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Experimental study of the effect of paint on embedded automotive antennas

Brendan Pell[1], Wayne Rowe[1], Edin Sulic[1], Kamran Ghorbani[1], Sabu John[1], Rahul Gupta[1], Kefei Zhang[1], Brian Hughes[2]

[1] RMIT University, Melbourne, Australia

[2] Composite Materials Engineering, Melbourne, Australia

Email: brendan.pell@rmit.edu.au

Abstract—**Recent years have seen the advent of new types of automotive antennas, such as blade or 'shark-fin' antennas and conformal planar roof mounted antennas. In many cases it is desirable to paint these antennas to improve the appearance of the vehicle. In this communication we present an investigation of the effect that both metallic and non-metallic two-pack polyurethane paint has on a structure radiating at approximately 1.5GHz (GPS L1-band), with a particular emphasis on the impedance bandwidth and radiation performance.**

Keywords: antenna; automobile; automotive; cover; embedded; encapsulated; integrated; metallic; paint; superstrate; vehicle

I. INTRODUCTION

Vehicles today are fitted with antennas for an increasing number of wireless services. In recent decades the list has expanded from the AM and FM radio antennas of the past to include GPS, mobile phone, collision avoidance radar, Digital Radio and Digital TV antennas. In the past the AM/FM antenna was typically a mast antenna protruding from the vehicle's exterior, however of late the trend has been to hide vehicular antennas as much as possible. Antennas have been designed for operation when laminated between sheets of glass in car windows or windscreens [1]. Likewise, patch antennas have been mounted on the inner side of automotive glass [2]. Other techniques of implementing vehicular antennas include 'shark-fin' or blade designs [3], and conformal planar designs [4-5]. Many of these antennas are located in places such that it would be desirable to paint them to make them more aesthetically pleasing.

Production examples of 'shark-fin' and conformal automotive antennas appear to have been painted, and yet there is little information in the literature about the effect that this paint might have on antenna performance. In this investigation, particular focus is placed on the effect of commonly used metallic paints, whose inherently conducting particles (metallic flakes) may interact with the radiating structure in a way which leads to degraded performance.

Previously the most thorough investigations in the literature involving paint and antennas have been completed by Chu and Semplak [6], Hombach and Kühn [7], and Otoshi et al. [8] who have all studied paint on the surface of the reflective element in reflector antennas. These papers report observed effects in cross polar performance, noise temperature and gain loss. To the Authors knowledge, a thorough investigation of the effect of paint on planar antennas has not been conducted. The other existing references to paint effects on antennas in the literature are side comments that excessive layers of paint have the potential to significantly affect automotive radar antennas in the mm-wave region [9], or that metallic paint has little effect for microwave frequency applications [10-11].

Considerable interest has been generated in the integration of antennas for various wireless services into polymer based exterior paneling. The antenna element would be encapsulated within the exterior shell of the automobile, and once painted, this would result in a conformal geometry that presents no visual evidence of a radiating structure. Such an antenna would increase the vehicle maker's freedom in exterior body design, whilst the antenna itself would create less wind resistance, and would be protected from accidental damage and vandalism.

Section II and III of this paper give detail on the paints examined in this investigation, and section IV describes the experimental method, while sections V and VI present the results and discuss the main findings.

II. OVERVIEW OF PAINT TECHNOLOGIES

Many different kinds of paint chemistry are used worldwide. Lacquers and enamels were traditionally used in the automotive industry, but these chemistries had the disadvantages of being fragile, easily damaged, and creating excess amounts of pollution. In the past 50 years, developments in the realm of automotive paints have included waterborne paints, base coat/clear coat systems and polyurethane topcoats [12]. For the purpose of this investigation, the paints used are modern two-pack polyurethane topcoats manufactured by BC Coatings in Australia, and marketed under the name VC800 Structure 105.

This paper presents results obtained with two different paints in the VC800 range, one of which has a metallic finish which is achieved by the addition of aluminium flakes. These aluminium flakes are small in size, yet are very densely packed and account for approximately 10% w/w of the paint in its liquid form. Each of these aluminium flakes is conductive. The aim of this communication therefore, is to examine the

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effect of the presence of thousands of tiny flakes of aluminium in the near field of an antenna, specifically on the antenna's impedance and radiation performance.

