Mixed Electromagnetic - Circuit Modeling for Rigorous Characterization of Cosite Interference in Wireless Communication Channels

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Abstract

The concurrent operation of neighboring individual receive-transmit modules, typically leads to cosite interference side effects, such as desensitization, inter- and cross-modulation that degrade the performance of radio networks. For the physical characterization of such effects, the full-wave solution of Maxwell's equations in the time domain is pursued in this paper, along with the use of circuit solvers (including large signal models of power amplifier geometries) that allow for the modeling of nonlinear effects, pertinent to transceiver operation.

I. INTRODUCTION

With the recent advances in mobile communications and their growing use in commercial and military applications, the rigorous analysis of electromagnetic interference between antenna systems mounted on neighboring vehicular platforms has become a topic of critical importance. In particular, the concurrent operation of individual receive-transmit modules, often gives rise to cosite interference side effects, such as desensitization, inter- and cross-modulation that eventually corrupt the performance of radio networks [1]. For the physical characterization of such effects, the joint modeling of electromagnetic wave propagation across a a given channel and the operation of transceiver front-end modules is pursued in this paper.

Time domain techniques such as the Finite Difference Time Domain (FDTD) offer a mathematically straightforward and inherently versatile method for the analysis of electromagnetic geometries. Thus, they serve a major objective of our study well, that being to capture the effect of the platforms on the radiative properties of the antennas that are mounted on them. Second, it was recently demonstrated that the incorporation of active element components and nonlinear circuits in the FDTD mesh can be easily accomplished by following a state equation based approach [2]. Hence, the simulation of nonlinear effects pertinent to cosite interference is made possible.

It is also worth noting that neighboring grounded VHF transceivers are typically located within the near field region of each other. Hence, while their interaction with a remote antenna can be described in terms of the well-known Friis formula, near field power coupling is usually evaluated empirically, using measurement data [3]. Alternatively, full-wave analysis can be employed for this purpose, taking into account specific channel characteristics through the complete incorporation of boundary conditions at the platform and elsewhere in the propagation channel.

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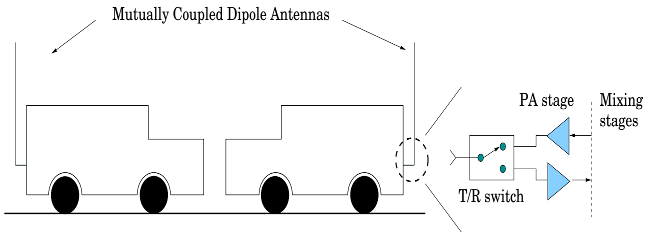

Fig. 1. Schematic representation of the cosite interference scenario under consideration.

In the following, the aforementioned modeling approach is explained in greater detail and numerical results that demonstrate the ability of this work to address typical cosite interference problems are provided.

II. Cosite Interference Modeling

A. Problem Specification

A typical cosite interference scenario that this paper deals with is shown in Fig. 1, where monopole antennas, mounted on vehicular platforms are loaded with transmit-receive modules, that consist of a power amplification stage that ultimately drives a mixer, followed by an IF (intermediate frequency) filter that carries out the task of signal detection. Signal processing stages that may follow, depending on the transmission scheme of choice, are not included in this modeling.

Evidently, three modes of operation are possible : Either both antennas transmit or both antennas receive or one transmits and one receives (hybrid mode) at the same time. Although all three modes of operation can be modeled in the framework of this work, particular emphasis is placed on the hybrid mode of operation, for the reason that significant power levels that parasitically enter a receiver due to the concurrent operation of a neighboring transmitter, may drive its amplifier away from its linear region, deteriorating its sensitivity. A particular example that illustrates this phenomenon is given below.

B. FDTD and MRTD Modeling of Wave Propagation

Apart from the conventional Finite Difference Time Domain technique, the Haar wavelet-based Multiresolution Time Domain technique is also employed for the time domain solution of Maxwell's equations. We limit ourselves to the use of one wavelet level in all three dimensions, that allows for an adaptive mesh aspect ratio 1 to 8. However, for this to be true, a certain condition regarding the arrangement of electric and magnetic field nodes need be imposed, as discussed in [4]. Namely, as the offset of electric and magnetic field nodes is half a cell in FDTD, in a zeroth order Haar MRTD (of one wavelet level) this offset must be set equal to one cell by 2^2, that is a *quarter* of a cell. As an example, the $x-$ component of the electric field is expanded in terms of Haar scaling and wavelet functions $\phi_m(\xi) = \phi(\xi - m)$, $\psi_m = \psi(\xi - m)$, $\xi = \lambda/\Delta\lambda$, $\lambda = x,\ y,\ z$, as :

