NUMERICAL MODELLING OF THE IMPACT OF AUTOMOTIVE SCREEN HEATERS ON VEHICLE EMC CHARACTERISTICS

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Abstract - Heating elements are commonly embedded in vehicle glazing, usually in the form of arrays of conductors, to provide a demisting or deicing function. Numerical models, based on representative vehicle geometry and simple conductor arrays, have been used to investigate the potential impact of such structures on the electromagnetic characteristics of vehicles. The results suggest that window heaters may significantly change both the emissions and immunity characteristics of vehicles. It is therefore concluded that it is essential to represent such features in electromagnetic models that are to be used in support of automotive EMC analysis. These results also have corresponding implications for the selection of vehicles in both emissions and immunity testing.

I. INTRODUCTION

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 is the introduction of heating elements into the front windscreens of some vehicles, where vertical conductors are often used. The polarisation and frequency dependent properties of arrays of parallel conductor are well known in microwave engineering, where they are used to modify the polarisation characteristics of antennas [1]. Meander-line arrays are also used in a similar way [2]. Consequently, heater arrays can also be expected to modify the EMC characteristics of vehicles.

Knowledge of the potential impact of such structures on vehicle EMC characteristics is necessary to assess their significance for numerical electromagnetic models of vehicles. A numerical study has therefore been carried out, both to demonstrate these effects for a realistic structure and to quantify the likely impact on vehicle emissions and immunity characteristics. These numerical simulations are based on a geometrical model of a real vehicle, which has been augmented with representative structures reflecting the geometry of typical screen heater structures.

II. PRELIMINARY ESTIMATES

A quantitative indication of the likely effects of heater arrays can be obtained using approximate closed form expressions for the equivalent circuits presented to plane waves by infinite planar arrays of parallel conductors [3]. The key parameters influencing the results are the array spacing, conductor geometry (ie. cross-sectional form and dimensions) and the orientation of the conductors relative to the polarization of the incident field, as well as the frequency and the angle of incidence of the incident field relative to the plane of the array.

Estimates based on these theoretical results (using equivalent circuit parameters for flat strip conductors in this case) indicate that typical rear screen heater geometry, where the conductors are horizontal and relatively widely spaced (~3 cm), is likely to be transparent to vertical polarisation whilst reflecting horizontal electric fields to a degree that depends on the frequency and the angle of incidence (see Fig. 1).

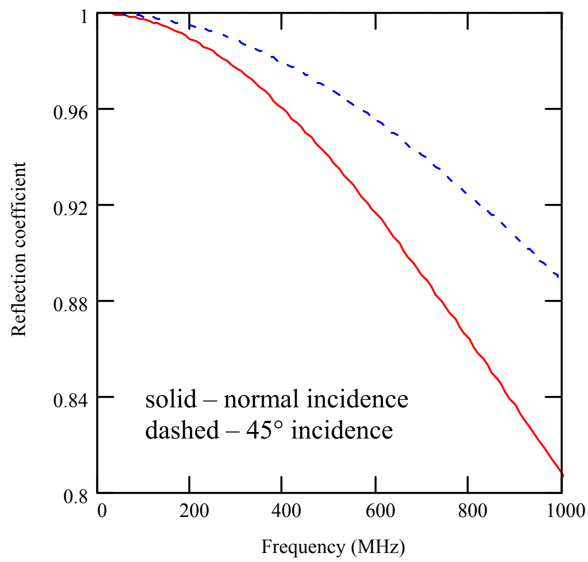

Fig. 1 Reflection coefficient for a planar array of parallel conductors 3 cm apart and aligned with the electric field of a linearly polarised plane wave

Typical windscreen heater geometry, where the conductors are often vertical as well as being more closely spaced (~0.5 cm) than in rear screen heaters, is expected to be effectively transparent to horizontal polarisation, whilst reflecting vertical polarisation almost entirely (up to 1 GHz). The variation with angle of incidence is much less significant in this case, as the reflection coefficient for normal incidence is >0.998 for this geometry up to 1 GHz.

Although these results give a useful indication of the likely effects of such structures, vehicle heater arrays are of finite size, curved rather than flat, embedded in glass and interact with each other as well as with a vehicle of very complex shape. Numerical models are therefore required to investigate the significance of these structures for realistic vehicle configurations.

III. NUMERICAL MODELS

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 rectangular mesh, very large models can be accommodated within relatively modest computing resources. Furthermore, sub-cell models are available for long, thin features, thus ensuring that common elements such as wires [6] (including multiconductor bundles [7]) and slots [8] can also be efficiently represented in models of large structures.

