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The influence of frequency separation on imaging properties in DFEIT

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Abstract. A Dual Frequency EIT is an extension of a traditional EIT that uses two sinusoidal signals for imaging. Appropriate selection of signals' frequency allows to achieve reasonable contrast of imaged structure. It has already been shown that frequency of the signals should cover a selected dispersion range (usually a beta dispersion) for living biological objects. Thus, in respect to different application the upper frequency may achieve (or at least it should achieve) a relatively large values. The upper limit of frequency used in DFEIT is considered in paper. An application of Laplace equation for solving of the forward model as well for a sensitivity calculation is verified and Maxwell equations are suggested for high frequency component. However, there is a limitation in increasing frequency resulting from current leakages and hardware properties. Increasing frequency above a certain one, determined both by object and measurement system properties, is worthless. A current-to-potential and a potential-to-current mappings were compared from a perspective of achievable properties of existing hardware solutions. The comparison was made using SPICE simulations. Additionally, the coupling between object and environment was considered for the high frequency component.

1. Introduction

Electrical Impedance Tomography (EIT) is an imaging technique that produces images of electrical properties distribution within an object on the basis of the knowledge of currents and potentials at its boundary. From a technical point of view it uses a set of cross-impedances measured between electrodes attached to boundary of the object.

Frequency-Difference Electrical Impedance Tomography (DFEIT) is a version of the EIT that utilizes data collected at two frequencies of applied current or voltage in reconstruction procedure [1, 2]. Obtained image presents the difference of the objects conductivity measured at these two frequencies. This imaging method is particularly useful for dispersive objects visualization e.g. biological tissues. Measurements, depending on the hardware complexity, may be made sequentially for each frequency of applied current or simultaneously. In the later case the applied signal is a sum of two sinusoidal signals $U(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$. In general, there are two approaches to use this signal. A first method utilizes sum of two signals of equal amplitudes (i.e. $A_1 = A_2$) and images are reconstructed using backprojection. However, weighted logarithms of measured values at two frequencies are used as measurement data [3]. Second approach is based on a weighted sum of two sinusoids. The frequency and amplitude of each component are selected appropriately to the objects spectral properties. The aim of a selection procedure is to achieve possibly the highest value of the contrast [1, 4]. It has been proved that selection of the frequencies when using DFEIT is essential for the whole reconstruction process. It has an influence on the procedures, accuracy of the measurements and calculations of the forward and inverse problems. An example of the measurement procedure fulfilling above mentioned requirements is shown in [1, 4]. It follows, both, from the literature and our studies that frequency should be chosen for the object presenting the highest contrast while another for the object behaving as uniform (or almost uniform). Typically, for the biological materials, the former frequency is lying in the range of kilohertz while the latter one should be as high as possible. However, there are several factors, both theoretical and experimental, arising when using this approach. It is forbidden increasing the measurement current frequency without changing a mathematical description of the problem. Furthermore, an increased level of errors in measurement data should be also expected. In the paper we consider three essential factors: the properties of the measurement strategies, the forward problem approximation and the coupling of the object with surroundings.

2. Materials and methods

2.1. Measurement strategy

There are two main measurement strategies used in EIT: a potential distribution is measured as a result of applied current pattern or vice-versa: the current division between electrodes is measured in response to applied voltage pattern (fig. 1).

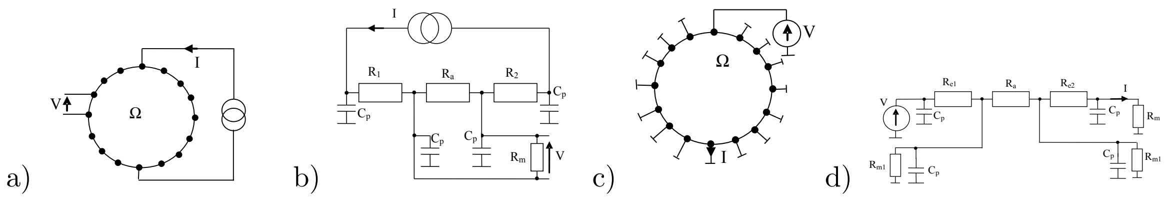

Figure 1. The measurement strategies: a) the current application and voltage measurement, b) an equivalent circuit model for single measurement, c) the voltage application and resulting current distribution between electrodes measurement, and d) equivalent circuit of voltage-current strategy.

