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Lightweight, Low-Profile 3-Port Antenna Using Additive Manufacturing Process

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Abstract — A 3D-printed 3-port antenna for MIMO communications is proposed. Its design relies on the combination of a cavity and annular slot structure. Originality of this work relies not only on its compactness and the method to excite the different radiating modes while preserving isolation, but also on its light weight obtained thanks to additive manufacturing process. The fabricated 3-port antennas, working at 5 GHz exhibit a low mass (less than 10 grams) and show a good agreement between measured and simulated electrical results.

Keywords — 3D printing, additive manufacturing, technological process, MIMO, antenna.

I. INTRODUCTION

Compactness of radio-frequency front-ends is an essential feature in any communicating object (connected sensor, autonomous radio base station, ...) or detection systems (on-board radar,...). It remains a major research and innovation topic, addressing different application domains such as space, health, defense, industry, or telecommunications. Of course, expectations regarding compactness must not be detrimental to functional performances, following requirements in terms of electrical losses, selectivity, radiation and associated efficiency to name a few.

In particular, because antennas have physical limitations in in terms of size versus functionality, size constraints are particularly challenging for antennas. MIMO antennas, which are highly required for enhancing data bit rate and minimizing sensitivity to propagation effects, are all the more affected by these requirements.

The integration of such multi-access ports antennas remains a great challenge for miniaturized systems such as WIFI terminals or pico-cells base-stations. Low-profile structures are highly expected for compactness and to avert implementation issues. Furthermore, as such devices are targeted to address mass-markets, maintaining low costs yet high performance is paramount.

In this context, the use of novel technological processes based on 3D-printing appears promising, as it opens the way to innovative designs without prohibitive fabrication costs. Amongst the numerous available additive manufacturing processes, metalized plastic appears a good candidate to antenna applications as it exhibits light weight, yet satisfactory electrical performance.

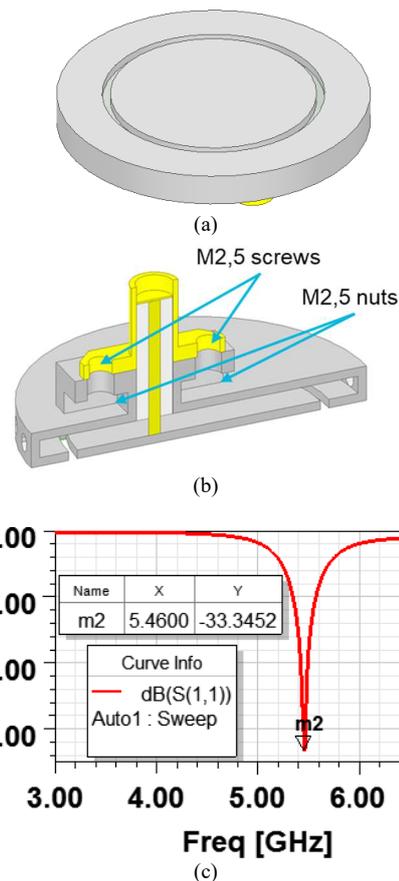


Fig. 1. Cavity backed ring slot antenna: (a) top view (gray=metal); (b) feeding; (c) reflection coefficient for the fundamental TM11 mode

This article presents the design and realization of a low-profile MIMO antenna taking benefit of metalized plastic obtained by additive manufacturing for a lightweight implementation.

II. A CONCEPT OF ANTENNA WITH MULTIPLE ACCESS PORTS

A topology of low-profile 3D antenna is proposed; which relies on the combination of cavity and annular slot structures.

A. Generic structure: a combination of a cavity and a circular radiating slot structure

The generic structure is depicted in Fig. 1-a. It consists of a circular cavity resonating at a given frequency, combined with a radiating slot placed on the upper side of the cavity, at its periphery.

By considering the fields distribution within the circular cavity, maximum and minimum E-Fields values appeared for the fundamental TE₁₁ modes, depending on the value of the circumference length with respect to the guided wavelength.

