3D PRINTING OF DOUBLE KA BAND HELICAL MICRO-ANTENNAS

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ABSTRACT

To reduce the extremely high launching costs related to the mass and volume of telecommunication and scientific satellites, their components must be more efficient, more compact and lighter. Here, we present a rapid and low-cost fabrication technique to build a small array of antennas operating in the Ka band (20-30GHz). The fabrication technique consists of the robotic deposition of an ink material extruded through a micronozzle under constant pressure. Two variations of the fabrication method were investigated: freeform printing and conformal printing on a rotating mandrel of small helices using a fast drying thermoplastic material. The non-conductive polymer helices obtained by the 3D printing methods where metallized and assembled on a printed circuit board (PCB) to create a small fully operational antenna. The conformal printing was shown to be a rapid and efficient method to build micro-antennas with good geometrical precision (fabrication tolerance of ~1-3%). However, the subsequent metallizing step degraded the geometry due to the heat generated and the low glass transition temperature of the thermoplastic used (60°C). Despite the improvements needed for the metallic deposition, the prototypes manufactured demonstrate the potential of this new approach to build a high frequency antenna at low cost. These antennas featuring a small volume and weight footprint provide new opportunities to modern satellites, ground and mobile communication stations.

Keywords: helical antenna, Ka-band, 3D printing, microfabrication, telecommunications

1 INTRODUCTION

Helical antennas operating in axial mode have been used for a few decades as circularly polarized elements in low frequency bands due to their high directivity. However, they had limited application in higher frequency bands (e.g., Ka, V and W) mainly due to manufacturability issues. Satellite helical antennas are usually built using time-consuming and costly traditional fabrication methods such as the machining from a large metallic cylindrical rod. Another method, the filament winding of metallic wires, was demonstrated impracticable for satellite antenna applications due to the creation of surficial micro cracks.

The flexible direct-write method has been previously used in various technological applications such as the fabrication of conformal micro-antennas [1], microvascular networks [2], and nanocomposite strain sensors [3]. The applicability of this microfabrication technique to build small Ka band antennas was studied. The mass and volumes being the principal constraint for satellites and new ground antenna applications, the elements of the antenna were designed to be highly directive and able to both receive and transmit a signal in different frequency bands.

2 DESIGN OF MICRO-ANTENNAS

Specific requirements were taken into consideration for the optimization of the antenna element geometry. These specifications are representative of modern telecommunications; uplink frequencies range from 30.0 to 31.0GHz and downlink from 20.2 to 21.2GHz. A right hand circular polarization (RHCP) is used for both links and an axial ratio inferior to 2dB is wanted. With these parameters, a single element (one helix) geometry was optimized with HFSS modeling software (Ansys Corp.). This optimization took into consideration the gain of the helix in both frequency ranges and the manufacturability of the antenna.

The dimensions of the designed antenna are listed in Table 1. The designed antenna prototypes have constant wire and helix diameters and 8 turns for a total height of 23.2mm. These helical antennas also feature a variable pitch for double band functionality [4], allowing them to both receive and transmit a signal in the different frequency ranges researched.

Parameter	Dimension (mm)
Helix diameter	3.4
Filament diameter	0.2
Total height	23.2
Height of pitch #1	1.6
Height of pitch #2	1.8
Height of pitch #3	2.6
Height of pitch #4	3.0
Height of pitch #5	3.4
Height of pitch #6	3.5
Height of pitch #7	3.6
Height of pitch #8	3.7

Table 1: Geometry of the helical antennas

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3 FABRICATION

For the freeform printing and conformal printing on a rotating mandrel versions of the direct write fabrication technique, a 3-axis deposition robot (I&J2200N-4, I&J Fisnar) and an air-operated dispenser (Ultra 2400 Series combined to HP7X, EFD Nordson) were used to control the position, the speed of deposition and the flow rate of the extruded filament. The ink material extruded through the micronozzle was a fast-drying thermoplastic solution composed of dichloromethane (DCM) as solvent and ~30wt% of polylactic acid (PLA). The DCM, being highly volatile, quickly evaporates after the material is extruded from the syringe increasing gradually the polymer concentration and thus the rigidity of the filament. This rigidity gradient enables the creation of self-supporting curved shape under ambient conditions. [5]

