Inkjet Printed and Folded LTE Antenna for Vehicular Application

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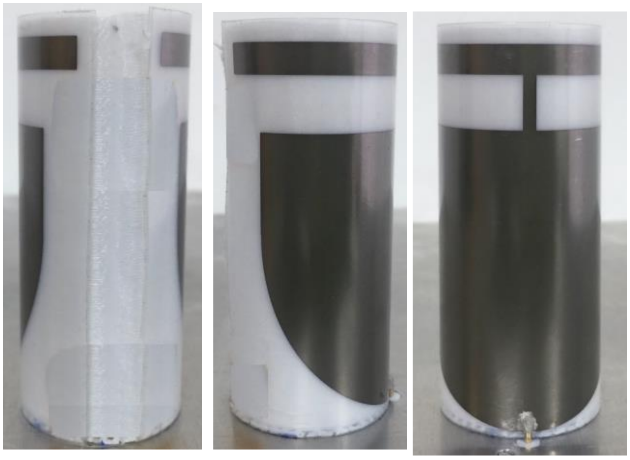
***Abstract*— A multi-band antenna suitable for Long-term Evolution (LTE) is inkjet-printed, and then folded around a cylindrical form. The plastic cylinder is also printed using additive manufacturing techniques, as a separate process. The antenna is based on a planar wideband monopole radiator concept with an additional resonator for the LTE700 frequency band. The aim is to study the potential of low-cost additive manufacturing (AM) techniques for the development of vehicular antennas. Two antennas have been fabricated, one on paper substrate, and a second on polyethylene terephthalate (PET) substrate. The one on paper is tested as a planar monopole antenna on a large ground plane. The one printed on PET is shaped onto the cylindrical form. The main aim is to investigate the use of low-cost inkjet printing techniques for the fabrication of disposable vehicular antennas that can be upgraded regularly. The antennas successfully operate at all LTE and mobile frequency bands. Finite different time domain simulations compare well with measurements.**

Keywords*— inkjet printing, 3D printing, additive manufacturing, vehicle antenna

I. INTRODUCTION

Vehicular communications are continuously expanding with new technologies and applications. Long Term Evolution or 4GLTE is one of the latest additions. 4G allows high-speed data on the move which can increase car connectivity and provide further infotainment systems. Vehicles are currently being prepared to incorporate LTE functionality. This translates into a significant update to the current antenna systems. LTE antennas are required to operate at many frequency bands and, in some cases, to support multiple-input-multiple-output (MIMO) systems. LTE frequency bands are located at 700MHz, 2300MHz, 2500MHz and 3600MHz. The existing GSM900, DCS1800, PCS1900 and UMTS should also be covered using the same antenna system.

Multi-frequency antennas suitable for vehicular applications were reported in [1] - [3]. LTE antennas intended for mounting on the rooftop of a vehicle have been proposed [4] – [6]. In [6], two LTE antennas were integrated in the typical shark fin plastic enclosure. There the antenna was attached to the plastic using laser direct structuring (LDS) technology.



(a) (b) (c)

Fig.1 Three views of the inkjet-printed LTE antenna folded around a cylindrical form: (a) back, (b) side, (c) front

The recent advances in nanoparticle silver inks has led to the development of electronic devices and circuits via inkjet printing. Sensors [7], RFID Tags [8]-[9], RF energy harvesting technology [10], and antennas [11]-[16] have been reported. The speed, accuracy and low-cost of inkjet printing is one of the main drivers of this trend.

This paper proposes the use of inkjet printing for the rapid manufacturing of low-cost LTE antennas for vehicular applications. The antenna presented in [5] has been tested when fabricated via inkjet printing, and when shaped around a 3D printed cylindrical structure. The antenna is first printed on paper substrate and tested as a planar structure. Then the same antenna is printed on a polyethylene terephthalate (PET) sheet and folded around the 3D form. The main application is LTE communications in public transport and military systems. The use of different additive manufacturing techniques could create customized antenna solutions for these systems.

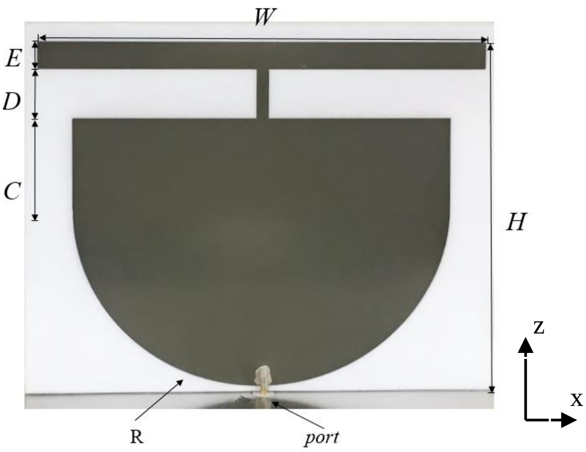


Fig.2 Inkjet printed antenna on paper. The main parameters of the antenna are included.

