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Impedance Spectroscopy and Cell Constant of the Electrodes for Deep Brain Stimulation in Humans

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Introduction

Deep brain stimulation (DBS) is the electrical stimulation of neurons to treat movement disorders such as Parkinson disease, Essential Tremor and Dystonie. Parkinson disease (PD) caused by the slow degeneration of nerve cells in the Substantia Nigra (grey matter) resulting in the synchronous firing of nerve cells in other parts of the brain (Nucleus Subthalamicus or Globus Pallidus).

Often, the effect of the treatment with drugs reduces during the course of the disease leaving DBS as an alternative treatment. The stimulation system consists of the electrode itself, an extension and the pacemaker. Various parameters such as electrode geometry, pulse frequency or applied voltage have a great influence on the size of the stimulated tissue volume. In experiments, often a sodium chloride solution is used as measuring medium. The cell constants [2] and the impedance curves of two DBS electrodes of different shapes (Fig. 1) were compared by numerical calculations.
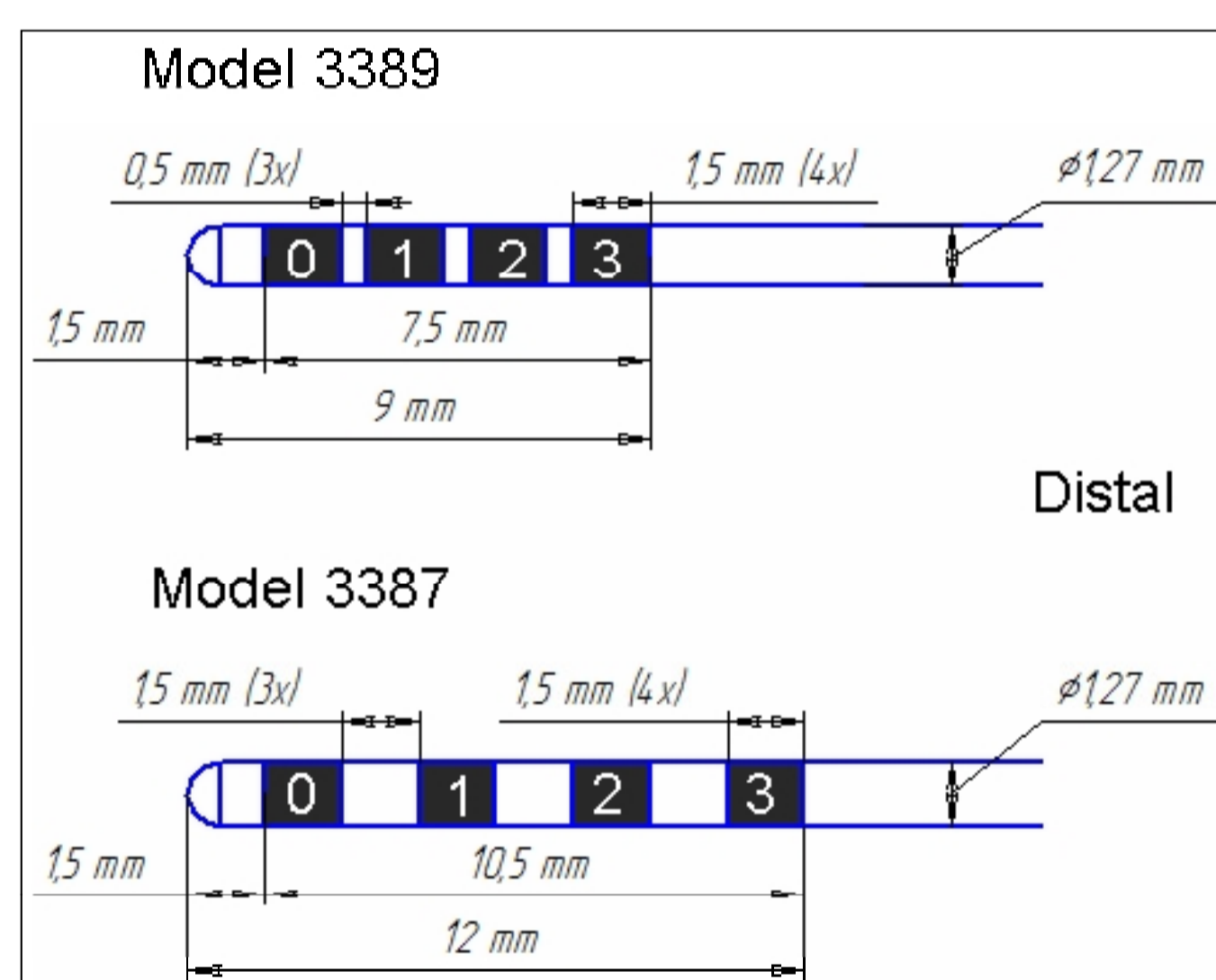

Figure 1. The electrodes for deep brain stimulation (drawn after Implant manual, Medtronic® [3]).

