MIMO LTE Vehicular Antennas on 3D Printed Cylindrical Forms

B. Sanz-Izquierdo, S. Jun and T. B. Baydur
School of Engineering and Digital Arts
The University of Kent CT27NT,
Canterbury, Kent, UK
b.sanz@kent.ac.uk

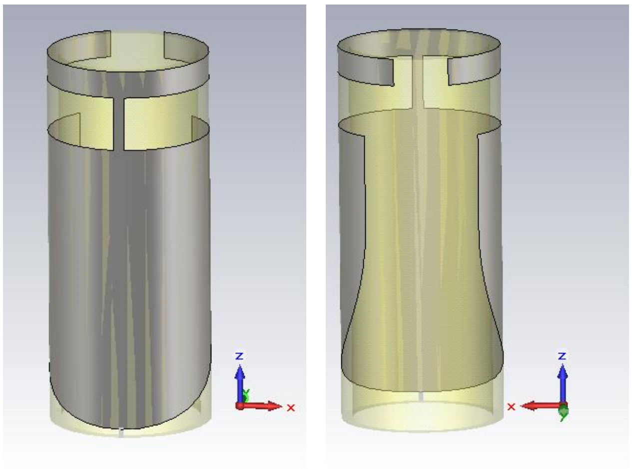
***Abstract*— A multi-band antenna suitable for Long-term Evolution (LTE) is shaped around a 3D printed cylindrical form, and arranged in a MIMO configuration. The antenna is based on a planar wideband monopole radiator with an additional resonator for the LTE700 frequency band. Conforming the antenna onto a cylindrical shape reduces its length while keeping performance. It also reduces the space used by the MIMO antenna system. Furthermore, the plastic cylinder improves the mechanical strength of the supporting substrate for the radiating element. The aim is to study the potential of additive manufacturing (AM) of substrates for the development of conformal vehicular antenna. Two antennas have been fabricated, one etched on a copper clad Mylar substrate, and a second painted directly onto the cylindrical form. The two antennas have been measured and the results are compared. Two copper based antennas have been tested in a MIMO configuration. The antennas successfully operate at all LTE and mobile frequency bands. Finite different time domain simulations compare well with measurements.**

***Keywords*—3D printing; Additive Manufacturing, vehicle antenna**

I. INTRODUCTION

Vehicular communications are constantly expanding with new technologies and applications. One of the latest additions is the Long Term Evolution or 4GLTE. It allows for high-speed data on the move. Next generation of vehicles are being prepared to incorporate the LTE functionality. This will lead to a significant update to the current antenna systems. The antennas are required to operate at many frequency bands, and to support multiple-input-multiple-output (MIMO) systems. LTE frequency bands at 700MHz, 2300MHz, 2500MHz and 3600MHz need to be covered in addition to the existing mobile bands (GSM/DCS1800/ PCS1900/UMTS).

Multifrequency antenna designs suitable for vehicle applications have been extensively reported [1] - [3]. Recently, LTE antennas intended for mounting on the rooftop of a vehicle have been proposed [4] – [6]. Of these designs, the antenna in [6] seemed to perform the best for the limited space available in the typical shark fin plastic enclosure. There the antenna was attached to the plastic using laser direct structuring (LDS) technology.



(a) (b)

Fig.1 LTE antenna onto cylindrical form: (a) front, (b) back

Three dimensional printing (3DP) enables the fabrication of structures from a digital model. This technology is able to fabricate complex shapes with unusual internal features. Fused filament fabrication (FFF) is the most common and accessible technology. It offers the lowest cost for 3DP. 3D objects are created by melting a plastic which is deposited in layers. FFF has recently been proposed for the development of frequency selective surfaces (FSS) [7] – [8] and to assist in the fabrication of wearable antennas [9]. In [8], an FSS fabricated by partially metalising 3D printed shapes was able to reduce the resonant frequency and improve the angle of incidence performance compared with the same but fully metallised design [10].

This paper proposes the use of 3D printing to create plastic forms for use in vehicular antenna application. The antenna in [5] has been adapted to operate successfully when shaped around a 3D printed cylindrical structure. Two different procedures to attach the antenna onto the form are discussed in section II. In section III, two cylindrical LTE antennas are studied in a MIMO configuration. The main application is LTE communications in public transport systems. The use of additive manufacturing could create customized solution for the intended application.

