ELECTROMAGNETIC MODELLING FOR EMC

A.R. Ruddle
MIRA Ltd, UK (alastair.ruddle@mira.co.uk)

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Abstract

Electromagnetic compatibility is a significant application area for electromagnetic modelling techniques. There is strong industrial interest in the development of numerical simulation methods that could allow EMC issues to be investigated in the early stages of design. Although modelling the functional EMC performance of complex systems remains challenging, for both technical and practical reasons, EM modelling of large and complex structures is already possible with relatively modest computing resources. As the results obtained from EM models do not directly provide the parameters of interest for EMC analysis, indirect approaches are needed to exploit EM model results in support of EMC engineering. This paper outlines some strategies employed in the automotive industry to support vehicle EMC engineering using EM models.

1 Introduction

Electromagnetic compatibility (EMC) is an increasingly important aspect of systems engineering. Consideration of EMC issues is essential to ensure the functional safety and reliability of complex modern products, which are increasingly reliant on electronic sub-systems to provide the communications, control and monitoring functions that are needed to provide enhanced levels of functionality. Typical examples include transportation vehicles (road, rail, sea and air), manufacturing plant, power generation and distribution, and communications. Opportunities for using numerical simulation techniques to predict and analyse system EMC and related issues (eg. human field exposure and installed antenna performance) are therefore of considerable interest in many industrial sectors.

The costs of mitigation measures for EMC problems that are not detected until prototype testing can be significant when compared with changes introduced at earlier stages in the development lifecycle. In addition, existing sub-system EMC specification methods (which are often uniform requirements on all sub-systems) may result in many sub-systems being over-engineered, whilst not ensuring that all sub-systems are adequately engineered. Models used to develop more realistic specifications and to identify potential EMC risks at the design stage could therefore lead to potential cost savings and problem avoidance in system integration.

Numerical simulation results also offer other potential benefits of commercial significance, such as reduced dependence on physical testing and a source of objective data for ranking product packaging options (eg. locations of sub-systems, cables and antennas).

Simulation of functional EMC performance, although feasible in principle, remains difficult in practice. Nonetheless, it is already possible to use results from electromagnetic (EM) models to support some aspects of EMC engineering, even though the simulation output does not directly provide the parameters of interest.

2 EM and EMC models

In EMC investigations it is necessary to consider both the immunity of the system to external sources and the emissions that the system will produce. Both aspects must conform to legislative requirements.

For a radiated immunity scenario, an EMC model should predict the functional effects of the applied field on the electronic systems. In an emissions scenario, the EMC model should provide the conducted and radiated emissions of the electronic sub-systems that will contribute to the total emissions of the system. However, functional EMC performance depends not only on the EM characteristics of the system, but also on the behaviour of the circuits and software that are used to implement the sub-systems. A single monolithic simulation for such purposes is not a practicable proposition, so a combination of appropriate modelling techniques [1] represents the most viable approach for modelling the functional EMC performance of vehicles and other systems with similar levels of complexity.

An EM model only describes the interaction between a structure and an applied field. An EM model, therefore, is not the same as an EMC model, which must also represent the functional performance of the electronic systems that are housed within the structure. Nonetheless, accounting for the 3D electromagnetic interactions that determine the coupling from or to cables and equipment within their housing (eg. a geometrically complicated vehicle bodyshell for automotive applications) is an essential element of the wider analysis that is needed in order to predict functional EMC effects.

3 Modelling functional EMC performance

In applications such as radiated emissions or immunity of vehicles the basic structure, as well as its cables and any on-board antennas, can be considered as a
complex multi-port antenna, which can be characterized using EM modelling techniques. For building an EMC model, however, it is necessary to consider a range of modelling techniques as outlined in Table 1, operating at a number of different levels. The clearest requirement for combining models of different types is the integration of circuit behaviour (“type D” models) with the electromagnetic performance of the installation (a “type A” model).

The most computationally expensive elements of such models (in time and computing resources) are the full 3D EM field computations. Thus, there may also be advantages in linking different type A models in order to maximize the efficiency of the 3D field calculation, particularly at higher frequencies (eg. [2]). It is possible to include cable models within some 3D field modelling techniques, which should provide a more rigorous solution. However, “separated methods” [3] may offer some advantages in terms of computational efficiency.

