, memory, thinking
Motor cortex	Control over the muscles
Temporal lobe	Auditory and visual processing
Broca's area	Language production
Wernicke's area	Language comprehension
Parietal lobe	Sensory perception
Somatosensory cortex	Touch
Occipital lobe	Receives visual information



Each hemisphere of our brain is divided into four parts: frontal, parietal, occipital and temporal. But, in addition to the topographic division, the cerebral cortex is also differentiated on a functional basis.

Therefore, with tDCS, it is very important to choose the right areas of the head to which electrodes should be applied, since different areas of the brain are responsible for different functions.

Cell model



Experimental (a) and electrical (b) schemes for measuring the electrical parameters of a spherical cell with a single microelectrode source.

$$c\frac{du}{dt} + \frac{u}{r} = j, \qquad (1)$$

where r is the input resistance of the cell, which is determined by:

$$r = \frac{R_m}{S}, \qquad (2)$$

where Rm - resistivity of the membrane, which is measured in units of Ohm • cm2,

S - area of the membrane.

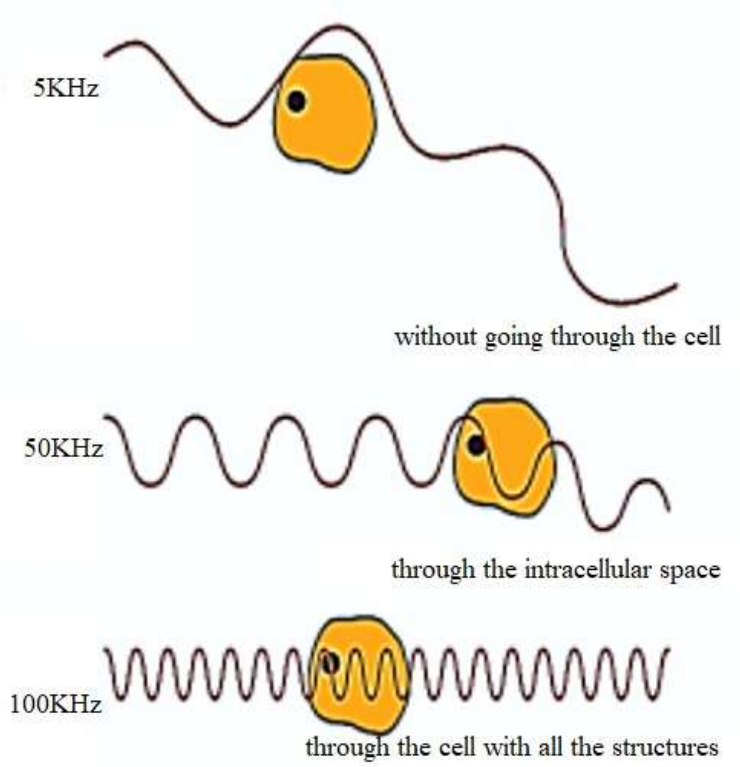
The capacity is similarly defined:

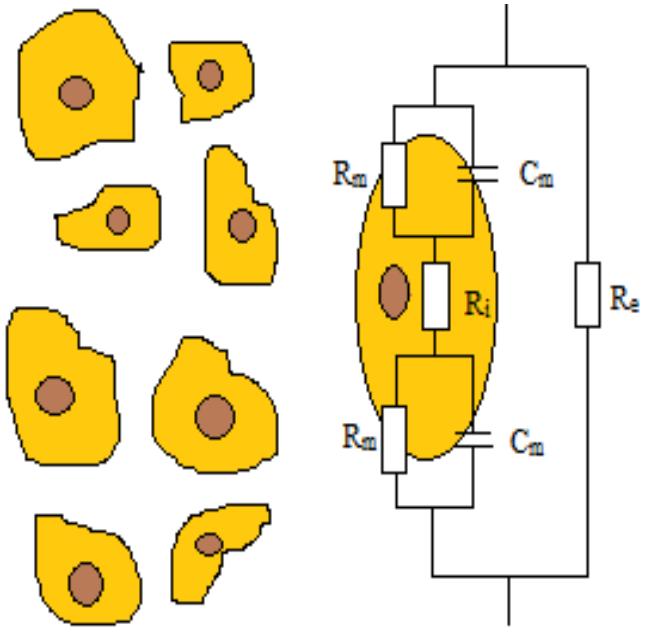
$$c = C_m S, \qquad (3)$$

where Cm - specific capacity of the membrane, which is measured in units of μF / cm^2

