# A New ABS Conductive Material to develop Fully 3D-Printed Patch Antennas

Javier Jiménez[1,2], Joseba Irigoyen[1], Maite Aresti[1], Iñigo Ederra[2,3], Javier Bravo[1], Juan Carlos Iriarte[2,3]
[1] NAITEC: Technological Center of Automotive and Mechatronics, Pamplona, Spain, jjimenez@naitec.es
[2] Antenna Group. Department of Electrical, Electronic and Communication Engineering, Universidad Pública de Navarra, Pamplona, Spain.
[3] Institute of Smart Cities (ISC), Universidad Pública de Navarra, Pamplona, Spain

***Abstract*— Additive manufacturing technology is rapidly overcoming some of its initial limitations and, thus, creating a very useful engineering option for prototyping complex geometries for a wide range of electronic devices. Based on important advantages such as turn-around, reliability, material waste reduction, and low implementation costs, the technology is being continuously developed and improved. This paper presents a completely 3D-printed microstrip patch antenna to demonstrate the feasibility of a new conductive Acrylonitrile Butadiene Styrene (ABS) material in the fabrication of three-dimensional (3D) antennas using additive manufacturing method. The prototype of the antenna has been fabricated using Raise3D E2 printer, commercial ABS and a new ABS filament developed by Naitec for dielectric and conductive parts of the antenna, respectively. The fabricated antenna is compact and light. Preliminary prototypes and fabrication techniques are presented.**

***Index Terms— additive manufacturing, conductive ABS, 3D-printed antenna, microstrip patch antenna.***

## I. INTRODUCTION

Recent advances in additive manufacturing allow to reproduce structures with levels of precision and tolerances difficult to achieve using conventional techniques [1]. 3D printing enables the manufacturing of complex structures with high precision in a very short time, which has generated interest in the design and manufacture of RF circuits and components [2], being used around the world by researchers and engineers for applications such as the Internet of Things (IoT), health monitoring and flexible and portable consumer electronics. The reliability of printed microstrip transmission lines carried out with 3D technology has been already demonstrated in [3], as well as microstrip patch antennas [4] using the commercial conductor filament Electrifi [5] with PLA base. Complex geometries have also been studied like in [6] where the development of a fully 3D printed Yagi-Uda antenna has been demonstrated using same commercial conductor filament. Other solutions realized through 3D printing are based in techniques such as the combination of evaporation and electrodeposition of copper on a printed SIW antenna [7] or in printing of the structure on which silver paint process is subsequently applied [8]. Different studies found in the literature are based on the combination of 3D printed substrates in which 2D inkjet printing is added to create the metallic structures, and thus obtain the desired radiating elements [9][10].

The motivation for this work is to demonstrate the manufacturing capabilities and potential applicability of the new conductive ABS material developed by Naitec. The difference between this new material and the commercial one, Electrifi, is that the latter has a PLA base, with inferior mechanical properties and shows a higher moisture absorption. ABS, on the other hand, is a more robust, impact-resistant material with lower water absorption, commonly used in industry, especially in automotive, household appliances and other consumer goods.

In this work, the use of this new material for the fabrication of 3D electromagnetic structures is shown. The proposed prototype is based on a microstrip patch antenna structure fully fabricated with a 3D printer. The design frequency chosen is 8.5 GHz, within the X-band, since a simple Lucas-Nülle UniTrain-I trainer system is available in the laboratory, with which the radiation pattern can be easily measured.

## II. METHOD

### A. *Development of new conductive ABS material*

The new conductive material is made by mixing ABS pellets with silver-based micro and nano particles (see Fig. 1).

Fig. 1. Mixture of ABS pellets with silver-based micro and nanoparticles.

Firstly, the ABS pellets are dissolved in acetone. Silver-based micro and nano particles are added to the solution to provide the conductive properties until a trade-off between conductivity and mechanical resistance is reached, so as to obtain a homogeneous mixture.

The result of this process is spread on a flat surface, and the mixture is evaporated in an oven at 80º C to obtain a doped plastic plate.

