Hidden Antennas for Vehicle Telematics Systems

Professor Richard Langley

(*University of Kent*)

This paper describes three different antenna systems for mobile vehicle applications. The antennas are either patches or derivatives in all cases. The first is a dual-band telephone antenna with a low profile and wide bandwidth. Operating at 900 MHz and 1800 MHz, with a VSWR of better than 1·7, it is a hybrid construction combining a monopole with a top-loading patch shorted to the ground-plane. Extra-shorted pins provide the upper frequency band coverage. It provides monopole radiation characteristics and can be hidden under a plastic panel or mounted on the vehicle roof. The second is a microstrip patch antenna integrated into a laminated glass windscreen for a vehicle. It is fed using a coplanar waveguide feed printed on the innermost layer of the glass, avoiding the need for a contacting feed within the laminate. The patch and ground plane are meshed for manufacturing in the glass to avoid distorting the heat profile when the glass is shaped and laminated. The patch is easily fed from inside the vehicle and is potentially a very low cost design. The final antenna discussed is a dual-band patch antenna specifically designed for the Globalstar satellite telephone system at 1·6 GHz and 2·45 GHz. It also covers the Iridium band at 1·6 GHz. A single circularly polarised patch is used. Dual-band operation results from truncating the corners of the square patch and judiciously placed slots to achieve a band spacing of 1·5.

KEY WORDS

1. Road. 2. Communications. 3. Telematics. 4. Antenna Design.

1. INTRODUCTION. Several novel antennas will be presented in this paper covering topics on meshed-patch antennas integrated into glass windscreens, dual-band telephone antennas and mobile satellite communication antennas. These address problems encountered when integrating antennas into vehicles so that they remain essentially hidden while performing to a high standard. The antenna constructions are simple to keep costs down.

The first section describes advances made on telephone antennas, presenting as dual-band design with a low profile. Many antennas have been presented recently in the literature (Delavaud *et al*., 1998; Dong Liu and Hall, 1997) and the designs are related to the work by Delavaud. Their properties are similar to those of equivalent monopoles while offering wide bandwidth operation at each band. The second section describes the performance of patch antennas printed into glass screens. The patches and ground planes are meshed to allow printing on glass without distorting the heat profile. The subject of glass-based antennas is not new (Lowes *et al*., 1994; Economou and Langley, 1998; Wu and Ito, 1991; Clasen and Langley, 1999) but patch antennas have not been widely investigated. The final section presents patch antennas specifically designed for satellite telecommunication systems including Global Star and the Iridium Systems. There are many ways of multi-banding patch antennas

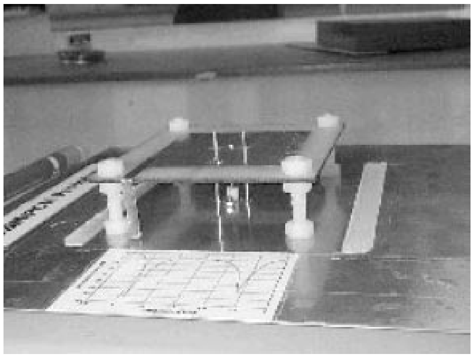


Figure 1. Dual-band 900/1800 MHz antenna.

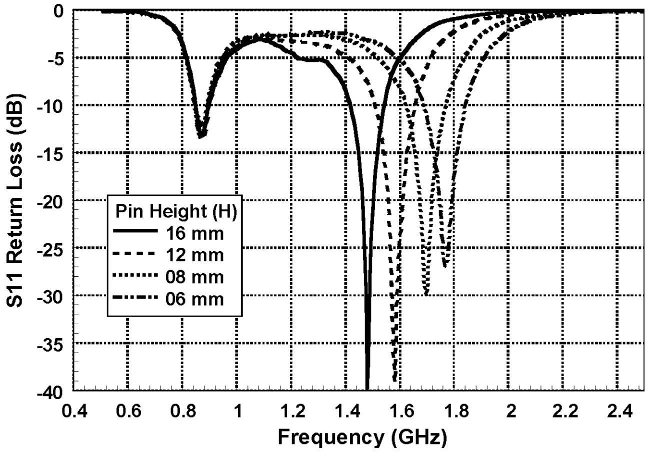


Figure 2. Fine tuning the DCS-1800 Band.

