Preprint of paper for 20th Zurich EMC Symposium, Zurich, 12th–16th January 2009. Not for further distribution.

Numerical Investigation of the Impact of Dielectric Components on Electromagnetic Field Distributions in the Passenger Compartment of a Vehicle

A.R. Ruddle [#1], H. Zhang [*], L. Low [*], J. Rigelsford [*], R. J. Langley [*]

[#] *Advanced Engineering Department, MIRA Limited*
Watling Street, Nuneaton, Warwickshire, CV10 0TU, UK
[1] `alastair.ruddle@mira.co.uk`

[*] *Department of Electrical and Electronic Engineering, University of Sheffield*
Mappin Street, Sheffield, S1 3JD, UK

***Abstract*—Numerical methods have been used to investigate the possible impact of various dielectric components of vehicles on internal electromagnetic field distributions for frequencies up to 2 GHz. The electrical parameters used in the models were derived from measurements on samples obtained from vehicle components. It is found that the dielectrics investigated have a relatively small impact on the internal field populations due to sources located inside the passenger compartment. Under plane wave illumination from the front, however, the dielectric parts dampen the low frequency resonances, while the glass reduces the internal fields for horizontal polarization. Simulations of lossy materials in a vehicle-like cavity indicate that it may be possible to reduce field levels using readily available materials.**

I. INTRODUCTION

Electromagnetic models of vehicles are now used for the analysis of vehicle EMC risks, as well as related issues such as installed antenna performance and human exposure to electromagnetic fields. In most cases these models neglect the many dielectric components that are present in the complete vehicle (eg. window glazing, seat cushions, dashboard, carpets and other internal trim). Validation studies using models based on only the major metallic parts show good correlations with measurements on complete vehicles up to 1 GHz [1]–[2]. Comparative measurements for frequencies below 1 GHz [3] also show relatively small differences due to dielectric components that are easily removed. However, there is a need to investigate vehicle behaviour at higher frequencies, where the dielectric materials may perhaps have a greater impact.

This paper presents the results of comparative simulations involving some of the major dielectric components that are present in cars, for frequencies up to 2 GHz. These models are based on measured data obtained from vehicle components. Preliminary results assessing the viability of possible field mitigation measures are also included.

II. MEASURED PROPERTIES FOR VEHICLE DIELECTRICS

There is very little data available regarding the electrical properties of dielectric materials that are used in vehicles. Representative values for the simulations were therefore obtained from measurements on samples of a variety of interior components that were harvested from vehicles.

The measurements were carried out using a cylindrical cavity method [4] and, in some cases, a rectangular waveguide transmission/reflection technique [5]. Sample preparation is simpler for the waveguide method, and larger samples can be accommodated (which can help to improve accuracy). However, the waveguide method can provide unreliable loss tangent data for low loss materials. The cylindrical cavity gives better results for low to medium loss materials, but sample preparation is more difficult and size is more restricted.

Measurements on the samples are not easy, because of the complicated shape and material composition of the dielectric components. Furthermore, many of the materials investigated are compressible (eg. foam and fibrous materials), which makes sample preparation difficult and the results potentially unreliable. Experiments suggest that the loss tangent is more sensitive to compression effects than the relative permittivity.

Preliminary measurements are summarized in Table I, for a range of large dielectric components found in the passenger compartment of a car. The electrical properties obtained may also be indicative of those for other parts (dashboard, storage boxes etc.). Loss tangents for the foam and fibrous materials are less reliable than those for more rigid materials.

TABLE I
MEASURED PROPERTIES OF DIELECTRIC SAMPLES FROM VEHICLES

Vehicle Component	**Material type**	**Electrical properties at 3 GHz**	
		Relative permittivity	**Loss tangent**
Windows	glass	6.5	0.03
Door skin	PVC	2.86	0.006
Seat	foam	1.12	0.001
	fabric	1.25	0.005
	leather	2.73	0.05
Sun visor	foam	1.05	0.00005
	ABS	2.46	0.006
	PVC	3.22	0.04
Door pillar covers	fabric	1.53	0.006
	polyethylene	2.12	0.0007
Roof lining	fibre	1.31	0.007
	fabric	1.53	0.006
	black lining	1.41	0.01
Carpet	fabric	1.19	0.02

III. IMPACT OF GLAZING AND INTERIOR TRIM

In order to investigate the impact of typical vehicle trim materials, a series of staged numerical models was constructed (for a free space environment) with content as follows:

- metal only (case A).
- metal and glass (case B);
- metal, glass and foam (case C);
- metal, glass, foam and thin plastics (case D).

