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Electromagnetic Interferences (EMI), Conducted and Radiated emissions of a harness towards a receiving antenna : comparison of numerical simulations with measurements.

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Abstract

This paper presents the comparison of experimental and simulated results for the electromagnetic fields radiated by a harness located over a ground plane towards a receiving antenna. The related measurements have been achieved by the Electromagnetic Compatibility (EMC) team at BMW and the simulation have been carried out jointly by ESI Group and BMW EMC teams. The voltage transfer function between the harness and the antenna is accurately reproduced by simulation as well as the scattering parameters characterizing the harness.

1 - Introduction

Electric and electronic components and systems must comply with increasingly tougher regulations. They must resist hostile electromagnetic environments and show reduced emissions. In the transportation industry, the usage of electronics in vehicles has increased at a phenomenal rate in the last decade, and continues to do so, for example to enhance automatization, driver comfort and vehicle safety.
This paper deals with Harness and Antenna ElectroMagnetic Interferences (EMI) and Conducted and Radiated Emissions design through the analysis of a simplified test case.
It is representative of a few typical cases of :

- **Autoperturbations** or **Electromagnetic Interferences** (EMI) which occur during emission of an equipment on a wire and lead to signal changes on near-by wires. Another example is the conducted emission of an internal wired system that emits towards a receiving antenna of a car,
- **Emission** configuration, dealing with Conducted Emissions of large harness systems towards the external environment (Electromagnetic pollution). In such a case, the internal harness of a car behaves like a very large emitting antenna.

The experimental setup and the measurement process are introduced in Section 2. In Section 3 the available EMC tools are reviewed and the simulation procedure used to model EMI is explained in details. Experimental and simulated results are depicted and compared in Section 4.

2 - Experimental test set-up

The experimental test set-up which is analyzed is depicted on Figure 1. The harness lies on a dielectric substrate which is not modeled having regard to the reduced value of its relative permittivity (ε_r=1.1). The ground plane is assumed to be perfectly conductive, as well as thin metal pieces (perpendicular to the ground plane) on which the wires are connected.
The geometrical dimensions of the ground plane are 1.85 m long and 0.95 m large. The height of the metal pieces is 5 cm for two of them and 10 cm for the last one, their width is 5 cm.

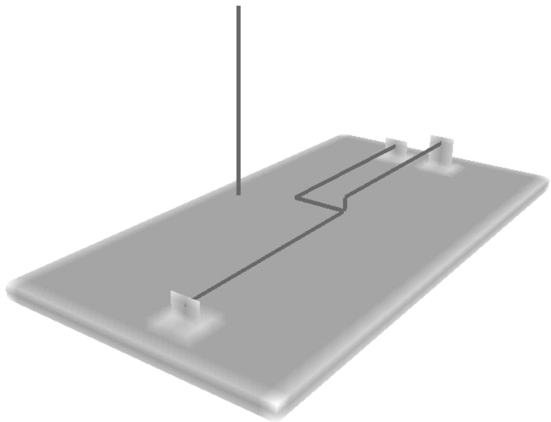

Figure 1 : Experimental test set-up

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.
The wire antenna is 80 cm long with a radius of 3 mm, it is connected to the ground plane through 50 Ω terminal loads. Two positions have been considered for the antenna (named position 1 and 2 in the following). The relative locations of antenna and harness are represented on Figure 2.

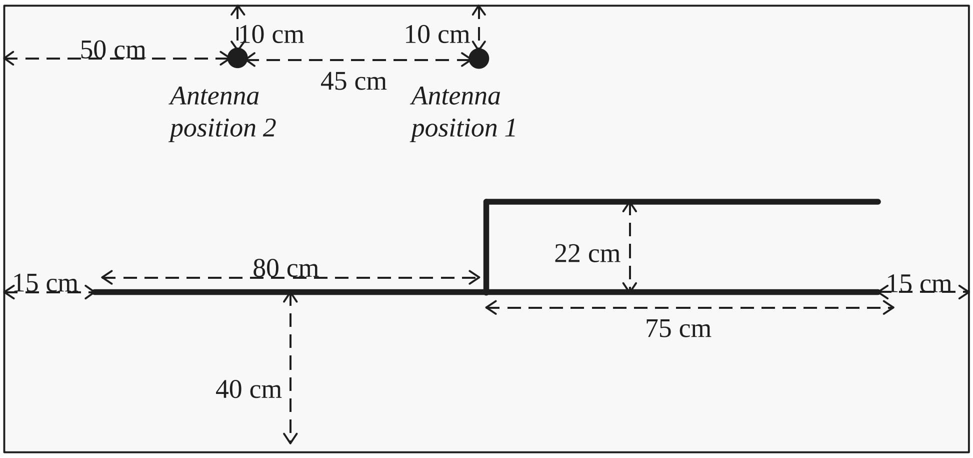

Figure 2 : Geometrical location of Harness and Antenna
(*Top view*).

