Car windshield behavior transient analysis by FDTD

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Abstract— the present article studies the influence of a car heatable windshield by means of an equivalent material that allows an appropriate meshing of the vehicle. This study has been performed analyzing the propagation of an electromagnetic radiated transient pulse generated by a wire inside a car with and without the windshield. The Finite Differences Time Domain (FDTD) is the method used to obtain the field coupled to antennas located inside and outside the car. We concluded that it is important to take into account the heatable windshield to make a suitable electromagnetic model of the vehicle.

Keywords: *Simulation, FDTD, Transient field, Time domain, Vehicle, Equivalent material.*

I. INTRODUCTION

Modern vehicles integrate a great variety of communication systems and electronic equipment that can be activated simultaneously. Those systems are particularly immune to continuous interferences, but their digital nature makes them vulnerable to impulsive noise [1]. Due to this behaviour, the study of transients or impulsive noise becomes an interesting subject concerning EMC.

Several studies have been published using numerical methods based on the time domain like FDTD to obtain the distribution of electromagnetic fields inside a vehicle [2], [3]. These studies consider essential to make a proper discretization and the materials present in the vehicle [4]. One important material that has been ignored in many analyses is the windshield.

The heatable windshield represents an important area of the car body. It must ensure good driver visibility, but due to the large area and its conductivity; it is able to modify the behaviour of electromagnetic fields present inside and outside the vehicle [5]. Therefore, when we want to use the simulation as a tool to evaluate the electromagnetic field distribution inside or outside a vehicle, it is very important to take into account the influence of the windshield.

FDTD method is used in this paper to study the radiated coupling between a transient signal in a wire located inside the car and several antennas placed inside and outside the car. This analysis is performed in time

and frequency domains and in the presence of the windshield and without it. To make a comparison it has been necessary to find an electromagnetically equivalent material of the windshield. This equivalent material allows the simulation of large structures improving the simulation time.

II. METHODS

A. Problem definition

Our aim is to analyse the effect the windshield introduces in the EM behavior of the car. The heatable glazing windshield contains very thin and closely positioned wires in comparison with the car dimensions. Due to the huge difference of sizes it is too difficult to solve the problem directly by the FDTD method. For this reason this study is divided into three stages. The first one is to make an electromagnetic simplified model of a small piece of a heatable glazing windshield (Figure 1). In the second stage of the investigation, we have performed the validation of the simulation with measurements in the car frame without the windshield. Finally, in the third stage, the car was simulated with and without the equivalent windshield to analyze its effect in the signal coupled to the antennas.

B. Equivalent Material for the windshield

The heatable windshield is composed of four relevant layers (Figure 1a). The external layers are considered to be a 2.1 mm thickness normal glass. One of the interlayers is polyvinyl butyral (PVB) and the other is a mesh of heatable wire (HW). The influence of the PVB material could be ignored because its electromagnetic effect is less significant than the HW. An electromagnetic simplified model of a small piece of a heatable glazing windshield is made (Figure 1b). The equivalent material avoids simulating the whole vehicle with such details of the thin heatable wires within the windshield, allowing us to reduce the simulation time and the hardware requirements.

Figure 1. (a) Windshield composition. (b) Electromagnetic equivalent material.

The corresponding value of conductivity for the equivalent material is obtained by means of simulation. Simulations have been performed to obtain the same electrical field attenuation when the equivalent material is used instead of the real modeling (windshield composition figure 1a).

For the simulation of the heatable windshield a piece of 100 x 5.8 x 100 mm is used. To mesh it properly 9.4 MCell are needed and the time step is 4.8e-14 s. On the other hand, when the equivalent material same size is simulated, the mesh is 1 MCell and the time step is 1.1e-12 s. The reduction of time step produces also benefits with car model simulation. Using the equivalent material the simulation¹ time is reduced by 30 when a Pentium Core™ 2 Duo 2.66 GB processor and 8-Gbyte RAM has been used for the calculation.

An optimization procedure varying the conductivity of the equivalent material is done to obtain the same electromagnetic behaviour as the real windshield. Figure 1b shows the electrical field, normalized by the value of the electrical field obtained when the real windshield composition is simulated, using different values of conductivity. The electrical field is compared in frequency considering the maximum and the average values. According to these criterions the optimal value of

conductivity is around 54 S/m (Fig. 3.). On the other hand, the value of the electrical permittivity is assumed to be same as the value of the glass (4.82 F/m).