Cable elements that are close to conducting parts of the system housing can be regarded as transmission lines if their separation is sufficiently small at the frequencies of interest. The separated approach involves the introduction of type B (2D) models in order to determine the transmission line parameters for the various elements of the network, and type C (1D) models to determine the propagation characteristics of the network branches. This approach has been applied to systems such as cars [4] and aircraft. Nonetheless, some cable elements will not meet the requirements of the transmission line approximation, and will therefore need to be represented in the 3D field model.

A representative scheme for modelling radiated immunity using the separated approach is illustrated in Fig. 1, which outlines the interactions between the various model types. It has been shown that module layout (length and position of PCB traces) also influences coupling to cables, and that these effects persist even when the randomness of cable bundles is taken into account [5]. Thus, EM modelling is also needed to represent sub-system level features that influence system level performance.

<table>
<thead>
<tr>
<th>Model type</th>
<th>Model order</th>
<th>Model nature</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3D + time or frequency</td>
<td>Electromagnetic - volume or surface meshing</td>
<td>3D electromagnetic field distribution and related parameters (eg antenna characteristics)</td>
</tr>
<tr>
<td>B</td>
<td>2D static</td>
<td>Electrostatic - planar or peripheral meshing</td>
<td>Characteristic impedance of transmission line segments (for electrically small separations)</td>
</tr>
<tr>
<td>C</td>
<td>1D + time or frequency</td>
<td>Transmission line - linear meshing</td>
<td>Accounting for wave propagation effects on transmission lines (length and load dependent)</td>
</tr>
<tr>
<td>D</td>
<td>0D + time or frequency</td>
<td>Circuit - lumped element models</td>
<td>Device physics in circuit models, but no account of physical layout</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software - behavioural models</td>
<td>Logical processes represented using discrete mathematics</td>
</tr>
</tbody>
</table>

Table 1: Classification of model types required to predict functional EMC performance for vehicle systems

At present, all of the model types outlined in Table 1 are possible, and the integration of some of these techniques has been demonstrated to some degree. However, comprehensive modelling for systems of realistic complexity is still relatively untried.

There are significant practical difficulties even for the EM elements of such models, which require detailed information concerning not only the vehicle geometry, but also the cable paths, the construction and material properties of the cables, and the frequency dependent termination impedances presented by the electronic sub-systems. At present much of this information is not readily available. In the short to medium term it seems likely that system-level analyses will be based on sub-system test results [6], during the development phase. In the longer term, it is expected that suitable models will be developed by sub-system suppliers, which can then be used with installation models to predict system level EMC performance. This would allow the significance of sub-system performance shortfalls to be quantified in terms of their system-level impact.

Recent developments in numerical methods and the falling cost of computing resources now make large scale EM modelling of complex systems increasingly practicable. Vehicle model validation studies also indicate that the quality of such simulation results is comparable with experimental repeatability (eg. [7, 8]). In the short term, therefore, exploiting the results of vehicle level 3D EM models is considered to represent the most practicable approach for introducing early analysis into automotive EMC engineering processes.
4 EM models in vehicle immunity analysis

This section outlines some strategies that have been employed for assessing radiated immunity risks based on EM modelling of the coupling of fields into the interior of a passenger car [9]. The 3D EM model was derived from a combination of CAD data for the main vehicle structure and cable routes, supplemented with mesh (developed for other types of model) for some of the additional components. A commercial TLM code [10] was used here, but the approach described below could use data from any EM simulation technique.

4.1 Module location

The results shown in Figs. 2-3 show the net field strength relative to the applied field strength computed at two likely module locations for four possible illumination configurations (plane waves with horizontal and vertical polarization, incident from front and side).

The results of Figs. 2-3 indicate that the electric field strength in location A is much higher than the applied field at certain resonant frequencies, and therefore represents potential immunity risks, while for point B the local field is always lower than the applied field, and is therefore considered to be at little risk of immunity problems due to direct field coupling. The results also show the differences in field response that can arise from different illumination configurations.

