

A MODIFIED PULSE SHAPE FOR SELECTIVE STIMULATION USING ANODAL BLOCK

Arantxa Uranga* and Nico J. M. Rijkhoff**

*Dept. Enginyeria. Electrònica, Universitat Autònoma de Barcelona, Spain

**Center of Sensory-Motor Interaction, Aalborg University, Denmark

Abstract

The main aim of this work is the study of different pulse shapes for selective small fiber diameter activation in order to minimize charge injection when using the anodal block technique.

Introduction

The recruitment order of nerve fibers is from large diameter fibers to small ones when using electrical stimulation. However a number of applications such as electromicturition and electrodefecation require activation of small fibers without activation of the larger ones [1].

Several studies have been done in order to achieve selective small fiber activation. The used methods are high frequency stimulation [2], slowly rising pulses [3] and the anodal block technique [4,5]. We will focus our attention on the anodal block technique.

When charge is passed from a contact to the tissue several electrochemical reactions may take place which products could be harmful to the tissue [6]. Charge injection should therefore be minimized in order to avoid tissue damage and contact corrosion. On the other hand, most electrochemical reactions can be reversed by adding a reversed pulse which would balance the charge injection. However, in order to reverse these reactions, the charge recovery has to be done quickly enough, since it needs to "recapture" the reaction products before they migrate away from the electrode surface.

Since anodal block needs a relative large amplitude and long pulse durations, the charge injected is larger than with a traditional stimulation pattern. The present study investigates new stimulus waveforms which are able to induce selective small fiber activation but with lower charge injection compared to rectangular pulses.

To obtain anodal block, a tripolar cuff electrode, with two anodes and a cathode, is used to deliver rectangular current pulses. Under the cathode, all fibers (small and large) are activated. However, depending on the current amplitude and pulse width, only action potentials generated in the small fibers can pass under the anodes since the large fibers are blocked due to hyperpolarization of their membranes. In this way, due

to the different fiber blocking thresholds, a selective block occurs.

Charge injection can be reduced by using the fact that it takes time for the action potential to travel from the cathode to the anode. Because of this delay, strong hyperpolarization is not needed at the beginning of the pulse. This would allow a lower current at the beginning of the pulse and thus lower charge injection. Computer simulations have been performed to investigate whether this could be used.

Methods

The electric potential field generated by a cuff electrode (2 mm inner diameter) with metal ring contacts, spaced 3 mm, has been calculated using a volume conductor model described by Rijkhoff et al. [7]. A nerve bundle with a radius of 0.7 mm has been used.

The nerve fiber model used to analyze the responses of the membrane to the extracellular electric potential field is described by McNeal [8]. The Frankenhaeuser-Huxley equations, adapted for a rabbit according to Chiu et al. [9], have been used to describe the membrane kinetics. All temperature-dependent parameters were scaled to 37 °C [10]. Two different fiber diameters have been analyzed to study the selectivity (12 μm and 4 μm). The 12 μm fiber has been placed on the axis of the bundle and the 4 μm has been placed at the border. The cathode was always situated right above the central node of Ranvier of the fiber.

Simulations have been done in order to investigate the different effects. The pulse shape was optimized so that it would result in a minimum charge injection, allowing a faster recovery of charge (with the subsequent possibility of increasing the signal frequency) and a safer stimulation pattern, able to generate fiber diameter selectivity.

Results

A study of the influence of the waveform on the charge needed to block a 12 μm fiber situated on the axis has been done. Two different waveform shapes have been used (see Fig. 1). A rectangular pulse with an A_1 amplitude during t_1 followed by an amplitude A_2

during the rest of the pulse has been applied.

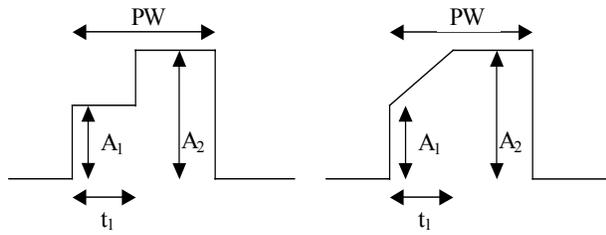


Fig. 1 : Stimulus waveforms for anodal blocking ($PW = 210 \mu s$).

Fig. 2 shows the relationship between the initial amplitude (A_1) and the maximum time (t_1), for a fixed amplitude A_2 , in order to block the action potential generated under the cathode. It is shown how an increase in the amplitude A_1 allows an increase in the time t_1 .

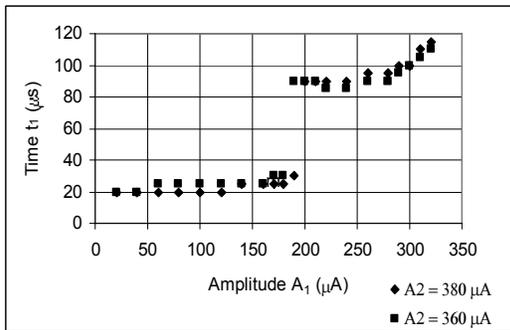


Fig. 2: Time t_1 as a function of the amplitude A_1 when stimulus waveform of fig. 1 (left) is used to block the $12 \mu m$ fiber.