III. Determination of Aluminium Flake size

Typically, the size of the aluminium flake in metallic paints ranges from 15 to 45µm [13]. To determine the size of the aluminium flake used in VC800 a small section of the paint from an off-cut was lifted away from the painted surface and examined with the use a Scanning Electron Microscope (SEM). It was found that the electrons would not travel through the polyurethane paint binder, so observation of the flakes from the top surface was impossible. By shifting the paint sliver onto an angle and looking at the fractured edge a useful image was obtained.

Fig. 1 shows the edge of the paint sliver using backscattered electrons for imaging. This technique assists with determining the difference between the aluminium and polymer material since it creates a contrast difference between materials of different chemical composition. The upper portion of the image shows the top surface of the paint which is smooth in appearance, while lower portion of the image shows the tape used to secure the paint sliver to a sample holder in the microscope. The horizontal stripe through the middle of the image is the area of interest and shows the fractured edge of the paint. Aluminium flakes can be seen to be protruding from the fractured edge and appear to be a lighter shade due to the backscattered electron sensor. The size of the flakes observed varies between 40µm and 70µm in maximum dimension, while the thickness of the paint layer is approximately 120µm for the metallic sample and 50 µm for the non-metallic sample (not shown).

IV. Testing Technique

In order to examine the effect of various paints on an encapsulated antenna, the system shown in Fig. 2 was employed. In this configuration, a simple microstrip patch antenna is used in conjunction with removable coverings which serve a dual purpose.

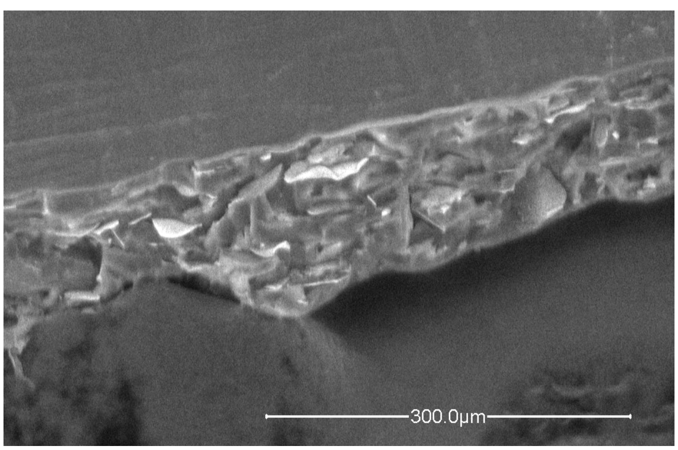

Figure 1. SEM image of the edge of the sliver of paint.

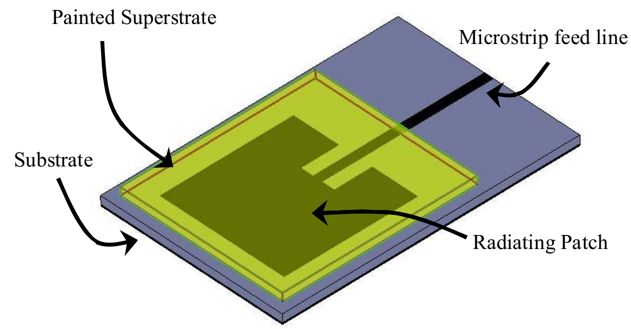

Figure 2. Paint test configuration

The coverings (or 'superstrates') primarily act as a carrier for the paint, but they also model the encapsulation scenario in an automotive panel, where a radiating element is embedded in a dielectric material.

The L1-band GPS frequency of 1.575 GHz (with a 20 MHz bandwidth) was chosen as the primary frequency for this investigation because of the ubiquitous satellite navigation facilities in modern vehicles. A simple edge-fed square microstrip patch antenna on Rogers RT/duroid® 5880 material in the 0.062" thickness was designed and simulated in Ansoft HFSS. Identical material in the same thickness was chosen for the superstrates, with the antenna being designed so that its resonance would be close to the GPS L1-band frequency when covered by a reference sheet of RT/duroid® 5880.

Four superstrates of equal size were cut from a sheet of RT/duroid® 5880 material and two of these samples were painted in a specialised facility, one in the metallic VC800, and one in the non-metallic VC800. The two remaining samples were set aside for use as control samples. One was left unpainted, whilst one retained its original copper cladding to demonstrate the effect of a solid conductive sheet in the near field of an antenna.