The results shown here are for net electric field. If more information concerning the construction and likely susceptibility of the module is available it may be more realistic to look at other components of the field. However, in the absence of more detailed information use of the net field is effectively a “worst-case” condition, since the analysis then assumes that the net field always represents the immunity risk.

4.2 Cable routes

The analysis of proposed cable routes from field data alone is much more difficult for various reasons, including:

- greater spatial extent of the cable network;
- complexity of the cable paths and construction;
- relative orientation of cable path and electric field;
- uncertain impact of noise currents induced by fields;
- large volume of data relating to cable exposure.
A possible approach for coping with these problems is to consider simple statistical measures of the field distribution associated with particular cable branches. The average field exposure over a number of points along a cable path is an obvious parameter of potential interest, but the maximum value is also useful to indicate “worst case” levels.

Sample results derived from a number of points representing a cable route are illustrated in Figs. 4-5, which show the peak and average levels over all points on the path at each frequency for the four illumination configurations. The average field levels of Fig 4 are considerably lower than the peak field results of Fig. 5, where maximum values of more than twice the applied field are common across the full frequency band.

A better representation of the severity of the exposure can be obtained by considering the proportion of the path for which the local field exceeds the applied field, or exceeds the requirements that are imposed for sub-system testing. This is illustrated in Figs. 6-7, which show the proportion of points along the path that exceed both the applied field and twice the applied field for the four illumination configurations. Although this approach results in four frequency responses for each illumination configuration (ie. 16 in total for the four illumination configurations), which is a significant increase over the amount of data needed to assess EMC risks associated with module locations. Nonetheless, the large volume of data that this represents remains at manageable levels when presented in this manner.
The results of Figs. 4-5 show that, while the average field exposure is less than half of the applied field, there are points where the field is greater than the applied field (and in some cases more than 5 times the applied field). Nonetheless, Figs. 6-7 reveal that the areas of high field exposure are actually highly localized, since the proportion of points with fields that exceed the applied field is less than 7% except around 550 MHz, while the proportion exceeding twice the applied field is less than 3% for all frequencies. Thus, this particular route is considered to be unlikely to present a significant risk for vehicle level immunity.

5 Conclusions

An EM model is not the same as an EMC model, which must also represent the functional performance of the electronic systems that are housed within the structure. As the results obtained from EM models do not directly provide the parameters of interest for EMC analysis, indirect approaches are needed to exploit EM model results in support of EMC engineering.

An approach to the assessment of risks for vehicle immunity has been presented based on the analysis of local field strengths predicted from an electromagnetic model of a vehicle. Field results are not in themselves sufficient to indicate whether there will be a functional effect on vehicle sub-systems. Nonetheless, they can be used to assess EMC risks for the vehicle installation, which can vary significantly between different locations within the vehicle due to resonance effects.

For electronic modules, the predicted local field strengths can be simply compared with vehicle and sub-system immunity requirements, as well as with sub-system test results when these become available. For cable routes, however, the volume of data that needs to be considered is much greater than is required for the evaluation of individual module locations. Consequently, an assessment based on simple statistical measures of the field along cable paths is proposed as a more practicable alternative. This approach avoids the need to model coupling onto the cables and the functional EMC performance of the sub-systems that terminate the cable network, both of which would require additional simulations and, more importantly, detailed information that is not readily available at present.

This type of information could be used by vehicle manufacturers to develop more realistic sub-system immunity specifications, thus avoiding the costs associated with both over-engineering systems for which the installed environment is relatively benign and under-engineering those that may be exposed to a more severe environment. Further possible applications include the identification of a “worst-case” illumination condition for physical tests (with potential to limit the cost and duration of physical testing that is required), and providing a source of objective data for ranking possible vehicle packaging options (such as the locations of modules, antennas or cable routes).

On-board transmitters, which could be either vehicle-mounted antennas or personal mobile systems, also constitute a potential EMC threat that can be assessed at the design stage using electromagnetic modelling.

Electromagnetic modelling can provide useful support to EMC risk assessments for cars and other vehicle types (trucks, trains, aircraft, ships etc.). Similar benefits could also be achieved in many other industrial sectors.

References