Visualization of non-invasive electrical impedance spectroscopy on the volar forearm

B. Tsai[1], E. Birgersson[2], U. Birgersson[3]

1. Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore
2. Department of Mechanical Engineering, National University of Singapore, Singapore
3. Department of Clinical Science, Intervention and Technology, Karolinska Institutet, Sweden

Introduction

Introduction: The human skin is a complex multi-layered entity of different compositions. Through this non-invasive electrical impedance spectroscopy (EIS) model set up in COMSOL, we aim to spatially resolve the current in the different layers between the electrodes. In comparison, the commonly employed electrically equivalent circuits do not provide mechanistic understanding of impedance (potential field and currents).

We model the volar forearm skin as a 3-layer entity – comprising of stratum corneum, viable skin consisting of both living epidermis and dermis, and adipose tissue.

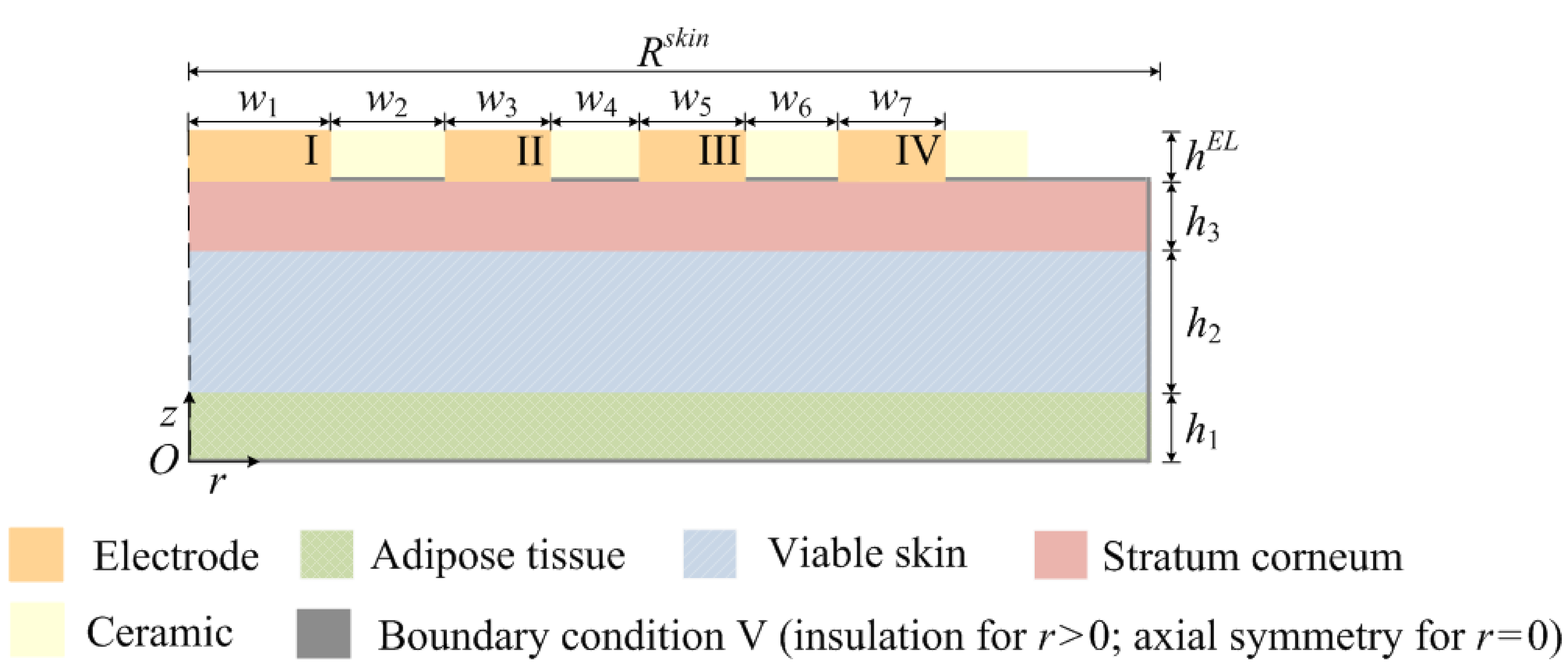

Figure 1. Schematic of a three-layer skin comprising stratum corneum, viable skin and adipose tissue with a four-electrode probe: sense (I), guard (II), 3rd electrode (III) and inject (IV).

Computational Methods:

- Two-dimensional axisymmetric model
- Multiphysics module, custom mesh
- Frequency spectrum 1 kHz to 1 MHz
- Mathematical model in the frequency domain [1]:

$$\nabla \cdot \mathbf{J}(\mathbf{r}) = 0, \qquad \Phi(\mathrm{I}) = 0, \qquad \Phi(\mathrm{II}) = 0,$$
$$\mathbf{J}(\mathbf{r}) = -\sigma^k_{eff}\nabla\Phi(\mathbf{r}), \qquad \Phi(\mathrm{III}) = \alpha V_0, \quad \Phi(\mathrm{IV}) = V_0,$$
$$\sigma^k_{eff} = \sigma^k + i\omega\varepsilon_0\varepsilon_r^k \qquad \mathbf{J}(\mathrm{V}) \cdot \mathbf{n} = 0$$

where the complex-valued phasors, $\Phi(\mathbf{r})$ and $\mathbf{J}(\mathbf{r})$, for the potential and current density are functions of space, $\mathbf{n}$ is the unit normal vector pointing outwards to any given boundary, V_0 is the applied voltage, and the location of the boundary conditions is given by the roman numerals. The effective conductivity, σ^k_{eff}, consists of σ^k the electric conductivity, ε_0 and ε_r^k the relative permittivities of vacuum and the material respectively, i the imaginary unit, and ω the angular frequency. The superscript, k, denotes either viable skin, stratum corneum soaked with a saline solution with 0.9% NaCl for 1 min, adipose tissue, or the electrode.

