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Wideband double monopole for mobile, WLAN and C2C services in vehicular applications

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***Abstract*—In this letter, a 3D-antenna solution for automotive applications is presented. The proposed solution is formed by two independent antennas, perpendicularly placed inside a plastic cover with a shark-fin shape. The antennas, designed with low-cost materials, exhibit omnidirectional radiation patterns in the azimuthal plane. The first antenna is a double-shorted monopole that provides service from 698 MHz to 960 MHz (in the LTE700, GSM850 and GSM900 bands), whereas the second antenna is a drop-shaped monopole that operates from 1.7 GHz to 2.7 GHz (in the DCS1800, PCS1900, WCDMA2100, WLAN2400, LTE2600, WiMAX2350, and Wi-Fi at 2.4 GHz bands), and from 5.1 GHz to 6 GHz (in the Wi-Fi at 5 GHz, and C2C bands). Results show a good matching and radiation efficiency at all bands.**

***Index Terms*—Wideband antennas, drop monopole, vehicular applications.**

I. Introduction

THE vast demand for new features and the intensified competition in the automotive industry have encouraged car manufacturers to turn their attention to mobile and wireless communication applications. With the inclusion of more sophisticated vehicle communications systems, the car producers have boosted the request of dedicated antennas that can operate at different frequency bands and are capable of coping with the needs of new mobile and WLAN standards, as well as with other services, such as GPS, Car-to-Car (C2C), or Remote Keyless Entry (RKE) [1]. Car producers require peculiar physical characteristics for the antennas in order to place the antenna inside an aerodynamic plastic cover that meets specific aesthetical needs [2]. A typical cover, made of PC-ABS and known as *shark-fin*, can be observed in Fig. 1 (a).

Current solutions adopt a single planar monopole antenna along the space inside the shark-fin shape to cover all bands [3], [4]. However, these solutions present problems at the lowest frequency bands caused by the limited height of the plastic cover. These problems are enhanced if the antenna must also operate in the LTE700 band (from 698 to 800 MHz) since at these frequencies a higher element is required to obtain a resonant antenna.

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Fig. 1: Configuration of the proposed antenna: (a) Plastic cover (shark-fin), and (b) Parts of the structure.

In order to address this problem, 3D solutions have been presented in the LTE700 band [5], [6]. These solutions, however, introduce an upper transverse metallic path that prevents the antenna to fit within the shark-fin shape. In this letter, a new 3D solution with the same shape as the shark-fin cover is presented. The proposed antenna covers the LTE700, GSM850, GSM900, DCS1800, PCS1900, WCDMA2100, WLAN2400, LTE2600, WiMAX2350, Wi-Fi, and C2C bands.

II. Design of monopoles

The proposed 3D-antenna is formed by two monopoles denominated *Shorted Monopole* and *Drop Monopole*. The former monopole covers the lowest LTE band (LTE700) and the GSM bands (GSM850 and GSM900), and the latter monopole is used to cover the remaining frequency bands. Unlike common solutions, where all monopoles are placed longitudinally to the shark-fin cover [7], [8], the proposed monopoles 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, as illustrated in Fig. 1 (b).

The monopoles, simulated with Ansys HFSS [9], are printed on FR4 substrate with permittivity 4.4 and thickness 0.813 mm and 1.5 mm for the Drop and Shorted monopole, respectively.

A. Drop monopole

The profile of the proposed drop monopole antenna, depicted in Fig. 2 together with its main parameters, is shaped according to the available space inside the plastic cover.

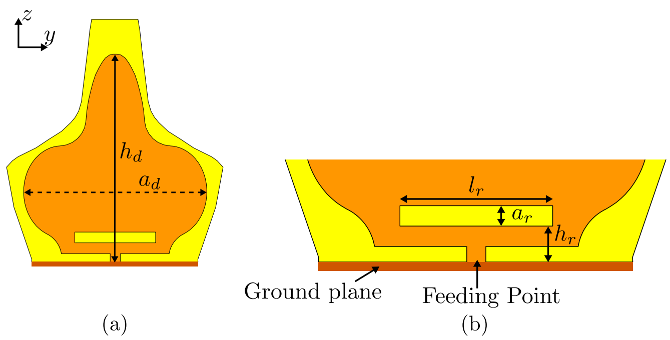

Fig. 2: Structure of the proposed drop-monopole antenna with its main dimensions: (a) General view, and (b) Matching slot located close to the feed of the monopole.

