Hybrid Time-Domain Performance Analysis of Multi-Antenna Systems on Vehicular Platforms

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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 cosite 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-domain analysis that combines electromagnetic modeling methods (such as FDTD and MRTD) with advanced SPICE-type circuit solvers. For the fast solution of such problems, MPI-based parallelization strategies are developed. Applications where the combined circuit and electromagnetic simulation of multi-antenna systems sheds light to the serious impact of mutual transceiver interference on wireless network operation are provided. In addition, the way in which a combination of the Method of Moments with the Finite Difference Time Domain can lead to the simulation of cosite interference within a forest environment is presented.

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 cosite interference side effects, such as desensitization, inter- and cross-modulation that eventually corrupt the overall system performance [1, 2].

In the past, modeling of such effects relied on measurement data [2], 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. Nevertheless, the advances in differential methods for computational electromagnetics, and the exploitation of parallelization techniques have made possible the full-wave simulation of large scale systems including multiple platforms [3]. In this work, we concentrate on the modeling of multi-antenna systems on a single platform, including potentially complex, nonlinear circuit models that represent realistic receiver architectures. This is accomplished via both the state-equation-based approach of [4] and the development of a numerical interface between FDTD and TRANSIM [5], an object-oriented, optimized, SPICE-type circuit solver, that facilitates the incorporation of built-in advanced circuit models into an FDTD simulation. Finally, cosite interference within the multi-path environment of a forest is also addressed by coupling the Method-of-Moment (MoM) based approach of [6] to our code, in order to assemble a hybrid tool for estimating in-forest receiver performance.

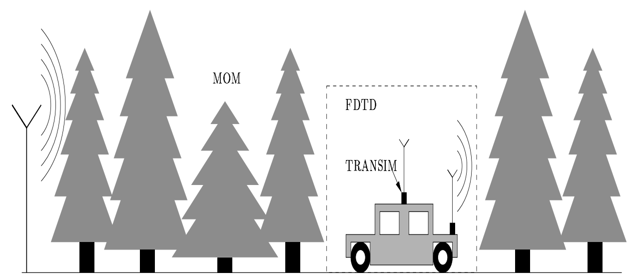

Figure 1: Scenario of two interfering antennas on a vehicle located in a forest.

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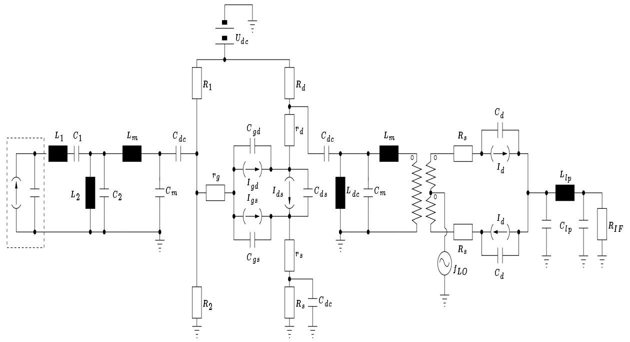

Figure 2: A nonlinear receiver circuit for the study of cosite interference.

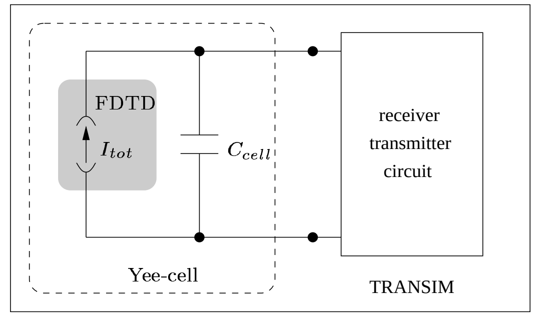

Figure 3: Concept for interfacing a circuit simulator with FDTD.

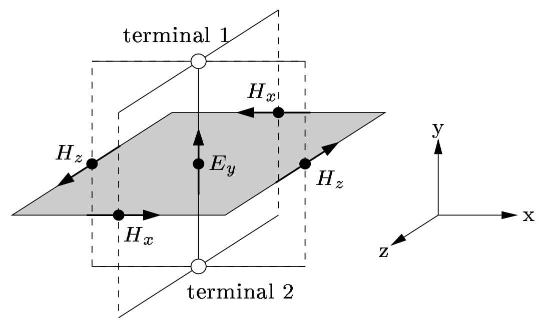

Figure 4: Device current inclusion into FDTD.