The antenna was fabricated and tested on a Vector Network Analyzer and was found to have a centre frequency of 1.583 GHz in the presence of the reference RT/duroid® 5880 superstrate. The slight variation from the centre frequency in the design is attributable to magnification inaccuracies in the photographic stage of fabrication.

With the antenna still connected to the Vector Network Analyzer successive S_{11} measurements were made and recorded as each superstrate sample was placed on the antenna in turn. Fig. 3 shows the fabricated antenna with the completed superstrates.

An anechoic chamber (Fig. 4) was also used to measure the changes in gain and radiation pattern that were caused by the painted superstrates.

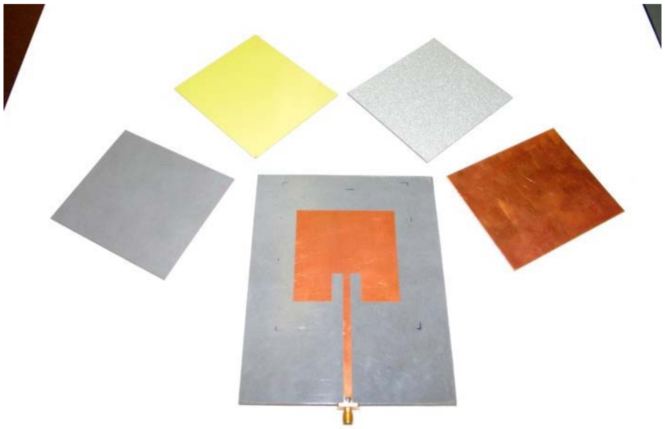

Figure 3. Antenna with various painted superstrates

V. Results

A. Return Loss

Fig. 5 shows the measured return loss of the antenna. The reference curve, shown in black, is the antenna with an unpainted superstrate, and indicates that the antenna is operating efficiently at approximately 1.583 GHz, yet has a narrow impedance bandwidth of 0.9% because the patch dimensions are large with respect to the substrate thickness.

When the unpainted superstrate is replaced with the superstrate bearing the non-metallic paint, the changes in return loss are subtle. The bandwidth remains relatively unchanged, and the magnitude of the return loss is decreased slightly while the centre frequency shifts down by approximately 0.2% to 1.580 GHz. The superstrate covered in metallic paint however, shows a more substantial change. The centre frequency is shifted further to 1.574 GHz, a change of 0.5%, and the magnitude of the return loss is increased compared to the unpainted reference sample.

The copper clad sample of RT/duroid® 5880 produces an extreme degradation in the antennas performance as expected. The presence of a conducting sheet essentially reflects all the energy back into the source.

B. Radiation Pattern and Gain

The co-polarized radiation patterns of the GPS antenna with various superstrates are shown in Fig. 6, while cross-polarized radiation patterns are presented in Fig. 7. The antenna produces hemispherical coverage which is appropriate for a roof mounted GPS antenna receiving signals from the sky.

Inspection of the co-polarized measurements of Fig. 6 reveals that there is a great deal of similarity between the radiation patterns of the painted and unpainted superstrates, with the differences being evident primarily to the rear of the antenna. This area of back radiation is of low importance as it is approximately 20dB down on the front lobe and contributes little to the received signal. Once again, the copper clad superstrate is seen to significantly degrade the antenna performance.

Figure 4. Antenna in anechoic chamber with metallic paint superstrate in place

Analysis of the cross-polarized radiation patterns in Fig. 7 indicates again that variation in the radiated fields are only minor. Although there is a noticeable difference in the shape of the cross-polarized patterns, the relative power level remains significantly below the co-polarized fields.

Examination of the maximum gain of the antenna with each superstrate provides useful information on the impact of the paint on real world performance. Table 1 shows that the presence of the "Reference" dielectric material without paint produces a gain of 8.0 dBi. Following this, the addition of non-metallic paint was found to have negligible effect on the measured gain. In the case where metallic paint was used, the gain of the antenna reduced by 0.7 dB to a value of 7.3 dBi. The copper clad superstrate can be seen to have radical consequences on the antenna radiation properties in Fig. 6 and Fig. 7. This is reflected by large negative value for the gain.