$$\begin{aligned} E_x(\bar{r}, t) = & \sum_n h_n(t) \sum_{i,j,k} \Big\{ \\ & {}_nE^{\phi\,\phi\,\phi}_{i',j,k}\phi_{i'}(x)\phi_j(y)\phi_k(z) + {}_nE^{\phi\,\phi\,\psi}_{i',j,k}\phi_{i'}(x)\phi_j(y)\psi_k(z) \\ + & {}_nE^{\phi\,\psi\,\phi}_{i',j,k}\phi_{i'}(x)\psi_j(y)\phi_k(z) + {}_nE^{\phi\,\psi\,\psi}_{i',j,k}\phi_{i'}(x)\psi_j(y)\psi_k(z) \\ + & {}_nE^{\psi\,\phi\,\phi}_{i',j,k}\psi_{i'}(x)\phi_j(y)\phi_k(z) + {}_nE^{\psi\,\phi\,\psi}_{i',j,k}\psi_{i'}(x)\phi_j(y)\psi_k(z) \\ + & {}_nE^{\psi\,\psi\,\phi}_{i',j,k}\psi_{i'}(x)\psi_j(y)\phi_k(z) + {}_nE^{\psi\,\psi\,\psi}_{i',j,k}\psi_{i'}(x)\psi_j(y)\psi_k(z)\Big\} \end{aligned} \quad (1)$$

where $i' \equiv i + 0.25$ and h_n are the pulse functions defined in [5]. The rest of the derivation follows the Moment Method based procedure that is outlined in [5].

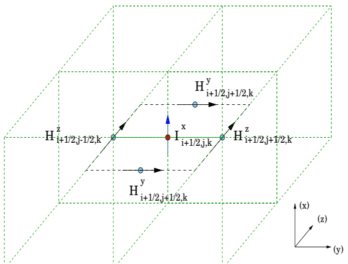

Fig. 2. Application of Ampere's law for the determination of the input current at a circuit port.

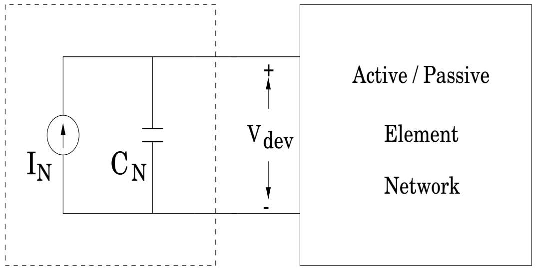

Fig. 3. Norton type equivalent circuit for the incorporation of a passive/active element network in the FDTD/MRTD mesh.

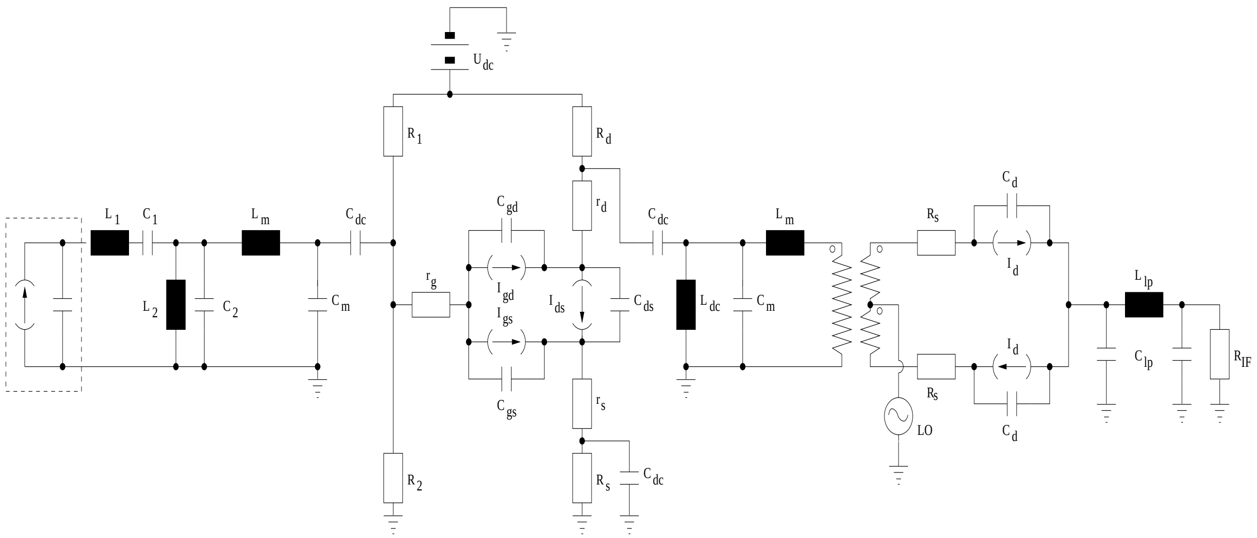

Fig. 4. MESFET based receiver architecture.

