Fabrication and Evaluation of Carbon-based Flexible RFID Tags on 3D-printed substrates

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***Abstract*—In this paper, we present flexible passive UHF RFID tag antennas fabricated by 3D dispensing and brush-painting on 3D-printed bendable substrates. A carbon-based stretchable conductor is utilized in antenna fabrication. Our measurement results confirm that tags fabricated using both manufacturing methods achieve great performance: The attainable read ranges of the 3D-dispensed and brush-painted tags are 2.4 and 3.1 meters, respectively. Thus, the established carbon-based tag antennas do not perform in the same high level as common metal-based tag antennas but these preliminary results are very promising, considering the current trend towards more environmentally friendly and cost-effective materials in electronics.**

***Index Terms* — 3D printing, antennas, passive UHF RFID, stretchable conductor.**

1. Introduction

The simple structure and low cost of passive ultra-high frequency (UHF) radio-frequency identification (RFID) tags has made them popular wireless platforms to versatile applications [1][2]. The current trend in all electronics materials is towards more environmentally friendly ingredients, at the same time demanding more cost-efficient material solutions. Thus, there is also a strong need for new type of antenna materials. Carbon-based materials are one extremely interesting solution to answer these challenges.

Recently, 3D printing with flexible thermoplastic filaments has gained a lot of attention [3][4]. 3D-printing enables customized substrate structures and modification of electrical and mechanical properties, which makes 3D-printed substrates great candidates for radio-frequency electronics and antennas [3]. 3D-printed Ninjaflex (a flexible thermoplastic filament) substrates are also used in this study, where antennas for passive UHF RFID tags are created from a carbon-based stretchable ink. These eco-friendly and cost-effective antennas are 3D dispensed and brush-painted into bendable 3D-printed substrates. The wireless performance of the fabricated flexible carbon-based RFID tags is evaluated and the results are compared to recently published results of tags with silver-based flexible antennas.

2. Tag Fabrication

The used 3D-printed Ninjaflex substrate has two printing layers, each having a thickness of 1.5 mm and an infill of 50 %. This makes the substrate height (thickness) 3 mm. A stretchable carbon conductor paste (DuPont PE671) is used as antenna material.

The 3D-dispensed antennas are fabricated with nScrypt tabletop series 3D direct-write dispensing system, and the main manufacturing parameters are defined in Table I. The brush-painting is done by hand, using a brush to paint the antennas on the 3D-printed substrates. Altogether 3 antenna samples are fabricated by both methods to also evaluate the reproducibility. After printing and brushing, the carbon-based flexible antennas are cured at 120 °C for 30 minutes.

NXP UCODE G2iL series RFID IC (integrated circuit), with a wake-up power of −18 dBm (15.8 µW), is utilized in this study to fabricate the RFID tags. The ICs are attached to the antennas with silver epoxy (Circuit Works CW2400). Samples of manufactured tags with the dimensions are shown in Fig. 1.

TABLE I
Main 3D Dispensing Parameters

3D printing parameters	
Material feed pressure	16.9 Psi
Printing spacing	125 microns
Printing angle	0°
Inner diameter of tip	125 microns

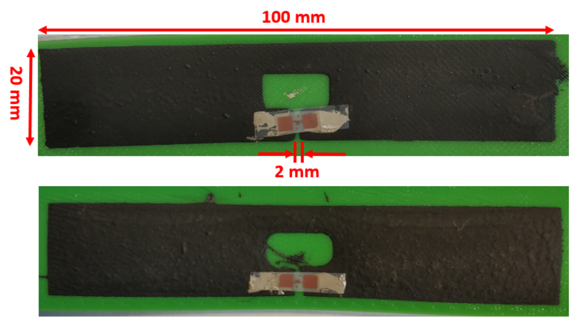

Fig. 1. 3D-dispensed (top) and brush-painted (bottom) tags.