Model

2D circular symmetric finite element models of the DBS electrode and its surrounding medium were created using COMSOL Multiphysics® 3.5a RC1.

The geometry (Fig. 1) of the simulated lead was taken from the Medtronic 3389 and 3387 electrode manuals (Medtronic® Inc, Minneapolis, MN, USA) [3]. The lead consists of four metal contacts and an outer jacket tubing. The main parameters of the simulation model are presented in table 1, were d is the diameter and h is the height of the respective cylinder.

	Size $d \times h$, mm	Conductivity, S/m	Permittivity	Material
Surrounding medium	70 x 77	0.005	80	Sodium chloride solution
Stimulating electrode	1.27 x 1.5	1e6	1	Platinum
Outer jacket tubing	1.27 x 67	1e-15	5	Urethane 80A

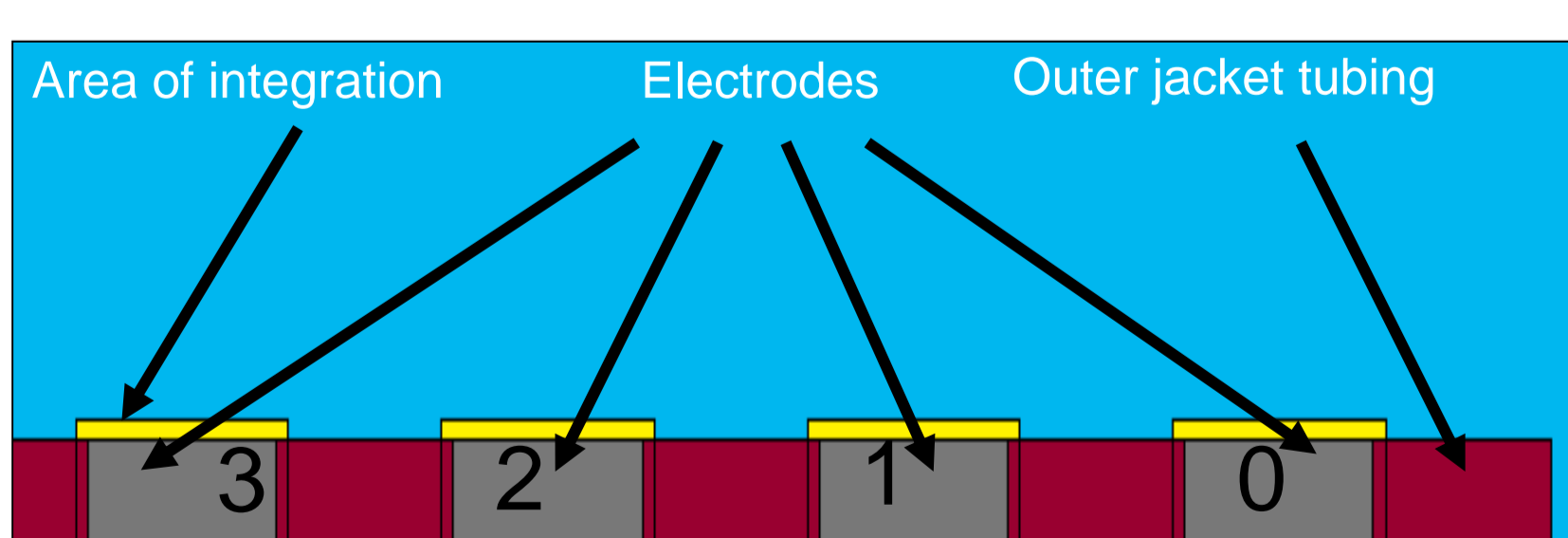Table 1. Materials of the simulation model and their properties.

Figure 2. The 2D-simulation model (sector).

