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COMMUNICATIONS

CONTRIBUTION TO A MODEL OF ELECTRICALLY STIMULATED INNER EAR (COCHLEA)

Marek Polák [*] — Marcel Mičan [**] — Pavel Gonda [**]

The clinical implantation of electrode field into the inner ear requires a better understanding of the electrical nerve stimulation, which allows the simulation of the behaviour of auditory nerve fibres. Our model was chosen as a spiral-shape duct with circular cross-section and a set of electrodes inside the conducting media with a bipolar current source. The mapping of the electric field has been performed by the Finite Element Method. The results of this mapping allow predicting some possible dimensions and positions of cylindrical and hemispherical excitation electrodes.

K e y w o r d s: electrical stimulation, computational modelling, inner ear, cochlea

1 INTRODUCTION

Since the first direct stimulation of the auditory nerve in man reported by Lundberg in 1950 several types of cochlear implants have been developed that can offer a sense of hearing to patients with a sensorineural hearing loss [1]. The implants electrically stimulate the auditory nerve inside the inner ear according to a signal from an external microphone, implemented speech-coding strategy in the speech processor and transducer, giving a bipolar ac current proportional to the frequency. Such a multi-channel prosthesis should give a better result for the speech understanding than the previous devices [2], [3]. Our model serves for a 3-dimensional electrical field modelling of cochlea, using a simplified picture as some other authors [4], with some new features, mainly replacing the usual point electrodes by cylindrical or hemispherical electrodes.

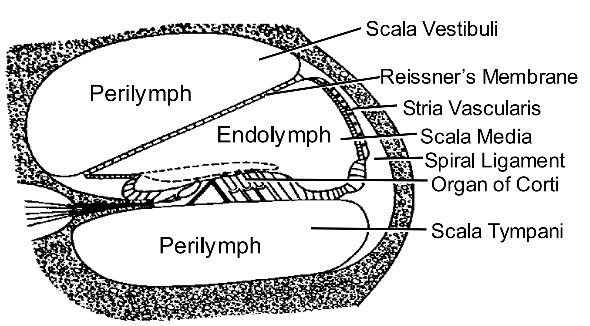

Fig. 1. A cross-section of the cochlea.

In this paper the mapping of the static electric field using electrical volume conduction due to an instantaneous dc current source is shortly described.

The results of the solution are given by pictures of equipotential surfaces, field lines and corresponding diagrams. The dynamic behaviour is not solved.

2 SOLUTION OF THE ELECTRIC FIELD IN THE COCHLEA

The Finite Element Method was chosen for the 3-dimensional calculation of the equipotential surfaces and the electric field intensity vectors, using the ANSYS program version 5.4 [7]. The model contains volumes of all basic structures assumed as linear and isotropic conductors, with their conductivities and typical edges between all physiological media with given properties, *eg* basilar membrane between the organ of Corti and scala tympani, Reissner's membrane between scala vestibuli and scala media and for the nerve tissue, spiral ligament and stria vascularis (Fig. 1).

The shape of the model for the inner ear is assumed as a cylinder with an exponentially decreasing cross-section area and its axis rolled in the shape of a spiral. The boundaries to the surrounding bone tissue are chosen as edges with a chosen equipotential surface in the cross-section area. The conductivities were given in paper [4] between $k = 1.4$ to $1.7\,\mathrm{S/m}$ for the inner-ear fluids and $k = 0.3\,\mathrm{S/m}$ for the nerve tissue. The highest resistivity is assumed in the organ of Corti ($k = 0.012\,\mathrm{S/m}$), stria vascularis ($k = 0.053\,\mathrm{S/m}$) and in Reissner's membrane ($k = 1 \times 10^{-3}\,\mathrm{S/m}$). The basilar membrane has $k = 0.065\,\mathrm{S/m}$ and the surrounding bone $k = 0.156\,\mathrm{S/m}$, scala vestibuli has $k = 1.43\,\mathrm{S/m}$. The diameter of the inner ear as a cylinder approximately 1.5 mm. The electrodes are small cylinders or spheres with a diameter of approximately 0.5 mm. In Fig. 2 only the first one as a

[*] Department of Radioelectronics, [**] Department of Electromagnertic Theory, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Bratislava, Slovakia

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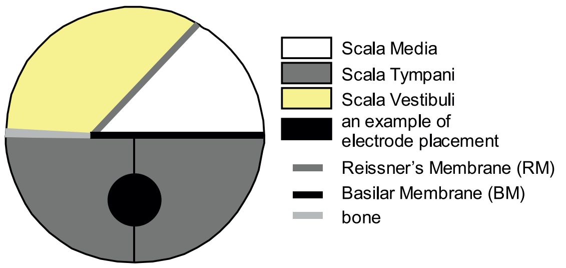

Fig. 2. A cross-section of the model of cochlea.

