# Comparative Analysis of Technical Parameters of Acupuncture-like Electrostimulation Device

**Gadir Gafarov**

*Department of Electronics and Automation*
*Faculty of Information Technologies and Control*
*Azerbaijan State Oil and Industry University*
*34 Azadliq Avenue, Baku, Azerbaijan*
*E-mail: qafarov1997@gmail.com*

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***Abstract:*** *The comparative analysis of technical parameters of acupuncture-like electrostimulation devices provides crucial insights into their performance, efficacy, and usability in therapeutic applications. This study evaluates a selection of commercially available electrostimulation devices, focusing on key parameters such as output frequency, pulse duration, current intensity, waveform characteristics, and safety features. A comparative analysis of the output signal frequencies of an acupuncture-like electrostimulator and commercial electrostimulator devices was designed and performed. The error percentage in the output signal frequency of the designed electrostimulator was determined. It was found that the designed stimulator is superior in terms of signal stability compared to existing electrostimulator devices.*

***Keywords:*** *Acupuncture-like electrostimulation, Therapeutic waveform characteristics, Therapeutic applications, Transcutaneous electrical nerve stimulation (TENS), Acupuncture.*

## Introduction

Transcutaneous electrical nerve stimulation (TENS), divided into two approaches, such as traditional electrical stimulation and acupuncture-like electrical stimulation, is widely used in alternative medicine. An example for transcutaneous electrical nerve stimulation device is given in Fig. 1. As is known, the application of the method is based on the theory of pain management [7]. Based on this theory, an analgesic effect is created, but its specific parameters are difficult to specify. Various stimulation parameters related to electrical stimulation are available in the literature. Traditional electrical stimulation is characterized by parameters such as high frequency (50-100 Hz), low intensity stimulation (painless paresthesia) and short duration (50-200 μs). Acupuncture-like electrical stimulation is characterized by parameters such as low frequency (2-10 Hz), high intensity stimulation (upper limit of pain threshold), and longer duration (100-400 μs) [4, 9]. The acupuncture-like electrical stimulation method was proposed as a hyperstimulation method in 1979 [8]. This method is used when traditional electrical stimulation does not provide effective treatment. The essence of the acupuncture-like electrical stimulation method is the activation of highly sensitive peripheral afferents (A-delta) through small diameter electrodes [9].

The main issue in acupuncture-like stimulation is the correct selection of electrical parameters and ensuring that they do not deviate from the standard parameters during the treatment process. During electrostimulation, the intensity, frequency and treatment mode (signal wave form) are considered as the main parameters [1, 3, 6].

The intensity parameter, measured in mA, determines the strength of the electric current flow between the positive (anode) and negative (cathode) electrodes.

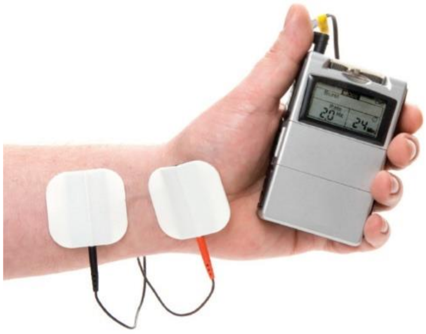

Fig. 1. Transcutaneous electrical nerve stimulation device

Frequency, measured in Hz, is the number of electrical impulses that affect a biological system per second [6]. Frequency parameter has a greater effect on the neurophysiological response than other variables. Lower frequencies (1-10 Hz or pulse waves per second) are suitable for muscle dysfunction or muscle damage studies. High frequencies (80-100 Hz) are effective in treating sensory symptoms such as neuropathy.

Treatment mode (signal wave form) determines how the stimulus signal varies in time. Continuous signal form is a sequence of pulsations whose pulse duration does not change with frequency adjustment. The biological system adapts quickly to the regimen and requires increasing intensity during treatment to maximise physiological responses. Intermittent/continuous signal form is a sequence of equally spaced pulsations (as in continuous) but characterised by periods of inactivity. As usual, the body will eventually adapt to this mode of delivery. The practitioner should regularly monitor the patient's response during treatment and adjust the intensity control accordingly. Dense/dispersed signal periods of high frequency (100 Hz) and low frequency (2 Hz) pulsations in equal proportion. It acts on both sensory and motor neurons and constitutes the most effective treatment medium as an endogenous pain regulator.

