Printed Wideband Antenna for LTE Band Automotive Applications

Andrea Michel, *Member, IEEE*, Paolo Nepa, *Member, IEEE*, Michele Gallo, Ilenia Moro, Andrea Polo Filisan, Daniel Zamberlan

***Abstract*— A low-profile printed antenna is here proposed for vehicular communications, covering wireless standards in a wide frequency range (698-2690 MHz) that includes the LTE (Long Term Evolution) band. Multiple monopole antennas are printed on the same compact substrate easily embeddable under a shark-fin cover, and they are properly optimized to resonate in the considered frequency band. A tapered profile and a thin slot have been introduced to achieve a good impedance matching, especially at the higher frequencies. Numerical simulations and measurement results on a prototype are here reported in terms of reflection coefficient, gain and radiation pattern. The proposed wideband antenna is suitable for other wireless scenarios in addition to the automotive industry.**

***Index Terms*—Long Term Evolution, printed monopole, wideband antenna, vehicular communication antenna.**

I. Introduction

In the framework of mobile and automotive applications [1] the number of infotainment communication and telematics services is rapidly increasing. At the same time, the increase of wireless functionalities results in a growing complexity of dedicated electronic systems, networks, and architectures, since satellite and terrestrial wireless applications cover a wide range of frequencies [2]. Several antennas are integrated in different locations on a vehicle to satisfy different wireless services requirements [1]. In some cases, integration is particularly challenging because several antennas must be accomodated into the same device, typically compact in size. That is, an antenna physical dimension is limited by the available volume of the device housing as well as by the presence of closeby radiating elements operating at different frequencies. In the automotive industry, a number of antennas are typically placed together under a shark-fin plastic cover located onto the car rooftop. Thus, the antenna design and arrangement must be carefully optimized to limit the mutual coupling between radiating structures, as discussed in [3], where four possible Dedicated Short Range Communications (DSRC, 5850-5925 MHz) antennas are studied to determine their position in a compact shark-fin module which guarantees optimum performance even in presence of other antennas for different services.

It is worth noting that achieving antenna requirements could be relatively easy for high-frequency applications (beyond 1GHz) [4], since the physical size of resonant radiating elements is compatible with the available space inside the device housing. On the other hand, miniaturization techniques are required to integrate antennas for low-frequency applications (below 1GHz) [5].

Such issues are recently discussed in the design of antennas for LTE700 applications, especially in the automotive field [6]-[14]. The design of antennas able to fulfill the application requirements in terms of gain and impedance matching in the entire LTE700 band is quite demanding.

Typically, patch antennas and monopole antennas printed on 2D substrates are designed for automotive applications. In [6]-[7] a compact monopole inspired by a wideband Vivaldi antenna is presented. Moreover, to efficiently utilize the small available space and to achieve better antenna performance, 3D LTE antennas have been proposed [8]-[11]. In [8]-[9] an efficient 3D Nefer-antenna is shown which is able to cover the entire LTE band without applying any matching network. However, the effect of other radiating elements close to the LTE antenna has not been analyzed. In [10], a 3D antenna is proposed for mobile, WLAN and C2C services in vehicular applications. Two printed substrates are mounted perpendicularly to each other in order to exploit all the available space and leave a wide space empty for an independent GPS antenna. For a better utilization of the available mounting space and to improve the antenna decoupling in LTE multiple-antenna technology, an antenna realized by Molded Interconnect Device (MID) Laser Direct Structuring (LDS) is presented in [11]. There, two LTE antennas are designed on an automotive rooftop plastic housing.

In this paper, a compact wideband antenna is proposed to cover LTE, GSM and UMTS bands (698-960 MHz, 1710-2170 MHz, 2490-2690 MHz) as well as the WLAN (2400-2485 MHz) band. Multiple-arm printed monopoles are designed on a low-cost and low-profile PCB to be installed on the vehicle rooftop. Multi-arm monopoles have been used in several wireless applications, as in [12]-[13]. In the proposed antenna, both the dominant and higher-order modes of a monopole antenna are exploited to get a wider operating frequency band. Moreover, a tapered profile of the feeding network and a thin slot have been introduced for a fine tuning of the input impedance matching at higher frequencies. Thanks to its compact size (25×76×1.53 mm^3), the antenna is a good candidate for mobile applications, especially in the automotive industry, and it may be also used for

Multiple-Input Multiple-Output (MIMO) systems [14].