3.1 3D freeform printing

The first technique investigated to build the 3D structure consisted in letting the PLA simply solidify by evaporation of the DCM immediately after the extrusion from the syringe without any support. The fabrication of self-supporting filament required a very slow deposition speed (~0.1-0.2mm/s) in order to reach a sufficient rigidity. The total deposition time was ~11 minutes for a complete helix. PLA being non-conductive, the helices were subsequently coated by a ~50µm copper layer using sputtering and an electrolytic bath. Figure 1 shows the printing process and microscopic images of a representative prototype antenna.

3.2 3D conformal printing on rotating mandrel

The second method tested consisted of the robotic deposition of a PLA-DCM ink filament on a rotating cylindrical mandrel controlled by nano-stage positioning motor (Pollux Drive, Micos), in order to create the helical geometry. The motor rotational speed varies over the fabrication time to obtain the desired variable pitch lengths. The total deposition time of one helical structure was ~120sec. After the filament extrusion and its complete drying (dry time is ~12 hours for a 0.2mm filament diameter), the PLA helices were released from the mandrel and copper coated using the same metallizing technique as described in Section 3.1. Figure 2 shows this second variation of our fabrication technique.

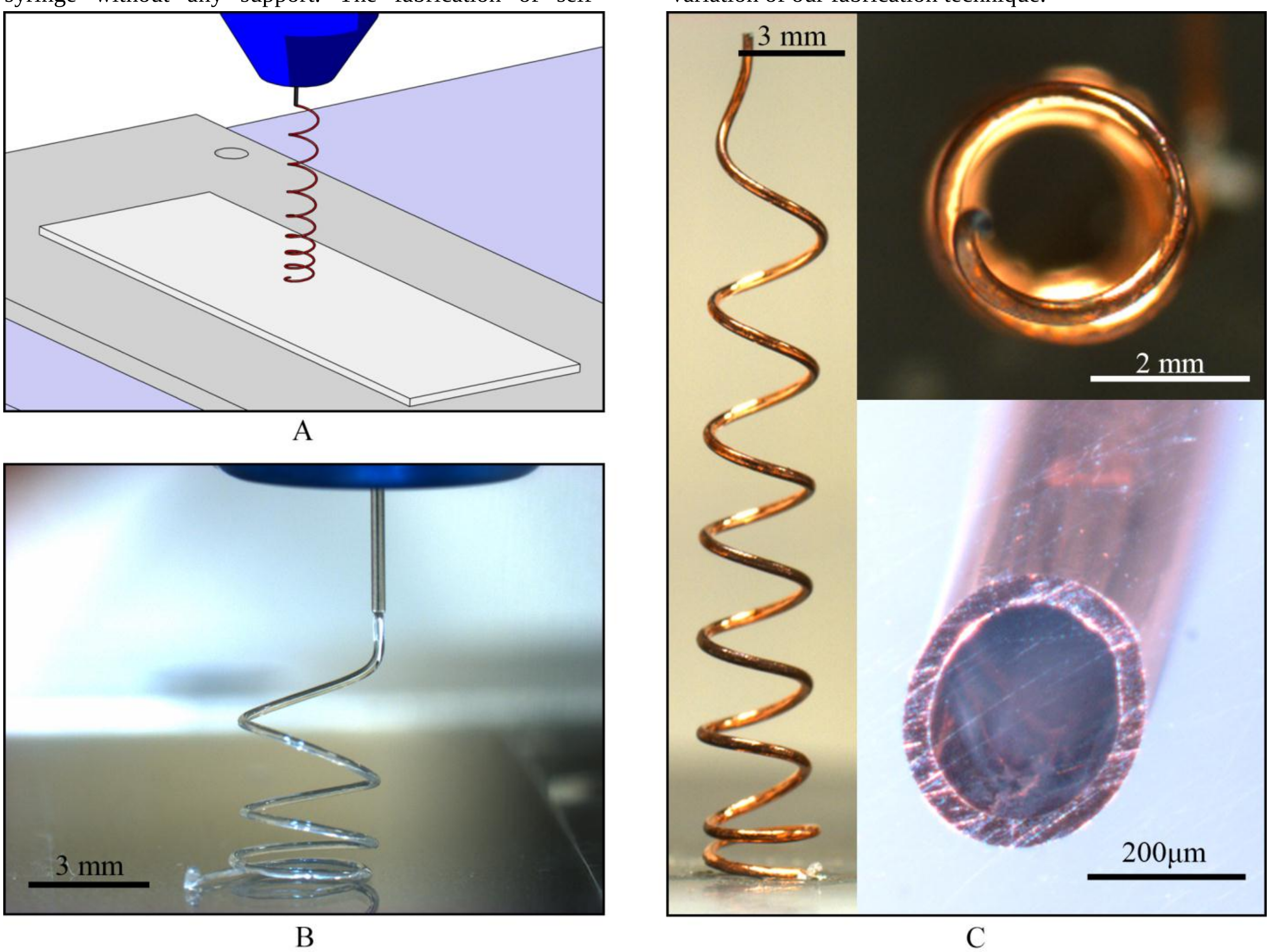

Figure 1: Fabrication of the helical antenna using the freeform printing technique. A) Schematic, and B) Optical image of the setup used for the freeform 3D printing of antennas. C) Optical side, top and cross-sectional view images of the fabricated copper coated helical antenna.

3.3 Coating and assembly of helical antenna

