A 3D-printed Prototype of a Miniaturized Top-Metalized Rectangular Dielectric Resonator Antenna

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***Abstract*—This paper presents a 3D-printed prototype of a novel top-metalized Dielectric Resonator Antenna (DRA). The inclusion of top metallization induces a modification in the boundary conditions, resulting in a frequency reduction in the fundamental mode of the DRA. Still, it does not degrade its radiation performance. The dielectric part is manufactured using fused deposition modeling (FDM) printing techniques and a commercially available Zirconia-loaded filament. The prototype presents a –10-dB bandwidth from 2.54 to 2.68 GHz with a minimum of –21 dB at 2.60 GHz. The radiation maxima occur in the top and bottom directions, with a simulated gain of 2.7 dBi. Thus, a low-cost and fast method to implement and manufacture a miniaturized DRA is presented.**

I. INTRODUCTION

The current trend in electronic devices emphasizes their size reduction, as they are often intended for portability, pocket-sized use, or integration into various objects such as clothing or medical systems. Consequently, the miniaturization of antennas has garnered the attention of researchers in recent decades [1]. Dielectric Resonator Antennas (DRAs) offer several advantages, including reduced size, high radiation efficiency, and multiple excitation possibilities [2]. However, conventional DRAs are usually made of ceramic materials. The usual manufacturing techniques for this type of material tend to be expensive and complex. On the other hand, additive manufacturing techniques, such as 3D printing by Fused Deposition Modelling (FDM), are quick and cheaper. For this reason, one of the current trends in antenna fabrication is the use of 3D-printing techniques [3]– [5]. However, up to the authors' knowledge, it is unusual to find antennas fabricated with low-cost commercial general-purpose ceramic-loaded filaments.

This paper introduces a novel top-metalized DR antenna. The proposed design significantly reduces size compared to a conventional DRA with the same permittivity. Moreover, the work's second goal is to use commercially available ceramic-loaded filaments for 3D printing without postprocessing techniques. A prototype of the proposed antenna is designed, simulated, and measured, achieving good results in terms of matching and radiation characteristics.

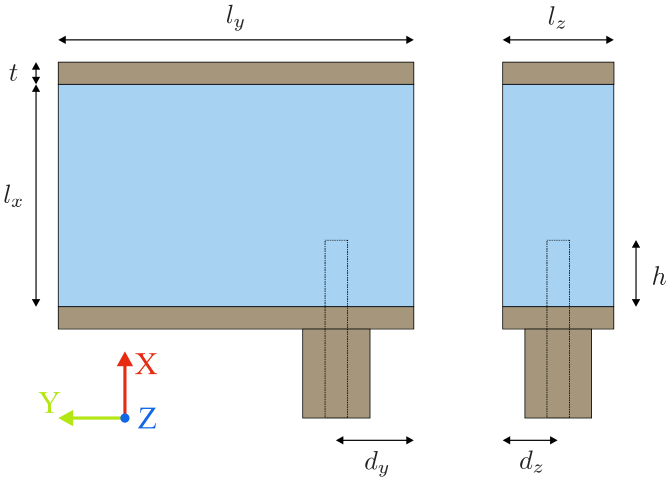

Fig. 1. Geometry of the proposed top-metalized DRA.

II. ANTENNA ANALYSIS

A. Antenna Geometry

The proposed antenna is shown in Fig. 1. It consists of a rectangular DR. The DR is metalized in the upper and lower parts. Thus, the lower metallization acts as a ground plane, but the upper metallization changes the boundary condition compared to a conventional rectangular DRA. The antenna is fed by a vertical probe made from a coaxial SMA connector. The inner pin of the coaxial connector is inserted into the dielectric material, acting as a vertical probe, while the outer connector is welded to the ground plane. The position of the vertical probe (d_y, d_z) and its height inside the resonator (h) are used to get a good matching.

B. Modal Analysis

In the conventional rectangular DRA without top-metalization, the ground plane is considered a Perfect Electric Conductor (PEC), and the rest of the walls are Perfect Magnetic Conductors (PMC) [6]. Therefore, the boundary conditions can be expressed as

$$E_z(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{1a}$$
$$E_y(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{1b}$$
$$H_x(0 \leq x \leq l_x, y=0, 0 \leq z \leq l_z) = 0, \tag{1c}$$
$$H_x(0 \leq x \leq l_x, y=l_y, 0 \leq z \leq l_z) = 0, \tag{1d}$$
$$H_y(x=l_x, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{1e}$$

and the vector potential F_z^+ is

$$F_z^+ = A_{mn} \cos(\beta_x x) \sin(\beta_y y) e^{-j\beta_z z}, \tag{2}$$

where

$$\beta_x = \frac{(2m+1)\pi}{2l_x}, \tag{3a}$$
$$\beta_y = \frac{n\pi}{l_y}. \tag{3b}$$

