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3D Automotive Antenna for 5G and V2X communications

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Abstract

In this paper a multiband automotive antenna for 5G and Vehicle to Everything (V2X) communications is presented. The antenna is designed to fit the commonly used sharkfin radome. To overcome the problem of the small volume available a 3D full metal radiating element is proposed. In order to validate the design a prototype is realized and measured. The proposed antenna achieves good matching conditions (Voltage Standing Wave Ratio (VSWR) < 2.5) trough the worldwide 5G frequency bands. Furthermore, the radiation characteristics fulfill the goal showing a Linear Average Gain (LAG) ranging between -5 dBi and 0 dBi.

1 Introduction

In recent years, the fast growing of mobile communications demand of throughput and connection reliability, led the allocation of new frequency bands for the mobile standard. In particular, the so-called 5G sub-6GHz band extends the previous Long Term Evolution (LTE) standard to frequencies up to 5GHz [1]. Four different frequency bands can be identified to cover the worldwide allocated frequencies. This bands are: 0.7 GHz – 0.96 GHz, 1.7 GHz - 2.7 GHz, 3.3 - 4.2 GHz and 4.4 GHz - 5 GHz. Furthermore, the automotive market nowadays requires a full connected vehicle as a mandatory feature. Thus, specific standards have been developed to allows direct vehicle communications (V2X). A dedicated band has been allocated for this purpose at 5.9GHz. Due to the need of an omnidirectional radiation pattern on the azimuthal plane, automotive commercial antennas are usually installed on the car roof top. In this placement, according to regulatory requirements, the antennas cannot be higher than 70mm in case of non-flexible elements [2]. The most commercial use radome for this type of antennas has a "sharkfin" shape [3], [4]. A sectional view of an example for this plastic case is illustrated in Figure 1. A sharkfin radome typically hosts more than one radiating element for different functions [5] e.g. Frequency Modulation (FM), Digital Audio Broadcasting (DAB), Global Navigation Satellite System (GNSS), mobile telephone. For the installation of these radiating elements the plastic case can be divided in three sections [6], [7] as it is shown in Figure 1. Section S#1 is the tallest and usually hosts the Radio (FM, DAB) antenna or the main telephone antenna. Sections S#2 and S#3 are usually used for GNSS or auxiliary antennas. In recent works [3], [5], radiating elements obtained through the folding of metal sheets are proposed to efficiently exploits the low space available. If the metal plate is sufficiently thick the radiating element is robust enough to be used in automotive environment. Furthermore, this type of technology allows to save costs respect to the commonly used Printed Circuit Board (PCB) fabrication technology [8], [9].

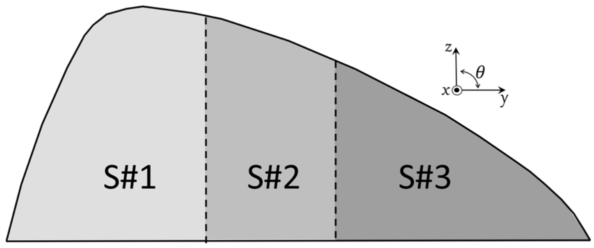
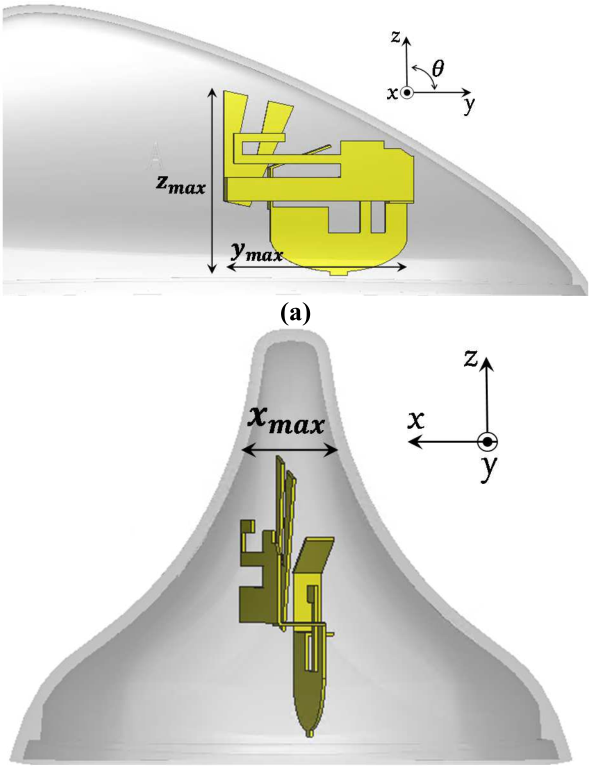


Figure 1: Sectional schematic view of a shark fin case. Three different sections of installation for the radiating elements are highlighted.