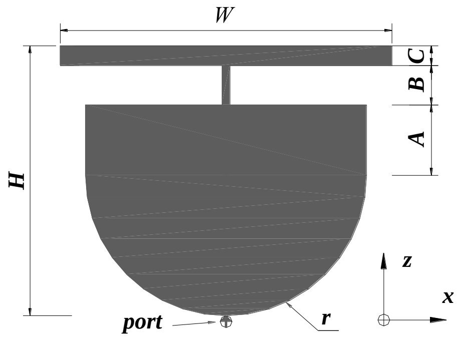


Fig.2 Antenna dimension

(a) (b)

Fig.3 Antenna shaped around a cylindrical form: (a) etched on a copper clad Mylar, (b) coated using silver conductive paint

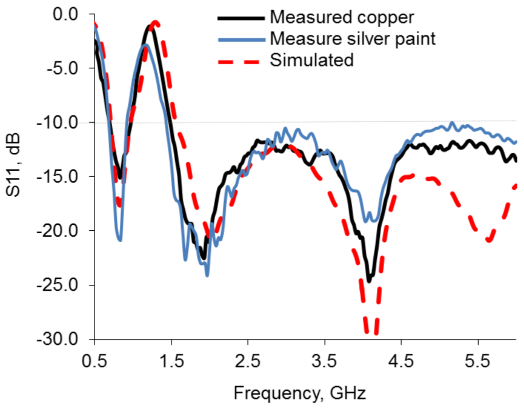


Fig.4 Reflection coefficients (S_{11})

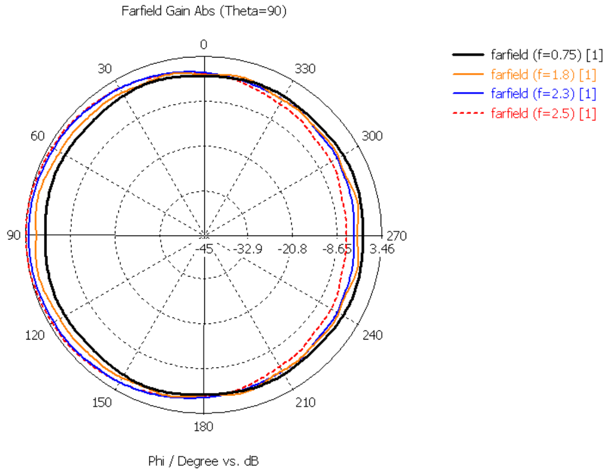


Fig.5 x-y radiation patterns for various frequencies

II. WIDEBAND CYLINDRICAL LTE ANTENNA

A. *Antenna design*

A wideband monopole antenna with an additional resonator is a relatively straight solution for achieving all LTE frequency bands with a single radiator [5]. An advantageous property of this type of antenna is that it can be shaped around forms, as illustrated in Fig.1. Note that the substrate has been made transparent for clarity. An antenna of these characteristics was attached to a cylindrical substrate with outer radius of 15mm and thickness of 3mm. The main dimensions of the antenna are shown in Fig. 2, where: W = 84mm, H = 68mm, A = 18mm, B = 10mm and C = 5mm. The structure was placed on a square metallic ground of 175mm^2. The distance between the radiating element and the ground was 1.6mm. The antenna was designed using CST Microwave Studio$^{\text{TM}}$.

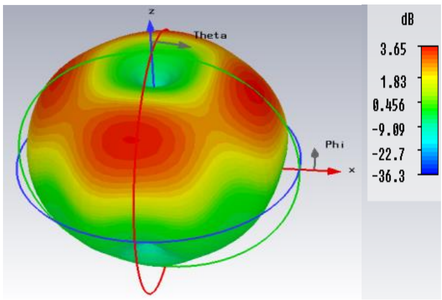
B. *Fabrication*

Fuse filament fabrication (FFF) technology was used for the fabrication of the cylindrical form. The specific machine employed was the low-end MBOT3D printer, with low-cost polylactic acid plastic filament (PLA) as input material. The machine was configured for a density of plastic inside the dielectric of 50%. Two prototypes were fabricated. In the first, the pattern of the antenna was etched on a copper clad Mylar substrate and then placed on the cylinder using double sided sticky tape (Fig.3a). The thickness of the Mylar substrate was about 0.05mm. In the second, the metallic tracks were made by coating the cylinder using a mask and painting with silver conductive ink (Fig.3b).The mask was fabricated by laser cutting a fiberboard sheet.