According to the graph, two different zones can be distinguished depending on the amplitude A_1 . Each one corresponds to a different behavior.

For small amplitudes A_1 ($A_1 < 200 \mu A$) the action potential generated under the cathode is blocked under the anode due to hyperpolarization. However, since the hyperpolarization is not strong enough, in order to keep the block, t_1 is only be short. If amplitude A_1 is maintained somewhat longer at the same level, the action potential will break through the block at the end of the pulse due to break excitation

However, for larger amplitudes A_1 ($A_1 > 200 \mu A$), since the hyperpolarization is large enough to stop the action potential, amplitude A_1 can be kept longer (up to $90 \mu s$). In this case, an increase in time t_1 generates the action potential propagation during first part (t_1) of the pulse.

If a rectangular pulse with the same total width ($210 \mu s$) is used, an amplitude of $330 \mu A$ is needed to block the $12 \mu m$ fiber situated on the axis. This pulse injects a charge of $69.3 nQ$. By analyzing and comparing the charge injected between both pulses (fig. 3), it is shown how up to a 13% charge reduction can be achieved by using this new shape ($A_1 = 190 \mu A$).

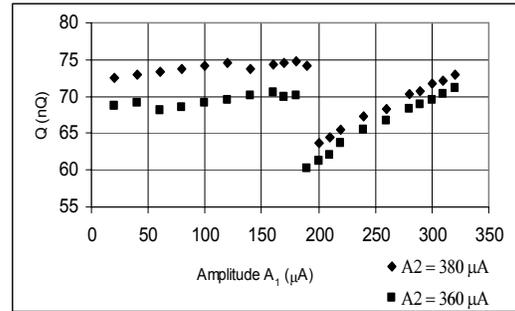


Fig. 3 : Total charge injected when stimulus waveform of fig. 1 (left) is being used to block the $12 \mu m$ fiber.

In order to increase the time t_1 and thus, decrease charge injection, a bigger hyperpolarization is needed. The first part of the waveform has been replaced with a linear increasing amplitude starting at A_1 which reaches amplitude A_2 after $t_1 \mu s$ (fig. 1 right). The value A_2 is maintained during the rest of the pulse.

Fig. 4 shows how this shape allows to increase the duration of the first part of the waveform (t_1). Again, an increase in the initial amplitude allows to have a bigger time t_1 .

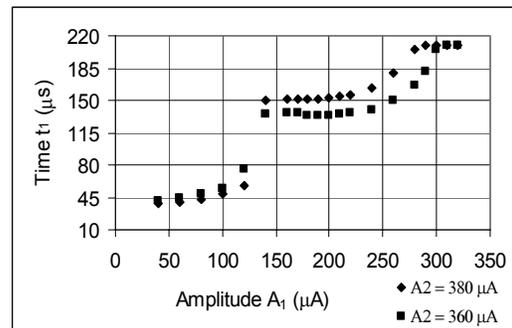


Fig. 4: Time t_1 as a function of the amplitude A_1 when stimulus waveform of fig. 1 (right) is used to block the $12 \mu m$ fiber.

However, comparing the total amount of charge injected (fig. 5), similar values to the ones achieved by means of the use of the previous waveform are found; additionally, a reduction of charge, related to the rectangular pulse, is obtained.

Discussion

The results of the simulations performed in this study indicate that new waveforms can be used to obtain selective stimulation, using anodal block technique, with a reduction in the amount of charge injected. This reduction produces a safer stimulation since less charge

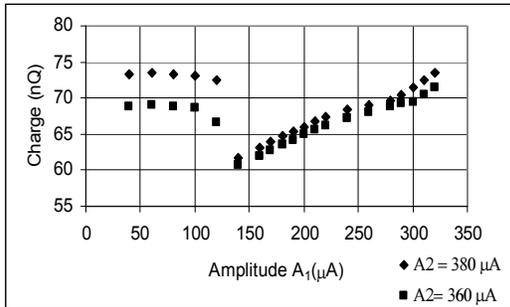


Fig. 5: Total charge injected when stimulus waveform of fig. 1 (right) is being used to block the 12 μm fiber

is involved in the process and, on the other hand, since less charge needs to be recovered, the recovery is faster. This fact allows us to work with higher stimulation frequencies.

Futures modifications can include the use of an anodal prepulse. In this case, several parameters such as hyperpolarizing pulse amplitude, pulse width and delay have to be taken into account. The influence of the hyperpolarizing pulse amplitude in the activation and blocking thresholds is being studied. It can be proven that an increase in the delay between anodic and cathodic pulse leads the threshold to the initial value (threshold without prepulse), indicating that the membrane has recovered to its initial state.

In addition to the possible threshold modification, the hyperpolarizing prepulse generates a previous charge extraction just before the injection, reducing the charge that needs to be extracted after the stimulation.

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