HIDDEN ANTENNAS FOR VEHICLES

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Summary
The introduction of new telematics and broadcast systems into vehicles has led to an explosion in the numbers of antennas required. Whereas only a radio reception antenna was once needed now it is common to have analogue and digital radio, television, telephone and navigation antennas. There is a need to hide all these antennas while improving antenna performance using diversity or adaptive systems. The plastic and glass areas of the car are obvious targets for mounting antennas where they are completely out of sight and hence secure, leaving the aerodynamics and styling of the vehicle unimpaired. This presents considerable challenges for the antennas community and this paper summarises some of the work currently carried out at the University of Kent on novel hidden antennas.

Introduction

This article will show various antenna designs for the following system types. (i) provision of analogue VHF frequency range broadcast radio using conformal printed antennas (ii) antennas suitable for mobile cellular communications using top loaded monopoles and PIFAs (planar inverted-F antennas). The article will concentrate on the effects of the car body on the radiation patterns.

Automobiles at VHF

Radio reception in cars has a long history beginning in the 1930s when car radios were introduced commercially under the brand name "Motorola". The use of radios in cars became so popular that in 1947, the manufacturing company name was changed to reflect the brand name. Although new higher frequency and digital systems are currently being deployed, consumer take up will be relatively slow due to high equipment costs and concerns over the untried service provision. It is important therefore that the facility to receive analogue VHF transmissions remains for the foreseeable future.

Tolerable reception of VHF and MF signals has been provided by long (sub resonant) monopole antennas usually mounted on the wing or the roof of the car body. Although AM and FM stations can be received via the single monopole, fading due to the shadowing and multipath effects of mobile environments causes a definite degradation of SNR. Additionally, the wavelength of the FM band (3m at centre) causes the car body to become a resonant cavity and deep nulls appear in the antenna radiation patterns as station frequency is varied. This loss of omni-directionality introduces further fading in the mobile channel.

Vehicle Antennas at VHF and MF

FM stations broadcast in the band between 87.5 and 108MHz. At these frequencies it is possible to produce a halfwave resonant structure by convoluting the antenna conductors. The favoured method for fabricating the convoluted structure is to print it on the front or rear windscreen. It is more common to use the rear, which means a reduced screen area is available due to the presence of the rear demister wires. An example of a rear printed analogue radio antenna is shown in Fig.1, where the wire convolution is visible together with its position above the demister. Successful antennas have been realized by using the demister as a ground plane grid and exciting the slot between the antenna element and the ground. Although the convoluted antenna allows it to be resonant, there is an effect on the polarization purity of the radiated fields and this must be investigated as part of the design process. Fortunately in Britain, FM is broadcast on both vertical and horizontal polarizations which makes a dual polarized antenna necessary in any case. Feeding printed antennas can be problematic as it is often not possible to connect to a local ground. The resulting floating ground can make input matching difficult. Finally, multipath fading can be significantly reduced by the use of spatial diversity in the receiving antenna. For the diversity to be effective, it is necessary to arrange for the separate receiving antenna patterns to be sufficiently uncorrelated that spatial fading points are received independently. The size of VHF antennas makes it impossible to implement more than one on the average automobile body and it is therefore of interest to introduce some controlled asymmetry in the antenna shape. This can be done by switching in shunts to ground at various points along the antenna structure.

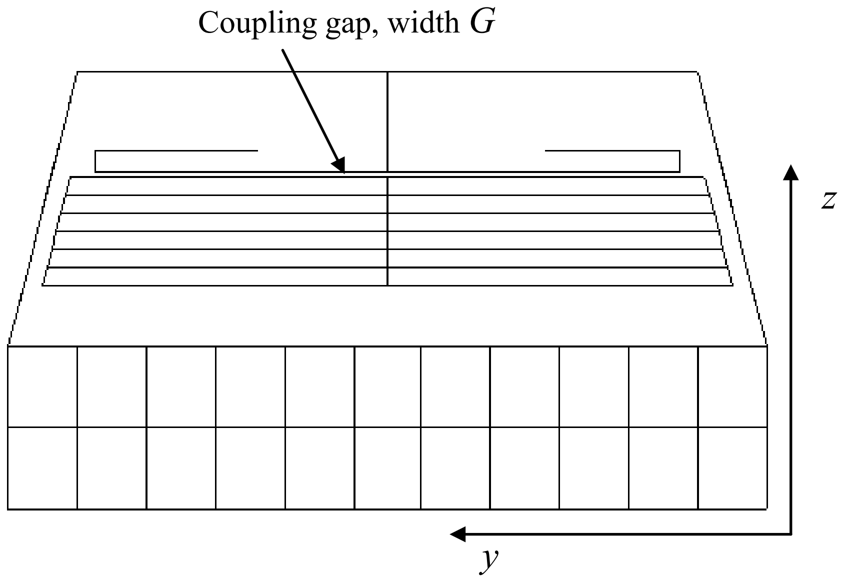


Figure 1.

Mesh rear view showing printed antenna configuration.