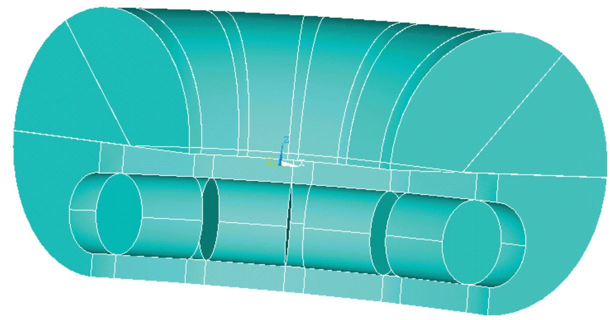

Fig. 3. The model of cochlea a general view.

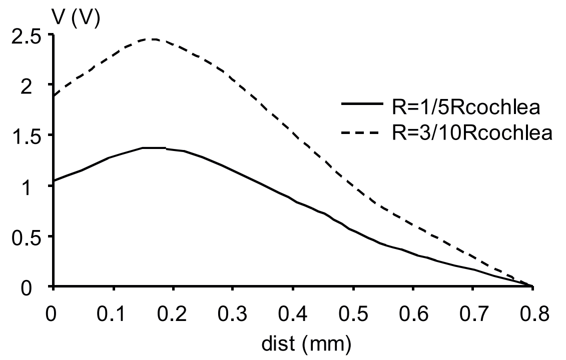

Fig. 4. Potential distribution of the electrical field for transversal direction on Basilar membrane for cylindrical electrodes with radii $R = 1/5R_{cochlea}$ and $R = 3/10R_{cochlea}$.

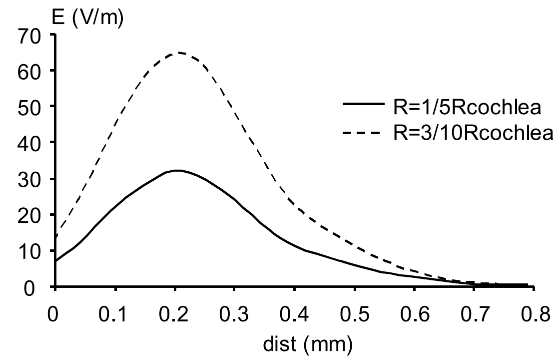

Fig. 5. Intensity distribution of the electrical field for transversal direction on Basilar membrane for cylindrical electrodes with radii $R = 1/5R_{cochlea}$ and $R = 3/10R_{cochlea}$.

positive electrode is shown, the negative electrode is behind it.

In Fig. 3 both positive and negative electrodes, assuming a bipolar stimulation, are shown in another view. The inner segment is assumed as a path for a bundle of nerve fibres, in the bone, then dendrite (0.3 S/m), Corti's organ, scala media (1.67 S/m), stria vascularis, spiral ligament (1.67 S/m) and finally the surrounding bone. The electrodes are situated beneath Corti's organ. The results of the solution show the potential pattern as a sum of currents produced by the two electrodes positioned one behind and beneath the other, if they are stimulated by opposite dc voltage polarities. The higher potential amplitude is always in the region of higher resistivity. There seem to be two main paths through which the dc current may flow, inside the scala tympani and through Corti's organ.

This second path is of basic interest for nerve stimulation.

The dependences on the potential distribution on BM in a chosen radial direction from the electrode are shown in Figs. 4 and 5. The zero point coincides for our model with the junction of RM and BM. The dependences show a similarity with some previous experimental results measured on cochlea of a human cadaver by Ifukube [5]. In Fig. 6, an example of a distribution of electrical potential and intensity in the cross-section area in our model of cochlea may be seen.

3 CONCLUSIONS

This initial study is a part of project VTP No. 95/5195/297 and most of the results together with a full description of the code and many other details concerning the dimensions, positions and shapes of the electrodes can be found in [6]. The results of the electrical fields may be valuable to those who are interested in the problems concerned in this type of stimulation and the identification of the parameters of the electrical prosthesis in order to improve speech comprehension in users of cochlear prostheses. Our contribution to these problems can be useful for new clinical implants of auditory and similar prostheses into the human body.

