Human Head Modelling at Microwave Frequencies Using Open-Source Electromagnetics Solver

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***Abstract*— A computational electromagnetics platform that can be used to study interactions between electromagnetic fields and human tissues is presented. The developed platform uses pre-existing triangle-represented geometry models and associated dielectric properties to create a finite-difference time-domain (FDTD) computation environment beyond the open-source MATLAN toolbox. Compared with most commercial simulation platforms, the presented platform provides a highly-transparent user interface to solve the complex electromagnetic scattering problems with adjustable texture resolution based on the skin depth value. Furthermore, the open-source functions under this platform can be easily integrated with other external MATLAB programs to conduct an algorithm-controlled computational project. As an example of the presented platform, the modelling and simulating of microwave signals propagation and scattering in a realistic human model are explained.**

Keywords*— *Computational electromagnetics; finite difference time domain; mobile devices; electromagnetics-tissues interaction.

I. Introduction

Understanding the interaction between electromagnetic (EM) fields and the human tissues has been of great interest for years [1-3]. In particular the accurate analysis of EM propagation and scattering due to the human head is significantly valuable for evaluating the biological effects of wearable or hand-held microwave devices for 4G/5G mobile communications (Fig. 1 a). Depending on the used microwave frequency in those devices as well as the specified problem under analysis, different levels of accuracy are required to figure out the electromagnetic field distributions in the head phantom. In general, the over-simplified EM models, such as [4], are no longer applicable to provide sound solutions. Therefore, EM modelling that includes a reasonable details of the human head tissues must be employed to accomplish the accurate analysis.

A human head is composed of many dielectric dispersive tissues, such as skin, skull, fat, dura, cerebral spinal fluid (CSF), grey matter, white matter and blood. The internal structure of a typical head phantom can been seen in Fig. 1. The field analysis in such a geometry-sophisticated model requires using the integral-based method of moments (MOM), finite-element method (FEM) or the finite difference time domain (FDTD) method [4]. Considering that FDTD can simultaneously simulate, accurately, a large bandwidth with lowest computation time, FDTD is the most straight forward approach for head/EM interaction.

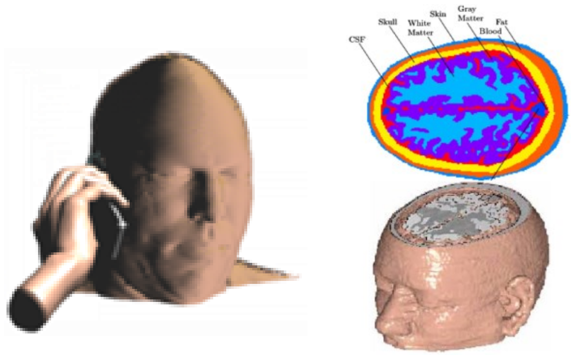

Fig.1 Physical model of EM/head interaction. (a) Biological effect of hand-held microwave devices, and (b) transverse slice of the head.

Undeniably, most head analysis platforms developed beyond commercial software packages have some restrictions and shortcomings. However, the commercial EM simulation packages require expensive licence, which might not be accessible to many who are not specialized in RF/microwaves. Also, the commercial software packages always lack transparency and flexibility to reconfigure its EM solver to balance between the calculation accuracy and time efficiency. Moreover, the EM solver cannot easily be integrated or embedded with other user-defined algorithms, which are always designed to adjust the microwave structure, monitor the simulation process, and perform different types of optimizations. On the other hand, some industrial/academic institutions carried out their own version of full-wave simulator on C++/MATLAB platform without using third party packages (such as [5]). However, those platforms are limited to certain scenarios, such as for 2D analysis.

In this paper, a full-wave FDTD-based head simulation platform developed on the open-source MATLAB toolbox (so called openEMS) is presented. The platform provide a highly-transparent user interface with adjustable texture resolution derived from skin-depth value. Meanwhile, it can be easily integrated with external program to conduct an algorithm-controlled computational project.

II. Skin-depth based Simulator on OpenEMS

OpenEMS is a free and open electromagnetic field solver using the FDTD method, it is developed as a free toolbox in MATLAB scripting interface [6]. Beyond the functions provided from openEMS, a wide range of pre-existing voxel-based geometry, including biological tissues, can be imported into the simulation interface. In order to balance the calculation accuracy and time efficiency of the simulator at frequency above 2.0 GHz, the penetration depth of signals should be considered to avoid any insignificant computation in deep head phantom. At microwave frequencies, the penetration depth (δ) is inversely proportional to the operating frequency (f) [7]:

$$\delta = \sqrt{\frac{\rho}{\pi \varepsilon_{avg} f}} \qquad (1)$$

where, ρ is the average resistance of the head model, ε_{avg} is the average permittivity value of head tissues. Obviously, the intensity of the electromagnetic field beyond this depth is weak and decaying; it has a negligible effect to the field outside the head model. Thus, in this scenario, the simulation of the fields in tissues deeply placed inside the head phantom is not very significant.

