Modeling ECAP in Cochlear Implants using Finite Element Method and Equivalent Circuits

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Abstract—Cochlear implants have been used to restore partial hearing to profoundly hearing impaired people. Evoked compound action potential (ECAP) has been used clinically to determine whether auditory nerves are responding to electrical stimulation in cochlear implant systems. In this paper, a novel scheme is proposed to model evoked compound action potential and its measurement using an equivalent circuit computed by the finite element method. A 3D finite element model of a cochlear implant is used in this scheme. The modeling result will be compared with clinical result for validation of the scheme.

Index Terms—finite element method, electrical stimulation, coupling circuits, equivalent circuits.

I. INTRODUCTION

Cochlear implants have been an effective treatment for hearing impaired patients. Evoked compound action potential (ECAP) has been used clinically to determine whether the auditory nerves are responding to cochlear implant stimulation. Also, ECAP has been used clinically as an objective mean to estimate stimulation parameters such as the threshold stimulation level and the most comfortable stimulation level.

In this paper, a novel scheme, which utilizes a 3D finite element model [1, 2] of cochlear implants, is proposed to compute an equivalent circuit to model the electrical coupling between nerve fibers and sensing electrodes. Subsequently, the equivalent circuit can be used to model ECAP.

II. METHOD

Finite element (FE) models of cochlear implants have been developed to study electrical stimulation [1, 2]. In Fig. 1, a 3D finite element model of a cochlear implant is used to study ECAP. This FE model is created by rotating a 2D cross section of a human cochlea (Fig. 2) spirally [1, 2]. The Poisson equation (1) is solved to compute the electrical potential distribution in the human cochlea (inner ear) and the auditory nerve fibers. The conductivity of the medium and other parameters are given in [2, 3, 4].

$$-\nabla^2\phi = f \qquad (1)$$

where ϕ is the electrical potential and f is the source function [3, 4, 5, 6]. First, a sufficiently large voltage input is imposed on the stimulating electrodes on the electrode array in the FE model. Next, the electrical potential distribution is computed to determine whether the potential on the nerve fibers are sufficiently large to excite (or evoke) the nerve fibers [7] as illustrated in light blue in the center of the Fig. 3. Stimulating electrodes (in blue) on the electrode arrays are used to excite

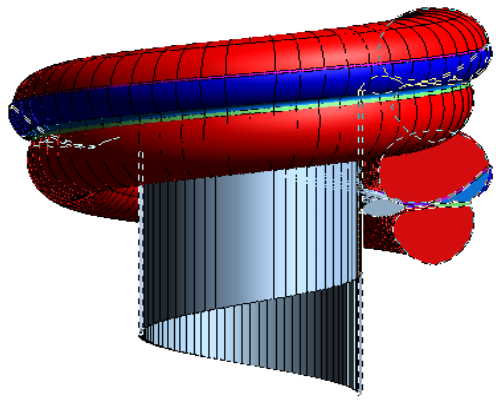

Fig. 1 A 3D finite element model of a cochlear implant.

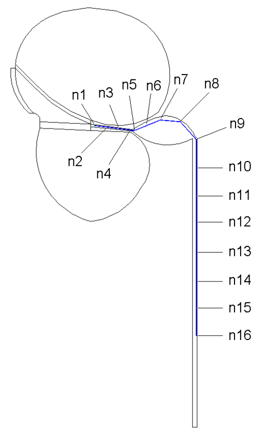

Fig. 2 The cross section of a human cochlea is shown. The nerve fiber with its 16 nodes is illustrated in blue.

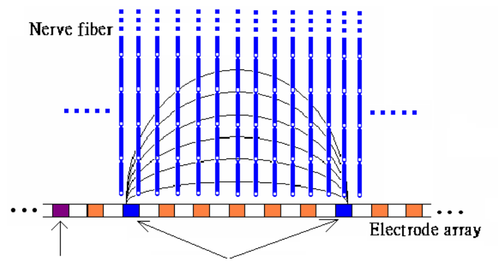

Fig. 3 An illustration of how evoked compound action potential (ECAP) is evoked and measured. The stimulating electrodes excite the nerve fibers in the top middle which generate action potential (Fig. 4). The action potential is coupled to the sensing electrode in the bottom left.

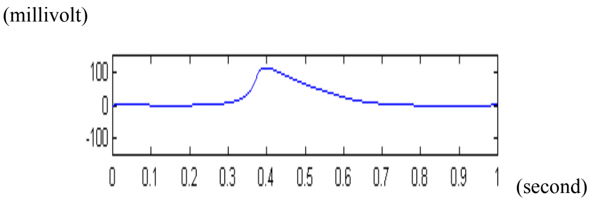

Fig. 4 Action potential generated by a nerve fiber (Fig. 2 and 3).

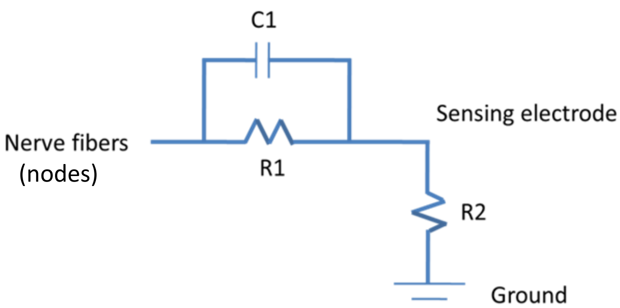

Fig. 5 An equivalent circuit between the nodes (n1 – n16) of the nerve fibers, the sensing electrode (refer to Fig. 3) and the system ground are illustrated. Equivalent parallel resistor and capacitor circuits are computed between nerve fibers and the sensing electrode based on the 3D finite element model as shown in Fig. 1. An equivalent resistor between the sensing electrode and the system ground is computed using the same 3D FE model.

(or evoke) the nerve fibers (top middle) in Fig. 3. Once the nerve fibers are excited, their action potentials are generated and are coupled electrically to the sensing electrode (purple) on the electrode array in Fig. 3. Typical action potential generated by a nerve fiber (Fig. 2 and Fig. 3) is shown in Fig. 4.

The coupling between the nodes of the nerve fibers and sensing electrode can be modeled by an equivalent parallel resistance and capacitor circuit (Fig. 5) from the 3D finite element model (Fig. 1). Likewise, the coupling between the sensing electrode and ground can be modeled by an equivalent resistor circuit from the same 3D finite element model. With the sixteen equivalent circuits for the sixteen nodes of the nerve fibers, i.e. n1 – n16 (refer to Fig. 2), action potential generated by the nerve fibers can be used to compute the evoked compound action potential based on the circuit model in Fig. 5.

The detailed modeling result from the proposed scheme will be validated by clinical results in the full paper. More result will be presented in the full paper.

III. References

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