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Three Patterns Programmable Russian Form Functional Electrical Stimulator

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ABSTRACT

In this paper, a programmable, multi-pattern, wide frequency and duty cycle range electrical stimulator is presented. Using a programmable micro-controller, two waves of carrier and modulating sources are produced. By modulating the two sources, 3 bi-phasic charge-balanced rectangular, triangular and sinusoidal stimulating patterns are produced. The frequency range of the carrier is fixed at 2.5 kHz and the carrier source frequency can be adjusted between 1 and 500 Hz. The duty cycle of both sources can be adjusted between 10% and 90%.

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1. INTRODUCTION

Electrical stimulators are used for the rehabilitation of patients [1] and for research [2-3]. One method for producing an electrical stimulation is current-mode in which a constant current over a specific time is applied to a bodily part and the other method is voltage-mode in which a constant voltage is applied.

Electrical stimulators are designed and developed in previous studies [2], [4-13]. A microcontroller is used for the generation of a electrical stimulation in [2], [4-13]. The convenience of micro-contrllers have made these devices also popular in other applications [14-15].

All of the developed electrical stimulators are unique and present one or several forms of electrical stimulaitons. However, none of the before mentioned researches apply the concept of generating two signals, carrier and modulating sources, with the same micro-controller for the generaiton of Russian form electrical stimulation. The objective of this research was to present a new method for the generation of 3 rectangular, triangular and sinusoidal stimulation patterns in Russian form. We show how it is feasible, simple and extendable to use a micro-controller to generate these 3 patterns of electrical stimulaitons.

2. RESEARCH METHOD

The architecture of the functional electrical stimulator is shown in Figure 1. The power source is isolated from the stimulating unit using galvanic medical power supply and DC-DC converters. The stimulating part consists of modulating (AD835), high pass filter (HPF) and low pass filter (LPF) sections and amplification units. For linearity and instant output response, buffers are added before and after HPF and LPF secions.

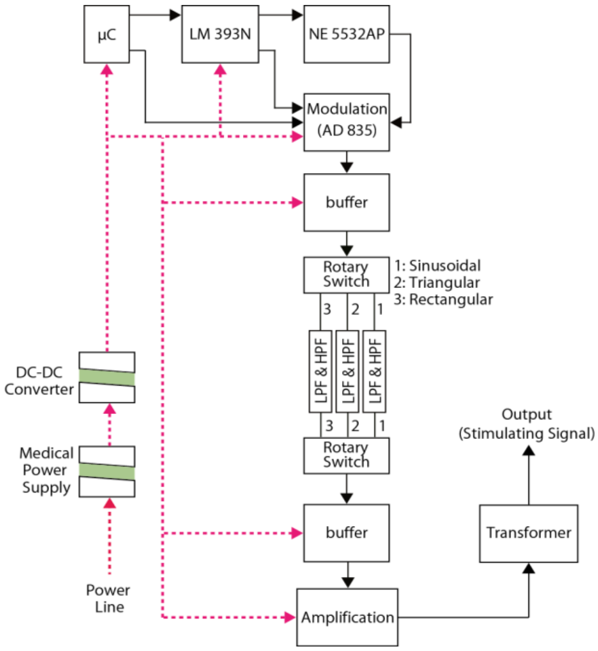

Figure 1. Functional Electrical Stimulator Architecture is Shown. HPF: High Pass Filter, LPF: Low Pass Filter

The carrier source was set to 2.5 kHz [16]. The modulating source can be changed between 1 and 500 Hz. The duty cycle of both the carrier and modulating sources can be adjusted between 10 and 90 percent.

2.1. Modulation Section

The amplitude modulation unit was used because of the need for the Russian forms of electrical stimulations of rectangular, triangular and sinusoidal wave patterns. The high input impedance of the unit makes signal source loading negligible while the unit's low output impedance or in other words its high output capability allows low impedance loads to be driven.

