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SIMULATION OF AN ELECTROMYOGRAPHIC SIGNAL CONVERTER FOR ADAPTIVE ELECTRICAL STIMULATION TASKS

The **subject** matter of the article is an electromyographic signal transducer, which are an integral part of devices for adaptive electrical stimulation of muscle structures based on reverse electromyographic communication. The **goal** of the work is to study the features, obtaining the corresponding theoretical relationships and computer modeling of a differential biopotential converter, providing amplification of the useful component and suppression of harmful interference, the spectra of which intersect. The following **tasks** were solved in the article: determining the effect of electrode width and electrode spacing on crosstalk; formation of the electrode-skin model and the input circuit of the transducer, obtaining theoretical relations for calculating the rejection coefficient, construction of the transducer circuit and its computer simulation. The following **methods** were used – methods of mathematical modeling of processes and technical devices; methods of analysis, structural and parametric synthesis of nonlinear electronic circuits; methods of machine design. The following **results** were obtained – a biopotential amplifier circuit with tracking feedback on power supply is proposed; modeling of dynamic processes by means of the Multisim program was carried out; on the basis of the constructed model of the electrode-skin input circuit and the obtained analytical relationships, the rejection coefficient of the input circuit of the equivalent circuit is calculated; the requirements for the signal registration module are formulated. **Conclusions:** The considered version of the electromyographic signal converter circuit based on tracking communication on power supply, effectively rejects 50 Hz common mode noise. On the basis of the constructed equivalent model of the input circuit of the amplifier, the theoretical relation for calculating the rejection coefficient of such amplifiers. The circuit is simulated in the Multisim program, the results confirmed the correctness of its functioning. The requirements for the interelectrode distance and the thickness of the electrodes themselves are also formulated. The results obtained can be used to design complexes for adaptive electrical stimulation.

Keywords: biopotential amplifier; useful signal; interference; muscle; electrode system; simulation; Multisim.

Introduction

Currently, the measurement of electromyographic (EMG) signals is widely used in clinical practice for the diagnosis of various diseases. Also, the measurement of human biopotentials is actively used in prosthetic technology. The main task is to measure the degree of tension of an individual muscle. There are various methods for determining the degree of muscle contraction [1-2]. But to amplify very weak signals, special biopotential amplifiers are needed.

Analysis of the problem and existing methods

When developing devices for receiving EMG signals, it is necessary to take into account a number of specific features of these devices.

The main difficulty in developing EMG signal amplifiers is that these signals have a low amplitude (from 20 μV to 2 mV at maximum muscle contraction), while the useful signal can be superimposed noise, the amplitude of which can significantly exceed the EMG-signal. It is necessary to take into account the fact that the amplitude characteristics of EMG signals for different muscles may differ significantly, they may have different values in different people [3-7].

The problem is the effect of 50 Hz guidance on the useful signal. The situation is complicated by the fact that the frequency of 50 Hz is in the spectrum of the useful signal, which has a range of 20-500 Hz. To attenuate this interference, signal filtering alone is not enough [3].

The next problem includes myographs, which have a different range of voltage measurement, which makes it difficult to register the full range of changes in the amplitude of the useful signal. For example, in the multifunctional complex for neurophysiological studies "Neuron-Spectrum-5" the voltage measurement range is 5 μV-50 mV, with a relative error of voltage measurement in the range from 0.1 to 50 mV - within ± 5% [8].

When the signal is diverted from any muscle group, there may be cross-interference from neighboring muscle groups. Thus, it is necessary to minimize the mutual influence of electrical activity of neighboring muscles. This is achieved by optimal selection of the shape of the electrodes, the interelectrode distance, the choice of points of application of the electrodes.

The effectiveness of the rehabilitation process using electrical stimulation in various skeletal muscle lesions is determined by the adequacy of stimulating effects. This applies to both the shape of the effects and the parameters, such as amplitude, frequency or others. These parameters are individual not only for the individual patient and the condition of the muscles, but also depend on the specific type of muscle. Therefore, it is important to have electromyographic feedback in the process of electrical stimulation. Therefore, in systems of adaptive electrical stimulation it is necessary to provide means of measuring the electrical activity of muscles. he electromyogram signal is low-frequency and in-phase interference, which are located in the spectrum of the useful signal, so special amplifiers are used to neutralize such interference. Amplifiers must provide active neutralization due to the feedback signal supplied to the neutralizing electrode.

