An FFT-Accelerated Multiregion Integral-Equation Method for Analyzing Antennas Implanted in Anatomical Human Models

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Antennas implanted inside the human body encounter highly inhomogeneous, dispersive, and variable near-field and propagation environments. While simplified human models/phantoms are often used to represent the antenna environment, the increasing fidelity and availability of anatomically accurate human models (J. W. Massey *et al.*, 34th Annu. Conf. BIOEM Soc., June 2012) promises to enable more predictive analysis and more effective site-specific designs of implanted antennas. Simulating the radiation from antennas embedded inside anatomical human models, however, is challenging. This is because (i) high-fidelity human models, which can comprise over 100 million voxels, give rise to large scale problems, (ii) antennas often contain thin good conductors and curved geometries that are positioned/oriented arbitrarily relative to the human model, and (iii) the human body and implanted antennas must be modeled jointly and meshed consistently. Because parametrized surfaces are generally unavailable for pixel-based human models, joint modeling requires removing voxels in the sites occupied by antennas, inserting antenna meshes in these volume, and connecting/matching the (geometrically intricate and potentially unstructured) antenna meshes with the (inflexible) voxel mesh of the body such that there are no unphysical gaps. Traditional methods, including the finite-difference time-domain method and single-region integral-equation methods (F. Wei, A. E. Yılmaz, ICEAA, Sep. 2012), become ineffective because they require the transition regions between the antennas and the surrounding tissues to be meshed and these meshes to conform to both the antenna and tissue meshes.

Recently, a multi-region integral-equation method was proposed for analyzing implanted antennas (J. W. Massey *et al.*, USNC/URSI Rad. Sci. Meet., July 2015). A major advantage of the method is that the transition region between the antenna and human body is not meshed, which allows antennas to be implanted at arbitrary locations and orientations (as long as they are inside a single tissue). The approach is similar to that used for composite materials (B. C. Usner *et al.*, IEEE Trans. Antennas Propag., 56, 68-75, Jan. 2006): Internal and external equivalent problems are formulated by placing electric and magnetic surface currents tangential to the outer boundary of the transition regions. The problems are coupled at the boundaries and solved simultaneously for surface/volume unknowns on/in the antenna model, surface unknowns on the outer boundaries of transition regions, and volume unknowns in the human body. In this article, the method is accelerated by an FFT-based algorithm, the multiple-grid adaptive integral method (M.-F. Wu *et al.*, IEEE Trans. Antennas Propag., May 2010), which uses a different auxiliary regular grid for each of the equivalent problems. Two alternatives are used for coupling the equivalent problems: (i) the PMCHWT formulation that combines electric- and magnetic-field integral equations and (ii) the JMCFIE formulation (P. Yla-Oijala, M. Taskinen, IEEE Trans. Antennas Propag., Mar. 2005) that combines electric- and magnetic-current type combined-field integral equations. The performance of the two approaches will be contrasted for various UHF-band antennas implanted in AustinMan and AustinWoman models at the meeting.