These simulations were carried out using CST Microstripes [6], and the numerical models were derived from 3D geometry for a passenger car. The impact of the dielectrics is evaluated in terms of the spatial field distribution over the region of the passenger compartment where the occupants may be located. Spatial field data was extracted from the models at more than two million points at selected frequencies up to 2 GHz.

The relative permittivity (ε_R) and electrical conductivity (σ_E) that were used to represent the different material types are detailed in Table II, based on measured values at 3 GHz (Table I), along with their physical thickness.

TABLE II
VEHICLE MODEL DIELECTRIC MATERIAL PARAMETERS

Model feature	**Dielectric component**	ε_R	σ_E **(S/m)**	**Thickness (mm)**
Glass	window panels	6.5	0.0325	windscreen – 5 others - 3
Foam	seats and headrests	1.14	0.0002	bulk material
Plastics	dashboard	2.46	0.00246	1–5
	door skins	2.86	0.00286	2.5
	B-pillar trim	2.12	0.00246	2.2

A. *External Plane Wave Illumination*

The dielectric materials (primarily the glass) reduce the amplitude of low frequency resonances that are a common feature of car passenger compartments as shown in Fig. 1 (by up to 30% in this case). Frequency shifts also occur in the field at specific points, particularly at higher frequencies. The approach adopted here is therefore to compare the field amplitude populations and average field levels for the interior.

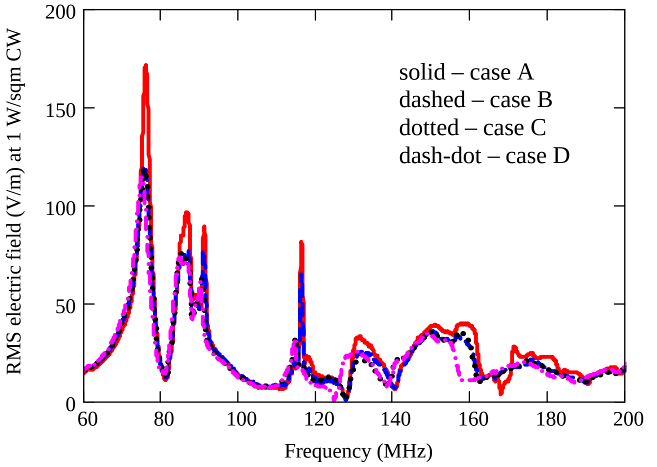

Fig. 1. Frequency dependence of the electric field at a point inside the passenger compartment under 1 W/m^2 vertical plane wave incident from front.

Average internal electric fields obtained under external plane wave illumination from the front of the vehicle are summarized in Tables III–IV, for an incident power density of 1 W/m^2. These results show a clear difference between the two polarizations. This is due in part to differences in the response of the metal vehicle structure to the two polarizations, which reduce as the frequency increases (see Table V). However, the glass reduces the average fields under horizontal illumination. This is more apparent from the field amplitude distributions for the sampled volume (see Figs. 2–5).

TABLE III
AVERAGE INTERNAL ELECTRIC FIELDS FOR VEHICLE MODELS UNDER VERTICAL PLANE WAVE INCIDENT FROM FRONT OF VEHICLE

Model case	**Average RMS electric field (V/m) at 1 W/m^2 CW**					
	70 MHz	**400 MHz**	**1000 MHz**	**1400 MHz**	**1800 MHz**	**2000 MHz**
A	17.32	14.19	15.99	16.68	16.78	16.19
B	19.05	13.15	15.41	16.27	16.67	15.82
C	19.23	13.32	15.63	15.92	16.16	16.24
D	20.44	13.16	16.55	16.25	16.12	16.12

