Journal of Engineering and Applied Sciences 12 (3): 587-592, 2017
ISSN: 1816-949X

Feature Research of Using Current Source in 2-Dimensional and 3-Dimensional Multifrequency Electrical Impedance Tomography Devices

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Abstract: The following study discusses current source using in 2 and 3 Dimensional multi-frequency electrical impedance tomography of biological objects. The biological object is a set of tissues with different values of electrical conductivity and dielectric permittivity, these values are not constant but depend on many factors including injection current frequency. The study describes the equivalent circuit of a biological object with nonlinear dependence of resulting resistance and capacitance values of frequency. Corresponding computer model of circuit source with a load of a biological object is offered. As the result of the simulation, main features of application of current source with biological object load are highlighted.

Key words: EIT, computer simulation, multi frequency electrical impedance tomography, current source, highlight

INTRODUCTION

Electrical Impedance Tomography (EIT) is a method of receiving and visualization of the conductivity distribution in internal structures of the object (Aleksanyan *et al*., 2015a-c). The algorithm of the method lies in the series connection of different pairs of electrodes to the source of the injection current and the potential values measurements on the rest of the electrodes according to a common point (Aleksanyan *et al*., 2016). The potentials obtained during the measurement used to restore the picture of the distribution of conductivities, i.e., a method of solving the inverse problem.

Research of Biological Objects (BO) by EIT using one current injection rate, do not account for the nonlinear dependence of the conductivity and permittivity of biological tissues of the frequency of the injected current and thus do not provide additional information about the tissue properties.

Multifrequency Electrical Impedance Tomography (MEIT) uses the injection of current at different frequencies either simultaneously (on different pairs of electrodes from different power sources) or at different times (representing a set of single-frequency measurements) (Aleksanyan *et al*., 2014).

Injecting Current Source (CS) is an essential component for the EIT device from its performance is primarily dependent measurement error. Special requirements for CS if it is applied in the multi-frequency measurement circuit when the high stability of output characteristics is required not only in a large range of load impedances but also at the same time over a wide frequency range.

CS used in various types of devices, the characteristics of them have been studied in detail but in the case of their application for solutions MEIT great interest tasks to study their output characteristics of the load which is the BO with its complex nonlinear and time-varying parameters depending in particular and on the output characteristics of the CS.

MATERIALS AND METHODS

The dependence of conductivity parameters and permittivity and accordingly the resulting values of resistance R_e and capacitance C_eBO injected current of frequency f is caused by a complex heterogeneous tissue structure, of which it consists (Aleksanyan *et al*., 2014). The equivalent circuit diagram of BO can be described as an electric circuit section consisting of 2 elements: resistance R_e and capacitance C_e connected in parallel (Fig. 1) and the corresponding conductivity and permittivity. It is worth noting that there are many more complex equivalent circuits which reflect the internal structure of BO.

For such an equivalent circuit with parallel elements of impedance Z may be defined by the following expression:

$$Z = \frac{R_{экв} \cdot jX_{C_{экв}}}{R_{экв} + jX_{C_{экв}}}$$

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where, $X_{сэкв}$ AC resistance of capacitor:

$$X_{Cэ,КВ} = \frac{1}{2\pi \cdot f \cdot C}$$

where, f is the frequency of the injected current. Figure 2 shows plots of the resulting reference values R_e resistance and capacitance C_e of the system "electrode the human body the electrode's of frequency f transmitted through them (Berezovsky and Kolotilov, 1990). As can be seen from the graphs on Fig. 2 parameters R_e and C_e depending on the frequency f of the injection current are non-linear and have a different character.