3. Measurements and Results

The wireless performance of these tags is evaluated in an anechoic chamber by using a Voyantic Tagformance RFID measurement system. The system is calibrated firstly using a reference tag to characterize the properties of the wireless channel from the reader antenna to the tag. The theoretical read range between the tag and the reader antenna is based on the measured path loss and threshold power, as given in (1),

$$d_{Tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{P_{TS}\,L_{fwd}}} \qquad (1)$$

where EIRP is the emission limit of an RFID reader, given as equivalent isotropic radiated power. In this study, EIRP = 3.28 W, which is the emission limit in European countries. λ is the wavelength transmitted from the reader antenna, PTS and Lfwd are the measured threshold power and forward losses, correspondingly.

Fig. 2 shows microscopic pictures of the cross-section of the fabricated tags. The conductive paste thickness of the 3D-dispensed tag varies from 94 to 100.8 µm, and the average value of the thickness is 96.2 µm. The thickness of the brush-painted tag varies from 206.1 to 237.3 µm, and the average value is 222.6 µm. Thus, the brush-painted antennas are significantly thicker than the 3D-dispensed ones.

Fig. 3 shows the attainable read ranges of both types of fabricated tags. As can be seen, the peak read ranges of the 3D-dispensed and brush-painted tags are 2.4 meters and 3.1 meters, respectively. The thicker conductor layers of the brush-painted tags results in slightly longer read ranges. Both types of tags are readable from distances more than 2 meters throughout the global UHF RFID band, which is a very promising result.

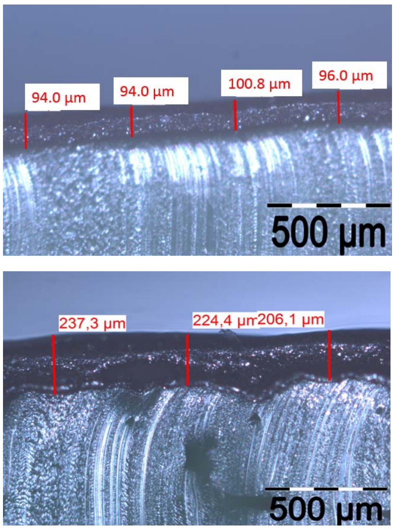

Fig. 2. Cross-section of 3D-dispensed tag (top) and brush-painted tag (bottom).

In a previously reported work [4], the same antenna geometry was fabricated by 3D dispensing, using a stretchable silver conductor, on similar 3D-printed substrates. The peak read ranges of those tags were 10 meters. Thus, the carbon-based stretchable conductor cannot yet offer comparable performance to the silver-based conductor. By optimizing the manufacturing parameters and the antenna thickness, improved antenna properties can probably be achieved. However, these results are already very promising as read ranges of 2-3 meters are suitable for many wireless applications.

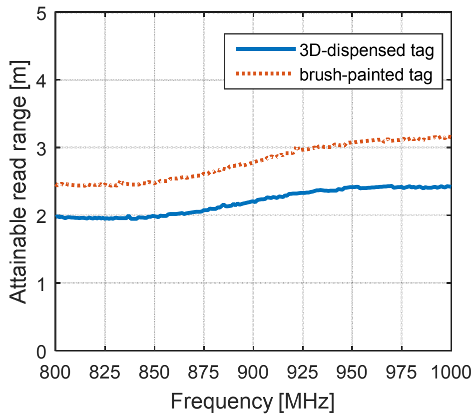

Fig. 3. Attainable read ranges of manufactured tags.

4. Conclusion

In this paper, we presented 3D-dispensed and brush-painted passive UHF RFID tags on flexible 3D-printed Ninjaflex substrates, fabricated from a stretchable carbon-based conductor. Based on our measurements, the tags showed promising wireless performance and peak read ranges of 2.4 meters and 3.1 meters, respectively. The read ranges of the 3D-dispensed tags were slightly shorter than the brush-painted ones, due to their thinner conductor layers. Thus, the wireless performance of the tags can possibly be improved by optimizing the manufacturing parameters and conductor thickness. Another next step is to study the reliability of these wireless components in different environmental conditions. Especially the effects of humidity, bending, and stretching will be studied.

References

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