OPTIMIZATION OF MULTI-POLE DEBYE FUNCTIONS FOR ELECTROMAGNETIC TISSUE MODELING

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Abstract

In this study we have used four algorithms to optimized multi-pole Debye parameters using Gabreil model [1] for 54 different body tissues for a wide frequency range from 500MHz to 10GHz. *and have produced best optimized parameter values.*

1. Introduction

The dielectric properties -- permittivity and conductivity-- have strong frequency dependencies and they vary by many orders of magnitude at frequencies up to microwave band. Multi-pole Debye is most widely used parametric model for the calculation of dielectric properties of tissues. This model can be easily expressed both in time and frequency domain and therefore, can easily be used with the Finite Difference Time Domain (FDTD) method which is a powerful tool to simulate the propagation of electromagnetic signals.

The complex relative permittivity $\hat{\varepsilon}$ is defined as

$$\hat{\varepsilon} = \sum_{i=1}^{n} \frac{\Delta\varepsilon_i}{1 + j\omega\tau_i} + \frac{\sigma_s}{j\omega\varepsilon_0} \qquad (1)$$

2. Optimization Algorithms

2.1 One Stage Genetic Algorithm

The design of GA used in this study is based on the work of Clegg et. al [2]. The cost function C_{GA} to be minimized by GA in Clegg's work was the sum of the squared differences and is given by the equation

$$C_{GA} = \sum_{f=10\times 2^0}^{f=10\times 2^{33}} \left(\log_{10}(c_f(f)) - \log_{10}(d_r(f))\right)^2 + \left(\log_{10}(c_i(f)) - \log_{10}(d_i(f))\right)^2 \qquad (2)$$

Where $d_i(f)$ and $d_r(f)$ are the imaginary and real parts of the Debye model at frequency *f*, and $c_r(f)$ and $c_i(f)$ are the real and imaginary parts of Cole-Cole model.

2.2 Two Stage Genetic Algorithm

Finn et. al [4] developed a two stage GA using two distinct cost functions. First a logarithmic cost function which is same as described in Eq. (2). Once the GA fails

$$C_{GA} = \sum_{f=10\times 2^0}^{f=10\times 2^{33}} \left|\frac{c_{r(f)} - d_{r(f)}}{c_{r(f)}}\right| + \left|\frac{c_{i(f)} - d_{i(f)}}{c_{i(f)}}\right| \qquad (3)$$

to decrease the cost function output by more than 0.1% in the previous 100 generations, a linear cost function (3) is used to further minimize the function.

2.3 Non-Linear Least Squares Algorithm

The same logarithmic cost function (2) is used with same number of poles as in above two cases.

2.4 Weighted Least Squares Algorithm

Masafumi modified the least squares procedure by introducing a weight factor which facilitates the control where to place more weight to enhance the accuracy. The weight factor was modified permittivity $\boldsymbol{e_\iota} \approx \{\dot{\hat{\boldsymbol{\varepsilon}}}(\boldsymbol{\iota})\}^{\xi}$ with $\xi = 0.75$.

3. Results

The results have shown that two stage GA has outperformed other algorithms.

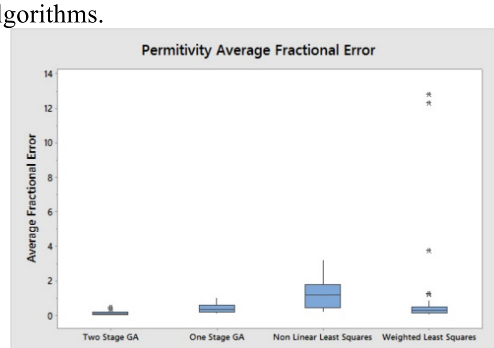

Fig. 1. Box plot illustrating the permittivity average fractional error of 54 tissue types by all four algorithms.

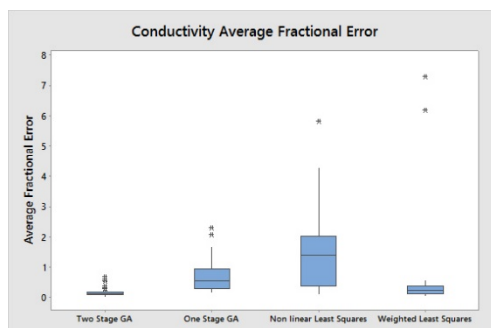

Fig. 2. Box plot illustrating the conductivity average fractional error by all four algorithms for 54 tissue types.

4. References

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