(Maci *et al.*, 1995; Maci *et al.*, 1997; Hsieh *et al.*, 1998) and providing circular polarisation; here, two designs are presented for different applications. The work was carried out at the University of Kent with assistance from Harada Industries.

2. MULTI-BAND TELEPHONE ANTENNAS.

This section presents a telephone antenna suitable for mobile telephone applications on vehicles, GSM-DCS. One requirement is for a good impedance match across the bands, 7% at 925 MHz (890–960 MHz), 10% at 1800 MHz (1710–1880 MHz) and 12·5% at UMTS (1920–2175 MHz), and this presents considerable difficulties for many antenna structures. In each case, the antennas are fed by a single coaxial feeder unlike many other designs recently reported, which have separate feed points for each band. All the above types must meet certain radiation characteristics. The most important are omni-directional azimuth coverage, high efficiency and high bandwidth. All the above are very sensitive to external conditions (human body proximity, weather) and dependent on the mounting area (in-car, rooftop).

The antenna shown in Figure 1 has a dual-band response. The design is based on a top-loaded monopole principle (Delavaud *et al.*, 1998), the upper plate being

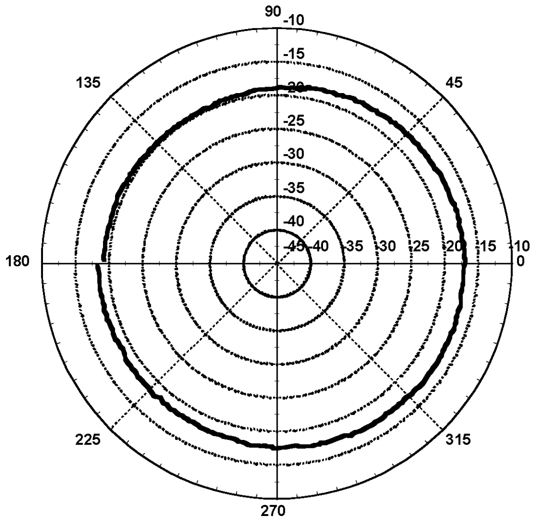


Figure 3. Polar azimuth radiation pattern.

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 × 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 are about one tenth of the wavelength long and provide the DCS-1800 MHz operation. All pins are 1·2 mm in diameter. The upper patch is 56 mm square. It is designed to fit under a plastic panel or on the roof of a car and is low profile-just 15 mm high. The antenna is coaxially fed at the centre via a SMA connector. There are two pairs of pins.

The DCS-1800 band can be fine-tuned by adjusting the length of the corresponding pins. The measured S11 return loss as a function of the DCS pin length is shown at Figure 2. The GSM band remains unaffected from any change in the pin length. This is important since each band can be fine-tuned independently. The GSM band matching can be further improved by adding a 10 mm wide metal strip running from the top of the patch to the ground plane. As can be seen from Figure 2 there is a significant improvement in the return loss.

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. They all are within the required limits. Figure 3 shows typical azimuth radiation patterns across the operating bands. Simulation results show that, at the GSM band, the two shorting pins are strongly excited, while at the DCS resonance, the second pin pair – which are isolated from the top patch – are excited. In both cases, the resulting radiation patterns are similar to a monopole, as shown in Figure 3. The antenna is equivalent to a top-loaded monopole radiating at two separate frequency bands.

3. MESHED PATCH ANTENNA INTEGRATED INTO A CAR WINDSCREEN.

With the growing number of telematic systems used in cars, there is an increased need for the integration of antennas into the structure. Microstrip patch antennas, which are lightweight and low cost, can be integrated into different