Equivalent structural diagram of a cell

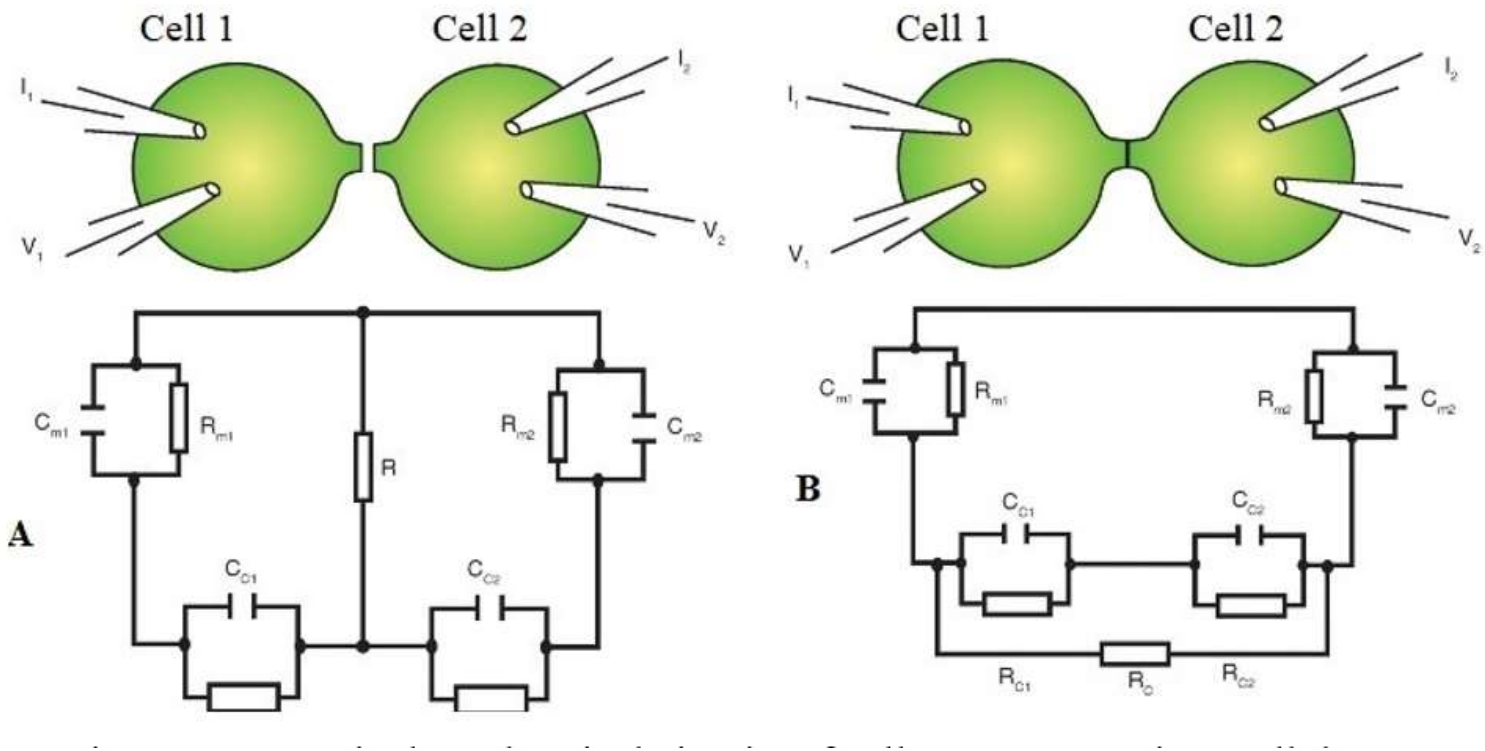
Electric current path at different frequencies (A) equivalent structural diagram of a cell (B)





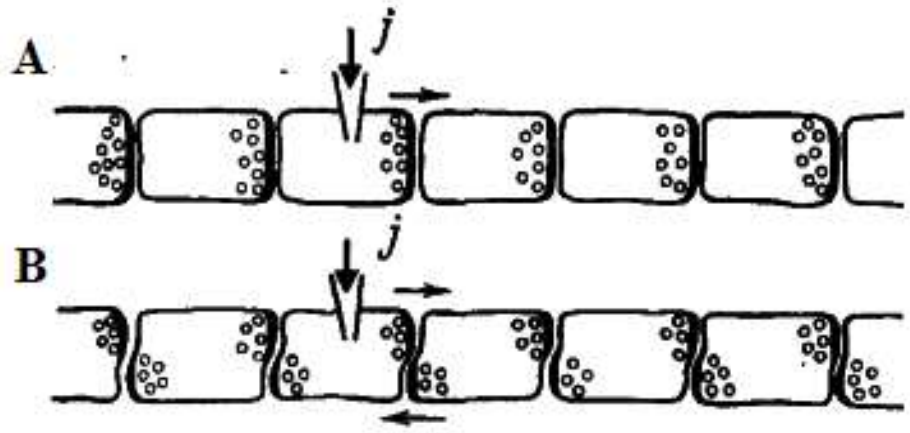
Cm = capacity of the membranes
Re = external resistance of cells
Rm = resistance of the membranes
Ri = internal resistance of the cells

