Numerical Simulation for Early EMC Design of Cars

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Abstract

Current innovative trends in the car industry are essentially based on more and more sophisticated and dense electric and electronic systems, leading to still growing electronic noise levels, and increasing the the risk to miss the EMC standards, as well as to perturb the functional integrity of the systems. This makes more and more acute the need for numerical prediction as early as possible in the design stages, to avoid the limited technical and economic efficiency coming from late stage management of EMC issues.

This paper describes the approach to early EMC design of cars experimented under the AutoEMC European Project, granted by the European Community, which gathered car makers, software providers and researchers to address this topic.

An original coupling procedure between 3D Finite Elements, Transmission Line propagation and circuit modeling is described and validated on basic cases of fundamental interest for automotive applications. The application of this approach to realistic full car modeling is then presented, with a short description of the software adaption performed to reach a correct level of industrial efficiency. The question of the sensitivity of EMC properties of the assembled system to uncertainty on local details like random bundling is addressed, and a conclusion regarding the practical use of numerical simulation at early stages of EMC design of cars is proposed.

Introduction

Mastering the EMC-related features of a full car 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 integration may create many sources of potential hazards for the overall electromagnetic behavior of the complete system, hazards detected only once the first complete prototype is available, and whose resolution is usually, at this point, difficult and expensive.

The numerical prediction of this behavior can lead to significant benefits [1], by avoiding late re–design and modifications of equipment implementation.

Practically, the major challenge for numerical simulation of such complex systems is to be able to deal with very different relevant geometric scales, related to the three main parts of the problem : the car body, the harness and the equipment.

This was the starting point of the AutoEMC European Project, which gathered car makers, software providers and researchers in view of addressing this topic, up to the design of effective methodologies and related tool sets. The approach developed under this project is essentially based on the close association of three complementary levels of modeling into a single simulation environment : full-wave 3D resolution at the car body level, transmission line propagation at the harness and bundles level, and circuit formulation for equipment of negligible size with respect to the wavelengths of interest.

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In order to predict the overall response of full systems, such a multi-level approach implies the cooperation of corresponding specialized codes [4] : this paper describes how the AutoEMC project implemented such a strategy, based on loose coupling of specialized solvers sharing common CAD information.

The main features of this multi-level approach are presented in Chapter 1 for the four main problems in car design : cross-talk, emission, immunity and antenna design. Chapter 2 presents some of the fundamental validations performed to check the relevance of this approach by isolating some critical articulations of the loose coupling paradigm. The application to industrial problems is then discussed in Chapter 3, where this numerical strategy is applied on a realistic vehicle with internal harness, while Chapter 4 adresses some specific issues related to industrial predictiveness.

Finally, the most salient conclusions of this work are drawn in Chapter 5, with emphasis on the difficult question of reachable numerical accuracy (formal predictivity) versus industrially relevant accuracy (product variability), and a suggestion is made about optimal use of numerical prediction in this area.

1 - The Multi-level Coupling Strategy

To be useful, numerical prediction has to bring answers to the usual questions of an EMC engineer in his every day work. The main questions addressed in this work are : crosstalk (coupling between wires inside a harness), emission (radiation from the harness towards the environment or an antenna), immunity (of equipment against external electromagnetic aggression).

The three main data of the problem have totally different geometric characteristics : large 3D structures (car body and free space), long but thin - almost 1D, "1,5D" when ground plane effects are taken into account - cables (harness), and small equipment components (essentially 0D). Of course, this scattering of geometric scales corresponds to different physical behaviours, usually leading to different modeling approaches (hence, different specialized software) : full 3D PDEs, Multiconductor Transmission Line (MTL) equations, and ODEs. It is worth noticing that the standard organization of CAD repositories echoes this scale-based distinction : usual structural CAD for car body, usual electronic CAD for equipment, and (more recently) specialized CAD representation of wiring (*e.g.* CATIA/E3D).

The multi-level approach retained in this Project was therefore to keep the use of specialized solvers at each level (rather than trying to target a global resolution), and to loosely couple them by allowing 2-ways transfer of relevant data and results between each solver pair, with the convenient reacting of this information when required.