The **aim** of this article is to study and computer model the differential biopotential amplifier.

Features of electrodes

The correct positioning of the electrodes on the skin surface is important. To obtain the maximum signal amplitude, the electrodes are superimposed on the socalled moving points [9].

To obtain a stable electrode-skin contact and to reduce the impedance of the skin, the skin must be properly prepared before applying the electrodes [10-11].

Fig. 1 clearly shows the dependence of the amplitude of the signal on the location of the electrodes over the area of the studied muscle. With the correct positioning of the electrodes increases the amplitude of the useful signal, increases the signal-to-noise ratio, reduces the effect of cross-interference from neighboring muscles.

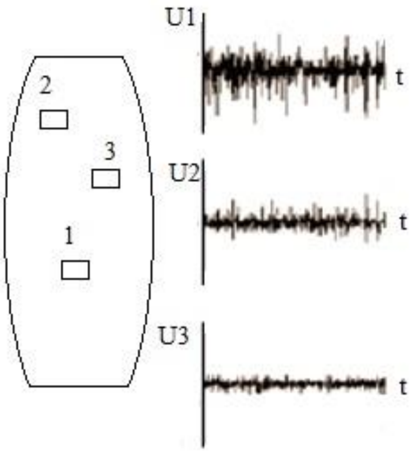


Fig. 1. The dependence of the signal on the place of application of the electrodes [3]

It is necessary to use electrodes made of materials that would ensure stable skin-electrode contact for a long time, and were not prone to polarization effects. In this case, it is advisable to use electrodes made of silver, silver chloride electrodes, or gold or platinum [3]. They do not oxidize, are weakly polarized, but are expensive.

Promising use of capacitive electrodes in which the conductive layer is covered with a dielectric.

With regard to the shape of the electrodes themselves, it should be noted that the geometry of the electrodes affects the amplitude of the signal being taken, as well as the level of crosstalk. The main parameters are the interelectrode distance and the area of the surface occupied by the electrode. Thus, the amplitude of the removed signal will be directly proportional to the interelectrode distance, while the bandwidth will decrease with increasing distance [12].

Fig. 2 presents the dependences of the level of cross-interference on the interelectrode distance and the width of the electrodes. These dependences are obtained by using electrodes with a width of 7.5 and 1 mm and changing the distance between them.

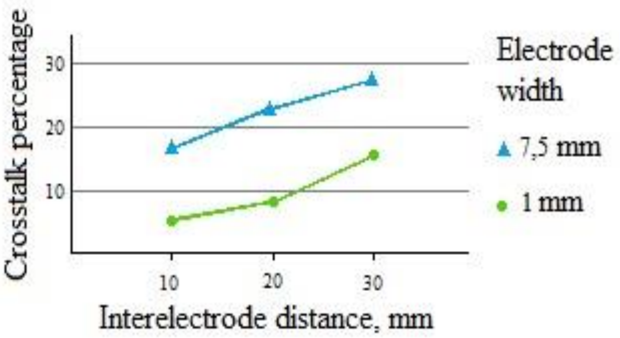


Fig. 2. Dependence of the level of cross-barriers from the interelectrode distance and width of the electrodes [3]

The conductivity of muscle tissues is due to complex biochemical and biophysical processes. The linearity of the obtained dependence of the amplitude of the EMG signal from the distance between the electrodes allows us to assume that in the inverted range, muscle fiber can be considered a homogeneous conductor [13].

One of the physiological properties of skeletal muscles is conductivity, that is, the ability to carry out an excitation wave. At the heart of the excitation rate is the rate of biochemical reactions occurring on cell membranes. Electric irritation of the muscle fiber leads to a change in the ion conductivity of the membrane due to passage through sodium, calcium and potassium channels of currents of the corresponding ions [14-15].

