# COMPUTED IMPACT OF OPTIONAL VEHICLE FEATURES (SUNROOF AND WINDSCREEN HEATER) ON AUTOMOTIVE EMC CHARACTERISTICS

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***Abstract:*** Measuring the impact of a sunroof or windscreen heater on vehicle EMC performance is difficult because of the need for access to vehicles that differ only in terms of these features. However, this type of change is relatively easy to implement in numerical models. Computed results suggest that such structures may significantly change both the emissions and immunity characteristics of vehicles. It is therefore concluded that features of this type need to be considered in the selection of vehicles for both emissions and immunity testing. It is also essential to represent such features in electromagnetic models that are to be used in support of automotive EMC and antenna engineering.

## 1. Introduction

It is becoming increasingly common for passenger vehicles to be produced in a wide range of variants that are derived from a common platform. These vehicle variants include not only different body styles (saloon, coupe, convertible etc.), but also more subtle differences in terms of the features and equipment that may be fitted to the vehicle. Given the large number of permutations that are possible, it is not possible to subject all variants to EMC testing for type approval [1]. Consequently, manufacturers normally select a representative subset of these vehicles for test purposes. Objective data concerning the likely significance of different body styles and optional features could therefore be of considerable benefit to engineers tasked with selecting a subset of vehicles for test. This paper considers the potential significance of a sunroof and a windscreen heater, which are common optional equipment for vehicles.

Window apertures provide a very significant path for the coupling of electromagnetic fields into and out of vehicles. Thus, the presence of an additional sunroof aperture in the roof of the vehicle is likely to have an impact on both emissions and immunity characteristics, as well as on the performance of vehicle mounted antennas. In most cases a sunroof is simply glazed and equipped with a non-conducting solar screen that can be pushed aside. Sometimes the sunroof is implemented using a movable metal panel, but in most cases it is a glass panel that is normally augmented with a non-conducting solar screen that can be pushed aside when required. In some cases conductive material is added to the glass in order to reduce the transmission of solar radiation (infra-red and ultra-violet) into the vehicle interior. Such schemes are implemented by doping the glass, by adding surface or embedded coatings, or by including a mesh structure.

Heating elements are commonly embedded in the rear windows of vehicles, usually in the form of an array of horizontal conductors, although more complex arrangements can also be found. A more recent development, however, is the introduction of heating elements into the front windscreens of some vehicles, where vertical conductors are often used. The polarization, angle and frequency dependent properties of arrays of parallel conductors are well known in microwave engineering, where they are used to modify the polarization characteristics of antennas [2]. Consequently, window heater arrays can also be expected to modify the electromagnetic characteristics of vehicles.

Knowledge of the potential impact of optional structures on vehicle EMC characteristics is essential to support the selection of a subset of vehicles for test. This information is also necessary to establish the significance of such structures for numerical electromagnetic models of vehicles that are intended for the analysis of automotive EMC and antenna engineering issues. However, measuring the effects of a sunroof or windscreen heater is difficult because of the need to obtain vehicles that differ only in terms of these features. Modifying a vehicle by blocking the sunroof or replacing the windscreen may be possible in principle, but do not provide a particularly easy or satisfactory solution in practice.

In view of the problems with practical measurements, a numerical investigation has been used to assess the likely impact of a sunroof and a windscreen heater on the electromagnetic characteristics of a vehicle. The increasing availability of geometrical models for vehicles and the falling costs of high performance computers now make it practicable to undertake 3D electromagnetic field modelling of vehicles. Using an existing vehicle model, it was a relatively simple (if tedious) step to add representations of window heater arrays, and to introduce an additional aperture to model the sunroof. Although such models are always an approximation to the real system, they are probably sufficiently representative to obtain a quantitative indication of the likely impact of these structures on the electromagnetic characteristics of the vehicle.

## 2. Implications for EMC performance

The vehicle structure and its wiring harness, as well as any on-board antennas, can be considered as a complex multi-port antenna. Differences in any of the elements of the system, such as those resulting from a different body style, adding a sunroof, repositioning a module or re-routing a harness element will re-tune this “antenna”, thus impacting on EMC.