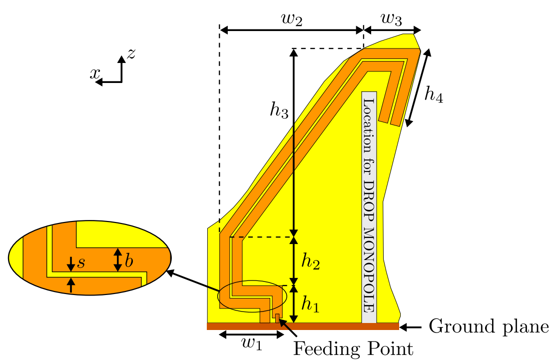

Fig. 3: Proposed shorted monopole antenna.

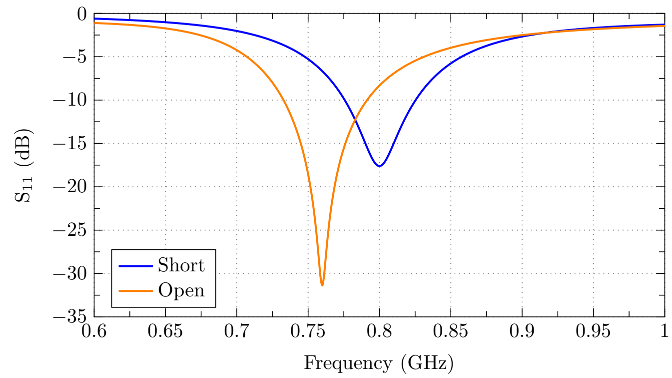

Fig. 4: S_{11} parameter of the shorted monopole ended in short and open circuits.

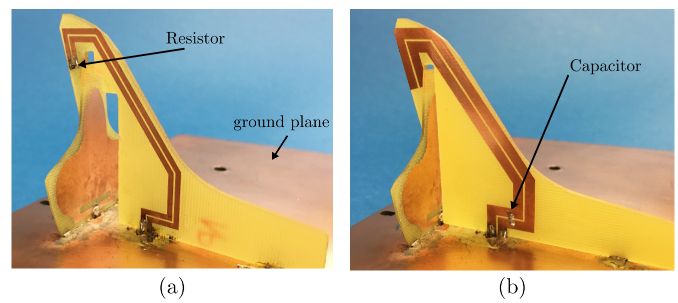

Fig. 5: Pictures of the fabricated prototypes. Shorted monopole with: (a) resistor, and (b) capacitor.

The behavior of the drop monopole antenna corresponds to the classical square monopole [10]. The upper-elliptical region of the monopole is responsible of the impedance matching from 1.7 GHz to 2.7 GHz since currents mainly flow in this area at these frequencies. Conversely, the maximum intensity of currents in the C2C band is concentrated in the lower region. For this reason, a slot is inserted close to the feed of the monopole to maximize the bandwidth at the higher operating frequencies [11]. Final optimized dimensions are: h_d=40 mm, a_d=36.5 mm, l_r=15 mm, a_r=2 mm and h_r=3.5 mm.

B. Shorted monopole

The operation in the LTE700 and GSM bands is provided by the shorted monopole. As can be seen in Fig. 3, the shorted monopole is a double-parallel metallic strip of thickness b and separated s=1 mm, with one strip shorted and the other one fed. Thus, the monopole is working in dipole mode [12], from the base to the end of the structure.

The design of an antenna for LTE700 band to be placed within a shark-fin cover is a strong challenge due to the limited available space. In [13], an antenna operating at 433 MHz was designed within a shark-fin cover achieving a 0.7% bandwidth. In the proposed application, the required bandwidth is wider (31.6%) and, hence, this kind of solutions cannot be applied. In order to deal with these issues, the shorted monopole has been printed along the boundary of the PCB and properly bent to increase the current path. Nevertheless, as illustrated in Fig. 4, this extension does not provide the required bandwidth either with the monopole ended in short or open circuit.