TABLE IV
AVERAGE INTERNAL ELECTRIC FIELDS FOR VEHICLE MODELS UNDER HORIZONTAL PLANE WAVE INCIDENT FROM FRONT OF VEHICLE

Model case	**Average RMS electric field (V/m) at 1 W/m^2 CW**					
	70 MHz	**400 MHz**	**1000 MHz**	**1400 MHz**	**1800 MHz**	**2000 MHz**
A	1.32	12.51	12.97	14.01	13.92	13.76
B	1.41	11.91	11.63	10.64	9.63	9.27
C	1.41	11.55	11.28	9.95	9.41	9.16
D	1.55	13.32	11.22	10.40	9.78	9.28

TABLE V
AVERAGE INTERNAL ELECTRIC FIELDS FOR VEHICLE MODEL WITHOUT DIELECTRICS UNDER PLANE WAVES INCIDENT FROM FRONT OF VEHICLE

Source case	**Average RMS electric field (V/m) at 1 W/m^2 CW**					
	400 MHz	**1000 MHz**	**1400 MHz**	**2000 MHz**	**2400 MHz**	**3000 MHz**
V	14.19	15.99	16.68	16.19	15.16	13.20
H	12.51	12.97	14.01	13.76	13.68	13.48

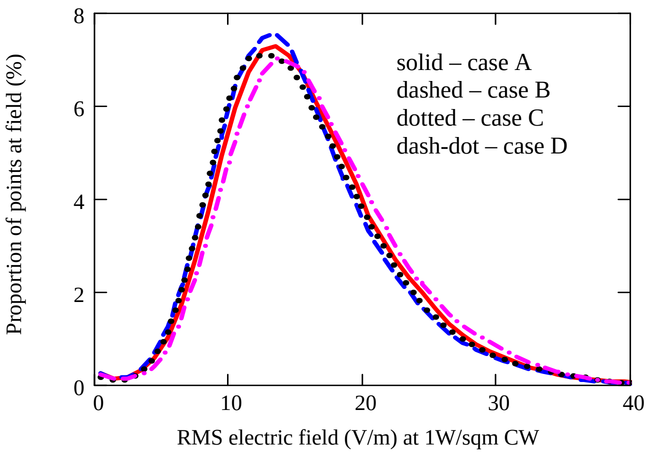

Fig. 2. Amplitude distribution for electric field over passenger compartment at 1 GHz under 1 W/m^2 vertical plane wave incident from front.

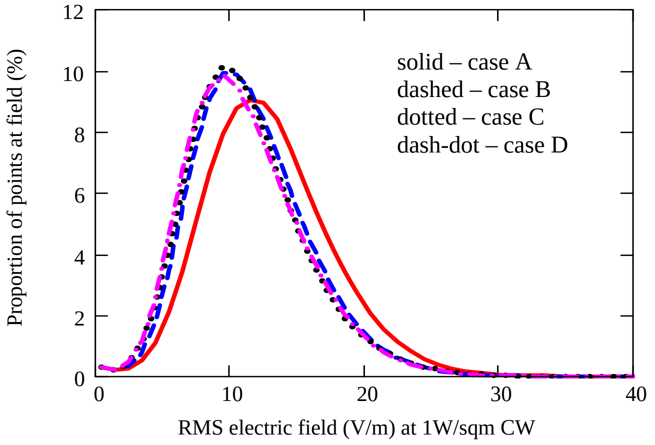

Fig. 3. Amplitude distribution for electric field over passenger compartment at 1 GHz under 1 W/m^2 horizontal plane wave incident from front.

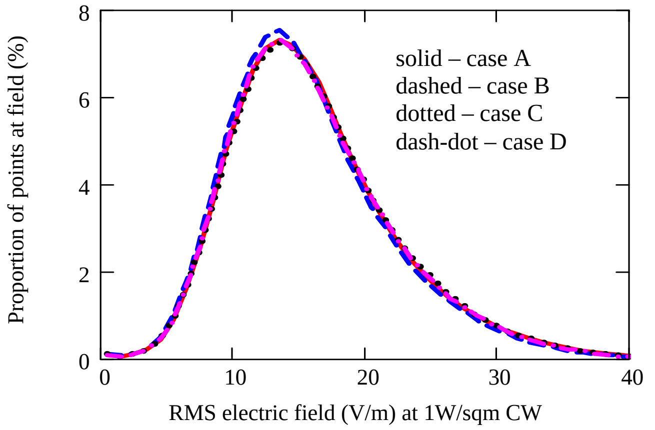

Fig. 4. Amplitude distribution for electric field over passenger compartment at 2 GHz under 1 W/m^2 vertical plane wave incident from front.