For example, adding a sunroof may, for certain frequency bands, change the field transfer function between a point inside the vehicle and the external point where an emissions measurement is to be made. If there is a source of emissions at any of these frequencies that is located at this internal point then the radiated emissions characteristics will vary between vehicles that differ only in whether or not they are equipped with a sunroof. In current automotive emissions measurement standards the noise floor can be as little as 10 dB below the legislative emissions limits [1]. Thus, if the differences in the transfer function are of the order of 10 dB or more at the problem frequencies, the overall impact may be to cause one of the vehicles to fail an emissions test at some frequencies, while for the other vehicle any emissions at these frequencies could be below the measurement noise floor.

Similarly, the presence of a windscreen heater may change the field transfer functions between points inside the vehicle and an external source (such as an antenna used for immunity testing) for a range of frequencies. If these points correspond to a region of the vehicle where electronic modules and wiring harnesses are located, and this equipment is sensitive at these frequencies (eg. the cables are of resonant length and the modules have some susceptibility), then any differences in the field transfer functions will also result in differences in the measured immunity performance of the vehicle.

Thus, changes in the field transfer functions between points inside and outside the vehicle that are associated with changes to the vehicle structure could result in changes to the EMC characteristics of the vehicle. However, it is not possible to determine the implications for vehicle level EMC from the electromagnetic properties alone. Additional information concerning the location and EMC characteristics of the equipment that is installed in the vehicle is also required for this purpose. Nonetheless, the ability to quantify likely changes in the field transfer functions through numerical modelling is of value and has already been used in practical applications, including assessing the implications for vehicle level EMC risk and to explain test results that were initially regarded as anomalous.

The analysis approach that has been adopted is therefore to use an electromagnetic model of the vehicle to calculate differences in relevant field transfer functions that arise from the introduction of optional vehicle features. The significance of these differences for vehicle level EMC performance characteristics can then be assessed from wider knowledge concerning the equipment that may be affected.

## 3. Numerical modelling approach

The numerical models were based on a geometrical model that was derived from vehicle CAD data. This reference model was then modified to produce additional models reflecting typical geometries for a sunroof and for front and rear window heaters.

An earlier paper [3] considered the effects of adding rear window and windscreen heaters to a base model comprising the vehicle body shell and doors. The main purpose of this work was to establish whether these features would need to be included in models of the coupling of electromagnetic fields into vehicles and their wiring harnesses that were intended for experimental validation. The extensions to this work that are presented in this paper are intended to illustrate and quantify the impact of adding optional components, such as a sunroof and windscreen heater, to a more realistic vehicle model comprising the bodyshell, doors and a rear window heater.

Numerical modelling of vehicle structures for EMC analysis is highly demanding in terms of computational resources because of the physical dimensions and frequency range that must be addressed. The TLM method [4, 5] is attractive for automotive EMC applications because it is a time-domain technique, thus permitting broadband frequency-domain results to be obtained from Fourier transformation of a single time-domain response. As TLM employs a structured mesh, very large models can be accommodated within relatively modest computing resources. Furthermore, sub-cell models are also available for long, thin features, thus ensuring that common vehicle elements such as wires [6] (including multi-conductor bundles [7]) and slots [8] can also be efficiently represented in models of large structures.

The TLM models developed for this work were intended to provide realistic but representative illustrations of the likely effects of a sunroof and screen heaters of vehicle EMC characteristics, rather than attempting to predict the detailed performance of a particular vehicle equipped with specific heater configurations. For the purposes of these studies, therefore, the models were based on representative heater dimensions and orientations (see Fig. 1 below) using perfectly conducting wires. Real screen heating elements are supported by layers of material of relatively high dielectric constant ($\varepsilon_r$~7 for typical glazing materials). Although the glass and the termination impedances are likely to modify the frequency response of the conductor arrays to some extent, these secondary effects were beyond the scope of this work.