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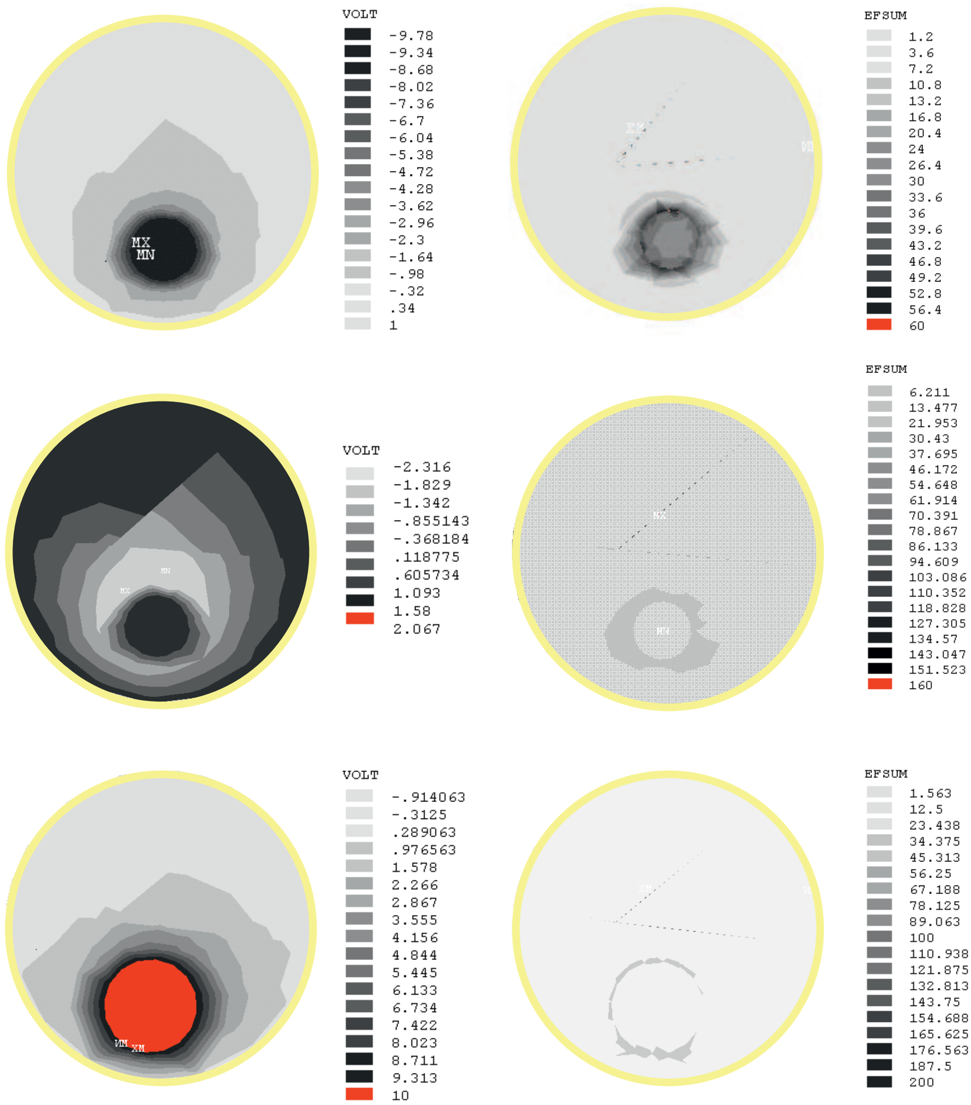

Fig. 5. Intensity distribution of the electrical field for transversal direction on Basilar membrane for cylindrical electrodes with radii $R = 1/5R_{cochlea}$ and $R = 3/10R_{cochlea}$.

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Marek Polk (Ing, PhD), received the MSc degree in electrical engineering from the Slovak University of Technology, Faculty of Electrical Engineering and Information Technology in Bratislava, Slovakia, in 1994 and PhD degree in 1999. He is now an assistant Professor at the Department of Radioelectronics. His recent research interests include the modeling of the inner ear and speech signal processing for cochlear implants.

Marcel Mičan (Ing), received Bc degree in electrical engineering from the Slovak University of Technology, Faculty of Electrical Engineering and Information Technology in Bratislava, Slovakia, in 1998 and the MSc degree in 2000 from the same institution. He is now a postgraduate student at the Department Electromagnetic Theory, where his research interests include physiological influences of electromagnetic fields upon the human body.

Pavel Gonda (Doc, Ing, PhD) received the PhD degree in 1976 and since 1979 he has been Associate Professor at the Department of Electromagnetic Theory at the Slovak University of technology, Faculty of Electrical Engineering and Information Technology, in Bratislava. His past and recent research interests are mainly electromagnetic field theory, methods of analytical and numerical solution of circuits, modeling and approximation of nonlinear processes and material characteristics.