The two wires system is depicted on Figure 3. Each termination of the wires is connected to a thin metal piece through 50 Ω terminal loads. In this system, stranded conductors are used with dielectric of relative permittivity ε_r=3.

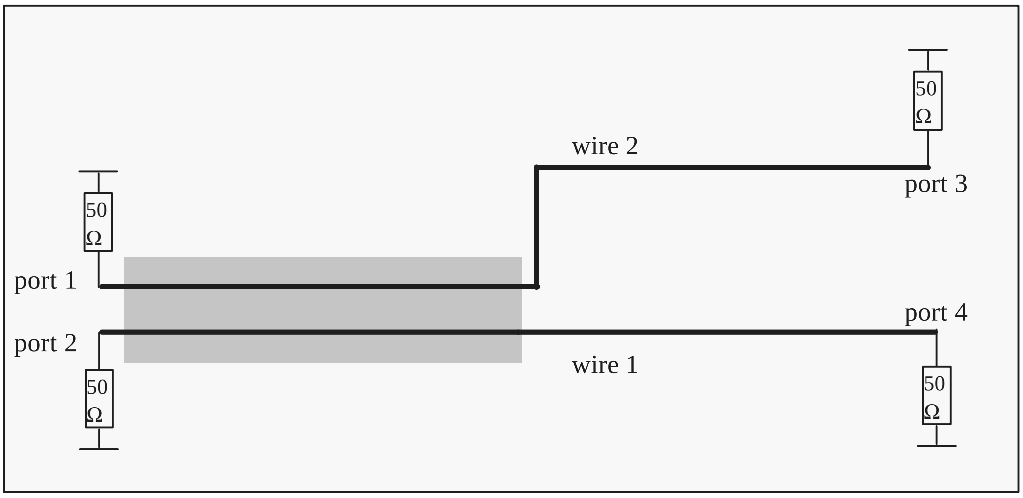

Figure 3 : Radiating two wires system
(*Top view*).

A Network Analyzer was used to deduce two types of results.
Concerning the harness itself, the scattering parameters corresponding to transmitted (S_{13} between port 1 and 3) and coupled (S_{14} between port 1 and 4) signals for wires #1 and #2 were measured.
In Emission configuration, the Transfer Function between the input voltage applied at the right extremity of wire #2 on port #3 and the drop of voltage induced on the 50 Ω load located at the bottom of the antenna was measured.
The bandwidth of interest ranges from 1 MHz up to 120 MHz.
For measurement accuracy, the whole experimental test set-up device was placed inside an anechoic chamber.

3 - EMC tools and simulation approach

The Electromagnetic Group at ESI has assembled a coherent simulation approach. It includes a set of three dimensional software (CEM3D : Finite Difference Time Domain or PAM-CEM : Finite Element Time Domain,), and specialized numerical tools (CRIPTE : Network Topology), to be used with databases of validated experiments and numerical components.

Within the framework of this approach, Electromagnetic Interferences (EMI) as well as Electromagnetic Susceptibility (EMS) problems are considered by coupling the numerical tools specialized in Cable Networks analysis with the 3D software. This method allows to describe accurately both the 3D structure and the harness. The 3D structure is discretized without the harness which is characterized using CRIPTE. It avoids some rough approximations which would occur if CRIPTE (structure reduced to an infinite ground plane) or the 3D solver (Thin Wire model) were applied in a stand-alone use.

The simulation process is whole integrated using ESI Group software, namely PRE-CEM (CAD pre-processor), Finite Difference or 3D Finite Element Time Domain solvers, C3M (interface) and Network Topology software.
The modeling of the previous experimental test set-up device in Emission configuration is performed in three steps :

1. 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. At the end of step 1, two types of results are available : the distribution of currents aimed to be used in the following steps and the scattering parameters (for Crosstalk characterization), which can be compared with experimental ones.
2. Due to the fact that Network Topology works in frequency domain, while our 3D solvers are time domain ones, it is necessary to deduce the currents temporal shape from their spectra using an inverse FFT (Fast Fourier Transform) calculation.
3. Using the 3D FDTD solver, 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 exact positions in 3D space. The induced currents and voltages along the receiving antenna are then computed.