Figure 2. Equivalent material optimization.

C. Numerical validation of the car model

The aim of this numerical validation, in time and frequency domains, is to optimize several parameters like the meshing or the simulation time in order to obtain acceptable results. The validation has been performed with measurements in a car frame (SEAT Cordoba²). Usually in cars the transients are present on the wires connecting the loads. To study those transient couplings a wire is placed inside the car (Figure 3) and two antennas are positioned in different locations.

Figure 3. Details of the numerical model used in the simulations, showing the position of the different antennas and the wire.

Measurements in time domain are recorded with an oscilloscope that shows typical low voltage sensitivity. To obtain meaningful data, the wire is excited with a high voltage transient. A transient pulse of 689 V was applied

1. The program used is SEMCAD [6].

2. The authors are grateful to SEAT SA, Martorell, Spain for the help providing the Cordoba car frame to perform the measurements. This work has been partially supported by the Spanish Ministerio de Educación y Ciencia under project DPI2007-63878.

to a 2.9 m conductor wire inside the vehicle (Source in Fig 4). Those transient signals were generated with a Schölder burst generator, according to the pulses defined in IEC 61000-4-4 [7].

Figure 4. Applied waveform, measured at the input connector of the wire (Source).

The monopole antennas used to measure the coupling are 200 mm long placed at the vehicle. One antenna is placed inside the car and another is placed outside the car as depicted in Figure 5. The coupled signal is measured directly with a Tektronix DPO7104 (sampling rate of 2GSa/s).

The validation results obtained are presented as a comparison between the simulated and measured waveforms, both in the time domain (Figure 5). The post processing process consist in a low-pass Butterworth filter with $F_c=500$ MHz applied to both, the measured and calculated signals. The cut-off frequency was selected to match the bandwidth of the oscilloscope used in the measurements. Additionally a delay of 15.7 ns was introduced in the simulated waveforms, to compensate the delays caused by the cables and equipment in the measurements. The magnitude of the delay was estimated by performing a cross-correlation between measured and simulated signals.

Figure 5. Measured (solid line) and simulated (dashed line) signals for the outside antenna.

It is clearly observed in both graphs that the calculated and measured signals have a very similar

trend. To quantify this similitude the Feature Selective Validation (FSV) method [8] is used in the frequency domain. The GDMt indicator obtained a value of 0.599. In time domain, the Transient Time Domain Validation (TTDV) method [9] is used, obtaining a value 0.102 for the TEA indicator.

D. Windshield effect

Finally the effect of the windshield is studied using in the numerical model the equivalent material exposed in previous part B. The wire located inside the car is feed with the same transient described before. Figure 6 shows the signal coupled to the car inside antennas, in time domain and in frequency domain, while the Figure 7 shows the signal coupled to the outside antenna.

(b)

(b)

Figure 6. Signal coupled at the inside antenna with and without windshield. (a) Time domain. (b) Frequency domain.

In time domain, the voltage measured at the inside antenna is similar neither the windshield is considered or not. In frequency domain the plot have small differences in some frequencies bands but the overall shape is similar. The measurements show those small differences because of two reasons: the wire and the antenna are inside the car and the distance between the antenna and the windshield is enough large to consider the presence of the windshield not relevant.

Figure 7. Signal coupled at the outside antenna with and without windshield. (a) Time domain. (b) Frequency domain.

On the other hand, while no significant effect is observed at the inside antenna, a big change is obtained at the outside one. As can be seen in Figure 7, a variation of 100 mV at maximum peak is observed in time domain. In frequency domain, the measured amplitude is, at 100 MHz, 20 dB lower when the windshield is considered.

III. CONCLUSIONS

In this paper a simplification method for complex materials is done by considering an equivalent material.

This method improves the FDTD simulation procedure, reducing the simulation time and, in complex situations, a proper meshing could be done.

The results obtained show that it is essential to take into account the heatable windshield to make a correct electromagnetic model of the vehicle, in particular when external antennas are considered.

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