Functional Electrical Stimulation Driver for a Werable-based Bio-stimulation System

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Abstract. Electrical stimulation is widely used in clinical applications as an auxiliary treatment method for muscle injuries or illnesses provoked by muscle atrophy. In most cases, the regular stimulation systems do not provide the proper flexibility to fit the patient's needs or do not provide the freedom of movement due to their size. This paper presents an electrical stimulation driver based on a MOSFET-Transformer topology controlled by a microcontroller. The circuit is integrated into a wearable bio-stimulation system that uses dry electrodes and is controlled by a mobile application. The main system requirements are the stimulation flexibility as well as the driver size. The circuit must be able to generate stimulation pulses according to the patient necessity and be small enough to fit a piece of wearable equipment. The pulses are generated by a microcontroller, controlled by a mobile application, the application sets the pulse parameters such as width, amplitude, and frequency, and the driver performs the signal conditioning, amplifies, and generates the output waveform.

Keywords: Functional Electrical Stimulation · Wearable Biostimulation · Stimulation Circuit · Electrostimulator.

1 Introduction

Electrical Stimulation can be used to produce changes in muscle action and performance, specifically in clinical settings it can be used to improve muscle strength, decrease atrophy, and increase range of motion, among others [2].

However, most electrical stimulation equipment's are bulky and does not provide the necessary flexibility regarding the stimulation parameters [4] [5].

This work presents the development and experimental results of an electrical stimulation driver developed for a Wearable-based Bio-stimulation System. The main objective of this work is to develop a circuit capable of generating flexible parameters to fulfill muscle stimulation according to the patient necessity and be small enough to fit in a wearable device.

This work has been developed in the environment of the NanoStim Project, this project aims the development a system capable of identifying walking movements by acquiring electromyogram signals and processing those signals using a machine learning protocol to create a stimulation pattern dedicated for each patient according to their illness and condition. This way, the patient that suffers from a motion deficiency can fulfill the required treatment at home, avoiding the setbacks of locomotion to the physiotherapy clinic without compromising the treatment efficiency. The description of the remaining blocks of the project can be seen at [8].

The rest of the document is organized as follows: Section 3 presents the system requirements, Section 2 presents the current state of art of the technology, Section

4 describes the system development, Section 5 presents the experimental results and Section 6 presents the conclusions of the realized work.

2 State of the art

Functional electrical stimulation is the most common treatment technique used in motor function improvement, aside from conventional therapy and occupational therapy [4]. FES can be used to treat a great variety of diseases, conditions, and disorders in a non-invasive manner [7] [3].

To fulfill this *Cheng at al.* [4] proposes two alternatives of implementation. The first implementation is based on two integrated circuits timers 555, with operational amplifiers to generate the pulses, and a transformer to step up the output voltage, the pulse parameters are controlled by changing the discrete components. The second implementation consists of a transistors pair and resonant converters where the pulse amplitude is regulated by changing a resistance.

Following the same principle, *Velloso et al.* [9] proposes a solution composedof operational amplifiers for conditioning and feedback, followed by a pair of transistors and a step-up transformer. The system is controlled by a *LabView 7.1* application to control the pulse parameters.

Similarly, *Basumatary et al.* [1] propose a microcontroller based system that produces biphasic waveforms using n ESP32, waveform converter, current amplifier, and a step-up transformer.

3 System Requirements

Electrical Stimulation consists of the generation of muscle contractions by artificially inducing a series of short electrical pulses applied to the muscle using electrodes. To promote the muscle contractions, the circuit must generate biphasic pulses controlled in amplitude, time, and frequency [4] [6], in a way that those parameters can be fully controlled.

Usually, the regular stimulation systems provide pre-determined programs for stimulation, in most cases, those programs do not fit the patient condition [7]. The development of a flexible system makes it possible to create a specific treatment for each patient and make the due adaptations according to the patient progress.

4 Stimulation Circuit

The proposed Stimulation Circuit is composed by a MOSFET - Transformer topology, associated with a DC-DC step-up converter where the pulses are applied using dry electrodes. With that in mind, the driver must generate an biphasic pulse where the parameters are determined by the system commands. The circuit can be observed in Figure 1.

