Optimization of Simulated RLC Circuit and Solenoid Coils used in the Magnetic Stimulation of Rat Sciatic Nerves

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Magnetic stimulation, as a means of evoking neuromuscular activity, has an advantage over direct electrical stimulation in that the stimulator need not directly contact the neural tissue. However, the high energy levels and large magnetic coils needed to elicit a response hinder the use of implantable magnetic stimulators for functional neural stimulation. Our group has previously reported a μm-scale computational model that quantifies the neurostimulation efficacy of a time-varying magnetic field on the myelinated axons of rat sciatic nerve, where discharging the voltage stored on a capacitor through an air-core solenoid coil creates the field. Further, we have validated the performance of this model with *in vivo* experiments in the rat using a small sample of solenoid coils, and we have observed that solenoid coils with ~1cm^3 volumes can evoke neural excitation with discharge voltages as low as 110 V. In this work, we report on using the computational model to optimize the stimulation system and the solenoid coil design to reduce the discharge voltage necessary to evoke neural activity (i.e., threshold voltage).

The stimulation system consists of a series RLC circuit where the capacitance is an available design parameter. We optimized this system by examining the effect of the capacitance value on the simulated threshold voltage for experimental coils and selected the capacitance that resulted in the least threshold voltage across these coils. We found that the capacitance used in previous experiments (6.9 mF) was near optimal and this value was used to further optimize coil design.

We optimized the design of air-core solenoid coils to reduce threshold voltage and coil volume via a genetic algorithm. The optimization was performed over four parameters (inner diameter, wire gauge, turns and layers) of the coils' design. We defined our cost function as the threshold voltage. Selection, based on the cost function, recombination, and random mutation, was implemented between successive generations. From these results, we fabricated and tested *in vivo* a series of optimal and near-optimal coils with small volumes.

Simulation analysis showed that layers and wire gauge were the most influential parameters on stimulation threshold voltage. According to our simulations, reduced threshold voltages occur by maximizing membrane current density and pulse width, which the layers and wire gauge parameters affect most strongly. In addition, *in vivo* tests resulted in an optimized coil (2.1 mm inner diameter, 20 AWG, 7 turns, 3 layers) with a 28% decrease in threshold voltage (79 V) and a 62% decrease in volume (300 mm^3) as compared to our previous best coil.