Brush-painted Silver Nanoparticle UHF RFID Tags on Fabric Substrates

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Abstract— Due to an increasing interest to wearable electronics, versatile electronics manufacturing methods are needed for numerous applications. Brush-painting is a simple and fast additive manufacturing method for electronics, which involves only two process steps: painting and sintering. In our study, passive UHF RFID tag antennas were brush-painted through a stencil on two different fabric substrates by using only one layer of silver nanoparticle ink. According to our measurements, the tags on Fabrics 1 and 2 showed peak read ranges of over 8 meters and of 2 meters, respectively, both on top of the fabric and while embedded between two layers of fabric. The brush-painted tags also showed suitable on-body read ranges. However, the characteristics of the fabric substrate had a significant effect on the tag performance.

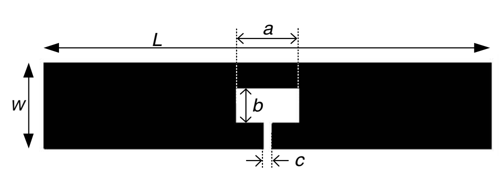
1. INTRODUCTION

A new generation of clothing will be able to sense, communicate data, and harvest energy in a nonintrusive way. These innovations in the area of wearable electronics are paving the way toward ambient intelligence and the internet of things [1, 2]. Wearable passive UHF (ultra high frequency) RFID (radio-frequency identification) tags, for instance, have enormous potential in future welfare and healthcare applications. This growing interest to wearable electronics has created a need for versatile antenna manufacturing methods that are needed for numerous applications. Screen and inkjet printing of metal nanoparticle inks, embroidery with metal-coated sewing thread and patterning of metallized fabrics are examples of technologies used to produce textile conductors [3–6].

Brush-painting is a simple and fast method, which enables mass production in the future. The manufacturing process involves only two process steps: painting and sintering, and it is possible to fabricate antennas with only one brushed layer on porous and fibrous fabric substrates. The brushing-method not only reduces process-steps, but also minimizes the amount of deposited conductive material (ink), because it is dispensed directly to the brush, and from the brush directly to the antenna area in the substrate. Brush-painting is also possible without a stencil. This novel fabrication method offers great competitiveness in future wearable RFID tag manufacturing and an appealing alternative to screen printing.

2. BRUSH-PAINTED UHF RFID TAGS

In our study, we brush-painted antennas for passive UHF RFID tags through a stencil on two different fabrics. The conductive material we used was Harima NPS-JL silver nanoparticle ink [7] which was deposited on both fabrics in a single brush. Fabric 1 was a mix of polyester and viscose used in pants and Fabric 2 was 100 % cotton used in coveralls. The stencil was patterned from 50 μm thick polyimide film. Figure 1 shows the geometry of the studied antenna and Figure 2 illustrates the manufacturing process steps.



Geometrical parameters in millimeters.

L	W	a	b	c
100	20	14.3	8.125	2

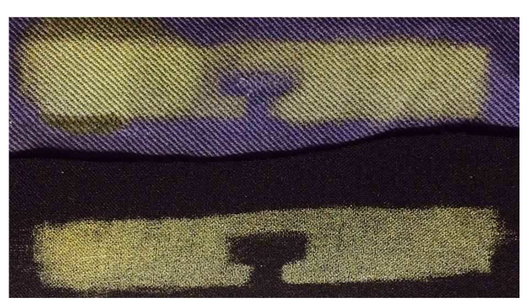


Figure 1: Antenna geometry and samples of brush-painted antennas.

