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OPTIMIZATION OF MULTI-POLE DEBYE MODELS OF TISSUE DIELECTRIC PROPERTIES USING GENETIC ALGORITHM

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Abstract: *In the past few decades many researchers have studied regarding the dielectric properties. Models of the dielectric properties of body tissues enable us to simulate the interactions of these tissues with electromagnetic fields. These properties are the permittivity and conductivity which vary many orders of the magnitude at frequencies after the microwave bands. To calculate the dielectric properties over broad frequency range, any different parametric models have been developed. Parametric formulae are available based on a multi-pole model of tissue dispersions, but although they give the dielectric properties over a wide frequency range, they do not convert easily to the time domain. An alternative is the multi pole Debye model which works well in both time and frequency domains. Optimization is needed to find the parameters that give the best fit to measured data, or to previously validated models. Genetic algorithms are an evolutionary approach to optimization and it is found that this technique is effective at finding the best values of the multi Debye parameters. Thus genetic algorithm optimizes these parameters to fit to Cole-Cole model and working well over wide frequency ranges.*

Keywords: *Genetic Algorithm (GA), Debye model, Cole-Cole model.*

1. INTRODUCTION

In electromagnetism, absolute permittivity is the measure of the resistance that is encountered when forming an electric field in a medium. In other words, permittivity is a measure of how an electric field affects, and is affected by, a dielectric medium. The permittivity of a medium describes how much electric field is 'generated' per unit charge in that medium. More electric flux exists in a medium with a high permittivity because of polarization effects. Permittivity is directly related to electric susceptibility, which is a measure of how easily a dielectric polarizes in response to an electric field. Thus, permittivity relates to a material's ability to transmit an electric field.

In SI units, permittivity ε is measured in farads per meter (F/m); electric susceptibility χ is dimensionless. They are related to each other through

$$\epsilon = \epsilon_r \epsilon_0 = (1 + \chi)\epsilon_0 \quad (1)$$

Where ε_r is the relative permittivity of the material, and $\epsilon_0 = 8.8541878176\ldots \times 10^{-12}$ F/m is the vacuum permittivity.

The (relative) complex permittivity $\hat{\epsilon}$is defined as:

$$\hat{\epsilon} = \epsilon' - j\epsilon'' = \epsilon' - \frac{j\sigma}{\omega\epsilon_0} \quad (2)$$

where$\epsilon'$is the dielectric constant, $\epsilon''$is the loss factor and σ is the conductivity of the tissue;the angular frequency $\omega = 2\pi f$ where $f$is frequency, and ϵ_0 is the permittivity of free space.

Owing to the complex cellular structure and the presence of numerous internal interfaceswithin typical tissues such as muscle, bone or fat, the parameters, ϵ', ϵ'' and σ all vary stronglywith frequency from static fields up to microwaves at tens of GHz [1].This is because there are several different mechanisms contributing to the polarization of thetissue in an electric field, each of which responds in a different timescale. This leads to anumber of 'dispersions' or 'relaxations' which can be seen in a plot against frequency as a fallin ϵ'between two steady values, and a corresponding increase in σ. The α-dispersion is dueto counter-ion flow in bulk tissues which has a time constant of milliseconds. Charging/discharging ofcell membranes at μs timescale is responsible for the β-dispersion. Finally the γ–dispersionis caused by the fastest process considered here, rotation of polar water molecules with time constant of picoseconds (ps).

2. PARAMETRIC MODELS

Some simplemolecules such as methanol have a single time constant $\tau$and the frequency dependence of their dielectric properties can be described by an equation introduced by Debye (1929):

$$\hat{\epsilon} = \epsilon_\infty + \frac{\epsilon_\infty - \epsilon_s}{1 + j\omega\tau} \quad (3)$$

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Where ϵ_∞ is the high frequency permittivity and ϵ_s is the 'static' permittivity (actually the value for frequencies well below the start of the relaxation effect). However, the dispersions in body tissues do not follow the Debye model so well and exhibit a broadening in which ϵ'falls more slowly with f.