TABLE I. Measured Antenna Gain

Superstrate	Gain
Reference	8.0 dBi
Non-metallic	8.0 dBi
Metallic	7.3 dBi
Copper	-19.3 dBi

Further testing is underway on additional paints with different properties, and over wider frequency ranges, the results of which will be presented at the conference.

VI. Discussion and Conclusions

The frequency shift caused by the paint is small, being less than 1%. However, in cases where a narrow impedance bandwidth antenna is used, such as this GPS application, the small frequency shift could cause significant detrimental effects. In the worst case a specific antenna would be required for each type of paint, with a different shift associated with each paint type. A broadband antenna could prove resistant to the frequency shifting effect. The inconsistent frequency shift caused by different paint types is likely to be a consequence of the electrical properties of each paint, and also the thickness with which they have been applied.

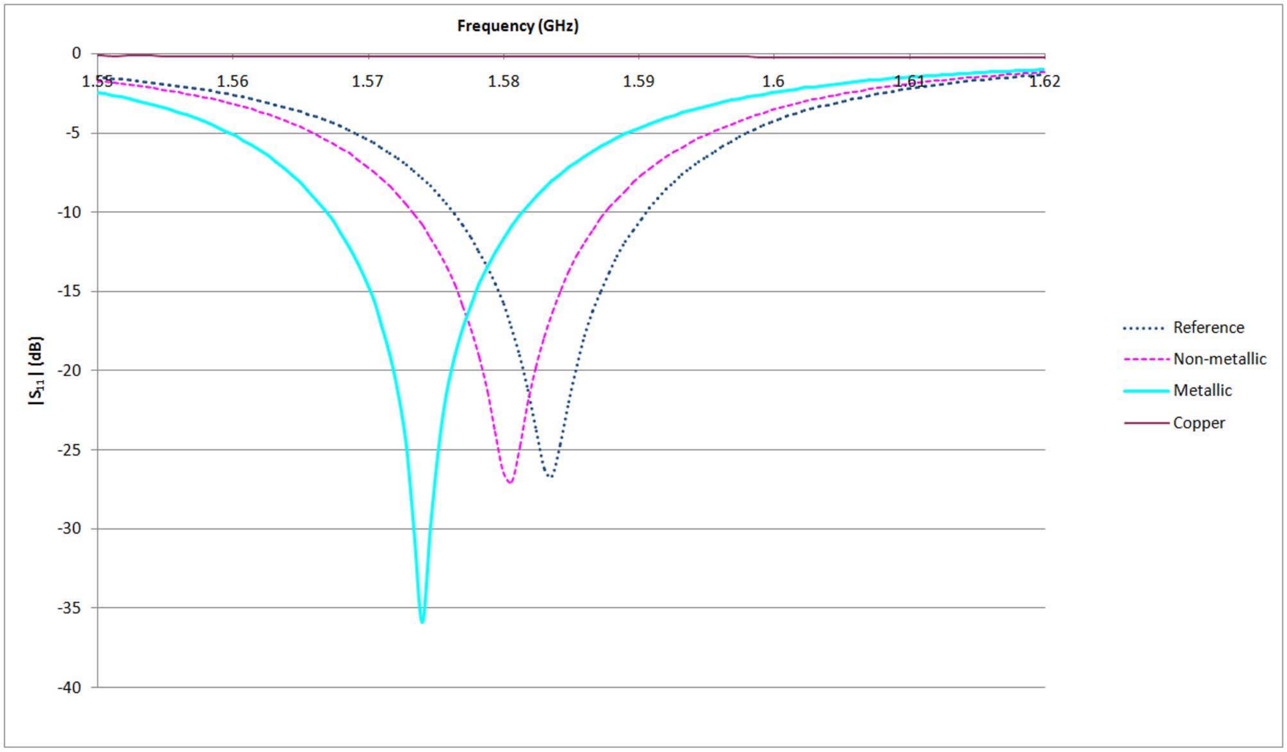

Figure 5. Measured return loss of the antenna with superstrates

The slight drop in gain of the metallic painted superstrate may be caused by the aluminium flakes scattering the radiated wave. Analysis of the co-polarized and cross-polarized fields from the antenna with each of the superstrates indicates that the addition of the paint has minimal effect on the radiation pattern.