Modelling Vehicle-Antenna Interaction at VHF

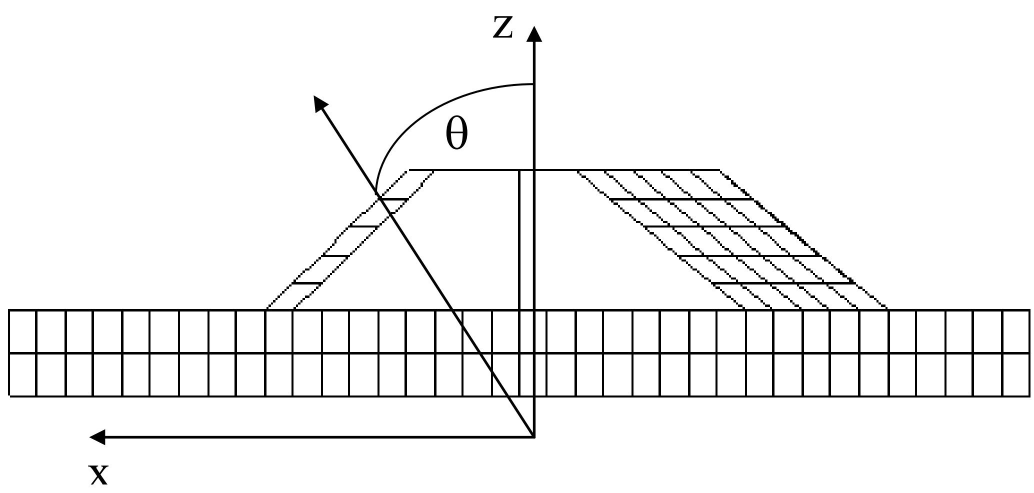
The automotive industry has not required accurate modelling of wing mounted monopole performance in the past. The simple antenna structures operated with a tolerable efficiency and any attempt at implementing a diversity system would be unpopular with consumers as the increased number of antennas would be unsightly. However, the advent of printed screen antennas has made detailed electromagnetic modelling and design more desirable [1,2]. The conformal nature of printed screen antennas means that they interact strongly with the structures of the vehicle body and research has been carried out at the University of Kent [3] to identify the electromagnetically significant parameters of a car body. The following simulations were calculated using the NEC-2 freeware developed in the States. This software uses thin current elements to model wire mesh representations of structures and has the advantage of simplicity and high simulation speed. A disadvantage of the code is its inability to model dielectric structures. This meant that the glass screens could not be included in the model. Although this limitation reduced the accuracy to an extent where input impedance could not be modelled, it was possible to obtain good predictions for the radiation patterns. The presence of the glass was only of secondary importance due to its electrical thickness of about one thousandth of a wavelength near the FM band centre.

Although much more powerful electromagnetic simulators are available which are capable of meshing automobile manufacturer's CAD files, the meshing process is often very laborious and much unnecessary detail is included in the structure. This increases the design time and development costs in an industry with very tight profit margins. This study therefore sought to identify how a vehicle body could be simplified for modelling at VHF frequencies and also show how particular structures on a car body are likely to affect radiation patterns from printed antennas.

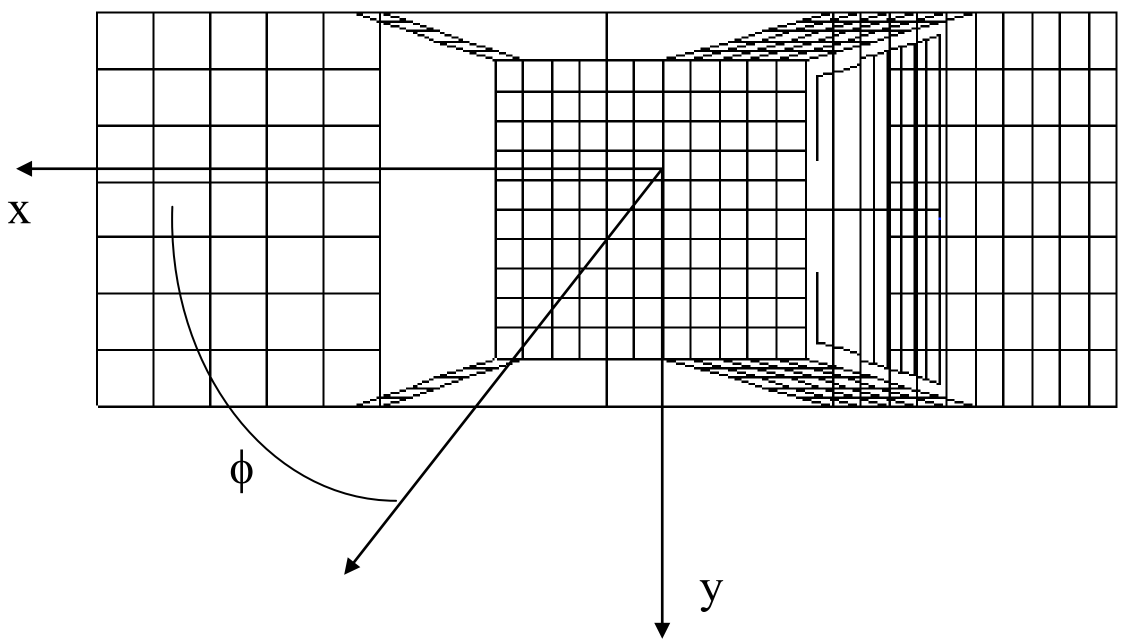
A simplified wire mesh model of a Nissan Gloria saloon car available in Japan is shown in Fig.2. The rectilinear nature of the mesh obviously deviates from the actual surface contours of the vehicle though it was found that providing the correct width to length aspect ratio was used in conjunction with the correct height above ground, these simplifications were not important. The important structure parameters with respect to radiation pattern shape will be identified in the following sections. As the antennas considered in this work are for use in terrestrial broadcast systems, only radiation at low elevation angles (2°) will be considered.

Firstly, the presence of a ground plane below the car was very important. Ground conductivities and permittivities representing a range of grounds from rural to urban were used, though very little difference resulted in the predicted radiation patterns. Although the exact electrical parameters of the ground were not significant, its presence was vital if accurate predictions were to be produced.