The generation of stimulating signal is based on the modulation of 2 sources, X (modulating) and Y (carrier) (Figure 2). The two signals X and Y are generated using an ARDUINO UNO (Arduino Co.) micro-controller. Their amplitudes are adjusted in such a way that the amplitude of Y be half of that of X. A HPF is used to remove the dc offset and for centering Y. By using a 4-quadrant multiplier AD835, X and Y sources are modulated as the output, W_{output}.

$$W_{output} = {}^{\mathrm{XY}}/_{\mathrm{U}} + \mathrm{Z} \tag{1}$$

where U and Z are 1 and 0 volts, respectively. Therefore,

$$W_{output} = \mathrm{XY} \tag{2}$$

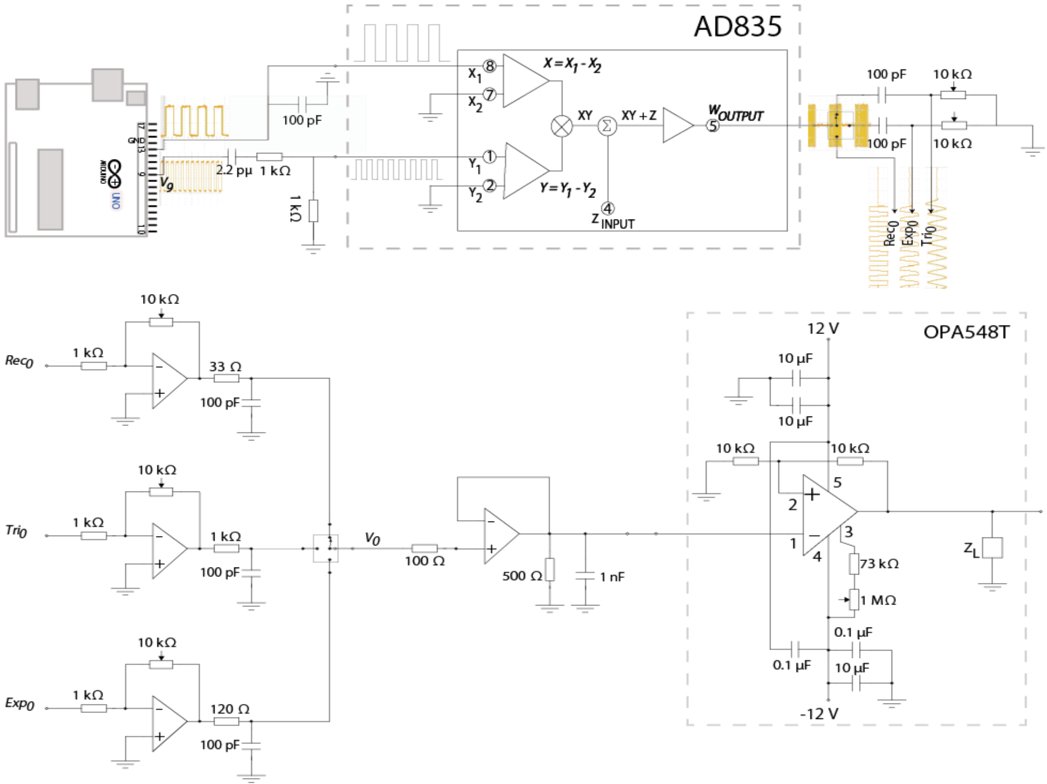

Figure 2. Electrical Stimulator Circuitry is shown. It Consists of Modulation Section (AD835), HPF Section, LPF and Amplitude Adjustment Sections, Buffering, Amplification and Current Limiting Sections

2.2. HPF and LPF Sections

The carrier source of the stimulating signal was chosen as 2.5 kHz. The HPF was used to remove the offset voltages and to convert the rectangular waves into waves of triangular and sinusoidal forms. The amplification and LPF sections were used for adjusting the amplitude and form of the waves of the 3 types of stimulating patterns.

2.2.1. Amplification and Current Limiting

In order to provide the inductor (Z_L) with stable amplitude and to limit the current of the stimulating wave between 0 and 300 mA, the output of the HPF and LPF (V_0) were passed through a buffer and an amplification section.

3. RESULTS

The plots of 5 and 500 Hz rectangular source waves and their respective patterns are shown in Figure 3. Plots of 3 rectangular, triangular and sinusoidal source waves of 20 Hz and the pattern of a 20 Hz triangular source are shown in Figure 4. The carrier source of all 3 stimulating patterns was 2.5 kHz.