Simulation

Neglecting electrode processes, the electrode impedance can be determined from the equivalent circuit of figure 3. From the equivalent circuit the complex impedance Z is calculated (Eq. (1)):

$$Z = \frac{1}{(1/R + j\omega C)}, \tag{1}$$

where R is the resistivity of the medium, ω is the angular frequency, C is the capacity of the electrodes and j is the imaginary unit. The resistivity was calculated from numerical simulation of the stationary current, neglecting the influence of the permittivity. Here the coupling of the electric field to the electric current density by Ohm's law [4] is taken into account and the following Poisson equation (2) is solved :

$$\nabla \cdot \sigma \nabla V = 0 \tag{2}$$

with σ and V being the specific conductivity and the potential, respectively. The ohmic resistance R of the equivalent circuit is calculated from Ohm's law ($R{-}U/I$, with U potential difference between two electrodes). The current I is computed using the area integral over the current density $\mathbf{J}$:

$$I = \iint \mathbf{J} \cdot d\mathbf{A}, \tag{3}$$

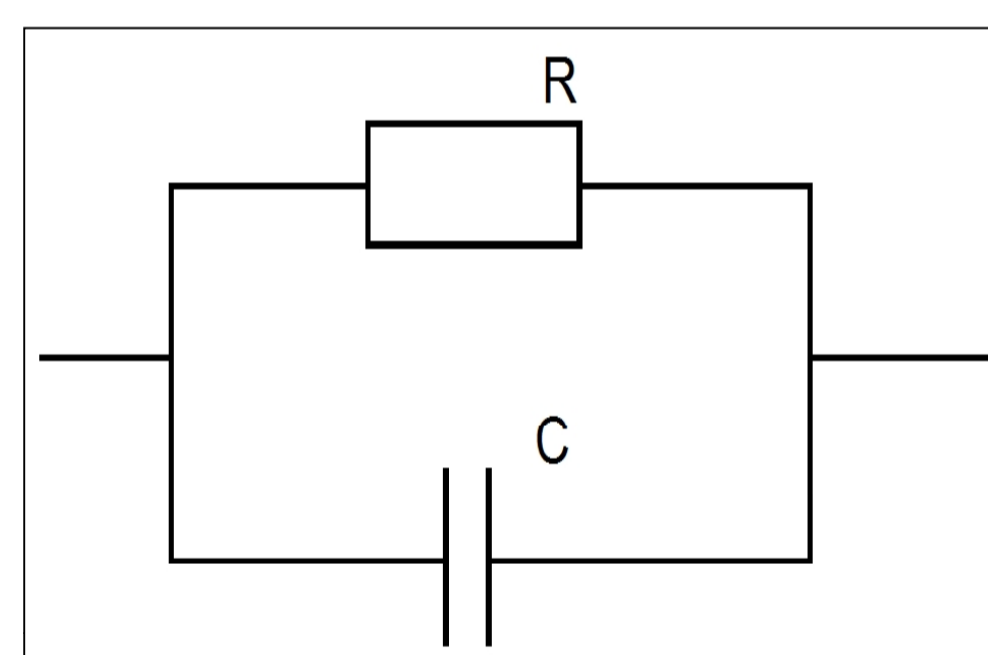where $\mathbf{A}$ is the area of integration shown in fig. 2.

Figure 3. Simple equivalent circuit for electrodes of deep brain stimulation.

The capacity is computed in a separate simulation of the electrostatic fields neglecting the influence of the conductivity. To compute the capacitance C of the equivalent circuit using the ratio of charge divided by the voltage ($C=q/U$, with U electrode voltage), Poisson's equation (4) was solved:

$$\nabla \cdot \varepsilon_0 \varepsilon_r \nabla V = 0, \tag{4}$$

where ε_0 is the permittivity of vacuum, ε_r is the relative permittivity and V is the potential. The charge is computed using the area integral over the dielectric displacement $\mathbf{D}$:

$$q = \iint \mathbf{D} \cdot d\mathbf{A} \tag{5}$$

where $\mathbf{A}$ is again the area of integration as shown in fig. 2.