The models developed for this work are intended to provide realistic but representative illustrations of these effects, rather than attempting to predict the detailed performance of a particular vehicle with specific heater configurations. For the purposes of these studies, therefore, the models were based on representative heater dimensions and orientations (as illustrated in Fig. 2) using perfectly conducting wires. These structures were added to a model of a vehicle bodyshell and closures (doors, hood etc.) that was derived from CAD data for a real vehicle.

Real screen heating elements are also supported by layers of material of relatively high dielectric constant (ε_r~7 for typical glazing materials). Although this is likely to modify the frequency response of the conductor arrays to some extent, these effects are not directly reflected in the models reported here. The termination impedances are also expected to modify performance, but were beyond the scope of this study.

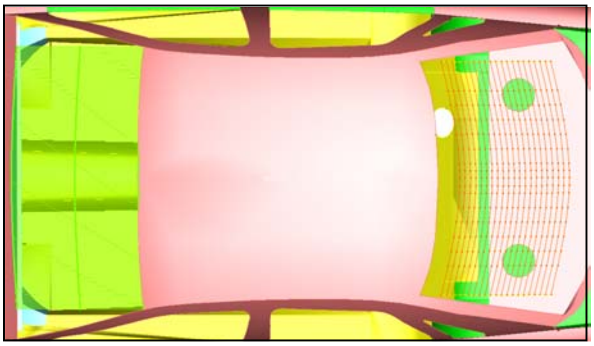

Fig. 2 Plan view of vehicle showing conductor arrays representing front and rear screen heaters

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 horizontal and vertical polarised plane waves, which were incident from the front (relative to the vehicle). In order to provide some indication of the "emissions" performance, a simple localised field source (with x, y and z field components) was excited in the interior of the vehicle. In both the emissions and immunity scenarios, the resulting electric field was recorded at a number of points in and around the vehicle.

In the emissions models, field values were also collected at a point placed 3 m from the vehicle and 1.8 m above the ground plane, on a line through the front axle of the vehicle. This corresponds to the 3 m emissions measurement configuration described in the automotive EMC directive [9]. Previous numerical studies of vehicle emissions measurements indicate that the raw 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 [10]. This approach 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. A semi-anechoic environment was also used in this case, both because it is a more common environment for emissions measurements and has the additional benefit of further limiting the increased volume of the model.

In each of the three different excitation cases the following three simulations were compared:

- no heaters (simplest model, but extremely unlikely in modern vehicles);
- rear heater only (the most common case for current vehicles);
- both front and rear heaters (not yet universal, but increasingly popular).

The three sets of results for each case allow the impact of these structures on vehicle EMC characteristics to be identified, as well as providing some quantitative indication of the errors that may result from neglecting these features in both electromagnetic models and in measurements.

IV. MODEL RESULTS

The results shown in Figs. 3-4 illustrate the impact of the heaters on the net field at an internal point under plane wave illumination from the front of the vehicle.

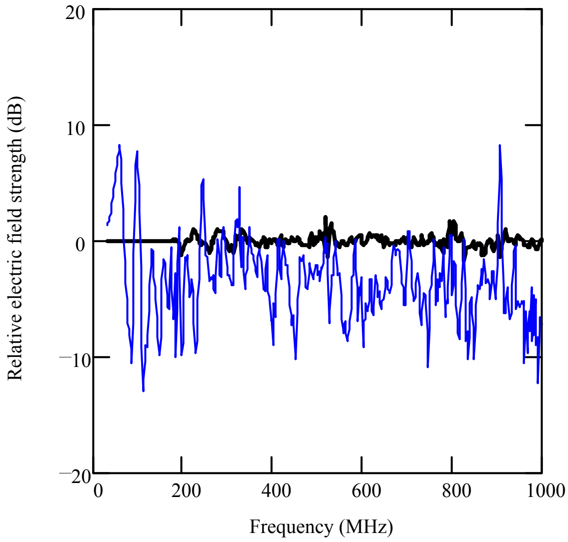

Fig. 3 Change in net field at interior point under vertical illumination: from no heater to rear heater (heavy) and from rear only to both heaters (light)

