A hybrid MoM/FDTD approach for an efficient modeling of complex antennas on mobile platforms

Werner Thiel[13], Kazem F. Sabet[1] and Linda P.B. Katehi[2]

[1]University of Michigan, Ann Arbor, MI 48109, USA
[2]Schools of Engineering, Purdue University, West Lafayette, IN 47907, USA
[3]EMAG Technologies, Inc., 1340 Eisenhower Place, Ann Arbor, MI 48104, USA
+1 734 973-6600, wthiel@emagtech.com

Abstract— **The use of a hybrid Method of Moments (MoM)/Finite Difference Time Domain (FDTD) method can be effective for solutions of electromagnetic propagation problems, which are intractable for single numerical methods. This paper presents a rigorous, hybrid full-wave analysis of effects pertinent to vehicular multi-antenna system performance for wireless communication applications. For a fast solution of such complex electromagnetic problems essential for an efficient design and optimization of high performance antennas under the influence of mobile platforms, MPI-based parallelization strategies are developed. Applications where the combined MoM/FDTD simulation of wire antennas mounted on a vehicle sheds light into the impact on the antenna performance are provided.**

I. INTRODUCTION

A variety of commercial and military radio network architectures adopt multi-antenna systems due to their simplicity. These types of antennas are in general realized as planar large phased arrays or sophisticated wire antennas since they can be manufactured inexpensively. For wireless communication used in outdoor applications, antenna systems are usually mounted on complex platforms such as buildings or vehicles and interfere with these complex scattering objects.

Nowadays, many commercial CAD tools are available for the design of different kinds of antennas, and especially, high speed computers and the introduction of MPI techniques even allow a full-wave based optimization of phased array antennas containing hundreds of elements. However these CAD tools are only able to model the antenna itself and are entirely incapable to address the platform on which they are mounted. This fact can be a severe limitation in the design process. In many cases though, the platform does not implact the antenna characteristic significantly and hence can be neglected without a remarkable loss in the antenna performance. For some applications, the interference with the platform or with other antennas may corrupt heavily the antenna performance or even the communication if cross-talk is encountered. A comprehensive solution is required e.g. on battleships, where many antenna types are mounted on one platform operating in different frequency bands and power levels. In the past, modeling of such effects relied on measurements data since the proximity of the interfering radiators and the presence of complex scatterers (such as the platforms themselves) within the near field of those, prohibits the use of the Friis formula or a straightforward computation of interference power levels.

With the advances in differential methods for computational electrodynamics, the FDTD [1] method has become one of the most popular numerical method because of its flexibility and has even been used for a brute forward full-wave approach for a variety of propagation problems. The analysis of complex antennas however, especially curved wire antennas or printed antenna arrays is highly inefficient using a pure FDTD approach since an extremly fine mesh enclosing the antenna structures is required. As a consequence, the MoM method [2], [3] is a natural choice for a fast and accurate modeling of these types of antenna structures and the operation frequency, bandwidth and side lobe levels can be predicted accurately. On the other hand, the FDTD method as a very flexible and fast technique can characterize efficiently arbitrary three-dimensional (3D) scatterers such as platforms whereas a pure 3D MoM approach for such an electromagnetic problem is computationally more expensive and is limited by finding a Green's function for the specific problem.

In this work, we focus the impact of vehicular platforms on the radiation pattern by applying a hybrid MoM/FDTD method. A short overview of the concept of the utilized hybrid technique is given in section II. In the following section, an improved near field to far field transformation is introduced to reduce the parasitic cross polarisation caused by the integration. Finally as an example, the radiation pattern of a wire antenna structure on a Hummer vehicle is characterized and the effect of the platform is discussed.

II. CONCEPT OF THE HYBRID METHOD

Based on two antennas mounted on a vehicle as shown in Fig. 1, the concept of the hybrid MoM/FDTD technique [4] is illustrated. According to Fig. 1, the entire structure is partitioned into sub-domains in order to solve them separately with either MoM [3] or FDTD [1]. In this problem, the antennas realized either as wire networks or printed structures and the vehicle as the platform are solved with the MoM and FDTD method, respectively. To invoke the Schelkunoff principle [4], Huygens surfaces are placed around the antennas. Three coupled equivalent problems are established where the antennas are modeled with MoM and the vehicle representing a fully 3D object with the FDTD method. The solution in the two sub-domains is equivalent to the original electromagnetic problem inside the enclosure of S_1 and S_2 and solution excluding the enclosures of the antennas is equivalent to the original problem outside of S_1 and S_2 as shown in Figure 1. To achieve a vanishing field outside the boundaries, electric and magnetic surface currents J_s and M_s have to be