For all the four problems of major interest for automotive EMC applications, this may be symbolized in the following way :

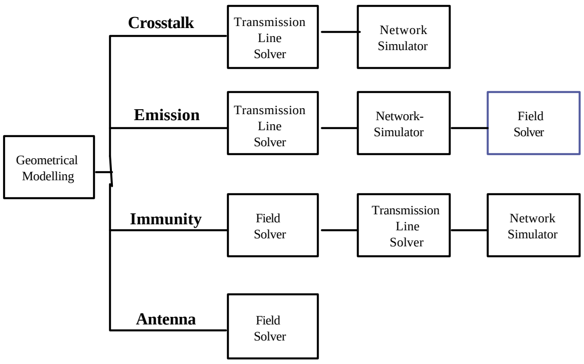

Fig. 1 - Multi-level coupled approach

This approach essentially follows the theoretical and practical outlines fully described in [2]. This choice leads naturally to a "loose coupling" (essentially a data transfer, involving direct and inverse Fourier transforms) between the three levels of modeling because of purely practical reasons : 1) time domain simulations are more efficient for extended frequency ranges in 3D; 2)most industrially referenced transmission line solvers work in the frequency domain; 3)all circuit simulators work in the time domain to deal with behavioural non-linearities. For instance, the commercial software[5] used in the AutoEMC Project were :

- for 3D fields : CEM3D (finite differences) and PAM-CEM™ (finite elements) in the time domain;
- for networks : CRIPTE and CableMod™, in the frequency domain

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[5] CEM3D is a property of ESI-Group; PAM-CEM™ is a product of PSI; CRIPTE is a property of ONERA, distributed by ESI-Group; CableMod™ is a product of SimLab Software GmbH; Saber™ and Saber™-Harness are properties of Analogy Inc.

- for circuits : Saber and Saber-Harness, in the time domain.

Not surprisingly, the "pivot" scale of the harness plays a major role in this modelization strategy : that is why a specific emphasis was put on the validation of its articulation with both the 3D field resolution and the equipement level modelling. The next chapter sketches the fundamental validations which were performed to assess the methodology at this level.

2 - Basic Investigations

The first methodology aspect to be validated is the effectiveness of the loose coupling between 3D field computations and network simulations (using MTL equation). This was performed by numerical / experimental confrontation on the radiation (EMR) of the following device :

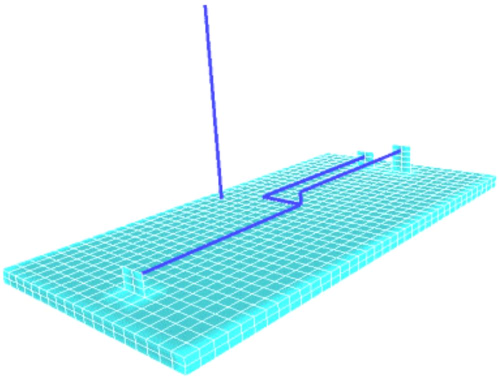

Fig. 2 - EMR : test set-up.

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 5cm above the metallic table. 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 50Ω terminal loads. This harness radiates towards a 80 cm. long wire antenna (radius 3 mm.), connected to the ground plane through 50Ω loads.

For this ElectroMagnetic Radiation (EMR) configuration, the validation criterion is the Transfer Function between the input voltage applied to the harness and the voltage drop induced on the 50Ω load at the bottom of the antenna, the frequencies of interest covering the FM band, from DC up to 120MHz. For measurement accuracy, the whole experimental test set-up was located inside an anechoic chamber.

The coupling methodology consists in building a MTL model of the harness (including ground planes), computing the currents generated along the harness path, and making these currents radiate as dipoles in the 3D simulation. The coupling only requires a data format transfer and a Fast Fourier Transform (FFT).

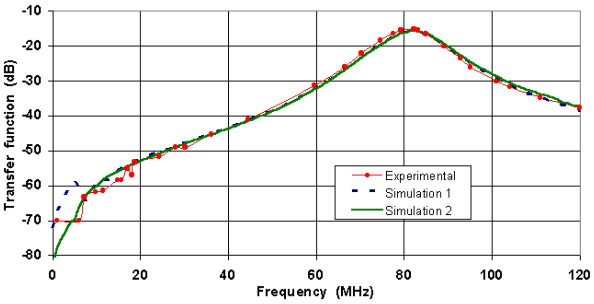

Fig. 3 - EMR : 3D/MTL *vs* Measurements

The figure 3 above shows the experimental results and the simulated Transfer Function for two different modelings 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.