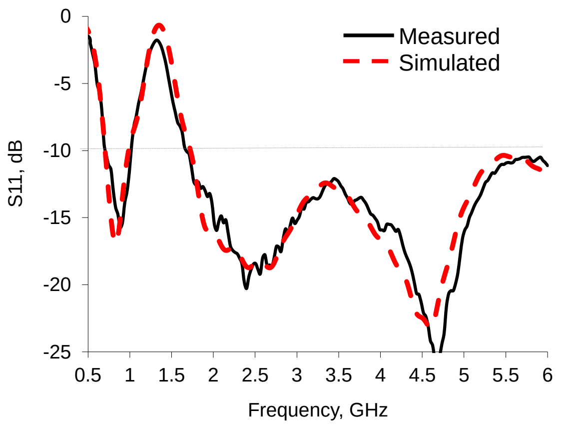
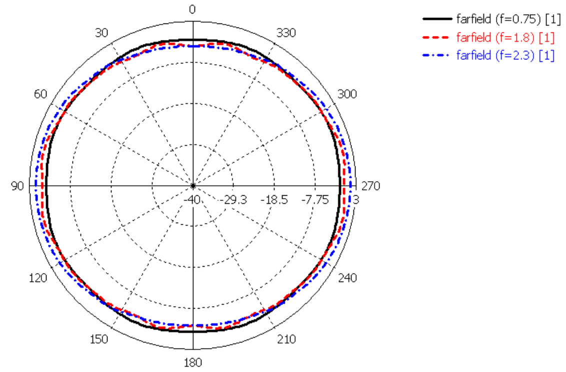


Fig.3 Reflection coefficients (S_{11}) for the planar inkjet-printed antenna on paper substrate

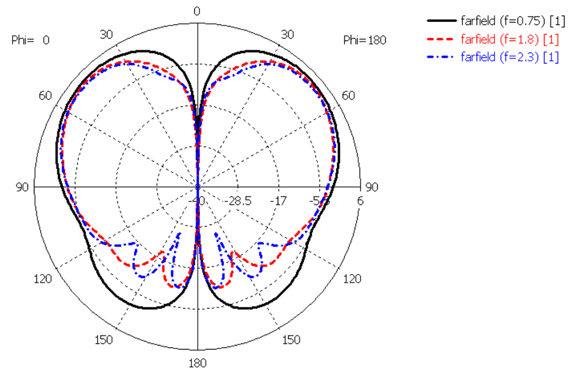
II. Wideband Inkjet Printed LTE Antenna

A. Antenna design

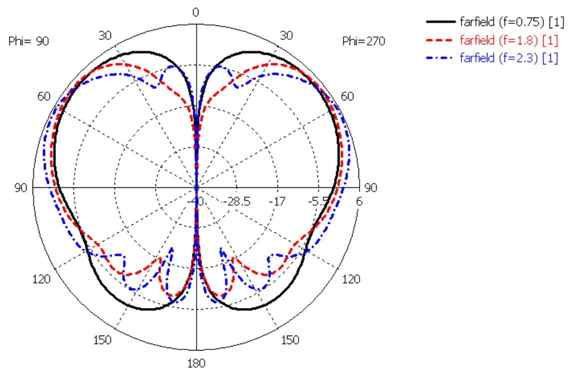
A wideband monopole antenna with an additional resonator is able to operate all LTE frequency bands on a single radiator [5]. One useful property of this type of antenna is that it can be shaped around forms, as demonstrated in Fig.1. Another advantage is that it has a very wide metal component which can decrease the resistance when fabricated via inkjet printing (see Fig.2). An antenna with these characteristics was reproduced by inkjet printing. The main dimensions of the antenna where: W = 84mm, H = 68mm, C = 18mm, D = 10mm and E = 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™ .



(a) x-y plane



(b) x-z plane



(c) y-z plane

Fig.4. Radiation patterns for the planar LTE antenna

B. Fabrication and Measurements

The antenna design was exported to a .gbr file and then converted to a .pdf file for printing. A Brother MFC-J5910DW inkjet printer was employed together with the AgIC-CP01A4 paper and AgIC-AN01 Silver Nano Ink [17]. Fig. 2 shows the fabricated antenna on the paper substrate. The substrate had a thickness of 177μm. The sheet resistance of the printed metallic layers was about 0.2Ω/sq [17]. The antenna was fed by a 50 **Ω** SMA connector which was attached using silver epoxy conductive glue. The resistance between any two two ends of the antenna was found to be less than 3Ω.

