Numerical EMC in Ground Transportation : How to Manage Efficiently Realistic Automotive Problems

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Abstract

An original coupling procedure between full–wave electromagnetic solutions operating directly in time domain (PAM–CEM™ and/or CEM3D, respectively based on 3D Finite Elements and Finite Differences) and transmission line propagation on cabled structures (CRIPTE) is presented in this paper allowing the numerical analysis of fully equipped realistic models in the field of automotive EMC (ElectroMagnetic Compatibility). The coupling procedure is first validated on simplified test cases, showing very good agreement when compared to experimental measurements before its application on realistic industrial problems. The Auto–EMC European project is also presented, featuring various car manufacturers, software companies and universities, with the aim of developing and validating a complete industrial chain of computer tools for predictive EMC simulations in the field of ElectroMagnetic Compatibility applications.

Introduction

Ensuring the ElectroMagnetic Compatibility (EMC) of a full system in its early design phase is becoming one of the major technical issues for automotive manufacturers. Even if all sub–systems were developed following an EMC compliant design, the convenient electromagnetic behavior of the full system is not guaranteed, creating many sources of potential hazards, difficult to handle through measurements once the first complete prototype is available.

In order to avoid re–design due to EMC problems, the numerical prediction of this behavior can lead to significant benefits already described in a previous paper [1]. At the time of this publication, some industrial examples were briefly discussed : full details are now given in the field of Numerical EMC when applied to realistic industrial automotive situations.

In many practical situations, EMC problems are often characterized by a wide span of ratio between size of geometrical features and wavelength of electromagnetic fields. This is a critical situation for conventional numerical simulation tools, that hardly meet at the same time the requirements of accuracy, memory storage and processing time. Therefore, conventional simulation tools offer limited help in modeling complex EMC situations. These considerations lead to the conceptual approach to numerical EMC, which consists of three complementary levels of simulation, based on different models : full-wave electromagnetic solution of 3D structures (e.g. the bodywork of a car), transmission line propagation on cabled structures (e.g. wire bundles) and circuit formulation for subsystems of negligible size with respect to wavelength (e.g. Printed Circuit Boards). In order to predict the overall response of full systems, such a multi-level approach implies the hybridization of various codes presently available and the definition of a new design paradigm, dealing with practical problems of different scale [4].

The main features of this coupling procedure or hybridization are presented in Chapter 1 for both EMS (ElectroMagnetic Susceptibility) and EMR (ElectroMagnetic Radiation) with some comparison between numerical results and experimental measurements performed on a simplified test case.

Industrial problems are discussed in Chapter 2, where the same coupling procedure is applied on a realistic vehicle for the electromagnetic analysis of an internal harness.

In Chapter 3, the Auto–EMC European project is presented, featuring various industrial partners (car makers, software houses, universities) with the objective of developing and validating a complete chain of computer tools for predictive automotive simulation in the field of Electromagnetic Compatibility (EMC) applications.

1 - Coupling Procedure

In addition to the previous considerations, when analyzing the electromagnetic behavior of full industrial systems, two different situations have to be considered : ElectroMagnetic Susceptibility (or EMS) of sub–systems to external aggressions and ElectroMagnetic Radiation (or EMR) of internal equipment leading to some electromagnetic pollution.

Both theoretical and practical aspects of this coupling procedure were fully described in reference [2] in the case of EMS (ElectroMagnetic Susceptibility) dealing with external aggressions. In that case, three-dimensional software tools were coupled with additional tools specialized in Cable Harnesses, leading to simulation results in very good agreement with experimental measurements. Within this framework where the CRIPTE software tool was coupling with the three–dimensional products developed by ESI Group (PAM–CEM and CEM3D), the external exciting wave interacts with the 3D car–body allowing us to define elementary sources located all along the cabling path. Once adapted to the modeling features of the CRIPTE software, those sources are considered as equivalent voltage generators to be included in a classical analysis model.
Once developed and validated on industrial problems, the same coupling procedure was then extended to ElectroMagnetic Radiation (EMR) of internal harnesses behaving like very large emitting antennas. After a CRIPTE characterization, all induced currents calculated along the internal harness were considered as elementary radiating sources to be taken into account through a three–dimensional explicit modeling applied directly in time–domain.
Fully integrated in ESI Group software tools (PRE-CEM for CAD pre-processing, automatic meshing, electromagnetic fields calculation through Finite Differences or 3D Finite Elements Time Domain solvers, interfacing and Network Topology software), this simulation process is performed in three steps. The resolution of BLT equation using Network Topology allows to calculate the distribution of currents and voltages all along the wires, taking into account the detailed internal structure of the harness. Due to the fact that Network Topology works in frequency domain, while explicit 3D solvers operate directly in time domain, it is then necessary to deduce the currents temporal shape from their spectra using an inverse Fast Fourier Transform calculation. Finally, using three–dimensional software tools, electromagnetic fields radiated by the distribution of current sources are calculated in the surrounding space. At this step the whole structure is taken into account and the current sources are located at their precise location in space. The induced currents and voltages along the receiving antenna are then computed.