The antenna is coaxially fed with its excitation being ensured by a port located on the inner ground of the cavity. The feed consists of the vertical elongated central pin of a conventional coaxial cable or SMA connector, as shown in Fig. 1-b. The reflection coefficient of this single-mode ring slot antenna designed at 5.5 GHz is presented in Fig. 1-c.

B. Multi-mode antennas: an oversized radiating cavity with 3 independent access ports

In order to achieve a MIMO antenna, the 1.5λ circular resonance (TM₁₁ mode) around 5 GHz is exploited. It leads to a slightly oversized cavity with respect to the one presented herein before. However, this mode, thanks to its null-E-fields regions, allows for three-mode excitation through the introduction of ports in these particular locations. A $0.58 \times 0.52 \times 0.05 \lambda_0^3$ antenna has been designed (Fig. 2-a) with a 10% bandwidth (@10dB return loss). However, inter-ports coupling levels remain greater than 6 dB in this configuration. To minimize those parasitic couplings between access ports, vertical walls are added within the cavity (Fig. 2-b), without modifying external dimensions. Isolation between access ports can be reduced by adjusting the design dimensions, particularly the relative position and dimensions of such internal shielding walls. Simulated reflection and isolation S-parameters (obtained from HFSS™) are presented in Figs. 3 and 4.

III. 3D DESIGN USING ADDITIVE MANUFACTURING TECHNOLOGIES

Once the complete structure has been designed, fabrication is achieved thanks to the additive manufacturing process from ELLIPTIKA company [5]. It consists in 3D-printing the low-profile antenna by using a SLA (Stereo Lithography Apparatus) Form3+ [6] machine from FormLabs™ with High Temp Resin [7]. These pieces are then fully metallized through copper electroless plating. In order to allow for a good flow of the electroless copper-based solution over all surfaces of the structure without impacting the electrical functionality, through holes are judiciously dimensioned and placed all over the structure.

Such a technological process offers almost endless design possibilities and materials with good mechanical and thermal properties. Furthermore, the resulting pieces are lightweight yet electrically performant.

Regarding feeding, two solutions are proposed: the first one (Prototype 1) consists in assembling SMA connectors directly onto the antenna, while the second one (Prototype 2) is based on transitions between a planar substrate (Printed Circuit Board

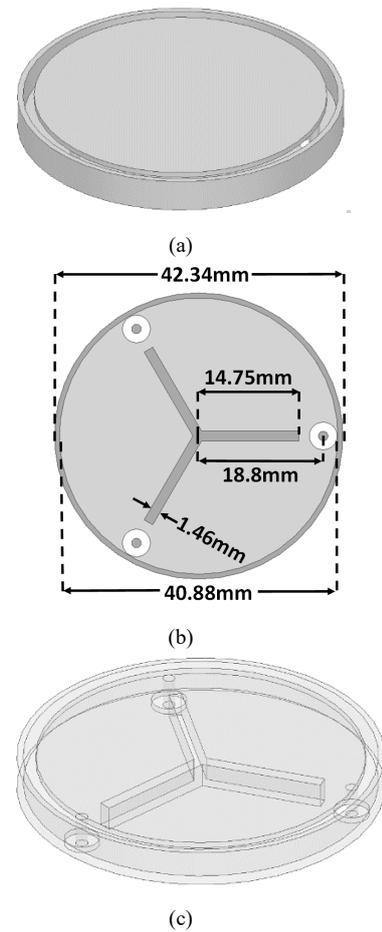


Fig. 2. Description of the structure based upon a circular resonant open-SIW Cavity with internal decoupling walls: (a) oversized cavity with peripheral slot; (b) introduction of internal walls for decoupling; (c) 3D view in transparency