2 Problem Specification and Modeling Approach

The most complicated cosite interference scenario that is addressed in this paper is depicted in Fig. 1. Two monopole antennas loaded with receive/transmit modules are mounted on a vehicular platform, within a forest. The hybrid operation of the transceivers is considered, where one antenna receives a signal from a base station far away from the vehicle, while the other antenna radiates a signal at a high power level in a neighboring channel. Since the (parasitic) transmitted signal also impinges on the receiver at a power level that is larger than the desired signal by orders of magnitude, interference effects up to complete desensitization may occur at the power amplifier stage of the receiver.

The hybrid FDTD/circuit simulation models the propagation channel between the two antennas under the influence of both the vehicular platform and the receiver front-end. In addition, the circuit simulator TRANSIM [5] is incorporated into the FDTD, for the purpose of handling arbitrarily complex receiver architectures.

The electromagnetic phenomenology of the case where communication between a receiver and a transmitter is attempted within a forest environment, is characterized by exploiting the method of [6], where a model including multiple scattering from tree trunks and the interaction of the resultant scattered field with lateral waves was presented. In this paper, time domain waveforms extracted by Fourier transforming MoM data on a box enclosing the multi-antenna system, represent an excitation field for the FDTD/MRTD mesh. Subsequently, the operation of transceiver amplification and mixing stages is rigorously estimated. Thus, the complete characterization of cosite interference in the given system is attained, assuming that retro-reflections from the vehicle to the forest and back, add up to second order effects only.

3 An FDTD/Circuit Simulator Interface

The schematic in Fig. 3 shows the basic concept of an interface between a circuit simulator and the FDTD solver. The current through the ports of the receiver circuit is included in the Yee-scheme across two nodes (Fig. 4) via Ampere's law as described in [4].

An equivalent circuit for the Yee-cell is incorporated into the circuit simulator and the voltage across the two nodes is updated by the latter. At each time step, the FDTD algorithm provides the total current, which is simply the loop integral of the magnetic field, as explained in Fig. 4. Since the equivalent circuit of the Yee-cell is linear, it can be readily added to the Modified Nodal Admittance Matrix (MNAM, [5]) and the source vector of TRANSIM. A trapezoidal integration leads to a stable, second order accurate scheme.

4 Receiver architecture

A typical example for the analog part of a VHF receiver circuit is shown in Fig. 2. The receiver network consists of a two-section Chebychev type RF-filter followed by a MESFET based amplifier. The transistor is given by its large-signal equivalent circuit, so that interference phenomena at high power levels can be investigated. A single balanced mixer converts the RF-signal into the IF-stage, where higher mixing

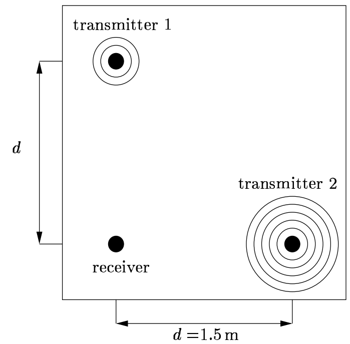

Figure 5: Antenna configuration above a perfect electric conductor.

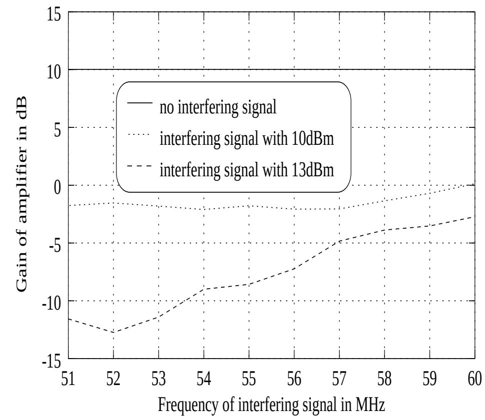

Figure 6: Drop in receiver sensitivity due to strong interference.