Results & Discussion

Figure 4 shows the imaginary vs. the real part of the impedance in the frequency range from 100 Hz to 5 MHz. Figure 5 shows the real part of the impedance vs. the frequency. The impedance of model 3387 is bigger than that for model 3389. This has an impact on the spread of the electric field and its magnitude. Model 3387 has a bigger spatial spread of the electric field but a smaller magnitude of the normal current density than model 3389.
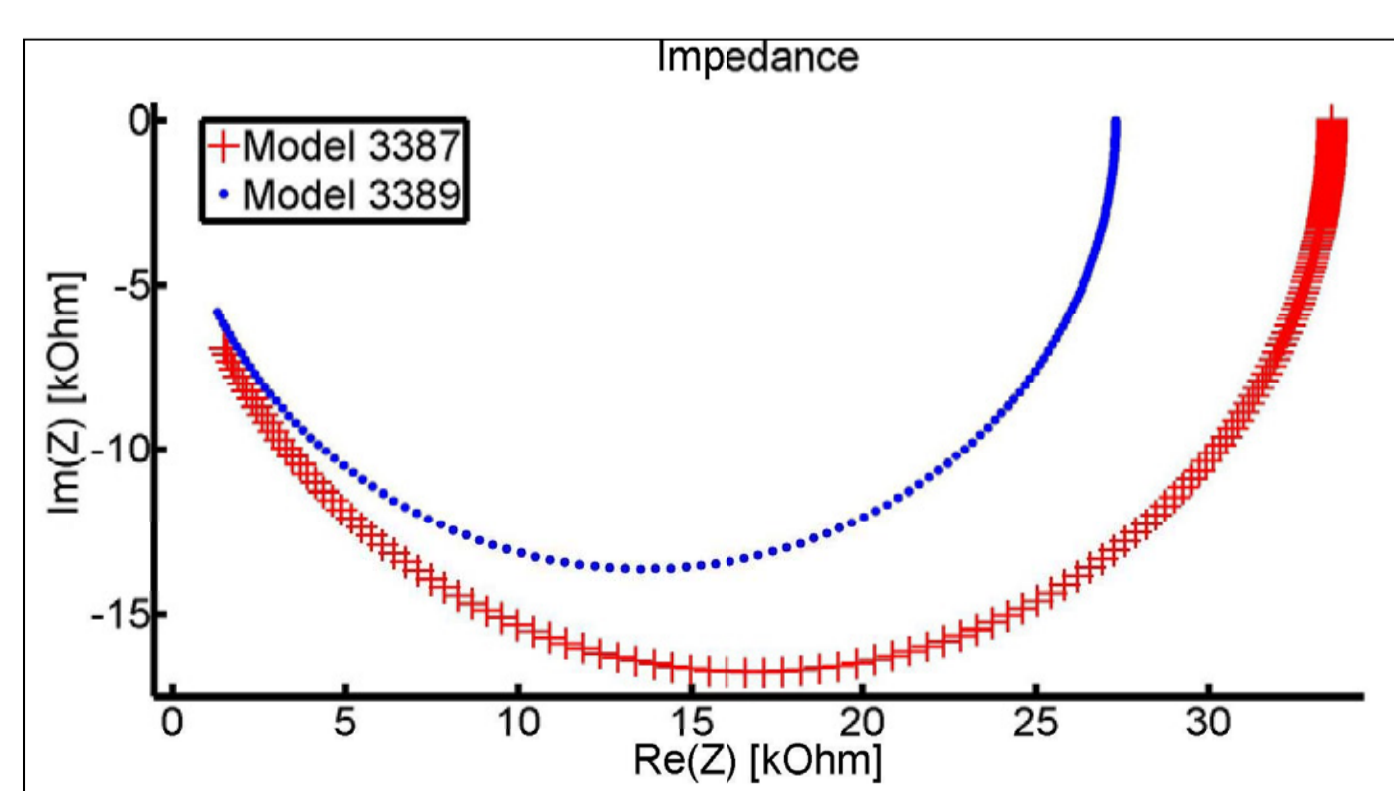

