Fourth Order Debye Model for the Skin at the Millimetre-Wave Band Using Heuristic Genetic Algorithm

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Abstract – **As an initial step towards developing a portable diagnostic system for skin cancer, an optimum fourth order Debye model for the human skin at millimetre-wave band is presented. The model is obtained using heuristic genetic algorithm, which enables the precise estimation of the dispersive nature of the human skin tissue when irradiated at a high frequency band of 10 GHz to 45 GHz. The precise derivation of the realistic skin model, having frequency dependent electrical properties, is essential for monitoring electromagnetic wave propagation and scattering in the simulation environment. The reported study indicates that the proposed model yields superior fitting to experimental results (error = 8.9e-4) compared to the existing first order Debye model (error = 5e-3) for the band in consideration.**

Index Terms — **Skin cancer, microwave imaging, millimetre-wave imaging, genetic algorithm**

1. Introduction

Millimetre-wave (MMW) and microwave imaging have been increasingly considered as a feasible solution for numerous medical applications such as skin abnormality characterization [1], [2]and brain tumour detection [3], [4], [5]. According to the latest survey [6], two out of every third Australian is at risk of being diagnosed of skin cancer by the time they reach an age of 70 years. Each year, above 434,000 people are being diagnosed with multiple categories of skin cancer. Therefore, the early detection of skin cancer is essential for reducing the rising fatality rate.

To test new systems or algorithms, a realistic simulation environment with a credible skin model is needed. The conventional Cole-Cole method is computationally complex when implemented with finite difference time domain (FDTD) technique [7], [2]. The skin property characterization at MMW band was performed by Gabriel [8] and Hwang [9] using Cole-Cole method, while Gandhi [10] and Alekseev [11] employed the first order Debye method to estimate the electrical properties of biological tissues. To develop a precise model of electromagnetic wave propagation in the skin tissue, it is necessary to develop an accurate representation of the frequency dependent electrical properties of the skin. In this paper, a fourth ordered optimized Debye model is preferred to integrate dispersion into the analysis. The optimization is performed using Genetic algorithm [12], [13]. The derived model in this study is compared with the available measured values and literature results. The comparison points out that the proposed higher order Debye model results in extremely low error across the investigated band. This precision will ensure building realistic simulation environment in future analysis.

2. Optimization Using Genetic Algorithm

To derive an accurate model for the skin, genetic algorithm is utilized. Genetic Algorithm (GA) is a type of evolutionary computing in which simulation of the natural selection is performed such that the search mechanism yields superior off-springs by selecting best properties from each parent. The fundamental notion behind this algorithm is to retain a quantity of chromosomes which provide optimum solution to the problem at hand by utilizing a controlled iterative stochastic process. In terms of optimization, the purpose of utilizing GA in this paper, is to develop a suitable individual vector that reduces objective function to the least possible value. The complex relative permittivity ε_r, is a function of frequency w, upper bound permittivity ε_∞, optical permittivity $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m, static conductivity σ_s, four dispersion permittivities $\Delta\varepsilon_n$ and relaxation times τ_n where $w\tau_n << 1$. Debye relaxation equation [12] for order $n = 4$ is expressed as:

$$\varepsilon_r = \varepsilon_\infty + \sum_{n=1}^{4} \frac{\Delta\varepsilon_n}{1 + jw\tau_n} + \frac{\sigma_s}{jw\varepsilon_0} \quad (1)$$

$$\epsilon = \frac{\sum_{k=1}^{F} \left[\frac{\varepsilon_e(w_k) - \varepsilon_d(w_k)}{median[\varepsilon_d(w)]}\right]^2 + \sum_{k=1}^{F} \left[\frac{\sigma_e(w_k) - \sigma_d(w_k)}{median[\sigma_d(w)]}\right]^2}{F} \quad (2)$$

Using GA, initial set of individuals are generated randomly and the acquired results are compared with experimental results of Gabriel [8] using (2). In (2), $\boldsymbol{F}$ is the total number of discrete frequencies, $\boldsymbol{\varepsilon_e}$ and $\boldsymbol{\sigma_e}$ are obtained from experimental data while $\boldsymbol{\varepsilon_d}$ and $\boldsymbol{\sigma_d}$ are the evaluated fourth ordered Debye permittivity and conductivity. Subsequently, individual parameters $[\varepsilon_\infty, \varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4, \boldsymbol{\tau_1}, \boldsymbol{\tau_2}, \boldsymbol{\tau_3}, \boldsymbol{\tau_4}, \boldsymbol{\sigma_s}]$ for the envisaged model are updated at each iteration till an optimum solution is obtained. The optimization results of fourth order Debye model indicate exceptional fitness to measured data of [8] while the conventional first ordered Debye model fitted with a considerable variance at initial frequencies. Table 1 presents derived Debye parameters for skin obtained after the iterative GA process.

