MEASURED IMPACT OF SEATS AND GLAZING ON THE COUPLING OF ELECTROMAGNETIC FIELDS INTO VEHICLES AND THEIR WIRING HARNESSES

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Abstract: Whole vehicle electromagnetic models are desirable to allow automotive EMC and antenna engineering issues to be analysed during the design stages of vehicle development. However, models of this scale and complexity can require very significant model development and computing resources. Thus, opportunities for limiting the scope of such models are of considerable importance in ensuring that this type of analysis is practicable. Measurements have been carried out on a complete vehicle to assess the impact of common components such as the seats and window glazing. The results suggest that these components could be neglected in many models without introducing significant errors.

1. Introduction

There is increasing interest in the development of whole vehicle electromagnetic models in order to allow automotive EMC [1-3] and antenna engineering issues [4-5] to be analysed during the design stages of vehicle development. The motivations for this include the need to ensure the functional safety and reliability of modern vehicle systems, which are becoming more closely integrated in order to provide enhanced functionality and increasingly reliant on wireless communications technologies, as well as pressure to shorten vehicle development costs and time to market.

For example, the costs of mitigation measures for problems that are not detected until prototype testing can be enormous when compared with changes introduced at earlier stages of the development programme. In addition, current sub-system EMC specification methods (often uniform requirements) may result in many systems being over engineered, but do not ensure that all systems are adequately engineered. Models used to develop more realistic specifications could therefore lead to potential cost savings and problem avoidance in system integration. Simulation results also offer other potential benefits, such as reduced dependence on physical testing and a source of objective data for ranking possible vehicle packaging options (such as the location of modules, wiring harness and vehicle mounted antennas).

A complete model containing all parts of a vehicle is unlikely to be practicable for the foreseeable future due to the computing resources needed for such models. Furthermore, in many applications it may not be possible because fully detailed geometry may not be available at the time that the model results are required. Consequently, it is necessary to establish which parts of the vehicle must be present in the model in order to ensure that an adequate representation of the characteristics of the real vehicle can be obtained.

2. Vehicle model content

The main metallic structure of a vehicle can be expected to have the most significant impact on its electromagnetic characteristics. The internal surfaces will determine the cavity resonances, while the apertures and external surfaces will determine scattering into and out of the interior cavities. Thus, the vehicle bodyshell and metallic closures (doors, tailgate etc.) are essential elements of vehicle electromagnetic models.

However, a complete vehicle includes many more parts than this, many of which may not be conductors. These include:

- window glazing;
- seats (metal frames with foam mouldings and leather or textile coverings);
- interior trim (carpets, instrument housing, plastic, leather and textile coverings);
- composite elements (eg. bumpers, body panels for some vehicles);
- mechanical components (engine, brakes, tyres, exhaust, powertrain, suspension, etc.);
- electrical components (ie. wiring harness, electronic modules and antennas).

Measurements have therefore been carried out to investigate the likely impact of a few of these additional components on the electromagnetic characteristics of vehicles.

3. Measurement procedures

The measurements were carried out on a complete vehicle in a large semi-anechoic chamber that is routinely used for automotive EMC testing. The working volume of this chamber, which is lined primarily with 1.8 m long twisted pyramidal absorbers, is 22 m long, 10 m wide and 8 m high. The vehicle was illuminated using a nearby biconilog antenna (for frequencies in the band 20–1000 MHz) in configurations that are representative of those used in typical automotive radiated immunity tests [6].

3.1 Antenna calibration

A preliminary calibration of the antenna and chamber was carried out as specified in automotive immunity measurement standards [6] by recording the power required to generate a field strength of 50 V/m in the empty chamber at a reference point that is located at 0.25 m behind the mid-point of the front axle of the vehicle and 1 m above the ground plane.

In automotive immunity measurements this approach 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 fields 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 used to produce computed field results that can be directly compared with results from measurements without the need to model the source characteristics in detail [7].