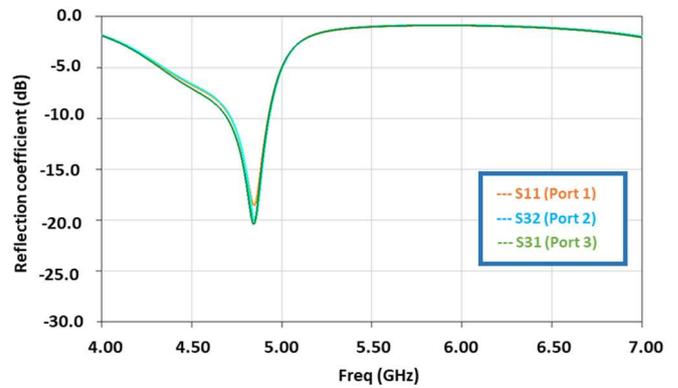


Fig. 3. Reflection coefficient of the multi-port cavity backed ring slot antenna

- PCB) and the antenna, as shown in Fig. 5. In this latter case, a conventional substrate is considered ($\epsilon_r = 4,3$) and the cavity is simply mounted and maintained to the PCB by screws to guarantee contacts. Electrical conductivity is insured thanks to conductive ink deposition.

Once the circuits are manufactured (Fig. 6 and 7), the next step is to proceed with measurements.

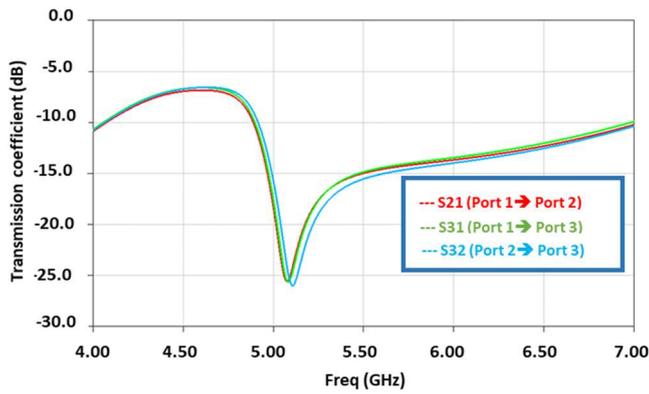


Fig. 4. Multi-ports cavity backed ring slot antenna: isolation performances between the different ports

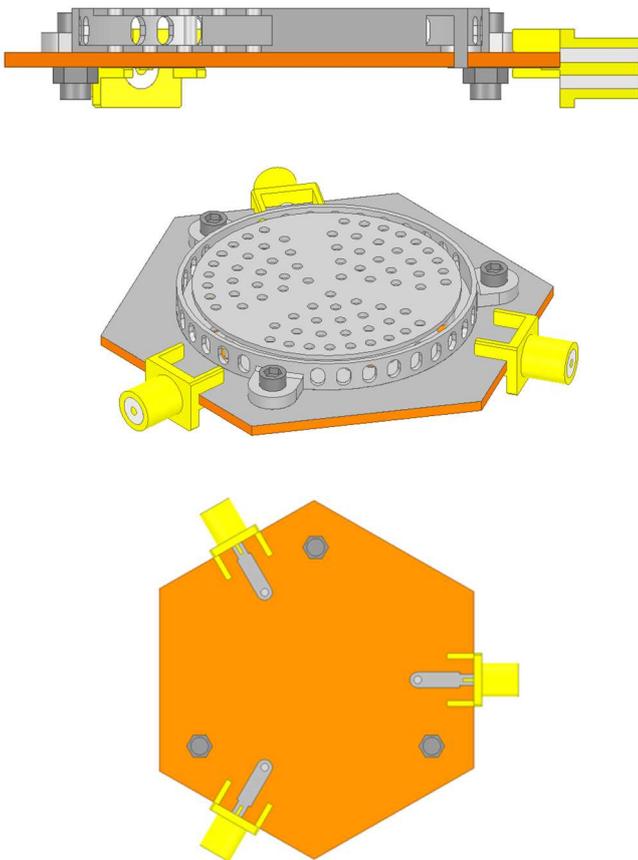


Fig. 5. Implementation of the additive manufactured structure with the PCB feeding part.