Intercellular contacts



Equivalent electrical circuits of cell contacts: A - intercellular gap without connexons, B - slit contact with connexons

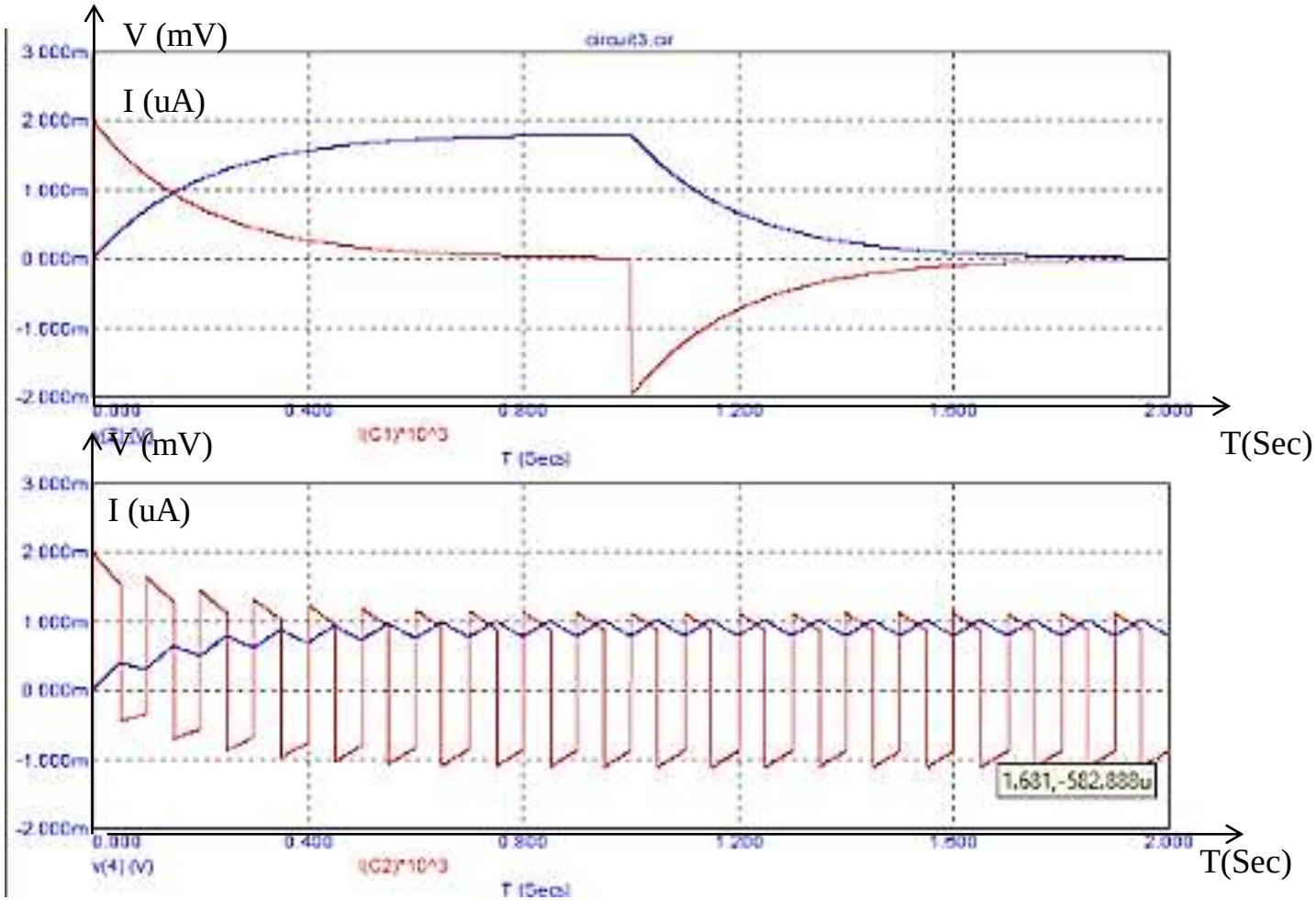
Schemes of biological neuron model



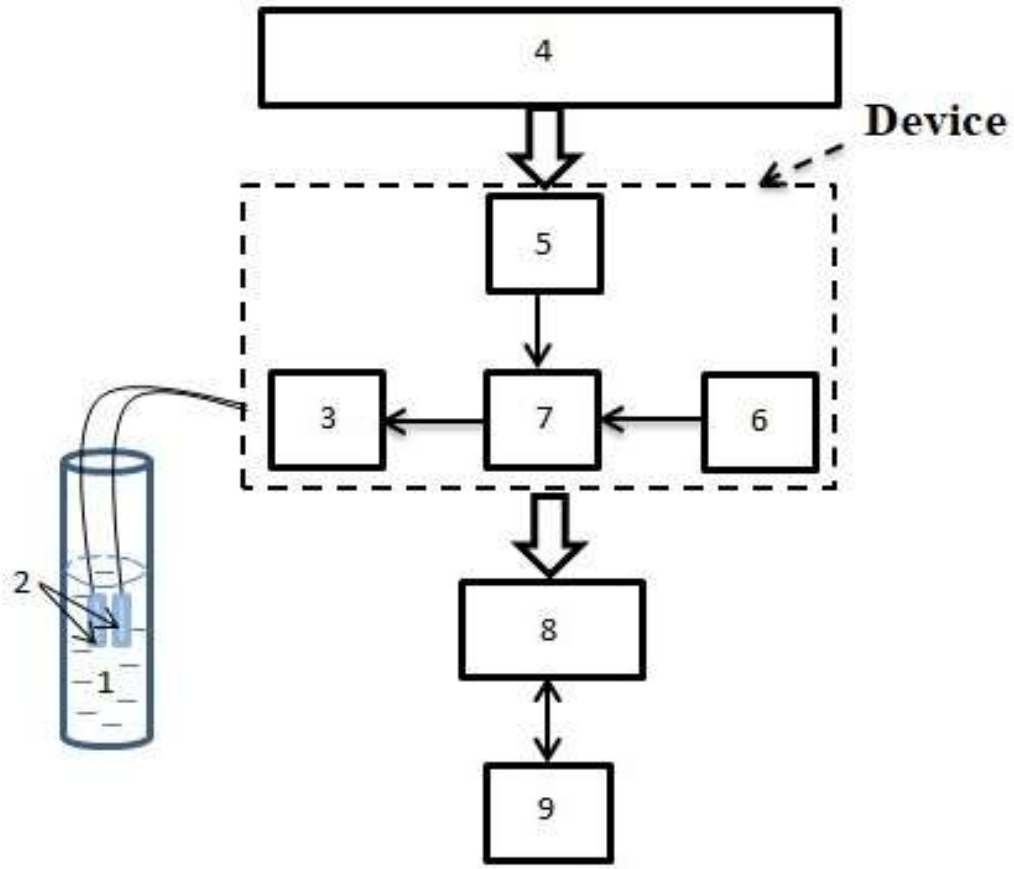
A is a column of cells with unilateral synaptic interaction, j is the current of the stimulating electrode, the arrow indicates the direction, B is a column of cells with bilateral interaction

The specificity of cell interaction via chemical synapses is most evident in the simplest model of nervous tissue - when cells lack axons and communicate via somatic contacts (A). A "hypothetical" column, each