Electric field tomography

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Abstract

EFT is a new kind of quasistatic electromagnetic tomography. It uses only electric component of RF-field. EFT is contact-less and promising method for imaging of spatial distribution of electrical properties inside object. Using set of spatially distributed electrodes the EFT system measures electric field phase shifts caused by the object. The physical cause of the phase shifts is a lag of free charges redistribution in a medium with finite conductivity relative to external field and appearing of corresponding lagging of scattering field. The image reconstruction is carried out by the method of weighted backprojection along electric field lines.

1. Introduction

Electric field tomography (EFT) is a recently introduced [1] kind of quasi-static electromagnetic tomography. The other modalities are: magnetic induction tomography (MIT) [2, 3], electrical capacitance tomography [4] and electrical impedance tomography (EIT) [5]. All quasistatic electromagnetic tomography methods work with oscillating electromagnetic field with wavelength much longer than investigated object size. EFT may have three main applications: security, bio-medical and, industrial control. As for medical application it is a new technique for bio-impedance imaging enabling contact-less investigation of human body. All bio-impedance methods are very promising for medical diagnostics. Due to changing in organs or tissues in diseases are not happened instantly. At first metabolism, blood flow, ion concentration is changing, that affect directly on electrical properties of tissue. And only after some time we can observe some morphological, functional or density changing in organs. Therefore quasistatic tomography potentially permits to detect illness on its preliminary stages. Moreover, owing to contact free, EFT is to become wide-spread measuring technique, quite cheap and very simple for operators in use. But there are some technical difficulties like soft-field smoothing, capacity changing impact on the measuring electronics etc. and lack of medical knowledge for certain tissues and organs diagnostic in term of conductivity and permittivity.

2. Materials and methods

For deeper understanding we have to remind you behavior of perfect conductor in electromagnetic field. Perfect conductor object placed in the field shields electromagnetic field inside itself. The cause of this is redistribution of free charges. They move under influence of external field and at every moment their distribution on the object's surface generates field which compensates external field inside object. The object surface is equipotential surface: electric potential phase and amplitude is same in all surface points. So perfect conductive object only increase wave propagation delay by time required for field to round the object. This propagation delay is negligibly small in quasi-static conditions (object size is much smaller than field wavelength). Now let us consider non-perfect conductive object, in this case free charges can not redistribute immediately, due to finite conductive of medium, therefore they get lag relative to external field. And accordingly compensating field has lagging relative to incident field. Sum of secondary field and incident field outside object has lagging relative to initial field too. That is so-called Maxwell-Wagner relaxation [6] in a heterogeneous conductive medium.

Consider parallelepiped non-perfect object-medium with permittivity ε and conductivity σ, correspondingly ρ – medium specific resistance, electrode-transmitter and voltage generator, electrode-receiver and phase sensitive voltmeter (see figure 1). Let object is placed near electrode-transmitter and there is no air gap between them. S is electrodes square, d_1- object thickness, d_2 – air gap between object and electrode-receiver, ε_0 – vacuum permittivity constant. This system can be approximated like equivalent circuit on figure 2: medium is presented by capacitor with capacity C and resistor with resistance R, air gap like only capacitor with capacity C_c. Phase shift provided by this circuit is Δ. Δ can be easily calculated from corresponding Kirchhoff's equations, see [6]. Moreover by getting derivation, we obtain that there is maximum of phase shift on frequency equal to medium relaxation frequency $\omega_r = \varepsilon_0\varepsilon/\sigma$. And value of this phase shift maximum is determined by equation $\tan \Delta_{max} \approx - d_1 / 2\varepsilon d_2$. In general case phase shift value depends on permittivity and conductivity of the medium, on the object's geometry and investigating RF-field frequency (1).

$$\tan\Delta = -\frac{\omega\varepsilon_0\varepsilon\rho d_1}{\varepsilon d_2(1+\omega^2(\varepsilon_0\varepsilon\rho)^2(1+\frac{d_1}{\varepsilon_0\varepsilon\rho d_2}))} \qquad (1)$$

In the quasi-static approximation the maximum phase shift value achieved on relaxation frequency does not depend on the conductivity of medium and is determined by permittivity and geometry only Δmax ~ 1/ε.