Figure 4. Imaginary vs. real part of the impedance for electrodes used for DBS, simulated with COMSOL Multiphysics® 3.5a RC1 (model 3387 and 3389, Medtronic®).
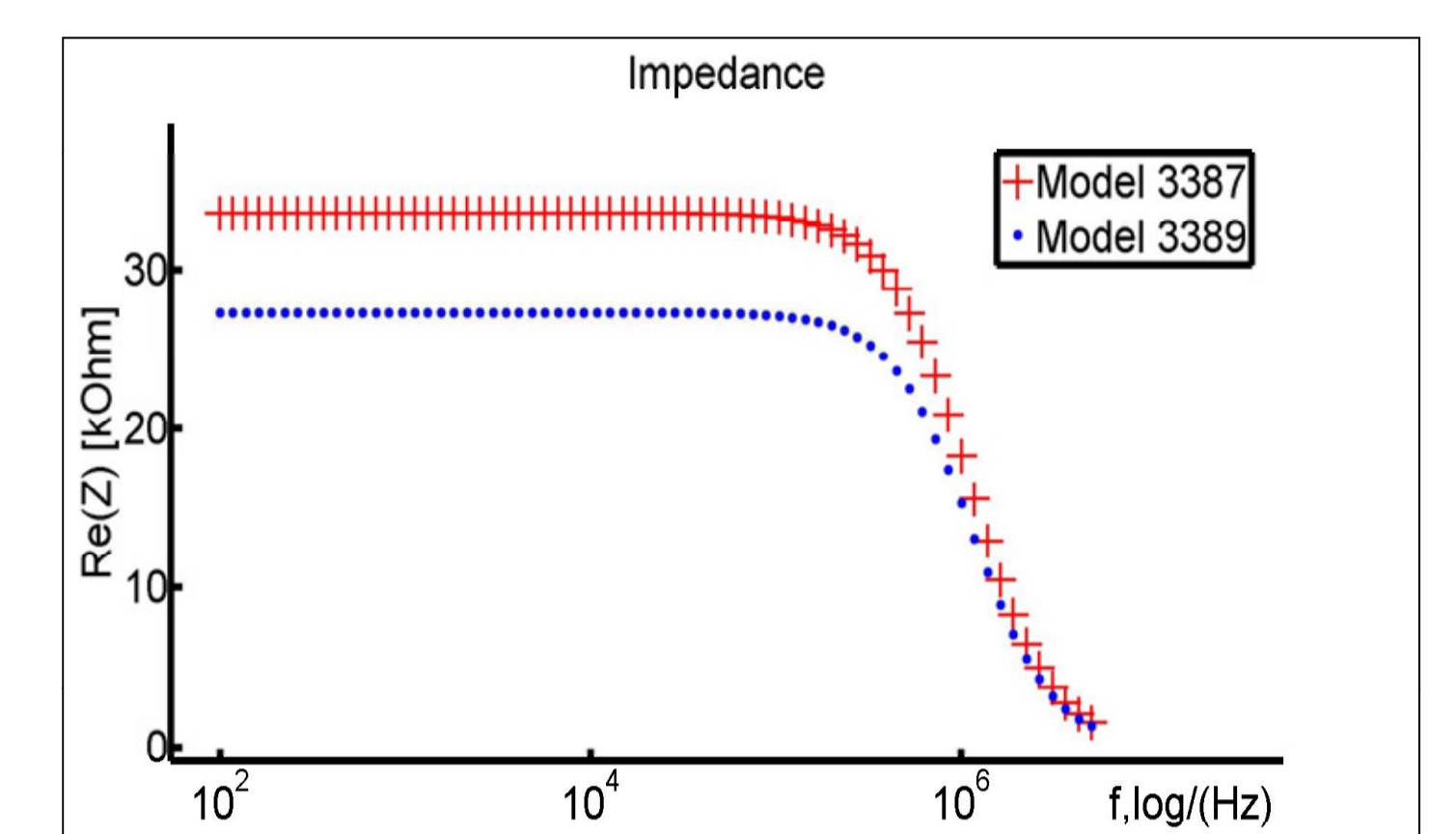

Figure 5. Real part of the impedance vs. frequency for electrodes used for DBS, simulated with COMSOL Multiphysics® 3.5a RC1 (model 3387 and 3389, Medtronic®).

Gimsa et al. [2] used an electrode geometry factor or a so called "cell constant" γ for the characterization of electrodes. Here, the cell constant was computed from equation (6) [2]:

$$\gamma = \frac{1}{\sigma R}, \tag{6}$$

where σ is the conductivity and R is the ohmic resistivity calculated in the same way as the impedance. The cell constants calculated for the electrode models 3389 and 3387 are presented in table 2.

	Potential of electrodes, V				Resistance, kOhm	Cell constant, 1/m
	0	1	2	3		
Model 3389	1	-1	floating	floating	26.6	0.0075
	1	floating	floating	-1	36.4	0.0055
Model 3387	1	-1	floating	floating	32.8	0.0061
	1	floating	floating	-1	38.5	0.0052

Table 2. Cell constant of electrodes used for DBS (model 3387 and 3389, Medtronic®).

As expected the cell constant is larger for model 3389 than for model 3387 which has a larger distance between the stimulation contacts. This means that model 3389 leads to a smaller stimulated volume than model 3387. The validation of simulation results with impedance measurements is in progress.

In future, the inhomogeneity and anisotropy as well as the complex electric properties of the brain tissue have to be taken into account for an improved numerical description of the stimulation effects.

References

1. Joachim K. Krauss, Jens Volkmann, *Tiefe Hirnstimulation,* 17-90, Steinkopff Verlag, Darmstadt (2004).
2. Jan Gimsa, Beate Habel, Ute Schreiber, Ursula van Rienen, Ulf Strauss and Ulrike Gimsa, Choosing electrodes for deep brain stimulation experiments – electrochemical considerations, Journal of Neuroscience Methods, 142:2, 251-265 (2005).
3. *Implant manual*, Medtronic Inc., 710 Medtronic Parkway, MN 55432-5604, Minneapolis, USA, http://www.medtronic.com.
4. Thorsten Steinmetz, Stefan Kurz, Markus Clemens, Domains of Validity of Quasistatic and Quasistationary Field Approximation, *ISTET'09,* 271-275 (2009).

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