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Waveform efficiency analysis of auditory nerve fiber stimulation for cochlear implants

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Abstract Evaluation of the electrical stimulation efficiency of various stimulating waveforms is an important issue for efficient neural stimulator design. Concerning the implantable micro devices design, it is also necessary to consider the feasibility of hardware implementation of the desired waveforms. In this paper, the charge, power and energy efficiency of four waveforms (i.e. *square, rising ramp, triangular and rising ramp-decaying exponential*) in various durations have been simulated and evaluated based on the computational model of the auditory nerve fibers. Moreover, for a fair comparison of their feasibility, a fully integrated current generator circuit has been developed so that the desired stimulating waveforms can be generated. The simulation results show that stimulation with the *square* waveforms is a proper choice in short and intermediate durations while the *rising ramp-decaying exponential* or *triangular* waveforms can be employed for long durations.

Keywords Cochlear implant · Computational model · Current generator circuit · Stimulation efficiency

Introduction

Application of safe electrical stimulation to stimulate auditory nerve fibers for rehabilitation of the person suffering deafness or profoundly hearing impairments is the main idea in the cochlear implant (CI) systems [1]. In CI systems, stimulation with the *square* waveforms due to its acceptable stimulation efficiency and simple implementation is very popular [2]. However, it has been proved that not all of the stimulation efficiency parameters such as charge, power and energy efficiency can be satisfied with a single waveform [3]. Therefore, in the design of CI systems, much importance can be attached to the waveform efficiency analysis of electrical stimulation of the auditory nerves.

In recent years, the effect of the stimulating waveforms and their parameters on the stimulation efficiency has been studied [3–6]. The amount of charge delivered (charge efficiency) to tissue directly determines the risk of the tissue damage. Maximum instantaneous power (power efficiency) of the stimulating waveform and consumed energy during stimulation (energy efficiency) affect the battery size and its life time. Unfortunately, in previous works, the probable challenges in hardware implementation of the stimulating waveforms were not considered. For proper design of CI systems, waveform efficiency analysis should be performed in terms of the implementation's capability of the analyzed waveforms. This paper has focused on the stimulation efficiency of four waveforms (*square, rising ramp, triangular, rising ramp-decaying exponential*) for electrical stimulation of the auditory nerve fibers, while considering their hardware implementation. First, the charge, power and energy efficiency of these waveforms have been simulated and evaluated. Then a fully integrated current generator circuit has been presented for provision of the selected stimulating waveforms. Finally, by comparison of the stimulation efficiency and the designed circuit blocks for each waveform, the efficient waveform for various durations has been provided.

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