However, this validation already exhibits an important feature for mastering the predictivity of numerical EMC : all relevant details (here, the precise modeling of the contacts) are of importance.

The second articulation to be validated stands between the MTL and the Circuit modeling. The two cases of emission and susceptibility led to different coupling approach, and to specific validations. In both cases, the objective of the coupling is to associate the harness (linear, with interference effects between wires) and the circuit (0D, but non linear) in an integrated simulation model.

For the susceptibility analysis, the MTL code is used to generate an "active" (*i.e.* including a representation of the sources) Z-model of the harness inside the car, which takes into account all wires coupling and ground planes. This Z-model is then used in the circuit simulator as a blackbox component, which allows to represent the realistic EMC behaviour of the aggressed harness when associated with its non linear terminal loads.

In the reverse way, for the modeling of the emission from an equipment, the MTL code is used again to generate a lumped model of the harness alone, still used in the circuit simulator as a blackbox component, able to represent the realistic signal propagation along the harness when excited by the associated non linear circuit[6].

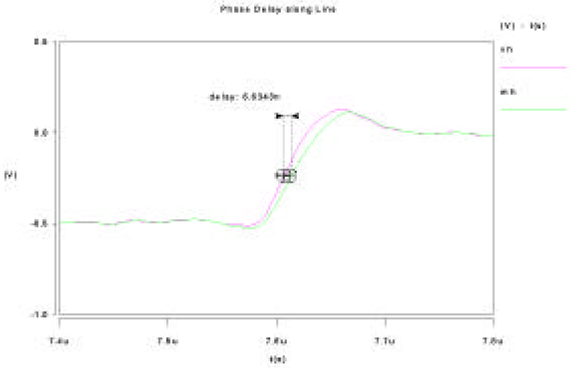

Fig. 4 : MTL/Circuit : Phase delay of current signal along a CAN bus

3 - Realistic Applications

Once the basic principles of the multi-level strategy have been validated on academic cases, the question of its practical exploitation in realistic industrial context arises : this chapter will essentially focus on complementary practical aspects of the methodology, essential from the point of view of industrial effectiveness, and which justified the work performed under AutoEMC to connect all required solvers into an efficient integrated tool set.

The first step to go through is the acquisition of the geometrical data, usually stored in CAD repositories.

For 3D simulations, a mesh has to be generated from the geometry of the car body : when addressing the early stages of the car design, the 3D geometric modeling has to face the problem of partial, approximate, and often topologically ill defined, geometrical descriptions, which, however, have never been built for EMC analysis. To circumvent this difficulty, a specialized pre-processor (PRE-CEM) has been built, to offer convenient CAD repair and cleaning tools. To take also into account the rarity of available geometry representations at this early stage, PRE-CEM can input both CAD models in IGES format, and pre-meshed models, typically in NASTRAN format.

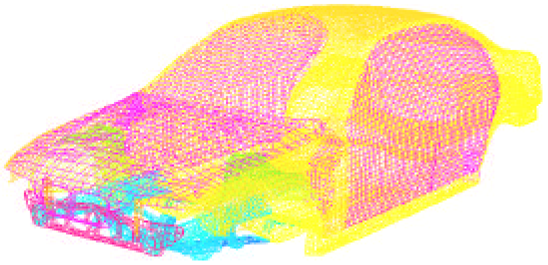

Fig. 5 : Typical early car geometry definition (Crash Mesh)

When it comes to the harness modeling, the MTL code needs to know the location of the reference structures to be taken into account to get a realistic modeling of the line parameters (capacitance and inductance). This led to the development of a "parser", able to extract automatically partial cuts of the 3D structure acting as ground planes, at user prescribed locations along the harness path. Finally, PRE-CEM is also able to input specific parts of the geometry files as representing wires, antennas or harness mean path : this information will be shared by the 3D and MTL solvers in coupled simulations.