In this research, the pre-existing datasets, so called the .stl file, is used to establish the 3D head geometry. The .stl datasets is a triangulated representation of a CAD model, it provides the advantage of classifying the tissue type (index) according to its depth level in an easy manner. In terms of the calculated skin depth (δ) from (1), the tissue index beyond the depth level can be discarded when conducting the simulation internally. Thus, the imported tissue index with maximum depth level can be simplified as an ABC boundary condition.

III. Simulation Result and Comparison

As an example of running this developed platform, a male head phantom is imported using the dataset from [8]. Also, a hand-held communication device operates over 2.4 GHz to 3.6 GHz is employed as the radiation element around the head model. The tissues beyond the depth level ($\delta = 80\ mm$) are configured as absorptive material with ABC (absorbing) boundary. As shown in Fig. 2, the interactive CSXCAD interface displays the entire geometry to be simulated as well as its mesh configurations.

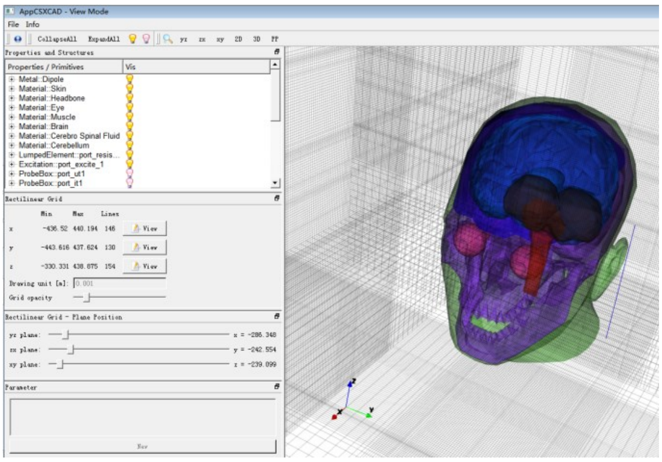

Fig. 2 CSXCAD interactive interface display showing the entire geometry to be simulated and its mesh configurations.

The processing of this simulation on a 4-core CPU cluster takes about 20 minutes to achieve a -50 dB iteration accuracy, and calculate the feed impedance and reflection coefficient of radiation element in both time and frequency domain. As illustrated by Fig. 3, the E-field distribution inside the head phantom on x-y and y-z plane are recorded and stored.

For the purpose of verifying the correctness of the FDTD simulation, the same environment (head phantom and radiation element configuration) is re-simulated using the commercial software package ANSYS HFSS (v.15). The E-field distribution in HFSS as shown from Fig. 4 agrees well with the calculated distribution using the open-source simulation platform and confirms its reliability.

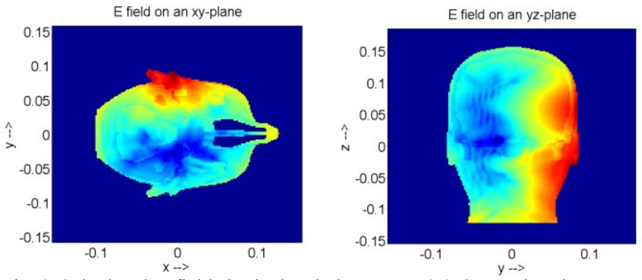

Fig. 3 Calculated E-fields in the head phantom at 3.0 GHz using the proposed platform. (a) x-y plane (b) y-z plane

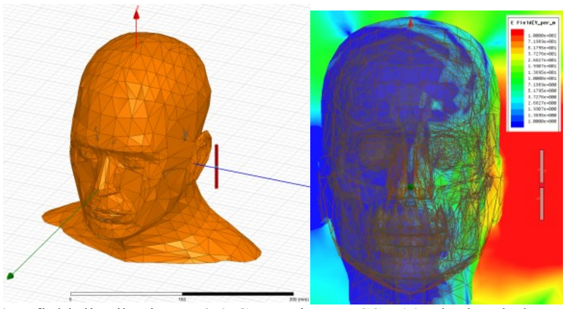

Fig. 4 E-field distribution at 3.0 GHz using HFSS. (a) The head phantom to be simulated and (b) the E-field distribution in y-z plane.

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