

A hybrid MoM/FDTD technique for the modeling of multi-antenna systems on vehicular platforms for wireless communication systems

Werner Thiel, Kazem Sabet and Linda P.B. Katehi

EMAG Technologies Inc.
1340 Eisenhower Place, Ann Arbor, MI 48104
wthiel@emagtechnologies.com

Abstract: The use of multi-antenna systems on vehicular platforms, for the implementation of ad-hoc wireless network architectures, is typically hampered by the problem of co-site interference between transceivers loading neighboring radiating elements. This paper presents a rigorous, full-wave analysis of effects pertinent to vehicular multi-antenna system performance, based on a hybrid time/frequency domain analysis that combines the method of moments (MoM) with the finite difference time-domain method (FDTD). For the fast solution of such problems, MPI-based parallelization strategies are developed. Applications are provided where the combined MoM and FDTD simulation of multi-antenna systems sheds light to the serious impact of mutual transceiver interference on wireless network operation.

Keywords: Hybrid techniques, FDTD, Method of Moments, wireless communication, antenna systems

1 Introduction

A variety of commercial and military radio network architectures adopt multi-antenna systems due to their simplicity. In particular, transmit-receive modules mounted on vehicular platforms are widely encountered in ad-hoc network configurations of VHF military radio and are also considered for future generations of mobile wireless systems. However, the concurrent operation of individual receive-transmit modules, often gives rise to co-site interference side effects, such as desensitization, inter- and cross-modulation that eventually corrupt the overall system performance. In the past, modeling of such effects relied on measurement 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 Friis formula for the straightforward computation of interference power levels [1]. Nevertheless, the advances in differential methods for computational electromagnetics, and the exploitation of parallelization techniques have made possible the full-wave simulation of complex large-scale systems including multiple platforms. In this work, we concentrate on characterization of the cross-talk between mutually coupled antennas and an intensive study of the impact of vehicular platforms and collocated antennas on the radiation pattern. The applied hybrid MoM/FDTD technique combines a powerful full-wave method in the frequency domain with a highly flexible method in the time-domain. The method of moments can accurately model

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arbitrary wire antenna structures or printed large-scale phased arrays whereas the FDTD method is predestinated to analyze the influence of the platform or scatterers, which are usually very complex three-dimensional objects. To this end, the hybrid full-wave approach delivers insight into the performance of multi-antenna systems and provides an efficient and highly accurate technique suitable for a performance evaluation of radio systems. Further, MPI techniques will also enable an optimization of antenna systems under the influence of vehicular platforms.

2 Problem specification and concept of the hybrid technique

A typical scenario for a multi-antenna system on a vehicular platform is shown in Fig. 1. Several

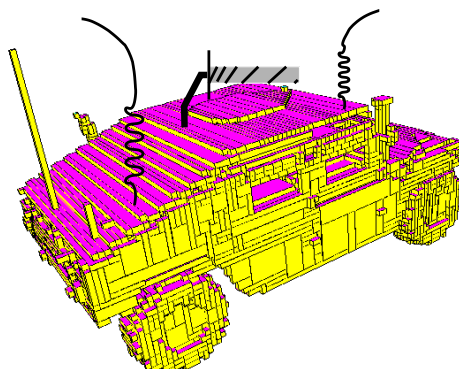


Figure 1: Helical antennas on a discretized Hummer vehicle.

helical antennas are mounted on the roof of a Hummer vehicle. The cross-talk between single antennas and the radiation patterns in presence of the vehicle are analyzed with the hybrid MoM/FDTD method. Complex antenna systems, especially wire antennas or printed arrays can only be modeled with the FDTD [2] method with an unacceptable computational effort including an extremely fine mesh enclosing the antennas. As a consequence, the MoM method [3, 4] is a natural choice for a fast and accurate modeling of antenna structures. On the other hand, the FDTD method as a very flexible method can take into account arbitrary 3D objects like the vehicle in this case. However, a pure 3D MoM approach for such an electromagnetic problem would yield a linear system of equations with an innumerable number of unknowns, which is completely inappropriate for such a problem. Based on two antennas mounted on a vehicle as shown in Fig. 2, the concept of a hybrid MoM/FDTD technique is illustrated. According to Fig. 2, the entire structure is partitioned into three sub-domains in order to solve them separately with either MoM or FDTD. 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 Schelkunoff's principle [5], Huygens' surfaces are placed around the antennas. Three coupled equivalent problems are established where the two antennas are modeled with the MoM method 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 the solution excluding the enclosures of the antennas is equivalent to the original problem outside of S_1 and S_2 as shown in Figure 2. To achieve a vanishing field outside the