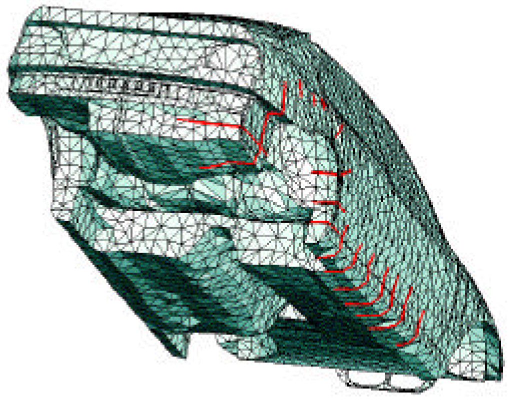

Fig. 6 : Parsing of ground planes for harness from 3D CAD data

The next step is mesh generation for 3D simulations. The project used a commercial unstructured, automatic mesh generator (PAM-

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[6] This has become a standard feature of Saber-Harness

GEN3D™) currently used for CFD applications. Its adaption to EMC models was limited to the development of two specific features, dedicated to the meshing of thin surfaces and of wires.

Thin surfaces : EMC models of cars have to deal with the thin metal sheets defining the car body; these metal sheets are physically perfectly conducting, thus avoiding the need to model explicitely their thickness. Therefore, for the sake of CPU efficiency, a specific treatment corresponding to infinitely thin surfaces was integrated into the advancing front algorithm of the mesher.

Wires : 3D field solvers usually use specific local models around the wires to accurately describe their EM radiation in emission simulations; the numerical counterpart of these specific modeling of emitting wires is the requirement for a semi-structured mesh around them, approximating correctly the natural near-field symmetry of revolution around the thin wires.

The discretisation is performed in two steps, allowing indifferent use of FD or FE resolution algorithms : first, a surface mesh is built. In a FD context, this surface mesh is thus intercepted by the structured FD mesh, while in FE context, after semi-structured meshing of the emitting wires, the mesh generator will continue to produce a complete tetraedral unstructured 3D mesh.

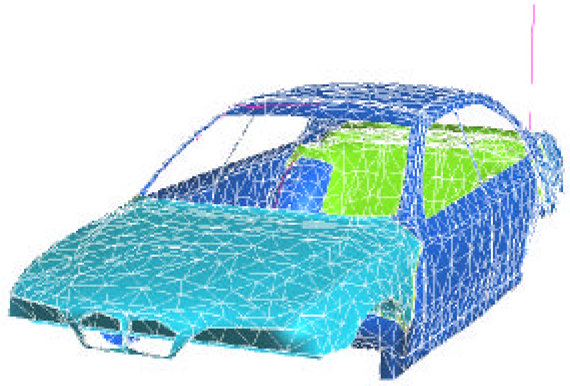

Fig. 7 : Surface + wire mesh

The last information needed to complete the computational model is the set of physical parameters. A specific direct interface between CATIA/E3D and Saber-Harness has been developed : however, the electric information provided by CAD sytems is usually poorly convenient for direct acquisition into a simulation model, and has to be recast in a convenient way by the user. These parameters can be defined for CRIPTE and PAM-CEM™ using their respective GUIs.

Using PRE–CEM and all the related tools described above, the complete modeling (CAD repair & cleaning, meshing, parsing, definition of physical parameters and simulation conditions) of a typical car can be performed within a couple of days.

As an application, we shall now briefly describe the simulation of the radiation of internal harnesses of a real car towards one receiving antenna located on the back hood of the vehicle. A single prototype cabling (CD audio network) was considered, running through the whole car from the front end to the back hood, with some additional parts around the front window (connected to the receiving FM antenna).

In this case, the generic multi-level coupling procedure reads as follows :

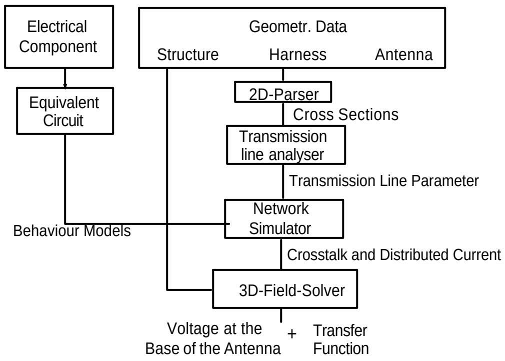

Fig. 8 : Multi-level approach for full car.