Acupuncture-like electrical stimulation devices usually have different technical parameters. Such devices have some basic parameters mentioned below.

**Frequency.** Electrical stimulation devices typically have a frequency range of 1-150 Hz. Within this range, the frequency range of 1-10 Hz is used for the stimulation of acupuncture points.

**Intensity.** This is an electrical parameter determined according to the intensity of pain (or type of pain) and the biophysical properties of tissues.

**Duration.** The duration of the pulse signal used for therapeutic purposes needs to be adjusted. This regulation is very important for the comfort of the patient and for preventing the overloading of the biological system.

**Mode.** Electrical stimulation devices have different modes of operation related to frequency parameter modulation. Each mode transmits a therapeutic electrical impulse to the biological system in a different form and rhythm.

**Therapeutic wave form.** Depending on the type of therapy, stimulators are available to support symmetric biphasic, asymmetric biphasic, or monophasic wave forms. Each signal form has its own characteristics and therapeutic effects.

**Timer.** In electrostimulation devices, a special timer circuit is built to regulate the treatment time. The operation of the timer depends on the type of treatment, as well as the shape and parameters of the signal.

**Battery.** Electrical stimulation devices are marketed by the manufacturer in different variants, such as rechargeable and those powered directly from the mains.

**Safety features.** High-quality electrical stimulation devices incorporate safety features such as overcurrent protection, automatic shutdown, and compliance with regulatory standards for medical devices.

## Designing an acupuncture-like electrical stimulator

The designed device has both pulse signal and exponential signal modes. The device has the ability to control the pulse width and frequency for the treatment of pain through acupuncture points (Fig. 2). As demonstrated in other studies, stimulating the cells with the electrical stimulator enables the treatment of pain [2]. The ability to control the type of pain and the physiological characteristics of acupuncture points within the device will increase the effectiveness of the treatment.