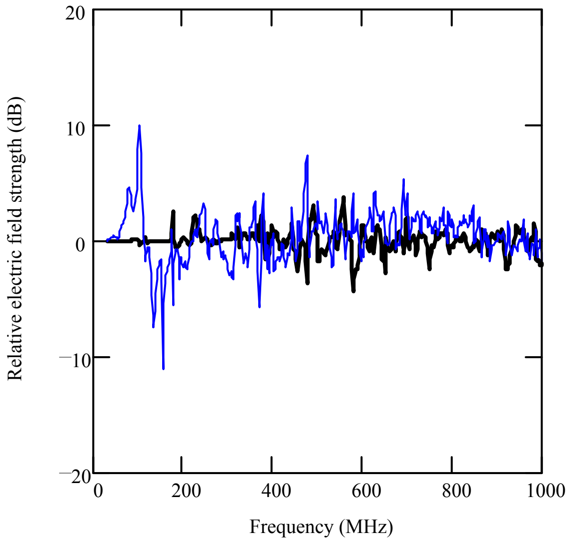

Fig. 4 Change in net field at interior point under horizontal illumination: from no heater to rear heater (heavy) and from rear only to both heaters (light)

The behaviour expected for vertical illumination, on the basis of simple arguments (see Fig. 3), is represented in that the windscreen heater generally reduces the internal field strength.

For horizontal illumination, the effect of the rear heater is greater and the effect of the front heater is smaller than for the vertical case, as expected from arguments based on the behaviour of planar arrays. However, the impact of the rear heater is negligible up to about 200 MHz for both source polarisations, where simple arguments suggest that the impact of the heater should be most significant for horizontal illumination.

The results of Fig. 5 show that, in the absence of heater arrays, the vertical electric field is larger than the horizontal component in the vicinity of the rear window for vertical plane wave illumination from the front of the vehicle. However, this is also the case at low frequencies for horizontal illumination. It is only at the highest frequencies that the horizontal field component becomes dominant in this region under horizontal illumination. This observation suggests that the impact of the rear screen heater on immunity characteristics will be small at low frequencies for both polarisations and smaller over the full band for the vertical case than for horizontal, as is seen in the results from models that include heaters.

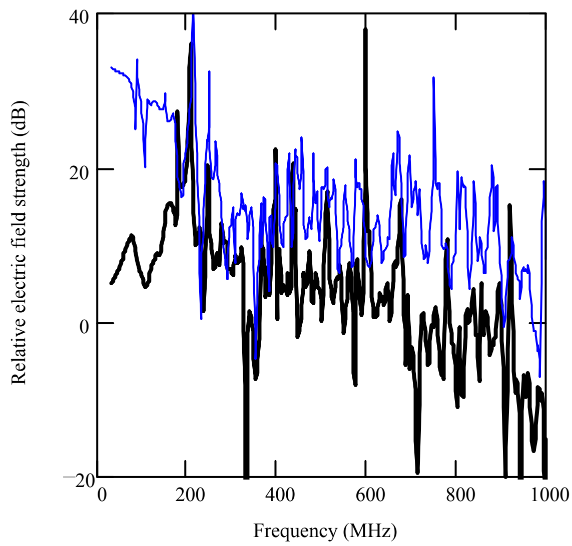

Fig. 5 Vertical electric field relative to horizontal component at a point adjacent to rear window: for horizontal (heavy) and vertical (light) illumination

For models with a localised internal source the vertical field is found to be the dominant component at the emissions measurement point (located at 3 m from the vehicle).

The results of Figs. 6-7, which show changes in the field for both vertical and horizontal fields, illustrate the likely impact of the heaters on the emissions due to such a source.

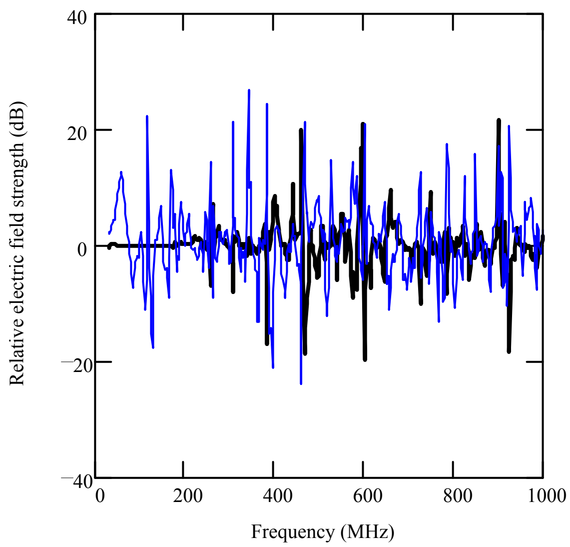

Fig. 6 Change in horizontal field strength at 3 m due to interior source: from no heater to rear heater (heavy) and from rear heater to both heaters (light)