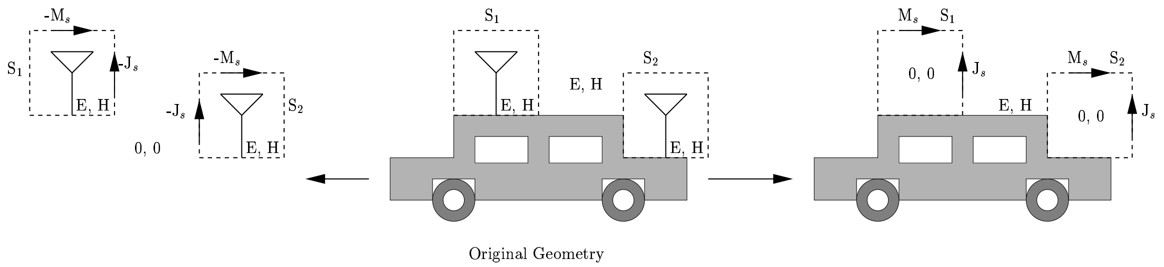

Fig. 1. Decomposition of the original problem into three sub-geometries modeled by MoM and FDTD.

imposed on S_1 and S_2, where $J_s = n \times H$ and $M_s = E \times n$ and vice versa. Because the fields on the Huygens surfaces of the original electromagnetic problem are not available and a brute solution of the coupled system is impossible, an iterative procedure is applied to approach the original field values in the entire domain.

For a performance evaluation of the hybrid MoM/FDTD method, a 3 m long dipole antenna inclined 21.8 degrees to the vertical was analyzed at 50 MHz in free space as an example. Fig. 2 shows the Huygens' surfaces enclosing the dipole antenna, which is embedded in a FDTD grid with a cell size of 0.3 m. A gap source in the center excites the dipole with 1 V and the current distribution in the wire is approximated with 12 rooftop functions in the MoM. The electric field is observed at seven grid points according to Fig. 2 and the results obtained with the hybrid method are compared to the pure MoM data. The magnitude and the phase for both methods are shown in Fig. 3 and 4. It has proven that the hybrid method and the pure MoM are in good agreement and that an error in magnitude and phase of less than 2.2 % and 6.5 % is achieved in the near field of the dipole for a cell size of $\lambda/20$, respectively. As a consequence, the excitation of the FDTD domain with equivalent surface currents on the boundaries leads to a very accurate image for the field distribution in the near field.

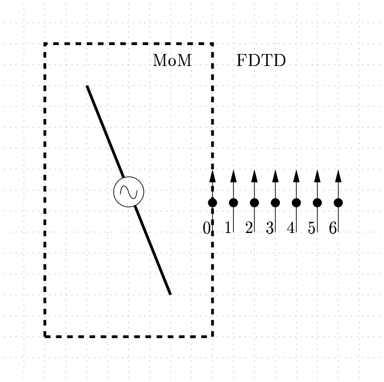

Fig. 2. Hybrid approach for a half-wavelength dipole - electric field is observed at seven points.

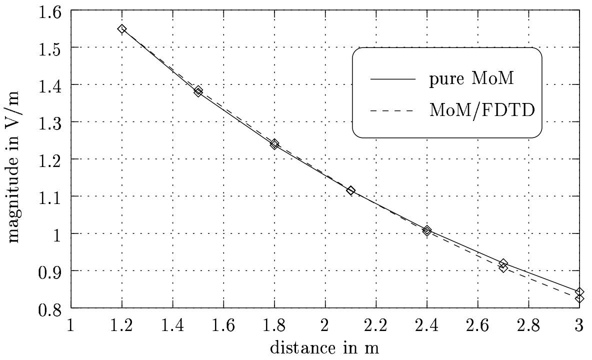

Fig. 3. Magnitude of the electric field at seven observation points in the near-field zone (Fig. 2).