II. Antenna Design

The antenna geometry is shown in Fig. 1, and its parameters are listed in Table I. The proposed antenna has been designed on a 25×76 mm^2 1.53-mm-thick FR-4 substrate (ε_r=4.3, tanδ=0.02). A 3.5×12.3 mm^2 protrusion has been added to fix the vertical substrate to the horizontal ground plane (for automotive applications, the latter could be represented by the metallic car rooftop). The microstrip feeding line and the radiating elements are printed on the top layer of the substrate, while a small ground plane is printed on the bottom and electrically connected (soldered) to the horizontal ground plane.

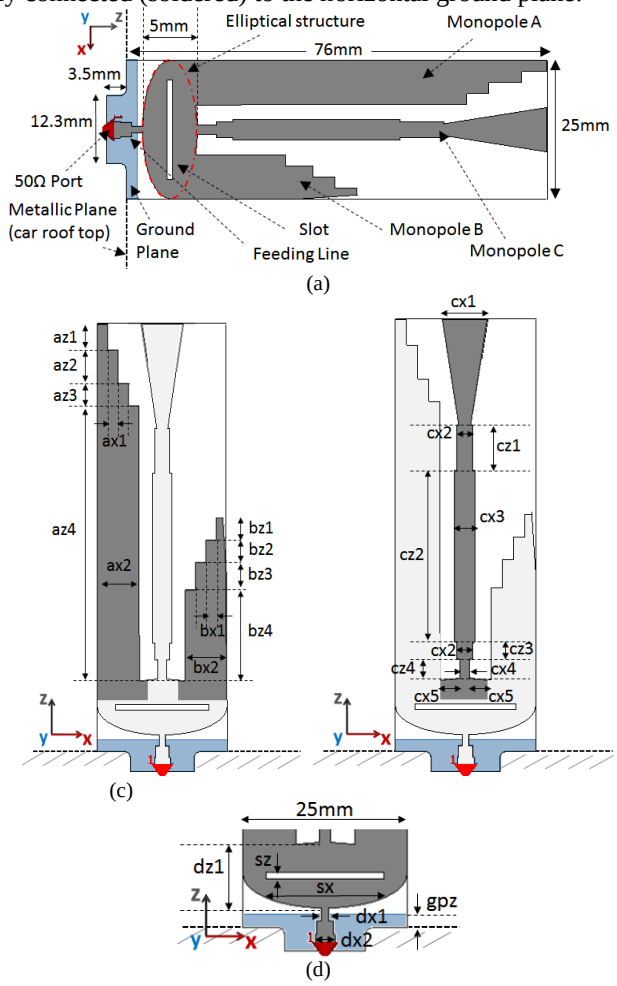


Fig. 1. Antenna layout: (a) overall antenna size and detailed definition of the geometrical parameters of (b) Monopole A and Monopole B, (c) Monopole C, and (d) feeding line and bottom part of the antenna.

The antenna consists of three monopoles (Fig. 1) with different lengths to resonate at different frequencies. The central monopole (Monopole C) is tapered on the top (as a

TABLE I
Antenna Main Parameters

Geometrical Parameters (mm)					
Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
ax1	2	**bz2**	4	**cz2**	30.4
ax2	8	**bz3**	5	**cz3**	3
az1	4.5	**bz4**	16.3	**cz4**	3.4
az2	6	**cx1**	8	**dx1**	1.2
az3	4	**cx2**	2.8	**dx2**	2.5
az4	49.3	**cx3**	3.8	**dz1**	5
bx1	2	**cx4**	1.7	**sx**	18
bx2	8	**cx5**	3.6	**sz**	1
bz1	4	**cz1**	8	**gpz**	2

bow-tie monopole) to slightly shift the resonance toward a lower frequency.

Monopole A and Monopole B are placed close to the central Monopole C. They are characterized by a stepped top profile, which provides a bandwidth enlargement around the resonant frequency.

