A Novel Dipole-Moment Based Hybrid Technique for Numerically Efficient Solution of Multi-Scale Problems

Kapil Sharma
EMC Lab
The Pennsylvania State University
University Park, PA, USA
kxs523@psu.edu

Raj Mittra
Department of Electrical and Computer Engineering
University of Central Florida
Orlando, FL, USA
rajmittra@ieee.org

***Abstract*—In this paper, we present a novel hybrid technique for efficient solution of multi-scale problems in the time-domain. The proposed technique utilizes a dipole-moment (DM)-based Method of Moments (MoM) type of formulation for arbitrarily shaped objects with fine features. Scattered fields are obtained in closed form, and directly in the time-domain at desired observation points on a planar interface, and are combined with Finite-Difference Time-Domain (FDTD) update equations. The time-domain scattered fields computed by using the MoM type of formulation presented herein is stable in its implementation.**

Keywords—Dipole-Moment (DM); Method of Moments (MoM); Finite-Difference Time-Domain (FDTD); time-domain.

I. Introduction

Conventional Method of Moments (MoM) technique [1] requires numerical integration and differentiation of current on scatterer, and does not provide scattered fields in closed form. Additionally, the scattered fields obtained using the conventional MoM technique are not accurate at low frequencies [2]. A universal dipole-moment-based approach [3] has been utilized for solving MoM-type problems to obtain scattered field expressions in closed form. However, the closed-form expressions in [3] do not provide scattered fields directly in the time-domain without Inverse Fourier Transform (I.F.T.) operation, and repeated computations are required at each frequency sample to compute scattered fields over a desired frequency band, thus requiring Inverse Fourier Transform operation to obtain time-domain scattered fields at desired observation point(s).

The paper introduces a novel hybrid technique to analyze multi-scale problems directly in the time-domain. Arbitrarily shaped objects with fine features are handled by using dipole-moment-based MoM type formulation, and electrically large objects are handled by the FDTD technique. The time-domain scattered fields computation using the MoM type formulation is stable in contrast to the computation using the time-domain integral equation technique [4].

II. Novel Hybrid Technique to Handle Multi-Scale Problems

A. *Arbitrarily Shaped Objects and Novel Dipole-Moment Approach*

Arbitrarily shaped objects with fine features are handled by using a novel dipole-moment based MoM type approach in this work, and objects with electrically large features are analyzed by using the FDTD technique, as shown in Fig. 1.

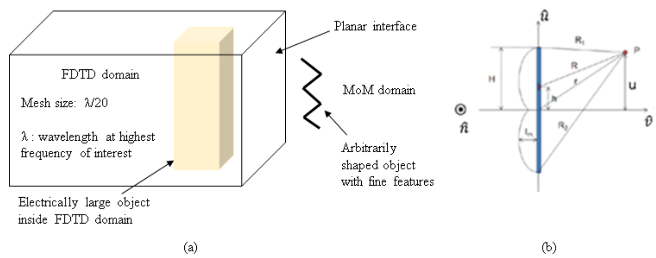

Fig. 1. (a) Proposed hybrid technique problem definition (b) current distribution and geometrical parameters associated with a u oriented dipole moment.

The current distribution along the dipole-moment is given as:

$$I = I_m \sin(\beta(H-h)), h > 0 \tag{1}$$

Weight coefficients for dipole moments corresponding to the current on a section of the object with fine features are found over the desired frequency range using far field matching [5] to obtain *w(f)*, and transformed to the time-domain to obtain *w(t)*.

Time-domain scattered field expressions for a dipole-moment oriented along u are given by (2)-(4).

$$E_u = -30\left(\frac{w(t-\frac{R_1}{c})}{R_1} + \frac{w(t-\frac{R_2}{c})}{R_2} - 2\cos(\beta_0 H)\frac{w(t-\frac{r}{c})}{r}\right) \tag{2}$$

$$E_v = 30\left(\left(\frac{u-H}{v}\right)\frac{w(t-\frac{R_1}{c})}{R_1} + \left(\frac{u+H}{v}\right)\frac{w(t-\frac{R_2}{c})}{R_2} - 2\left(\frac{u}{v}\right)\cos(\beta_0 H)\frac{w(t-\frac{r}{c})}{r}\right) \tag{3}$$

$$H_{\phi} = \frac{30}{\eta v}\left(w\left(t - \frac{R_1}{c}\right) + w\left(t - \frac{R_2}{c}\right) - 2\cos(\beta_0 H)\, w\left(t - \frac{r}{c}\right)\right) \quad (4)$$

In the above equations, c corresponds to the phase velocity, η corresponds to the intrinsic impedance of the medium, and β_0 corresponds to the phase constant at the center frequency of the desired frequency band. The scattered field solution of the MoM domain is combined with FDTD domain update equations directly in the time-domain without involving Inverse Fourier Transform operation at observation points on the planar interface. The following subsection demonstrates numerical results for a multi-scale problem solved by utilizing the proposed hybrid technique.