In this paper an antenna able to fit the section S#3 of a sharkfin module is designed. Since the available space is limited, in order to reach the lower frequencies, i.e. make the electrical length of the radiating element as long as possible, a 3D metal design is exploited.

2 Antenna Design and Simulation

The antenna has a monopole like structures with multiple branches that resonate at different frequencies. The longer branches are involved in the lower frequency radiation while the shorter ones are tuned to reach the desired matching in the whole frequency band. The feeding part has an elliptical shape to achieve a wideband behavior [9]. The simulated structure is illustrated in Figure 2. Simulations include also the dielectric cover that is made of plastic with ε_r = 2.6 and $tan\delta$ = 0.01 at 2GHz. The overall maximum antenna dimensions, as highlighted in Figure 2, are z_{max} = 43mm, y_{max} = 44mm and x_{max} = 15mm. Moreover, in order to takes into account the installation on the roof top, simulations are performed on a square ground plane with a 1m side. VSWR simulation results are illustrated with blue solid line in Figure 3. For this type of antennas, in the automotive market a VSWR < 3.5 is considered acceptable for the lowest band (i.e. 0.7GHz to 0.96 GHz) while a VSWR < 2.5 is necessary for the highest frequencies.



(a)

(b)

Figure 2: Simulation setup. (a) Side view. (b) Front view.

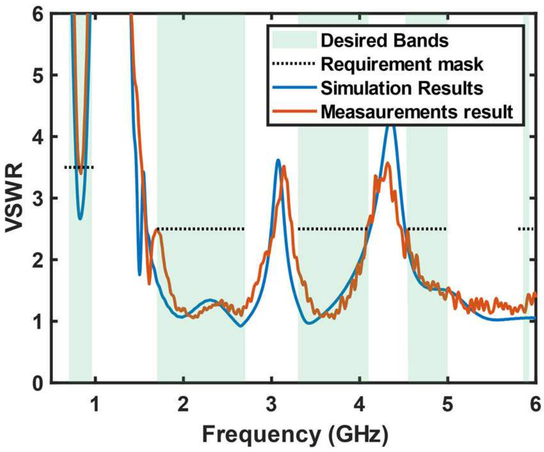


Figure 3: Simulated and measured VSWR results, highlighted areas represent the desired frequency bands of operation while black dotted lines are the matching requirement masks.

3 Antenna Prototype and Measurements

To keep the production costs as low as possible the proposed radiating element is designed to be feasible on a single metal sheet. In this way the antenna needs to be cut and folded only without any additional welding process. The prototype is realized through laser cut on a 0.5mm thick tin sheet. Left side of Figure 4 shows the unfolded metal sheet. The final folded antenna prototype is illustrated in the right side of Figure 4. Measurements are performed on a square metallic ground plane with 1m side. The feeding of the antenna is performed by welding the radiating element to the central conductor of an SMA connector connected to a Network Analyzer. VSWR measurements result are shown in Figure 3.

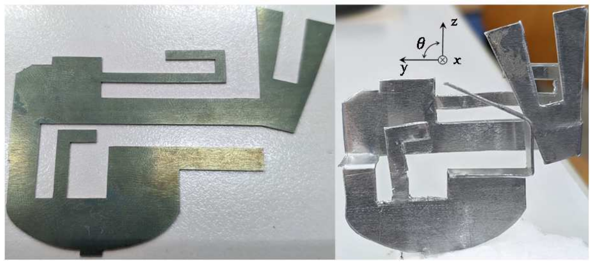


Figure 4: Realized prototype. Left side, unfolded antenna after the laser cut. Right side, final antenna prototype.

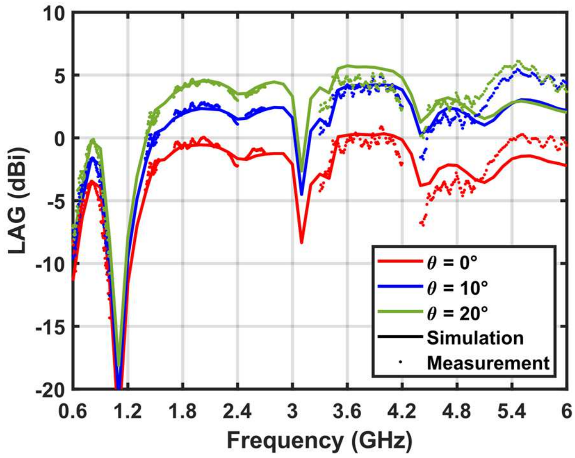


Figure 5: Linear Average Gain of the proposed antenna for three different θ cut. Solid lines represent the simulations while dots are the measurements.

