A Multiregion Integral-Equation Method for Antennas Implanted in Anatomical Human Models

Jackson W. Massey*, Fangzhou Wei, and Ali E. Yılmaz
Department of Electrical and Computer Engineering
The University of Texas at Austin, Austin, TX 78712, USA

To aid the design of power- and spectrum-efficient implanted antennas, efficient computational methods that can account for the presence of nearby inhomogeneous and dispersive human tissues are needed. While layered planar or spherical tissue models are often used to represent the antenna environment, the increasing fidelity and availability of anatomical human models can enable site-specific modeling, more accurate analysis, and better designs. Simulating radiation from antennas near/on/in anatomical human models, however, gives rise to large-scale problems as the latest high-fidelity models are composed of over 100 million voxels (J. W. Massey *et al.*, 34th Annu. Conf. Bioelectromagn. Soc., June 2012). Such large problems can be solved by coupling the surface and volume electric-field integral equations and using a preconditioned, parallel FFT-accelerated iterative solver (F. Wei and A. E. Yılmaz, USNC/URSI Rad. Sci. Meet., July 2013). Unlike traditional finite-difference time-domain based methods, this approach (i) does not require the antenna model to conform to a regular grid to avoid staircasing errors and (ii) accurately models complex antennas by using irregular meshes. Moreover, as is the case for integral-equation methods in general, it requires meshing neither free space (to propagate fields) nor an extended computational domain (to truncate the problem with local boundary conditions that approximate the radiation condition); therefore, for antennas outside the body, this approach does not require the region between the antenna and the body to be meshed. For antennas implanted in voxel-based anatomical human models (by removing tissue voxels at the antenna site from the human model and inserting the antenna mesh), however, the method becomes impractical because it requires the transition region between the antenna and human tissues to be meshed such that the mesh conforms to both the irregular (triangular/tetrahedral) antenna mesh and the voxel tissue mesh.

This article presents a multiregion integral-equation approach for analyzing radiation from implanted antennas; similar approaches were used for analyzing scattering from composite materials (B. C. Usner *et al.*, IEEE Trans. Antennas Propag., 56, 68-75, Jan. 2006) and voxel-based head models with smoothed skin (J. W. Massey *et al.*, USNC/URSI Rad. Sci. Meet., July 2014). In this approach, internal and external equivalent problems are formulated by placing electric and magnetic surface currents $\{\mathbf{J}^{\pm},\mathbf{M}^{\pm}\}$ tangential to the outer boundary of the transition region. In the internal-equivalent problem, $\{\mathbf{J}^{-},\mathbf{M}^{-}\}$ radiate (together with currents on/in the antenna) in a homogeneous background with the same material property as the removed tissue. In the external-equivalent problem, $\{\mathbf{J}^{+},\mathbf{M}^{+}\}$ radiate (together with currents in the human body) in free space. As a result, a linear system of equations is formulated in terms of surface/volume unknowns (on triangular/tetrahedral elements) on/in the antenna model, volume unknowns (on voxel elements) in the human body, and surface unknowns (on voxel faces) on the outer boundary of the transition region. A major advantage of this method is that it does not require the transition region to be meshed, allowing antenna models to be easily implanted in voxel-based anatomical human models at arbitrary locations and orientations. At the conference, the utility of the method will be demonstrated for various antennas implanted in the AustinMan and AustinWoman models.