Electromagnetic Analysis of Time Varying Media Using Volume Integral Equations

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1. Extended Abstract

Externally controlled electrical properties of materials are a mechanism to realize various types of outputs in electromagnetic and optical systems and devices, such as optical modulation, frequency shifting, and polarization transformation [1]. The external control is oftentimes implemented through a biasing field or an applied pressure that results in a change in dielectric permittivity of an exotic material. This type of material is termed "time varying" medium here.

Among several techniques developed for transient analysis of electromagnetic scattering from time varying media, integral equation solvers offer several advantages over differential equation solvers [2]. In this work, a time domain volume electric field integral equation (TD-VEFIE) solver is developed for this purpose. The solver discretizes the TD-VEFIE in unknown electric flux density $\mathbf{D}(\mathbf{r},t)$ and unknown field intensity $\mathbf{E}(\mathbf{r},t)$, and the time varying constitutive relation between $\mathbf{D}(\mathbf{r},t)$ and $\mathbf{E}(\mathbf{r},t)$, separately. The unknowns $\mathbf{D}(\mathbf{r},t)$ and $\mathbf{E}(\mathbf{r},t)$ in this coupled system of equations are expanded in terms of full and half Schaubert-Wilton-Glisson (SWG) functions in space [3]. Inserting these expansions into the coupled system and testing the resulting equations with the SWG functions yield a matrix system of equations, which is cast in the form of an ordinary differential equation (ODE) in time. The time dependent coefficients of the unknown expansions are computed by integrating this ODE system using a linear multistep method [4]. The resulting time marching scheme calls for solving a system with a Gram matrix at every time step. This can be done very efficiently using an iterative scheme since the Gram matrix is always sparse and well conditioned regardless of the time-step used. Additionally, this approach allows for easy incorporation of the time varying parameters of the constitutive relation in the time marching. It should be noted here that the time retardation in the TD-VEFIE operator is accounted for using approximate prolate spherical wave (APSW) functions as an interpolator between time samples [5]. Additionally, the complex-exponent extrapolation scheme developed in [6] is used to ensure the stability while maintaining the causality of the time marching scheme. Numerical results, which demonstrate the proposed solver's accuracy, efficiency, and applicability, will be presented.

2. References

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