Cole and Cole [2] modified the Debye formula by introducing an empirical parameter α to broaden the dispersion. Gabriel et al (1996) developed a parametric model that can be applied to 17 different body tissues, in which four separate Cole–Cole dispersions are summed, and the static (DC) conductivity is also accounted for (the β-dispersion is made up from two Cole–Cole terms and the other dispersions from one each):

$$\hat{\epsilon} = \epsilon_\infty + \sum_{i=1}^{4} \frac{\Delta\epsilon_i}{1+(j\omega\tau_i)^{(1-\alpha_i)}} + \frac{\sigma_s}{j\omega\epsilon_0} \qquad (4)$$

Where $\Delta\epsilon_i$ is the change in permittivity due to the i th dispersion and $\sigma_s$the static conductivity.

Gabriel et al used a Microsoft Excel spreadsheet to optimize the parameter values, to fit their Cole–Colemodel to measured data. At each stage of the optimization graphs would be visually analyzed for their quality of fit andparameters would be changed systematically to improve the fit. A useful feature of the Cole–Cole model is that when $\epsilon''$is plotted against $\epsilon'$for a single dispersion, the points lie on the arc of a circle [3], and so this graphical method can be used to estimateα. However when more than one dispersion is included this advantage is less apparent, and the addition of the parameters αi causes difficulties when transforming to the time domain because the fractional powers of frequency lead to fractionalderivatives [4]. This makes it harder to implement in computational EM methods such as FDTD or TLM [5-7]. A model of tissue dielectric properties is needed that applies over a broader range of frequencies, and can easily be transformed to the time domain. The most popular approach has been to fit either the Cole–Cole values or the measured data to a 'multi-pole Debye' model [8]:

$$\hat{\epsilon} = \epsilon_\infty + \sum_{i=1}^{n} \frac{\Delta\epsilon_i}{1+j\omega\tau_i} + \frac{\sigma_s}{j\omega\epsilon_0} \qquad (5)$$

Where n is the number of dispersion or 'poles' in the model. The broader the frequency range, the more poles that are needed for a given required accuracy.

Within the GA the values of the parameters $\Delta\epsilon_i, \tau_i, \epsilon_\infty$and σ_s were allowed to vary. The ranges of these parameters are as follows [9]:

$\epsilon_i \in (10^{-3}, 10^{8})$

$\tau_i[s] \in (10^{-12}, 10^{-1})$

$\epsilon_\infty \in (1, 10^{1})$

$\sigma_s[S/m] \in (10^{-4}, 1)$

3. RESULTS

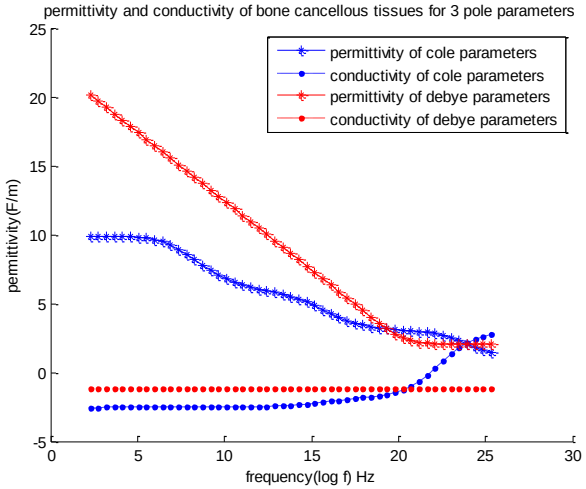

Figure 1(a) Dielectric properties of Bone cancellous tissues using 3-pole Debye parameters to be optimized