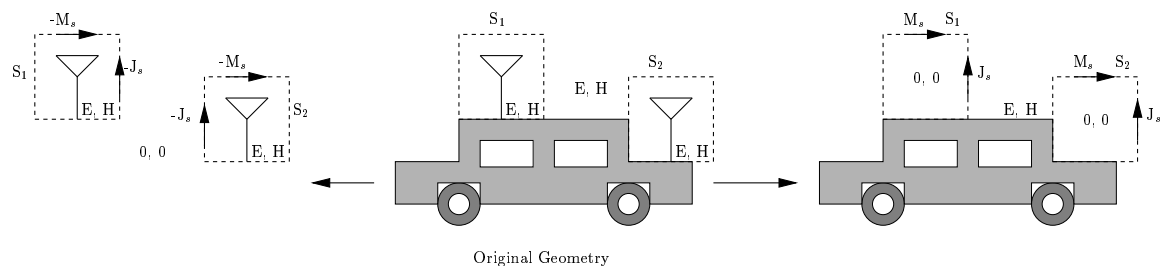


Figure 2: Decomposition of the original problem into three sub-geometries modeled by MoM and FDTD.

boundaries, electric and magnetic surface currents J_s and M_s have to be 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.

3 Numerical results

For a performance evaluation of the hybrid MoM/FDTD method and a demonstration of the incapability of the FDTD method to characterize the entire problem, a 3 m long dipole antenna in free space was analyzed at 50 MHz as a first example. Fig. 3 shows the Huygens' surfaces enclosing the dipole antenna, which are 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 magnitude of the normal magnetic field at 50 MHz is shown in Fig. 4. In the hybrid method, the equivalent electric and magnetic

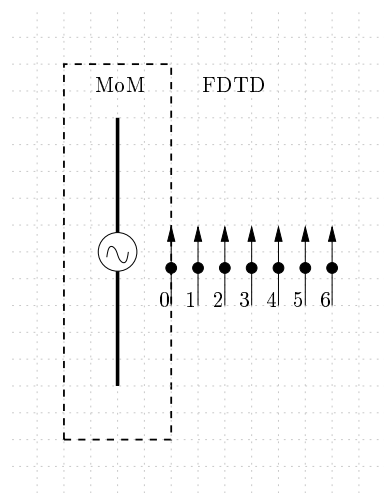


Figure 3: Hybrid approach for a half-wavelength dipole - electric field is observed at seven points.

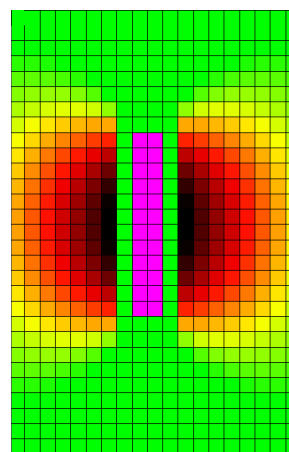


Figure 4: Normal magnetic field of the dipole antenna in a cross through the antenna.

current sources excite the FDTD domain on the boundary of the MoM sub-domain with a size of $4 \times 4 \times 14$ cells. The dipole antenna was defined as a perfect electric conducting wire with a gap source imposing a sinusoidal signal with a magnitude of 1 V across two cells. The three methods are compared based on the electric field parallel to the dipole at seven grid points according to Fig. 3. The magnitude of the pure MoM, pure FDTD and the hybrid technique as a function of the distance from the center of the dipole is depicted in Fig. 5. The hybrid and the MoM results are in good agreement whereas the pure FDTD and MoM results significantly deviate from each other. A similar order of magnitude for the error is observed for the phase of the electric field shown in Fig. 6. In this case, the error in phase increases for points further away from the

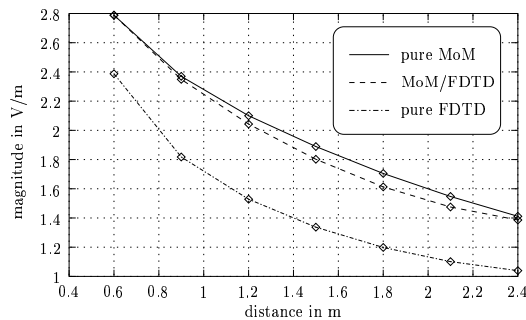


Figure 5: Magnitude of the electric field.