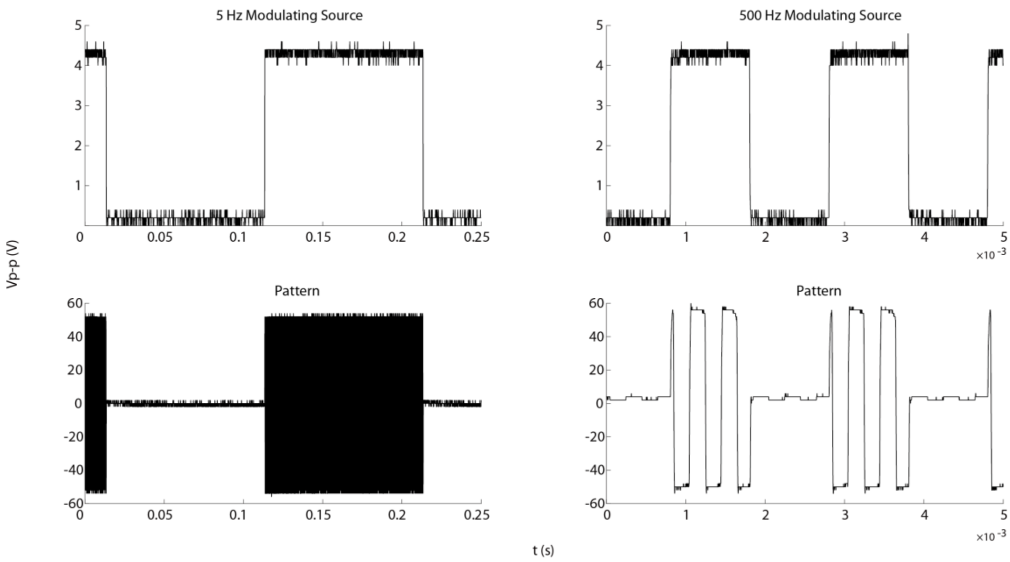

Figure 3. The modulating sources of frequencies of 5 and 500 Hz and their respective stimulating patterns for a rectangular waveform are shown. The duty cycles of both modulating and carrier sources are 50%

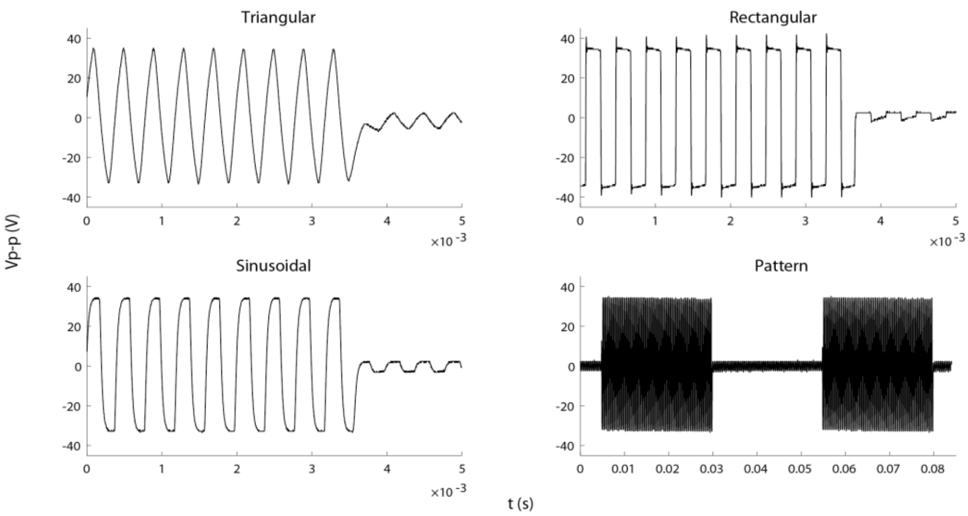

Figure 4. Three stimulating carrier sources of triangular, rectangular, and sinusoidal together with the pattern of a 20 Hz modulating triangular source are shown. The duty cycles of both modulating and carrier sources are 50%

4. DISCUSSION

A new form of electrical stimulation, Russian, was popular amongst athelets [16]. In order to investigate the effect of such alternating electrical stiumulaiton, comparison to other wave forms were made in these researches [17-18]. Other forms of electrical stimulaitons have also been developed [2], [4-13]. In terms of charge, phase, and form, the developed electrical stimulations can be classified as it is shown in Table 1. Triangular and quasi-trapezoidal stimulating waves are also designed and developed in this research [12].