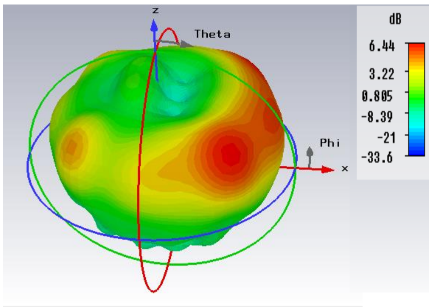
A. *Simulation and Measurement resutls*

The dielectric permittivity (ε_r) of the PLA substrate was measured by 3D printing a sample and placing it inside a two-port transmission waveguide system. The resulting ε_r was about 2.4 and the loss tangent was less than $5\text{x}10^{-4}$.

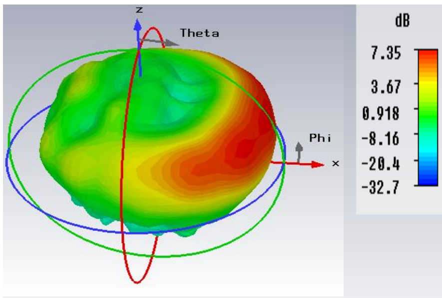
The measured input matching (S_{11}) of the two antennas (Fig.3 (a) and (b)), together with the simulation are shown in Fig. 4. Note that the metal tracks that make the antenna were simulated as perfect electric conductor. All three curves have nulls of about 9.5dB or more at all the LTE bands and mobile bands. Both the copper and the silver painted antennas compared very well with the simulations. Simulated radiation patterns were mostly omnidirectional in the x-y plane at the low LTE700 band (Fig.5). Radiation patterns were more directional at higher frequencies as shown in the 3D patterns in Fig. 6. The gain levels also increased for the higher frequency modes compared with the ones reported for the planar structure in [5].



