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LOW-COST SHAPING OF ELECTRICAL STIMULATION WAVEFORMS FOR BIOELECTRONIC MEDICINE WITH IMPROVED EFFICIENCY AND SELECTIVITY

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ABSTRACT

Electrical stimulation is proven to be an effective way of neuromodulation in bioelectronic medicine (e.g. cochlear implants, deep brain stimulators, etc.), delivering localized treatment by the means of electrical pulses. To increase the stimulation efficiency and neural-type selectivity, there is an increasing interest to employ non-rectangular stimulation waveforms [1-4]. Even though delivering and storing digital data at the stimulator provides the highest flexibility for generating stimulation waveforms, state-of-the-art approaches suffer either from poor resolution or the requirement of high data bandwidth for wirelessly powered implants [2]. Using Analog waveform generators is an alternative approach at the cost of extra implementation complexity for each type of waveform [3].

To fulfill the same goals as employing arbitrary waveforms for stimulation, we propose to shape the typical rectangular waveform using a programmable first-order low-pass filter, mimicking the natural filtering characteristic of the neural membrane. Using bio-realistic modeling, we show that such a pre-filtered waveform requires less or equal energy for the activation of neurons when compared with other energy-efficient waveforms (e.g. Gaussian). Notably, this comes at the low cost of only one extra programmable parameter (i.e., the filter's corner frequency), on top of the typical duration and amplitude parameters.

The basic concept of this work is driven by the fact that the natural low-pass characteristic of the neuron's membrane limits the energy transfer efficiency from the stimulator to the cell. Thus, it is proposed to pre-filter the high-frequency components of the stimulus [4]. The method is validated for a Hodgkin-Huxley (HH) axon-cable model using NEURON v8.0 software. The required activation energy is simulated for rectangular, Gaussian, half-sine, triangular, ramp-up, and ramp-down waveforms, all with pulse durations of 10-1000µs, and low-pass filtered with cut-off frequencies of 0.5-50kHz. Simulations show a 51.5% reduction in the required activation energy for the shortest rectangular pulse (i.e., 10-µs pulse width) after filtering at 5kHz. It is also shown that the minimum required activation energy can be decreased by 11.04%, 9.49%, 8.28%, 1.81%, 0.17%, and 0% when an appropriate pre-filter is applied to the rectangular, ramp-down, ramp-up, half-sine, triangular, and Gaussian waveforms, respectively. Finally, a perspective usage of this method to improve the selectivity of electrical stimulation is drawn.

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