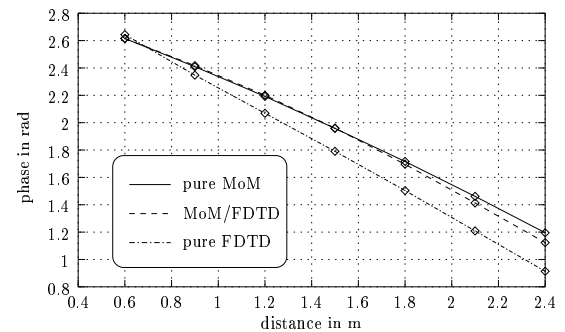


Figure 6: Phase of the electric field.

dipole. In addition, the relative error in magnitude and phase of the electric field was calculated in Table 1 using the MoM data as a reference. The relative error in magnitude is below 5.5 % and

distance in m	0.6	0.9	1.2	1.5	1.8	2.1	2.4
MoM/FDTD							
magnitude	0.0000	0.008825	0.02708	0.04819	0.05413	0.04685	0.01818
phase	0.0000	0.003154	0.004107	0.0009701	0.01201	0.03353	0.06023
pure FDTD							
magnitude	0.1440	0.2331	0.2722	0.2924	0.2974	0.2885	0.2637
phase	0.0107	0.02557	0.05617	0.08583	0.1240	0.1731	0.2359

Table 1: Relative error in magnitude and phase for the hybrid and the pure FDTD technique based on the pure MoM method.

is less than 6.1 % for the phase in the near field of the dipole. These small deviations result from FDTD method for two reasons: The MoM provides a highly accurate solution for the electric and magnetic fields on the Huygens' surfaces at the required positions in the Yee grid so that these electric and magnetic fields do not satisfy a discrete solution in FDTD. As a consequence, $\nabla \cdot B$ and $\nabla \cdot D$ do not vanish on the boundary and consequently, the field can be assumed as a superposition of the discrete solution and an error term. Second, the numerical dispersion of the FDTD method affects the magnitude and the phase for a coarse grid. Since the phase of the field components on the boundary calculated by the MoM do not satisfy the dispersion relation of FDTD method the phase will be erroneous regarding a discrete solution, which results in an error in magnitude, too. In contrast to the hybrid method, the pure FDTD method leads to a

large error unacceptable for a reasonable characterization of antennas on complex platforms. The error in magnitude exceeds 29 % and the error in phase is about 23 % 2.4 m away from the dipole. Finally, the magnitude of the normal magnetic field at 50MHz for the hybrid method is shown in Fig. 4 illustrating the near-field region of the dipole.

The previous example was repeated for the same dipole antenna tilted by 21.8 degrees. Again the pure MoM and hybrid MoM/FDTD method were compared at 50MHz. The grid-size in the FDTD method, the number of rooftop functions per wavelength in the MoM and other parameters were adopted from the previous simulation. However, a FDTD characterization of a tilted dipole is impossible in this case showing nicely the severe limitations of FDTD. In order to model curved wire structures, which are not aligned to the Yee-grid, an extremely fine mesh or a conformal grid has to be applied increasing the computational effort drastically. Further, even if such an effort is undertaken, mediocre simulation results for the antenna impedance or the near field will be obtained because an increasing error in the FDTD method is observed in the vicinity of field singularities or for resonant structures. Fig. 7 shows the tilted dipole antenna enclosed by the Huygens' surfaces and the positions of the electric field components used for an evaluation of the hybrid method. In contrast to the previous example, the size of MoM sub-domain had to

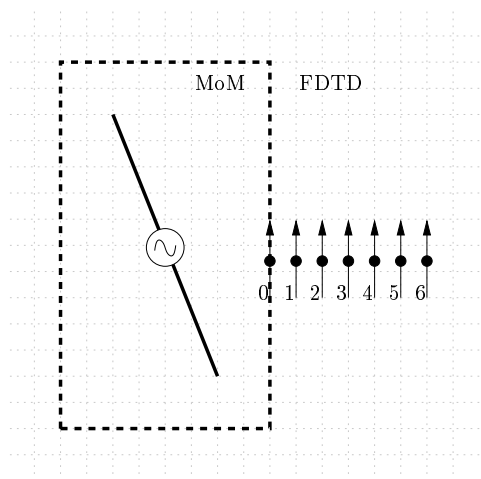


Figure 7: Hybrid approach for a tilted half-wavelength dipole - electric field is observed at seven points.