A microprocessor is used in this study [13] to produce 26 fixed and programmable protocols of treatments (eg. traebert, diadynamic, exponential, Russian, etc). Rectangular and triangular waveforms are not amongst the programmable or fixed protocols and it is not mentioned whether they have applied the modulation of waves priniciple for the generation of Russian form of stimulating waves. In these studies, [2], [4-5], [7], [9], [11-12] micro-controllers are also used. It is just in this work [9], that rectangular and triangular wave forms are generated amongst 6 distinct wave forms.

Table 1. Characteristics of previously designed electrical stimulators in terms of charge, form and phase of the stimulating waves

Previous Researches	Charge		Wave Form				Phase	
	balanced	not-balanced	Rec	Sin	Exp	Spike	mono-phasic	bi-phasic
[2]	–	✓	✓	–	–	–	✓	–
[4]	✓	✓	–	–	–	–	✓	✓
[5]	–	✓	✓	–	–	–	–	✓
[6]	✓	–	✓	–	–	–	–	✓
[7]	✓	–	–	✓	–	–	–	✓
[8]	–	✓	✓	–	–	–	✓	–
[9]	✓	✓	✓	–	–	–	✓	–
[10]	✓	–	✓	–	–	–	–	✓
[11]	–	–	–	–	–	✓	✓	✓
[12]	✓	–	✓	✓	✓	–	–	✓
[13]	–	–	–	–	✓	–	–	✓

Rec: Rectangular, Sin: Sinusoidal, Exp: Exponential

None of the developed devices mentioned earlier generate 3 rectangular, triangular and sinusoidal in a Russian form. To our knowledge, the concept of applying the carrier and modulating sources of a single micro-controller together with a modulator for generating 3 commonly used electrical wave forms in a Russian electrical stimulating pattern is new. One advantage that our designed device has in common to other methods also applying a microcontroller is the minimum number of components required that makes the final design compact. The 2nd advantage of our design is its user interface capable extendability. This can be realized for example by adding an input port for reading the input signal. This input signal can be the electromyogram activity of a specific muscle such as tibialis anterior muscle. By modifying program of the microcontroller, the input signal can be used for triggering the electrical stimulation. Finally, the micro-controller provides the user with precise and large range of frequency and duty cycle generations options.

5. CONCLUSION

We applied 2 waves of carrier and modulating sources for the generation of 3 rectangular, triangular and sinusoidal waves in Russian stimulating patterns at different frequencies between 1 and 500 Hz. The duty cycle of both the carrier and modulating sources can be adjusted between 10 and 90 percent. The carrier waveform is fixed at 2.5 kHz which is one limitation of our developed functional electrical stimulator. This is due to the fact that we convert a rectangular waveform to triangular and sinusoidal ones using high pass filters. One solution to this can be the generation of both modulating and carrier waves in 3 rectangular, triangular and sinusoidal waves from the beginning in the micro-controller. Such modification of architecture of the functional electrical stimulator at the micro-controller also allows the generation of monophasic stimulating patterns which are preferred in some applications.

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Abbas Orand obtained his B.Sc. and M. Sc. degrees in electrical and mechatronics engineerings from Dalhousie University in Canada and Siegen University in Germany in 2003 and 2008, respectively. From 2007 to 2008, he worked at Daimler AG in Germany as a researcher. He obtained his doctor of philosophy degree in the field of informatics and biosciences from Keio University in Japan in 2012. He is with the Rehabilitation Department of Fujita Memorial Nanakuri Institute at Fujita Health University since 2011. His fields of research interests are robotics, neuromuscular electrical stimulation, biomedical engineering and rehabilitation.

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