C. Lumped Element Modeling and Receiver Architectures

For the purpose of introducing receiver architectures in the FDTD / MRTD mesh, the "extended" FDTD method of [2] has been utilized. According to the method, circuit state equations (the circuit being the load at the antenna input port) are coupled with a Thevenin/Norton equivalent of the FDTD cell (derived by Maxwell's curl equations) in order to represent the circuit/ wave interaction. This technique has been successfully incorporated in MRTD simulations [6], due to its versatile, circuit theory based character. As an example, Figs. 2, 3 explain the derivation of an equivalent circuit representation of an FDTD cell from Ampere's law applied at a circuit port, supporting an $x-$ directed current element $I^x_{i+1/2,j,k}$.

Furthermore, Fig. 4 shows a MESFET based receiver that is employed in later numerical experiments. The MESFET transistor, that consists the main building block of the amplifier stage (preceded by a two-section Chebyshev band-pass filter), is replaced by its large signal equivalent model [7]. The amplifier is followed by a single balanced mixer and a three-section Chebyshev filter (IF filter).

In order to demonstrate the effect of cosite interference on the performance of the amplifier, a simple case study was performed on a commercial simulation tool (ADS). The MESFET based receiver was tuned to 50 MHz. Then, the gain of the amplifier with a -10 dBm input signal alone and with that signal superimposed with a 30 dBm parasitic signal, was computed. The result of this case study, shown in Fig. 5, demonstrates the dramatic drop in the amplifier's sensitivity by about 45 dBs.

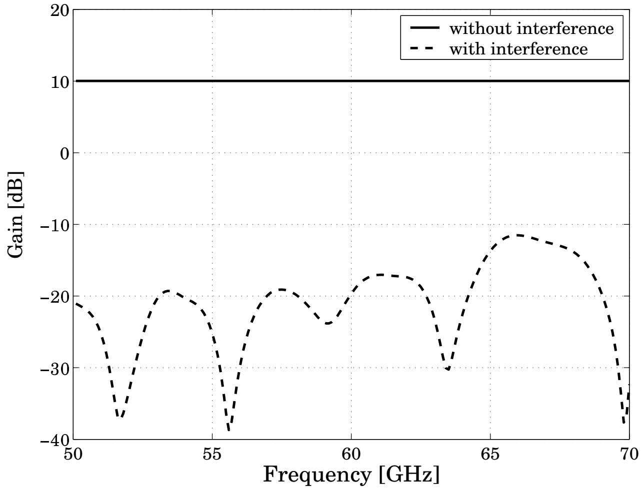

Fig. 5. Sensitivity loss of the MESFET based receiver due to interference (up to 45 dBs).

III. NUMERICAL EXAMPLES

As an example, the receiver of Fig. 4 is used as a load for a monopole antenna on a vehicle of the simplified shape of Fig. 6. This system is placed 1.5 m away from an identical one, in a back-to-back configuration (Fig. 7). The antenna on vehicle 1 is assumed to be in receive mode, communicating with a remote transmitter, represented by an infinitesimal current element, parallel to the antenna direction. This is placed 2.25 m away from vehicle 1, and transmits a sinusoidal signal at 50 MHz, of current amplitude 12.223 mA.

Two cases are considered : Initially, the second antenna is shorted out. Then, the communication between the receiver on vehicle 1 and the Hertz dipole transmitter is accomplished with no interference. The simulated (by FDTD) time and frequency domain patterns of the received voltage are shown in Figs. 8, 9 respectively. The clear spectrum of the received signal with its peak at 50 MHz confirms the unimpeded reception of the information signal. Figs. 10, 11 depict the output of the mixer before the IF filter stage, containing the IF frequency of 1 MHz, since the mixer LO frequency is set at 49 MHz. The power level of the IF is at -31.5 dBm.