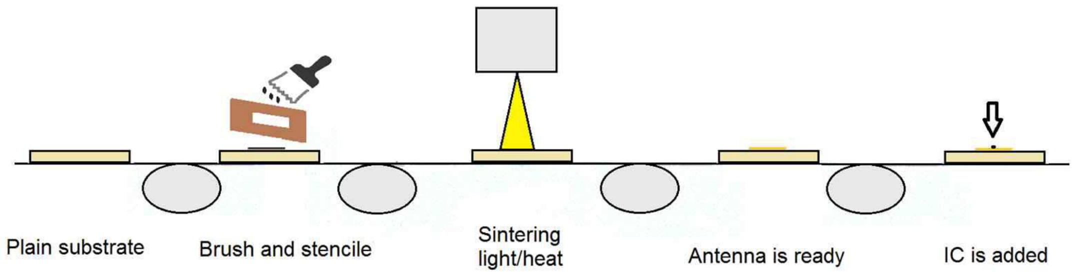


Figure 2: Brush-painting process.

After brushing the ink through the stencil, the tag antennas were sintered with two different methods: by Xenon photonic sintering system and by heat sintering in an oven. The parameters for the photonic sintering were found by experimenting while manufacturer recommendations were used in heat sintering. In photonic sintering we used a single flashpulse mode, but it was used 3 times with a break of 1.5 seconds between the flashes. The used voltage for Fabrics 1 and 2 was 2800 V and 3000 V, respectively. In heat sintering, the antennas weresintered in 150°C for 1 hour. The prototype antennas are shown in Figure 1.

The tag IC utilized in this study is NXP UCODE G2iL series IC with the wake-up power of −18 dBm (15.8 µW) [8]. The manufacturer had mounted the chip on a strap (copper on a plastic film). After sintering, we attached the pads of the strap to the antenna using a conductive silver epoxy resin. In this study, we did not concentrate on IC bonding process, but the main goal was to investigate the novel additive manufacturing method on fabric substrate.

3. TAG PERFORMANCE EVALUATION

Normally, the read range of passive tags is limited by the forward link operation [9], i.e., the efficiency of the wireless power transfer from the reader to the tag IC. Assuming free-space conditions for site-independent comparison, the attainable tag read range in the directions ϕ and θ of a spherical coordinate system centered at the tag is given by [9]

$$d_{tag}\left(\phi,\theta\right)=\frac{\lambda}{4\pi}\sqrt{\frac{\chi_{pol}\left(\phi,\theta\right)\ ,\tau\, e_{r,tag}D_{tag}\left(\phi,\theta\right)EIRP}{P_{ic0}}};\quad \tau=\frac{4\mathrm{Re}\left(Z_{tag}\right)\mathrm{Re}W\left(Z_{ic}\right)}{\left|Z_{tag}+Z_{ic}\right|^2}, \tag{1}$$

where τ is the antenna-IC power transfer efficiency determined by the antenna and IC impedances Z_{tag} and Z_{ic}, resepectively, λ is the wavelength of the reader's carrier signal, $EIRP$ is the regulated equivalent isotropic radiated power, P_{ic0} is the wake-up power of the tag IC, χ_{pol} is the mutual polarization power efficiency between the tag and reader antennas, $e_{r,tag}$ is the tag antenna radiation efficiency and D_{tag} is the tag antenna directivity.

Equation (1) show explicitly how the electromagnetic properties of the tagantenna and tag IC determine the attainable read range of the tag. However, the measurement of small antennas and accurate characterization of the non-linear IC frontend is problematic [10, 11]. Thus, the required measured data to evaluate (1) is difficult to obtain. Moreover, uncertainties may accumulate from the radiation pattern, antenna impedance, and tag IC measurements. Hence, the performance evaluation of fully assembled RFID tags based on the reader-to-tag communication threshold is advantageous. This can be with using readers with adjustable output power and RFID testers [12]. Weused Voyantic Tagformance RFID measurement system.

During testing, the lowest transmission power (threshold power: P_{th}) at which the tag remains responsive is recorded. Here wedefined P_{th} as the lowest power at which the identification code can be read from the tag's memory based on ISO 18000-6C communication standard. In addition, the wireless channel from the reader antenna to the location of the tag under test was characterized using a system reference with known properties. As detailed in [13], we computed the attainable read range of the tag under testbased on the measured threshold power from

$$d_{tag}=\frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{\Lambda}\frac{P_{th*}}{P_{th}}}, \tag{2}$$

where P_{th} is the measured threshold power of the tag under test, Λ is a constant provided by the system manufacturer to describe the sensitivity of the reference tag at each frequency, and P_{th*} is the measured threshold power of the reference tag. In this article, we report the results under the European RFID emission regulation: $EIRP = 3.28\,\mathrm{W}$.