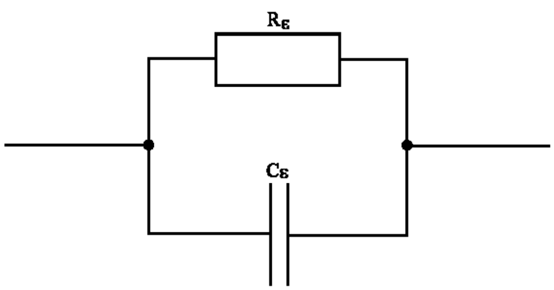

Fig. 1: The equivalent circuit diagram of the BO

To simulate CS circuitry current-voltage converter with a grounded load was selected. In this scheme, the control does not depend on the load impedance common-mode signal is absent and output impedance of circuit tends to infinity with accurate selection of nominal values of Tietze and Schenk (2007) (Fig. 3). The amplitude of the output current in this circuit depends on the ratio of the input voltage uin to the resistance R6.

To investigate the characteristics of the output of CS with load as an equivalent circuit BO, simulation was conducted with R_e and C_e values according to dependencies shown (Fig. 2) in the range f_{min} = 1 kHz frequency, f_{max} = 200 kHz, the data presented in Table 1.

To model was chosen amplitude of the injection current I_{out} = 5 mA that avoids undesirable biological effects in the tissues of the test BO (Pecker *et al*., 2004). Micro cap package was used for simulation (Amelina, 2007) and some physical values observed during the study CS output characteristics such as the amplitude of the current passing through the BO and the voltage falling on it.

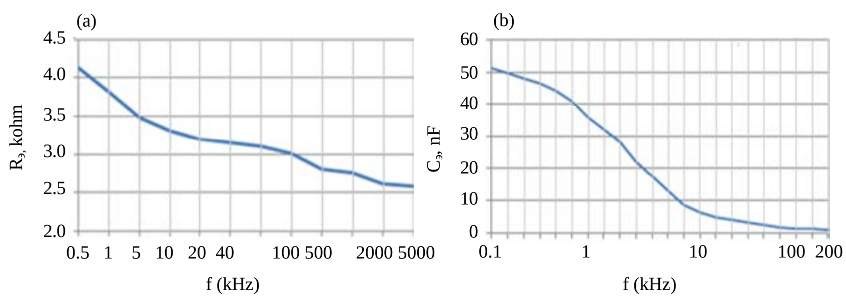

Fig. 2: The graphs of values of resistance R_e: a) and capacitance C_e and b) of the frequency f

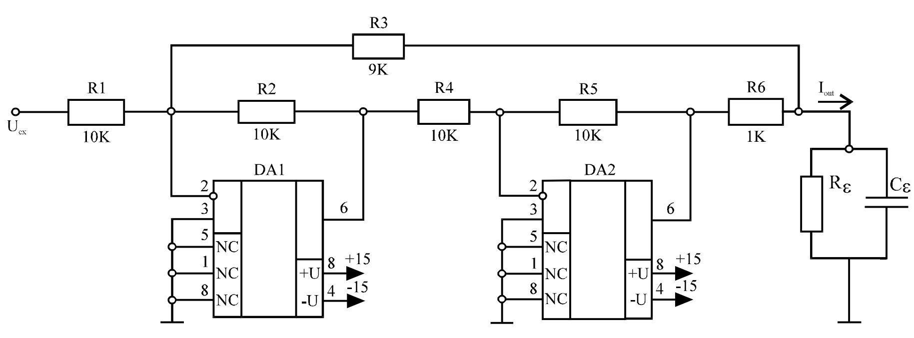

Fig. 3: Electrical schematic diagram of the current source connected to the load of an BO equivalent circuit

Table 1: Dependency of resistance R_e and capacitance C_e on frequency f

Frequency (f, kHz)	1	10	20	40	60	80	100	120	140	160	180	200
R_e (kOhm)	3.817	3.311	3.204	3.175	3.121	3.072	3.011	2.997	2.985	2.965	2.928	2.904
C_e (nF)	36.20	6.400	3.870	3.110	2.080	1.440	1.210	1.140	1.080	1.030	0.960	0.810