The stimulation driver is divided in two blocks, conditioning and amplification. The conditioning block is composed by a pair of MOSFETs, each MOSFET receive and switch one pulse from the microcontroller.

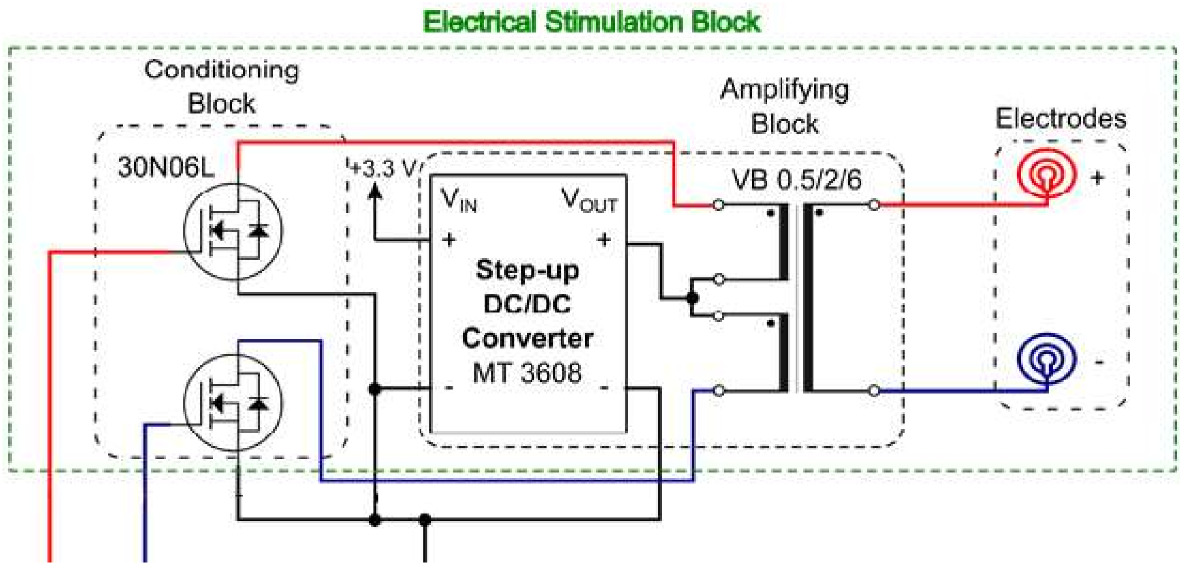

Fig. 1: Electrical Stimulation Circuit, divided in conditioning and amplification block.

The amplification block generates the biphasic waveform, and amplify the output signal. This block is composed by a DC-DC step-up converter with a 1:20 conversion rate, and a transformer VB 0.5/2/6 with a 6:230 conversion rate. The step-up was chosen due to its conversion rate and price, and the transformer due to its size (22/22.7/19mm) and disposition of the pins. The chosen transformer have four pins in the low voltage size, this make it possible to generate the biphasic waveform, and amplify the output signal simultaneously.

The pulses are generated by the microcontroller, modulated in amplitude by the conditioning block, and applied to the pins at the ends of the low voltage side of the transformer, while the step-up converter feeds the transformer with a constant voltage. This configuration makes it possible to generates the biphasic waveform, and reach the necessary amplitude to fulfill the muscle stimuli.

The complete NanoStim architecture is described by Sestrem et. al in [8]

5 Experimental Results

The application of the circuit consists in the command, generation and application of pulses modulated in amplitude, time and frequency. The pulses are generated by a ESP32 microcontroller, commanded by a mobile application connected via Bluetooth Low Energy (BLE) Protocol, and applied to the patient skin using dry electrodes.

The pulse amplitude is increased by changing the pulse width by applying a PWM, and the frequency is altered by changing the time between pulses. During the experimental tests, the pulse width was changed between 10μs and 250μs, once the stimulation voltage vary for each subject the pulse width was changed until the signal generates visible muscle contractions. Figure 2 illustrates an example of an output waveform acquired during a stimulation application.