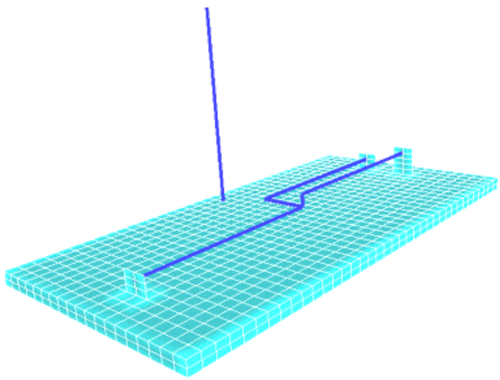


Figure 1 : The test set-up device.

The experimental test set–up device which was analyzed in order to validate this coupling procedure is illustrated in Figure 1. The harness lies over a metallic plane (1.85 meter long, 0.95 meter large), assumed to be perfectly conductive. From left to right, the first section of the harness includes two parallel wires located above the metallic table, at a height of 5 cm. In the middle of the ground plane, they separate : the height of the first wire remains unchanged while the other one rises to 10 cm. Each termination of those wires is connected to a thin metal piece through 50 ohms terminal loads. This harness radiates towards a 80 cm. long wire antenna (radius 3 mm.), connected to the ground plane through 50 ohms loads.
In order to validate all intermediate steps of the entire coupling procedure, a Network Analyzer was used to deduce two types of results. Concerning the harness itself, the scattering parameters corresponding to transmitted and coupled signals for both wires were measured (see Figure 2 and [3]).

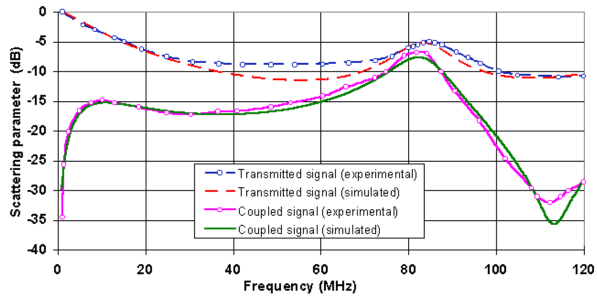


Figure 2 : Transmitted & coupled signals
on cable network (CRIPTE Vs. Measurements).

In EMR configuration, the Transfer Function between the input voltage applied at one end of the harness and the drop of voltage induced on the 50 ohm load located at the bottom of the antenna was measured (Figure 3). The bandwidth of interest ranges from 1 MHz up to 120 MHz. For measurement accuracy, the whole experimental test set-up device was located inside an anechoic chamber.

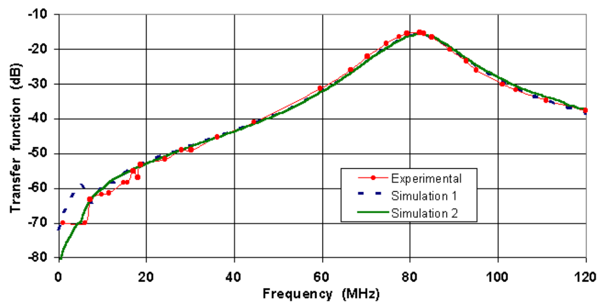


Figure 3 : Transfer function as a function of frequency
(3D / CRIPTE coupling Vs. Measurements).

Results concerning experimental and simulated scattering parameters and depicted on Figure 2 for both transmitted and coupled signals show good agreement. In both cases, the shapes are well reproduced as well as position and value of maximum amplitude. A discrepancy of about 4 dB appears between experiment and simulation, for the minimal values of transmission (between 40 MHz and 70 MHz) and cross–talk (at about 115 MHz). For the EMR

(ElectroMagnetic Radiation) configuration, experimental and simulated Transfer Function are presented for both models of the metallic connectors : short circuit wires into CRIPTE (simulation 1) and metallic surfaces within the three–dimensional model (simulation 2). The agreement is excellent between experimental measurements and simulation results in the whole frequency range whatever the modeling of connectors is.