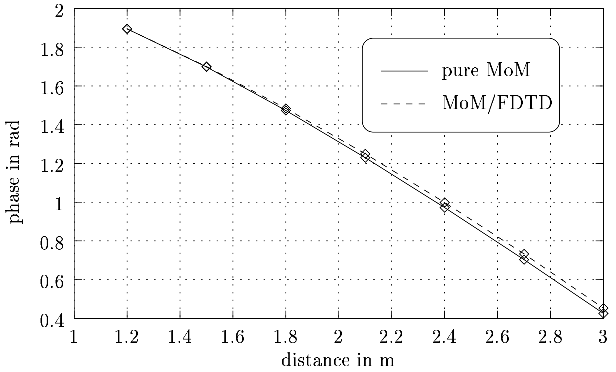

Fig. 4. Phase of the electric field at seven observation points in the near-field zone. (Fig. 2).

III. AN IMPROVED NEAR FIELD TO FAR FIELD TRANSFORMATION

This section focuses on an improved version of the standard near field to far field transformation to calculate the radiation patterns of antenna structures in the presence of scattering objects like buildings or mobile platforms. Special emphasis was given the performance and the accuracy of this algorithm because high performance antennas with low cross polarization and side lobe levels require an extremely high dynamic range and consequently a precise discrete integration in order not to corrupt the antenna diagram by numerical errors. If these characteristics important for the operation of the antenna disappear into the numerical noise floor the antenna itself and further the influence of the platform cannot be predicted. In contrast to the basic near-to-far field transformation method [5] the algorithm was modified related to a technique published in [6].

The equivalent electric currents J are in fact derived from the magnetic field but appear as a source term in the update equations for the eletric field components as illustrated in Fig. 5. The same applies to the equivalent magnetic currents M in return. Hence, in order to conform to the Yee-scheme the equivalent current sources have to be considered on their corresponding position in the dual grid. For symmetry reasons, the near field to far field transformation is finally performed over three planes as shown in Fig. 5.

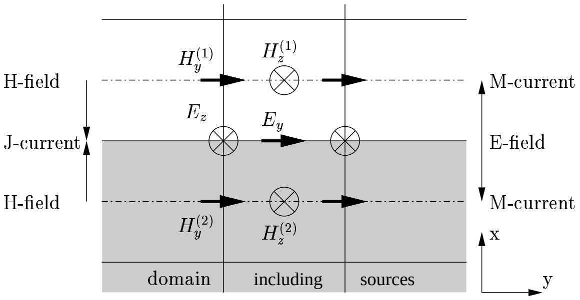

Fig. 5. Field components in the Yee-scheme considered for the near field to far field transformation.

Specifically, the magnetic current sources are assumed to be on the two adjacent planes in the dual grid at one half each whereas the electric current sources are considered in the plane between after taking the arithmetic means of two corresponding magnetic current sources according to Fig. 5.

Further, the near-to-far field transformation is based on a linear dispersion relation whereas the phase of the equivalent current sources determined on the boundary surfaces are calculated with a differential method and hence underlie the dispersion relation of the FDTD algorithm. As a consequence, the phase mismatch results in an error in the far field yielding a high noise floor especially for coarse grids. As a solution, the numerical dispersion relation can be introduced in the far field transformation. In order to calculate the propagation constant k analytically, a Taylor expansion is applied to the sinus-functions in the dispersion relation and terms up to the third order are inserted in the dispersion relation [5]. The equation can be resolved for the propagation constant after neglecting fifth and higher order terms. The corrected propagation vector is finally given by

$$\tilde{k} = \sqrt{\frac{6}{p^2}\left\{1-\sqrt{1-\frac{4}{3}p^2\left[\frac{1}{c\Delta t}\sin\frac{\omega\Delta t}{2}\right]^2}\right\}}$$

with $p^2 = s_x^4\Delta x^2 + s_y^4\Delta y^2 + s_z^4\Delta z^2$, where s_x, s_y and s_z are the components of the unit vector indicating the propagation direction. This problem, however, can only be solved partially and will always be a trade-off between lowering the noise floor and obtaining an accurate phase of the electric field in the far field. The improved near-to-far field algorithm was tested for a dipole array in the E-plane consisting of two in-phase dipoles with a distance of a wavelength to each other. A cell size of a twentieth of a wavelength was chosen and the far field was calculated for different box sizes enclosing the dipole array. The electric field in the H-plane is shown in Fig. 6. The magnitude of the error can be extracted from the radiation pattern in the H-plane, which is supposed to be constant from 0 to 360 degrees. A maximum error of 0.125% results for the smallest box size of 0.3λ by 0.15λ by 0.15λ. According to radiation diagram in H-plane it turns out that the larger the enclosure the smaller the error since the integral approximated by a sum is more accurate if more sampling points are available. A further problem is the parasitic cross polarization added by the far field transformation. To this end, the resulting cross polarization for the same dipole array is depicted in Fig. 7 and 8. using the maximum amplitude of the electric field as a reference. A similar behavior can be observed and the parasitic cross polarization also decreases for larger enclosures. With the new algorithm the parasitic cross polarization drops down to -120 dB in the E-plane and about -90 dB in the H-plane. As a consequence, the new algorithm provides a large dynamic range for a hybrid FDTD/MoM analysis of high performance antennas and exceeds the dynamic range of measurement devices by far.