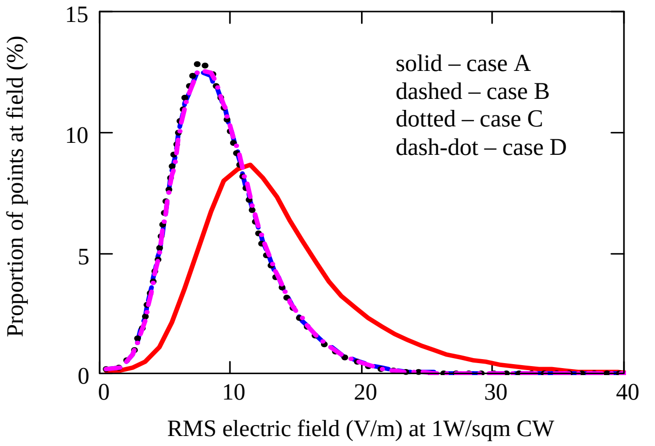

Fig. 5. Amplitude distribution for electric field over passenger compartment at 2 GHz under 1 W/m^2 horizontal plane wave incident from front.

At normal incidence the reflectance for a dielectric slab is independent of the incident field polarization. At non-normal incidence, however, the reflectance for field polarizations that are parallel or perpendicular to the plane of incidence can diverge significantly. At low frequencies the difference is small, but becomes greater as the frequency increases. Simple calculations for a lossless sheet 5 mm thick and of relative permittivity 6 indicate that the reflectance at 60° incidence (representing the sloping windscreen) rises to 25.4% at 2 GHz for the horizontal case, but only 0.02 % for the vertical case. Thus, this seems the most likely cause for the differences in the impact of the glass for the two incident field polarizations.

B. *Internal Dipole Sources*

Average internal electric fields obtained with simple dipole sources located inside the passenger compartment (located in the vicinity of the rear seat) are summarized in Table VI, for both vertical and horizontal orientations, while Figs. 6–9 show the field amplitude distributions for the sampled volume (which includes the source). In this case there is very little difference between the two polarizations, or between different dielectric contents. The magnetic field results are very similar.

TABLE VI
AVERAGE INTERNAL ELECTRIC FIELDS FOR HORIZONTAL AND VERTICAL DIPOLES LOCATED INSIDE MODEL VEHICLE PASSENGER COMPARTMENT

Model case	**Average RMS electric field (V/m) at 1 W CW**					
	1 GHz		**1.5 GHz**		**2 GHz**	
	V	**H**	**V**	**H**	**V**	**H**
A	22.30	22.72	23.30	24.30	22.52	22.89
B	21.79	22.39	23.89	24.35	23.69	24.43
C	22.69	23.03	24.44	23.06	23.59	25.41
D	22.63	22.00	23.28	22.92	22.71	24.18

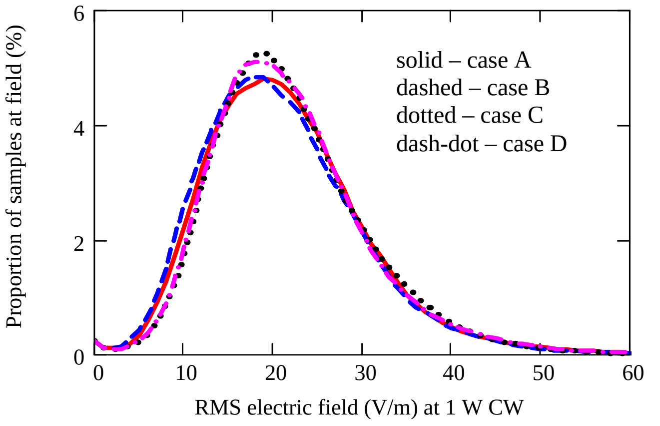

Fig. 6. Amplitude distribution for electric field over passenger compartment at 1 GHz with 1 W vertical dipole source.