The width to length aspect ratio of the car body is a dominant parameter on radiation patterns as it is resonant at FM frequencies and behaves as a leaky cavity. The effect



(a) Side elevation



(b) Top plan. Bottom wires removed for clarity.

Figure 2. Mesh of car body.

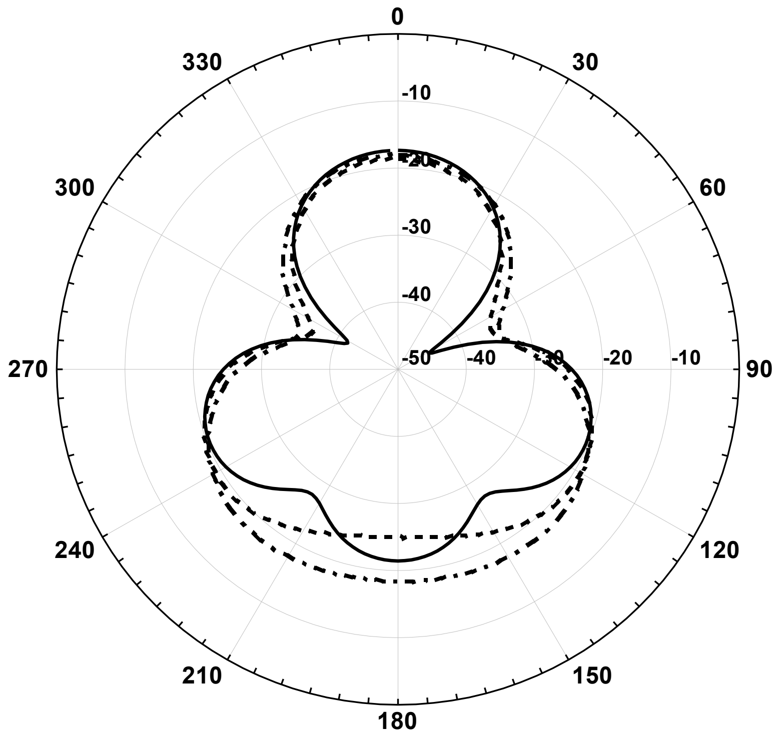
of altering car length, keeping the width constant at 1.7m is shown in Fig.3. When the total length was 2.6 times the width, 10dB nulls were observed at ±150° for vertical polarization in the azimuthal plane, while 20dB nulls occurred at ±60°. As the car length is reduced by 20%, the forward nulls fill by 9dB. Vehicle mounted antennas usually exhibit vertically polarized nulls at angles close to ±60° caused by the cabin length being close to half a wavelength. The horizontally polarized gain is much less affected by cabin length, the most notable change being a broadening in the forward null as length is decreased, Fig.3b.

Lowering the roof from its correct level towards the boot-bonnet plane mainly affected the horizontally polarized fields by increasing the depth of a forward directed null. The only notable difference to the vertical polarization was an overall reduction in gain with the rear angles affected most. While the height of the car roof did not strongly affect the correlation between measured and simulated patterns, though the relative positions of the roof support pillars was important. The front A-pillars most significantly affected the scattered fields in the cabin, and these fields then interacted with the door supports (B-pillars). The A- and B-pillars were modelled as single wires and it was observed that their relative positions were important to within about 3% of a wavelength. Additionally, the slope of the A-pillars had to be correct to ensure correct coupling between the vertical and horizontal polarizations. Although the A- and B-pillars could be adequately modelled as single wires, the surface area needed to be approximately that of the physical pillar areas. This was quite easily implemented with the thick wire kernel in NEC and allowed the mesh to remain relatively simple. Finally, the total removal of the B-pillars caused vertically polarized null depths of 13dB and 20dB at ±60° and ±130° respectively. This finding was interesting as modern car manufacturing practice seeks to reduce the amount of metal in bodywork. The fabrication of the door pillars by plastic materials could adversely affect antenna omni-directionality.

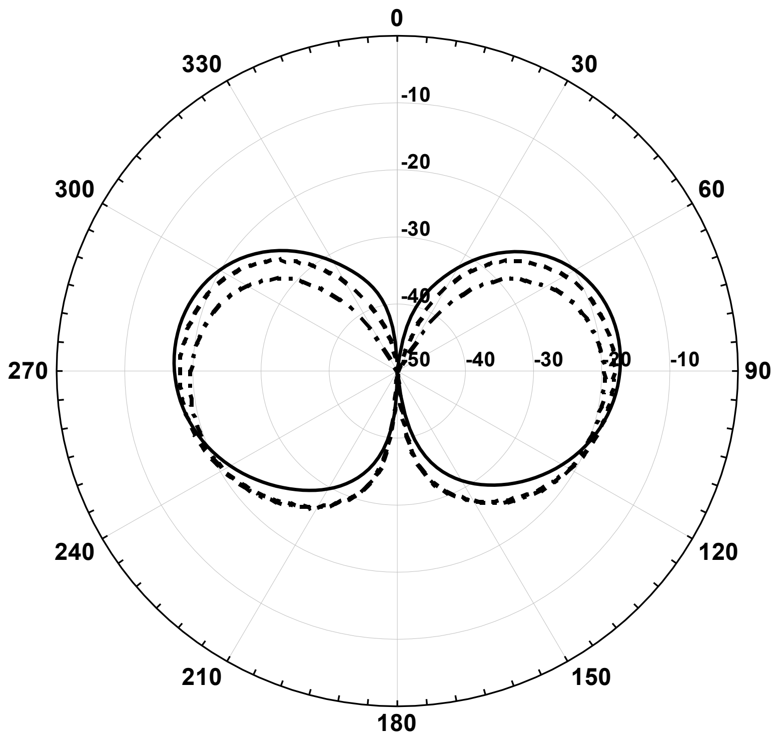
As the antenna is integrated directly onto the rear glass, the slope of the screen is expected to be significant to antenna performance. This is illustrated in Fig.4 where the screen slope is varied from 40° to 46°. The horizontal polarized fields are influenced most strongly as rear screen slope changes with both rear and forward nulls filling as the slope is reduced.