For the biconilog antenna that was used for the measurements reported in this paper, comparison of such normalized results (derived from measurements in the semi-anechoic chamber and from various models for an infinite ground plane [8]) indicates that chamber resonances are present below 100 MHz (see Figs. 1-2). However, the main features of these plots are due to the antenna and its position relative to the ground.

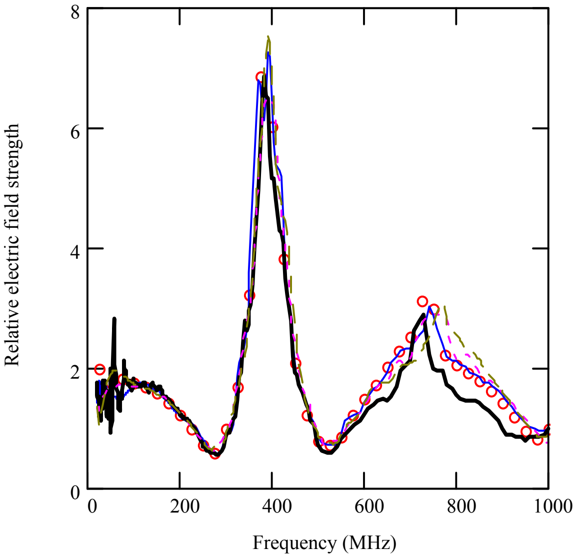

Fig. 1: Electric field at a point relative to that at reference point for horizontal biconilog antenna above a ground plane (heavy line is measured, others are modelled)

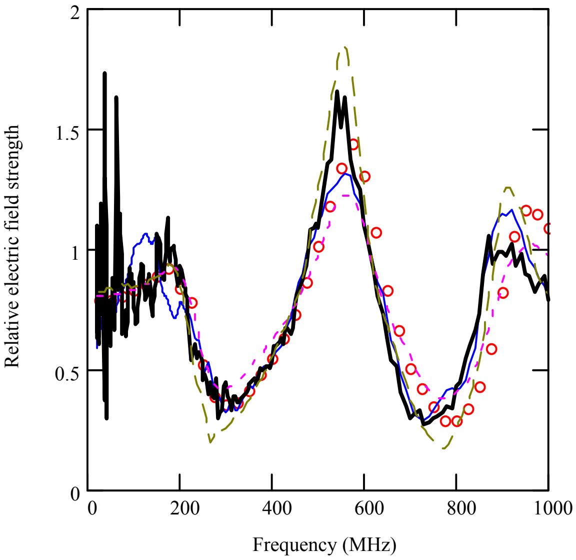

Fig. 2: Electric field at a point relative to that at reference point for vertical biconilog antenna above a ground plane (heavy line is measured, others are modelled)

3.2 Vehicle measurements

Measurements were made under illumination from the front and side of the vehicle, for both horizontal and vertical antenna polarizations, with the tip of the antenna located at a distance of 2.5 m from the reference point and 1.2 m above the ground plane. Separate calibration results were used to normalize the data for each of the four antenna illumination configurations. 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 in relation to identified fixed points. Three probes were mounted on the board, at the centre and 36.4 cm to either side of centre.

Part of the primary vehicle harness path was also augmented with an additional cable with three branches, which was terminated with coaxial connectors. This allowed reproducible and accurate measurements of the coupling from an external antenna to the terminals of the test wire to be made using a vector network analyser. The terminating connectors were located adjacent to the door apertures for the rear cavity and the two front doors of the passenger compartment (in the front foot wells), while the junction was located on the floor of the rear luggage space. Thus, there was a continuous cable run along the floor of the vehicle from the left-hand front door, over the rear wheel arch and into the rear cavity, around the luggage space and then over the second rear wheel arch and down to the right-hand front door, with a spur leading from a point on the floor of the boot up to a termination on the ceiling of the rear cavity (see Fig. 3).