The CRIPTE analysis of the harness is performed in a way similar to what has been described in chapter 2 above, as is the coupling between the equipment and the harness.

At the end of this simulation process, the entire electromagnetic environment of the car is available for visualization of radiated fields around the vehicle (as depicted in Fig. 9 below, using isolines display in a cutting plane), as well as far field radiation pattern, induced voltages and currents on the receiving antenna (leading directly to the evaluation of the Transfer Function), and currents along the harness. The relevance of those various outputs, which can be used for building transient movies, depends of course on the type of problem under investigation (emission, interference, etc…).

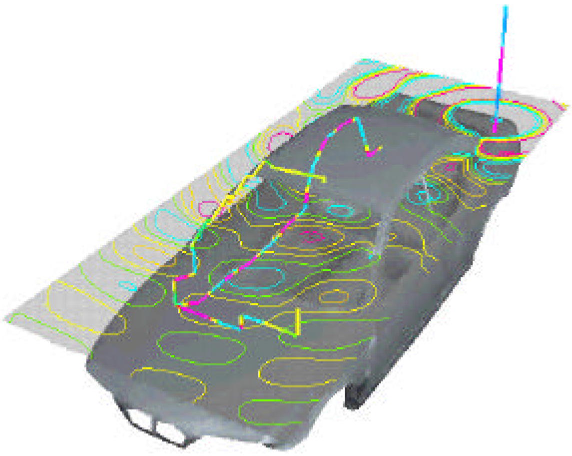

Fig. 9 : 3D field and harness currents

In this specific example, simulated and experimental Transfer Function were compared at the level of the back-hood receiving antenna. This comparison evidenced the frequent necessity to take into account geometric details : here, to obtain a good fitting between simulation and measurements, the slots located above the back hood had to be taken into account (while the initially given mesh defined for crashworthiness did not represent them).

For early EMC design, when the exact geometry is still not totally fixed, this requirement clearly brings some practical limitation to the theoretical predictivity of such numerical analysis : an approximate geometric description may be fairly satisfactory for the bulk car body, while some specific parts (slots, shelters, …) have mandatorily to be precisely known to ensure the reliability of the conclusions.

4 - Complementary Investigations

All the validation tests sketched in the previous chapters demonstrated that the predictivity of the proposed approach to numerical EMC enjoys a fairly satisfactory level of formal predictivity. But it is of importance to notice that, for obtaining a precise fitting between numerical and experimental results, the latter had to be obtained in strictly controlled conditions.

Indeed, the industrial effectiveness of this formal predictivity is not straightforward, since cars, as real industrial products, are subject to a lot of local uncertainties, both at the level of individual components design (*e.g.* detailed wiring of bundles) and at the level of system integration (*e.g.* exact path of harness).

Starting from this fact, the AutoEMC project developed also two specific actions, focusing the issue of making, through numerical simulation, early EMC design decisions which would not be over-sensitive to the uncertainty occurring in the real-life process of the product building and integration. The first task addressed the problem of the sensitivity of EMC behaviour of harnesses to the dispersion of their main geometric and physical parameters, and their statistical handling. The second task focused on best practice rules able to ensure that early numerical EMC design decisions would still hold at the level of the complete, deliverable, car.

A very simple device, made of a pair of parallel wires running over a ground plane to which they are connected, was used to numerically analyse the dependency of crosstalk and transmission properties on geometric parameters (wires diameter, distance to ground) and on wire permittivity. The main result is that the major factor of influence is the distance to the ground, the other effects, while not totally negligible, decreasing quickly with this distance.

Using the same device, and allowing the wires to stand at a wavy distance from the ground, numerical experiments were performed, using a random-wire model developed by Politecnico di Torino [6]. The figure 10 below shows the results that can be obtained for crosstalk by different methods :

- bold : experimental result
- dotted: uniform distance to the ground (standard numerical simulation)
- light : results for 100 random realisations
- solid : one typical "random distance" result.

