Parallel Higher-Order DG-FETD Simulation of Antennas

(Invited Paper)

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Abstract—A discontinuous Galerkin finite-element time-domain (DG-FETD) code is developed to simulate some interesting and challenging antennas. It incorporates several advanced techniques, such as higher-order tetrahedral elements, conformal perfectly matched layer (PML), and local time-stepping scheme. To further speed up the calculation, the DG-FETD method is parallelized by using Message Passing Interface (MPI).

I. INTRODUCTION

The discontinuous Galerkin finite-element time-domain (DG-FETD) method [1]-[5] is one of the most important time-domain methods for solving complex electromagnetic (EM) problems. The DG-FETD method is not only globally explicit, but also capable of dealing with arbitrarily-shaped and inhomogeneously-filled objects. In this paper, the well-developed DG-FETD code is applied to simulate some interesting and challenging antennas. It involves the implementation of the higher-order tetrahedral element technique [6]-[8], conformal perfectly matched layer (PML) technique [1], local time-stepping (LTS) scheme [4], and parallelization scheme using Message Passing Interface (MPI) [3]. Good numerical results demonstrate the validity and capability of the parallel higher-order DG-FETD method.

II. BASIC FORMULATION

The Maxwell’s curl equations in the non-PML region are written as

\[ \nabla \times \mathbf{E} = -\frac{\mu_r}{c} \frac{\partial \mathbf{H}}{\partial t}, \quad \nabla \times \mathbf{H} = \frac{\epsilon_r}{c} \frac{\partial \mathbf{E}}{\partial t} \]  

(1)

where \( \mathbf{H} = \eta_0 \mathbf{H} \). The boundary conditions is imposed on the interface of elements [1]-[3]

\[ \mathbf{J}_s = \mathbf{n} \times (\mathbf{H}^+ - \mathbf{H}), \quad \mathbf{M}_s = -\mathbf{n} \times (\mathbf{E}^+ - \mathbf{E}) \]  

(2)

Applying the Galerkin’s approach in each element \( V_i \) [1]-[2] and taking advantage of the leap-frog (LF) scheme [2], one can obtain the matrix equations [2]

\[ A_{hhv}(h^{n+\frac{1}{2}} - h^{n-\frac{1}{2}}) = -(A_{hev}e^n + A_{hex}e^{+n}) - b_{hs} \]  

(3a)

\[ A_{evv}(e^{n+1} - e^n) = A_{ehv}h^{n+\frac{1}{2}} + A_{ehs}h^{+(n+\frac{1}{2})} - b_{es} \]  

(3b)

In the simulation, the conformal PML is applied to terminate waveguide. The corresponding differential equations of auxiliary variables \( \mathbf{E}, \mathbf{H}, \mathbf{P} \), and \( \mathbf{Q} \) are given by [1]-[2]

\[ \nabla \times \tilde{\mathbf{E}} = -\frac{\mu_r}{c} \frac{\partial \tilde{\mathbf{A}}}{\partial t} - \mu_r \tilde{\mathbf{A}} \cdot \tilde{\mathbf{H}} - \mu_r \tilde{\mathbf{A}}_3 \cdot \mathbf{P} \]  

(4a)

\[ \nabla \times \tilde{\mathbf{H}} = \frac{\epsilon_r}{c} \frac{\partial \tilde{\mathbf{A}}}{\partial t} + \epsilon_r \tilde{\mathbf{A}}_2 \cdot \tilde{\mathbf{E}} + \epsilon_r \tilde{\mathbf{A}}_3 \cdot \mathbf{Q} \]  

(4b)

\[ \tilde{\mathbf{A}}_5^{-1} \cdot \tilde{\mathbf{H}} - \tilde{\mathbf{A}}_1 \cdot \mathbf{P} = \frac{1}{c} \frac{\partial \mathbf{P}}{\partial t} \]  

(4c)

\[ \tilde{\mathbf{A}}_5^{-1} \cdot \tilde{\mathbf{E}} - \tilde{\mathbf{A}}_4 \cdot \mathbf{Q} = \frac{1}{c} \frac{\partial \mathbf{Q}}{\partial t} \]  

(4d)

where \( \tilde{\mathbf{A}}_j = \tilde{\mathbf{J}}^T \Lambda_j \tilde{\mathbf{J}}, \quad j = 1, \ldots, 5 \). \( \Lambda_j \) are 3 × 3 diagonal matrices. \( \tilde{\mathbf{J}}^T \) is a tensor related to the local coordinate system on the interface between the PML and non-PML regions. Discretizing the above differential equations yields [2]

\[ (A_{hha} + A_{hhb})h^{n+\frac{1}{2}} = (A_{hha} - A_{hhb})h^{n-\frac{1}{2}} - A_{hpb}h^n - (A_{heve}e^n + A_{hex}e^{+n}) - b_{hs} \]  

(5a)

\[ (A_{qq} + A_{qdd})q^{n+\frac{1}{2}} = (A_{qq} - A_{qdd})q^{n-\frac{1}{2}} + A_{qre}e^n \]  

(5b)

\[ (A_{eev} + A_{eeb})e^{n+1} = (A_{eev} - A_{eeb})e^n - A_{eqq}q^{n+\frac{1}{2}} + (A_{ehv}h^{n+\frac{1}{2}} + A_{ehs}h^{+(n+\frac{1}{2})}) - b_{es} \]  

(5c)

\[ (A_{pp} + A_{pdd})p^{n+1} = (A_{pp} - A_{pdd})p^n + A_{ph}h^{n+\frac{1}{2}} \]  

(5d)

The higher-order interpolatory vector basis functions on tetrahedral elements are applied in the above coefficient matrices. The surface magnetic current \( \mathbf{M}_s \) is imposed on the excitation port. The incident electric fields can be found in terms of \( \mathbf{M}_s \). Hence, pre-simulation of uniform waveguide can be avoided [2].

III. NUMERICAL RESULTS

As an example, the Vivaldi antenna shown in Fig. 1 is simulated. This antenna is fed by a shielded microstrip line that is homogeneously filled with the dielectric \( \epsilon_r = 2.32 \). Figs. 2 and 3 show the incident and reflection coefficients in the time domain, respectively. The S-parameters are shown in Fig. 4. Fig. 5 shows the directivity patterns at 10 GHz. The DG-FETD results agree well with the HFSS results.
IV. CONCLUSIONS

This paper presents the simulation of antennas using the parallel higher-order DG-FETD method. The successful simulation of the challenging antennas demonstrates the capability of the DG-FETD method as an important time-domain technique in the computational electromagnetics.

REFERENCES