From the preliminary results for painted encapsulated antennas, it is desirable for the antenna to have a greater impedance bandwidth than the desired application. If a slight decline in the achievable gain is tolerable, there seems to be little restriction on the type of paint used, be it metallic or non-metallic. Further tests on a wider range of paint samples at additional frequencies will confirm these findings.

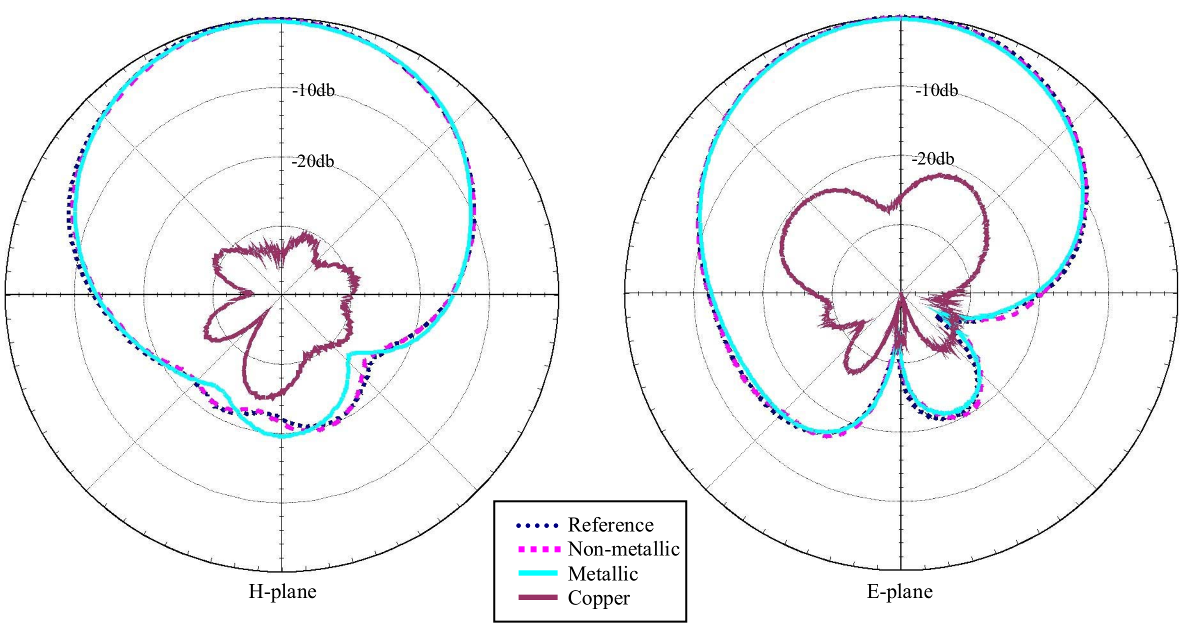

Figure 6. Measured co-polarized radiation patterns of the antenna with different superstrates