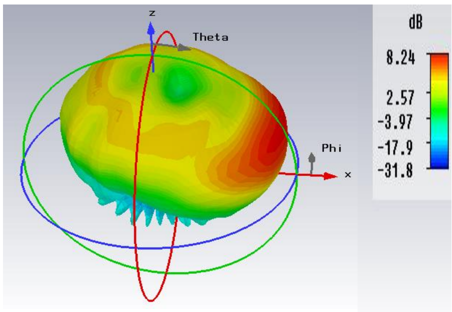
(a) 750MHz



(b) 2000MHz



(c) 2500 MHz



(d) 3600 MHz

Fig.6. 3D radiation patterns for vertical polarization

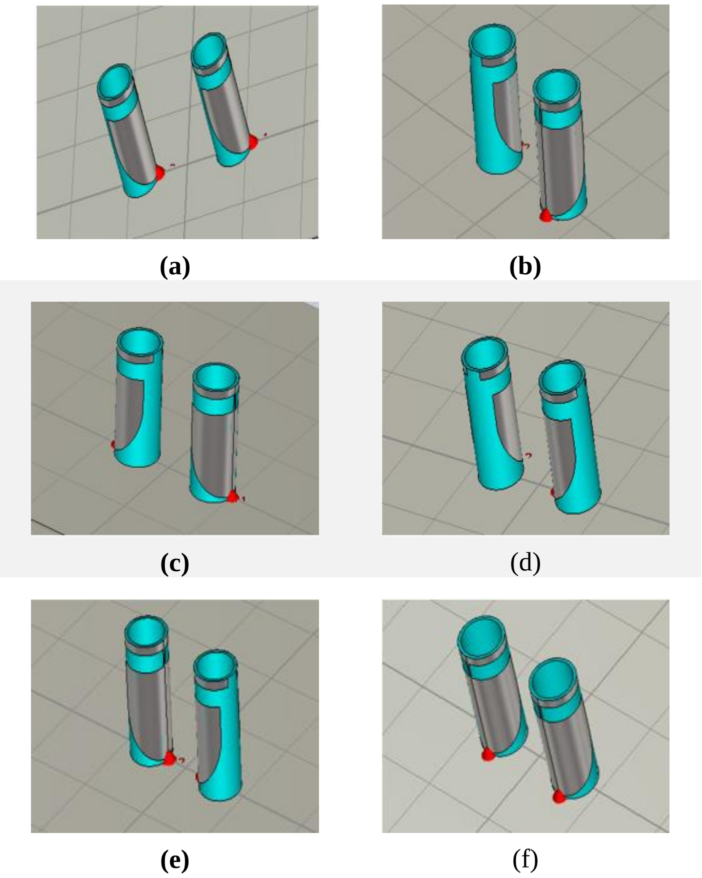


Fig. 7 Cylindrical LTE antenna configurations

TABLE I

Maximum S-parameters level at the 700MHz to 960MHz band for different configurations

Configuration	S_{11} (dB)	S_{21} (dB)
(a)	-7.4	-8.94
(b)	-7.5	-9
(c)	-9.6	-9
(d)	-7.1	-8.6
(e)	-6.8	-8.3
(f)	-7.4	-9

III. MIMO ANTENNA CONFIGURATION

A study was carried out with two LTE antennas placed at various distances and orientations. Fig. 7 shows the different configurations tested for the two antennas. As described in [5], the most sensitive to the proximity of a second radiator is the lowest LTE700 and GSM900 frequency band which expand from about 700MHz to 960MHz. Thus the study focused on obtaining the minimum S_{11} and S_{21} in this frequency range.

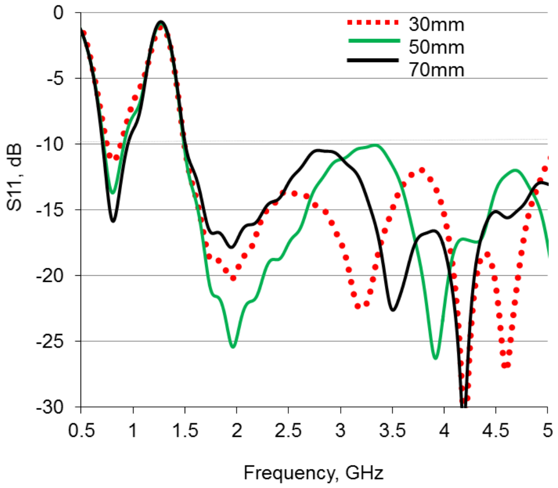


Fig.8. S_{11} for varous distances for configuration in Fig. 7 (c)

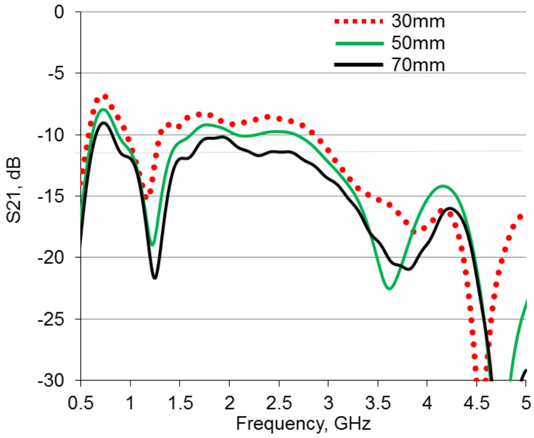


Fig.9. S_{22} for varous distances for configuration in Fig. 7 (c)