2 - Realistic Car Body

The simulation procedure presented in the previous Chapter in order to deal with Electromagnetic Interferences (EMI) has been fully validated on a simplified test case. The Transfer Function between a radiating harness and a receiving antenna is well reproduced by coupled simulation, when compared with measurements performed by the EMC team at BMW. Due to the fact that EMI phenomena are modeled by coupling three–dimensional software with Cable Networks tool, nothing stands in the way of applying such a method to handle more complicated structures (full car body) with some complex internal harness. As a result, the next step of this study is its extension to a fully equipped industrial car body.

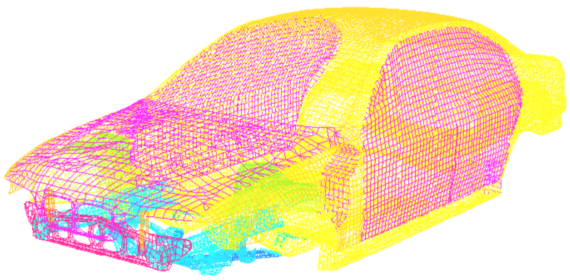


Figure 4 : Existing input data for EMC/EMI analysis.

As far as numerical EMC has to be included in the early design phase of new prototypes, convenient CAD models remain unavailable most of the time and existing meshes have to be managed in order to perform electromagnetic analysis as it was the case in the present application.
Figure 4 is illustrating this typical situation where models defined for crashworthiness studies have to be re–used for EMC/EMI. With the aim of managing efficiently such kind of existing data, a preliminary "cleaning" or adaptation phase is necessary in order to fit numerical requirements of electromagnetic modeling.
All those required capabilities were included in the PRE–CEM pre-processing tool shared by both PAM–CEM and CEM3D computational chains. Existing CAD models can be managed through IGES files but additional PRE–CEM functionalities were developed in order to merge or to split automatically basic entities such as lines or surfaces, to suppress some of them doubly defined, etc.
Using this PRE–CEM pre–processing tool, the adaptation of existing meshes can be performed within a couple of days leading to the definition of a "new" geometry as depicted in Figures 5, illustrating side and top views of the new "geometry" thus created.

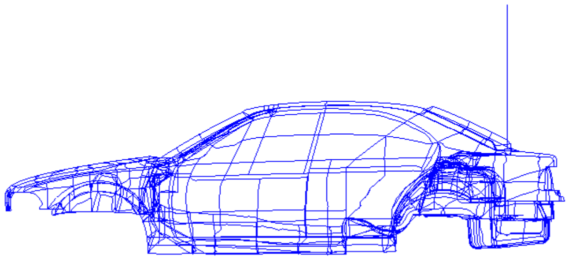


Figure 5a : "new EMC model" (side view).

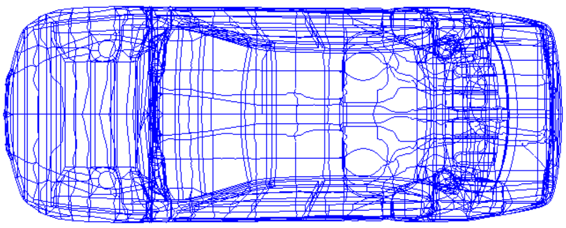


Figure 5b : "new EMC model" (top view).

At that time, the previous coupling procedure can be applied on this realistic model, dealing with the electromagnetic radiation of internal harnesses towards one receiving antenna located on the back hood of the vehicle. One prototype cabling (CD audio network) was considered running inside the whole car, from the front end up to the back hood with some additional parts around the front window (connected to the receiving FM antenna).

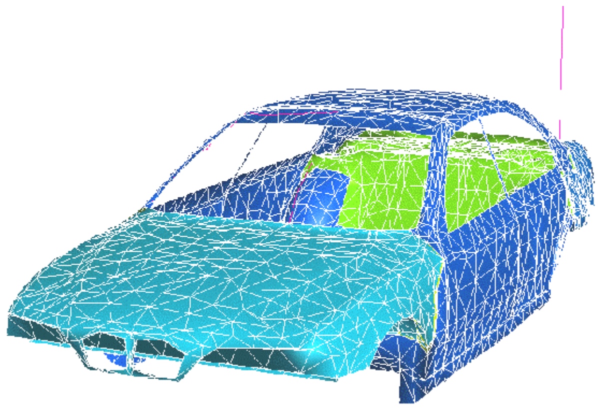


Figure 6 : Surface triangle mesh.