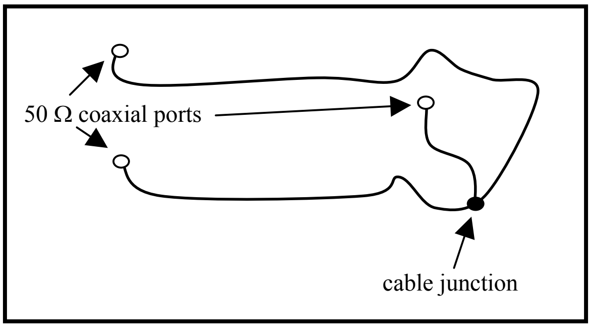

Fig. 3: Topology for single conductor network added to vehicle harness to allow measurement of transmission between antenna terminals and coaxial ports

4. Impact of vehicle glazing on electric field coupling

Although glazing materials have a relatively high dielectric constant ($\varepsilon_r \sim 7$ for typical glasses), the thickness of vehicle windows is sufficiently small to suggest that their effects will be minimal at frequencies up to 1 GHz. Comparative field measurements carried out for the front of the passenger cavity with the side windows up and down show little difference between these two conditions (see Figs. 4-5), except in the upper part of the band. At these frequencies, however, probe positioning errors as well as the impact of the glass are likely to be more significant. Consequently, the differences that are seen between the measurements are probably a combination of these two effects, but it is not possible to say which is the more significant of the two possible causes. Measurements carried out at points in the rear of the passenger cavity show similar behaviour (see Figs. 6-7).

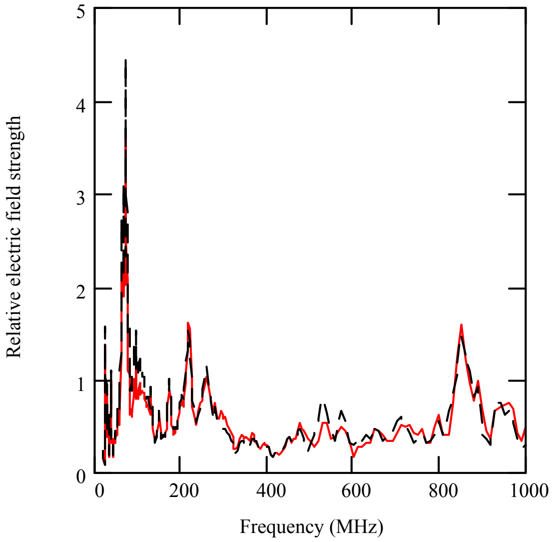

Fig. 4: On-axis in front, vertical illumination at front: with (solid) and without (dashed) side windows

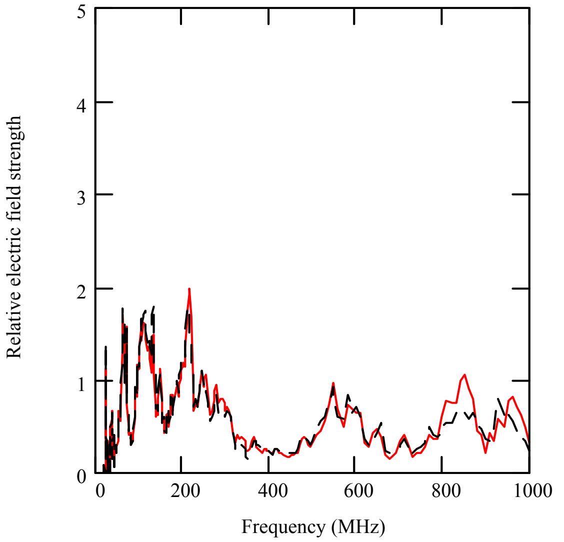

Fig. 5: Above front right-hand seat, vertical illumination at front, with (solid) and without (dashed) side windows