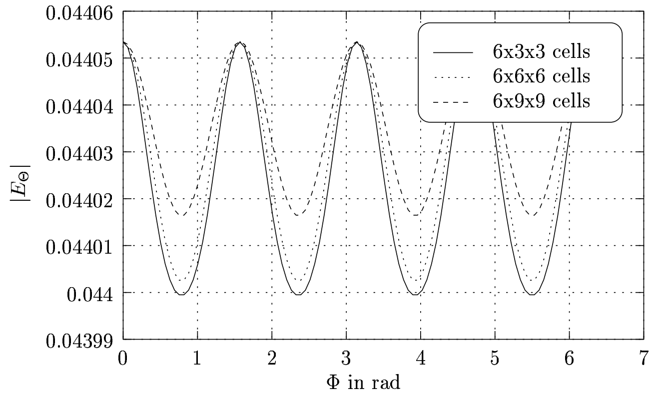

Fig. 6. Radiation pattern in the H-plane for an array of two dipoles located in a distance of a wavelength.

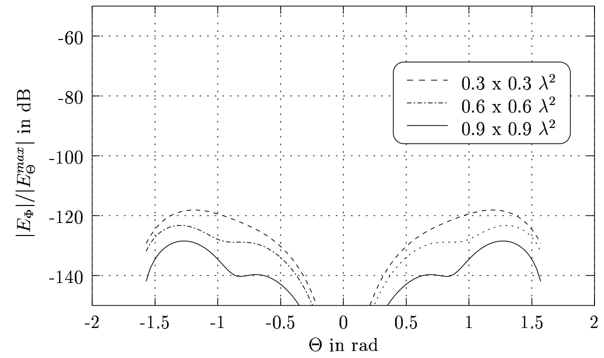

Fig. 7. Parasitic cross polarisation in the E-plane for an array of two dipoles located in a distance of a wavelength.

IV. RADIATION PATTERNS OF ANTENNAS ON VEHICLES

In this section, the radiation pattern of an antenna mounted on a military vehicle was modeled with the hybrid MoM/FDTD technique. According to Fig. 9 the antenna is located on the roof of a Hummer vehicle and is represented by equivalent surface currents in the FDTD method. The enclosure including the boundary surfaces are indicated in Fig. 9 as a box on top of the vehicle. In this case, the radiation diagram of a monopole inclined 21.8 degrees to the vertical is analyzed. The monopole under such an angle cannot be modeled efficiently with a pure FDTD approach unless the grid is locally refined in the region around the antenna. However, subgridding schemes in FDTD are well known for instabilities and reflections caused at the boundaries if a high refinement factor is applied. In addition to numerical problems and loss in sensitivity these techniques especially suffer from an enormous increase in computational effort. Since the antenna is placed on the roof of the vehicle, which is assumed as a perfectly conducting surface, the image principle has to be applied in the MoM to obtain zero tangential electric fields on the ground surface. Fig. 10 shows the antenna

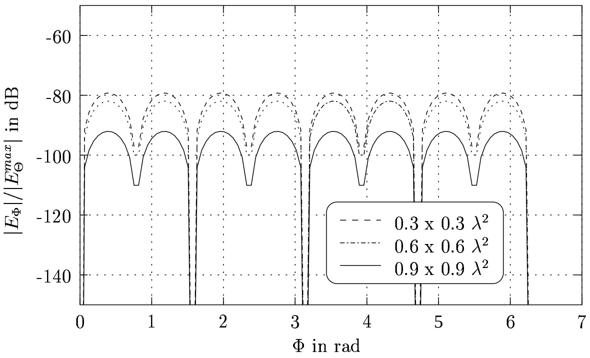

Fig. 8. Parasitic cross polarisation in the H-plane for an array of two dipoles located in a distance of a wavelength.