The three monopoles are connected together to an elliptical printed structure directly fed by a microstrip line. The ellipse main axis are 25mm and 5mm wide (Fig. 1a). To demonstrate the effectiveness of the presence of such an elliptical structure, in Fig. 2 the simulated reflection coefficient is shown as a function of the frequency, with (solid line, *i.e.* final layout) and without the tapering (dotted line). It is worth noting that the tapered profile of this structure allows for a better input impedance matching, especially at frequencies higher than 1700MHz.

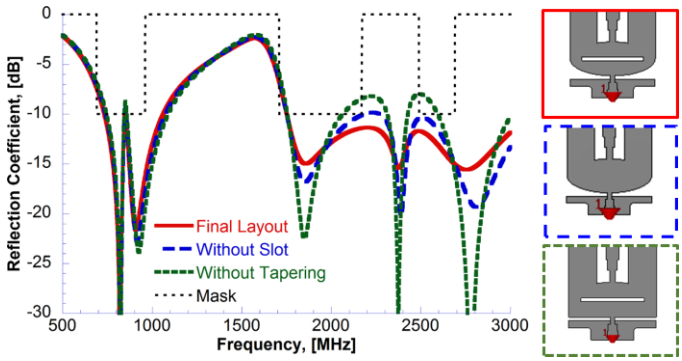
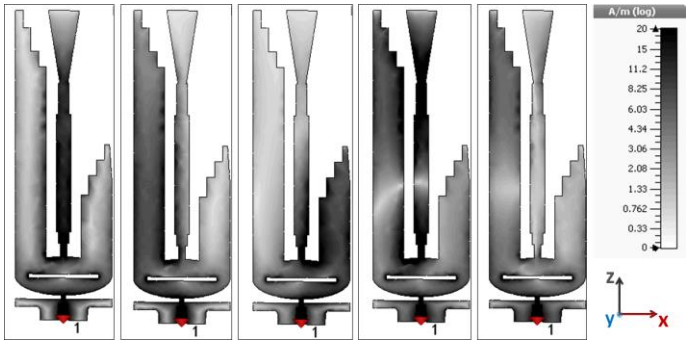


Fig. 2. Simulated reflection coefficient of the proposed antenna with different feeding layouts, to highlight the effect of the tapered profile and slim slot.

In Fig. 3, the surface current distribution is shown at the frequencies corresponding to the minima of the reflection coefficient (see the final-layout curve in Fig. 2), *i.e.* at 700MHz, 900MHz, 1850MHz, 2450MHz and 2800MHz. As expected, each monopole resonates at different frequencies. Generally, their lengths can be arbitrarily chosen in order to get resonances in the desired frequency bands. However, it should be highlighted that the monopoles are very close to each other, so the mutual coupling effects cannot be neglected. Thus, their length do not correspond exactly to the theoretical λ/4 value, but it has to be optimized by tuning the parameters shown in Fig. 1. Moreover, to achieve the impedance matching at the higher frequencies, higher-order modes on the radiating elements are excited, as shown by the current distributions in Fig. 3. This causes a slight tilt of the maximum gain direction with respect to the horizontal plane, but an almost omnidirectional radiation pattern is still guaranteed.

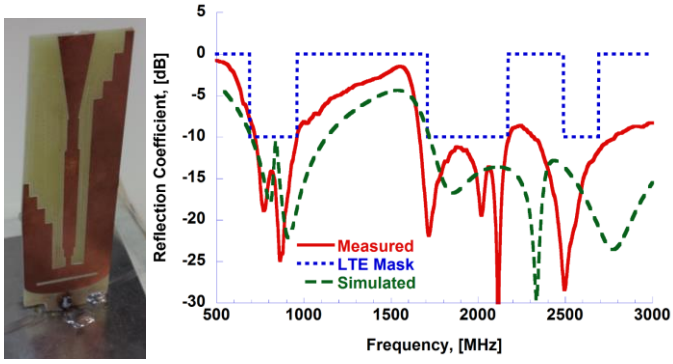


(a) (b) (c) (d) (e)

Fig. 3. Surface current distribution (dBA/m) on the radiating elements at the frequency of (a) 700MHz, (b) 900MHz, (c) 1850MHz), (d) 2450MHz, and (e) 2800MHz.