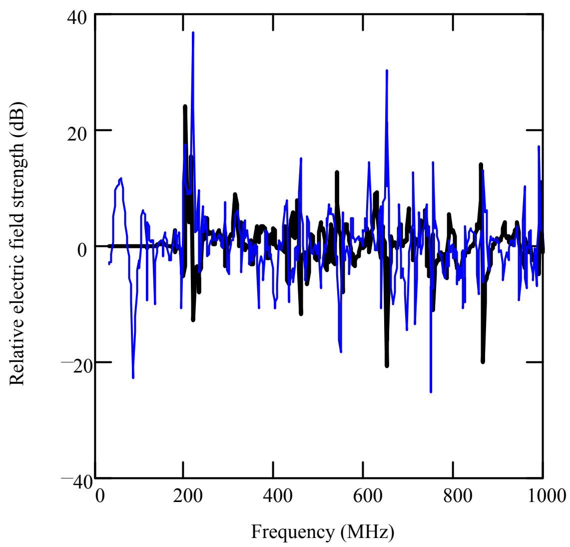

Fig. 7 Change in vertical field strength at 3 m due to interior source: from no heater to rear heater (heavy) and from rear heater to both heaters (light)

It can be seen that variations of order ±10 dB are associated with the introduction of a rear screen heater, while adding a windscreen heater may introduce further variations of order ±15 dB. The rear heater again has little impact at frequencies below about 200 MHz, since the vertical field is also the dominant component at the rear window in this case.

V. DISCUSSION

Numerical models have been used to demonstrate that arrays of conductors with geometrical characteristics that are representative of the heating elements embedded in automotive glazing are likely to have a profound effect on the electromagnetic properties of vehicles. These effects could result in significant changes in the fields coupled to points inside the passenger cavity, particularly for the densely spaced arrays that are used for demisting vehicle windscreens, where changes of order ±10 dB can be predicted for the coupling of electric fields.

In the immunity scenarios described here the impact of the rear screen heater is relatively small, particularly at low frequency where a larger effect was expected. The models show that the electric field reaching this structure is predominantly vertical under front illumination even with a horizontally polarised source. This would not be the case for rear illumination with a horizontal source, but it is difficult to be certain what conditions would arise under side illumination without recourse to further simulations.

Simulations of the external emissions at 3 m due to a simple source placed inside the vehicle indicate that variations of order ±10 dB in the frequency response are associated with the introduction of a rear screen heater, while adding a windscreen heater may introduce further variations of order ±15 dB.

These results suggest that, in physical testing, those vehicles with a windscreen heater could provide higher levels of immunity to vertically polarised illumination from the front of the vehicle than those without such structures. The model results also suggest that the external emissions profile may be modified by ±15 dB in vehicles equipped with a windscreen heater (relative to vehicles without such features).

Models of vehicle-mounted monopoles also confirm expectations that the wider vehicle structure can have a significant impact on the gain, radiation pattern and input impedance of vehicle antennas [11]. Thus, the presence of heating elements embedded in vehicle glazing can also be expected to modify to the installed performance characteristics of automotive antennas.

Direct verification of the predicted effects was beyond the scope of this study, so the models described are only representative of real structures, with the objective of illustrating the likely behaviour. Further work is required to establish the significance of secondary issues, such as the dielectric properties of the glazing that hosts the heater arrays and the termination impedances presented by heater circuits.

Detailed validation of such predictions would require access to geometrical models of a suitable vehicle and its heater arrays, as well as to corresponding vehicle hardware for test. The latter presents some significant practical difficulties, since one must either obtain vehicles that differ only in whether they are equipped with heater arrays, or remove the heated windows to allow comparative measurements to be obtained from the same vehicle.

VI. CONCLUSIONS

One of the most important benefits of automotive electromagnetic models is that they can be used to investigate issues, such as the impact of heater arrays embedded in window glazing, that are often not easy to reproduce reliably in physical measurements. Models of this nature can also be used to investigate practical measurement issues, thus contributing to our understanding of electromagnetic measurements on complex systems and their interpretation.

Despite the limitations of the models developed in this work, they are thought to be sufficiently representative to allow preliminary investigation of the likely impact of automotive screen heaters on the electromagnetic performance characteristics of vehicles to be achieved. The results indicate changes in field coupling into the interior of the vehicle of order ±10 dB, as well as changes in emissions levels of order ±15 dB at 3 m.

It is concluded that screen heaters represent key elements for electromagnetic models that are intended for automotive EMC and antenna analysis The expected impact of these structures on vehicle EMC characteristics also suggests that, for those vehicles where they represent optional equipment, the possible effects of heaters must be taken into account in the selection of vehicles for emissions and immunity testing. Similar arguments also apply to the experimental verification of installed performance characteristics for automotive antennas.

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