cell forms only one chemical synapse, for example with the right neighbor, the transfer of effects is possible only in one (positive) direction. Bilateral transmission is possible with a special organization of synaptic contacts (B).

Processes that take place in the cell when it is stimulated by current



Block diagram of the device



The design of a block diagram is required for the development of any device

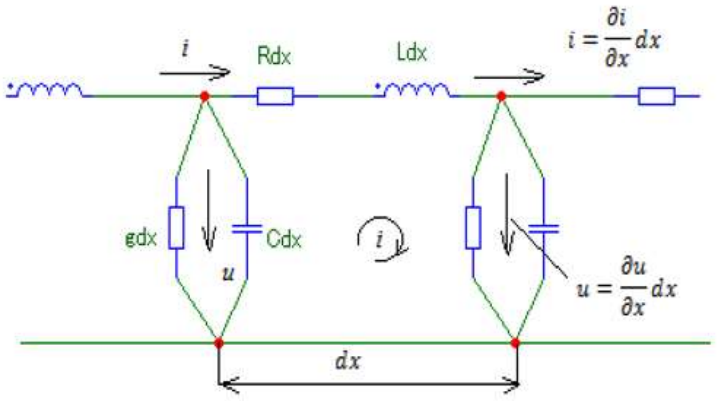
1 - the studied object,
2 - electrodes,
3 - current source,
4 - power supply,
5 - filter,
6 - reference voltage source,
7 - current reference,
8 - PCSGU-250 analyzer,
9 - personal computer (PC)