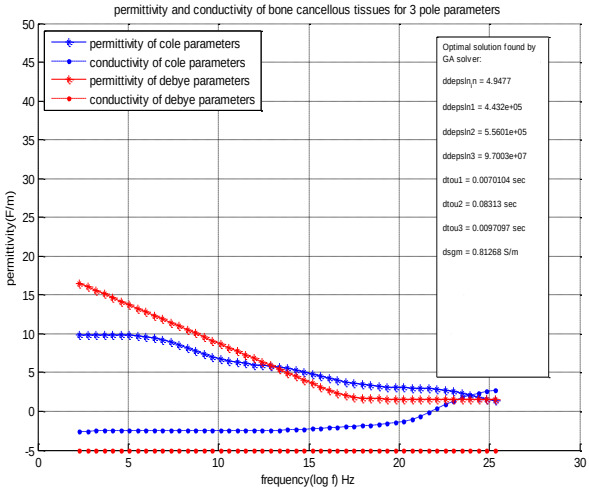

Figure 1(b) Dielectric properties of Bone cancellous tissues using 3-pole Debye parameters after optimization with the parameters given by Genetic Algorithm solver

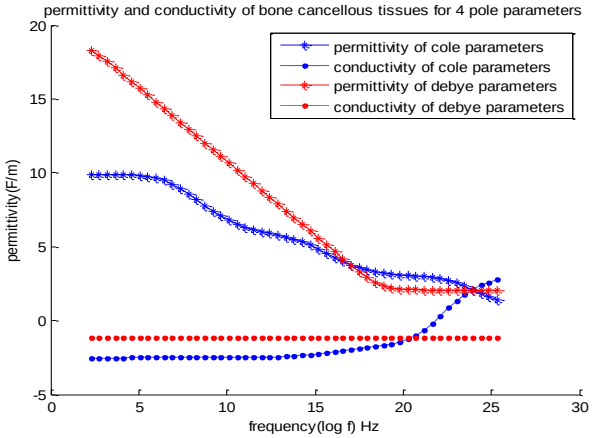

Figure 2(a) Dielectric properties of Bone cancellous tissues using 4-pole Debye parameters to be optimized

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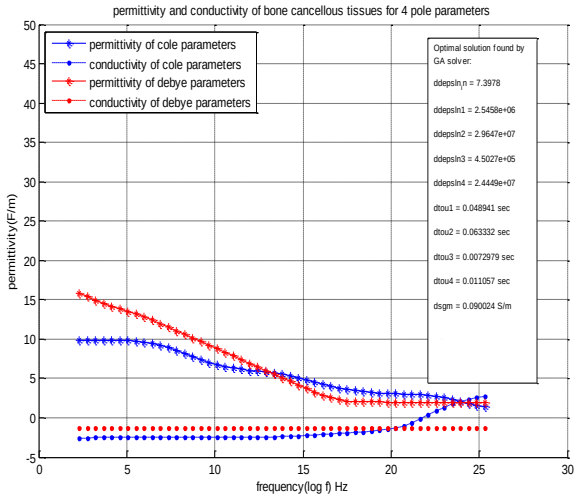

Figure 2(b) Dielectric properties of Bone cancellous tissues using 4-pole Debye parameters after optimization with the parameters given by Genetic Algorithm solver

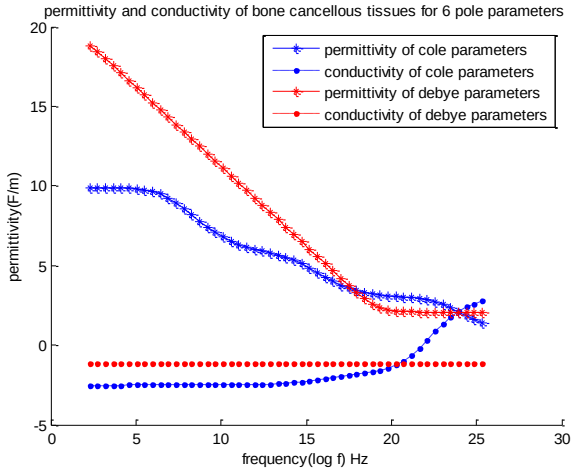

Figure 3(a) Dielectric properties of Bone cancellous tissues using 6-pole Debye parameters to be optimized