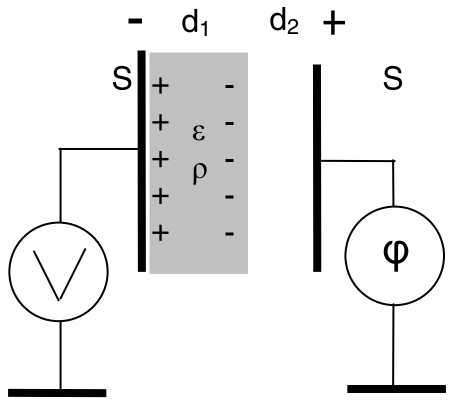


Figure 1. Non-perfect conductive media object in measuring setup.

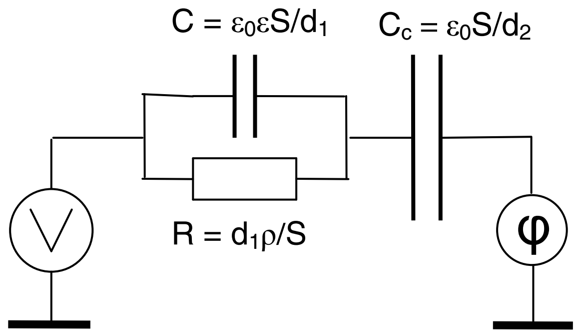


Figure 2. Equivalent circuit.

In quasistatic approximation metal object does not case phase shift, only increases transfer ratio between generator and receiver, hence increases field amplitude on electrode-receiver. But in real conditions, as it was pointed out in previous papers [7] all electrodes have ground capacity and metal object may change it too. Real generator has finite output impedance and so changes phase of signal under capacitance load changing. We should measure generator phase shift and take it for reference signal phase to avoid metal object influence on generator. Nevertheless the main difficulty in EFT is to detached medium phase shift from lagging in real receiver amplifier stage. Commercial operational amplifier do not provide accuracy about 0.01° degrees (working phase shift is up to 0.2° degrees) upon input capacity and signal amplitude changing. Manufacturers do not specify information about such parameters. So minimization of this influence is possible only by method of trial and error. Our empirical solution provides minimization of capacity changing influence to acceptable range.

To reconstruct image we should have spatial distributed set of electrodes. Electrodes one by one generate field, and all remaining measure phase shifts. When we have got sufficient data set obtained from electrodes, we can reconstruct image. The image reconstruction is carried out by the method of weighted backprojection along electric field lines.

3. Previous experimental results briefly

As it was published before [8, 9] computational experiments and physical experiments on one channel setup with commercial lock-in voltmeter have confirmed the theoretical estimations and conclusions given in previous publications on electric field tomography [6]:

- quasi-static model for EFT is suitable and adequate;
- there is maximum phase shifts on medium relaxation frequency;
- value of maximum phase shift depend on permittivity and geometry only;
- character of dependence phase shift on frequency (shown on figure 3);
- well-conductive objects do not cause noticeable phase shift;
- superposition principle for complex objects is adequate for EFT.

Later several computational experiments have been done to evaluate characteristics of multi-channel system [9] using FDTDPro software to solve full Maxwell equations set by the finite difference time domain method.

After that phase measuring module have been developed with AD8302 implementation and tested with external digital signal generator. Module phase signal measuring accuracy and stability was 0.007° (confidence interval was taken 3 root-mean-square error). Such precision phase measuring requires spatial separation and shielding on PCB for measuring trace and clock frequency, to avoid crosstalk between them.