The metallization of the helices without deforming their geometry was difficult due to the heat generated during the process and the low glass transition temperature of the PLA (~60°C). In some cases, the helices showed important geometrical deformation after the flash procedure. The hybrid polymer-metallic helices presenting the smallest geometrical deformations were then connected at their base on a PCB (substrate Duroid 5880, Rogers Corp.) with a highly conductive paste (Silver conductive grease CW7100, CircuitWorks) in order to achieve a fully functional small antenna.

4 RESULTS AND DISCUSSION

Two types of analyses have been performed on the helices: (1) geometrical comparison with the optimized numerical model (i.e., HFSS) and (2) radio-frequency measurements.

4.1 Comparison of fabrication methods

The freeform printing technique offers a high flexibility and freedom but the prototypes manufactured featured moderate geometric tolerances on the pitch dimensions. The maximum error was observed at the first pitch which was deformed under the weight of the subsequent spires during the printing process. This Ka band antenna required total unsupported height of 23.3mm which approaches the upper limits of this microfabrication technique using this PLA solution.

The conformal printing method using the rotating mandrel provided the best geometrical results for PLA helices: errors of ~1-3% versus ~10-15% for the freeform method. After being removed from their supporting mandrel, conformal printed helices were measured and photographed with an optical microscope in order to determine the fabrication tolerances. Figure 3 shows a side by side comparison of an optical image of a non-coated helix along with the optimized model drawn with HFSS. The only geometrical aspect of the helix slightly affected by the mandrel support is the circularity of the filament (see Fig. 2C). The conformal printing method enabled a faster fabrication with much better geometric tolerances but with an increased complexity, a higher number of fabrication steps and less flexibility on the shape of the helices.