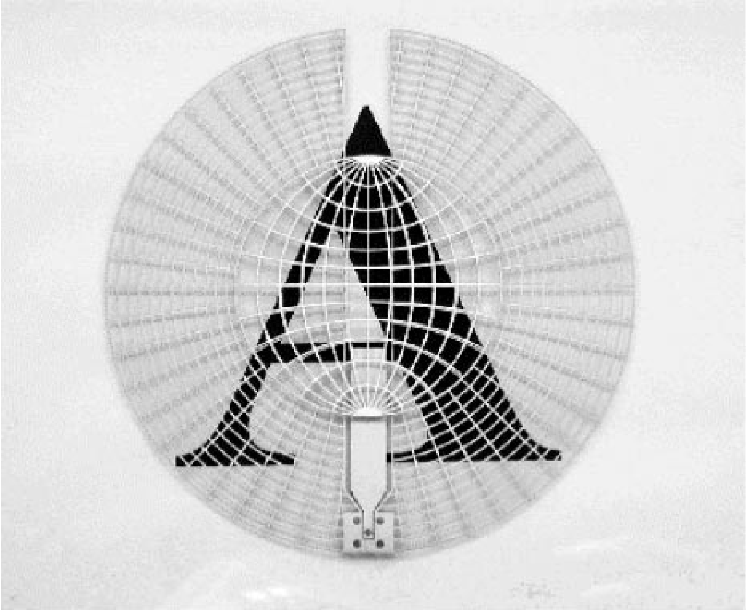


Figure 4. Meshed patch antenna over ground plane with co-planar waveguide feed printed on glass. Antenna is placed on a piece of paper with the letter 'A' printed.

parts of the car body. Previous work has examined their performance with glass substrates and superstrates (Lowes *et al.*, 1994; Economou and Langley, 1998). Integrating the patch antenna into the windscreen poses two practical problems:

(a) It is not possible to screen-print large solid metal areas (e.g. a patch at 1·5 GHz) because this would distort the windscreen during the heating process by which it is formed.

(b) It is not possible to drill holes through the glass and, therefore, it is impossible to use a conventional coaxial probe feed. Nor is it possible to feed the patch directly using a microstrip line.

The first problem is overcome by replacing the solid metal areas of the patch by a mesh structure (Wu and Ito, 1991; Clasen and Langley, 1999); this gives the additional advantage that the antenna gains a degree of transparency. The second problem is tackled by using a co-planar wave guide feed structure printed on the inside of the screen glass for simple connection.

Figure 4 shows the patch antenna structure. The patch, which is 60 mm in diameter, is in the centre region over the larger ground plane. It resonates at 1·32 GHz. The mesh geometry is printed for the TM_{11} mode in this instance and follows the mode currents. Figure 5 shows the layer geometry for the proposed antenna. The windscreen consists of two pieces of glass held together with a plastic interlayer material (PVB). The meshed patch is printed onto the lower side of the top glass layer, and it is thus protected from environmental influences by the glass. The meshed ground plane is printed onto the bottom side of the lower glass; this geometry allows access to the ground plane and feed from the inside of the car. In order to feed the patch antenna, a co-planar waveguide feed is etched into the ground plane and

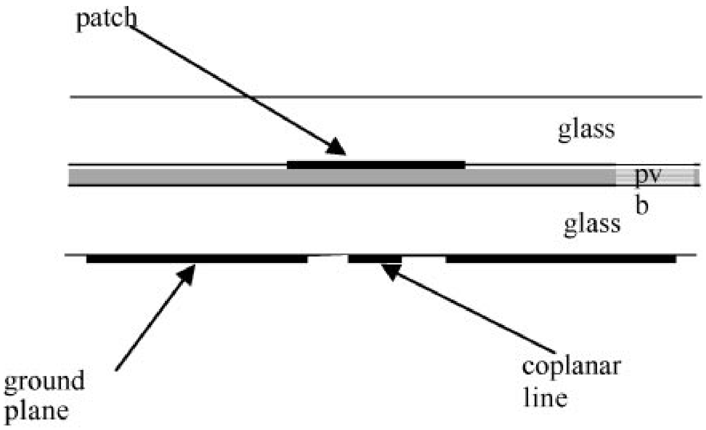


Figure 5. Layer geometry of patch in windscreen.