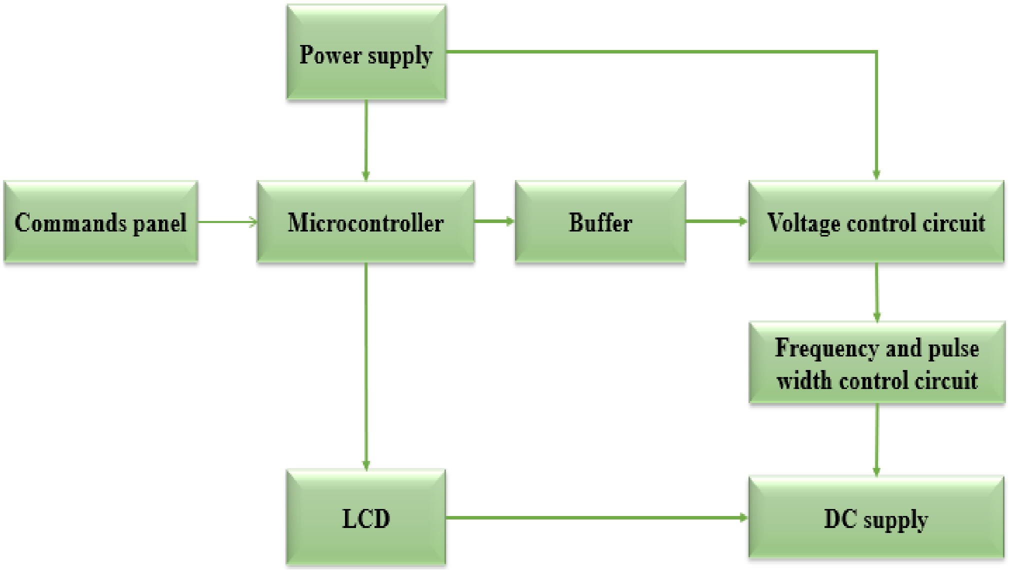


Fig. 2 Architecture of an acupuncture-like electrical stimulator

The stimulation signal parameters are controlled by means of a potentiometer connected to the output. The main task of the potentiometer is to determine the period (duration) of the stimulation signal. A type of microcontroller was used to manage and regulate the system. The PIC16F877A microcontroller was selected as the control system element of the device. The PIC16F877A is a popular 8-bit microcontroller manufactured by Microchip Technology. This model is widely used in microelectronics and automation projects. The main reason for its use is its wide functionality and easy programming capabilities. The device uses a NE556 microcircuit, which enables the generation of pulse signals based on the parameters entered from the microcontroller. To program the microcontroller, the MicroC software package was used in the C language. A maximum of 2 V was selected at the output for impacting acupuncture points.

## Material and methods

The test circuit, shown in Fig. 3, is based on a function generator and a frequency counter. The input of the circuit is connected to the output of the stimulator and fed to the voltage divider through the 1N914 diode. A low-frequency and high-precision KM3165 model frequency counter was used to measure the frequency of the stimulation signal.

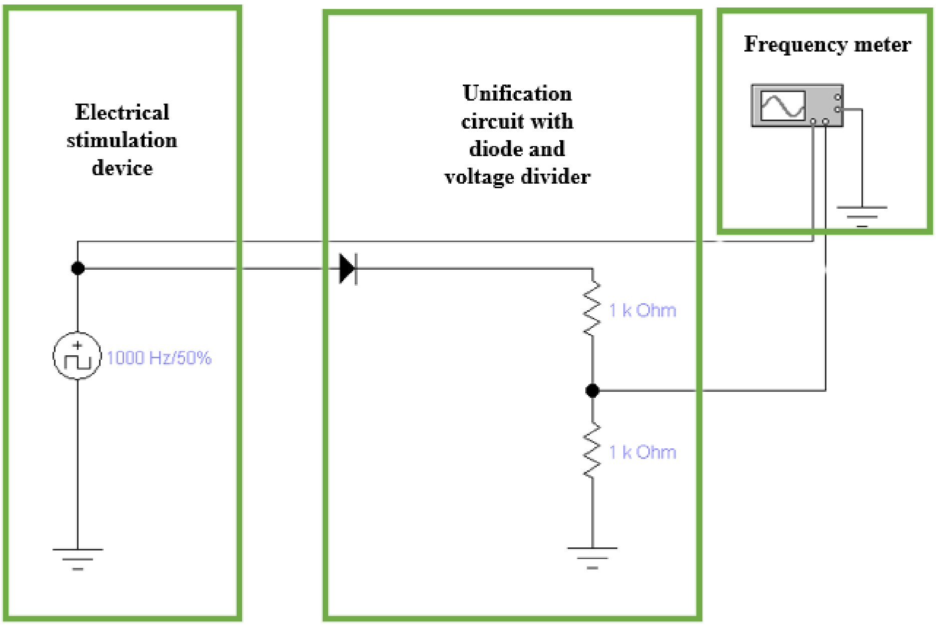


Fig. 3 Scheme for measuring the frequency of the stimulator

Two commercially available stimulation devices were used (Fig. 4) [10, 11]. Both devices are calibrated, taking into account calibration after manufacture [5]. Stimulators were adjusted at 5 different values of the frequency range, and measurements were made. Similarly, 5 different frequencies were measured in the newly designed stimulator.


AUVON TENS unit muscle stimulator [10] MEDVICE TENS unit muscle stimulator [11]

Fig. 4 Commercially available stimulation devices

## *Research methodology*

The output frequencies of the electrical stimulation devices, which we call Stimulator 1 and Stimulator 2, were measured repeatedly, 10 times at 5 different frequency values: 1 Hz, 2 Hz, 4 Hz, 8 Hz, 9 Hz. The measurement results are shown in Table 1.