Similar models have been used in both cases (along with identical resistance of electrodes). The voltmeter of input resistance equals 10 MΩ and parallel capacitance of 30 pF has been used in current-voltage strategy. An ideal current to voltage converter has been assumed for voltage current strategy. Ideal current and voltage sources have been assumed in both cases. It allowed calculation of frequency characteristics for both strategies.

2.2. The forward problem

In general, the electrical current distribution within the object is described by Maxwell equations [5]. Maxwell equations reduce to Laplace relationship where a quasi-static condition is fulfilled:

$$\omega l\left(\frac{\mu_0\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma_{DC}+\omega\varepsilon''}{\omega\varepsilon'}\right)}+1\right)\right)^{1/2}<<1 \qquad (1)$$

where σ_{DC} - constant-current conductivity, $\varepsilon^* = \varepsilon' + j\varepsilon''$ - the complex permittivity, l - the largest dimension of the object. If the condition (1) is not fulfilled a set of Maxwell equations should be used to solve the forward problem [5].

A model containing a circular object of radius equal 0.16 m and surrounding medium (air or other objects) has been developed (figure 2). Sixteen equally spaced electrodes have been attached to the boundary of the object. Conductivity of the object has been assumed to be independent on frequency and equal 10 S/m while the surrounding medium has been described by permittivity equal to that of free space. A potential distribution inside the object and in surroundings has been calculated.

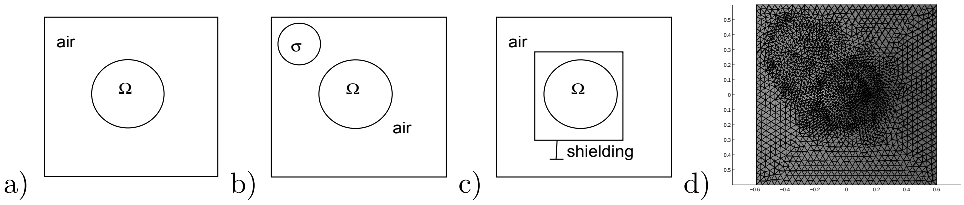

Figure 2. The model considered in the study: a) the object surrounded by air, b) the object and another one located in the vicinity both surrounded by air, c) the object surrounded by shielding surface and d) a developed FEM mesh.

In presence of two conductive objects conductivity of both has been assumed to be similar. Conductivity of the shielding screen attached to ground potential has been equal 10^4 S/m for the last modeled case.

3. Results

Assuming that the examined object is resistive, the potential distribution or the measured current flowing into electrodes should be independent of applied signal frequency. However, the current leakage to the surrounding can evolve and as a result the final signals are subject to change (figure 3).

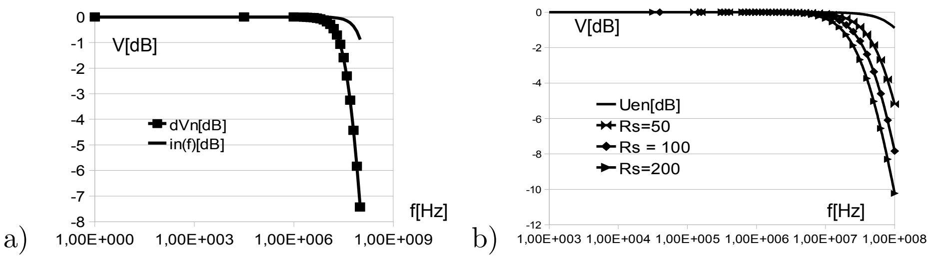

Figure 3. . Influence of measurement circuit properties on achieved frequency band: a) comparison of current and voltage application strategies, b) dependence of frequency band on a quality of the voltage source