The modelling of the C-pillars is important as these are immediately adjacent to the rear screen and they have a significant influence on the radiation patterns. The C-pillar width affects both the vertical and horizontal polarization. Figure 5 shows how a narrower C-pillar results in a deeper horizontally polarised null at the rear, while the front horizontal gain is also reduced slightly and nulls at ±70° deepen by several decibels. The main effect on the vertical polarization when the C-pillar is narrowed from 0.5 to 0.3m is to increase the side gain by about 3dB. The actual C-pillar of the Nissan Gloria tapers towards the top, in the model however, numerical errors results when adjacent wire volumes overlap as the wires converge. This inaccuracy was avoided by modelling the C-pillars with parallel wires with surface area equal to that of the physical roof support. No significant loss in accuracy was observed as a result of this simplification.

Although the simulated radiation patterns were not sensitive to the exact height of the roof, they were influenced by the size of the mesh elements used. In fact the roof



(a)



(b)

Figure 3. Radiation patterns resulting from varied vehicle length. Cabin width = 1.7m.

(a) Vertical polarisation (b) Horizontal polarisation

Length = 4.4m

Length = 4.0m

Length = 3.6m

meshing proved to be more important than the element size anywhere else in the car model. Roof mesh elements 0.04λ long caused the simulated radiation patterns to be 3dB below the correct gain levels, while reducing the mesh size to 0.03λ length elements gave gains which correlated well with measurement.

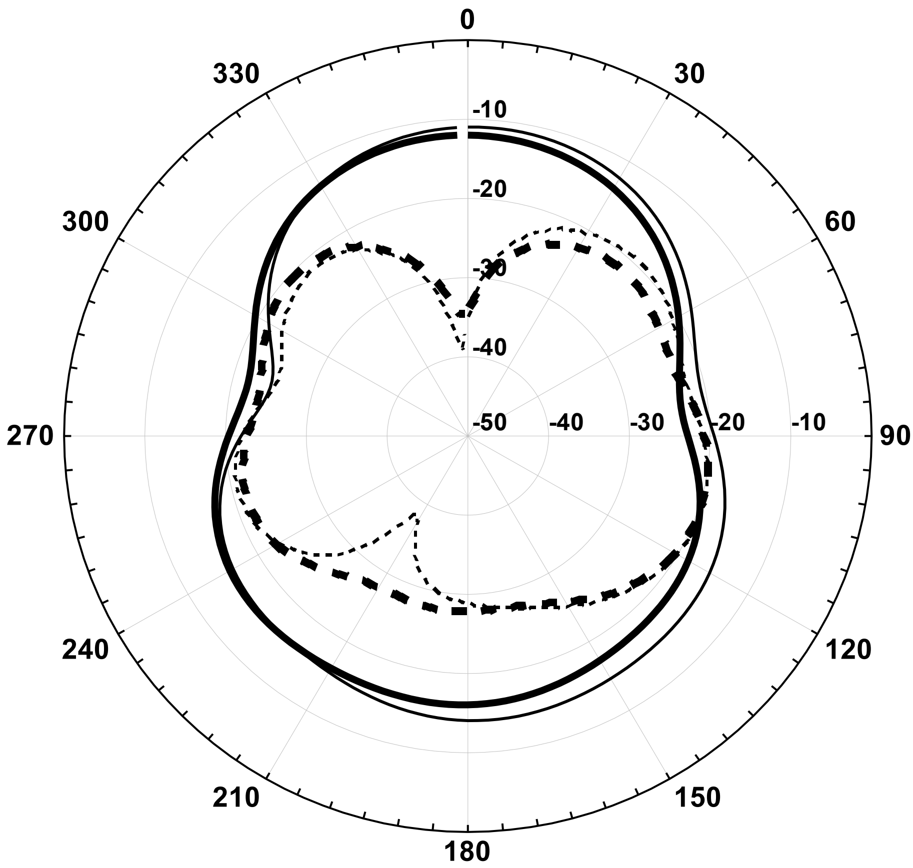


Figure 4. Radiation patterns resulting from varied rear screen slope.

