HUMAN ORGANS DOSIMETRY FOR TRANSIENT ELECTROMAGNETIC FIELDS

M. Mrozowski, M. Okoniewski, E. Okoniewska and M. A. Stuchly
Department of Electrical and Computer Engineering
University of Victoria, Box # 3055, Victoria, B.C., Canada V8W 3P6

Abstract

A fast, flexible and accurate technique for evaluation of the induced electric fields and SAR in various organs and tissues of the human body is presented for exposure to arbitrarily long transient fields. The technique reduces the simulation times by several orders of magnitude as compared with previously used techniques, such as the finite-difference time-domain technique (FDTD). The computational efficiency and speed are obtained by building a parametric digital filter model of the object-transient field interaction. Very small errors have been demonstrated for transients having vastly different spectral composition from the pulse used to obtain the model.

Introduction

Quantification of interactions of electro-magnetic fields with the human body and health protection standards, e.g. [1], are based on the tissue induced electric field and the specific absorption rate (SAR). These quantities can and have been computed previously by various techniques for any selected single frequency [2]. Only limited amount of work has been done on dosimetry of pulsed or transient fields [3]. Convolution and the impulse response have been used to compute the induced currents in the layers of the human body [4]. The approach taken in this work is aimed at maximizing the computational efficiency and accuracy of computations.

Methods of Analysis

Three distinct novel techniques have been developed and are presented in this work. The dispersive properties of the tissue have to be taken into account in simulations for wide-band fields. A new algorithm has been developed to represent tissue complex permittivity accurately and in a manner compatible with the FDTD. The available literature does not contain data on the dielectric properties of the dispersive biological tissues that can directly be used in FDTD calculations. Recently, new wideband (10 Hz - 100 GHz) models have been created [5] based on extensive experimental data collected. The model uses the 5 term Cole-Cole representation of the frequency dependent relative permittivity. A frequency domain system identification procedure in Matlab was used to find the rational function representation of the complex permittivity corresponding to the Debye representation. Secondly, a new more efficient implementation of the dielectric dispersion in the FDTD was developed [6]. The formulation is based on the auxiliary differential equation, but requires fewer operations and is more general than previously developed schemes. This is obtained through a reformulation of the ADE method in such a way that the solution of the system of linear equations is not required.

The creation of the parametric model from the FDTD simulation is based on the idea of the time-domain system identification. This approach is analogous to a classical time-domain system identification problem where the transfer function of an unknown linear system is reconstructed from the time signatures of the input and output signals sampled at a given rate. The parametric model constructed in such way is a digital filter. In this work, we implemented a non-orthogonal zero-pole filter, and orthogonal filters using the Laguerre and Kautz-Laquerre basis.

0-7803-4603-6/97/$5.00 (c) IEEE

Results

The parametric implementation of the dispersion model was performed for 16 tissues in the frequency range of 1-250 MHz. For three terms in the Debye model the maximum absolute difference at any frequency between the model and the permittivity measurement data was not greater than 15% for both the dielectric constant and the loss factor for 17 different tissues modeled.

The dispersion algorithms for the FDTD were evaluated by measuring the absolute errors in the magnitude and phase of a uniform plane wave (TEM) incident on the medium from free space. For Debye media the magnitude of the reflection coefficient was below 0.1% for frequencies from a few MHz to 60 GHz, and the phase error was below 0.007 radian up to 60 GHz (the phase error increases monotonically with frequency). At the same time the memory requirements and speed were significantly improved compared to previously published ADE schemes.

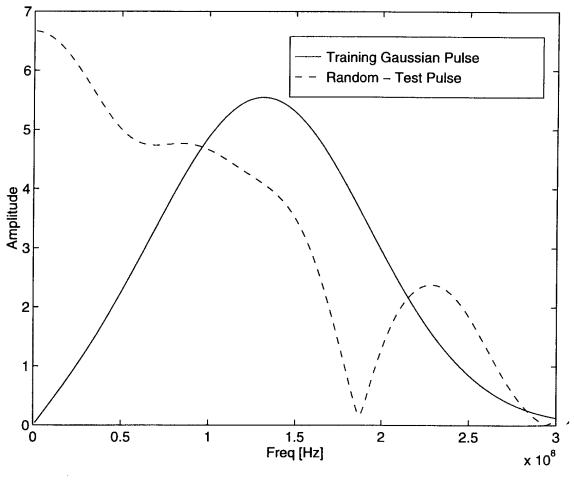

Fig. 1 Spectral composition of the training and test pulses.