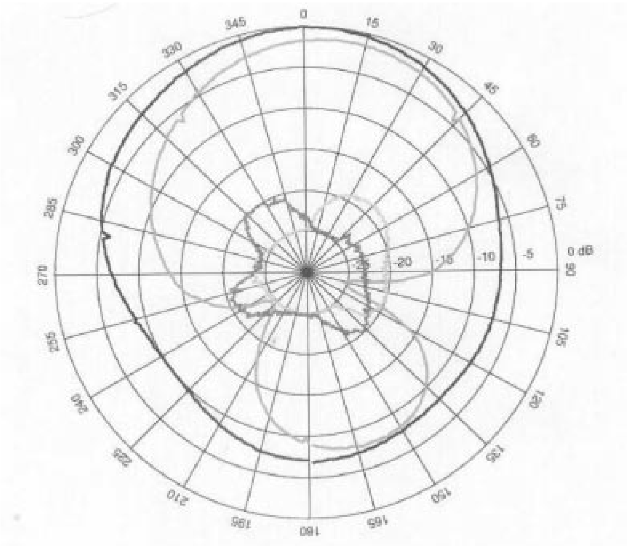
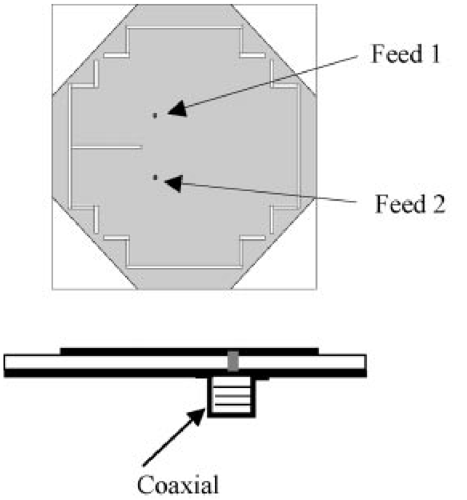


Figure 6. Principle plane radiation patterns for patch in windscreen.

connected to a surface mount connector (not shown but the pad is visible at the bottom of Figure 4). This allows the positioning of the patch antenna anywhere on the windscreen. Both patch and ground plane are meshed, only the relatively small area of the centre strip of the co-planar waveguide is solid metal. Figure 4 also demonstrates the degree of transparency that can be achieved using a meshed patch antenna. The letter A is clearly seen through the antenna.

Figure 6 shows the normalised radiation pattern measured in the E- and H-plane, respectively. Circular meshed patch antennas also have a very low cross-polar component (Maci *et al.*, 1995). Figure 6 shows that the meshed patch antenna integrated into the windscreen has indeed a low cross-polar component in the principal planes. The beam in the E-plane is shifted by a few dB this was found to be due to radiation from the CWP-feed. Backward radiation is quite high at -7 dB. This is partly due to the relatively small ground plane but also due to radiation through the holes in the meshed ground plane. The gain was about 3 dB lower than a conventional patch antenna, accounted for by losses in the glass and meshing of the structure. The return loss was measured giving a −10 dB bandwidth of 2%.

4. COMPACT MOBILE COMMUNICATION ANTENNAS. The launch of new mobile satellite communication links for telephone and data applications demands development of small, low profile, and low-cost antennas. Examples include Teledesic operating at 19 GHz and 29 GHz and Globalstar at 1·6 GHz and 2·5 GHz. The bandwidths are not demanding, but the band spacings provide a challenge to the antenna engineer. Microstrip patch antennas are obvious candidates as antennas for these applications. Dual banding techniques for patch antennas have often focused around stacked patch designs (Maci *et al.*, 1997; Hsieh *et al.*, 1998) where each patch radiates at a different frequency. Maci *et al.* (1995) describes single rectangular patch geometries with slots cut near the edges to operate at two frequency bands with dual linear polarisation and an operating frequency spacing ratio greater than 2·5, below which unwanted higher order modes exist. The suppression of unwanted modes in circular patch antennas using slots was discussed in Maci *et al.* (1997). Hsieh *et al.* (1998) develops this technique further and describes a circularly polarised circular patch operating at dual bands. The paper presented here combines both approaches to give a single antenna with either hand of circular polarisation. Figure 7 shows the first microstrip patch antenna geometry specifically designed for the Globalstar system.



Feed points for coaxial probe excitation - Feed 1 gives left handed circular polarisation and Feed 2 right handed.

Figure 7. Slot patch antenna geometry.