The CRIPTE analysis of this harness was performed in a similar manner as the previous one and coupled to some three–dimensional modeling of the vehicle (see Figure 6 illustrating the intermediate triangle model used for the 3D mesh generation). At the end of this simulation process, the entire electromagnetic environment can be managed by the user in order to visualize radiated fields around the vehicle (as depicted in Figure 7 using isolines display in a cutting plane), as well as far radiated ones or induced voltages and currents on the receiving antenna leading directly to the Transfer Function as described in the previous Chapter.
In this application, simulated results were compared to experimental measurements performed in terms of Trans-

fer Function at the level of the receiving antenna located on the back hood of the car. During this comparison, it appeared that preliminary simulations showed very poor agreement with those measurements, mainly due to the fact that the slots located above the back hood were not taken into account in the initial mesh defined for crash-worthiness studies.

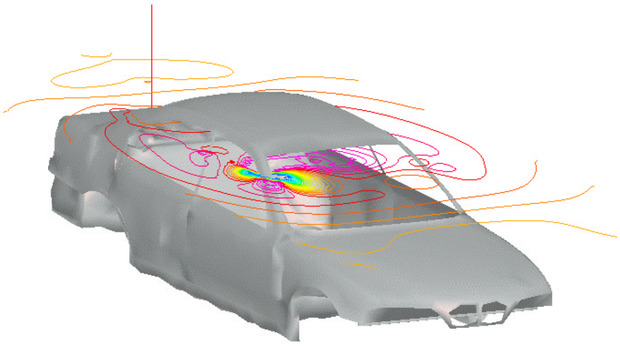


Figure 7 : Electromagnetic radiation of internal harnesses.

One of the most important conclusions of this analysis is that even if existing input data can be easily managed in order to define some possible EMC/EMI models, this adaptation has to be performed with the aim in view of future electromagnetic simulations. As a result, whatever the user–friendliness level of dedicated tools, this CAD or CAE "cleaning" stage should be always checked by EMC experts, controlling that all significant parameters have been precisely taken into account in the final model.
This is one of the objectives underlying the European project described in next section and featuring various industrial car makers, software companies and universities.

3 - The Auto–EMC Project

The main industrial objective of this BRITE EURAM project is to develop and validate a complete chain of computer tools for predictive automotive simulation in the field of Electromagnetic Compatibility applications. Secondary ones are to control the accuracy and performance of automotive test equipment and to contribute to some emerging standards in key areas like car makers / suppliers EMC technical databases and test equipment. The main expected achievement is the validation and the demonstration of an EMC predictive simulation capability : on industrially representative full car size problems from various car manufacturers and integrated in design loops allowing concurrent engineering. Five partners are involved with ESI Group (Prime) in the Project : three of them are car manufacturers (BMW A.G., Centro di Ricerche FIAT, RENAULT), while the other ones are some CAD Software supplier (Analogy Inc.) and a Research Center (Politecnico di Torino). The technical programme is structured as follows.

– Task 1 : CAD interface.
With the aim of creating some adequate geometries allowing the easy generation of CEM meshes, the CAD interface will be mainly dealing with the Car Body, the internal Harness and its Electronic equipment. Various ways will be examined as the classical one (pure CAD data) and for example solutions starting with Crash or CFD meshes. Following industrial requirements defined by our partners, some specialized CAD tools will be defined to exploit data cleaning and mesh generation from other disciplines (see previous Chapter).

– Task 2 : Tool integration.
Three types of numerical tools are necessary for EMC simulation : 3D Maxwell codes (as PAM–CEM™ or CEM3D) for the full equipped 3D car geometry, Harness specialized codes (CRIPTE) for the complex Cable Networks modeling, Circuit codes (SABER) dealing with electronic equipment, loads and sources. Following the experience accumulated in the aerospace industry, these tools were upgraded for automotive applications and coupled one with the other in order to deal efficiently with the complexity of automotive harnesses (see Figure 8 for the Integration level & Figures 9 for the harnesses).

