

Experimental validation of time-domain electromagnetic models for field coupling into the interior of a vehicle from a nearby broadband antenna

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Abstract: Numerical electromagnetic models based on a typical automotive immunity measurement scenario have been built from a vehicle manufacturer's CAD data and compared with corresponding measurements on a complete vehicle. The simulations were carried out in time-domain using the TLM and FDTD techniques. Despite the many limitations of both the numerical models and the measurements, the models are found to provide a satisfactory representation of the measured field coupled into the passenger compartment from a nearby broadband antenna.

1 Introduction

Modelling automotive immunity test scenarios is a particularly challenging activity. Not only is the vehicle both geometrically complex and electrically large at the frequencies of interest (to 1 GHz in current legislation, although some manufacturers already test up to 3 GHz), but the measurements also employ a broadband antenna placed in very close proximity (~ 1 m) to the vehicle. In addition, the most common test environment is a semi-anechoic chamber. The use of idealized plane waves and simple antennas to excite the system model is therefore unsuitable for automotive immunity models that are intended for experimental validation purposes. To be successful, such a model must include details of the source antenna as well as the vehicle geometry.

2 Experimental measurements

The measurement configuration used here was based on standard automotive immunity test arrangements [1]. A complete vehicle was placed in MIRA's large semi-anechoic chamber (with a working volume 22 m x 10 m x 8 m) and illuminated from the front and side using a "biconilog" antenna. This device is essentially a log-periodic dipole array augmented with a pair of "bow-tie" elements in order to obtain improved low frequency performance. The bandwidth was 20–1000 MHz.

The antenna and chamber were calibrated as specified in [1], by recording the power required to generate an electric field of 50 V/m in the empty chamber at a reference point that is specified in relation to the vehicle geometry. This point is located 0.2 m behind the front axle, on the longitudinal axis of the vehicle at 1 m above the ground plane. The antenna was positioned with the feed point at a height of 1.2 m, at a distance of 2.5 m to the front or side of the reference point (see Fig. 1). The calibration data is used to estimate the power needed to generate the required "threat" field during vehicle measurements.

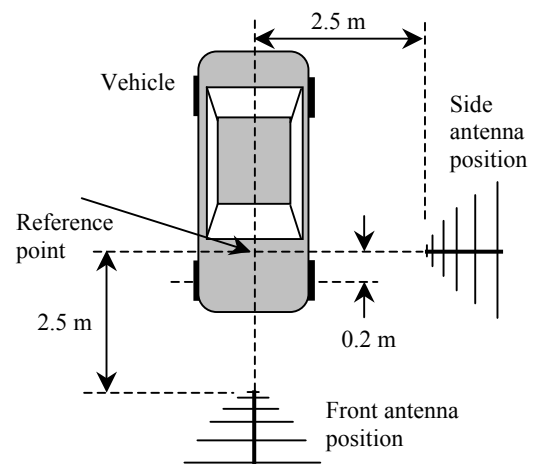


Fig. 1 Antenna positions relative to vehicle and calibration reference point

In standard measurements, this allows deviations in the functional performance of the vehicle to be referenced to the corresponding field at the reference point in the empty chamber. In this work, the electric field strengths measured at selected points within the vehicle were similarly normalized using the field at the reference point for the empty chamber. Thus, the measured relative field strength represents the resulting field at the measurement point under a notional threat of 1 V/m at the reference point. This approach may also be used [2] to produce computed field results that can be directly compared with results from measurements without the need to model the antenna source characteristics in detail, and to reduce the impact of systematic errors.

Electric field measurements were made at selected points in the passenger compartment using isotropic field probes. Reproducible positioning of the probes was achieved by mounting the probes on a thin wooden board that could be reliably located between the armrests in the front and rear of the vehicle relative to readily identified fixed points. This allowed the field measurement points to be related to the vehicle CAD data, and also ensured that they could be easily reproduced in the course of measurements, which required the probes to be moved between the front and rear of the passenger compartment (see Fig. 2).