On the other hand, when the antenna on vehicle 2 transmits a sinusoidal signal at 51 MHz at an amplitude of 16.233 Volts, the communication between the receiver on vehicle 1 and the remote transmitter is corrupted by interference that is quantitatively evaluated in Figs. 12-15. In particular, Fig. 13 shows that the input voltage spectrum is dominated by the interfering signal at 51 MHz. Also, the output of the mixer (Fig. 15) contains a parasitic IF frequency at 2 MHz, that corresponds to the detection of the interfering signal at 51 MHz. In this case, the LO frequency is again 49 MHz.

Finally, platform characterization can be performed, by extracting field distributions at various frequencies, by Fourier transforming time domain data. For linear radiators, such as the monopoles of the geometries under consideration, the distribution of the electric field component parallel to the antenna is of primary interest, since this brings about the parasitic coupling between neighboring elements. Results at several frequencies are extracted “on the fly” via time domain simulations in a single run. Normalized field plots at the plane of the monopole gap of an antenna on a vehicle are shown in Figs. 16, 17, for frequencies 35 and 75 MHz respectively.

IV. CONCLUSIONS

A research effort to rigorously model cosite interference problems by means of time domain methods has been described in this paper. The versatility of the FDTD technique allowed for the incorporation of large signal receiver models in the mesh and thus the accurate modeling of nonlinear effects that are potentially produced by cosite interference. Hence, this work has led to the development of an integrated analysis tool for

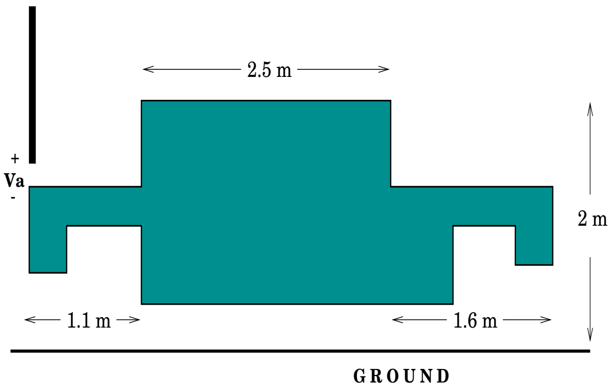

Fig. 6. Simplified vehicle model. Perfect electrically conducting walls are assumed.

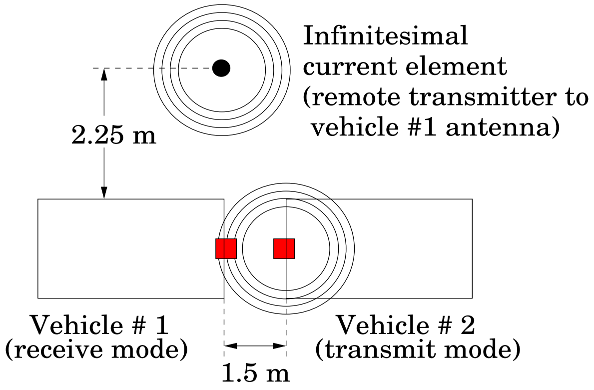

Fig. 7. Cosite interference scenario.

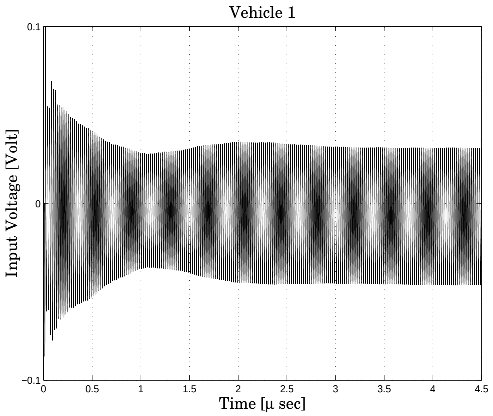

Fig. 8. Input voltage at the receiver antenna (under no interference).

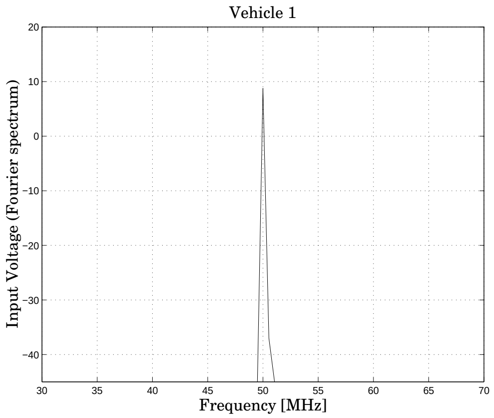

Fig. 9. Fourier spectrum of input voltage at the receiver antenna (under no interference).