IV. MEASUREMENTS

Both prototypes were measured using a calibrated 2-ports vector network analyser. As the devices are 3-port antennas, return losses and isolations were measured with the third port terminated with a 50-ohms load, as presented in Fig. 8.

Measurement results are shown in Fig. 9 (Prototype 1 with direct accesses) and Fig. 10 (Prototype 2 with PCB line feeds).



Fig. 6. Prototype 1: 3-port antenna prototype with direct SMA connectors excitations.

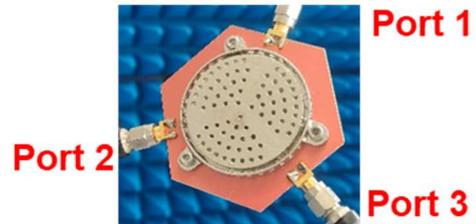


Fig. 7. Prototype 2: 3-port antenna prototype with PCB microstrip to vertical pin excitations.

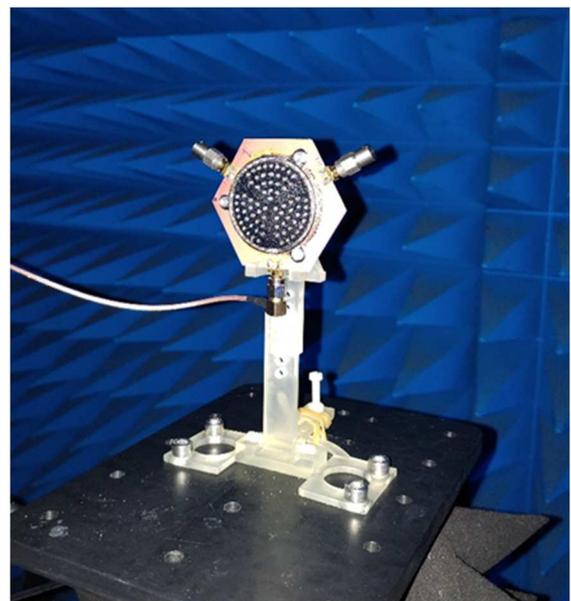
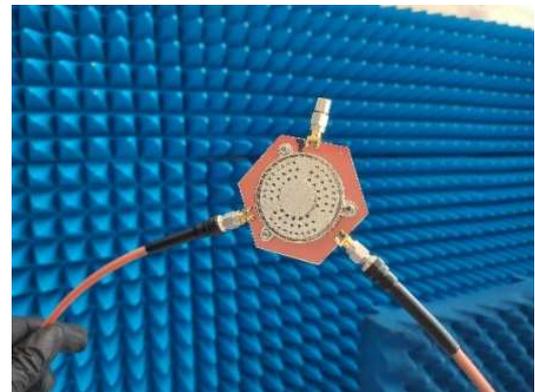