The pieces of metal on which the wires are connected have been taken into account either in step #1 (CRIPTE network) or in step #3 (3D mesh of the structure). When using CRIPTE, they are modeled like short circuit wires : the related wires are characterized by a high admittance and a low impedance.

When introduced in CEM3D, they are represented by infinitely thin perfectly conductive metallic plates. Numerical simulations have been performed in both situations : a view of the related meshes and harness is depicted on Figure 4a (with terminal ends considered as thin metallic wires) and Figure 4b (with terminal ends considered as metallic surfaces).

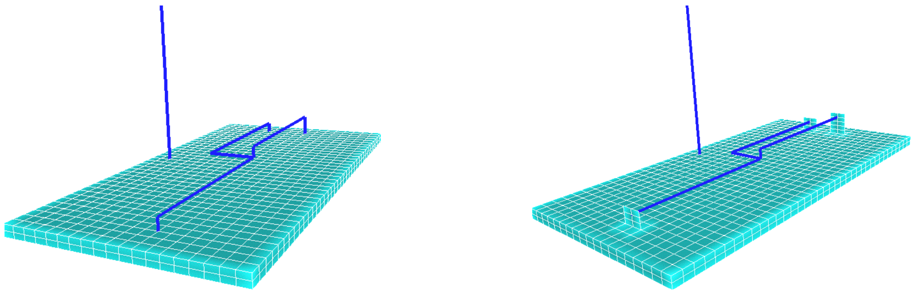

Figure 4a Figure 4b

Figure 4 : FDTD mesh

4 - Comparison of experimental and simulated results

The results concerning experimental and simulated scattering parameters are depicted on Figure 5 for both transmitted and coupled signals (for a definition of scattering parameters see Section 2 above). The simulated results fit quite well experimental ones. 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 crosstalk (at about 115 MHz).

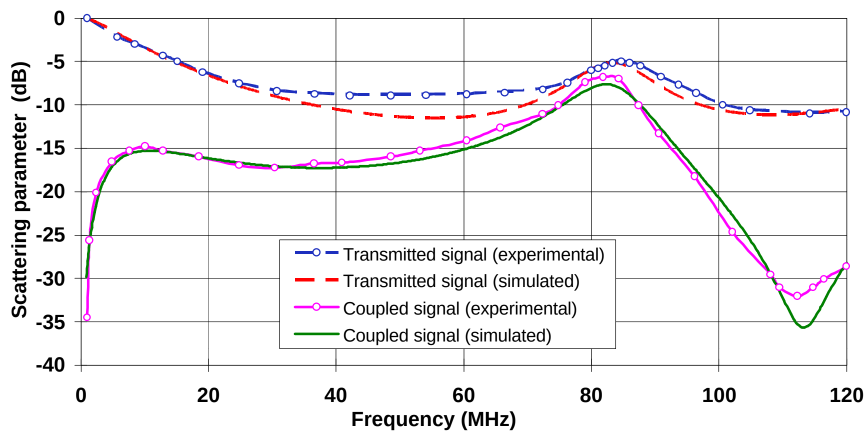

Figure 5 : Wiring response

For the Emission configuration, the experimental and simulated Transfer Function (see Section 2) in position 1 of antenna is depicted on Figure 6. Simulated results are presented for both models of the metallic connectors : short circuit wires into CRIPTE (simulation 1) and metallic surfaces using CEM3D (simulation 2). The agreement is quite good between experiment and simulation in the whole frequency range whatever the modeling of connectors is.

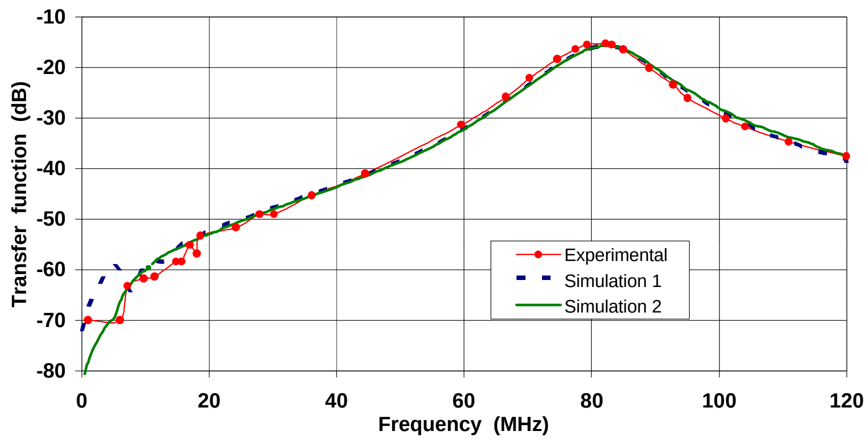

Figure 6 : Antenna response in position 1.