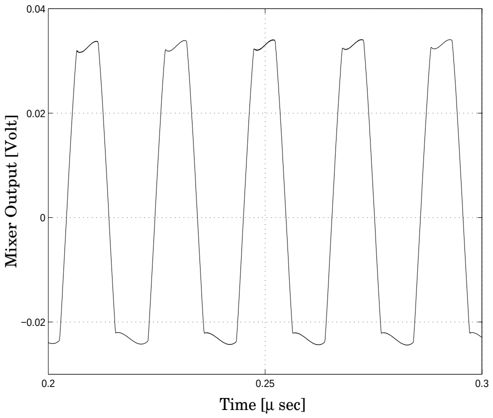

Fig. 10. Mixer output that drives the IF filter (under no interference).

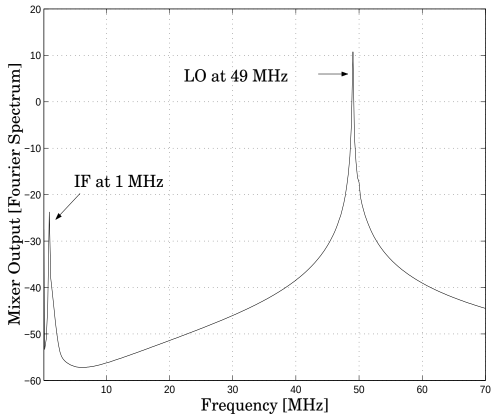

Fig. 11. Fourier spectrum of mixer output (under no interference).

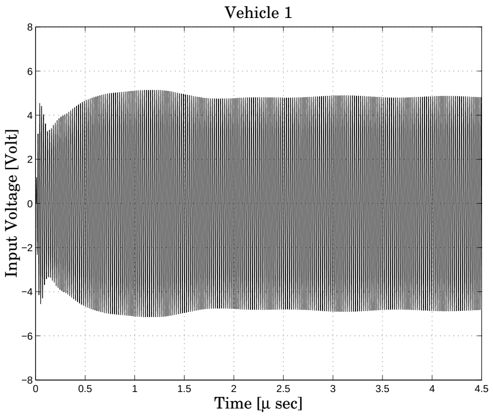

Fig. 12. Input voltage at the receiver antenna (with interference).

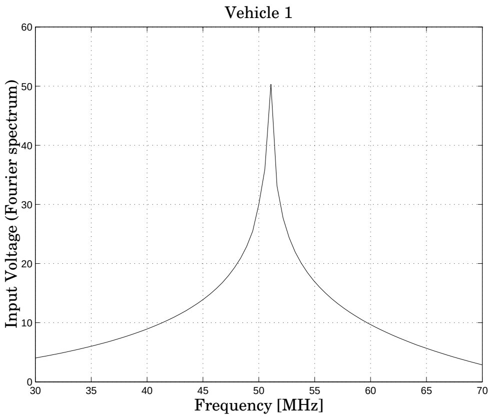

Fig. 13. Fourier spectrum of input voltage at the receiver antenna (with interference).

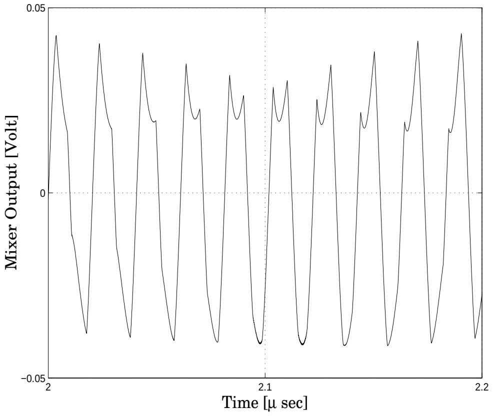

Fig. 14. Mixer output that drives the IF filter (with interference).

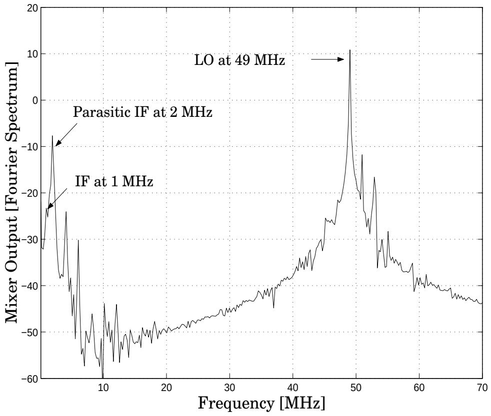

Fig. 15. Fourier spectrum of mixer output (with interference).