The values obtained from the measurements allow us to say that the parameters specified in the technical specifications of the electrical stimulation devices produced by the manufacturing companies are not identical. Accordingly, in commercially manufactured stimulator devices, the frequency parameter was observed to deviate from its true value by 0.13% to 25%, respectively. The same measurement operations and calculations were carried out for the acupuncture-like stimulation device, which was designed using a modern element base. The measurement results are shown in Table 2.

Table 1. Results of the output frequencies of stimulators

| **Stimulator 1** | | | | | |
|---|---|---|---|---|---|
| **Frequency** | **1 Hz** | **2 Hz** | **4 Hz** | **8 Hz** | **9 Hz** |
| **1.** | 0.978 | 1.971 | 3.899 | 7.963 | 9.125 |
| **2.** | 0.955 | 1.988 | 3.978 | 8.02 | 9.03 |
| **3.** | 0.945 | 1.988 | 3.902 | 8.09 | 8.84 |
| **4.** | 0.978 | 1.988 | 3.9 | 7.85 | 8.951 |
| **5.** | 0.979 | 1.967 | 3.91 | 7.841 | 8.951 |
| **6.** | 0.97 | 1.991 | 3.9 | 7.89 | 8.894 |
| **7.** | 0.969 | 1.552 | 3.897 | 7.761 | 8.749 |
| **8.** | 0.873 | 2.021 | 3.980 | 8.098 | 8.894 |
| **9.** | 0.984 | 2.022 | 3.908 | 7.894 | 8.853 |
| **10.** | 1.024 | 1.952 | 3.905 | 7.919 | 8.851 |
| **Average price** | **0.9655** | **1.9440** | **3.9179** | **7.9326** | **8.9138** |
| **Error, [%]** | **4.00** | **5.60** | **8.21** | **6.74** | **8.92** |
| | | | | | |
| **Stimulator 2** | | | | | |
| **Frequency** | **1 Hz** | **2 Hz** | **4 Hz** | **8 Hz** | **9 Hz** |
| **1.** | 0.887 | 1.941 | 3.78 | 7.920 | 8.755 |
| **2.** | 0.941 | 1.951 | 3.978 | 7.812 | 8.863 |
| **3.** | 0.748 | 1.786 | 3.971 | 7.687 | 8.851 |
| **4.** | 0.895 | 1.901 | 3.755 | 7.833 | 8.591 |
| **5.** | 0.79 | 1.812 | 3.755 | 7.814 | 8.851 |
| **6.** | 0.82 | 1.901 | 3.689 | 7.833 | 8.884 |
| **7.** | 0.789 | 1.901 | 3.897 | 7.781 | 8.740 |
| **8.** | 0.789 | 1.855 | 3.971 | 7.812 | 8.740 |
| **9.** | 0.789 | 1.901 | 3.800 | 7.84 | 8.851 |
| **10.** | 0.789 | 1.895 | 3.858 | 7.66 | 8.745 |
| **Average price** | **0.8237** | **1.8844** | **3.8454** | **7.7992** | **8.7871** |
| **Error, [%]** | **17.63** | **11.56** | **15.46** | **20.08** | **21.29** |

The frequency values used in the study were selected according to the frequency range employed to stimulate the acupuncture points using the TENS method.

## Results and discussion

The frequency parameter of the acupuncture stimulation device designed with modern architecture was measured using a phasometer at different amplitude values: voltage levels of 0.5 mV, 1 mV, 2 mV, 3 mV, 4 mV. Based on the obtained frequency values, the frequency bias and percentage of error were calculated. The resulting graphs are shown in Fig. 5 and Fig. 6, respectively.