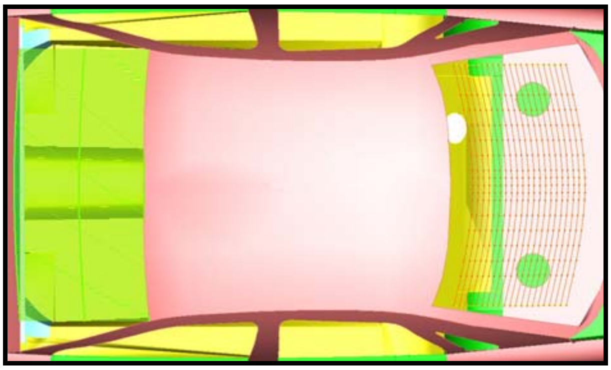

**Fig. 1:** Plan view of vehicle geometry showing conductor arrays representing front and rear screen heaters

Similarly, the size and position of the aperture that was introduced into the roof of the vehicle model to represent the sunroof (illustrated in Fig. 2), is only representative of such features. It may be that the real vehicle that provided the basis for this study is not produced with a sunroof or windscreen heater as possible options, but there are certainly other vehicles that are equipped with both of these features.

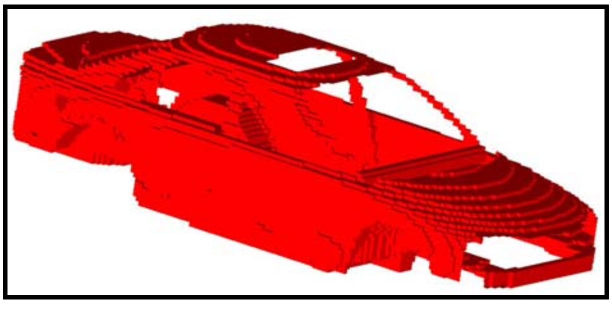

**Fig. 2:** View of vehicle TLM model illustrating additional roof aperture representing sunroof

In the interests of computational efficiency, the "immunity" characteristics were investigated using simple plane wave excitations under free-space conditions. Simulations were carried out for both horizontally and vertically polarized plane waves, which were incident from the front (relative to the vehicle). In order to obtain an indication of the "emissions" performance, a simple localized field source (with *x*, *y* and *z* field components) was excited in the interior of the vehicle. The source point was located in the lower part of the dashboard area, representing a likely module location.

In the emissions models, field values were also collected at a point placed 3 m from the side of the vehicle and 1.8 m above the ground plane and in line with the position of the front axle. This therefore corresponds to the 3 m emissions measurement configuration described in the Automotive EMC Directive [1]. Numerical studies of vehicle emissions measurements indicate that the raw electric field at 3 m from a vehicle provides a good estimate of the value that would be obtained from measurements using a broadband antenna in this position [9].

Computing the field at 3 m from the vehicle therefore yields results that are representative of an automotive emissions measurement, but at considerably lower computational cost than including an antenna at 10 m distance (where the antenna height is 3 m, further increasing the model size and computing requirements). In addition, a semi-anechoic environment was used for the emissions scenarios, both because it is a more common environment for emissions measurements and has the added benefit of further limiting the increased model volume that results from computing the field at 3 m from the car.

In both the emissions and immunity scenarios, the computed electric field was recorded at a number of points inside the vehicle. These interior points were located as follows:

- behind the windscreen (P1);
- middle of the passenger compartment (P2);
- adjacent to the rear window (P3);
- front seat area (P4);
- middle of rear luggage compartment (P5);
- dashboard area (P6).

In each of the three different excitation cases simulations were carried out for five vehicle configurations:

- no sunroof or heaters;
- sunroof only;
- rear screen heater only;
- sunroof and rear screen heater;
- sunroof and both front and rear screen heaters.

Comparison of the results from these simulations allows the impact of these structures, in terms of changes to the field transfer function, to be identified. This provides a quantitative indication of the errors that may result from neglecting these features in both physical measurements and in electromagnetic models.

## 4. Results for sunroof alone

Differences in the field at points in the dashboard area, and in the middle of the passenger cavity, due to the introduction of a sunroof aperture are illustrated in Figs. 3-4 below. These results are presented in terms of the net electric field predicted for the two points under external illumination with the sunroof relative to the values obtained from the corresponding reference models (ie. without sunroof or heaters).