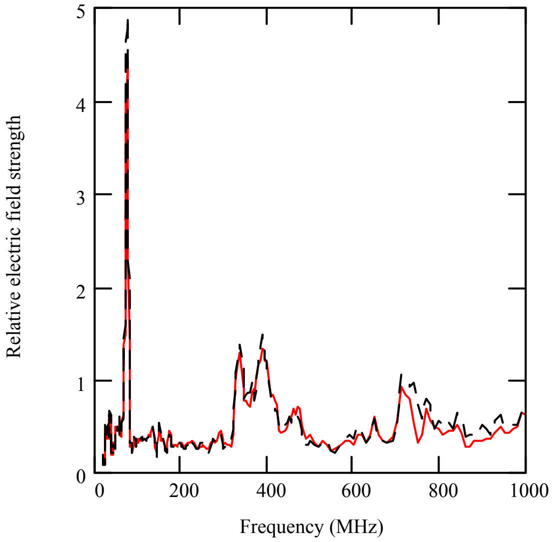

Fig. 6: On-axis in rear, horizontal illumination at front: with (solid) and without (dashed) side windows

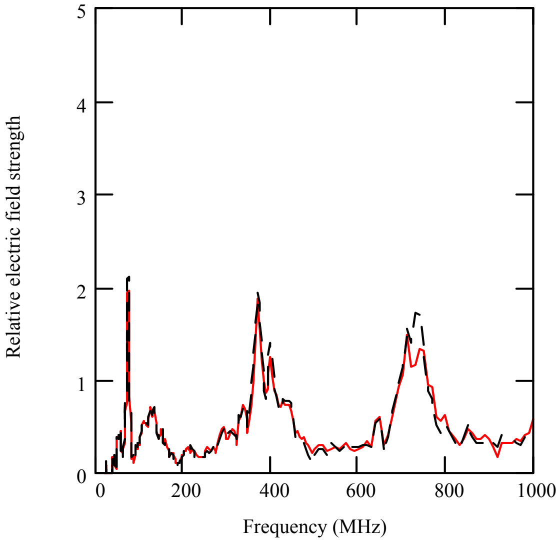

Fig. 7: Above rear right-hand seat, horizontal illumination at front: with (solid) and without (dashed) side windows

In general, therefore, it seems reasonable to ignore the vehicle glazing where simple glass panels (including laminated structures, which are essentially transparent when the thickness is a small fraction of the wavelength) are present. It should be noted, however, not all windows are of such simple construction, as conductive materials (such as coatings and additives to limit infra-red and ultra-violet solar radiation) and structures (eg. heaters and antennas) are sometimes included in the vehicle glazing and will modify the coupling effects.

5. Impact of vehicle seats on electric field coupling

Vehicle seats are normally constructed from a metal supporting frame supplemented by stiff plastic parts, shaped foam and a thin covering of textile or leather. The rear seats are generally of much simpler geometry than the front seats as they obtain their rigidity from the floor pan and a simple metal panel between the passenger cavity and the rear luggage space. The rear seat cushions are therefore shaped foam with very little metallic content (apart from wire stiffening adjacent to the metal panels). Their electromagnetic significance is therefore likely to be smaller than that of the front seats.

The front seats, by contrast, are much more complicated. The seat itself must provide rigidity for the user, including head-rests, and numerous adjustment mechanisms are provided to maximize comfort. In addition, the seat may be fitted with heaters, motors, and even sensors for assessing the mass and position of the user (for the restraint systems). Airbag modules are also often embedded in seat structures. The back of the seat is normally constructed from a stiff but open frame, with thick wires running across the open central area to provide support. It would seem likely, therefore, that the front seats would have a marked impact on the EMC characteristics of a vehicle.

5.1 Rear seat measurements

Measurements of the field above the rear seat with and without the lower rear seat cushion present (see Figs. 8-9) indicate that this structure makes very little difference. These observations suggest that other foam and fabric components within the vehicle are also unlikely to be significant for electromagnetic models for frequencies up to 1 GHz.