III. Measurements

An antenna prototype has been fabricated (Fig. 4a) and experimental tests have been carried out. In Fig. 4b, the measured reflection coefficient is plotted, showing a good agreement with the simulated results.



(a) (b)

Fig. 4. (a) Picture of the fabricated prototype and (b) simulated and measured reflection coefficient.

The prototype has been mounted at the center of a 1m-diameter circular metallic plane to emulate the car roof effect. The radiation patterns have been measured in the Calearo SG 3000F NF site [15] provided by Satimo. In Fig. 5, the simulated and measured gain of the proposed antenna are shown as a function of the frequency. Despite some differences in the LTE2600 band, the simulated and measured gains are in a good agreement and they are higher than 2dB in the entire operative frequency band (from 700MHz to 2700MHz). Moreover, an omnidirectional radiation pattern is achieved in the azimuthal plane (Fig. 6), which is required for automotive applications. The simulated and measured radiation patterns in the elevation plane are also shown in Fig. 7, for different frequencies.

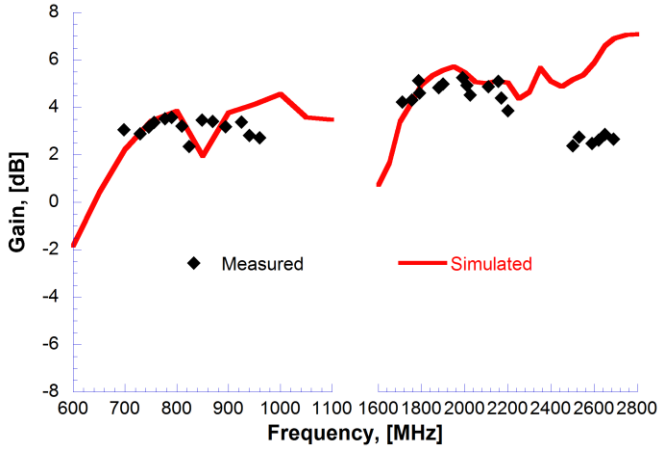
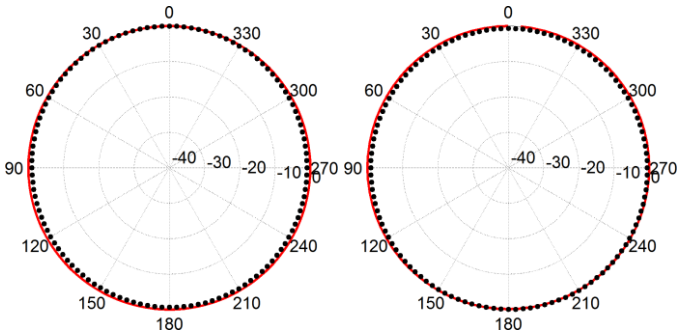


Fig. 5. Simulated (solid line) and measured (markers) gain of the proposed antenna.



(a) (b)