The results obtained for horizontal plane wave illumination are shown in Figs. 3, while Fig. 4 illustrates the corresponding results obtained under vertical plane wave illumination.

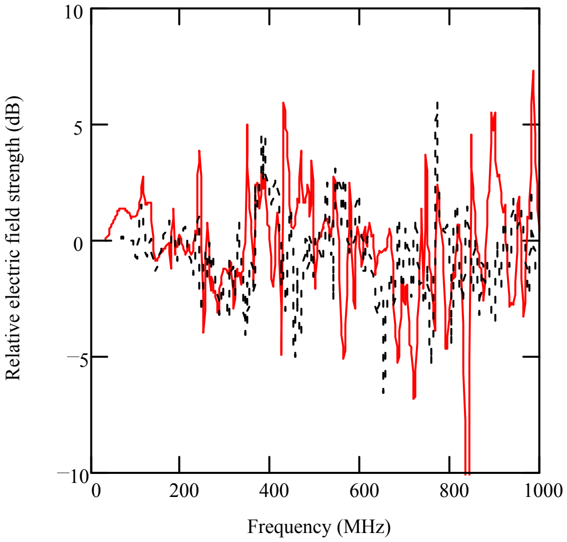

**Fig. 3:** Change in net electric field for horizontal plane wave from front: P6 (dotted) and P2 (solid)

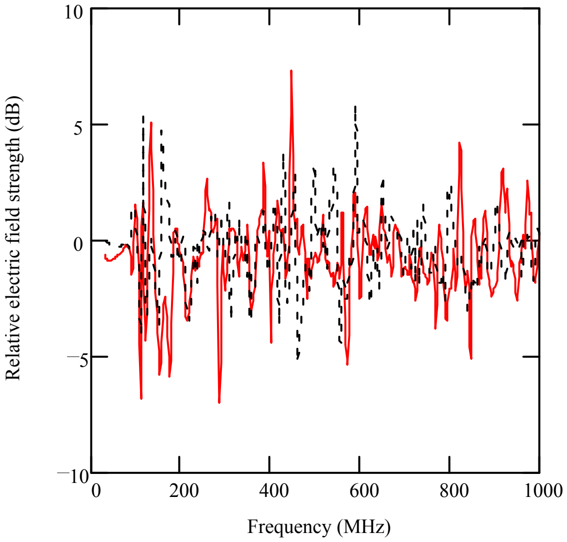

**Fig. 4:** Change in net electric field for vertical plane wave from front: P6 (dotted) and P2 (solid)

The differences are generally no more than ± 5 dB in both cases, although there are a few significantly larger differences. The effects of the sunroof are greater at higher frequencies for horizontal polarization (Fig. 3), while for vertical polarization the differences are greater at lower frequencies (Fig. 4). The results vary in detail depending on the exact location of the point under consideration, but are not significantly different overall for any of the points that were investigated in this study.

Results for predicted radiated electric fields due to the simple internal source are illustrated in Fig. 5 (for the horizontal component) and in Fig. 6 (for the vertical component). The computed differences are generally no more than ± 10 dB in both cases, although changes in excess of 20 dB can be seen. The differences are also a little larger for the horizontal electric field component than for the vertical component.