The simulated and measured reflection coefficient (S_{11}) of the antenna are shown in Fig.3. Simulations matched very well with experimental results across all frequency bands. The antenna was able to cover the lower band, from 700MHz to 960MHz, with a S_{11} level lower than -9.5dB. The higher band covers from 1.7GHz to well over 6GHz with S_{11} less than -10dB. The computed radiation patterns for various frequencies is shown in Fig.4. Patterns were mostly omnidirectional in the x-y plane at all frequency bands. The calculated gains were 3.9dB, 5.5dB, 6.1dB and 5.9dB at 750MHz, 2000MHz, 2500MHz and 3600MHz respectively.

III. Inkjet Printed LTE Antenna Folded on Plastic 3D Printed Cylinder

A. Antenna design

The LTE antenna described in the previous section was shaped around a cylindrical form as illustrates Fig.5. The cylindrical shape was chosen as it reduces the length of the antenna, and increases mechanical strength. Owing to its round and symmetrical design features, it is also likely to work well in terms of vehicle aerodynamics. The substrate has been made transparent for clarity. The outer radios of the cylindrical substrate was 15mm, and the thickness 2mm.

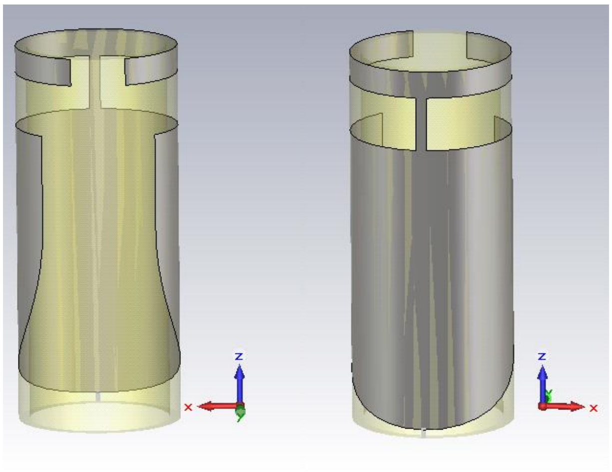
B. Frabrication and Measurements

Fig. 1 shows the fabricated antenna on the cylindrical form. Fuse filament fabrication (FFF) 3D printing technology was used for the fabrication of the plastic cylinder. The specific machine employed was the low-end MBOT3D printer. Low-cost polylactic acid plastic filament (PLA) was used as input material. The machine was configured for a density of plastic of 50%.

The pattern of the antennas were inkjet printed using the same procedure as the one described in section II. In this case, the substrate used was polyethylene terephthalate (PET) sheet of thickness 135µm. The substrate was attached to the cylinder using double sided sticky tape.

The dielectric permittivity, ε_r, of the PLA substrate was measured by printing a sample and placing it inside a two-port transmission waveguide system. The resulting value of ε_r was about 2.4 and the loss tangent was less than $5x10^{-4}$.

The measured input matching (S_{11}) together with the simulation are shown in Fig. 6. Note that the metal tracks that make the antenna were simulated as perfect electric conductor. The two curves have S_{11} of less than -9dB at the lower band and less than -10dB at the higher bands. Simulation and measurements compared well, particularly at the lower frequency band. Simulated radiation patterns were mainly omnidirectional in the x-y plane at the low LTE700 and GSM bands (Fig.7). Radiation patterns were more directional at higher frequencies. The gain levels also increased compared with the ones for the planar structure in section II. The calculated gains were 4.0dB, 5.2dB, 7.0dB and 8.1dB at 750MHz, 2000MHz, 2500MHz and 3600MHz respectively.