The structure and features of the electrode-skin contact

One of the requirements when using surface electrodes is to reduce the transition resistance of the electrode-skin. The structure of the electrode-skin contact is shown in fig. 3.

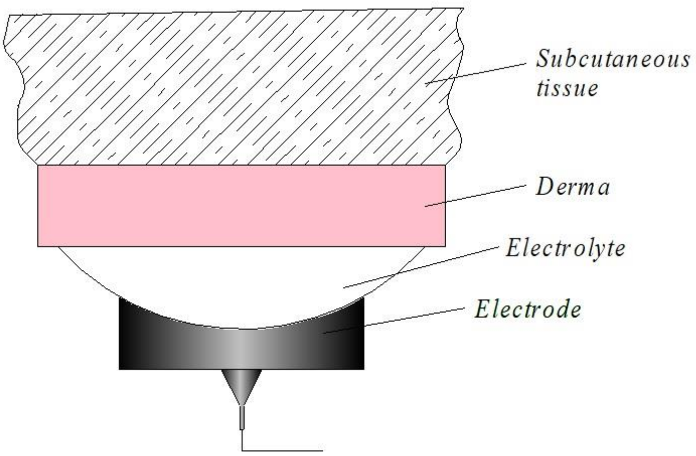
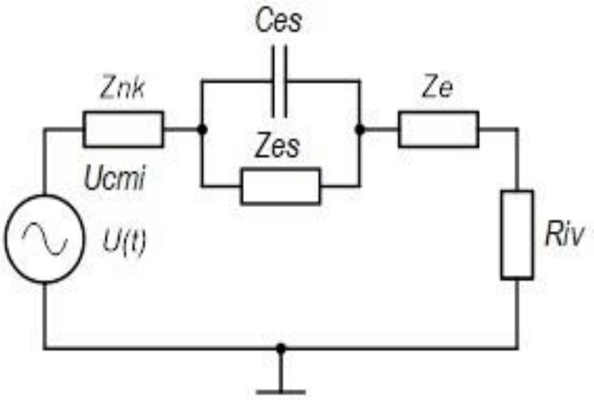


Fig. 3. Electrode-skin contact structure

An equivalent electrode-skin contact scheme can be represented as follows (fig. 4).



U(t) – source of biopotential; *Znk* – resistance of subcutaneous tissues; *Ces, Zes* – capacitance and resistance of electrode-skin contact; *Ze* – electrode resistance; *Riv* – input resistance of the biopotential amplifier.

Fig. 4. Equivalent electrode-skin circuit

Differential biopotential amplifier

Different transition supports of the electrode-skin through different channels leads to the fact that the in-phase interference, which is present on the human body, acts as a useful differential signal, and then significantly amplified. Therefore, it is necessary to reduce the transient resistance to equalize the difference between the interelectrode potentials.

Construct an equivalent circuit that includes a transient resistance electrode-skin (Res) and the input circuit of the differential amplifier (Rd, Rcmi) (fig. 5). The voltage source Ucmi simulates the presence of in-phase interference on the human body. The difference in the transition supports of the electrode-skin is taken into account by the presence of the correction ΔRes.

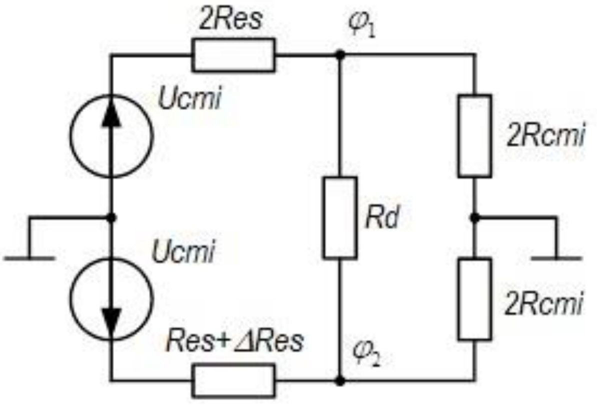


Fig. 5. Equivalent scheme for calculating the resection coefficient

Since in practice the relation Rdif »Res is always fulfilled, then for the potentials of nodes 1 and 2 the following difference is applied to the input of the amplifier:

$$U=\phi_1-\phi_2=U_{es}2R_{cmi}\left(\frac{\Delta R_{es}}{(R_{es}+\Delta R_{es}+2R_{cmi})(R_{es}+2R_{es})}\right), \quad (1)$$

where ϕ_1 – node 1, ϕ_2 – node 2, U_{cmi} – source of power, R_{cmi} – input circuit of the differential amplifier, ΔR_{es} – the difference in the transient resistances of the electrode-skin, R_{es} – transient resistance electrode-skin.Neglecting the values Res and ΔRes in comparison with Rcmi (since Rcmi»Res), we obtain:

$$U\approx U_{cmi}\frac{\Delta R_{es}}{2R_{cmi}}. \quad (2)$$

This difference is a differential signal, i.e.

$$U_{in.dif}=\frac{\Delta R_{es}}{2R_{cmi}}U_{cmi}, \quad (3)$$

and the cophasal signal transfer factor to the output in the form of a differential:

$$K_{rc}=\frac{U_{in.dif}}{U_{cmi}}=\frac{\Delta R_{es}}{2R_{cmi}}. \quad (4)$$

Taking into account the formula for finding the coefficient of rejection:

$$H=\frac{K_{rr}}{K_{rc}}, \quad (5)$$

at $K_{rr}=1$ we finally find:

$$H=\frac{2R_{cmi}}{2\Delta R_{es}}. \quad (6)$$

Thus, the difference in the transition resistances of the electrode-skin limits the rejection coefficient of the input circuit. Therefore, in order to reduce the transient resistance, it is necessary to carefully apply special pastes.

Biopotential amplifier modeling and signal registration module requirements

It is advisable to use AD620 chips from AnalogDevices as an instrumental amplifier, which requires only one external resistor to set the gain from 1 to 10000. AD620 has low voltage input noise and low current input noise, which makes it a good choice for pre-amplification [16]. The characteristics of AD620 are given in table 1. Four-channel operational amplifier AD704 from AnalogDevices on bipolar transistors, which has a small input bias current, typical of amplifiers based on BiFET technology (a combination of bipolar and field-effect transistors), but has a much lower temperature drift IB [17]. The characteristics of AD704 are given in table 2. Fig. 6 shows an electrical schematic diagram of the biopotential amplifier.