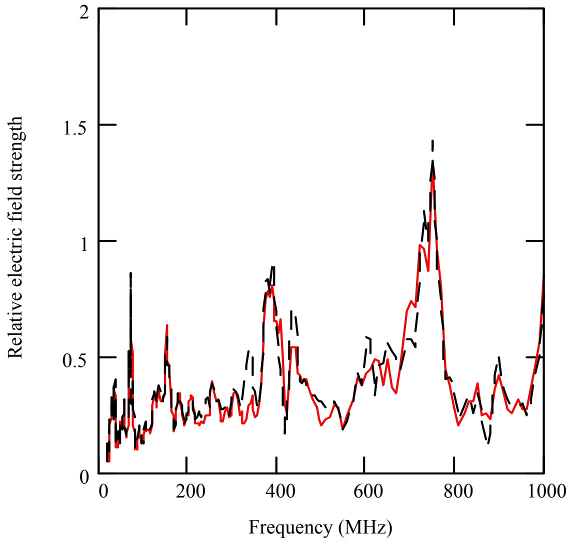

Fig. 8: Off-axis in rear for horizontal illumination at side: with (solid) and without (dashed) rear seat cushion

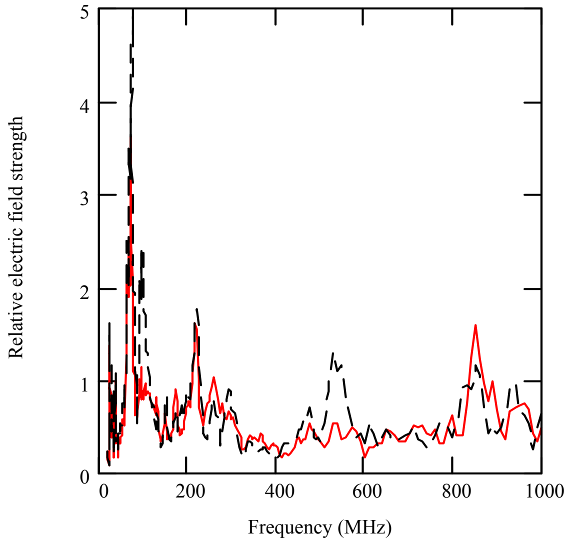

Fig. 10: On-axis in front for vertical illumination at front: with (solid) and without (dashed) front seats

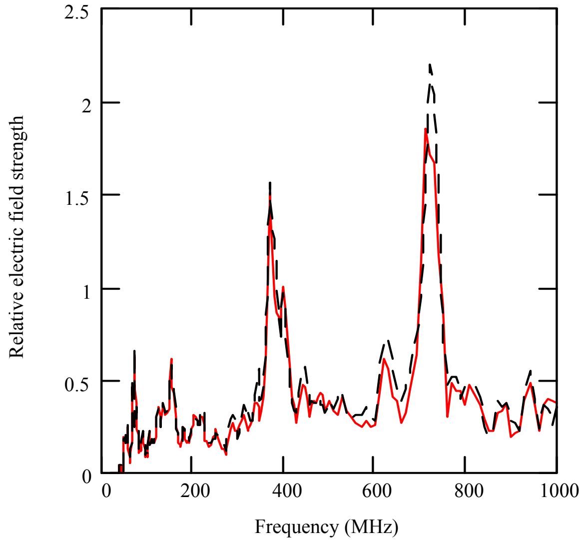

Fig. 9: On-axis in rear for horizontal illumination at side: with (solid) and without (dashed) rear seat cushion