(a) (b)

Fig.5 Folded LTE antenna: (a) back, (b) front

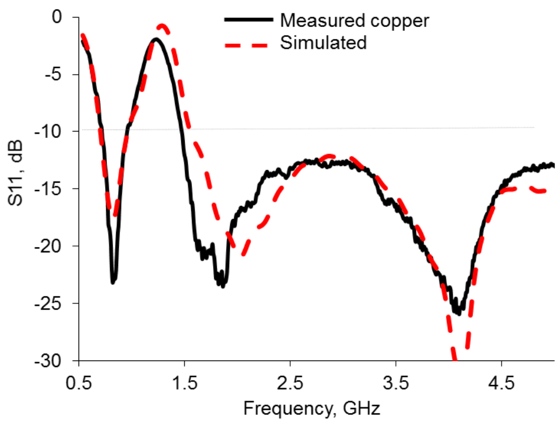
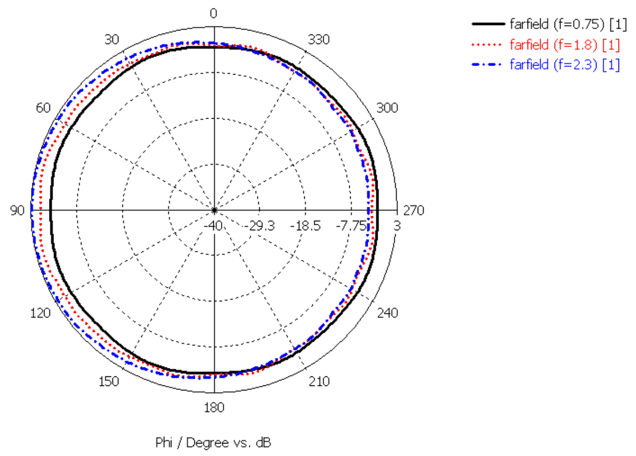


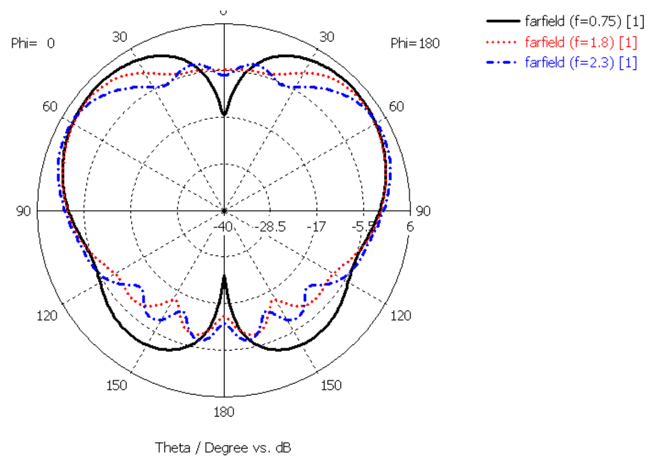
Fig.6 Reflection coefficients (S_{11}) for the inkjet-printed antenna folded on the 3D form.

IV. Conclusions and Discussion

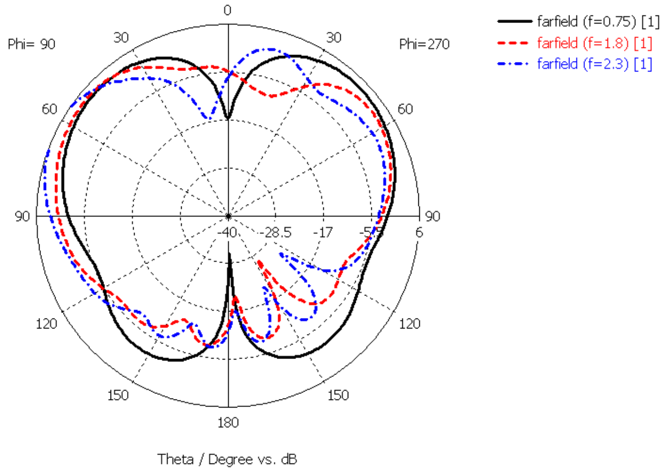
The use of inkjet printing techniques for the development LTE antennas for vehicular applications have been demonstrated. Readily available inkjet printers and commercial cartridges with nanoparticle silver inks offer an alternative solution to traditional subtractive techniques. Inkjet-printed LTE antennas have similar impedance matching to those obtained using etching techniques [5]. Furthermore, photopaper substrates used in inkjet printing offer the possibility of creating solutions that can be disposable, and also rapidly replaceable. This may allow antenna systems to be upgraded more frequently. 3D printed forms can also be used to shape around inkjet-printed LTE antennas. Cylindrical substrates are able to reduce the length of planar LTE antennas while keeping performance. In this illustrative example, the cylindrical form has been placed inside the antenna. In practical vehicular applications, the cylindrical form would be placed outside the antenna, and should be capped or closed at the top. This would protect the antenna from external environment factors which could degrade the printed metallic layers.



(a) x-y plane



(b) x-z plane



(c) y-z plane

Fig.7 Radiation patterns of the cylindrical antenna at various frequencies

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