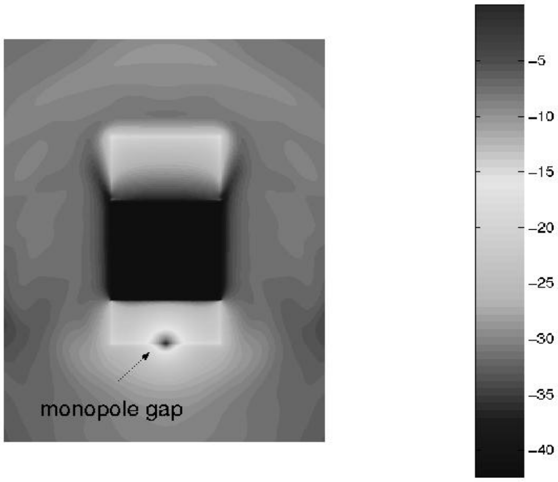

Fig. 16. Normalized magnitude of $x-$ component of the electric field [in dBs] around a vehicular platform at 35 MHz.

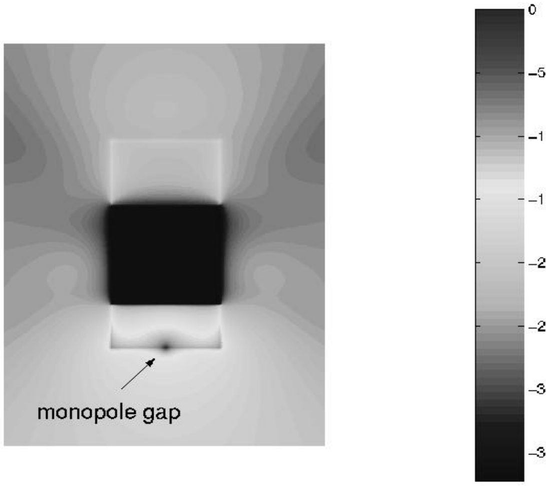

Fig. 17. Normalized magnitude of $x-$ component of the electric field [in dBs] around a vehicular platform at 75 MHz.

circuit and electromagnetic phenomena pertinent to tranceiver system performance under electromagnetic interference (EMI) conditions. Parallelization strategies, based on the MPI (message passing interface) library have also been implemented to accelerate the analysis of large scale geometries [8].

REFERENCES

[1] J. Gavan, M. B. Shulman, "Effects of desensitization on Mobile Radio System Performance, Part I : Qualitative Analysis", *IEEE Trans. Vehicular Tech., vol. VT-33, No.4, November 1994, pp. 285-290.*

[2] B. Houshmand, T. Itoh, M. Picket-May, "High-Speed Electronic with Active and Nonlinear Components", *ch. 8, in Advances in Computational Electrodynamics, the Finite Difference Time Domain Method, A. Taflove ed., Artech House, Boston, 1999.*

[3] J. Gavan, F. Handler, "Analysis, computation and mitigation of the interference to a remote receiver from two collocated vehicular transceivers", *IEEE Trans. Vehicular Tech., vol. VT-45, No.3, August 1996, pp. 431-442.*

[4] C. D. Sarris, L. P. B. Katehi, "Fundamental Gridding Related Dispersion Effects in Multiresolution Time Domain Schemes", *IEEE Trans. Microwave Theory Tech., December 2001.*

[5] M. Krumpholz, L.P.B. Katehi, "MRTD: New Time Domain Schemes Based on Multiresolution Analysis", *IEEE Trans. Microwave Theory and Techniques, vol.44, no.4, pp.555-561, April 1996.*

[6] R. L. Robertson, C. D. Sarris, L. P. B. Katehi, "Analysis of Lumped Element Transistor Structures Using MRTD : The State Equation Approach", *submitted to the IEEE Microwave and Guided Wave Letters, October 2000.*

[7] P. Antognetti, G. Massobrio, *Semiconductor Device Modeling with SPICE*, New York : McGraw-Hill, 2nd ed., 1993.

[8] C.D. Sarris, K. Tomko, P. Czarnul, S.H. Hung, R.L. Robertson, D. Chun, E.S. Davidson, L. P. B. Katehi, "Multiresolution Time Domain Modeling for Large Scale Wireless Communication Problems", *Proceedings of 2001 IEEE AP-S International Symposium on Antennas and Propagation.*