B. *Numerical Results*

A meandered cross dipole, as shown in Fig. 2, is positioned in y-z plane at a distance of 1 cm from the planar interface. The dipoles extend 10 mm along y and z directions, and have a cross section radius equal to 0.02 times the dipole length. The two dipoles are excited in transmit mode at delta gaps positioned at the middle of the dipoles.

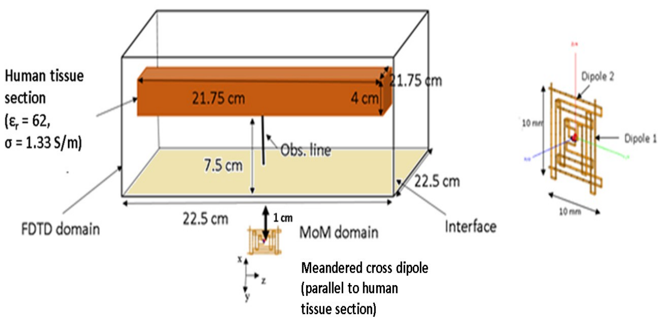

Fig. 2. Problem definition for the numerical example solved using the proposed hybrid technique.

Time-domain scattered fields from the MoM region are combined with FDTD update equations at the FDTD nodes on the planar interface. Scattered field results obtained using the proposed hybrid technique are transformed to frequency-domain to obtain results at 200 frequency samples for a frequency band spanning 40 MHz – 8 GHz by performing Fourier Transform operation on the sampled time-domain fields along the observation line. Hybrid technique results are compared to the results from commercial MoM code along the observation line at different frequencies of interest as shown in Fig. 3 to Fig. 5.

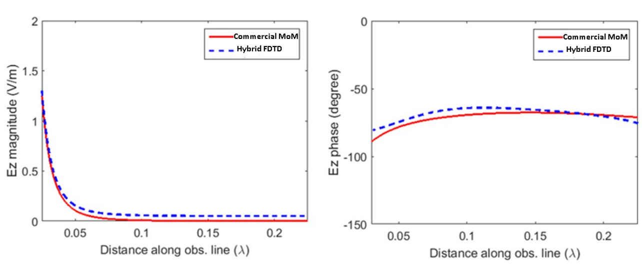

Fig. 3. Comparison of hybrid technique and commercial MoM E_z field results along the observation line at f = 1 GHz.

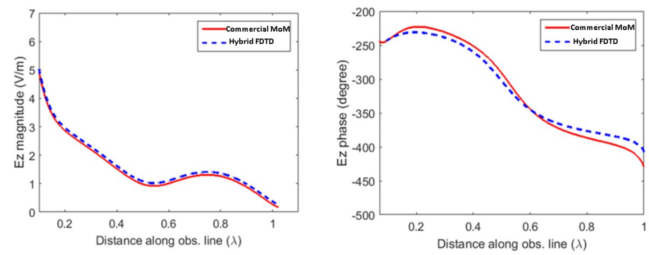

Fig. 4. Comparison of hybrid technique and commercial MoM E_z field results along the observation line at f = 4 GHz.

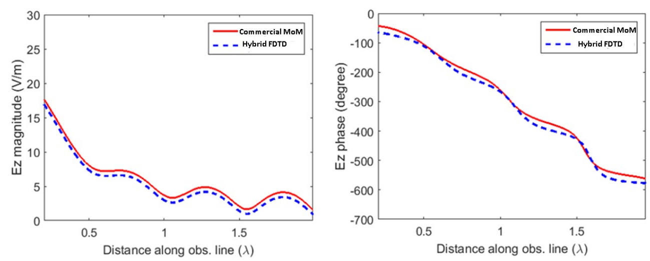

Fig. 5. Comparison of hybrid technique and commercial MoM E_z field results along the observation line at f = 8 GHz.

The comparison of time resources utilized by the proposed hybrid technique and commercial MoM solver is provided below in Table I.

TABLE I. TIME RESOURCE COMPARISON FOR THE PROPOSED HYBRID TECHNIQUE AND COMMERCIAL MOM SOLVER

Time resource comparison: hybrid technique and commercial MoM solver			
Solver	***f=1GHz***	***f=4 GHz***	***f=8 GHz***
Hybrid technique	0.75 hour (entire frequency band)		
Commercial MoM	27.77 hours	30.1 hours	32.1 hours

III. OBSERVATIONS AND CONCLUSIONS

The proposed hybrid technique provides good accuracy and efficiency when compared against commercial MoM solver results. The time resource comparison in Table I shows that the proposed hybrid technique exhibits a large efficiency factor ($>10^3$) when compared to commercial MoM solver. The proposed technique is stable in its implementation.

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