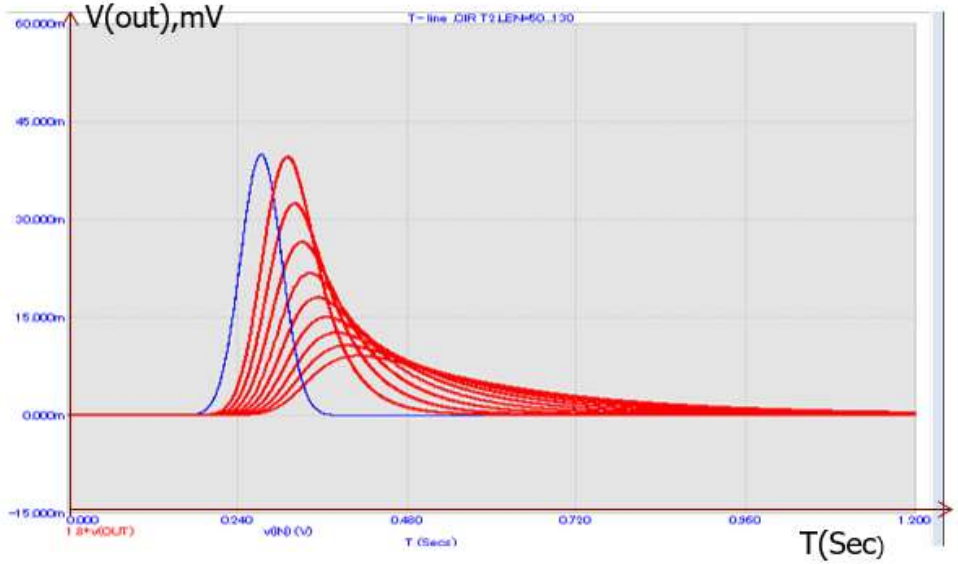
Technical requirements

Features	Value
Output current, mA	0.01-1.0 ± 5%
Maximum patient electrical impedance, kΩ	8
Stimulation time, min	5-40
Supply voltage, V	9
Device parameters must be saved at	30% battery discharge
Climatic performance of the product according to GOST 15150-69 [34]	NF 4.2

Using the macro T-Line

$$\begin{cases} -\dfrac{\partial u}{\partial x} = iR + L\dfrac{\partial i}{\partial t} \\ -\dfrac{\partial i}{\partial x} = gu + C\dfrac{\partial u}{\partial t} \end{cases} \qquad (4)$$



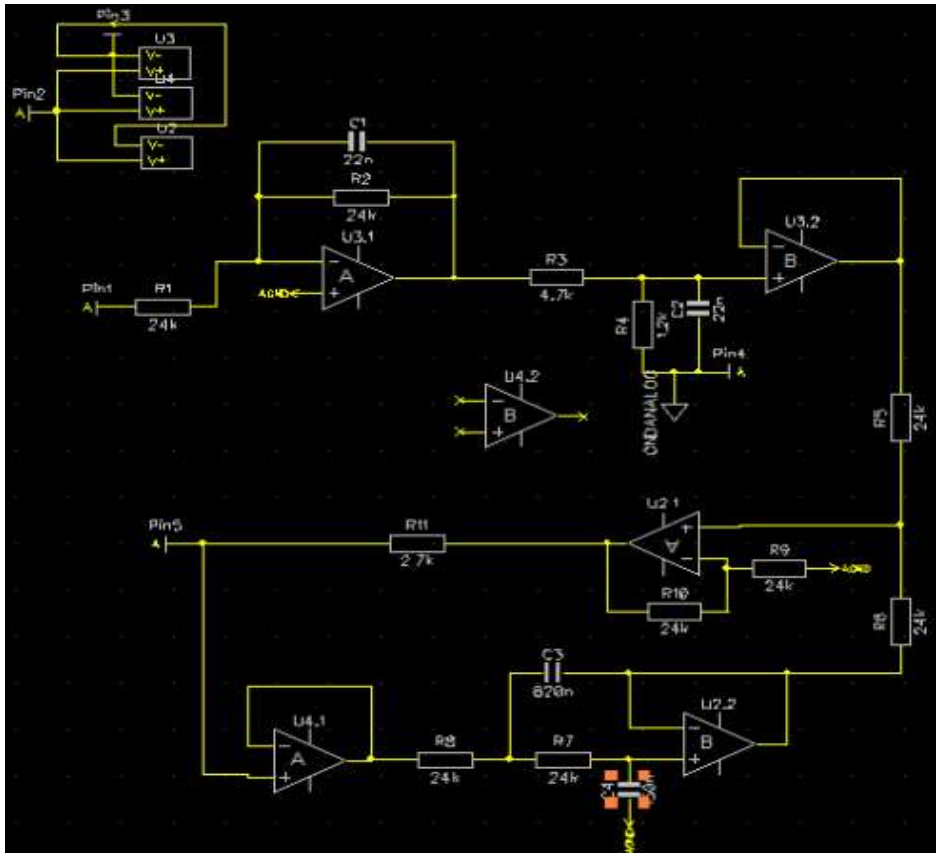


Equivalent electrical circuit of nerve tissue with equipotential cells described by equations