Slots cut at strategic points within the octagonal shape (not equal-sided) provide the correct resonating modes. The corner lengths provide unwanted mode suppression and adjustment. The method of feeding the patch is conventional, a coaxial cable probe (Figure 7) or an electro-magnetically coupled microstrip line exciting the antenna either through a slot or directly. The antenna uses the TM_{10} and TM_{30}

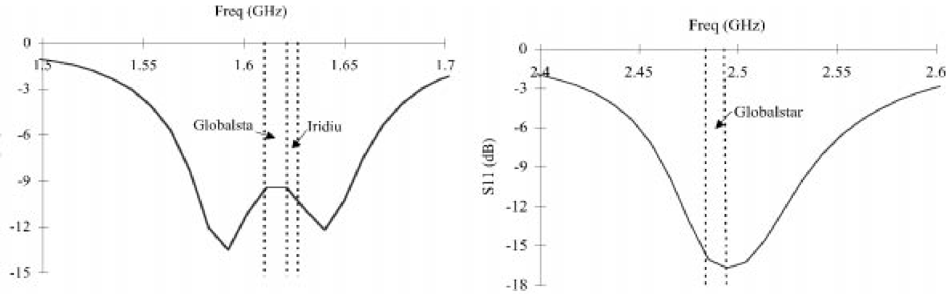


Figure 8. Measured return loss for patch antenna.

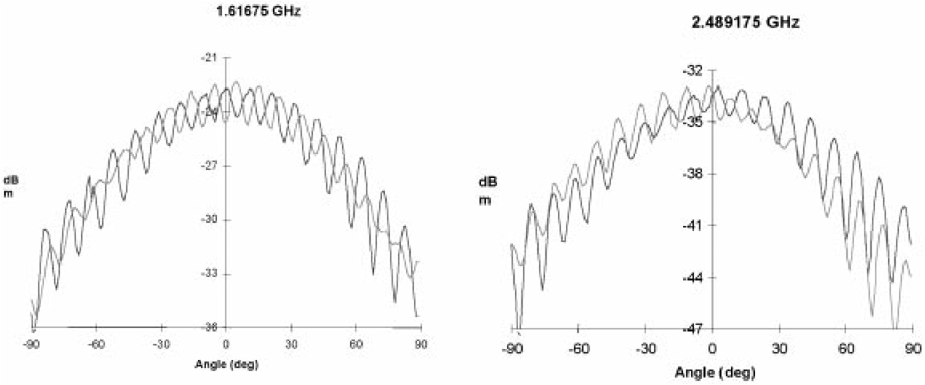


Figure 9. Measured radiation patterns for circular polarisation.

resonant modes to achieve the two frequency communication bands. The TM_{20} mode naturally resonates at about 1·5 times the frequency of the TM_{01} mode, and this generates a null in the radiation pattern on axis. To suppress the TM_{20} mode and reduce the resonant frequency of the wanted TM_{30} mode the slots are used. Using the correct length of slot, the resonant frequency of the higher order TM_{30} mode is lowered to 2·49 GHz, the centre frequency for the Globalstar upper-band. This in turn creates a mixture of resonating modes which generates a squinted beam. In order to further suppress the TM_{20} mode excitation, the corners are truncated. This moves the TM_{20} mode to a higher resonant frequency due to shortening of the current path. This allows the TM_{30} mode to dominate creating an un-tilted broadside beam.

The return loss is plotted in Figure 8 for the bands of interest at 1·6 GHz and 2·5 GHz. Other resonances exist at 2·06 GHz, due to the TM_{11} mode and at 2·86 GHz is the suppressed TM_{20} mode. The match is adequate across the bands at present being better than -10 dB; improvements in the design are being investigated. Radiation patterns were measured across the operating bands. Those shown in Figure 9 were typical with axial ratios of about 3 dB at wider angles. The gain of the patch was 6·5 dB as expected and an axial ratio of better than 3 dB was measured across the bands.

5. CONCLUSIONS.

A hybrid telephone antenna was described that 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. The second part described how a patch antenna can be integrated into a car windscreen. Feeding via a co-planar waveguide feed and a surface mount connector allows it to be positioned anywhere on the windscreen and avoids drilling holes. Creating the patch from a mesh structure allows the antenna to be printed onto the glass and gives a degree of transparency. Performance is adequate for many applications. The slot patch offers dual-band operation with circular polarisation at each band for a wide range of band spacing ratios. The slot profile is chosen to suppress higher order modes giving good radiation pattern performance particularly for a frequency band ratio of 1·5.

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