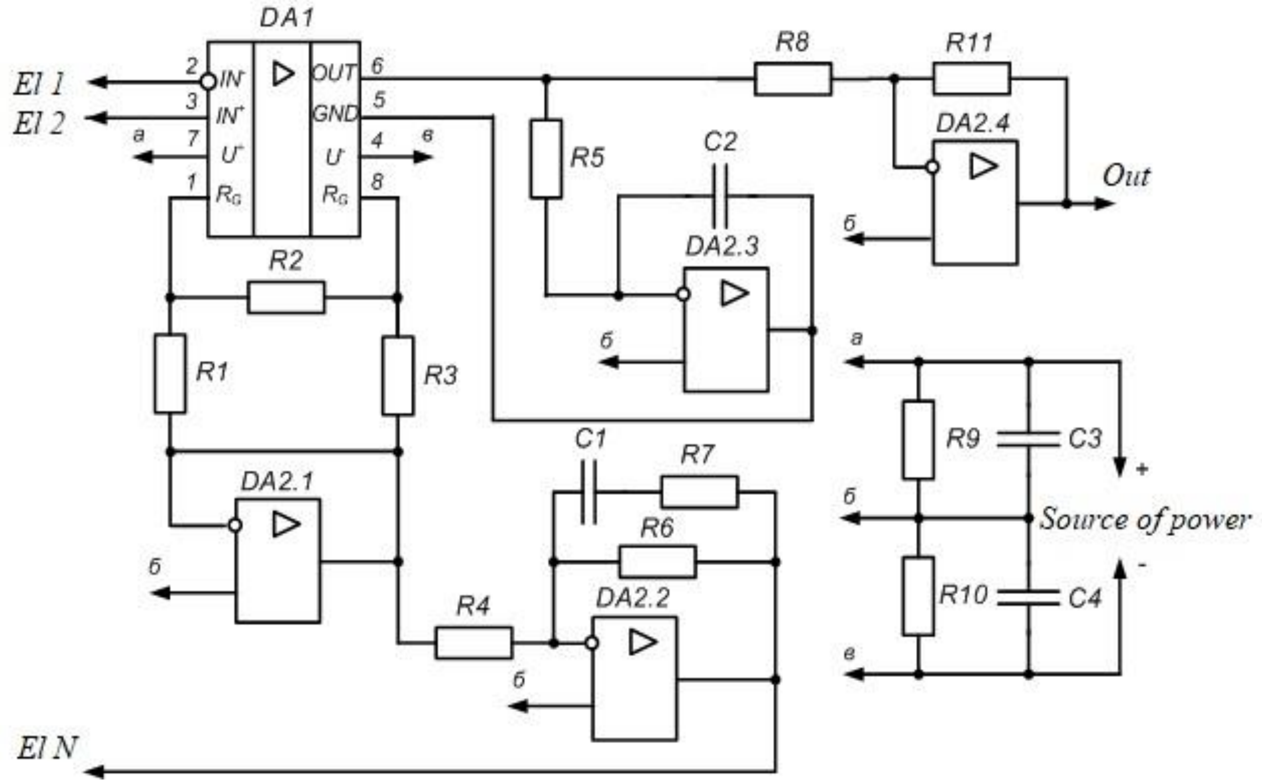


Fig. 6. Schematic electrical circuit of the biopotential amplifier

Table 1. *Characteristics of the chip AD620*

Name	Value
Supply voltage	4.6… 36 V
Current of own consumption	900 μA
Programmable gain	none
The maximum growth rate of the output signal	1.2 V/μs
Operating temperature range	-40…85°C
Technical feature of OP	Low Power
Frequency of single gain	1 MHz
Noise level	9 nV/Hz

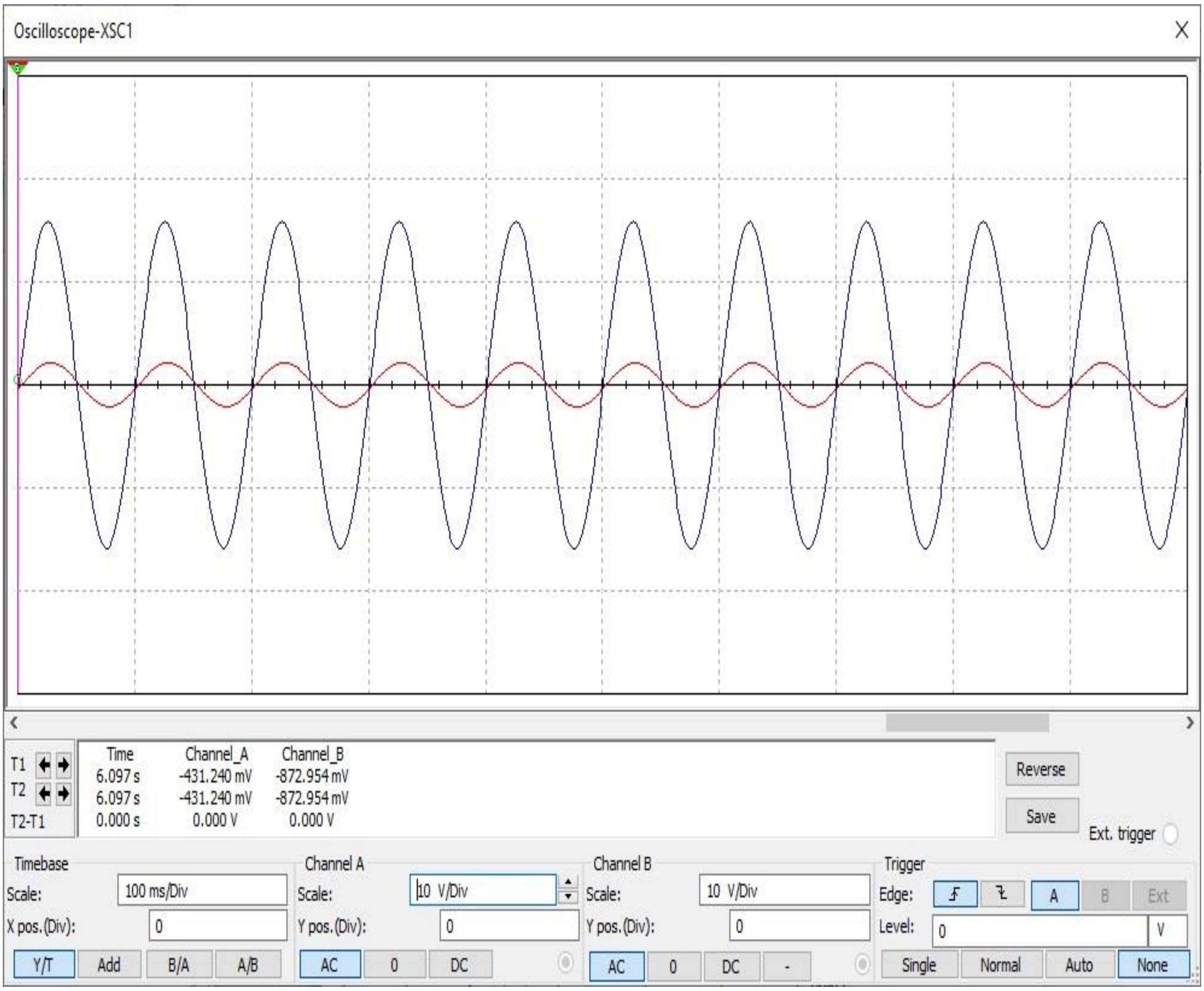
Table 2. *Characteristics of the chip AD704*