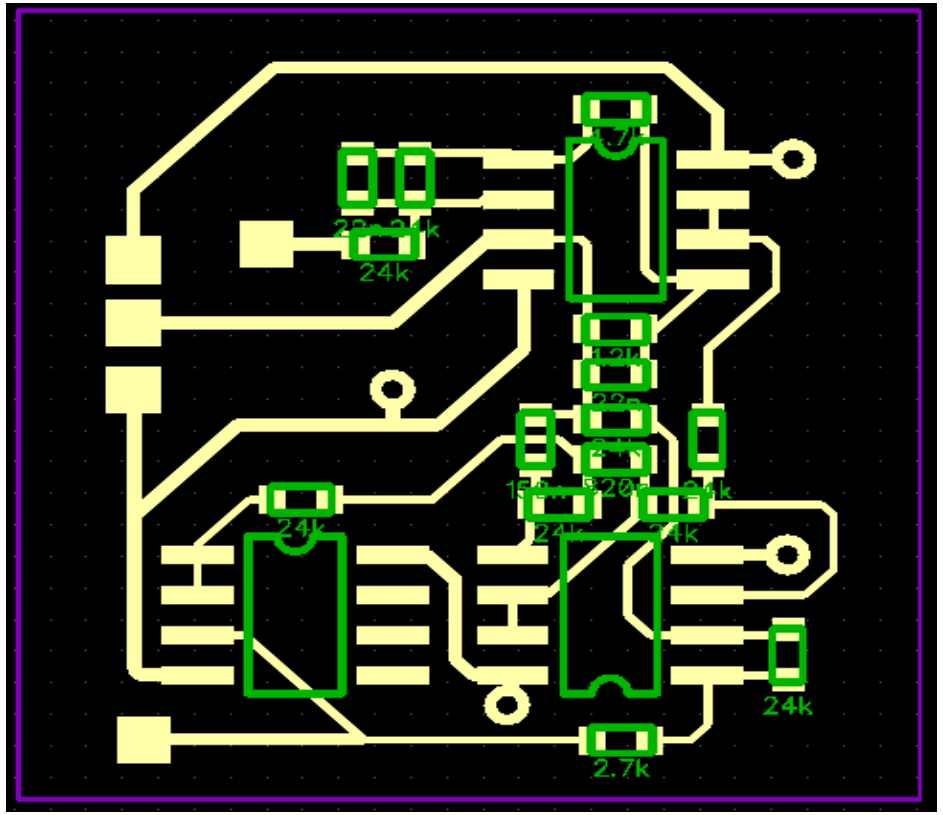
Propagation of action potential through a sequence of cells simulated using a lossy macro T-Line

Development of a printed circuit board

A printed circuit board was developed in the DipTrace software. The pre-assembled circuit is transferred to the DipTrace Schematics module, adding the necessary structural elements, such as connectors, junctions, etc.