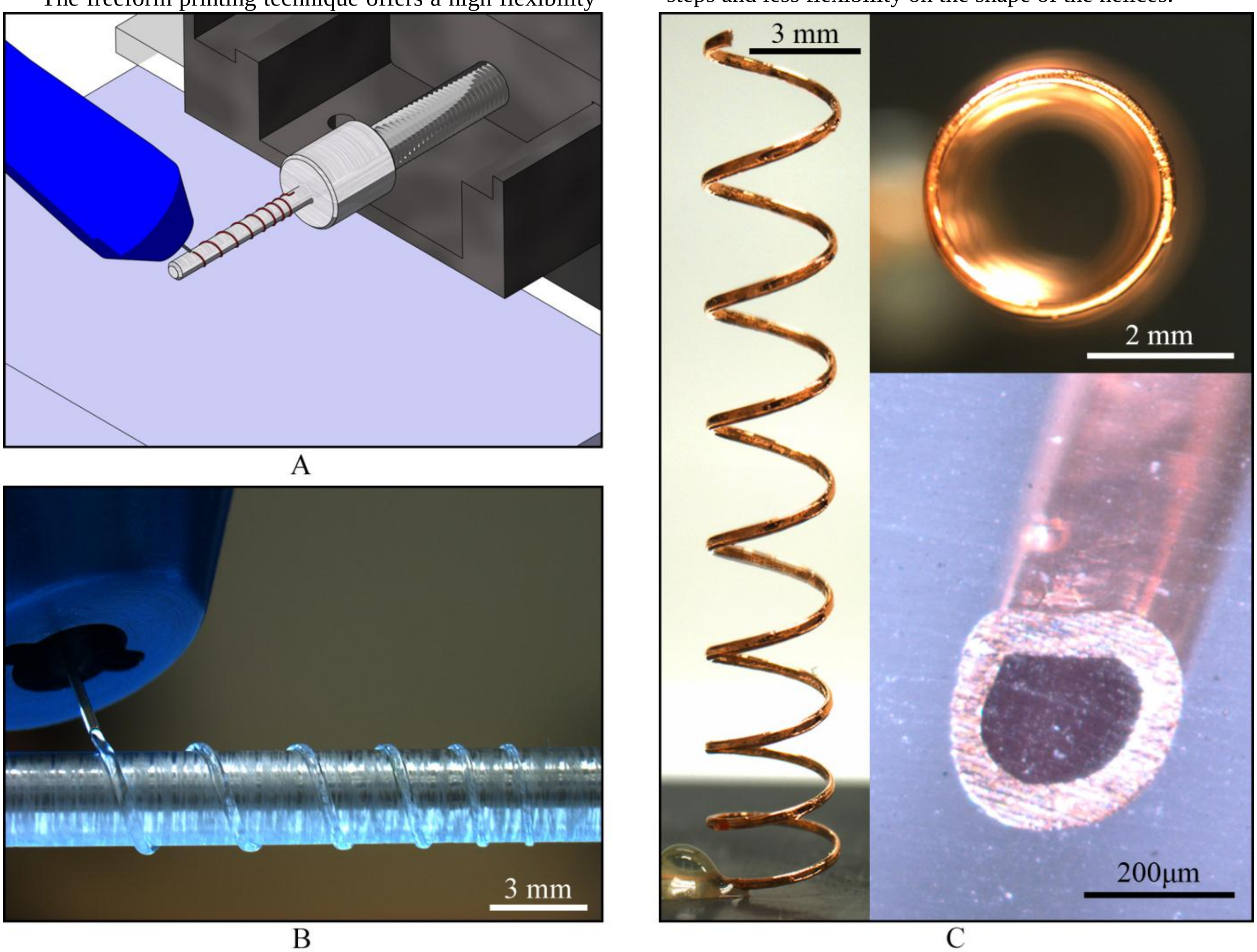

Figure 2: Fabrication of the helical antenna using the direct-write method and rotating mandrel as building support. A) Schematic, and B) Optical image of the setup used for the printing onto the rotating mandrel. C) Optical side, top and cross-sectional view images of the fabricated copper coated helical antenna.