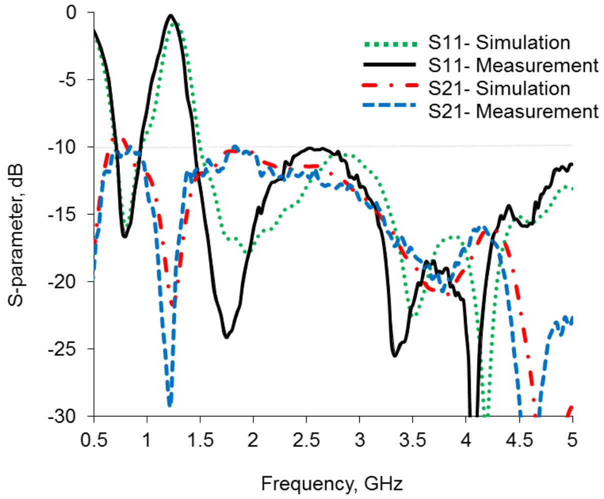


Fig. 10. Simulated and measured S-parameters

Table I. shows the maximum S_{11} and S_{21} level obtained at the lower band for the different MIMO antenna configurations in Fig.7. The distance between the two cylindrical antennas was 70mm. This is the shortest distance for obtaining a level of S_{11} less than -9.5dB (VSWR less than 2) and mutual coupling less than -9dB across the lower frequency band. As we can see from the table, the only configuration able to achieve this level is the one in Fig. 7 (c). Fig. 8 and Fig.9 show the effect on S_{11} and S_{21} of varying the distance between the two antennas from 70 mm to 30 mm. The S_{11} and S_{21} degraded as the proximity between the antennas was reduced. At a distance of 30mm, the S_{11} remained below -10dB at the higher frequency bands but it was reduced to less than -7.8dB at the lower band. The S_{21} decreased to -8.2dB and -6.7dB at the higher and lower band respectively.

Two identical antennas were fabricated by etching the patterns on copper clad Mylar substrates and attaching them onto 3D printed cylinders (Fig.3 (a)). The antennas were arranged in the configuration in Fig. 7 (c), at a distance of 70mm. The simulated and measured S-parameters are shown in Fig.10. Measurements matched well with simulations. At the lower band, S_{11} and S_{21} levels were less then -9dB and -10dB respectively. S_{11} and S_{21} were less than -10dB at the higher band.

Simulated 3D radiation patterns at 700MHz, 2000MHz, 2500MHz and 3600MHz are shown in Fig. 11. As in [5], the gain increased with the increase in frequency. Patterns differs from those for two planar antennas in MIMO LTE configuration, and gain levers were lower than in [5].

IV. CONCLUSIONS AND DISCUSSION

The use of additive manufacturing for the development of functional substrates for vehicular antenna has been demonstrated. A 3D printed cylindrical structure can be used to shape around planar LTE antennas with little modification to the original antenna design. The cylindrical substrate is able to reduce the size while keeping performance. Painting the tracks of the antenna with silver conductive is is a good additive manufacturing solution. It produces similar antenna matching to more conventional techniques such as etching on copper clad Mylar film, and then attaching the film to the cylindrical form. In this illustration, the silver conductive ink has been painted by hand, but other more automatic techniques could be used. A study of the efficiency of the silver ink antenna will be carried and discussed in the future. The higher the conductivity of the silver ink the higher antenna efficiency will be achieved.

Two cylindrical LTE antenna allows for a total of 6 different MIMO configurations. A configuration were the two port of the antenna were at the farthest distance gave the best results in terms of reflection coefficient and mutual coupling. This configuration is able to decrease the volume used between the two antennas by about 35% compared with the best configuration with two identical planar antennas [5].