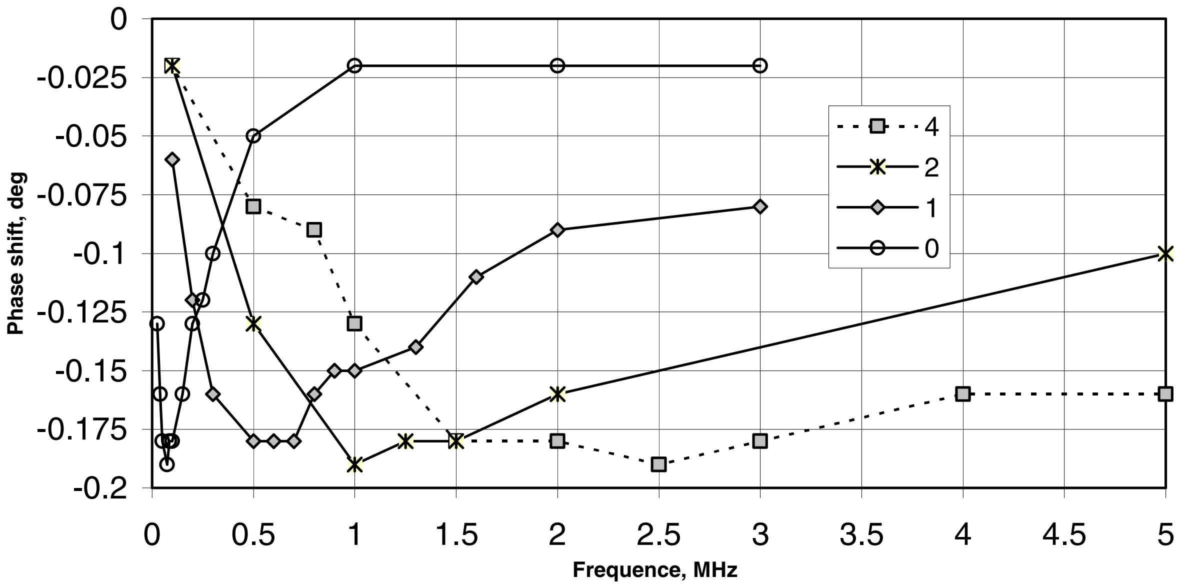


Figure 3. Phase shift dependence on frequency. Water with sodium chloride solutions with different conductivity: "0" – 0.00037 S/m (distilled water), "1" – 0.002 S/m, "2" – 0.0053 S/m, "4" – 0.011 S/m.

4. Image reconstruction

To obtain data sets for testing of reconstruction algorithm both FTDTPro and FEM (for quasistatic 2D-modeling) software were used. The reconstruction was carried out by the weighted backprojection along electric field lines from simulated data sets. Set of experiments shown possibility to reconstruct image for both system: with planar and round electrodes array.