In this case, m can take values 0,1,2,3... whereas n can take values 1,2,3... The fundamental mode is TE_{01}, whose resonant frequency is calculated from

$$(f_c)_{mn} = \frac{c_0}{2\pi\sqrt{\varepsilon_r}}\sqrt{\beta_x^2 + \beta_y^2}. \tag{4}$$

On the other hand, in the proposed top-metalized rectangular DRA, the ground plane and the top metallization are considered PEC, whereas the other walls are still PMC. The boundary conditions are now

$$E_z(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{5a}$$
$$E_z(x=l_x, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{5b}$$
$$E_y(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{5c}$$
$$E_y(x=l_x, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{5d}$$
$$H_x(0 \leq x \leq l_x, y=0, 0 \leq z \leq l_z) = 0, \tag{5e}$$
$$H_x(0 \leq x \leq l_x, y=l_y, 0 \leq z \leq l_z) = 0. \tag{5f}$$

Although the vector potential F_z^+ and β_y are given by the same expressions (see Eq. (2)), the value of β_x is now

$$\beta_x = \frac{m\pi}{l_x}. \tag{6}$$

where m can take again values 0,1,2,3 ...

This difference is because, in this case, the parallel walls of the x-axis have the same boundary condition. In contrast, in the previous case, the boundary conditions of that axis were different. The fundamental mode of the proposed antenna is TE_{01}, but its resonant frequency computed from (4) is smaller than in the case of the conventional antenna due to the change in β_x. This leads to the desired miniaturization of the electrical size of the DRA.

III. ANTENNA DESIGN FOR WIFI APPLICATION

One of this work's main goals is to use low-cost 3D printing techniques to implement the dielectric part of the DRA. Thus, this part is implemented by FDM printing using a Zirconia-based commercial filament from Zetamix. This material is made of PLA with a 50% load of Zirconia ceramic. This general-purpose ceramic filament is usually postprocessed after 3D printing (e.g., sintering of the printed part). However, as one of the main objectives of this work is to produce easy-to-manufacture and low-cost antennas, no postprocessing techniques are considered. On the other hand, the filament is printed with 100% infill density and electromagnetically characterized under these conditions. For this reason, a Split Post Dielectric Resonator (SPDR) from QWED was used for measuring the relative permittivity, ϵ_r, and the dielectric $\tan\delta$ of the laminar dielectric Zirconia-based material. SPDR functions as a resonant cavity equipped with a slot designed for the insertion of samples. A brick of the material under study with dimensions of 60 x 100 x 2 mm (height x width x thickness) was 3D-printed to be tested on the SPDR. A VNA (Anritsu MS46122B) was connected to the cavity to extract the desired parameters. This test revealed a relative permittivity $\epsilon_r = 8.16$ and $\tan\delta = 0.0073$ for the material under study.

TABLE I
MAIN DIMENSIONS OF THE PROPOSED ANTENNA PROTOTYPE

Parameter	l_x	l_y	l_z	d_z	d_y	t	h
Value (mm)	17	25.25	11.50	5.75	5	0.035	8

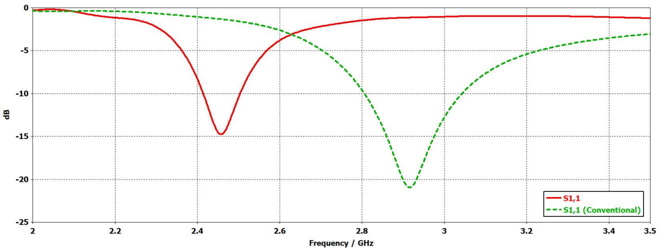

Fig. 2. Simulated reflection coefficient of the proposed (solid red) and conventional (dashed green) DRAs.

Considering the extracted dielectric parameters, a top-metallized rectangular DRA has been designed to work in the 2.45 GHz WiFi band. The proposed antenna dimensions are shown in Table I. In this design, the metallizations are considered copper with 35 μm thickness.

The conventional and the proposed DRAs have been simulated in CST Studio Suite by Simulia. Fig. 2 shows the reflection coefficient of both antennas. The proposed top-metalized DRA has a -10 dB bandwidth from 2.41 to 2.51 GHz, covering the desired WiFi band. The minimum of the reflection coefficient (-15 dB) is achieved at 2.46 GHz. On the other hand, the conventional antenna has the minimum $|s_{11}|$ value at 2.92 GHz. Thus, an important reduction in electrical size is achieved with the proposed design. Fig. 3 shows the simulated radiation pattern of the proposed antenna, where the maxima are located at the top and bottom directions (x-axis) while the minima are along the z-axis. The gain at 2.45 GHz is 2.7 dBi, and the radiation efficiency is 85.5%.