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Fig. 2 Positioning of the electric field probes for measurements above the front seats

3 Numerical models

Time-domain methods are particularly suitable for EMC applications, because of the need for broadband results. For large and complex systems, methods based on structured meshing (using hexahedral cells) offer many advantages, including more frugal use of memory than unstructured meshing methods and the ability to accommodate additional surfaces without increasing the memory needed. The main disadvantage for vehicle applications is the resulting “stair-cased” approximation of curved surfaces. The results reported here were generated using two such time-domain, structured meshing techniques: FDTD [3] and TLM [4]. The simulations were carried out using ONERA’s “ALICE” FDTD code [5] and the “Microstripes” TLM solver [6] from Flomerics.

Although the FDTD and TLM models aim to represent the same system, the numerical representations in fact differ for a variety of practical and operational reasons. In the FDTD model for the antenna, the dipole elements were represented using thin wires. For the TLM model, however, it was found to be more practicable to use solid bars. The antenna used for the measurements had 20 dipoles in addition to the bow-tie elements, all of which were represented in the TLM model. In the FDTD model, however, the smallest 4 elements (with lengths less than 8 cm) were neglected in order to limit the size of the final system model, while the bow-tie elements were modelled as triangular conducting sheets. In the real antenna and the TLM model the bow-tie elements are formed from conducting rods. Nonetheless, both antenna models were found to provide a good representation of the real antenna performance.

Although the vehicle used for the measurements was complete and fully functional, the content of the numerical models had to be constrained in order to ensure that the resulting models did not exceed the available computing resources. Since the measurements were limited to the passenger compartment the engine bay and under-body components were not included. Comparative measurements on the complete vehicle [7] indicated that the window glazing and seat cushions did not impact significantly on the electric field coupled into

the vehicle interior, for frequencies up to 1 GHz. This suggested that all such dielectric materials within the vehicle interior could reasonably be neglected. The models were therefore limited to the vehicle shell and significant metallic parts in the passenger compartment, which included the seat frames and those elements of the steering that are located in this region.

The FDTD vehicle model (see Fig. 3) was based on a geometrical model that had been simplified and reduced to single surfaces, augmented with simplified models for the seat frames and steering gear. This is because the FDTD model was obtained by re-meshing a triangular surface patch mesh that was generated by EADS CCR (France) from a simplified, single surface model for boundary element simulations. The number of surfaces is crucial for model size in boundary element and related techniques, but for TLM and FDTD the model size is determined primarily by the number of cells within the computational volume, while the number of surfaces within this region has very little impact on the memory requirements. The TLM model (Fig. 4) was constructed directly from the original vehicle CAD data using specialized meshing tools, and thus included both the inner and outer surfaces of structures such as the doors, together with higher fidelity models of the seat frames and steering gear.

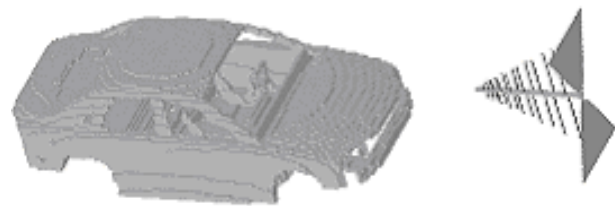


Fig. 3 FDTD model: front vertical illumination

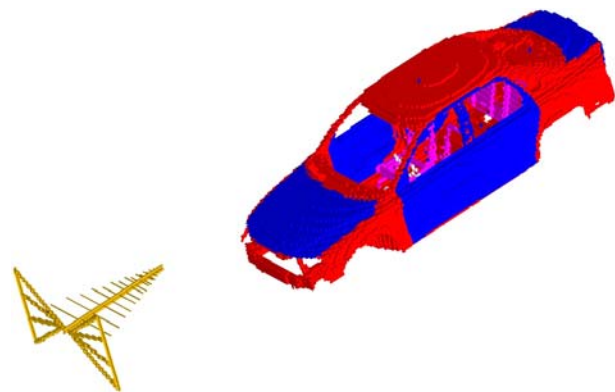


Fig. 4 TLM model: front horizontal illumination

The TLM model for front horizontal illumination was 9.1 million cells and required 860 Mbytes, while that for side illumination was almost twice as big, with 17.3 million cells requiring 1.6 Gbytes. The cell sizes ranged from 4 mm (to capture the antenna geometry and local field gradients) to 30 mm (for a model with 1 GHz bandwidth). A free-space absorbing boundary condition was used to truncate the model above the ground plane.