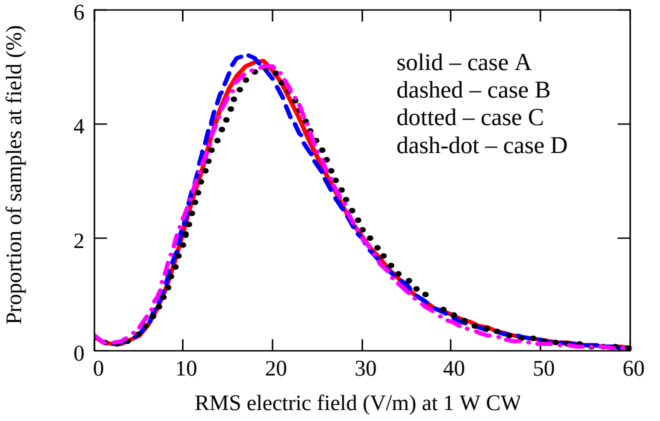

Fig. 7. Amplitude distribution for electric field over passenger compartment at 1 GHz with 1 W horizontal dipole source.

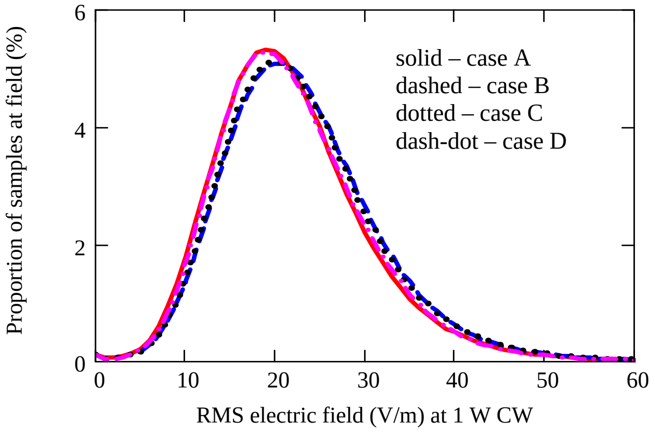

Fig. 8. Amplitude distribution for electric field over passenger compartment at 2 GHz with 1 W vertical dipole source.

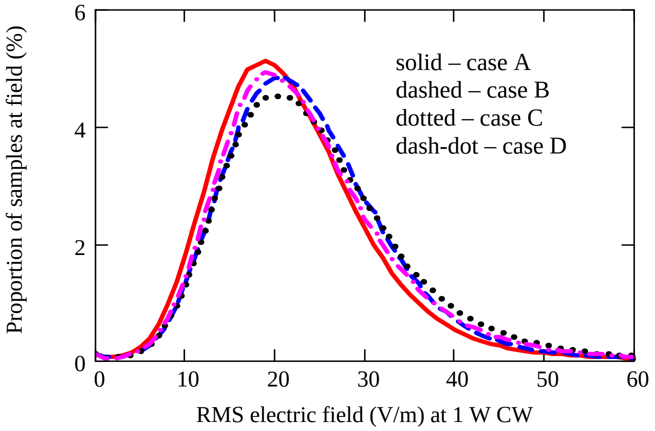

Fig. 9. Amplitude distribution for electric field over passenger compartment at 2 GHz with 1 W horizontal dipole source.

IV. INVESTIGATION OF DAMPING MATERIALS

The low loss materials that are found inside the passenger compartment have little impact on the computed internal field levels. Investigations have therefore been initiated to assess whether more lossy materials might be incorporated into the vehicle in order to reduce internal field strengths.

Preliminary simulations have been carried out for a simple structure with vehicle-like features [7] using CST Microwave Studio [6]. Preliminary results indicate that lining the walls or covering the seat with material of relative permittivity of 6.5 and a loss tangent of 0.1 are both effective strategies for damping the cavity resonances at 900 MHz (see Figs. 10–11).