RESULTS AND DISCUSSION

The graphs of the amplitude value of the output current I_{out} from the circuit resistance R_e and capacitance C_e resulting from simulation are shown in Fig. 4. The graph shown in Fig. 4, shows instability I_{out} of CS at f = 1 kHz. The data illustrated in Fig. 4 shown in expanded form in Table 2. Figure 5 shows the divergence of Iout amplitude values of CS on the frequency f, the difference was estimated by the equation:

$$\delta = \frac{\left|I_{out} - I_{out э}\right|}{I_{out э}}$$

Where:

I_{out3} = Predetermined injection current amplitude

I_{out} = Current resulting from the simulation of the load

Analysis of the resulting data modeling shows that with the fall of the frequency f and a corresponding increase in the quantities R_e and C_e difference between the set point I_{out3} and obtained I_{out} is rising from δ = 0.87% at f = 20 kHz, δ = 1.86% at f = 10 kHz to δ = 3.96% at frequency f_{min}. With increasing frequency f from f_{min}-f_{max} discrepancy delta falls to a value δ = 0.14%. For max accuracy of the output current CS δ = 1% frequency range f_{min}, f_{max} is 20, 200 kHz. It should be noted that in human body EIT injecting current frequency <10 kHz are not used as in the contact electrode and the skin begins unwanted electrochemical reactions that introduce significant error in the result of the measurement process and may cause painful feelings to the patient (Pecker *et al*., 2004).

Graph of the phase voltage φ, depending on the frequency f, resistance R_e and capacitance C_e, obtained by simulation, shown in Fig. 6. As can be seen from this graph, load voltage phase value varies significantly depending on the injection current frequency f and the nature of the load.

The phase φ depends only on the change of capacitive component of the load FE (Fig. 7a, b). Thus, for solving the inverse problem MEIT it's possible to obtain additional information about the impedance of the reactance BO data based on the phase shift angle φ and frequency f.