The FDTD model for front horizontal illumination was 1.85 million cells and required 85 Mbytes, while that for side illumination was 1.95 million cells and required 89 Mbytes. The cell sizes used in this model

ranged from 12.5 mm, to capture the antenna geometry, up to a maximum of 40 mm. A 5-layer perfectly matched layer was applied at the 5 free-space boundaries.

4 Validation results

The success of the antenna models was investigated by comparing the relative field (normalized to the field at the reference point) at selected points without the vehicle present. Results for the TLM and FDTD antenna models are compared with corresponding measurements in Figs. 5-6, for horizontal and vertical polarization.

Since the low frequency resonances that are present in the measurements are not duplicated in the simulations it is believed that these features result from

finite wall reflections in the semi-anechoic chamber, which are not represented in the models. However, the main features of these plots are due to the antenna and its position (together with that of the measurement points) relative to the conducting ground: these show a satisfactory correspondence between the simulated and measured results.

The antenna calibration results were used to normalize the field coupling results in both the real and simulated measurements. Sample results, which take account of the estimated uncertainties for the measurements, are shown in Figs. 7-8 for a particular field measurement point under two different illumination configurations. The low frequency measurements (below 100 MHz) are corrupted by chamber effects that are not

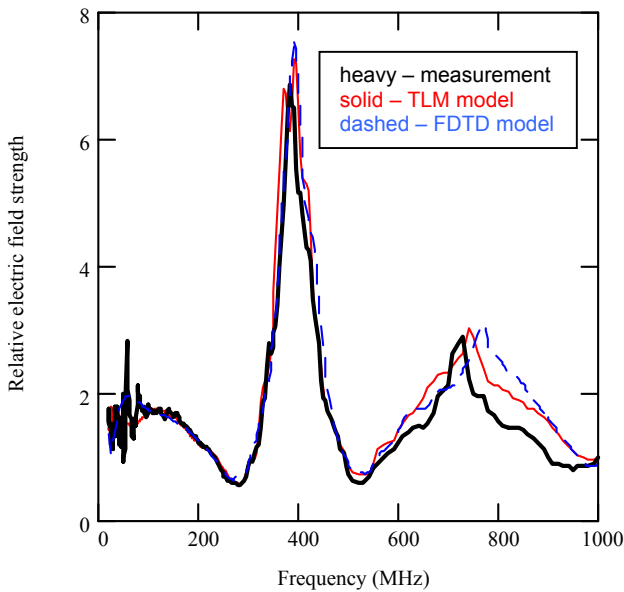


Fig. 5 Relative electric field at a point for horizontal biconilog antenna above a ground plane

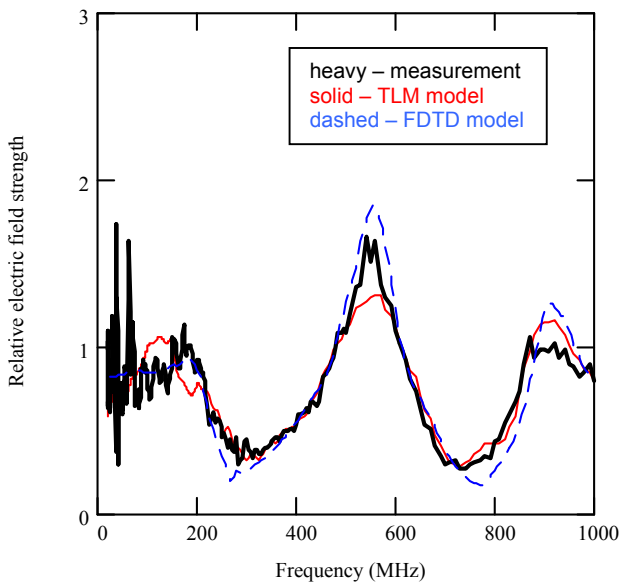


Fig. 6 Relative electric field at a point for vertical biconilog antenna above a ground plane