4. RESULTS AND DISCUSSION

The measurement results obtained in an anechoic chamber are presented in Figure 3. In our measurements, the RFID tags with heat sintered antennas did not respond. Thus, heat sintering was found to be unsuitable method for sintering this nanoparticle ink on the studied fabrics. However, the RFID tags with photonic sintered antennas on Fabric 1 showed a peak read range close to 9 meters. Also, the photonic sintering process was much faster than the heat sintering process; only a few seconds. As in practice the antenna pattern would not likely be exposed at the outer fabric layer, we used normal textile glue join the two fabric layers so that the antenna is embedded in between the two layers of fabric. This did not affect the tag performance significantly: the peak read range remained close to 8.5 meters with a slight 10 MHz downward shift in frequency. In contrast, tags on Fabric 2 showed much smaller read ranges of 1.5-to-2 meters both on top of the fabric and embedded in between two layers of fabric. Thus, in addition to the chosen sintering method, the characteristics of the fabric substrate have a huge effect on the characteristics of the brush-painted RFID tag antennas. Similar results have been found in case on screen-printed antennas on different fabric substrates [14]: the uneven fabric surface caused discontinuities and breaks, making the tag very poorly matched to the IC and hence reducing the realised gain and read range.

We also compared the performance of the brush-painted tag against two other types of textile-based tags with the same antenna (described in Figure 1) fabricated using screen printing and patterned from a metallized fabric. The screen-printed antenna was fabricated from polymer thick film silver ink on stretchable fabric substrate with the same ink and process described in [14]. The electro-textile tag was cut from Less EMF Stretch Conductive Fabric (Cat. #321), which is silver plated stretchable fabric made of nylon (76%) and elastic fibers (24%) [15]. As seen from Figure 3, the measured peak read range of the brush-painted tag on Fabric 1 is very close to that of the screen-printed tag and nearly three meters higher than that of the electro-textile tag. It is worth noticing that unlike the screen-printed and electro-textile antennas, the brush-painted antenna did not exhibit accurately defined edges (see Figure 1). Still, the performance of the brush-painted tag on Fabric 1 operated very similar to the screen-printed one, suggesting that the studied antenna geometry is not sensitive toward edge roughness.

Finally, we measured the practical on-body read range of the tags on Fabric 1, as it was a more suitable substrate to be used with the chosen silver nanoparticle ink and brush-painting method. The measurement was conducted in an office room with some absorbers placed to reduce scattering. The tag is separated 3–4 mm from the body only with a shirt layer. During the measurements,