The resulting material is cut into pieces and introduced into a filamenting machine model 3devo Precision 350 to obtain the filament with the desired diameter, 1.75 mm.

## B. Printing process

The RAISE3D E2 dual extruder FDM (Fused Deposition Modeling) printer has been used in the prototyping process of the different designs. Simultaneous printing of two filaments in same process is used thanks to its dual independent system with retractable heads. One extruder has been used to deposit the commercial 1.75 mm diameter dielectric filament BLACK ABS-E, while the other extruder is used to deposit the self-developed conductive filament with the same diameter.

Using both materials with identical polymeric base in the same designs solves line discontinuity problems, lack of adhesion between layers, delamination and warping, problems observed in different tests carried out by mixing PLA, ABS, Electrifi (commercial conductive PLA) and conductive ABS in the same design (see Fig. 2).

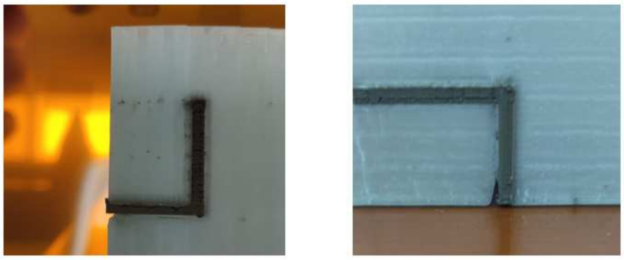


Fig. 2. Discontinuities, interlayer adhesion, delamination and warping observed problems in conductive ABS printed on PLA.

The extrusion temperature and speed, shrinkage and flow have been optimized to adjust the manufacturing process with the new material trying to optimize the material conductivity, as well as to control the amount of deposited material.



Fig. 3. RAISE3D E2 dual extruder FDM printer used for prototype fabrication.

## C. Design and simulation

A microstrip patch antenna has been designed using the commercial software CST Studio as a preliminary feasibility test of the new material use in RF applications. Dimensions have been optimized to obtain a resonant frequency response of the patch at 8.5 GHz. The complete stack of the microstrip patch antenna can be seen in Fig. 4, as well as its structure in Fig. 5.

Naitec's in-house developed conductive ABS has been used for the top and bottom layers, working as the antenna structure and ground plane, respectively. The ABS material embedded between the two conductive layers acts as a dielectric substrate for antenna operation, and is made of commercial ABS BLACK-E.

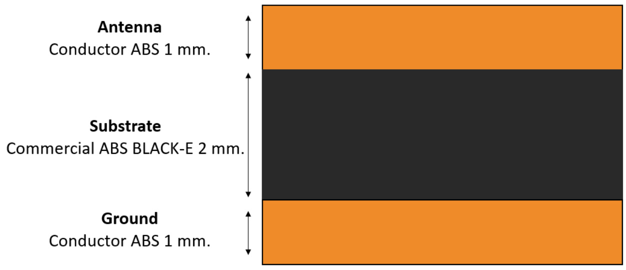




Fig. 4. Cross section of the proposed stack with dimensions in millimeters.

The 3.08 mm width input microstrip line has been designed to obtain a 50 Ohms characteristic impedance. An inset type feed has been chosen, which brings the feed point closer to the center of the radiating element, thus reducing the input impedance and improving the antenna matching [11].

In addition to the patch dimensions shown in Fig. 5, parameters describing the conductive and dielectric properties of the different materials were considered for the design, initially taking a dielectric constant of $3.18 \pm 0.06$ and loss constant $0.012 \pm 0.003$ for ABS [12]. A resistivity value of 0.015 Ohms·cm was measured for the new conductive ABS presented.