In order to guarantee a good matching level within the LTE700 and GSM bands, a lumped element is inserted between the two metallic strips of the shorted monopole to work as a matching circuit. Two different proposals are considered. In the first solution (Fig. 5 (a)), a resistor (R=160 Ω) is placed at the end of the double monopole to avoid reflected signals [14]. The optimized dimensions of the structure are: h_1=6.75 mm, h_2=12.00 mm, h_3=34.97 mm, h_4=11.50 mm, w_1=11.50 mm, w_2=25.64 mm, w_3=11.91 mm and b=1.50 mm. In the second proposal (Fig. 5 (b)) a capacitor (C=3.9 pF) is inserted near the feed of the monopole to produce a matched response. The optimized dimensions of this structure are: h_1=8.70 mm, h_2=8.34 mm, h_3=38.03 mm, h_4=16.40 mm, w_1=14.10 mm, w_2=30.14 mm, w_3=9.90 mm and b=2.80 mm.

Pictures of the fabricated prototypes, together with the fabricated drop monopole, are illustrated in Fig. 5. The antennas are fed by two independent SMA connectors mounted below the ground plane.

III. Results

The S-parameters and the radiation efficiency of the prototypes shown in Fig. 5 have been measured to compare their performance. Fig. 6 shows the S_{11} parameter of the two shorted monopole solutions (resistor and capacitor). In both solutions, measured and simulated values agree well, apart from a small shift in frequency caused by an inaccurate estimation of the FR-4 permittivity.

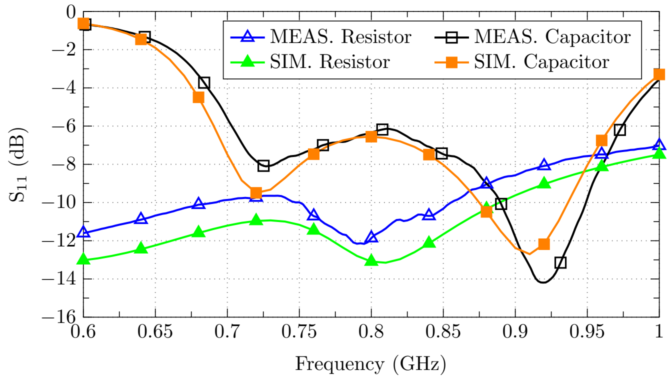

Fig. 6: S_{11} parameter of the shorted monopole antenna.

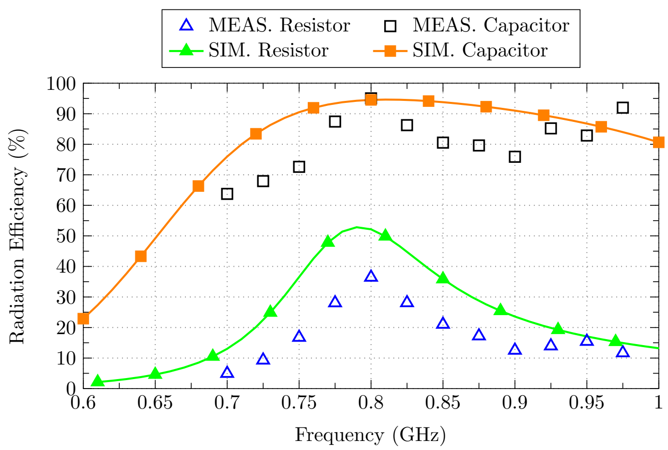

Fig. 7: Radiation efficiency of the shorted monopole versus frequency.

The response of the shorted monopole with a resistor presents a better matching than the design with a capacitor because the resistor works as a matched load that minimizes the reflected signals. Nevertheless, the solution with capacitor presents a S_{11} parameter below -6 dB from 698 MHz to 960 MHz, which is a typical reference value in mobile terminals [15].