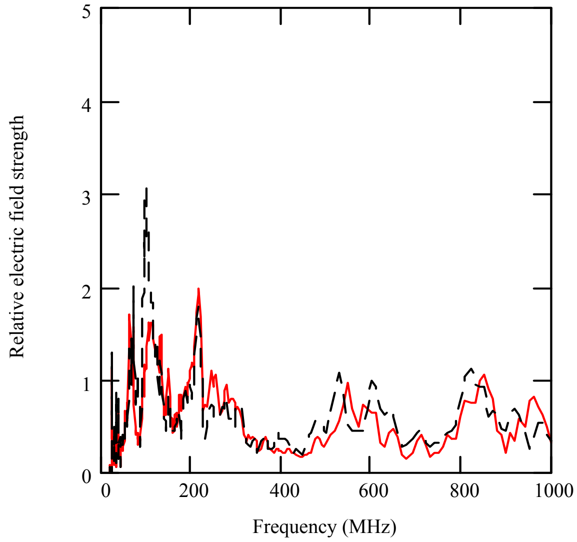

Fig. 11: Above driver's seat for vertical illumination at front: with (solid) and without (dashed) front seats

5.2 Front seat measurements

Measurements of the field above the front seats have been made with and without the seats present (see Figs. 10-11) in order to quantify the impact of front seats. The effect of the seats on the low frequency resonance (~70 MHz) is to reduce the magnitude of the local field on the axis of the vehicle, but the true value without the seats is not known as the field probe was out of range (we know only that the relative field strength was greater than 5). Models of a variety of different vehicles suggest that the 70 MHz resonance is a common feature of passenger car geometries. The seats also suppress the electric field strongly for the feature around 550 MHz. Nonetheless, over much of the frequency range of interest the fields with and without the seats are remarkably similar. The differences are even smaller for the off-axis measurement point.

Thus, a model without the front seats will give a good indication of the internal field distribution under external illumination for most frequencies. At some frequencies the fields may differ when the seats are neglected, but neglecting the seats will generally represent a worst-case condition since the field is more likely to be over-estimated.

6. Impact of front seats on harness coupling

In addition to field measurements, the coupling between an illuminating antenna and coaxial ports on a single conductor cable (added to the vehicle harness in the passenger cavity as indicated in Fig. 3) has also been measured, both with and without the front seats present (see Fig. 12-13). Although there are clearly differences between the coupling results obtained with and without the seats, the impact of these structures is generally much smaller than might be anticipated given the nature of these structures. Despite the differences in detail, the overall level of coupling is generally quite similar, and it is not obvious which of the responses relates to either of the test conditions.

This suggests that a model without the seats could still provide an adequate indication of the coupling to vehicle harness terminals, in terms of the overall envelope of the response, but without the added complexity of the front seat geometry. This represents a considerable saving in model building effort, and could make the difference between a model being practicable or not for numerical methods based on surface meshing, for which the number of surfaces determines the model size.

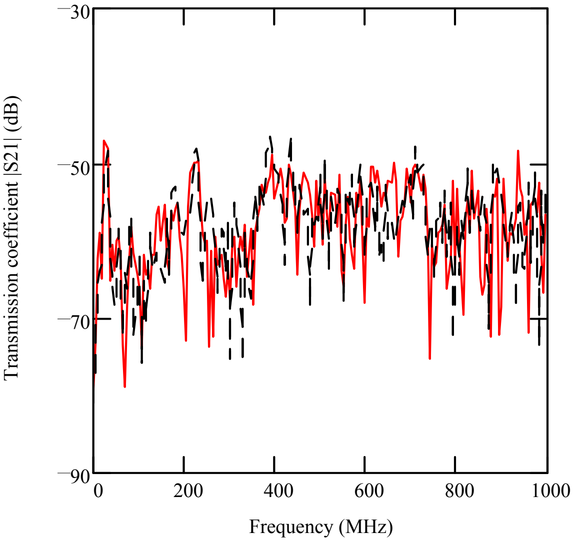

Fig. 12: Transmission coefficient for vertical illumination at side: with (solid) and without (dashed) front seats