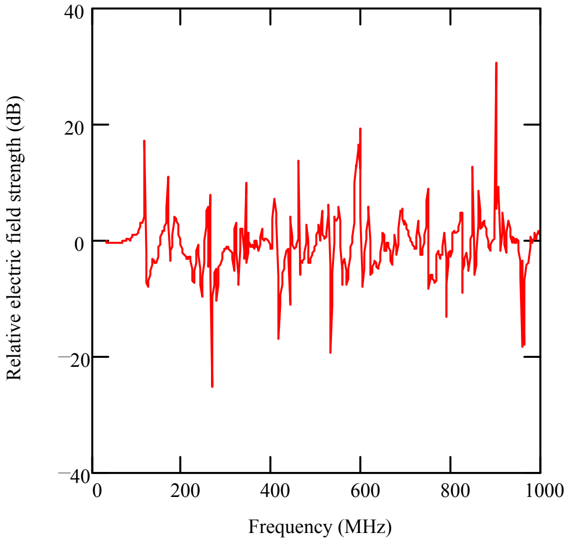

**Fig. 5:** Change in horizontal electric field component at 3 m emissions measurement point due to sunroof

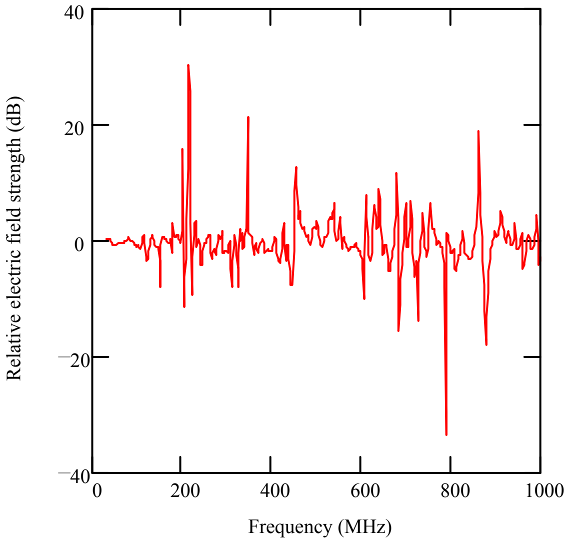

**Fig. 6** Change in vertical electric field component at 3 m emissions measurement point due to sunroof

Thus, these models suggest that the presence of a sunroof is likely to have a greater impact on the radiated emissions of a vehicle (~10 dB) than on its immunity characteristics. Nonetheless, the impact in field coupling into the interior of the vehicle (~5 dB) is not insignificant. However, the nature of the variations is such that it is not possible to say that performance is better or worse with a sunroof, only that it is different and that the differences are large enough to be significant.

### 5. Results for sunroof with front and rear heaters

The results shown in Figs. 7-8 illustrate the impact of the sunroof with the rear screen heater and with both front and rear heaters (relative to the reference model with a rear heater only) on the net field at two internal points under horizontal plane wave illumination from the front of the vehicle. For the central point (Fig. 7) the additional impact of the windscreen heater is relatively small at the higher frequencies but close to the heater (Fig. 8) much greater changes can be seen. The strongest effects are around 100 MHz in both cases.