The radiation efficiency for both cases is plotted in Fig. 7. As can be observed, the efficiency of the solution with capacitor is above 63% at any frequency within the LTE700 and GSM bands, whereas the maximum efficiency of the solution with resistor is 35%. This difference is caused by the resistor, which dissipates the received power.

Previous results indicate that the solution with capacitor may offer a better performance in a practical scenario due to the higher radiation efficiency. Nevertheless, the shorted monopole with resistor might be also useful in those situations in which a lower S_{11} parameter is required. In this sense, it is worth noting that a low efficiency may not restrict the applicability of the antenna since the low efficiency in the LTE700 and GSM bands can be compensated by the low free-space losses at these frequencies.

Considering the solution with capacitor for the shorted monopole, Fig. 8 compares the simulated and measured S_{11} parameter of the drop monopole in the intermediate

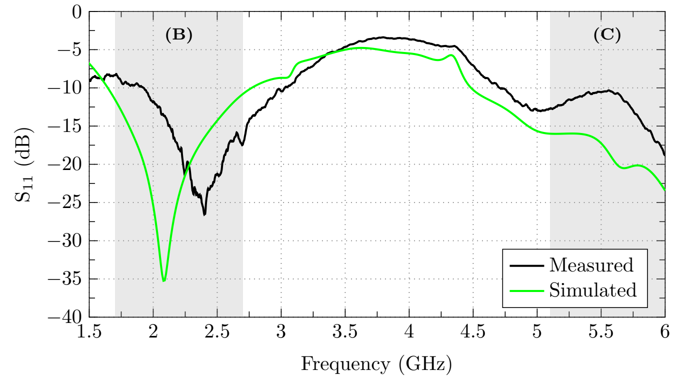

Fig. 8: S_{11} parameter of the drop monopole at intermediate frequency bands (B), and Wi-Fi at 2.5 GHz and C2C bands (C).

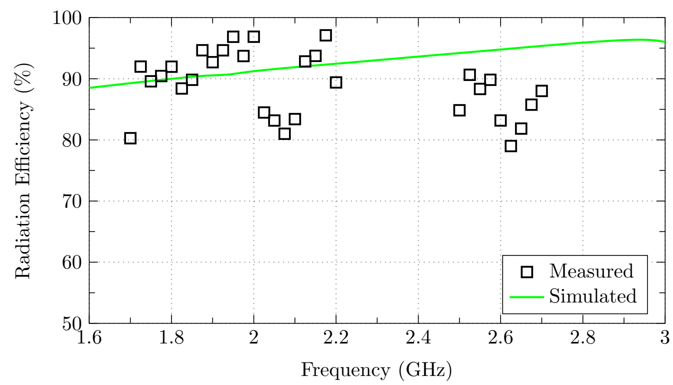

Fig. 9: Radiation efficiency of the drop monopole at the intermediate frequency bands.

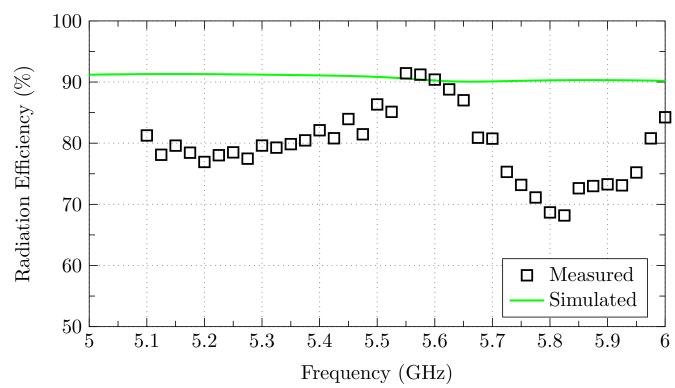

Fig. 10: Radiation efficiency of the drop monopole at the WiFi at 2.5 GHz and C2C bands.

frequency band (1.7-2.7 GHz), where DCS1800, PCS1900, WCDMA2100, WLAN2400, LTE2600, WiMAX2350 and Wi-Fi at 2.4 GHz services operate, and in the Wi-Fi 5 GHz and C2C bands (5.1-6 GHz). As can be observed, despite measured results are slightly shifted towards high frequencies, the S_{11} parameter is below -10 dB within the bands of interest.