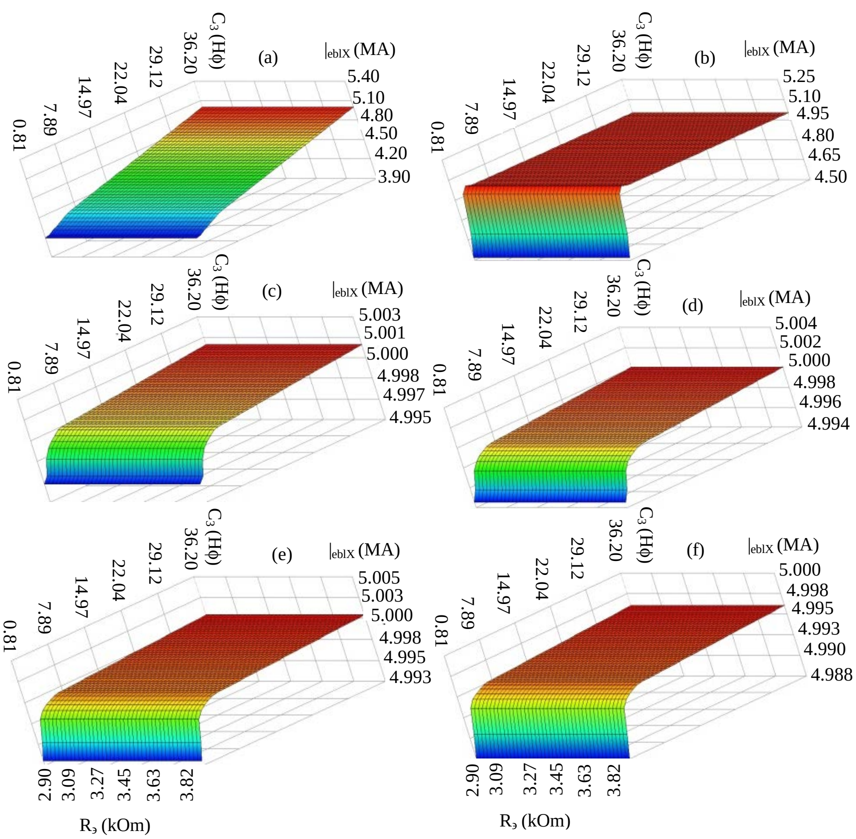

Fig. 4: Graph of the output current I_{out} on resistance R_e and capacitance C_e at frequencies f = 1 kHz: a) f = 10 kHz; b) f = 20 Khz; c) f = 40 kHz; d) f = 100 kHz and e) f = 200 kHz (f)

Table 2: Dependency I_{out} on frequency f, resistance R_e and capacitance C_e

Frequency (f, kHz)	1	10	20	40	60	80	100	120	140	160	180	200
R_e (kOhm)	3.8170	3.311	3.2040	3.175	3.121	3.072	3.011	2.997	2.985	2.965	2.928	2.904
C_e, nF	36.200	6.400	3.8700	3.110	2.080	1.440	1.210	1.140	1.080	1.030	0.960	0.810
I_{out} (mA)	4.8020	4.907	4 .957	4.966	4.972	4.981	4.990	5.008	4.993	4.994	4.992	4.993