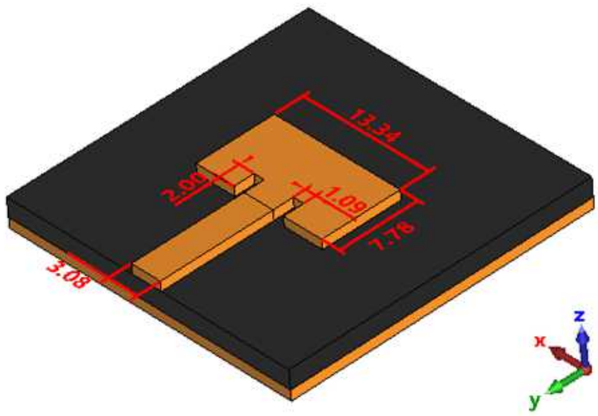




Fig. 5. Dimensions of the proposed patch antenna for 8.5 GHz operation (all dimensions given in mm).

As it can be seen in Fig. 6, a -38 dB value at 8.5 GHz for the return losses is obtained using conductive ABS material presenting a -10 dB bandwidth between 8.2 and 9.5 GHz.

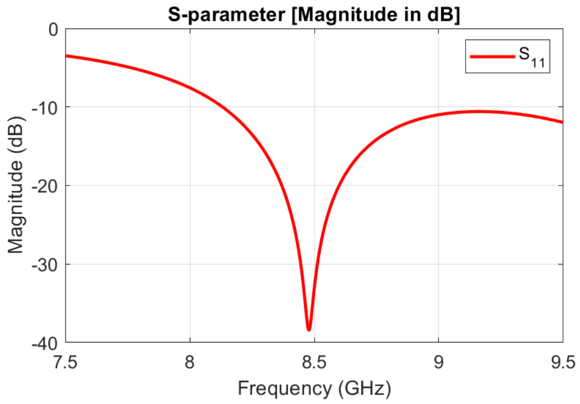



Fig. 6. Simulated return losses coefficient of the proposed antenna.

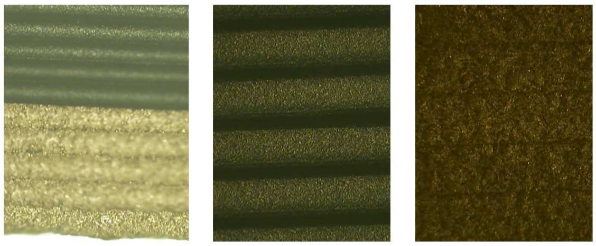
## III. FABRICATION AND MEASUREMENT

Several prototypes of the designed antenna were printed. As an example, a prototype is shown in Fig. 7.

A characterization of the printing precision of the RAISE3D E2 was performed using an optical microscope. Thanks to the images obtained (see Fig. 8) it has been possible to characterize the correct adhesion of the commercial ABS with the conductive ABS (Fig. 8 a), the homogeneity of the thickness of the commercial ABS layers (Fig. 8. b) and the homogeneity of the thickness of the conductive ABS layers (Fig. 8 c).

The different dimensions of the antenna have been adjusted to reduce the size discrepancies between the printed antennas and the simulated ones, obtaining the values presented in Table I.

Fig. 7. 3D printed prototype.



a) b) c)

Fig. 8. Deposition of the different layers of commercial ABS (black) and conductive ABS (gold colour). a) commercial ABS + conductive ABS, b) commercial ABS detail and c) conductive ABS from above. Images obtained under the microscope.

TABLE I. SIMULATED AND MEASURED DIMENSIONS

| Parameter | Simulated (mm) | Measured (mm) |
|---|---|---|
| patch_x | 13.34 | 13.39 |
| patch_y | 7.78 | 7.91 |
| inset_x | 1.09 | 0.99 |
| inset_y | 2 | 2.11 |
| line_w | 3.08 | 3.07 |
| patch_h | 1 | 0.99 |
| sustrate_h | 2 | 1.87 |
| ground_h | 1 | 1 |

Different connectorization techniques have been used, such as soldering with tin, conductive adhesives (LOCTITE® EDAG 5915 E&C) or even silver paint that favors the adhesion of the solder to the conductive ABS (see Fig. 9). The best results in terms of fixation and electrical continuity have been obtained through the conductive epoxy LOCTITE 5915.