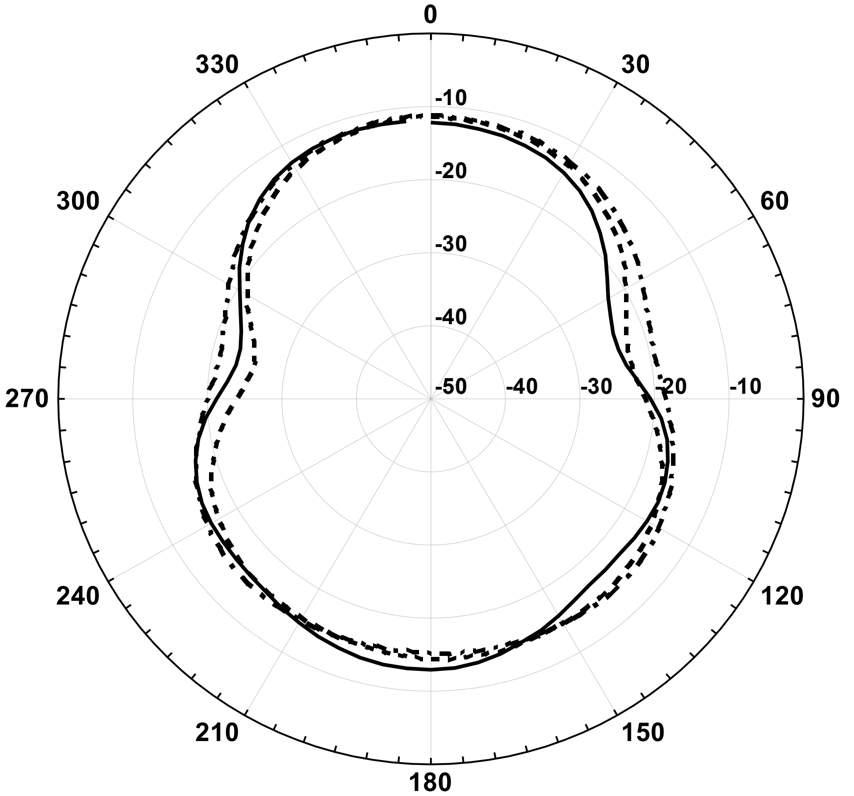
θ = 40°; Vertical polarisation
θ = 40°; Horizontal polarisation
θ = 46°; Vertical polarisation
θ = 46°; Horizontal polarisation

Simulated radiation pattern accuracy

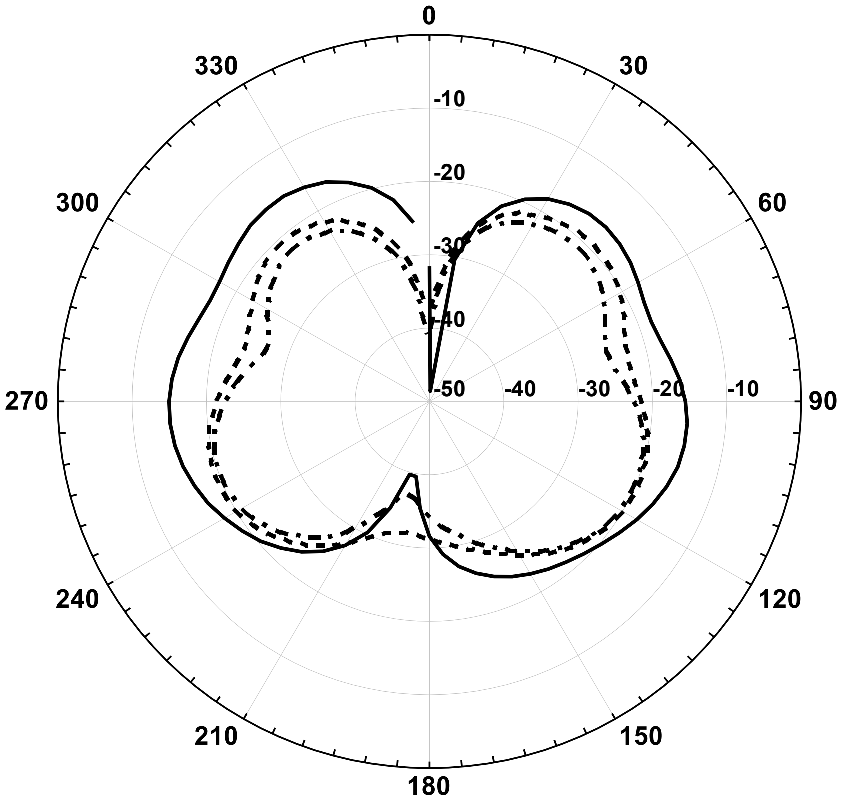
When the model was meshed according to the points outlined above, it was possible to gain good agreement between simulation and measurement. The vertical gain was modelled to within 1dB of measurement, though it was more difficult to obtain such close horizontal gain agreement. This was partly because the measured horizontal patterns were asymmetric. Despite the symmetry problem, it was possible to simulate horizontal gains to be within about 3dB of measurement. The conclusion can therefore be drawn that good simulated patterns can be obtained from highly, though carefully simplified vehicle bodies.

Spatial Diversity from On-glass Antenna

The on-glass antenna is shown in Fig.1. The slot between the excited horizontal antenna wire and the demister grid forms the main radiating element. Fig.6 shows vertical radiation pattern measurements indicating the change when the slot width, G, is altered from 5 to 10mm. The asymmetry in the measured patterns is useful as it facilitates the use of pattern diversity using a single antenna, with shunts switched in along the slot length.



(a)



(b)

Figure 5. Radiation patterns resulting from varied C-pillar width.
(a) Vertical polarisation (b) Horizontal polarisation