Name	Value
Shear voltage	150 μV
Shear voltage drift	1.5 μV/°C
Input bias current	270 pA

Fig. 7 presents the result of modeling the circuit of the electrical principle of the biopotential amplifier in the graphic editor of the Multisim program.

The simulation results confirm the efficiency of the circuit and allow to obtain the necessary characteristics.

The quality of registration of biosignals is influenced by many factors, among which the properties of the electrodes play an important role. Elimination of influence of antiphase physical obstacles and leads is reached by reduction of the area of the closed contour formed by wires of assignments, application of shielding methods.



	Time	Channel_A	Channel_B
T1	6.097 s	-431.240 mV	-872.954 mV
T2	6.097 s	-431.240 mV	-872.954 mV
T2-T1	0.000 s	0.000 V	0.000 V

Timebase
Scale: 100 ms/Div
X pos.(Div): 0

Channel A
Scale: 10 V/Div
Y pos.(Div): 0

Channel B
Scale: 10 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Fig 7. The result of simulation in Multisim program

Conclusions

As a result of the research, the scheme of the biopotential amplifier in the Multisim program was proposed and tested. The operation of the electric schematic diagram of the notch filter for attenuation of network interference is simulated, and also on the basis of the constructed model of the input circuit electrode-skin and the received analytical relations the coefficient of resection of the input circuit of the equivalent circuit is calculated. The requirements to the signal registration module are offered and the necessary element base is selected. Such amplifiers can be used, in particular, to amplify weak electromyographic signals in diagnostic devices or monitor the effectiveness of therapeutic procedures of the human musculoskeletal system.

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МОДЕЛЮВАННЯ ПЕРЕТВОРЮВАЧА ЕЛЕКТРОМІОГРАФІЧНОГО СИГНАЛУ ДЛЯ ЗАДАЧ АДАПТИВНОЇ ЕЛЕКТРОСТИМУЛЯЦІЇ

Предметом дослідження в статті є перетворювачі електроміографічного сигналу, які є складовою частиною пристроїв для адаптивної електростимуляції м'язових структур на основі зворотного електроміографічного зв'язку. **Мета** роботи –