Table 2. Frequency results of the designed stimulator

| Designed stimulator | | | | | |
|---|---|---|---|---|---|
| **Frequency** | **1 Hz** | **2 Hz** | **4 Hz** | **8 Hz** | **9 Hz** |
| **1.** | 0.998 | 2.001 | 3.999 | 8.000 | 9.000 |
| **2.** | 0.998 | 1.998 | 4.000 | 8.002 | 9.001 |
| **3.** | 0.987 | 1.998 | 4.002 | 8.003 | 9.24 |
| **4.** | 1.000 | 2.000 | 3.999 | 8.000 | 8.999 |
| **5.** | 0.997 | 1.998 | 3.991 | 7.999 | 8.998 |
| **6.** | 1.000 | 1.991 | 4.000 | 8.001 | 8.996 |
| **7.** | 1.000 | 2.000 | 3.997 | 8.000 | 8.995 |
| **8.** | 1.000 | 2.000 | 4.001 | 8.001 | 9.000 |
| **9.** | 0.993 | 2.001 | 4.001 | 8.000 | 9.001 |
| **10.** | 1.000 | 2.002 | 4.000 | 7.999 | 9.001 |
| **Average price** | **0.9973** | **1.9989** | **3.9990** | **8.0005** | **9.0231** |
| **Error, [%]** | **0.27** | **0.11** | **0.10** | **0.05** | **2.31** |

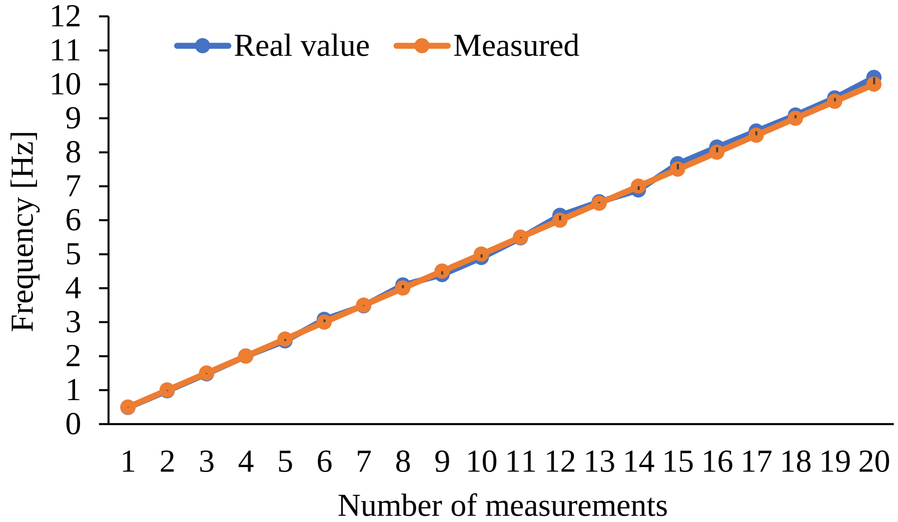


Fig. 5 Comparison of frequency results


Fig. 6 An error caused by a change in a frequency of the device

From the obtained results, it is observed that the error in the frequency values after 8 Hz is around 0.5%. A comparative analysis of the error distribution of the designed acupuncture-like stimulator and the commercial stimulator was performed in Table 1 and Table 2. It can be seen that the error of the designed stimulator is smaller compared to the other two stimulators. This indicates that the device is suitable for use.

The minimum value of the output frequency errors of both commercial stimulators is 4.0%, and the maximum value is 21.29%. The minimum error of the designed device is 0.27%, and the maximum is 2.31%. Both commercial stimulators have high errors at higher frequencies. At frequencies higher than 4 Hz, the minimum error is 6.74%, and the maximum is 20.29%. The designed stimulator has a minimum error of 0.05% and a maximum error of 2.31% at the highest frequency.

## Conclusion

The designed acupuncture-like stimulation device generates pulse signals with variable frequency and voltage levels ranging from 1-10 Hz and 0-2000 mV. By making additional modifications to the circuit, it is possible to obtain sawtooth, sinusoidal, and exponential signals. The acupuncture-like stimulation device can be used in physiotherapy, rehabilitation, neurology, and neurophysiological research, with further modification as a device for stimulating acupuncture points. This feature also differentiates it from existing medical devices on the market by offering a functional advantage.

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**Gadir Arzu Gafarov**
E-mail: qafarov1997@gmail.com

Gadir Gafarov is a Senior Lecturer at the Department of Electronics and Automation at Azerbaijan State Oil and Industry University, Baku, Azerbaijan. The main scientific direction of the author focuses on the complex assessment of electrical parameters that characterize biological systems and the study of the effects of electric current on the human body.