It is important to notice that the influence of connectors is far from negligible as can be viewed on Figure 7, where the Transfer Function deduced from a simulation run is considered without precise connectors models. The comparison of Figures 6 and 7 show that these connectors produce a significant part of the antenna response. This is likely to be a consequence of the geometrical configuration of the interaction, indeed the antenna is perpendicular to all the wires leading to a minimum coupling effect between the antenna and the wires.
At the same time, the connectors are parallel to the antenna leading to a maximum coupling effect between antenna and connectors (see Figure 4). Moreover, neglecting the connectors leads to an enhancement of the Transfer Function in the low frequency range (1 MHz - 10 MHz). This result is not astonishing if we consider that the current loop is not closed anymore, when neglecting the connectors. An accumulation of charges occurs at the ends of the harness which are floating into the air, generating some static electromagnetic field.

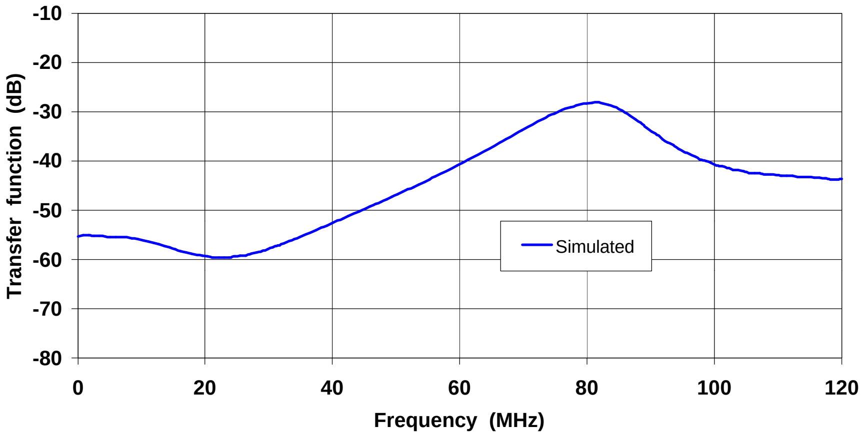

Figure 7 : Antenna response in position 1 without connectors.

The measured and simulated Transfer Function (see Section 2 above) for position 2 of antenna is depicted on Figure 8. Simulated results are presented when modeling metallic connectors as short circuit wires into CRIPTE (previous results have shown the equivalence of both models).
As for previous situation (antenna in position 1), the agreement is quite good between measurements and simulations in the whole frequency range (experimental results are not depicted for frequencies below 50 MHz due to their noisy aspects).

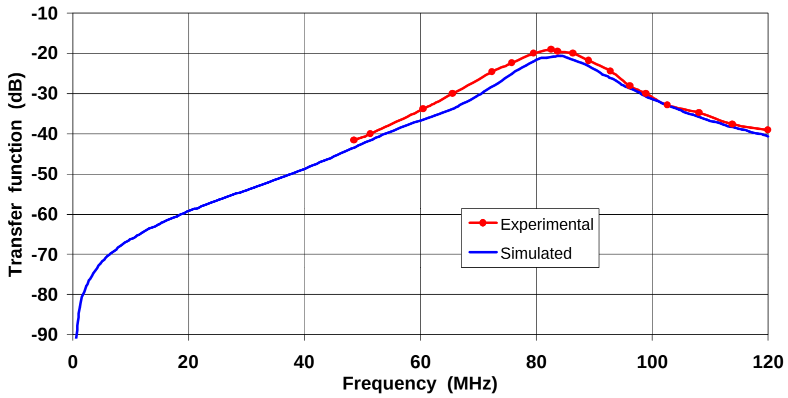

Figure 8 : Antenna response in position 2

5 - Conclusion

The simulation procedure proposed in this paper 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 simulation, when compared with measurements performed by the EMC team at BMW.
Due to the fact that EMI are modeled by coupling some 3D software with Cable Networks specialized tool, nothing stands in the way of applying such a method to handle more complicated structures (like a full car body) with some complex internal harness (as an example, bundles made of 10 wires with different radius and insulators).
As a result, the next step of this study (in progress at the present time) is its extension to a fully equipped industrial car body.