The potential distribution was calculated using the Laplace and Maxwell equations (fig 4). Thus, it was possible to compare obtained solutions. A significant influence of measurement strategy was also noted. It was due to different arrangement of boundary conditions which were specific for each considered strategy. For a low frequency the obtained solutions were the same. However, increase in frequency led to big discrepancies (figure 5). A norm of voltage (current) difference $||v(f) - v(1kHz)||$ has been calculated as well for both strategies (figure 6).

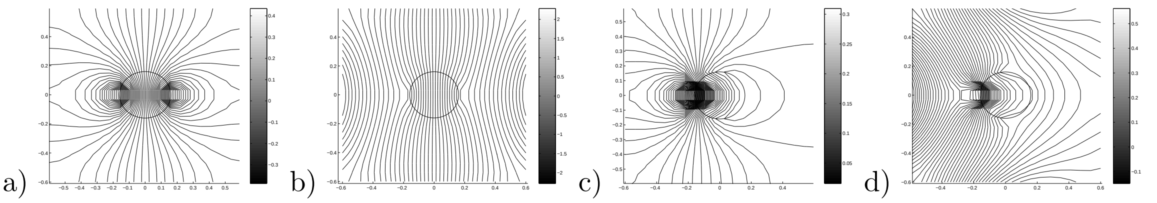

Figure 4. Voltage distribution for model presented in figure 2a): a) current strategy 1 kHz, b) current strategy 10 MHz, c) voltage strategy 1 kHz and d) voltage strategy 10 MHz

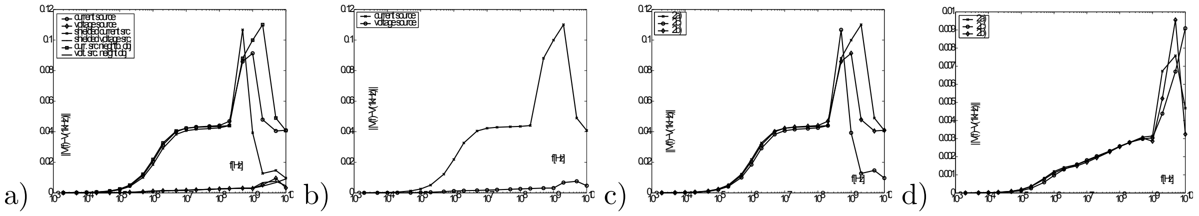

Figure 5. Difference between results obtained using Maxwell and Laplace solutions. Norm of difference between the potential distribution inside the object is presented: a) all cases considered, b) voltage and current strategies for model presented in figure 2a), c) the current strategy for all cases considered presented in figure 2a-2c, d) the voltage strategy for the cases as in c)

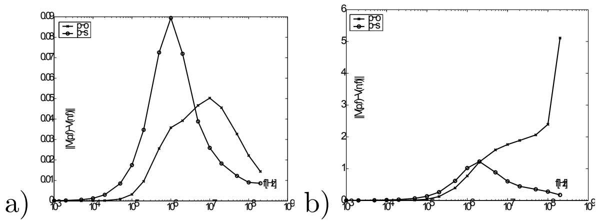

Figure 6. Influence of the object's surrounding on potential distribution inside it. Curves express the norm of potential difference between model 2a, 2b (p-o) and 2a, 2c (p-s) for: a) voltage application strategy, b) current application strategy

4. Conclusions

The obtained results suggest that increase frequency of applied signal involve a necessity of changing type of forward problem. There is also a relatively significant difference between potential distributions when using different signal application strategies. It follows from the fact that the considered strategies inherently create different boundary conditions.

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