IV. EXPERIMENTAL RESULTS

A prototype of the proposed antenna has been manufactured. The dielectric part of the Zirconia/PLA material was printed with a TUMaker Pro Dual printer. The main printing parameters are shown in Table II. Both copper parts, namely the ground plane and the top metallization, were implemented with copper adhesive tape. After that, an SMA female panel

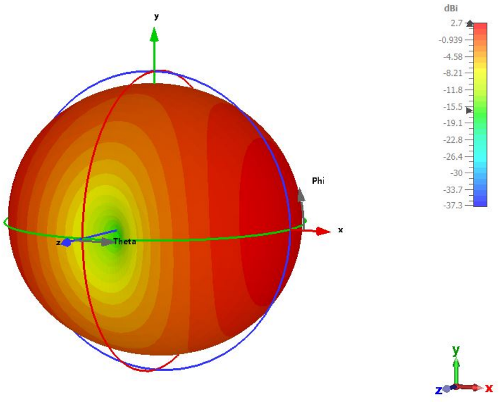

Fig. 3. Simulated radiation pattern of the proposed antenna.

TABLE II
MAIN PRINTING PARAMETERS

Printing Temperature	185°**C**
Bed Temperature	45°**C**
Infill	100%
Layer Height	0.2 mm
Printing Speed	30 mm/s
Retract Distance	0.4 mm
Cooling	ON
Nozzle Diameter	0.6 mm

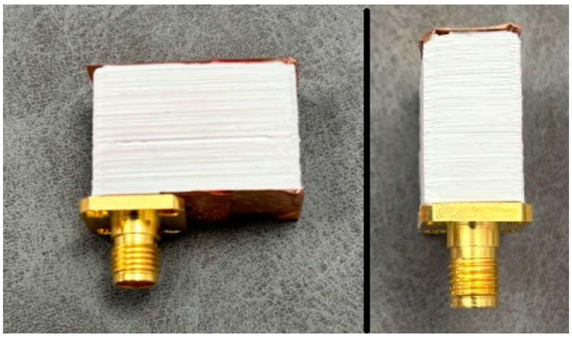

Fig. 4. Pictures of the manufactured prototype.

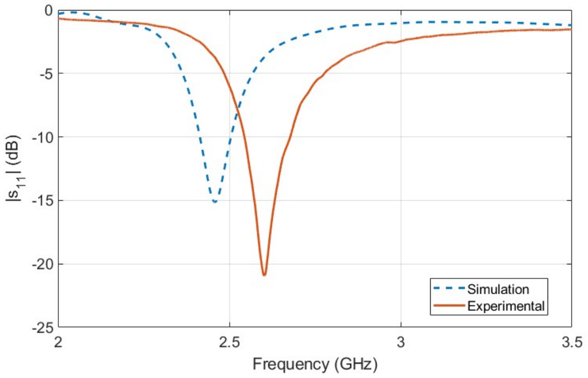

Fig. 5. Measured (red) and simulated (dashed blue) reflection coefficient of the proposed antenna.

mount connector was integrated with the antenna. The inner pin was inserted inside the printed dielectric part, and the panel was bonded to the ground plane. Fig. 4 shows the pictures of the manufactured prototype.

The reflection coefficient of the prototype was measured with a VNA (Anritsu MS46122B). Fig. 5 shows the measured reflection coefficient and the comparison with the simulated model. The prototype antenna has a measured -10 dB bandwidth from 2.54 to 2.68 GHz. The antenna is well matched with a minimum in the $|s_{11}|$ of -21 dB at 2.60 GHz. Although there is a good matching between the simulated and experimental results, a slight frequency shift $(< 6\%)$ is observed. This is mainly due to the tolerances of the FDM 3D-printing technique and the adhesive layer of the copper tape, which were not considered in the simulation. Further radiation measurements will be provided at the conference.

V. CONCLUSION

This work shows that including a top metallization in a rectangular DRA induces a modification in the boundary conditions, resulting in a frequency reduction in the fundamental mode of the antenna but not degrading its radiation performance. Moreover, it has been demonstrated that the dielectric part can be manufactured using FDM 3D-printing techniques and commercially available ceramic-loaded filaments. No postprocessing techniques are needed to obtain a dielectric part with useful electromagnetic properties. Thus, a low-cost and fast method to implement a miniaturized DRA has been developed. These results have been corroborated through the design and fabrication of a prototype. There is a good matching between the simulated and experimental results, except for a slight shift $(< \ 6\%)$ in the central frequency of operation. This will be solved in the future thanks to optimizing the simulation and fabrication processes.

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