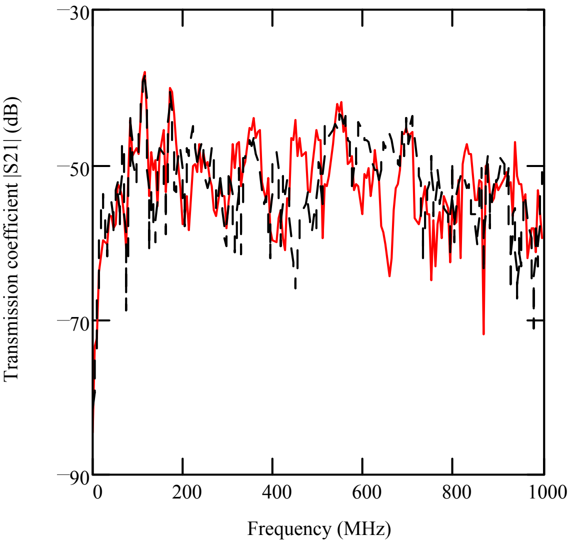

Fig. 13: Transmission coefficient for horizontal illumination at side: with (solid) and without (dashed) front seats

Thus, even the front seats, which might be expected to have a significant impact on coupling into the vehicle and its wiring harness, can reasonably be neglected in automotive electromagnetic models for many applications. Nonetheless, they are likely to be essential in models that aim to predict effects in areas that are either within, or at least in very close proximity to, the front seat structures.

7. Implications for other vehicle components

The very limited impact of seat cushions and window glass that is observed from these electric field coupling measurements suggests that much of the interior trim of a vehicle could probably be neglected in many vehicle models without incurring significant error. Much of the plastic used inside vehicles is thinner than the window glass and is likely to have a smaller dielectric constant ($\varepsilon_r \sim 3$ for many such materials). Similar arguments would also apply to composite body panels and bumpers, provided that antennas are not associated with such parts.

Many mechanical components represent large conductors, but their locations are such that their influence is likely to be rather limited in many modelling applications. The majority of the wiring harness and the electronic modules are located around the periphery of the passenger compartment, with some in the engine bay and rear luggage space, with the result that the under-body components are likely to be of limited importance for most systems.

The engine bay is packed with mechanical components of many kinds, including metal pipes that may resonate, and also houses several key electrical components. The latter may include engine management systems in internal combustion engined vehicles, or electric motors and their associated power conditioning electronics in alternative powertrain vehicles, together with their associated wiring harness elements.

There are often sensors and actuators, and therefore harness elements, associated with the braking system, and perhaps the suspension elements if active suspension systems are used. Nonetheless, this represents a relatively small proportion of the total, and the bodyshell and closures will provide a degree of isolation between the interior cavities and these under-body components.

For models where the focus of interest is in the passenger compartment, most of the major mechanical components of the vehicle are expected to be of limited importance, except for those associated with the steering column, which is inside the passenger cavity. These parts cannot be easily removed for comparative measurements. However, the measured electric fields above the front seats of the vehicle do show evidence of asymmetries, both with and without the front seats. The most significant geometrical asymmetry in the passenger compartment is associated with the steering gear.

Without the front seats, the asymmetries are much stronger below 200 MHz (see Fig. 14) than they are with the seats installed (see Fig. 15). With the seats present, however, the asymmetries below 200 MHz are suppressed, although stronger asymmetries appear in this case above 400 MHz. As already noted in section 5, the front seats appear to reduce the impact of certain resonances in the passenger compartment (most notably in terms of the on-axis field).