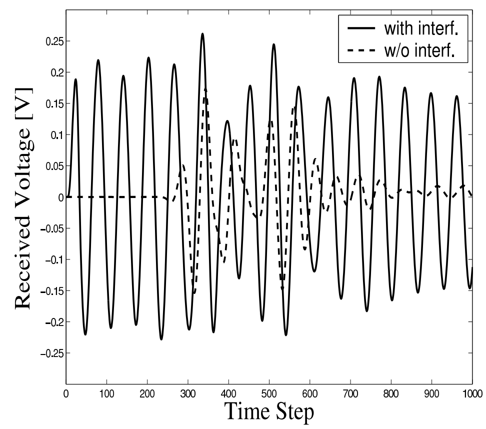

Figure 7: Input voltage at the receiving antenna of the in-forest cosite scenario with and without interference.

products are rejected by the three-section Chebychev type IF-filter to decrease the conversion loss of the mixer. Based on this nonlinear receiver model, studies concerning desensitization effects and its impact on the signal-to-noise ratio are performed when parasitic signals in neighboring channels are received at a high power level.

5 Numerical results

5.1 Cosite Interference

To demonstrate the desensitization of the first amplifier stage, a simple scenario is studied, consisting of two transmitters and one receiver, arranged in a triangle according to Fig. 5. The antennas are located over a perfect electric conducting surface and the computational domain is terminated by absorbing boundary conditions in each direction. The antennas have an input impedance of 37 Ohms at a length of 1.2 m and are loaded with the receiver circuit of Fig. 2 and two 50 Ohm resistive sources, respectively. In the first case, one transmitter radiates a -20 dBm signal and the other transmitter is turnt off. Simulation results show an unimpeded receiver operation in this case. In the case of interference, the second antenna radiates a 40 dBm parasitic signal at 51 MHz. Hence, a power level of about 31.4 dBm is available at the receiving antenna due to the free space attenuation. Finally, the RF-filter of the receiver tuned to 50 MHz attenuates the parasitic signal by an additional 15 dB so that a power level of around 16.4 dBm is still available at the input of the amplifier stage. As a consequence, a simulation of this scenario shows that the IF-signal drops down to -52.4 dBm, and thus the gain of the amplifier is decreased by about 21.7 dB. Furthermore, taking into accout the rise of the noise figure of the transistor caused by the interfering signal, the signal-to-noise ratio is significantly degraded. Thus, the receiver operation may fail completely. This case is graphically demonstrated in Fig. 6.

5.2 In-forest cosite interference

A typical military vehicle geometry with two monopole antennas, 1.2m long, 0.9 m apart, within the forest environment simulated at [6] is considered next. As a remote in-forest transmitter, a Hertzian dipole, emitting a 10-100 MHz pulse is chosen, 1 km away from the vehicle. The input filter of the receiving antenna is tuned at 49 MHz. The second antenna operates as a transmitter, sending a 1 Volt amplitude, 50 MHz tone. Figures 7, 8 depict our simulation results, regarding received voltage and IF spectrum, comparing reception under interference to the interference-free case. Evidently, in the first case, the transmitted tone is dominant and finally is down-converted to a 2 MHz IF signal, as the frequency of the local oscillator of the receiver is set at 48 MHz. It is worth noting that in both cases, the pulse arrives at the antenna having suffered a significant distortion due to the multi-path forest environment (Fig. 7). Moreover, Fig. 8, clearly shows the effect of cosite interference on the amplification of the received

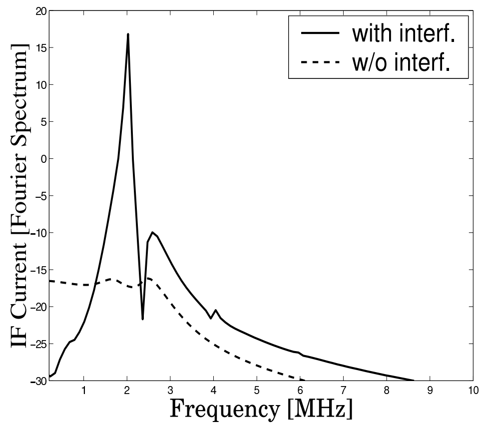

Figure 8: Fourier spectrum of the IF signal at the receiver of the in-forest cosite scenario with and without interference.

pulse, through the up to 15 dB decrease in the IF power level under interference at the passband of the IF filter (whose cut-off frequency is 2 MHz).

6 CONCLUSION

A research effort to completely characterize cosite interference problems in multi-antenna vehicular platforms, by means of full wave techniques combined with advanced circuit solvers, is presented in this paper. Several aspects of such effects were rigorously taken into account, including the operation of front-end electronics and system performance in a forest environment.

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