The radiation efficiency of the drop monopole is shown in Figs. 9 and 10. Note that measured efficiency is only plotted at frequencies within the exact operating frequency bands where

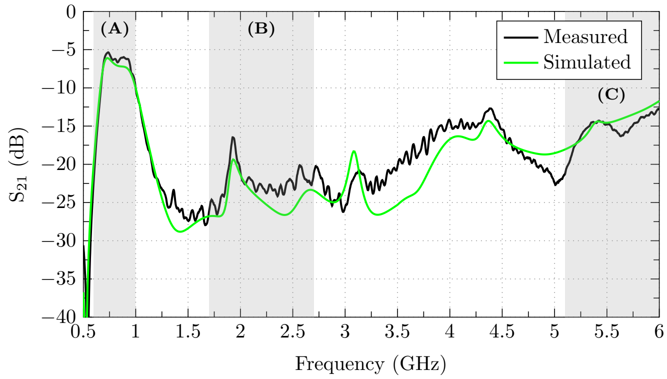

Fig. 11: Mutual coupling (S_{21} parameter) between shorted and drop monopoles. Shadowed zones indicate the operating frequency bands for each monopole: (A) shorted monopole, (B) drop monopole at the intermediate frequency bands, and (C) drop monopole at WiFi at 2.5 GHz and C2C bands.

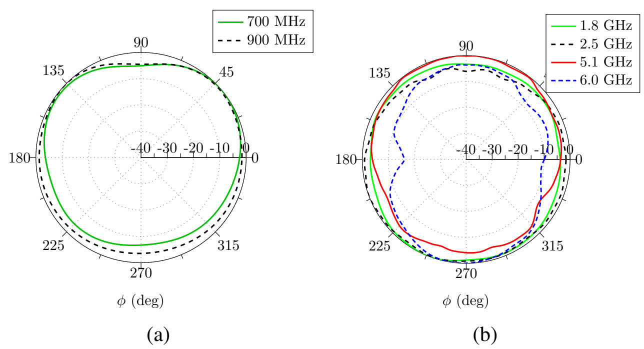

Fig. 12: Radiation pattern at several frequencies in the XY plane: (a) Shorted monopole, and (b) Drop monopole.

the different services are located. These figures illustrate that the efficiency of the antenna is above 68% at all frequencies, reaching values above 80% at most frequencies. The discrepancy between the measured and simulated efficiency is caused by the high loss tangent of the low-cost FR-4 substrate.

The S_{21} parameter between the two ports of the proposed wideband double monopole antenna is shown in Fig. 11. As can be observed, the mutual coupling is below -15 dB in the drop monopole operating bands, and below -6 dB in the shorted monopole. In order to minimize the effects produced by this coupling, a filter must be introduced in the drop monopole to eliminate the signal coupled from the shorted monopole. This is a common strategy in mobile terminals to discriminate signals belonging to different services.

Finally, Fig. 12 shows the measured radiation pattern of both antennas in the XY plane. As it can be observed, diagrams are quite omnidirectional, from 700 MHz to 5.1 GHz. The diagram presents a small pointing towards 90° and 270° around 6 GHz due to the larger electrical size of the antenna at this frequency.

IV. Conclusion

A 3D-antenna is presented as an alternative solution for vehicular applications. The antenna has been designed as a way to exploit the complete 3D volume inside a standard plastic cover with a shark-fin shape. The antenna is formed by a shorted monopole to cover the LTE700, GSM850 and GSM900 bands, and a drop monopole to operate in the DCS1800, PCS1900, WCDMA2100, WLAN2400, LTE2600, WiMAX2350, Wi-Fi, and C2C bands. Additionally, two solutions based on the use of a lumped element have been proposed for the shorted monopole.

Results show a good matching level in all cases, though the insertion of a resistor introduces additional losses that reduce the radiation efficiency. Considering the solution with capacitor, a return loss above 6 dB and a radiation efficiency above 70% are obtained at all the aforementioned operating bands. The next task will be the insertion of a filter in the input ports to mitigate the mutual coupling problem in the LTE700 and GSM bands.

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