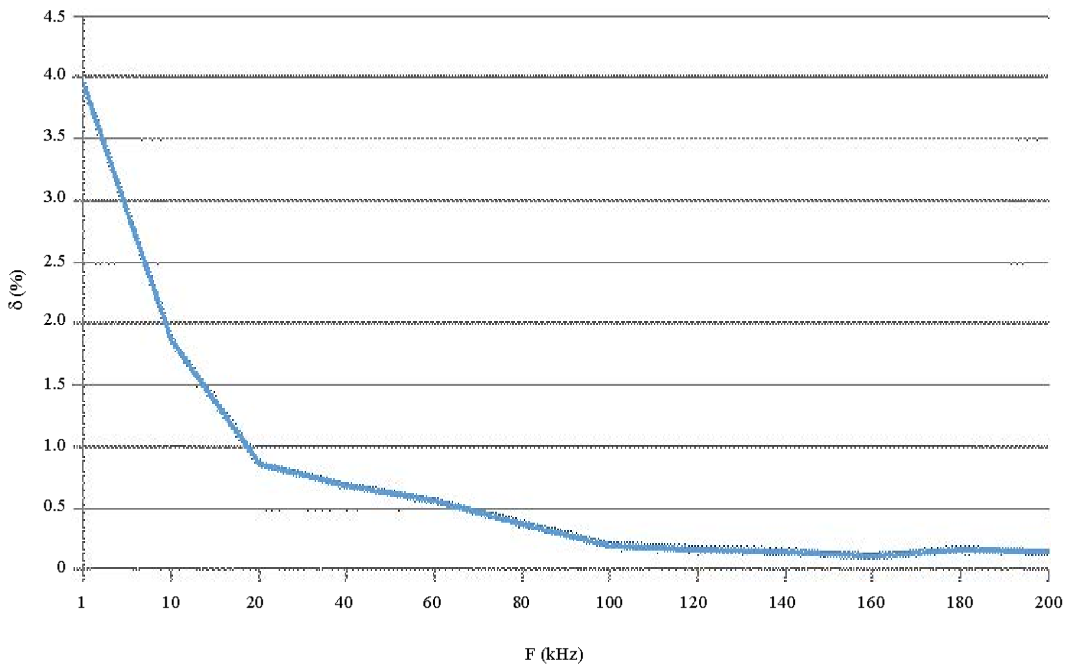

Fig. 5: Dependence of divergence of I_{out} amplitude values on the frequency f

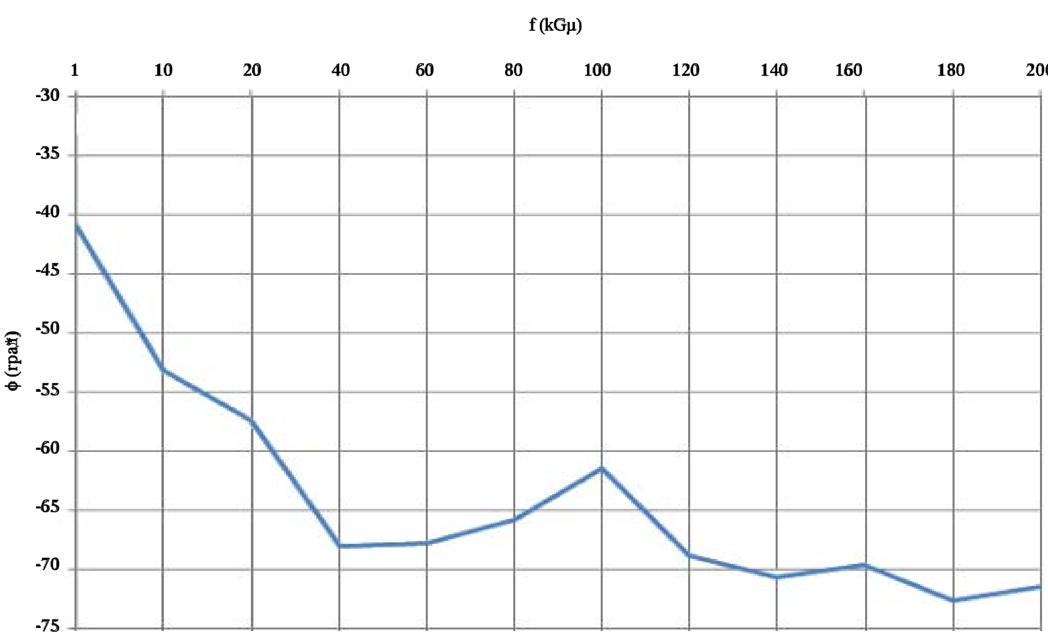

Fig. 6: Graph of voltage phases on the load on the frequency f and the corresponding resistance R_e and capacitance C_e values