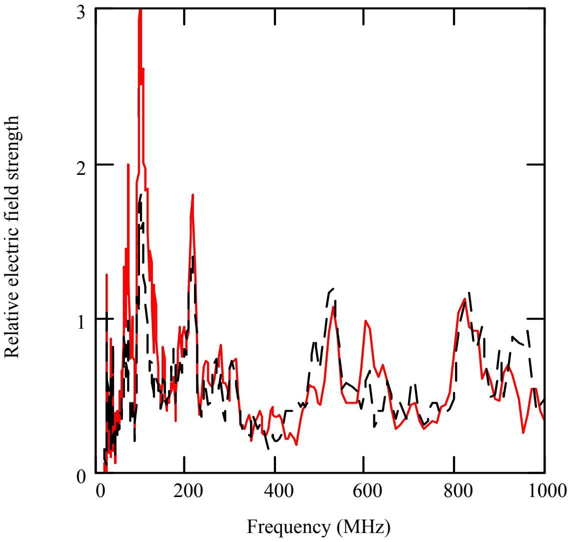

Fig. 14: Electric fields in front for vertical illumination at front without front seats: for driver's (solid) and passenger's (dashed) sides

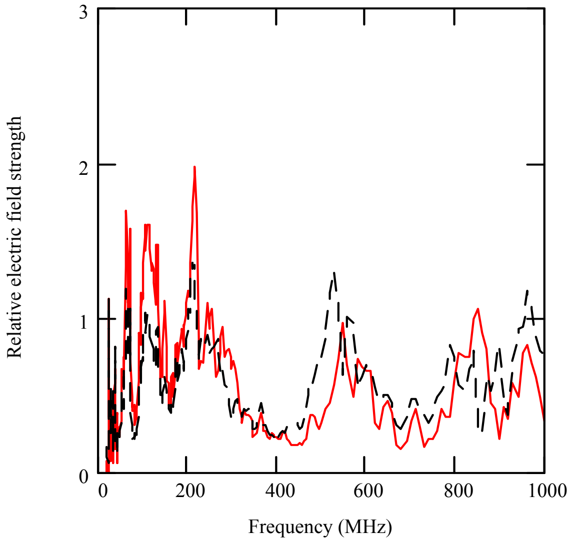

Fig. 15: Electric fields in front for vertical illumination at front with front seats: for driver's (solid) and passenger's (dashed) sides

In the engine bay and behind the dashboard the harness elements do not always meet the criteria needed to allow the transmission line approximation to be reliably employed. Thus, the use of "separated" methods for computing the impact of external fields on such cables will not be valid in this case. In these areas, therefore, it is likely that 3D field models with embedded cable models will be needed to predict the coupling onto the wiring harness. Building electromagnetic models for these regions of a vehicle is therefore likely to be particularly challenging.

8. Conclusions

Whole vehicle electromagnetic models are desirable to allow automotive EMC and antenna engineering issues to be analysed during the design stages of vehicle development. However, models of this scale and complexity can require very significant model development and computing resources. Thus, opportunities for limiting the scope of such models are of considerable importance in ensuring that this type of analysis is practicable.

Measurements have been carried out on a complete vehicle in order to assess the electromagnetic impact of vehicle seats and window glazing for frequencies up to 1 GHz. It is found that simple window glass and seat cushions have negligible impact on the coupling of electric fields from an external antenna. These results suggest that a large proportion of the components that make up a vehicle could be neglected in many numerical models without introducing significant errors. These include simple window glazing and, by implication, the foam, fabric and plastic components that are commonly found in the passenger compartment.

Even the front seats, which are supported by substantial metal frames, have surprisingly little impact on electric field coupling or on the currents induced at harness terminations. However, the significance of the front seats is likely to depend to some extent on the details of particular modelling applications. Asymmetries in the electric field measured inside the vehicle with the seats removed suggest that the effect of the steering gear is significant. This also confirms observations from numerical models of other vehicles.

The components addressed in this paper were relatively easy to remove from a vehicle for comparative testing. There are many other components, however, that are very difficult or even impossible to isolate for analysis in this manner. These include major mechanical components such as the engine and steering gear, as well as features such as window heaters or a sunroof. Numerical modelling provides a much more practicable alternative for investigating the electromagnetic impact of such features [9], since these items can be easily deleted from a model once they have been created.

9. Acknowledgements

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