Transient Analysis of Electromagnetic Wave Interactions in Magnetized Plasma using Volume Integral Equations

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Frequency dependent permittivity tensor of a plasma medium can be dynamically tuned using a biasing magnetic field (F. Hunsberger *et al.*, *IEEE Trans. Antennas Propag.*, 40, 1489-1495, 1992). The dependence of the permittivity to the biasing field can be mathematically modeled as a nonlinear relation between the biasing field and the current density. Electromagnetic solvers developed for characterizing magnetized plasma either convert the nonlinear equation into a permittivity tensor for a given frequency using linear approximations or directly use the nonlinear relation as an auxiliary equation to complement the Maxwell equations. The former approach has been usually preferred in frequency domain finite element solvers (G. Torrisi *et al.*, *J. Electromagn. Waves Applicat.*, 28, 1085-1099, 2014), whereas the later approach has been mostly used in finite difference time domain (FDTD) schemes (A. Samimi and J. J. Simpson, *IEEE Trans. Antennas Propag.*, 63, 269-279, 2015). It should be clear here that the later approach has to be implemented within a time domain solver because the nonlinear relation between the biasing field and the current density is employed as it is without any linear approximation.

Among the groups of transient electromagnetic simulators, integral equation solvers offer several advantages over their differential equation counterparts (E. Michielssen *et al.*, in *Proc, ECCOMAS CFD*, 2006). In this work, a time domain volume integral equation (TDVIE)-based scheme is formulated and implemented for analyzing electromagnetic wave interactions in magnetized plasma. The TDVIE provides a relation between the unknown electric field intensity and flux density, and is complemented by the nonlinear relation, which is now expressed in these two unknowns. The proposed scheme expands the field intensity and flux density in terms of half and full Schaubert-Wilton-Glisson (SWG) basis functions, respectively. Inserting these expansions in the coupled system of the TDVIE and nonlinear auxiliary equation, testing the resulting equations at discrete points in time, and using polynomial temporal interpolators to facilitate the computation of retarded-time integrals yield a matrix system of ordinary differential equations. This system is integrated in time using an explicit $\mathrm{PE(CE)^m}$ scheme to yield the unknown expansion coefficients (H.A. Ulku *et al.*, *IEEE Trans. Antennas Propag.*, 61, 4120-4131, 2013). Explicitness of time marching allows for incorporation of the nonlinearity as a straightforward function evaluation; therefore, the resulting marching-on-in-time (MOT) scheme does not call for Newton-like nonlinear solvers.

Numerical examples, which demonstrate the applicability and accuracy of the proposed MOT scheme in analyzing electromagnetic wave interactions in magnetized plasma, will be presented.