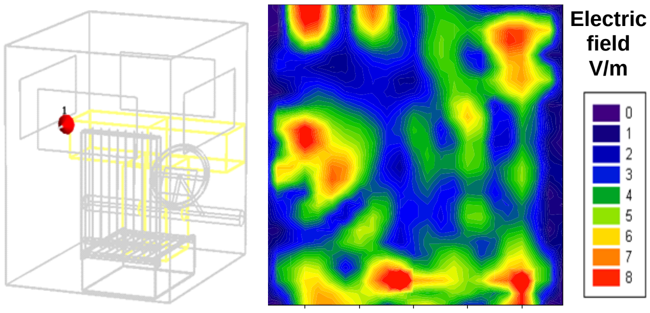

Fig. 10. Simple vehicle-like partial cavity (left) and computed 900 MHz electric field distribution over a horizontal plane (right).

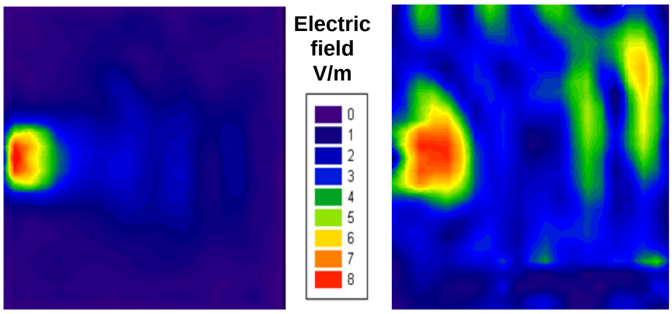

Fig. 11. Computed 900 MHz field distribution over horizontal plane for models with lossy material on walls only (left) and covering seat only (right).

V. CONCLUSION

Simulations based on real vehicle geometry and measured dielectric properties indicate that the dielectric components investigated here have a relatively small impact on the internal field populations due to sources located inside the passenger compartment for frequencies in the band 1–2 GHz. Under plane wave illumination from the front, however, the dielectric parts dampen the low frequency resonances, while the glass reduces the internal fields for horizontal polarization.

Preliminary simulations also suggest that readily available lossy materials (measured rubber material has a loss tangent of 0.1–0.3 and a relative permittivity of 6.5) could be used to dampen resonances within the passenger compartment of a car.

ACKNOWLEDGMENT

The work outlined above was carried out as part of SEFERE (see *http://www.sefere.org*), a collaborative research project supported by the UK’s Technology Strategy Board (contract reference TP/3/DSM/6/I/15266) and Engineering and Physical Sciences Research Council (grant reference EP/D033187/1). The project consortium includes MIRA Limited (coordinator), ARUP Communications, BAE Systems Limited, Harada Industries Europe Limited, Jaguar Cars, University of Sheffield, UK National Policing Improvements Agency and Volvo Car Corporation (Sweden).

REFERENCES

[1] A.R. Ruddle, X. Ferrières, J.P. Parmantier and D.D. Ward, “Experimental validation of time-domain electromagnetic models for field coupling into the interior of a vehicle due to a nearby broadband antenna”, *IEE Proc. A: Science, Measurement and Technology*, Vol. 151, No. 6, November 2004, pp. 430–433.

[2] A.R. Ruddle, “Validation of predicted 3D electromagnetic field distributions due to vehicle mounted antennas against measured 2D external electric field mapping”, *IET Science, Measurement and Technology*, Vol. 1, No. 1, January 2007, pp. 71–75.

[3] A.R. Ruddle, “Measured impact of vehicle seats and glazing on the coupling of electromagnetic fields into vehicles and their wiring harnesses”, *Proc. 15th Int. Zurich EMC Symposium*, Zurich, Switzerland, February 2003, pp. 487–492.

[4] N. Damaskos, *General Cavity Material Measurement System Manual*, September 2003.

[5] Ding Sun, “Measurement of complex permittivity and permeability of microwave absorber ECCOSORB MF-190”, Pbar note 576, Fermi Lab, August 1997.

[6] (2008) The CST website. [Online]. Available: http://www.cst.com/

[7] H. Zhang, L. Low, J. Rigelsford, R. J. Langley, “Field distributions within a rectangular cavity with vehicle-like features”, *Proc. LAPC 2008*, Loughborough, UK, March 2008, pp. 205–208.