Measurement
C-pillar width = 0.5m
C-pillar width = 0.3m

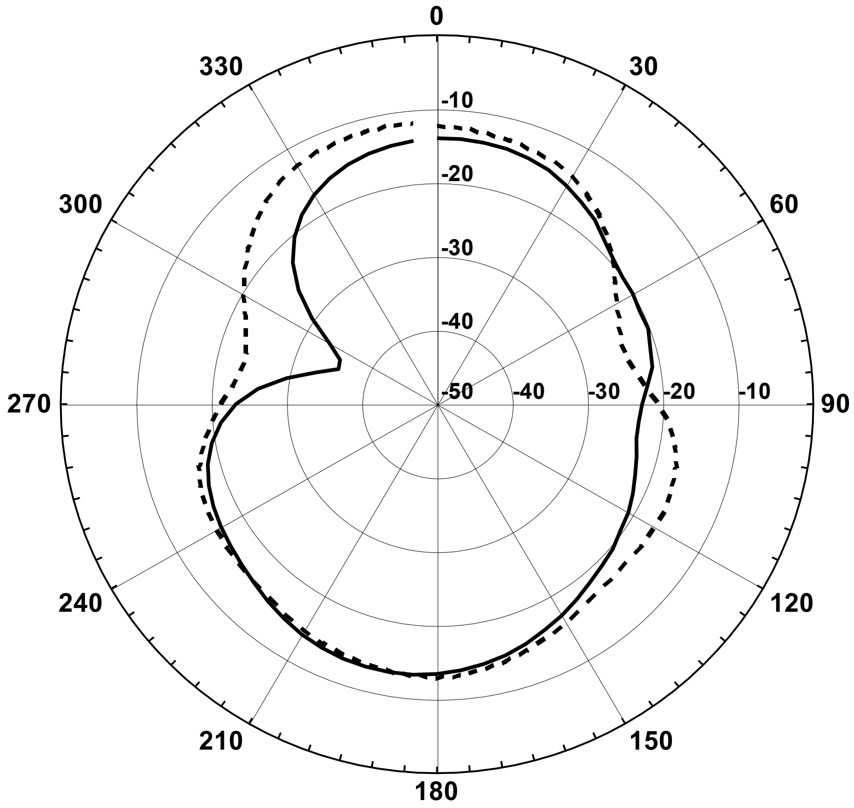


Figure 6. Measured vertically polarized radiation patterns with coupling gap width, G.

G = 5mm

G = 10mm

Multi-band telephone antennas

This section describes advances made on telephone antennas, presenting two dual band designs with a low profile operating at 900 and 1800MHz. The first is a wide bandwidth printed inverted F (PIFA) antenna [4,5] while the second is hybrid antenna based an antenna by Delavaud [6], both being designed to fit under plastic panels on a vehicle. The operating bands were initially for dual 900/1800MHz operation and more recently adding the UMTS band at 2GHz. In each case the antennas are fed by a single coaxial feed, possess good bandwidth characteristics and provide full azimuth coverage around the vehicle.

DUAL BAND PIFA TELEPHONE ANTENNA – Fig. 7 shows the geometry of a PIFA antenna designed to operate at the 900 and 1800 MHz telephone bands. The conductors have been cut away to provide a dual resonant frequency response with wide bandwidths [5]. This antenna was specifically designed as an emergency call antenna to be mounted in the bumper of a car. It was tested in various different positions. The aim was to give equal radiation performance around the car and examine the blocking effects due to the bodywork. The current distribution plots show that at 900 MHz the outer parts of the structure are responsible for the radiation. At the higher band the inner section is excited. Fig. 7 compares the measured and computed return loss for this antenna. There is good agreement at the upper band but it is less so at the lower band. Nevertheless a good bandwidth is measured at each band with a vswr < 1.6.

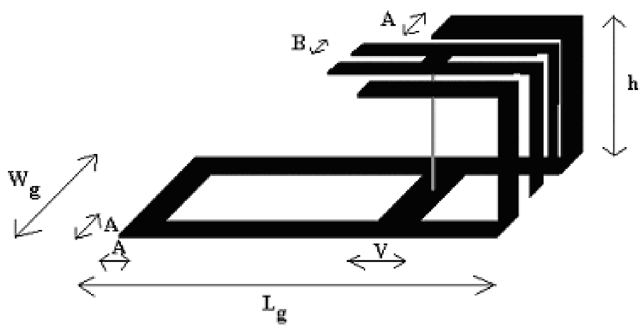


Figure 7 View of the dual band antenna
L_g = 124 mm, L_{p1} = 82.5 mm, L_{p2} = 83.5 mm
W_g = W_p = 30 mm, h = 15 mm.

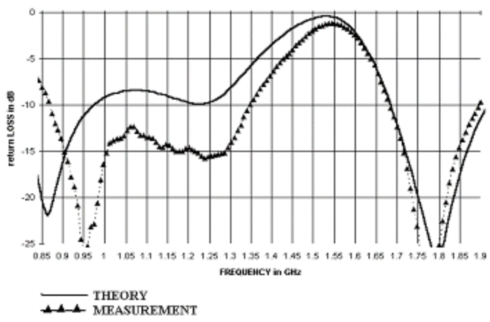


Figure 7 Return loss: measurement and simulation

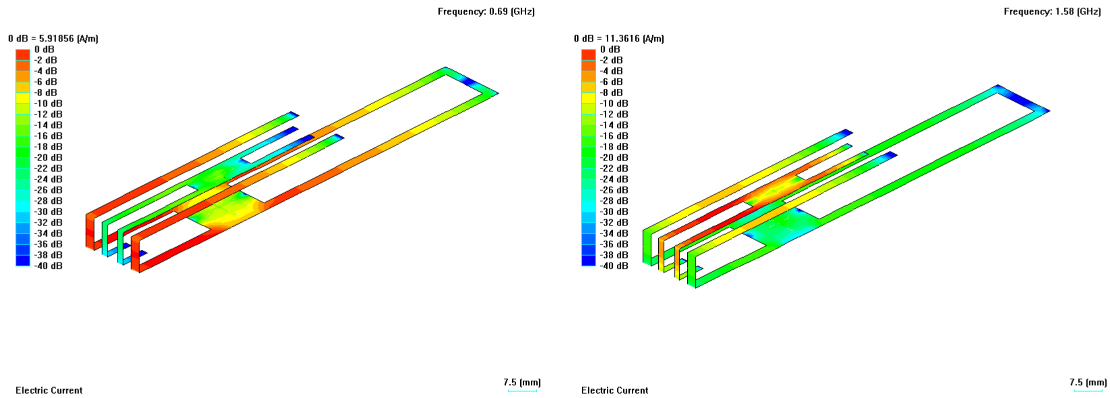


Fig. 8 Current excitation on PIFA antenna at 900 MHz and 1800 MHz

The current excitations shown in Fig.8 indicate that the outer region resonates at the lower 900 MHz band while the inner section resonates near 1800MHz. The corresponding current pattern on the antenna without the metal cut away were very similar, low currents flowing in the excluded areas. The bonus of cutting away the conductors is an improved bandwidth.