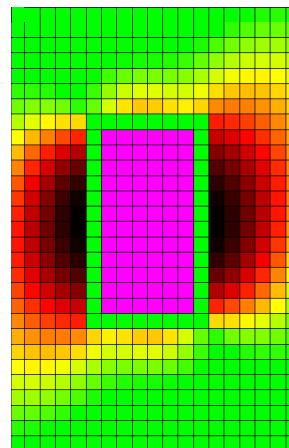


Figure 8: Normal magnetic field of the dipole antenna in a cross through the antenna.

be increased by 4 cells in one direction. Again, the magnitude and the phase of the electric field were compared at seven grid points in the near field of the dipole. Fig. 9 and Fig. 10 show the magnitude and the phase obtained with the pure MoM and the hybrid method. Finally, the relative error was calculated and listed in Table 2. Both methods are in good agreement and the error in magnitude and phase is less than 2.2 % and 6.5 %, respectively. In Fig. 8, the visualization of the normal magnetic field shows the change of propagation direction. Since the antenna is tilted, the beam is also turned by the same angle. Based on the results showed for a tilted dipole the hybrid method has proven to be an appropriate technique to characterize accurately and efficiently arbitrarily shaped wire antennas.

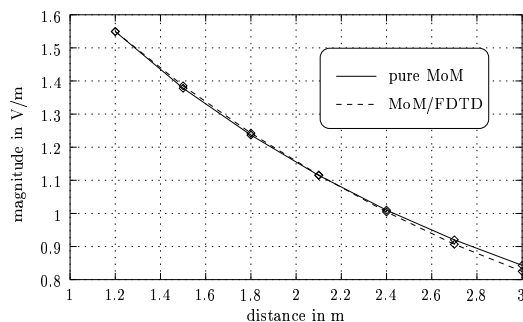


Figure 9: Magnitude of the electric field.

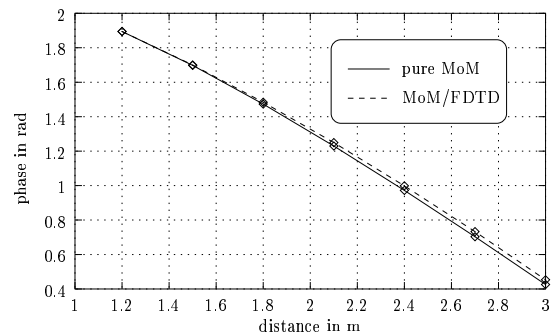


Figure 10: Phase of the electric field.

distance in m	1.2	1.5	1.8	2.1	2.4	2.7	3.0
MoM/FDTD							
magnitude	0.0000	0.005261	0.004761	0.001251	0.005370	0.01465	0.02168
phase	0.0000	0.001166	0.007468	0.01610	0.02736	0.04209	0.06410

Table 2: Relative error in magnitude and phase for the hybrid MoM/FDTD technique based on the pure MoM method.

4 Conclusion

A research effort to completely characterize cosite interference problems in multi-antenna vehicular platforms, by means of hybrid full wave techniques, is presented in this paper. So far, the concept of a hybrid technique has been demonstrated for an zero order approach only to model arbitrary wire antennas. Future work will focus on the modeling of wire antenna systems on vehicular platforms with an higher order hybrid MoM/FDTD approach and results regarding antenna diagrams and cross-talk issues will be studied in detail.

References

- [1] CONSTANTINE BALANIS: *Antenna Theory, Analysis and Design*. John Wiley & Sons, New York, 1982.
- [2] K.S. YEE: *Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equation in Isotropic Media*. IEEE Trans. Antennas Propagation, 14(5):302–307, May 1966
- [3] HISAMATSU NAKANO: *Helical and Spiral Antennas - A Numerical Approach*. Research Studies Press LTD., Letchworth, England, 1987.
- [4] ROGER F. HARRINGTON: *Field Computation by Moment Methods*. IEEE Press, New York, 1993.
- [5] 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, 37(6):2692–2698, Nov. 1999.