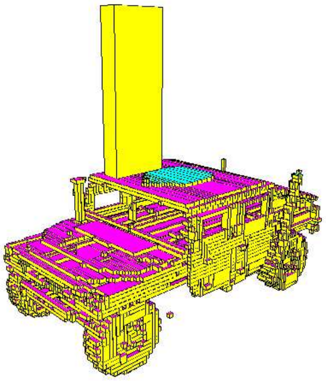

Fig. 9. Antenna replaced by Huygens' surfaces.

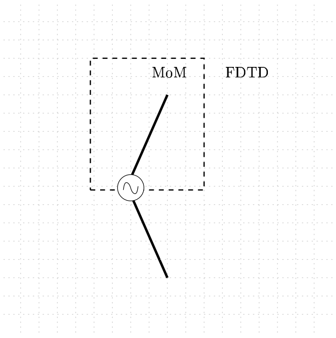

Fig. 10. Slanted monopole antenna modeled with MoM.

structure simulated with the MoM method. The equivalent surface currents are calculated on the boundaries indicated by the dashed lines in Fig. 10 at 50 MHz. A grid size of $\lambda/120$ was chosen for the subsequent FDTD simulation so that all electrically important details of the Hummer vehicle can be taken into account in the mesh. Fig. 11 and Fig. 12 show the far field (E_Θ) of the slanted monopole mounted on the Hummer vehicle in the E- and H-plane. Compared to a vertical monopole over an electric conducting surface the antenna also radiates vertically and a fluctuation of less than 6 dB is observed both in the E- and H-plane so that this configuration almost represents an omnidirectional radiator due to the electromagnetic interference with the vehicle.

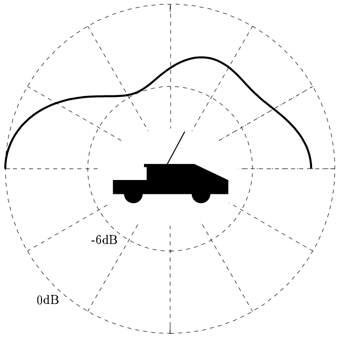

Fig. 11. Radiation pattern (E-plane).

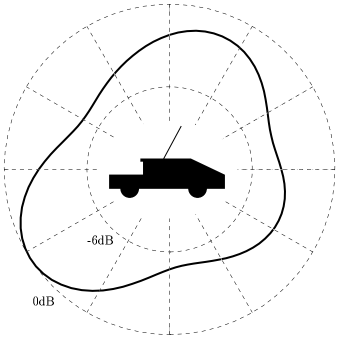

Fig. 12. Radiation pattern (H-plane).

V. CONCLUSION

In this paper, a hybrid MoM/FDTD method was applied for an efficient and accurate characterization of complex antennas on vehicular platforms. A wire antenna mounted on a vehicle has been chosen for a feasibility study and has shown the potential of this computational approach. As an example, the effect of a military vehicle on the radiation pattern of a slanted monopole antenna was demonstrated. In conclusion, the hybrid full-wave approach effectively delivers insight into the impact on the performance of antenna systems where a single numerical method would computationally be too expensive. Furthermore, the application of MPI techniques will enable a fast optimization of printed large phase-array antenna systems under the influence of mobile platforms.

ACKNOWLEDGEMENT

This work was supported by the Naval Surface Warfare Center through a Phase I SBIR project for ”Numerical Modeling of Complex Systems” (N00178-02-C-3059).

REFERENCES

[1] K.S. Yee, “Numerical Solution of Initial Boundary Value Problems Involving Maxwell’s Equation in Isotropic Media,” *IEEE Trans. Antennas Propagation*, vol.AP-14, no. 5, pp. 302–307, May 1966.

[2] Roger F. Harrington, *Field Computation by Moment Methods*, IEEE Press, New York, 1993.

[3] Hisamatsu Nakano, *Helical and Spiral Antennas - A Numerical Approach*, Research Studies Press LTD., Letchworth, England, 1987.

[4] Z. Huang, K.R. Demarest, and R.G. Plumb, “An FDTD/MoM Hybrid Technique for Modeling Complex Antennas in the Presence of Heterogeneous Grounds,” *IEEE Trans. on Geoscience and Remote Sensing*, vol. 37, no. 6, pp. 2692–2698, Nov. 1999.

[5] Allen Tafbve, *Computational Electrodynamics - The Finite Difference Method*, Artech House, Boston-London, 1995.

[6] T. Martin, “An Improved Near-to-Far Zone Transformation for the Finite Difference Time-Domain Method,” *IEEE Trans. Antennas Propagat.*, vol. 46, no. 9, pp. 1263-1271, September 1998.