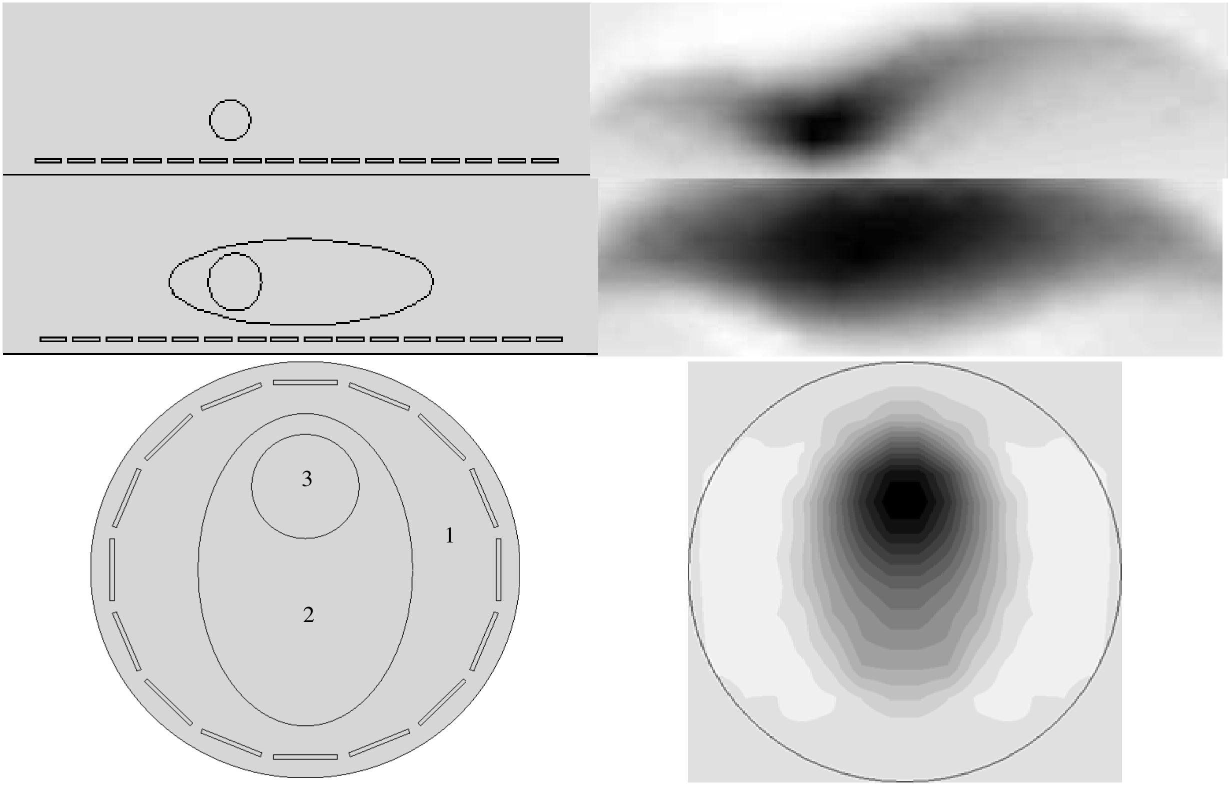
The most interesting results are 2D image reconstruction comparison for system with planar electrodes array and for system with round electrodes array (see figure 4). It is clear to see that system with planar electrodes constructions does not provide enough quality for further visual image analysis. Still we can easily locate single object, even we can guess that the second object has some asymmetry or inclusion. As for system with round electrodes array there is image with high accuracy quite enough for further image analysis. So round electrodes array is the most suitable for application requiring visual analysis of image, for example bio-medicine. But planar electrodes array has very compact and easy-to-use geometry. EFT system with such electrodes array is to be portable and may be very useful for security or industrial application, which requires only evaluation or detection of some object, process. This task can be solved through such a methods as artificial neural networks.

The image reconstruction quality for planar electrodes is quite worse because less field lines pass through each object voxel and between two electrodes of array. Lots of field line from electrodes-generator goes off planar system. And we have not sufficient number of independent field line passed through voxel to evaluate its electrical parameters for correct image reconstructions.

5. Conclusions

Now we have everything to create tomography system prototype for real application: theoretical base, experimental confirmations, image reconstruction algorithm, input amplifier stage, phase measuring unit. So the next step to make successful image reconstruction of real object is to develop and build multi-channel EFT system. At the beginning the EFT system will consist of 16-channel hardware system to obtain data sets and PC with special software to reconstruct image. Hardware system should consist of 16 replacement single data acquisition modules and one interface modules to provide data transfer to PC software though USB.

Electric field tomography (EFT) is a new kind of quasistatic electromagnetic tomography providing contact-less visualization of electrical properties spatial distribution inside investigated conductive object.



(a) (b)

Figure 4. Image reconstruction from 2D simulated data sets with planar (a) and circular (b) system. Larger elliptical cylinder corresponds to muscle tissue (σ = 0.6 S/m, ε = 150 at f = 10 MHz), circular cylinder corresponds to fat tissue (σ = 0.03 S/m, ε = 10 at f = 10 MHz).

7. References

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