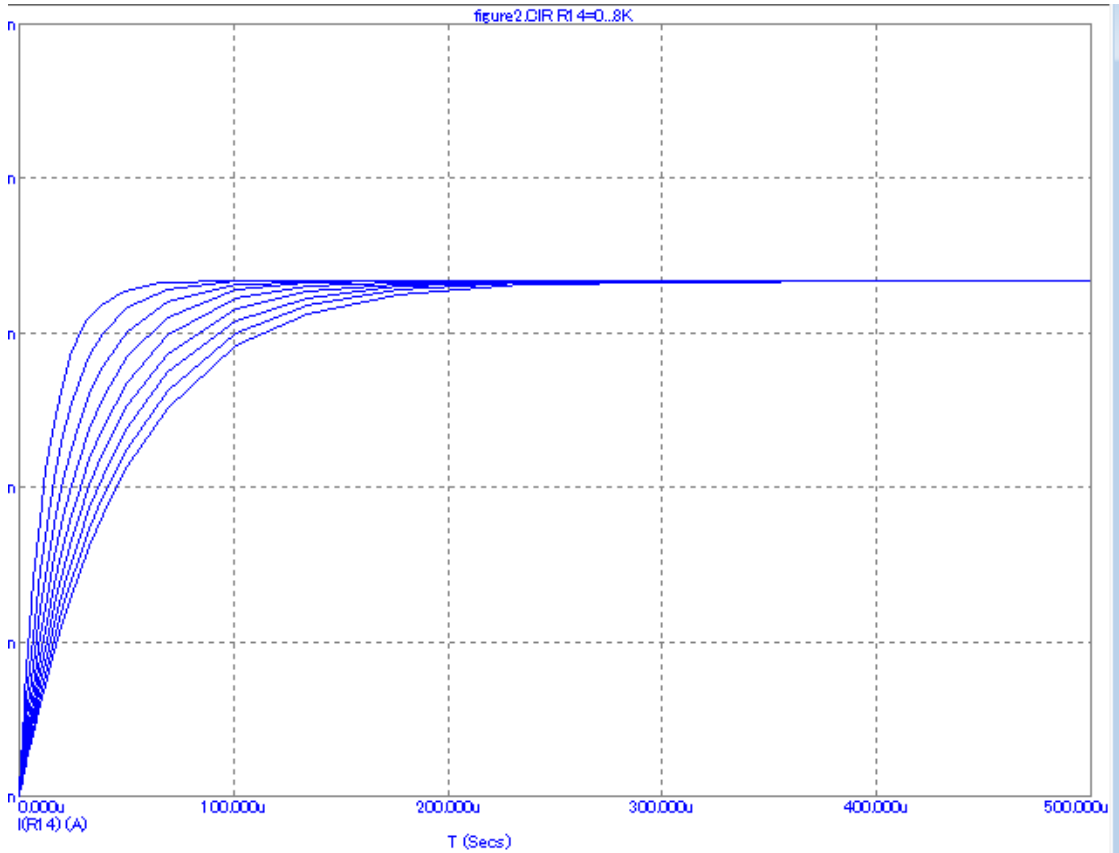
Schematic electrical diagram

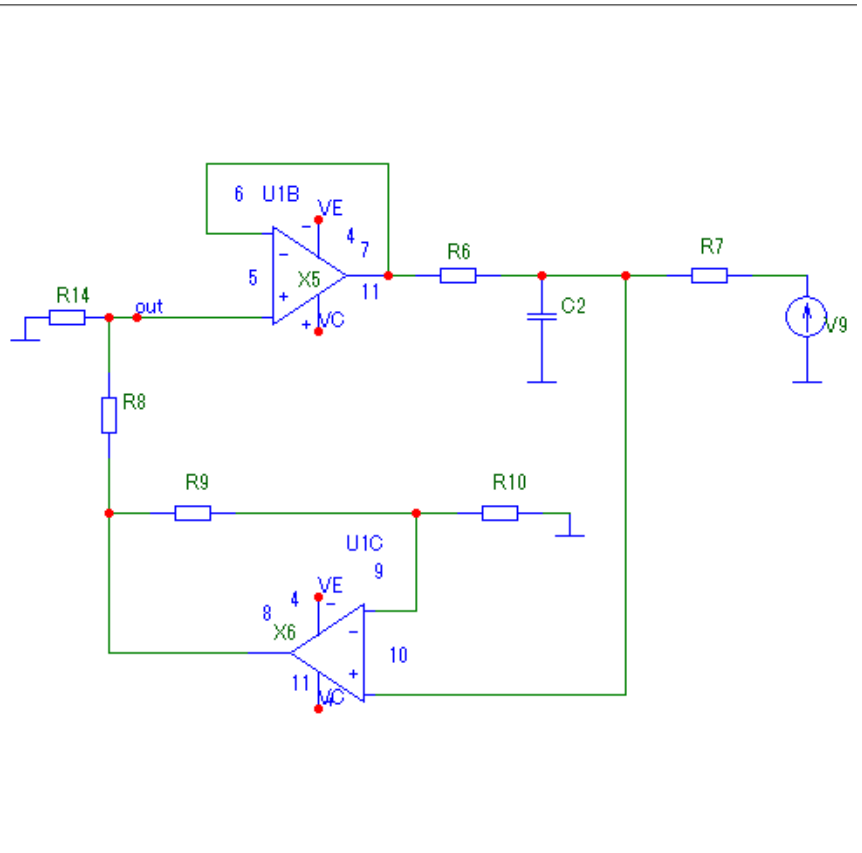


PCB tracing

Simulation of current source

Precision current source (B) and simulation of the performance (A) in Micro-Cap 9