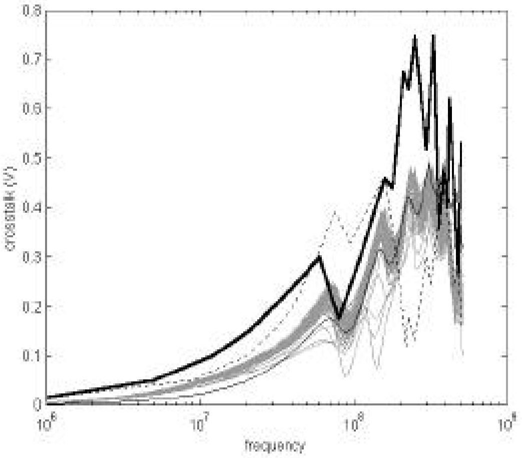

Fig. 10 : Random Wire Model

The "random distance" wire is, practically, a series of concatenated wire sections, each of these sections having a specific "distance to ground", determined from a pseudo-random method based on fractal algorithms.

It appears clearly that, while a "theoretical" numerical modeling based on uniform parameter hypothesis gives poor experimental fitting for the overall crosstalk level throughout the whole frequency range, averaging "random wire" models brings noticeably better overall results. The fact that the crosstalk level is still not correct using Random Wire modeling would need a deeper analysis in two directions : modeling of the wires connections, of course, but also reproducibility of the experimental device and related measurements.

This same Random Wire modeling, which may be applied to any set of parameters attached to the wires and/or bundles physics, may also be used for the description of the consequences of random bundling, which is the other major effect on the dispersion of cross-talk, as illustrated by the histogram below, computed for different realisations of a 9-wires bundle (using a traditional, deterministic simulation method) :

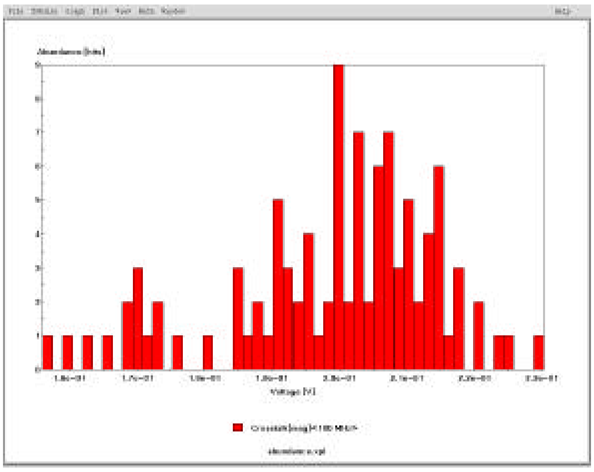

Fig. 11 : Effect of random bundling on crosstalk

On the front of methodology, rational guidelines for effective use of numerical simulation in early EMC design were looked for [5].

This work reviews the peculiarities of EMC problems in the car industry, the related standardisation and legal requirements (with special focus on the 95/54/EC directive), and the existing software tools. Some proposals are made regarding a set of standard basic test-cases able to qualify the simulation codes for automotive EMC applications, as well as elements of best practive rules.

Conclusions

A multi-level, loosely coupled procedure has been presented, validated on fundamental cases, and proven to be efficiently applicable to realistic full car problems. This procedure can be implemented without major difficulties on the basis of standard relevant simulation software. In addition, some insight is given on the effect of the natural dispersion of bundles characteristics on EMC properties, and the application of a specific "Random Wire" model has been demonstrated.

With respect to the use of numerical simulation for early EMC design of cars, some conclusions appear clearly.

1- For 3D field calculations, geometric modeling accuracy is a critical factor in sensitive areas, where diffraction may occur. This, combined with the need for results across wide frequency ranges, promotes the choice of Finite Elements methods in this applicative area.
2- The formal predictivity of the numerical simulation may be demonstrated on well mastered situations; taking into account some more features (welding points, geometry defects, etc…) could still improve this predictivity.
3- However, as regards early design, this formal predictivity cannot be fully exploited, because of the still inaccurate and moving definition of EMC relevant details (harness paths, small shielding metal sheets, …). Of course, this is strongly related to the organization each car maker applies in the design process, but it seems to be today's state of the industrial design art.
4- In this context, it has been clearly evidenced that numerical EMC can noticeably help EMC engineers to choose between different design options, in order to avoid late and expensive design modifications, and to assess from the beginning the EMC properties of a full vehicle. As of today, the main limitation for a full exploitation of numerical predictivity seems to be the limited precision in car making and assembly : it is still unclear whether - and when - car industry will need to evolve in this direction.

Acknowledgments

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