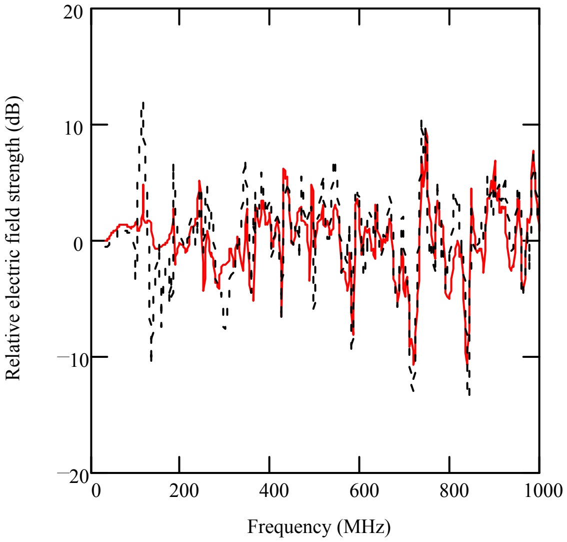

**Fig. 7:** Change in electric field at P2, horizontal plane wave: sunroof with rear (solid) and both (dotted) heaters

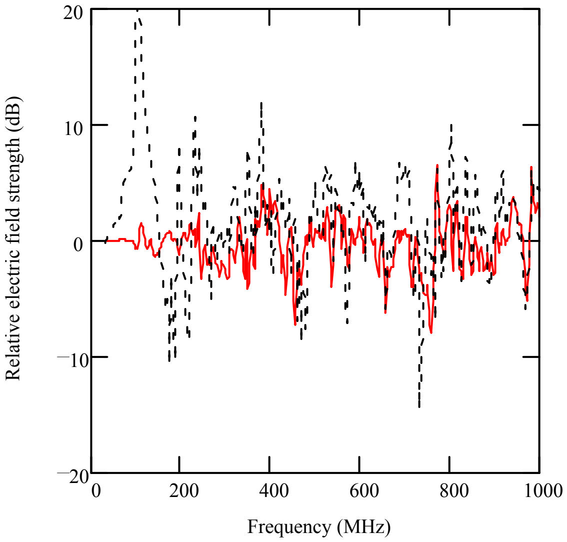

**Fig. 8:** Change in electric field at P6, horizontal plane wave: sunroof with rear (solid) and both (dotted) heaters

From well-established theory for the behaviour of infinte planar arrays of parallel conductors [10], the windscreen heater geometry that is assumed in these models (ie. wires spaced ~0.5 cm apart and running from top to bottom of the windscreen aperture) is expected to be effectively transparent to horizontal polarization, whilst reflecting vertical polarization almost entirely (up to 1 GHz). The variation with angle of incidence is much less significant in this case than would be expected for the much sparser rear screen heater array (where the conductors are horizontal, and ~0.5 cm apart) since the reflection coefficient for the windscreen geometry at normal incidence is greater than 0.998 up to 1 GHz.

The corresponding results for a vertically polarized source are shown in Figs. 9-10 below. The windscreen heater has a more obvious impact on the internal fields in this case, but does not always result in reduced field strengths, which simple arguments based on the properties of infinite conductor arrays would suggest. As for the horizontal case, the effects of the windscreen heater are smaller for central point (P2) than for the point close to the heater (P6).

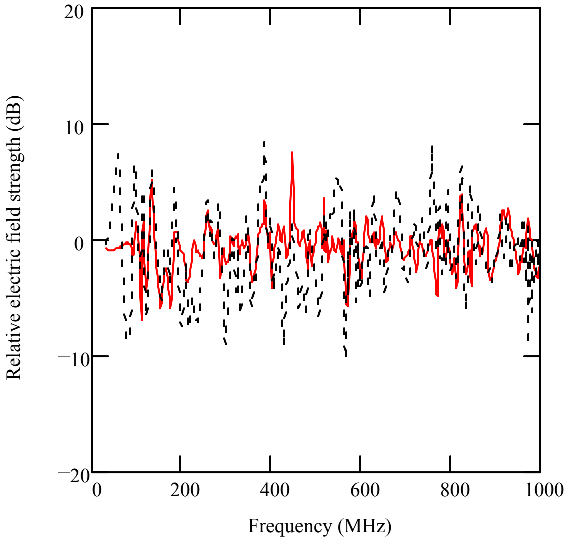

**Fig. 9**: Change in net electric field at P2 for vertical plane wave: sunroof with rear (solid) and both (dotted) heaters

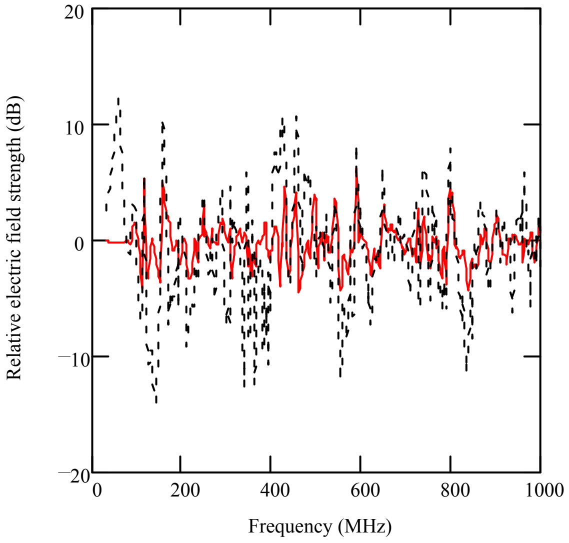

**Fig. 10:** Change in net electric field at P6 for vertical plane wave: sunroof with rear (solid) and both (dotted) heaters