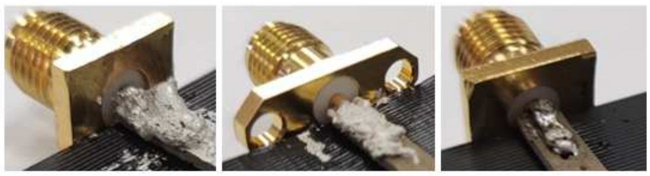


Fig. 9. Connectorization through conductive glues and tinning of the different prototypes.

Electrodeposition has also been tested to improve the conductivity of the material, trying to bring its properties closer to copper based conventional devices (see Fig. 10).

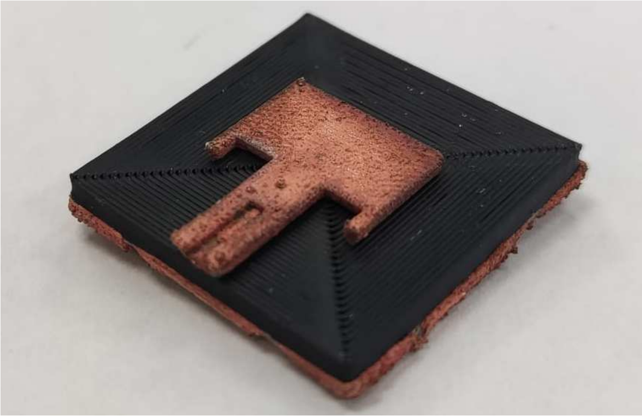


Fig. 10. Copper electrodeposition on conductive ABS material to improve its conductivity.

The simulated and measured $S_{11}$ parameters of the antenna fabricated without electroplating and with the connector fixed by silver glue are shown in Fig. 11. The return losses parameter of the measured antenna presents a working bandwidth between 7.75 GHz and 9.5 GHz.

Differences between simulation and measurements are due to manufacturing and connectorization limitations, as well as mismatches in the values used in the simulation for the printed materials. The antenna simulation is currently being optimized by adjusting the materials characteristics and several manufactured prototypes are being characterized.

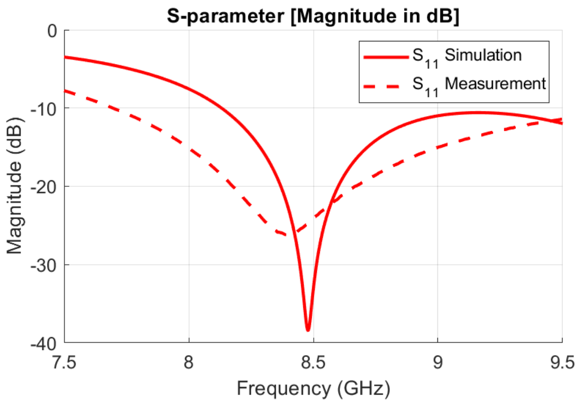



Fig. 11. Simulated and measured return losses of the proposed antenna through PNA E8361C.

Measurements of different prototypes will be shown at the congress together with their radiation pattern diagrams.

## IV. CONCLUSIONS

This paper shows the study carried out on the feasibility of applying a new conductive ABS material developed by Naitec in the design of RF devices through 3D printing. The design and fabrication of a patch antenna using this material has been carried out. The device has a compact, easy-to-print and lightweight structure. The 3D fabrication process has been optimized, as well as the connectorization of the antenna, measurements are currently being carried out and the parameters to be used in the design are being adjusted to minimize the differences obtained between measurements and simulations.

The results obtained show that conductive ABS can be a good candidate for the fabrication of fully 3D printed electromagnetic structures.

## ACKNOWLEDGMENT

The authors would like to thank Navarre Government for the funding provided by “Ayudas para la contratación de doctorandos y doctorandas, Doctorados industriales 2021”, Resolución 87E/2021 and Project AMELEC, PC017-018 AMELEC - Advanced Manufacturing of Materials, as well as the Spanish Research Agency, for funding the Project PID2019-109984-RB-43/AEI/10.130 39/501100011033.

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