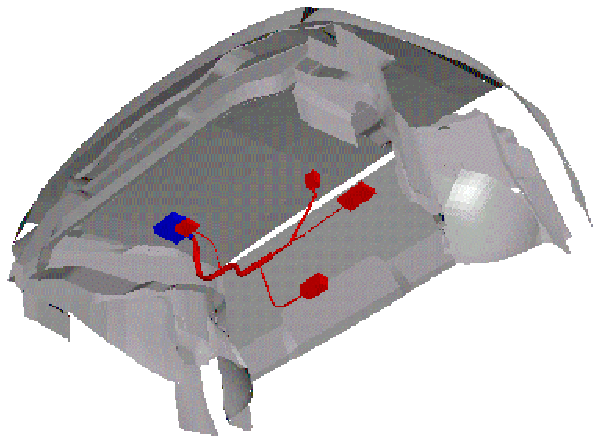


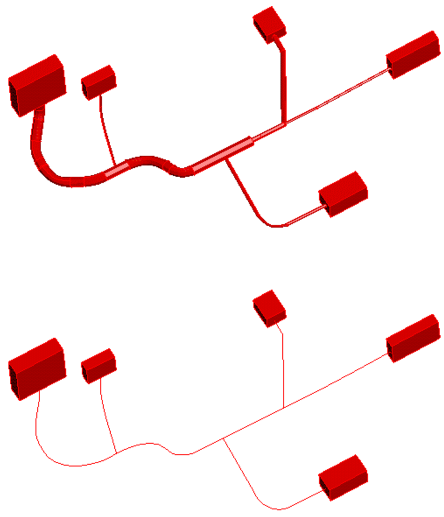
Figure 8 : Engine compartment with internal cabling.

– Task 3 : Scientific validation.
Before the full car analysis, typical situations dealing with Auto–perturbations and Interferences (EMR/EMS) will be analyzed through representative test cases performed using reduced test set-up facilities. Progressively, the complexity of these test cases will be increased (automotive mock-ups) in order to ensure that the integrated tool set is sufficient to be physically representative of critical industrial problems.

– Task 4 : Industrial validation.
As an extension of the previous task, critical areas for each problem considered in Task 3 (Auto–perturbations, Emission and Susceptibility problems) will be managed following industrial needs, depending on the timing within the time frame of the design cycle. The relative role of the assemblers and suppliers will be here clarified and detailed in Task 6.

– Task 5 : Advanced methodologies.
This task is dedicated to the analysis of typical Harness problems due to the lack of information concerning the precise location of sensitive wires inside cable bundles.

This task was included in the project following the request of RENAULT which consider such studies as important ones for the EMC phenomena understanding. Politecnico di Torino is directly involved in such Advanced Methodologies.



Figures 9 : Cabling of Electronic Control Unit (ECU).

– **Task 6 : Contribution to standards.**
This project will contribute to precise various EMC Tests Standards, the Assemblers-Suppliers relationship and some Simulation standards which are currently non-existent. The know-how accumulated in the project will propose typical simulation methodologies to be used in the early phase of Automotive EMC Design.

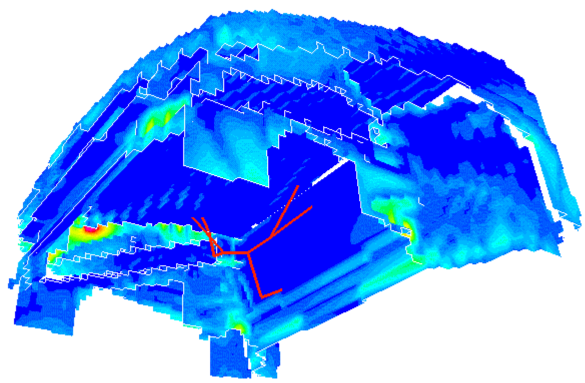


Figure 10 : EM radiation of the Electronic Control Unit.

Conclusions

An original coupling procedure was presented in this paper allowing the numerical prediction of the electromagnetic behavior of fully equipped realistic models in the field of automotive EMC (ElectroMagnetic Compatibility). In addition to their stand–alone use, various simulation tools are coupled one with the other in order to manage efficiently full–wave electromagnetic solutions as well as transmission line propagation on cabled structures or circuit formulations for electronic equipment connected through this cable networks. The coupling procedure was first validated on simplified test cases, showing very good agreement when compared to experimental measurements before its application on realistic industrial problems. The Auto–EMC European project was presented as well, featuring several car manufacturers, software companies and universities, with the aim of developing and validating a complete industrial chain of computer tools for predictive EMC simulations in the field of ElectroMagnetic Compatibility applications.

Acknowledgments

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