TABLE I
Fourth Order Debye Model Parameters for Skin Tissue

ε_∞	$\Delta\varepsilon_1$	$\Delta\varepsilon_2$	$\Delta\varepsilon_3$	$\Delta\ \varepsilon_4$ e+3	τ_1 (ps)	τ_2 (ps)	τ_3 (ns)	τ_4 (μs)	σ_s
4.2	27.3	11	28	62.56	6.3	0.35	1.24	50.6	0.1

GA fitness relies on initial definition of linear and non-linear constraints for individual parameters. This assignment results in random creation of first generation parent individuals within the pre-defined range. The variable set is utilized to evaluate minimum of objective function in (2). The generation created at the first stage is ranked on basis of previously calculated objective function. This means that set of variables giving minimum objective function are ranked first for each generation. Subsequently, an iterative loop is initiated for which the simulation time and rapid derivation of optimal solution is based on the computational capability of system. The iteration number is kept around 150 to ensure the algorithm is not trapped in local minima. This is followed by execution of a stochastic tournament called selection, for which the probability is set to 0.8. Individual parameters compete with each other by generating random numbers between 0 and 1. If the generated number is more than the predefined probability, the entire individual is selected for further processing. The selection probability is kept high in order to ensure that only the best parent individuals are selected for the next process. Crossover process is significant for extracting enhanced information from each parent and transferring to offspring individual. For this reason, a probability of 0.6 allows good quality parent individual characteristics to be transferred to the next generation. The mutation process happens rarely, therefore the probability is set to 0.01. It can either create the best solution from the worst parents or vice versa. The global solution is chosen after comparison of all best local minima. Finally, the best global solution is updated and is displayed as the optimum solution obtained from the algorithm.

3. Simulation Results

The optimization process was performed by building an efficient MATLAB code which, after simulating crossovers and mutations, was able to generate best possible individuals for each generation. Fig. 1 and Fig. 2 illustrate comparison of optimized fourth order Debye model relative permittivity and conductivity with measured results of [8] and first order Debye model results of [11] at a frequency range of 10 GHz to 45 GHz. The results indicate that there is a notable difference between the first order Debye model compared with experimental results [8] with an error of 5e-3 across the entire frequency range under consideration. On the other hand, the obtained results using the derived model in this study provide excellent fitting with an error of 8.9e-4 for the entire frequency range under consideration.

4. Conclusion

A fourth order Debye model for the human skin has been presented. The model was derived using heuristic genetic algorithm, which enables precise estimation of the dispersive nature of human skin tissue when irradiated at millimetre wave frequency band of 10 GHz to 45 GHz.

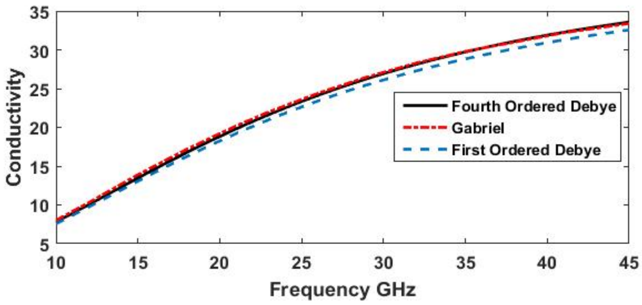

Fig. 1. Comparison of fourth ordered Debye model for the permittivity with the literature and measured results

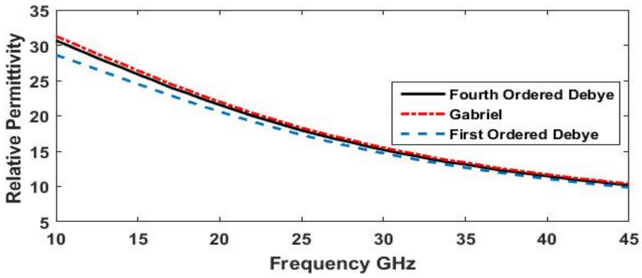

Fig. 2. Comparison of fourth ordered Debye model for the conductivity with existing and measured data.

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