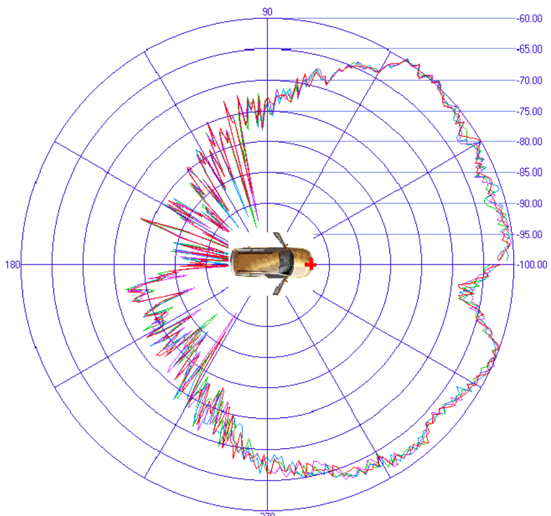


Figure 9 Radiation pattern for antenna

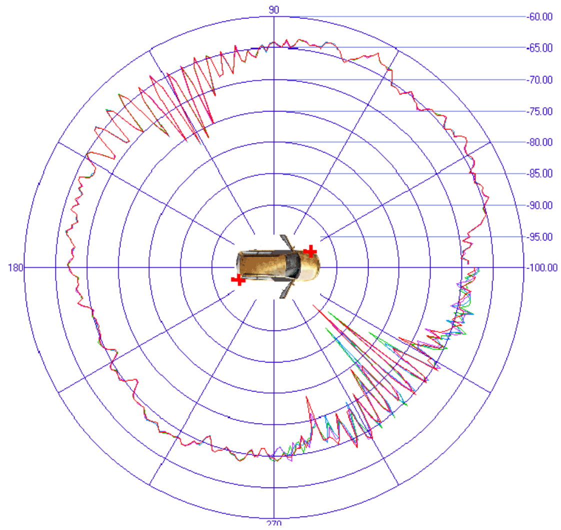
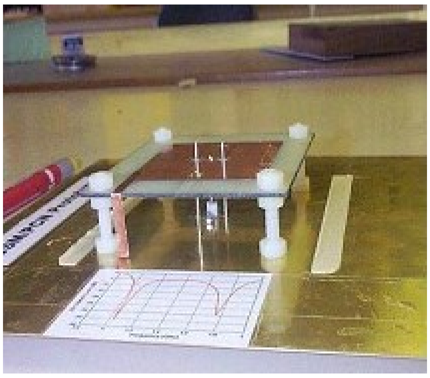


Figure 10 : Antennas installed diagonally on the two bumper corners

The vertically polarised radiation pattern measurements are shown for the 900 MHz band in Fig.9, and Fig.10. The red crosses on the car drawing give the position of the antenna/s which in both cases were just behind the plastic bumper. The PIFA antennas were mounted with the side L_g vertical to give vertical polarisation. The antenna alone gives monopole like radiation patterns in this orientation and hence an omnidirectional azimuth coverage.

In Fig.9 with the antenna placed in the centre of the bumper the forward visiblity is good but the car body blocks the rear directed radiation. Similar blocking is found in other positions. Therefore two antennas were used, the best coverage being obtained when the antennas were placed on opposite corners of the bumpers front and rear as shown in Fig. 10. Here we observe that there is good all-round coverage with ripple where the two radiation patterns overlap. A simple signal combiner was used to add the signal from each antenna. At the higher frequency band similar results were measured although the ripple increased due to increased scattering of the signal from the bodywork. This was corrected by correct phasing of the feed cables at each frequency.

HYBRID ANTENNA - The antenna shown in Photograph 1 is a design based on the top loaded monopole principle [6], the upper plate being shorted to the ground plane by a pair of pins strategically placed to tune the antenna to the 900 MHz band. A second pair passes through two 6 mm x 6 mm square clearance holes on the patch surface and extends beyond it. The holes are located at 5.5 mm from the centre. This second pair provide the DCS-1800 MHz operation. All pins are 1.2 mm in diameter. The upper patch is 56mm square and is low profile, just 15mm high. Fig.11 shows the computed current distribution at the 1800 MHz band. The two pins protruding above the upper plate are responsible for the radiation at this band, see Fig.11, while the shorting pins together with the feed are responsible for the radiation at the lower band. The DCS-1800 band can be fine-tuned by adjusting the length of the corresponding pins. The GSM900 band remains unaffected from any change in the pin length. The maximum return loss for the GSM band is –26 dB at 0.925 GHz and for the DCS is –27 dB at 1.785 GHz. The corresponding bandwidths are 90 MHz and 170 MHz respectively. Fig.12 shows typical azimuth radiation pattern measured for the antenna placed under the rear screen at the top with the antenna earthed to the roof. It is compared with a roof mounted monopole. The radiation to the rear of the car is slightly enhanced while that at the front is reduced when compared to the monopole as in Fig.12.