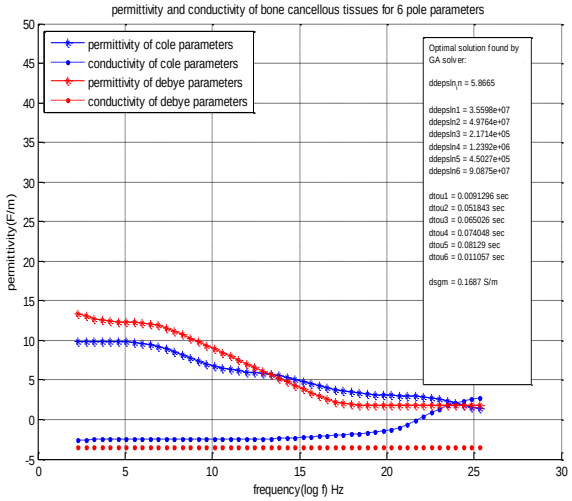

Figure 3(b) Dielectric properties of Bone cancellous tissues using 6-pole Debye parameters after optimization with the parameters given by Genetic Algorithm solver

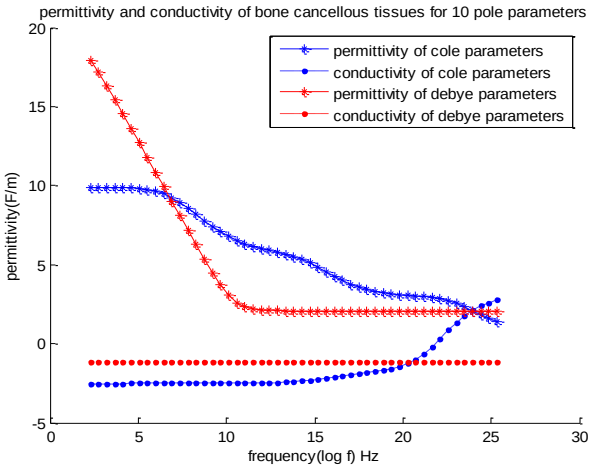

Figure 4(a) Dielectric properties of Bone cancellous tissues using 10-pole Debye parameters to be optimized

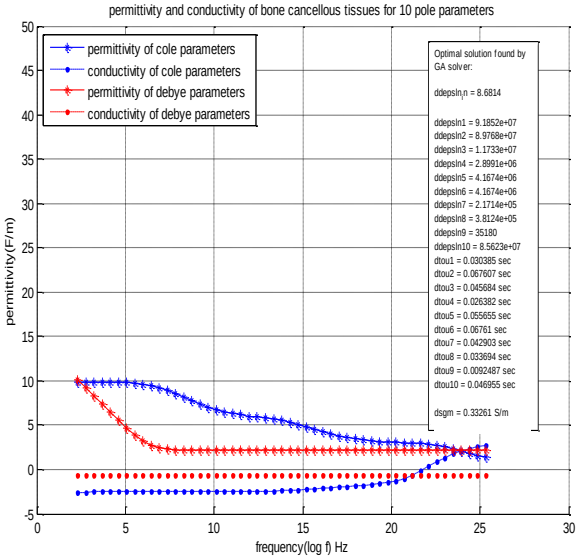

Figure 4(b) Dielectric properties of Bone cancellous tissues using 10-pole Debye parameters after optimization with the parameters given by Genetic Algorithm solver

4. CONCLUSION

In this paper the parameters of multi-pole Debye model for the tissue dielectric properties have been optimized and the best parameters have been chosen using Genetic Algorithm. This optimization is done by comparing the population among the ranges of the Debye parameterswith the Cole model using standard Gabriel Cole parameters.

This process is repeated for different poles of Debye model of tissue dielectric properties such as 3, 4, 6 and 10. Thus the best values of parameters have been optimized to fit the multi-pole Debye model for the dielectric properties of biological tissues. Hence, the best values of Debye parameters for 3, 4, 6 and10 poles for the tissues of bone cancellous have been optimized.

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BIOGRAPHY

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