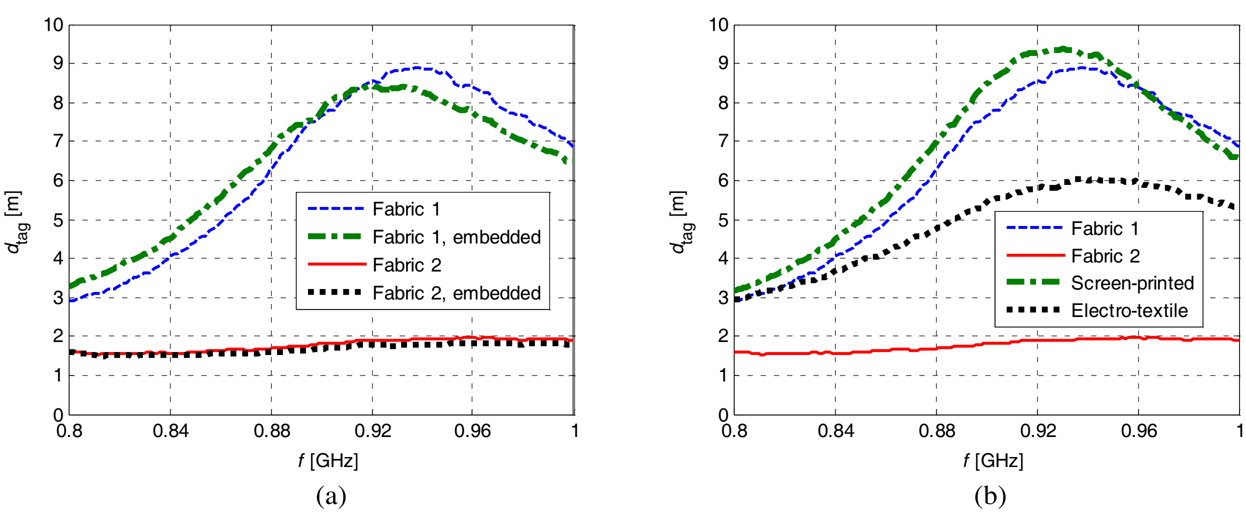


Figure 3: (a) Maximum read ranges for brush-painted tags on top of the fabric and while embedded between two layers of fabric and (b) maximum read ranges of brush-painted, screen-printed, and electro-textile UHF RFID tags.

the tag was attached to the body on the right arm and was measured from 3 different directions, as shown in Figure 4. The tags achieved the best read ranges, 3–5 meters, when measured from direction 1. However, also read ranges from directions 2 and 3, which were 1.5-to-2.5 meters and 2-to-3 meters, respectively, can be considered suitable for many applications. The fluctuations seen in the graph are manifestation of the scattering, which was not completely compensated from the results via the system reference tag measurement. This was because the presence of the human body changed the environment.

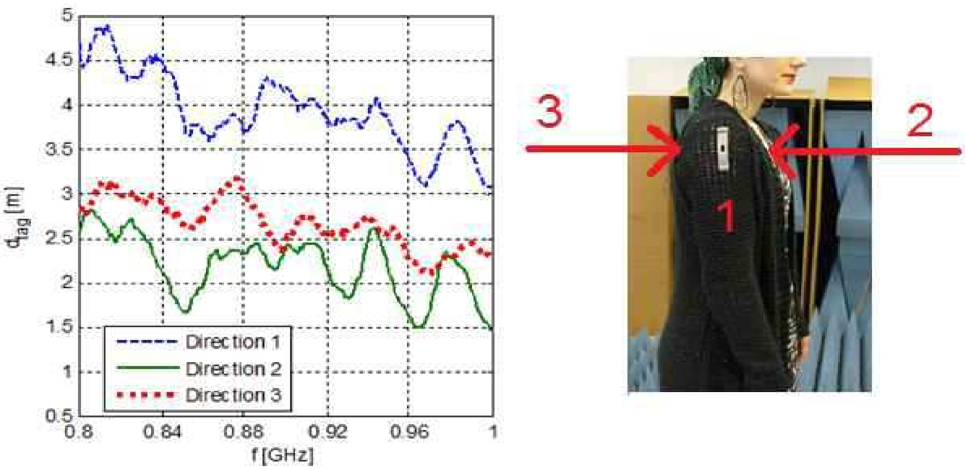


Figure 4: Measurement results for on-body read ranges from 3 different directions.

5. CONCLUSIONS

According to our results, brush-painted silver nanoparticle passive UHF RFID tags have great potential for future wearable applications. Brush-painted tags on fabric substrate achieved maximum read ranges of over 8 meters, also when embedded inside two layers of fabric. In addition, the measured on-body read ranges were found to be suitable for many future applications. It should be noted that the characteristics of the fabric substrate have a huge effect on the tag performance and the right sintering parameters for each substrate have to be studied individually. Future work will include finding the best manufacturing parameters for different types of fabric substrates and testing different types of nanoparticle inks.

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