Photograph 1 Dual band 900/1800 MHz antenna

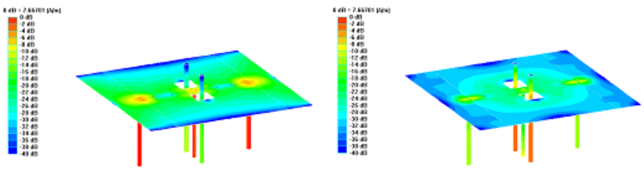


Figure11 **Computed current distributions**

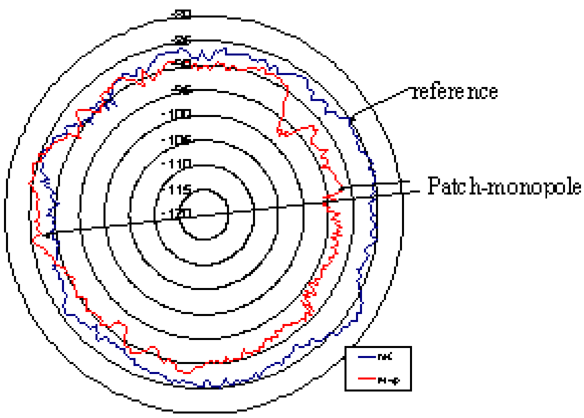
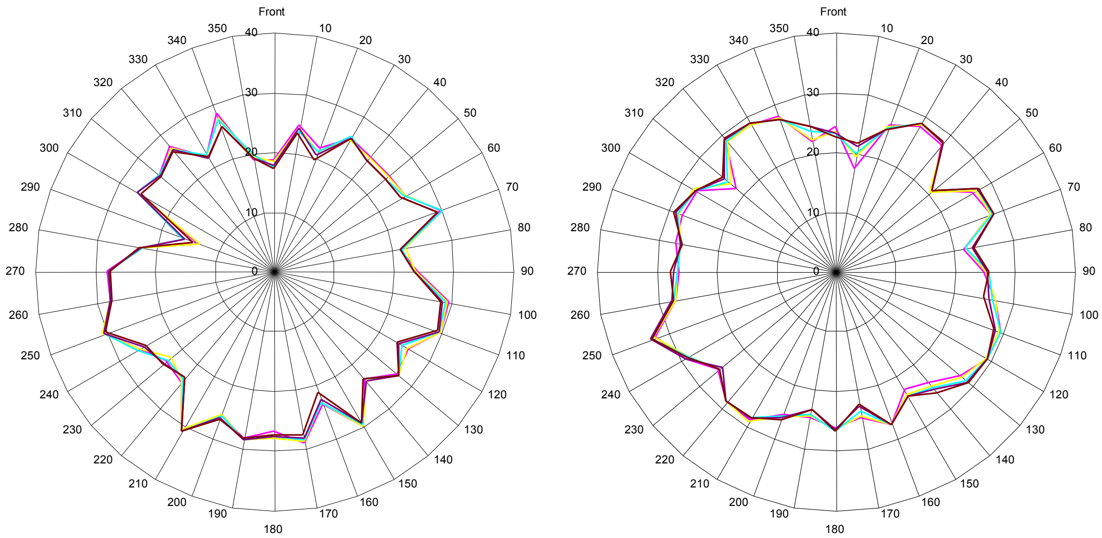


Figure 12 Polar Azimuth Radiation Pattern-antenna at top of rear screen at 900MHz

Further work measured the radiation patterns when the antenna were situated about 10mm below a plastic panel in the roofline of the vehicle, Fig.13. In this case a DAB antenna sample was measured that had the same hybrid antenna geometry. These patterns were measured at 10 degree intervals rather than continuously accounting for the irregular plots. The monopole was not symmetrically mounted on the vehicle roof and hence the pattern is not quite round. The hybrid antenna, hidden below the roofline, gives a similar performance which is within 2dB of the roof mount monopole on average. This result illustrates that it is possible to get good performance from hidden antennas below the roofline. In years to come many vehicles are expected to have composite roof and body panels.



(a) Hybrid antenna below panel (b) Roof monopole antenna

Fig. 13 Hybrid antenna below plastic roof panel compared with monopole roof mounted at 1470MHz

CONCLUSIONS

The paper has presented results for hidden antennas, that can be placed on glass or under plastic panels on a car, providing reception at radio and telephone frequency bands.

The effects of the car body on on-glass printed antennas have been investigated, and it can be concluded that the screen slope together with the relative positions of the various roof supports has the dominant effect on the radiation patterns. It is the roof pillars that tend to introduce the deep nulls characteristically seen at azimuthal angles of ±60°. Interestingly, the door pillars can alleviate the nulling and it will be worthwhile to assess the effect of fabricating more body parts from light weight non-conducting materials in the future. Concerning the modelling of on car antennas, it can be concluded that simplified structures will suffice, providing that adequate meshing is used and the physical areas of the roof supporting structures are represented in the model. Finally, as expected, the ground plane must be included and a model able to include the dielectric of the glass would be essential if correct input impedances are to be obtained.

A wide bandwidth dual band PIFA antenna has been presented and basic properties discussed. Based on information from modelling the currents this PIFA antenna has been modified, removing metallic areas where current flow is shown to be low thereby improving the operating bandwidth. Using two antennas, placed at the corners of the bumpers, all round coverage can be obtained. A hybrid telephone antenna is described which gives omni-directional radiation patterns in azimuth while providing wide bandwidths at two frequency bands, 900 and 1800 MHz. The antenna is low profile and designed to be roof mounted or hidden under a plastic panel with little degradation in performance.

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