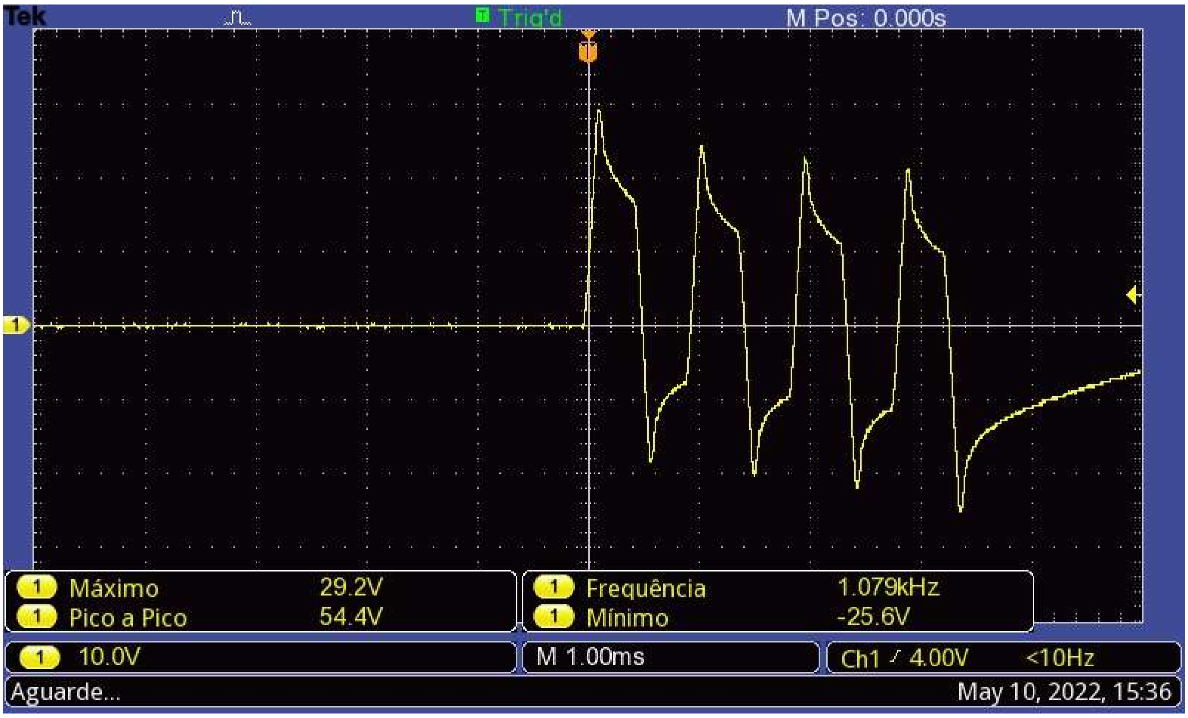

Fig. 2: Output signal acquired during a stimulation test using a 34mm Titanium based dry electrode.

This output signal is an example of an output signal obtained during a stimulation test performed on the forearm muscle. The pulses were applied using titanium-based dry electrodes, and visible muscle contractions were generated by applying an output voltage around 54V peak-to-peak.

6 Conclusions

The proposed stimulation driver based on a MOSFET-Transformer topology considers the use of dry electrodes and a flexible pulse generation applied by a microcontroller controlled by a mobile application. Preliminary tests were performed and show that the main objectives of the circuit were achieved, mainly in the production of flexible pulses according to the system command. Also in the generation of muscle contractions by the application of the pulses using dry electrodes concerning the patient comfort, in a way that the stimulation was performed without any signs of discomfort or pain.

During the tests, it was noticed that the position and condition of the skin were critical to obtaining a quality stimulation output, so the skin needs to be cleaned properly and the electrodes have to be fixed in the optimal position to recruit the right muscle fibers.

Future work is devoted to minimizing the circuit volume by changing the components to smaller ones that achieve a satisfying result. Developing a PCB prototype integrating the stimulation driver with the remaining NanoStim blocks is also considered a future work.

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