Performance of the parametric filter model was tested on two examples, a relatively simple heterogeneous object consisting of three selected tissues arranged as intercepting spheres and parallelepipeds and an anatomically correct model of a human body. Only the latter will be discussed here. A model of the human body was developed based on segmentation of the Magnetic Resonance Images (MRI). The original resolution of the model was 3.6 mm, but resolution of 10 mm was used in the computations presented here. The height of the model was 1.77 m and estimated weight 76 kg. The overall quality of the model was verified using data visualization software Data Explorer (product of IBM).

In this initial test we selected only two organs for modeling (but the method can be extended to an arbitrary number of organs of interest), namely the liver and heart. A Gaussian excitation with the spectral content shown in Fig. 1 was selected for construction of the parametric model. A full scale FDTD simulation was performed for the time and bandwidth limited excitation and a relatively short simulation time. Because of the significant oversampling in the FDTD, the recorded sequences of the response (in selected locations) and the excitation were desampled by a factor of 44, and used for "training" the filters. The filters were tuned in the bandwidth 20 - 260 MHz. The least square technique was used to find the filter coefficient of a selected order. Once the filter coefficients has been found, the quality of the model is tested with the input "tuning" sequence by comparing the filter output with the recorded output training sequence. Thus optimized and validated filter coefficients are saved. After this, the parametric model is ready for use. We tested its performance by computing the error in response for a randomly selected transient also shown in Fig. 1. A very different composition of this transient signal from the training pulse can be noted.

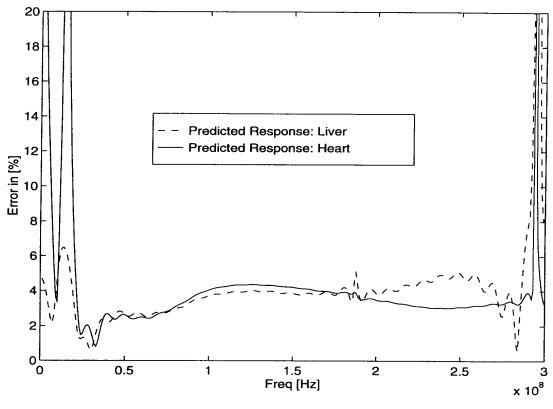

Fig. 2 The maximum error in any electric field component obtained for the text pulse for two organs as a function of frequency.

Figure 2 gives the maximum response error in any electric field component. This error is below 5% except at the very edge of the low frequency range, and where the frequency content of the transient is nearly zero (approx. 190 MHz). The errors for the energy density and SAR are below 0.5%. Further improvement in the performance can be obtained by using a training pulse with a more uniformly distributed energy within the band of interest.

Conclusions

We developed a more advance and accurate technique than has been previously reported for rapid evaluation of the electric fields and SAR in the human body [4], specifically organs and specific locations within them. The addition of new algorithms for simulations of dispersive biological tissues to the FDTD code resulted in acceleration of this code. But the major innovation and tremendous increase in the computational efficiency and accuracy in dosimetry of transient electromagnetic fields was achieved through development and optimization of a parametric digital filter model.

References

[1] ANSI C95.1-1992, "American National Standard safety levels with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 100 GHz", The Inst. Electrical & Electronics Engineers, New York, 1991.

[2] Lin, J.C. and O.P. Gandhi, "Computational methods for predicting field intensity", Handbook of Biological Effects of Electromagnetic Fields (2nd Ed.), Editors: C. Polk and E. Postow, Chapter 9, pp. 343-402, 1996.

[3] Furse, C.M., J-Y. Chen and O.P. Gandhi, "The use of the frequency-dependent finite-difference time-domain method for induced current and SAR calculations for a heterogeneous model of the human body", *IEEE Trans. Electromagnetic Compatibility*, Vol. 36, #2, pp. 128-133, 1994.

[4] Chen, J-Y., C.M. Furse and O.P. Gandhi, "A simple convolution procedure for calculating currents induced in the human body for exposure to electromagnetic pulses", *IEEE Trans. Microwave Theory and Techniques*, Vol. 42, #7, pp. 1172-1175, 1994.

[5] Gabriel, S., R.W. Lau and C. Gabriel, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues", *Phys. Med. Biol.*, Vol. 41, pp. 2271-2293, 1996.

[6] Okoniewski, M., M. Mrozowski and M.A. Stuchly, "Simple treatment of multi-term disperson in FDTD", accepted for publication in *IEEE Microwave and Guided Wave Lett.*, Vol. 7, 1997.