Evaluation Of The Induced Excitation Of The Peripheral Vestibular System Using Micro Scale Inductors

S. Mukesh[1], P. Bhatti[1]

[1]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, USA

Abstract

According to the National Health and Nutrition Examination Survey data, 35 % of US adults aged 40 years and older have evidence of balance dysfunction based on the modified Romberg test. In this vestibular dysfunction, patients are not able to see stabilized images on their retina during head movement. This leads to severe dizziness and vertigo. The severe form of this disability, bilateral vestibular dysfunction, is known to significantly reduce quality of life and may incur a significant monetary burden on the patients in form of lost productivity due to dizziness and postural imbalance. The options available to these patients consist of rehabilitation therapy, home exercises, medication and surgery. While these treatments have been shown to be effective in patients with single-sided vestibular disorder, many individuals suffering from bilateral dysfunction fail to improve.

For these individuals, one emerging solution is electrical stimulation of the semicircular canals to overcome sensory loss. However, for electrical stimulation the electrodes need to be in direct contact with the vestibular neurons which are present inside a bony labyrinth. This is usually achieved by drilling into the bony labyrinth. Experiments have also demonstrated that neighboring neurons may be excited when encoding high acceleration rates. The goal of this work is to evaluate magnetic stimulation of these canals, through finite element modeling, as an alternative to electrical stimulation.

A sub-millimeter inductor is modeled in presence of the different layers of biological tissues and fluids present in a semicircular canal to model the strength and spatial extent of induced electric fields. 2-D axis-symmetry in conjunction with low-frequency magnetic fields physics is chosen (AC/DC module). The inductor (~100 nH) dimensions are 0.5 mm x 0.5 mm consisting of a quartz core surrounded by a 21-turn copper coil. A layer of Parylene-C is modeled around the entire assembly for representing insulation. The surrounding domains are modeled to represent the different layers of a semicircular canal comprising of bony labyrinth, perilymph, membranous labyrinth, and Endolymph using their electrical properties.

Single-turn coil physics with the coil group feature was used to introduce the stimulation signal in the form of pulses designed using rectangle and analytic features of the global definition functions. The current amplitude is modeled to be 2.125 amperes and the pulse width is maintained at 40 µs.

An electrical stimulation array is also modeled using Electric Currents feature of the AC/DC module and efficacy of magnetic stimulation is compared to that of electrical stimulation. The induced electric fields and the first derivative of these induced fields are plotted. The derivative of induced electric field, Activating Function, is a measure of spatial extent of induced electric fields. It provides a fair basis of comparison between electrical and magnetic stimulation as it is measured as the second derivative of electrical potential in case of electrical stimulation. It is thus shown that magnetic stimulation can provide desired neural stimulation without the need to drill

into the bony labyrinth.

Figures used in the abstract

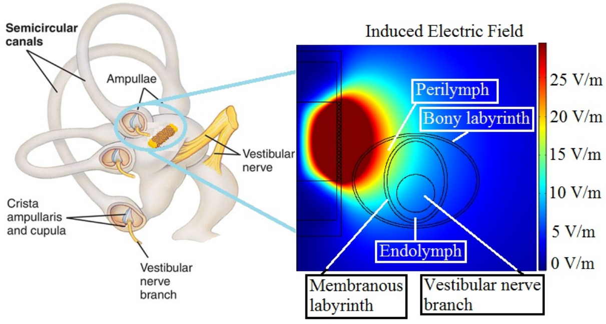

Figure 1 : This figure illustrates the anatomy of semicircular canals on the left. The vestibular nerve fibers are shown in yellow. Additionally, an inductor is positioned proximally to the ampulla of a semicircular canal. The inset shows the COMSOL model and the electric fields induced by the inductor. The anatomical features of a semicircular canal are depicted to illustrate the penetration of induced electrical fields. In the model, the bony labyrinth, perilymph, membranous labyrinth, Endolymph and vestibular nerve branch exiting the ampulla are modeled as the different structures.