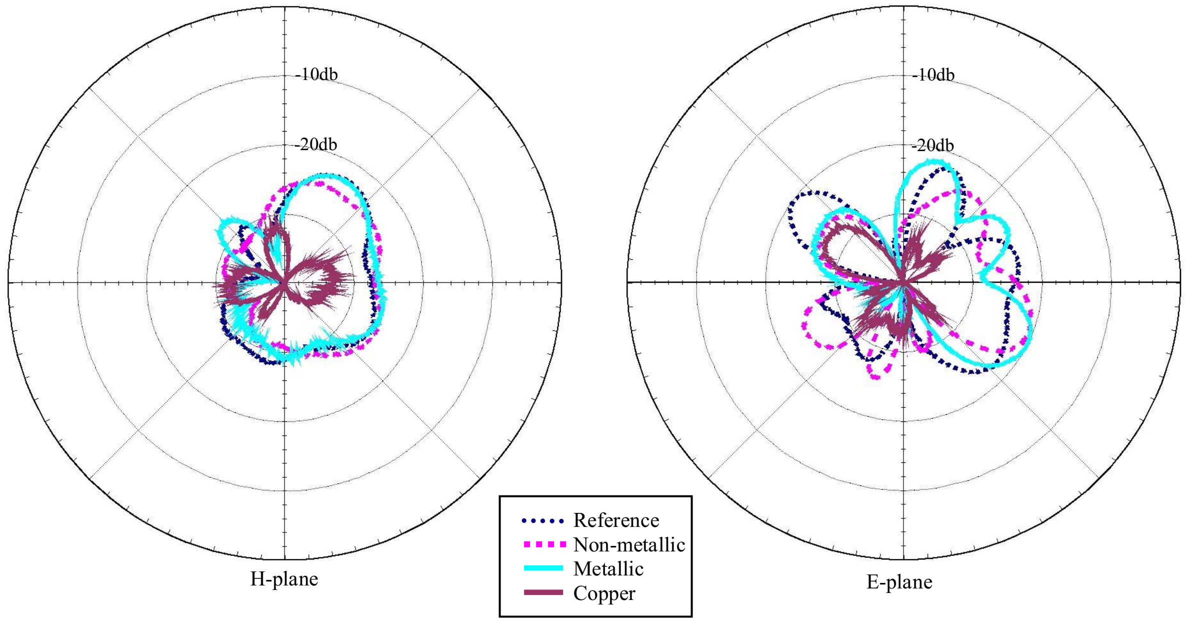

Figure 7. Measured cross-polarized radiation patterns of the antenna with different superstrates

REFERENCES

[1] Lindenmeier, H., Hopf, J., Reiter, L., "Active AM-FM windshield antenna with equivalent performance to the whip now as standard equipment in car production," Antennas and Propagation Society International Symposium, 1985, June 1985, pp. 621- 624.

[2] Economou, L., Langley, J., "Circular microstrip patch antennas on glass for vehicle applications," IEE Proceedings - Microwaves, Antennas and Propagation, Volume 145, Issue 5, October 1998, pp. 416-420

[3] Walbeoff, A., Langley, R.J., "Multiband PCB antenna," IEE Proceedings - Microwaves, Antennas and Propagation, December 2005, pp. 471- 475.

[4] Low, L., Langley, R., Breden, R., Callaghan, P., "Hidden Automotive Antenna Performance and Simulation," IEEE Transaction on Antennas and Propagation, Volume 54, Issue 12, December 2006, pp. 3707-3712.

[5] Gschwendtner, E., Wiesbeck, W., "Ultra-broadband car antennas for communications and navigation applications," IEEE Transaction on Antennas and Propagation, Volume 51, Issue 8, August 2003, pp. 2020-2027.

[6] T. S. Chu and R. A. Semplak, "A Note on Painted Reflecting Surfaces," IEEE Transactions on Antennas and Propagation, AP24, 1, January 1976, pp. 99-101.

[7] Hombach V., Kühn E., "Complete Dual-Offset Reflector Antenna Analysis Including Near-Field, Paint-Layer and CFRP-Structure Effects," IEEE Transaction on Antennas and Propagation, AP-37, 9 September 1989, pp. 1093-1101.

[8] Otoshi, T.Y., Rahmat-Samil, Y., Cirillo, R., Jr., Sosnowski, J., "Noise temperature and gain loss due to paints and primers: a casestudy of DSN antennas," IEEE Antennas and Propagation Magazine, Volume 34, Issue 3, June 2001, pp. 11-28.

[9] Hoare, E.G., Hill, R., "System requirements for automotive radar antennas," IEE Colloquium on Antennas for Automotives, 2000, pp 1/1-111.

[10] Lyons, C.T., Taskin, I., "A low-cost MMIC based radar sensor for frontal, side or rear automotive anticipatory precrash sensing applications," Proceedings of the IEEE Intelligent Vehicles Symposium, 2000. IV 2000., pp. 688-693.

[11] Sabatier, C., "2 GHz compact antennas on handsets," Antennas and Propagation Society International Symposium, 1995. AP-S. Digest, June 1995, Volume 2, pp. 1136-1139.

[12] Pfanstiehl, J. 1998. Automotive Paint Handbook: paint technology for auto enthusiasts and body shop professionals. 1st ed. (pp 1). New York: The Berkley Publishing Group.

[13] Lambourne, R., Strivens, T.A. 1999. Paint and Surface Coatings - Theory and Practice. 2nd ed. (pp. 443).Woodhead Publishing.