Fig. 8. Measurement set-up for the tests in the anechoic chamber

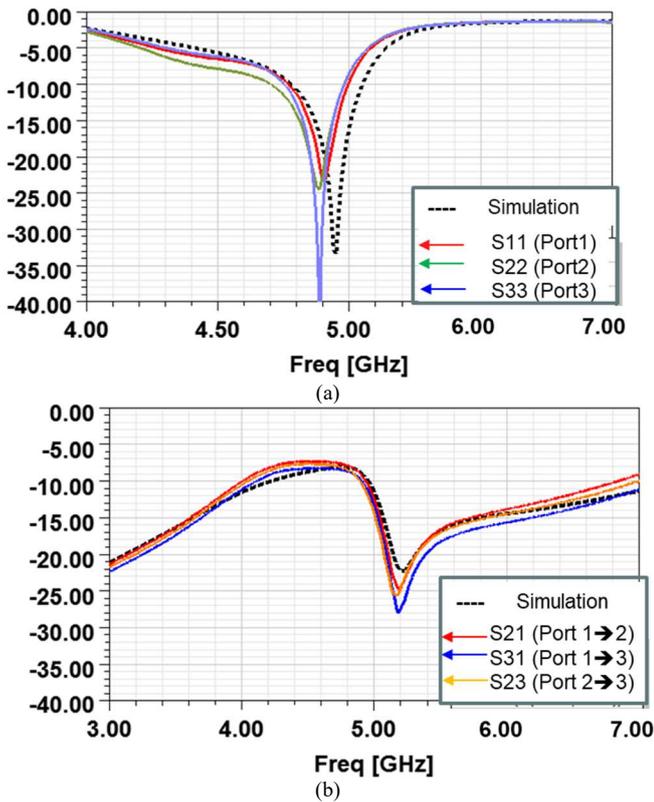


Fig. 9. Prototype 1: Measurements & Comparison with simulations: (a) reflection coefficient; (b) inter-port coupling

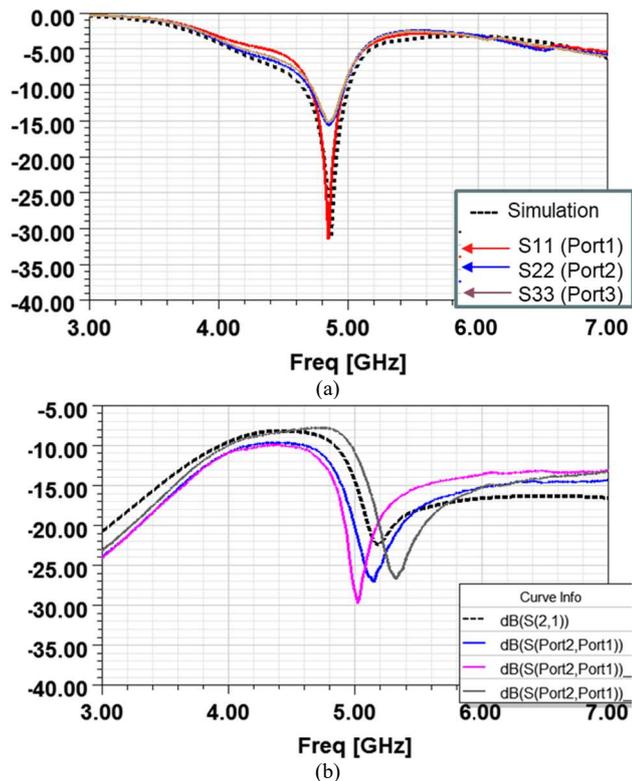


Fig. 10. Prototype 2: Measurements & Comparison with simulations: (a) reflection coefficient; (b) inter-port coupling

The corresponding simulations are overlaid on these graphs to allow for direct comparisons. A fairly good agreement between measurements and simulations is observed.

The measured prototypes achieve an overlapped impedance bandwidth of about 6% @-10dB. For prototype 1, the isolation is about than -10dB, which can still be optimized by considering a dimensional optimization of the internal decoupling walls of the cavity. This will conduct to a resynchronisation between peak isolation values and perfect matching conditions. For prototype 2, the isolation is lower than -10dB, thanks to an improved accordance between isolation and matching conditions.

Finally, the circuits were weighted and their mass is 8.6 grams for the prototype 1 and 7.7 for the prototype 2. These masses do not include neither connectors nor the PCB substrate (in the case of the Prototype 2).

V. CONCLUSION

In this paper, we have proposed a concept for designing low-profile multi-port antenna, dedicated to MIMO systems. The antenna is based upon a cylindrical shallow cavity with a circular radiating slot. The 3D capabilities of an additive manufacturing process were exploited to devise an approach to control coupling phenomena between the 3 co-integrated feeding ports.

Compact and lightweight prototypes have been implemented for experimental validation, with alternative solutions to incorporate excitations and inter-ports coupling structures. Experiments have been presented, with a satisfactory agreement with 3D EM simulations. We will also discuss during the conference about tuning capabilities to improve drastically isolation levels and bandwidth.

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