Monte Carlo method

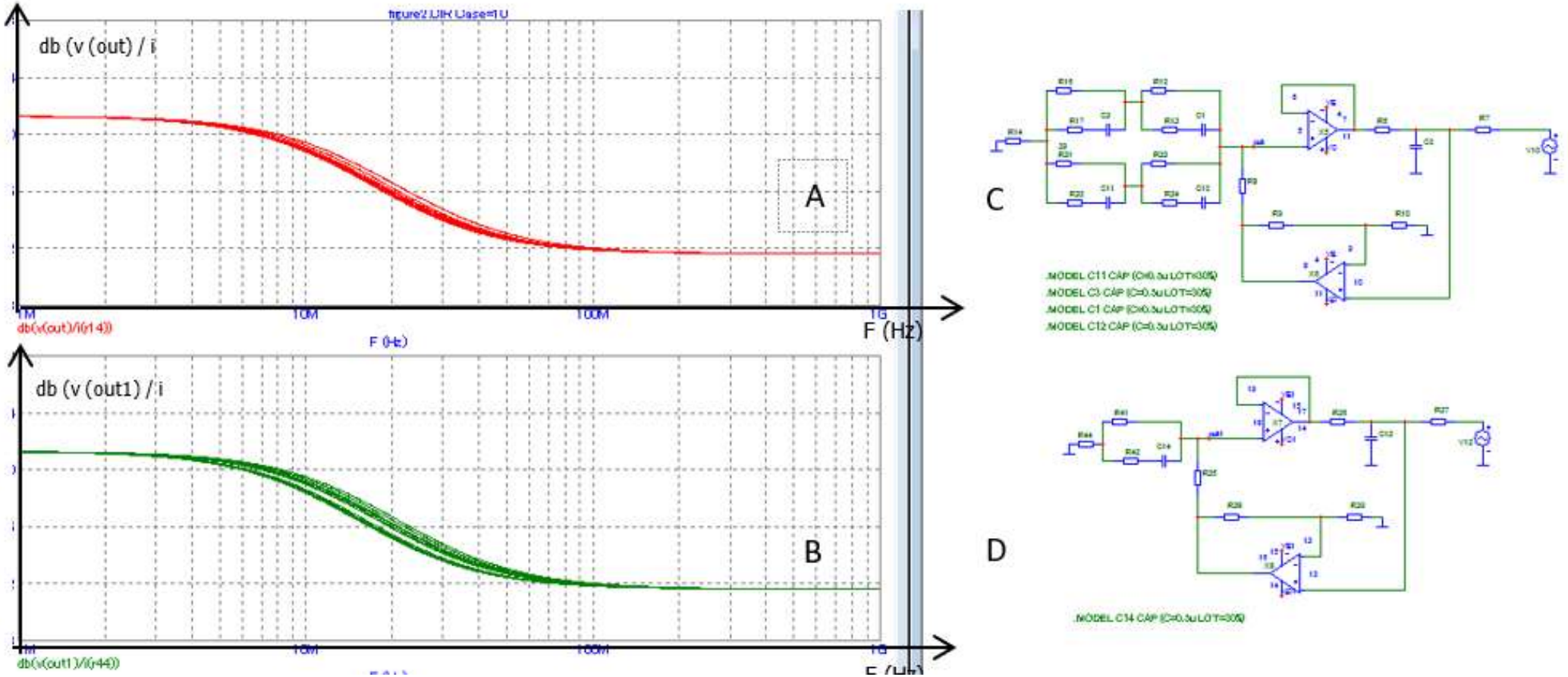
Monte Carlo Simulation, also known as the Monte Carlo Method or a multiple probability simulation,

Is a mathematical technique, which is used to measure the possible outcomes of an unexpected event.

All such combinations of parameters are written to a numerical output file and can then be analyzed in detail, recalculating the results several times, each time using a different set of random numbers

Since Monte Carlo analysis necessitates a large number of calculation choices, it takes a long time.

Simulation of the impedance curve



If the equivalent part of the object is taken 4 (C) and 1 (D) cells, the nature of the impedance curve A and B, respectively, does not change, and only disperse when changing denominations. As a result, we conclude that the analysis of a group of cells can be replaced by an equivalent scheme of one cell.

The device created

- The created prototype in addition to the printed circuit board contained some other components, such as DC converter, potentiometer, battery, etc. Then all these elements were placed in the case

Electromagnetic compatibility

- Example of measuring conductive interference installation in real conditions

Operating instructions

Preparing the device for work
Before starting, make an external inspection of the device and check: integrity, completeness, absence of visible mechanical damage to the device and electrodes.

1.Electrodes preparation

2.Unpack the contact wires and electrodes. Connect the contact wire plugs to the electrode sockets. Then connect the plug of the common part of the contact wires on the body of the device.

1.Procedure preparation

2.Make sure the skin where the electrodes are applied is clean, without cosmetics, there are no rashes and damage. It is recommended to wipe the skin with a lotion or a weak alcohol solution.

1.Conducting tDCS

2.During the operation, the patient should be calm, comfortable, and awake. Some patients may experience discomfort during the initial period of tDCS. In these cases, the current can be reduced progressively over a short period of time. The duration of the session should not exceed 10-15 minutes.

Conclusions

As a result of processing the theoretical material, construction of a precision current source and an equivalent model of the object under study, modeling in the Micro-Cap 9 software, testing a sample of the device, it was found that:

- by influencing brain activity, it is possible to positively influence most of the body's processes
- the conglomerate of cells in the equivalent scheme can be replaced by the equivalent scheme of one cell.

• The choice of real components was made taking into account their technical characteristics, price and availability. Passive circuit elements were selected using standard series for resistors and capacitors and by simulation in MC9 software.

• Technical specifications for the unit, as well as structural and electrical schematic diagrams, were also created. Laboratory tests showed that the designed sample of the device meets the specified technical requirements. The results of the experiment confirmed the results of computer simulation.

• The developed device is safe to use and mostly meets the standards of labor protection, but certain measures have been proposed to reduce the physical danger.

THANK YOU!