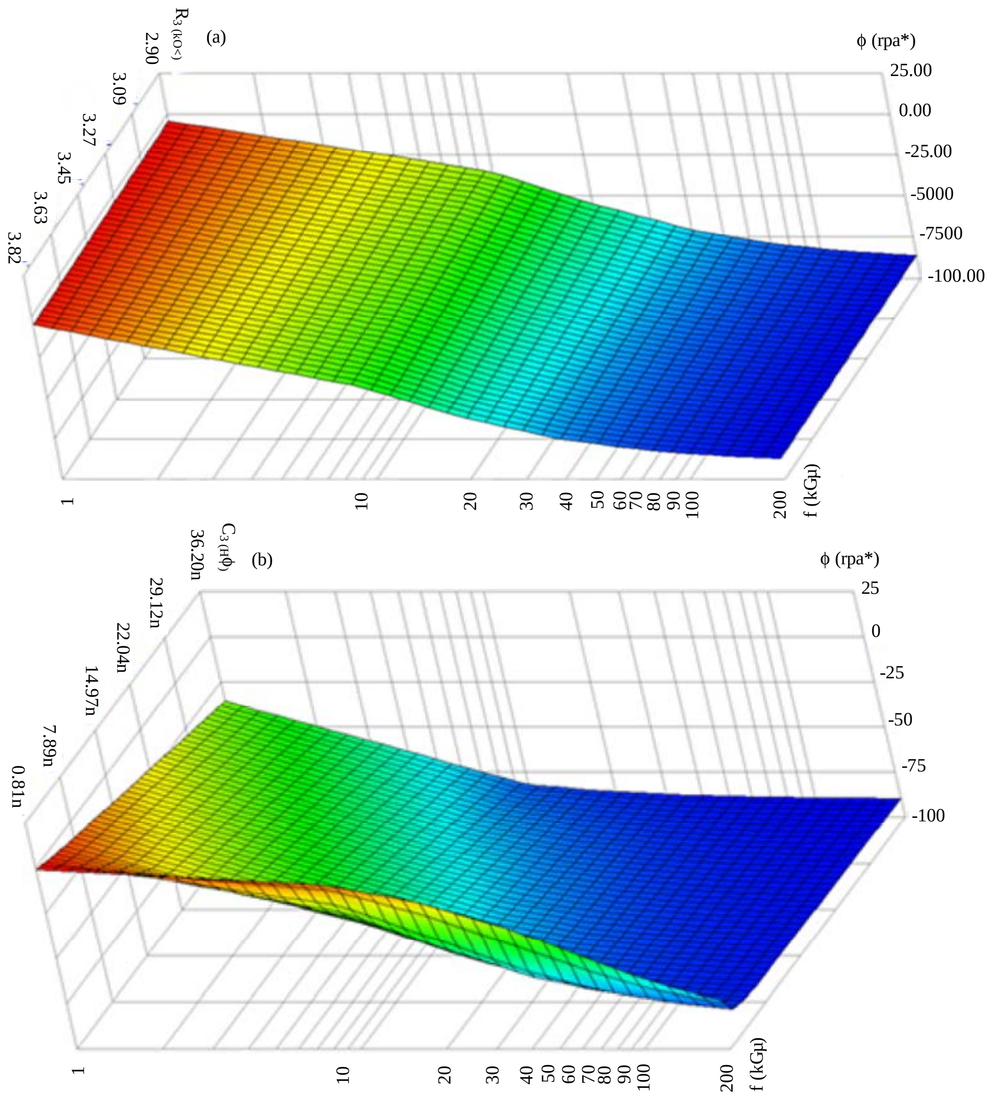

Fig. 7: Graph of the phase voltage φ: a) depending on the load resistance of R_e and b) capacitance C_e

CONCLUSION

Computer modeling of the IT circuit with a load in the form of equivalent BO equivalent circuit to indicate the range of applicability of its to the 2-Dimensional and 3-Dimensional MEIT BO tasks was performed. Following range of input parameters was given:

- The frequency f: f_{min} = 1kHz, f_{min} = 200 kHz
- The active component of R_e: R_{emin} = 2908 Ω, R_{emax} = 3817 Ω
- The reactive component (electrical capacitance) C_e: C_{emin} = 0.81 nF, S $Ce_{Эmax}$ = 36.2 nF

Electrical parameters R_e and C_e, respectively selected as reference data for the system "electrode the human body-electrode "(Berezovsky and Kolotilov, 1990) and are non-linear dependence of the frequency f value. Simulation performed on a given range of the input parameters to determine the error δ of the output current on the basis of which has been designated the range of applicability given CS schemes for problems of 2 and 3 dimensional MEIT:

- The min frequency of the injection current: f_{min} = 20 kHz
- The f_{min} corresponding max value of the R_{emax} = 3204 Ω
- The f_{min} corresponding max value of C_{emax} = 3.87 nF

The simulation results show that with increasing frequency f error δ falls (Fig. 5). As on I_{out} accuracy error depends entire device measurement accuracy and thus the quality of the reconstruction of the internal structure of BO further work is needed to improve the stability of the output characteristics of the CS.

Also, studies have been conducted phase-frequency characteristics of the equivalent circuit of BO which showed the dependence of the phase φ voltage incident on the load of the capacitive component BO C_e and frequency f. Thus, the data of the injection phase of the voltage signal can be used to obtain extended information about the internal structure of the object under study.

ACKNOWLEDGEMENTS

This research was supported by the Russian foundation for basic research, grant No. 16-38-60173 "Technology mining electrical impedance tomography for three-dimensional reconstruction and visualization of the conductivities of the internal structures of biological objects".

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