The excellent tolerances obtained with the conformal printing technique were however deteriorated during the coating procedure. Deformations were mainly observed in the first pitches which tended to shrink and in the verticality of the helices. These differences are potentially caused by the copper sputtering which exposes the PLA helices to temperatures close to their glass transition temperature and thus might induce permanent plastic deformation.

4.2 Electrical analysis

The antennas were tested in an anechoic chamber in order to measure their gain in the two frequency ranges, axial ratio and impedance adaptation. For all electrical parameters measured, the results are inferior (5 to 25% differences) to what was predicted using theoretical models.

Numerous factors might have caused these differences: (1) the altered helix geometry due to the coating process, and (2) the installation of the helices on the PCB using conductive grease instead of soldering. Other contributors to the deterioration of the electrical parameters are the losses induced between the antenna and the measuring instruments by the connectors.

5 CONCLUSIONS AND FUTURE WORKS

We have investigated two innovative approaches to rapidly fabricate customized and very directive double band small antennas. The conformal printing on a rotating mandrel method enabled geometrical fabrication tolerances as low as 1 to 3%. Despite the need for a more efficient coating and assembly techniques, our 3D printing method was fast, flexible and precise. Our manufacturing approach shows high potential to rapidly and cheaply build high-frequency compact antennas.

A different option to improve the geometrical and electrical results of the conformal printed antennas would be to eliminate the coating process. This could be achieved by using a conductive material as ink for the 3D printing. A conductive filament would also offer the possibility to build the helices on sacrificial rotating mandrels and subsequently fix them, along with their mandrels, on the PCB. The mandrel would thus act as a support during fabrication and during the lifetime of the helix. Research to design a conductive material suitable for 3D printing is currently undergoing at LM^2.

A complete antenna, powerful enough to communicate with a satellite placed in geostationary orbit would need approximately a thousand of the small helices presented in this article. Among the future works of this project is the development of an automated process to build the helices and fix them in place on the circuit before this innovative antenna can be commercially produced.

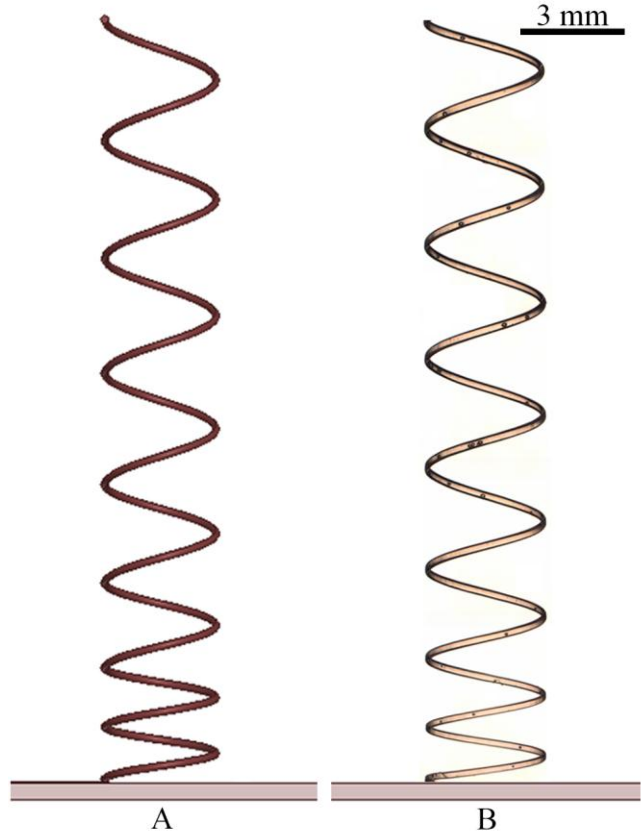

Figure 3: A) Schematic of the designed helical geometry drawn using HFSS modeling software. B) Optical image of PLA helical structure built using direct-write and rotating mandrel method (a PCB support was drawn at the base of the helix for visual comparison).

6 AKNOWLEDGMENTS

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