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An (FD)^{2}TD Approach for Ultra-Wideband Analyses Including Biological Bodies

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This paper presents a new implementation of frequency-dependent finite-difference time-domain ((FD)^{2}TD) method for ultra-wideband analyses including biological bodies. Biological tissues were empirically found to be well represented by four Cole-Cole relaxations. However, in order to incorporate the Cole-Cole expression into the FDTD method, formulation of fractional derivatives in the time domain is required, which raises the complexity and computational burden. In this paper, a new implementation of an (FD)^{2}TD method applying the fast inverse Laplace transform (FILT) and Prony's method is proposed and validated by comparison with analytical Mie's results for scattering problem including homogeneous and multilayer dielectric spheres. Finally, some examples of numerical exposures due to ultra-wideband electromagnetic pulses are demonstrated.

In the proposed method, the FILT is utilized to transform the Cole-Cole expressions in a frequency domain into the impulse responses in the time domain and Prony's method is then applied to find their z-domain representations. It was found that any Cole-Cole model can be expressed as a sum of the Debye relaxations in the z-domain as [1]

$$\chi_i(z) = \sum_{l=1}^{L_i} \frac{A_l^{(i)}}{1 - p_l^{(i)} z^{-1}}, \tag{1}$$

where L_i is the number of real poles for the i^{th} relaxation (i = 1, 2, 3, or 4) of biological tissues. Note that the number of real poles, determined by Prony's method, for each relaxation term may be different. $A_l^{(i)}$ and $p_l^{(i)}$ are the coefficients for each Debye pole. It should be also noteworthy that $A_l^{(i)}$ and $p_l^{(i)}$ depend on the time step interval, meaning that we need to recalculate $A_l^{(i)}$ and $p_l^{(i)}$ if the time step interval is changed. The FDTD formulation for the update of the electric field is then directly derived by using the z-transformation.

In order to demonstrate the validity of the proposed method, numerical analyses of homogeneous and multilayer spheres, having dielectric properties represented by four Cole-Cole relaxation terms, illuminated by an EM pulse were performed. It was found that the analytical Mie's solutions in the time domain, which were determined by the inverse Fourier transform of the Mie's solutions in the frequency domain, were in good agreement with numerical results obtained by the proposed (FD)^{2}TD method. Electric field distributions at frequencies ranging from 10 MHz to 1 GHz were compared with those of the Mie's solution. As a result, numerical results closely matched Mie's solutions over a wide range of frequencies, demonstrating the effectiveness and validity of the proposed method.

Next, numerical dosimetry of a human head exposed to an EM pulse was performed. The human head model was extracted from the Japanese male model "TARO" developed by the National Institute of Information and Communications Technology. The maximum specific energy absorption (SA) was approximately 3.97 x 10^{-14} J/kg when a Gaussian pulse with an E-field magnitude of 1 V/m is illuminated. It was also found that most of the pulse energy was absorbed at the skin and the tissues just beneath the skin, and a small part of the energy was also absorbed at deep tissues, such as cerebral spinal fluid. In conclusion, it has been demonstrated that the proposed (FD)^{2}TD method can fully take into account the dispersion characteristics of biological media.

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1. Jerdvisanop Chakarothai, Soichi Watanabe, Kanako Wake, "Numerical dosimetry of electromagnetic pulse exposures using FDTD method," *IEEE Trans. Antennas Propagat.*, vol. 66, no. 10, pp. 5397-5408, Oct. 2018. doi: 10.1109/TAP.2018.2862344