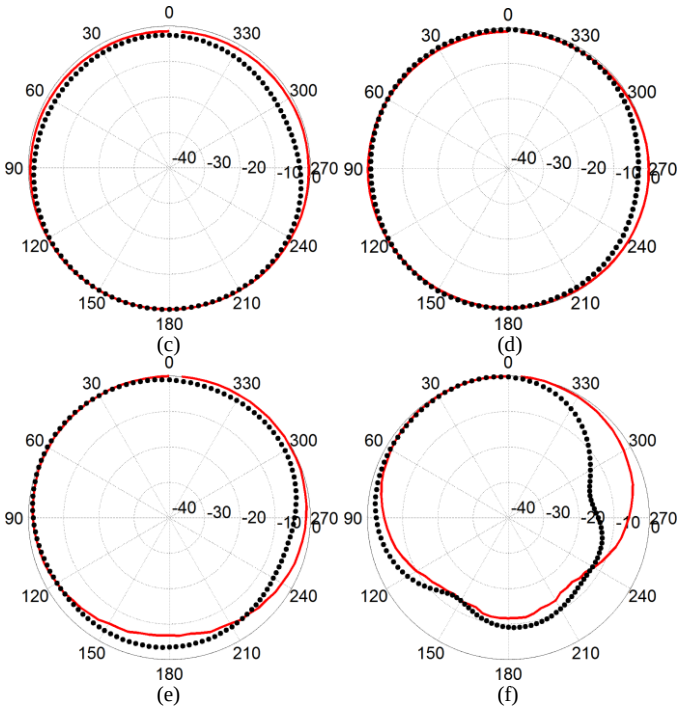


Fig. 6. Simulated (red solid line) and measured (black markers) normalized radiation patterns in the azimuthal plane (XY plane in Fig. 1) at (a) 700MHz, (b) 900MHz, (c) 1850MHz, (d) 2000MHz, (e) 2450MHz, and (f) 2700MHz.

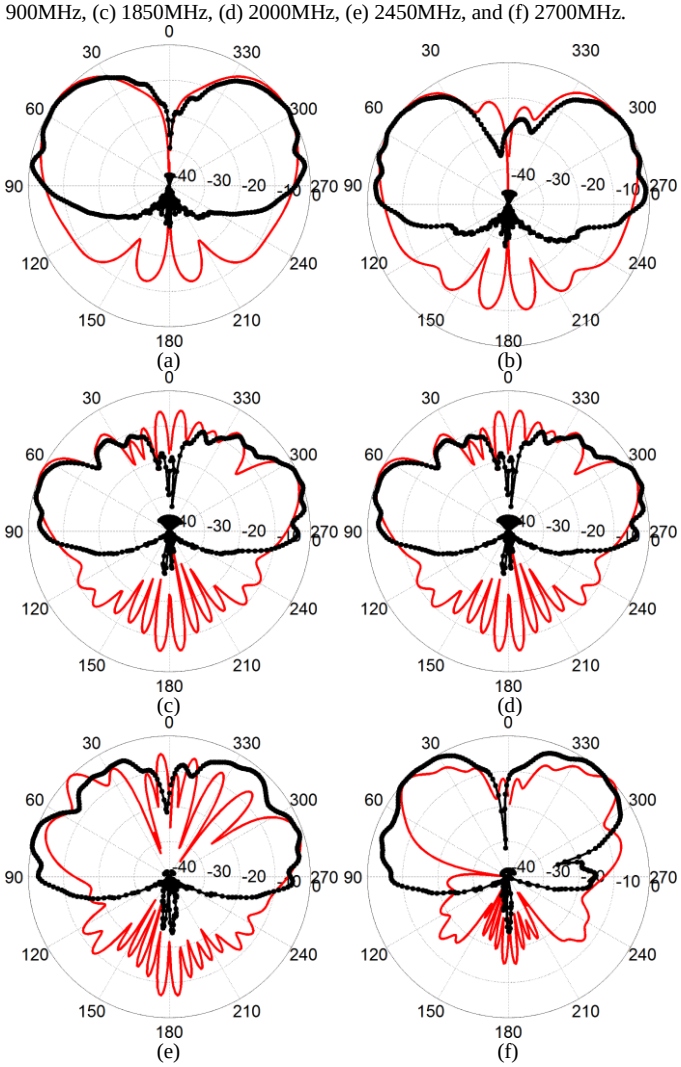


Fig. 7. Simulated (red solid line) and measured (black markers) normalized radiation patterns in the elevation plane (XZ plane in Fig. 1) at (a) 700MHz, (b) 900MHz, (c) 1850MHz, (d) 2000MHz, (e) 2450MHz, and (f) 2700MHz.

IV. Conclusions

A compact and low-profile wideband antenna has been proposed to operate in the 698-2690 MHz frequency range, so covering the LTE700, GSM, UMTS, WLAN and LTE2600 bands. The 25×76mm^2 antenna consists of three printed monopoles with different lengths to get resonances at some assigned frequencies. The monopoles are connected to the microstrip feeding line through an elliptical feeding structure on the bottom part of the antenna. The impedance matching is improved by properly optimizing the tapered profile of such a structure and by introducing a thin slot. Measured results have been shown and compared with simulation results. The proposed compact antenna represents a good candidate for a number of wireless applications, especially in the automotive industry where the available space under the shark-fin cover is limited.

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