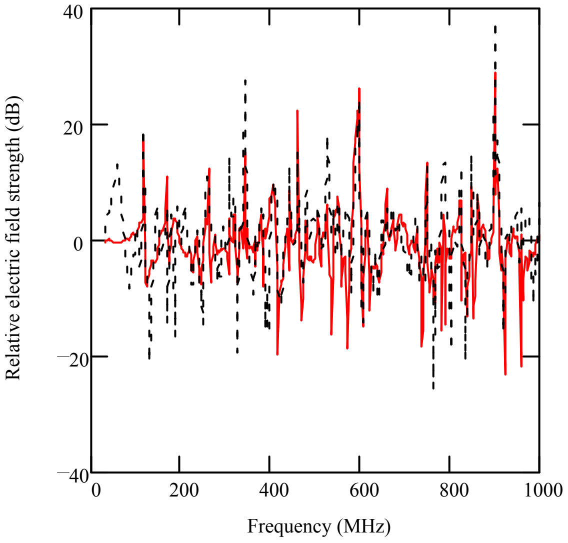

**Fig. 11** Change in horizontal electric field at 3 m emissions measurement point: sunroof with rear (solid) and both heaters (dotted)

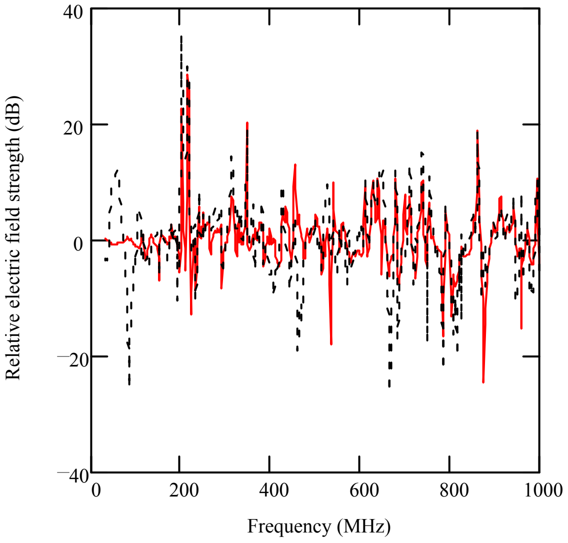

**Fig. 12:** Change in vertical electric field at 3 m emissions measurement point: sunroof with rear (solid) and both (dotted) heaters

Changes in the predicted electric field components at the 3 m emissions measurement point are illustrated in Figs. 11-12, and again indicate that the impact of the sunroof and windscreen heater are likely to be more significant for the emissions performance of the vehicle than for the immunity characteristics. Based on these simulations, a windscreen heater is likely to have a greater impact on the EMC characteristics of a vehicle than a sunroof, although the impact of a sunroof alone is not insignificant.

The peaks at around 60 MHz that can be seen in Figs. 9-12 due to the windscreen heater have also been found in models of other vehicles of similar size and shape when a similar model for the windscreen heater is added to the vehicle geometry. The magnitude of this feature is also similar for these different vehicles. At higher frequencies, the differences between the results are greater, since the differences in the detailed geometry of the vehicles have greater impact on the field transfer functions.

## 6. Discussion

The numerical models indicate that a windscreen heater is likely to have a greater impact on the EMC characteristics of a vehicle than a sunroof, although the impact of a sunroof alone is not insignificant. The magnitudes of the differences that are predicted in these cases are very similar to those already reported for the heaters alone [3]. The simulations also suggest that the impact on emissions characteristics is greater than for immunity (~10 dB for a sunroof, ~15-20 dB for a windscreen heater). Nonetheless, the impact in terms of external field coupling into the interior of the vehicle (~5 dB for a sunroof, ~10 dB for a windscreen heater) could be sufficient to result in failure for some systems.

The nature of the variations in field coupling that have been predicted is such that it is not possible to draw simple conclusions as to whether performance is improved or degraded by the presence of a sunroof or a windscreen heater.

At some frequencies the field transfer function is greater for one configuration, but for other frequencies it is greater for the other case. Consequently, it is only possible to say that the field coupling differs between different vehicle configurations, and that the magnitudes of the differences that have been predicted would be large enough to make the difference between passing or failing whole vehicle EMC tests. Whether these changes in fact represent a problem, however, depends on the EMC characteristics of the systems that are installed in the vehicle.