Automotive antennas need to have an omnidirectional behavior on the azimuthal plane ($\theta = 0°$; xy plane). The omnidirectional radiation characteristics is confirmed from the radiation pattern plot Figure 6(a) where the measured pattern at $\theta = 0°$ plane is plotted for three different frequencies. In Figure 6(b) it is possible to observe the monopole-like radiation behavior of the antenna. Unlike what it is expected from a monopole on an infinite ground plane, since the radiation element is positioned on a finite ground plane, the maximum value of the realized gain does not appear at $\theta = 0°$. From Figure 6(a) it is clear that the maximum occurs between 30° and 10° depending on the operating frequency. In fact, for higher frequencies the metal plane appears bigger respect to the wavelength causing a more ideal ground plane behavior. A common figure of merit used to evaluate the radiation performances for automotive antennas is the Linear Average Gain (LAG). LAG is computed as the linear average of the antenna gain on the azimuthal cut. LAG is considered acceptable if greater than -5 dBi at $\theta = 0°$. LAGs measurement results are reported in Figure 5 in comparison with

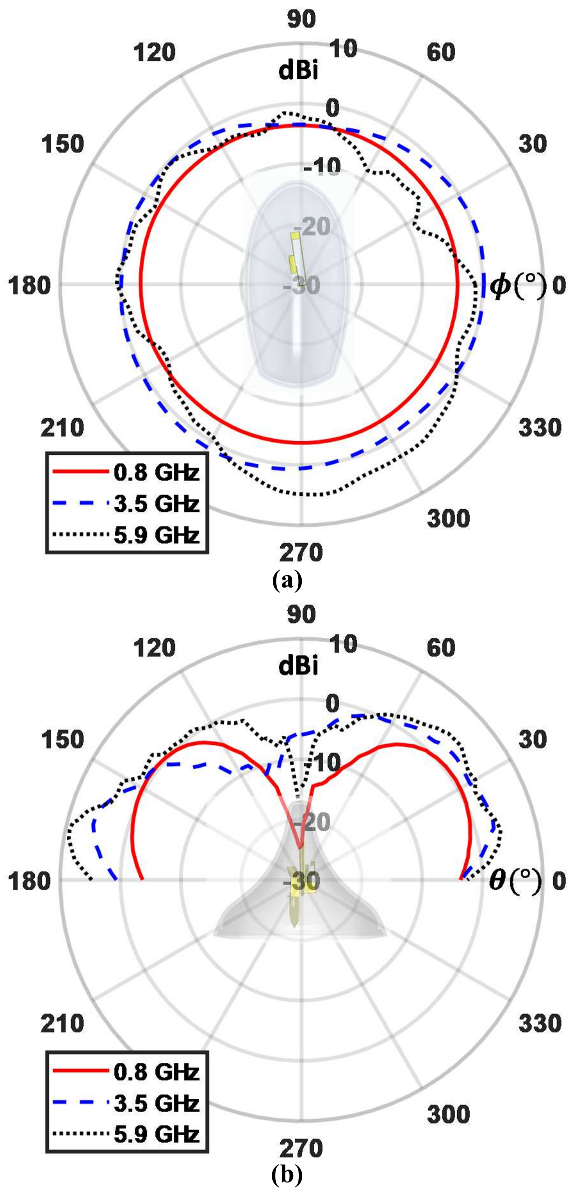


Figure 6: Measured radiation patterns at three different frequencies. (a) Azimuthal cut at $\theta = 0°$. (b) Elevation cut at $\phi = 0°$.

simulation results. The previously illustrated concept about the ground plane with non-infinite dimension is confirmed from the $\theta = 10°$ and $\theta = 20°$ LAGs plot in Figure 5. In these curves the gain is higher respect to $\theta = 0°$ with a stronger difference at the lower frequencies.

4 Conclusions

In this paper an automotive antenna for 5G and V2X communication is presented. The described antenna is designed to be produced with the 3D shaping of a metal sheet. Furthermore, the radiating element is suitable for low cost mass production because it does not need any welding process for the assembly. The design has been performed through numerical simulations. A prototype is realized and measured. Measurements results show a very good agreement with simulations. The antenna achieves a good matching condition without any additional matching network. The radiation pattern shows the required omnidirectional characteristic with a good gain. Finally, an explanation of the radiation pattern shape is provided.

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