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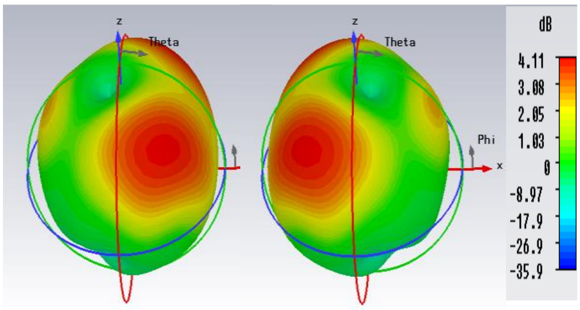
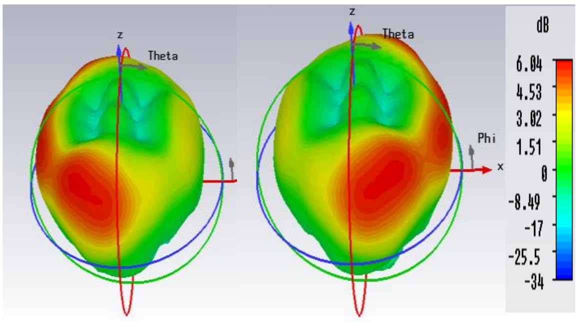
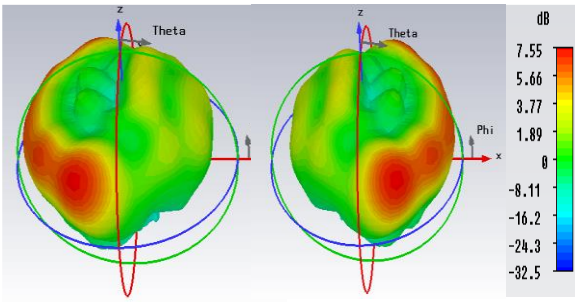


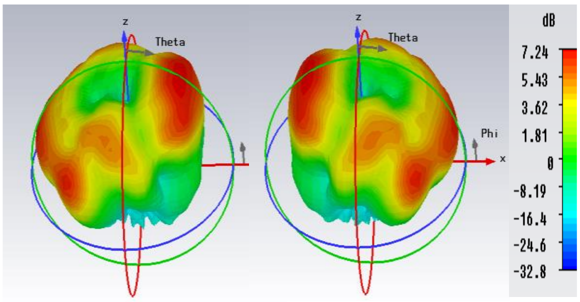
a) 750MHz



(b) 2000MHz



2500MHz



3600MHz

Fig. 11. 3D radiation patterns

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REFERENCES

[1] R. Leelaratne, R. Langley, “Multiband PIFA Vehicle telemetics Antennas”, *IEEE Transactions on Vehicular Technology*, vol. 54, no. 2, pp. 477–485, 2005.

[2] E. Gschwendtner,; W. Wiesbeck, “Ultra-broadband car antennas for communications and navigation applications”, *IEEE Transactions on Antennas and Propagation*, 51 (8). pp. 2020-2027, 2003

[3] B Sanz-Izquierdo, and J.C. Batchelor, and R.J. Langley, and M.I.Sobhy, “Singly and Double Layer Planar Multiband PIFAs”, *IEEE Transactions on Antennas and Propagation*, 54 (5). pp. 1416-1422, 2010

[4] A.Thiel , L. Ekiz, O. Klemp, M. Schultz, “Automotive grade MIMO antenna setup and performance evaluation for LTE-communications”, International Workshop on Antenna Technology (iWAT),pp. 171-174, 2013

[5] B. Sanz-Izquierdo and Rusiru Leelaratne, “Evaluation of Wideband LTE Antenna Configurations for Vehicle Applications”, Loughborough Antennas and Propagation Conference, Nov. 2014

[6] A.Friedrich, ; B.Geck, ; O.Klemp, ; H Kellermann, “ On the design of a 3D LTE antenna for automotive applications based on MID technology”, Microwave Conference (EuMC), 2013 European, p.p: 640-643, 2013

[7] B. Sanz-Izquierdo, and E.A Parker, ‘3D Printing Technique for Fabrication of Frequency Selective Structures for Built Environment’, *Electron. Lett.*, 2013, **49**, (18), pp. 1117-1118.

[8] B. Sanz-Izquierdo, and E.A Parker,.: ‘Frequency Selective Surfaces Formed by Partially Metalising 3D Printed Shapes’, in, *Antennas and Propagation (EuCAP), 2015 9th European Conference on*, (2015),

[9] B. Sanz-Izquierdo, and J. Sungyun,: ‘WLAN Antenna on 3D Printed Bracelet and Wrist Phantom’, in Loughborough Antennas and Propagation Conference (LAPC), 2014 Loughborough, (2014),

[10] B. Sanz-Izquierdo, and E.A Parker,.: ‘3-D Printing of Elements in Frequency Selective Arrays’, IEEE Trans. Antennas Propag., 2014, 62, (12), pp. 6060-6066.