It is important to note, however, that the implications of these results are that the types of modification to the vehicle structure that have been considered here could radically alter the vehicle level EMC characteristics. Thus, the absence of any discernible emissions from one vehicle configuration does not guarantee that a different vehicle configuration would not fail an emissions test. This effect has been observed in real world vehicle measurements, and numerical models have already been used to confirm that what was initially assumed to be a test error was actually a real effect resulting from the presence of optional equipment of the types that have been considered here.

These issues are probably more significant for modules that radiate directly or are susceptible to radiated fields. Where the attached cables represent the most significant mechanism for coupling fields into and out of a system (which is more commonly the case than direct coupling to circuit boards) the spatial averaging that is provided by the physical extent of the cables is likely to average the effects of local changes, and therefore reduce the overall impact on the transfer function relating the external field to the noise voltage at the harness terminals.

## 7. Conclusions

Numerical models have been used to investigate the possible impact of optional vehicle equipment (sunroof and windscreen heater) on vehicle EMC characteristics, since reliable comparative physical measurements are difficult to achieve in practice. These models are not intended to provide detailed predictions for specific vehicle configurations, but are believed to be sufficiently representative to allow general conclusions to be derived from the results.

The windscreen heater is found to have a greater effect than the sunroof, and in both cases the impact on emissions characteristics is greater than for immunity. It is concluded that the optional vehicle features considered here could have a significant impact on vehicle EMC characteristics and must therefore be taken into account in the selection of vehicles for emissions and immunity testing.

Similar arguments also apply to the experimental verification of automotive antenna performance, since numerical models indicate that the installed antenna performance characteristics are likely to be influenced by the local geometry [11]. Considerable differences are also expected for vehicle variants that use different body styles. In addition, features such as a sunroof and screen heaters also represent key elements for electromagnetic models that are intended for automotive EMC and antenna analysis, particularly where experimental validation of the results is to be carried out.

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## 9. References

[1] "Commission Directive 95/54/EC", *Official Journal of the European Communities*, No. L 266, 8th November 1995, pp. 1-66

[2] S. Cornbleet, *Microwave optics: the optics of microwave antenna design,* Academic Press, London, 1976, Chapter 6

[3] A.R. Ruddle, "Numerical modelling of the impact of automotive screen heaters on vehicle EMC characteristics", *Proceedings of 5th European EMC Symposium*, Sorrento, Italy, September 2002, Vol. 2, pp. 721-725

[4] P.B. Jones, "A symmetrical condensed node for the TLM method", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 330, No. 10, 1985, pp. 882-992

[5] W.J.R. Hoefer, "The transmission-line matrix method: theory and applications", *IEEE Transactions on. Microwave Theory and Techniques*, Vol. 330, No. 10, 1985, pp. 882-892

[6] A.J. Wlodarczyk and D.P. Johns, "New wire interface for graded 3-D TLM", *Electronics Letters*, Vol. 28, No. 8, pp. 728-729

[7] A.J. Wlodarczyk, V. Trenkic, R.A. Scaramuzza and C. Christopoulos, "A fully integrated multiconductor model for TLM", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 12, December 1998, pp. 2431-2437

[8] V. Trenkic and R.A. Scaramuzza, "Modelling of arbitrary slot structures using transmission line matrix (TLM) method", *Proceedings of 14th International Zurich EMC Symposium*, Zurich, Switzerland, February 2001, pp. 393-396

[9] A.R. Ruddle, D.A. Topham, D.D. Ward and P.J. Page, "Theoretical analysis of automotive emissions measurements at 3m and 10m ranges", *Proceedings of 13th International Zurich EMC Symposium*, Zurich, Switzerland, February 1999, pp. 285-289

[10] N. Marcuvitz, *Waveguide handbook*, Peter Peregrinus, London, 1986, Chapter 5

[11] A.R. Ruddle, A. Sarantidis, and D.D. Ward, "Modelling the installed performance of vehicle-mounted antennas", *Proceedings of IEE National Conference on Antennas and Propagation*, York, UK, 1999, pp. 3-5