дослідження особливостей, отримання відповідних теоретичних співвідношень та комп’ютерне моделювання диференційного перетворювача біопотенціалів, що забезпечує підсилення корисної складової і приглушення перешкоди, спектри яких перетинаються. В статті вирішуються наступні **завдання**: визначення впливу ширини електродів і міжелектродної відстані на перехресні перешкоди; формування моделі електрод-шкіра і вхідного кола перетворювача, отримання теоретичних співвідношень для розрахунку коефіцієнта режекції, побудова схеми перетворювача та її комп'ютерне моделювання. Використовуються такі **методи**: методи математичного моделювання процесів і технічних пристроїв; методи аналізу, структурного і параметричного синтезу нелінійних електронних схем; методи машинного проектування. Отримано наступні **результати**: запропоновано схему підсилювача біопотенціалів, що стежить зворотним зв'язком по живленню; проведено моделювання динамічних процесів засобами програми Multisim; досліджено схему підсилювача біопотенціалів у програмі Multisim; на основі побудованої моделі вхідного кола електрод-шкіра і отриманих аналітичних співвідношень розраховано коефіцієнт режекції вхідного кола еквівалентної схеми; сформульовано вимоги до модулю реєстрації сигналу. **Висновки**: Розглянутий варіант схеми перетворювача електроміографічного сигналу на основі зв'язку, що стежить по живленню, дозволяє ефективно гасити синфазну перешкоду 50 Гц. На основі побудованої еквівалентної моделі вхідного кола підсилювача отримані теоретичні співвідношення для розрахунку коефіцієнта режекції таких підсилювачів. Схема промодельована в середовище програми Multisim, результати підтвердили ефективність її функціонування. Сформульовано вимоги до міжелектродної відстані і товщини самих електродів. Отримані результати можуть бути використані для проектування комплексів адаптивної електростимуляції.

Ключові слова: підсилювач біопотенціалів; корисний сигнал; перешкода, м'яз; система електродів; моделювання; Multisim.

МОДЕЛИРОВАНИЕ ПРЕОБРАЗОВАТЕЛЯ ЭЛЕКТРОМИОГРАФИЧЕСКОГО СИГНАЛА ДЛЯ ЗАДАЧ АДАПТИВНОЙ ЭЛЕКТРОСТИМУЛЯЦИИ

Предметом исследования в статье являются преобразователи электромиографического сигнала, которые являются составной частью устройств для адаптивной электростимуляции мышечных структур на основе обратной электромиографической связи. **Цель** работы – исследование особенностей, получение соответствующих теоретических соотношений и компьютерное моделирование дифференциального преобразователя биопотенциалов, обеспечивающего усиление полезной составляющей и подавление вредной помехи, спектры которых пересекаются. В статье решаются следующие **задачи**: определение влияния ширины электродов и межэлектродного расстояния на перекрестные помехи; формирование модели электрод-кожа и входной цепи преобразователя, получение теоретических соотношений для расчета коэффициента режекции, построение схемы преобразователя и ее компьютерное моделирование. Используются следующие **методы**: методы математического моделирования процессов и технических устройств; методы анализа, структурного и параметрического синтеза нелинейных электронных схем; методы машинного проектирования. Получены следующие **результаты**: предложено схему усилителя биопотенциалов со следящей обратной связью по питанию; проведено моделирования динамических процессов средствами программы Multisim; на основе построенной модели входной цепи электрод-кожа и полученных аналитических соотношений рассчитан коэффициент режекции входной цепи эквивалентной схемы; сформулированы требования к модулю регистрации сигнала. **Выводы**: Рассмотренный вариант схемы преобразователя электромиографических сигнала на основе следящий связи по питанию позволяет эффективно подавлять синфазную помеху 50 Гц. На основе построенной эквивалентной модели входной цепи усилителя получены теоретические соотношение для расчета коэффициента режекции таких усилителей. Схема промоделирована в среде программы Multisim, результаты подтвердили эффективность ее функционирования. Сформулированы требования к межэлектродному расстоянию и толщине самих электродов. Полученные результаты могут быть использованы для проектирования комплексов адаптивной электростимуляции.

Ключевые слова: усилитель биопотенциалов; полезный сигнал; помеха; мышца; система электродов; моделирование; Multisim.

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