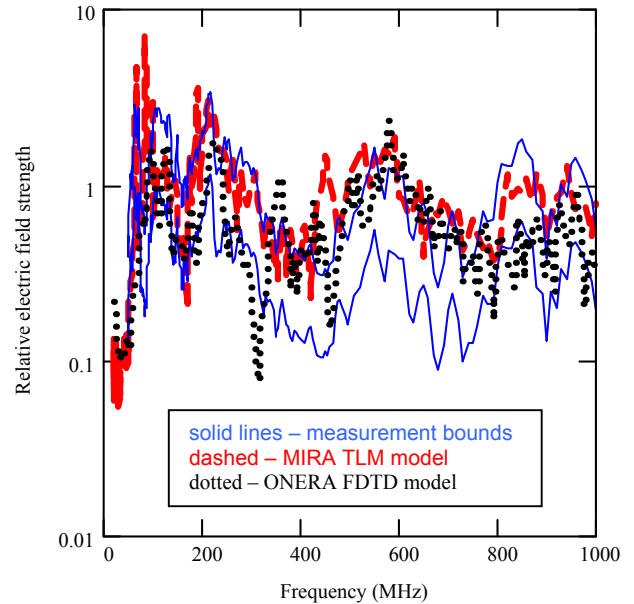


Fig. 7 Electric field at front left-hand monitoring point: vertical polarization, front illumination

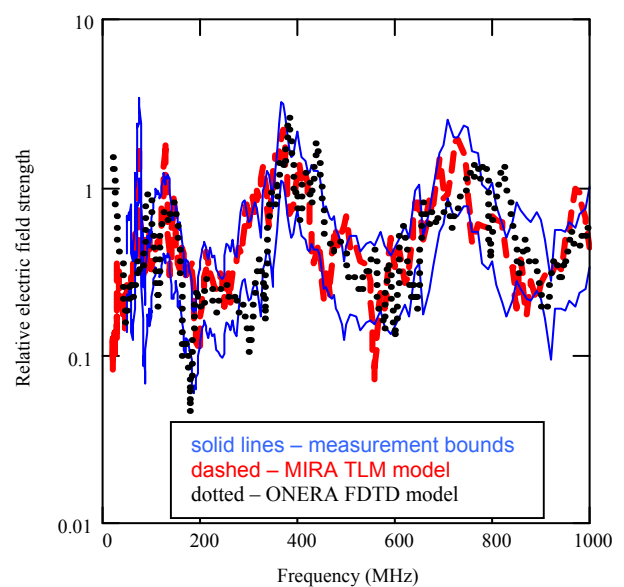


Fig. 8 Electric field at front left-hand monitoring point: horizontal polarization, side illumination

represented in the models. At the higher frequencies, however, both the TLM and the FDTD models generally show very similar topologies to the measurements, while the absolute levels are generally are within the estimated error bounds of the measurements.

5 Conclusions

Despite the many approximations and limitations of both the simulations and the measurements, the TLM and FDTD models are found to provide a satisfactory representation of the measured electric field coupling. Such models therefore have potential to provide objective information to support automotive EMC (electromagnetic compatibility) engineering activities, both during the design stages of vehicle development and in problem resolution. Furthermore, such models allow automotive electromagnetic measurement issues to be investigated theoretically using realistic models, thus aiding the understanding and development of practical test methods.

It is also found that the quality of the two models is not markedly different, indicating that the heavily simplified geometry used for the FDTD model can still yield satisfactory predictions for the field coupled into the interior of the vehicle. This suggests that approximate vehicle geometry, as well as more computationally efficient, lower fidelity models, can probably be used in practical applications with reasonable confidence in the quality of their results.

For vehicle design studies it would be more efficient to use models that are excited by idealized plane wave sources, which would significantly reduce the size of the model compared with the validation test cases described here. In the models reported here the need to represent the details of the illuminating antenna represented a significant overhead for the simulated measurements, which required both the antenna and the vehicle to be present in the same model.

In addition to EMC related applications, whole vehicle electromagnetic models are also beginning to be used in to predict installed performance characteristics for vehicle antennas, and to assess occupant field exposure due to on-board transmitters.

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7 References

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