Results:

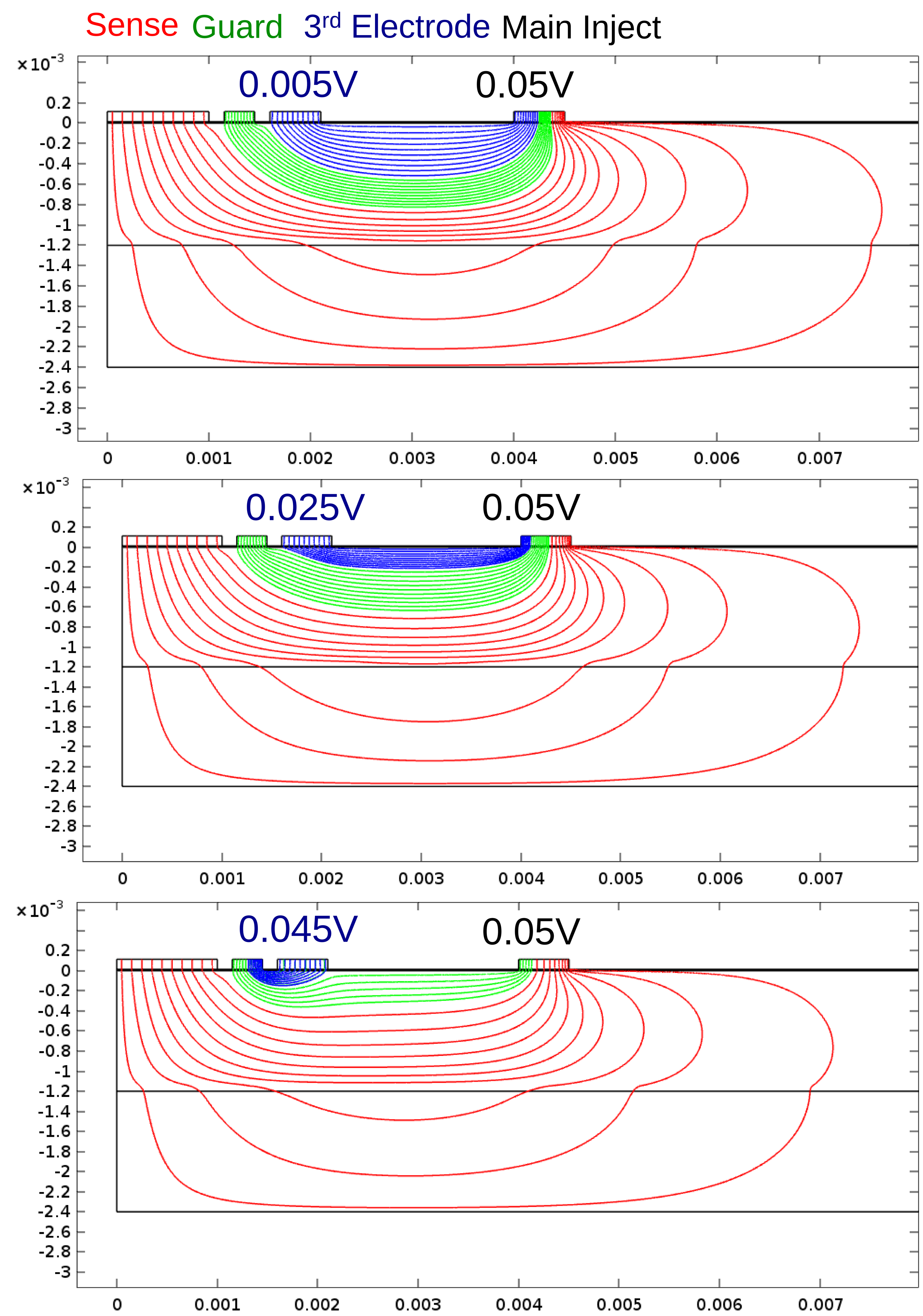

Figure 2. Current density of a 4-electrode EIS probe with third electrode is set at (a) 10% (b) 50% (c) 90% of the potential of the primary inject.
Current streamlines passing through the sense (red), guard (green) and secondary inject (blue).

Conclusion

Conclusion: COMSOL allows us to visualize the current pathways of different electrode configurations – especially in non-trivial cases with one electrode acting either as a guard or inject depending on its potential and/or the applied frequency.

Reference:

1. Birgersson UH, et. al. Estimating electrical properties and the thickness of skin with electrical impedance spectroscopy: Mathematical analysis and measurements. Journal of Electrical Bioimpedance. 3(1): 51-60, (2012)