Washing Reliability of Painted, Embroidered, and Electro-Textile Wearable RFID Tags

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Abstract

In this paper, we present textile antennas fabricated for wearable RFID applications by cutting from commercially available electro-textile, by sewing with conductive thread, and by painting with conductive paint on a 100 % cotton fabric. The ready tags with attached ICs are coated with a protective encapsulant. The wireless performance of the tags is evaluated initially, after moisture testing in tap water, and after five washing cycles in a household washing machine. The initial read ranges of the electro-textile, embroidered, and painted tags are around 10, 6, and 4 meters, respectively. Based on the reliability testing results, the coating protects the components from moisture but the mechanical stress during washing cycles has a major effect on the tags' reliability.

1. Introduction

A passive RFID (radio frequency identification) tag consists only of an antenna and an IC (integrated circuit), and it uses the power from the reader to energize itself and backscatter its data. As no onboard power sources or complex systems are needed, these wireless platforms offer versatile possibilities when embedded into clothing. In addition to light and conformal wearable identification and tracking applications, RFID technology could be utilized in healthcare and sports related wireless systems, such as in passive on-body sensors [1]-[3].

Conductive fabrics, i.e., electro-textiles, are a great example technology, which can be used to utilize cost-effective antennas for wearable solutions [4][5]. Electro-textile materials are easy to cut and can be unnoticeably embedded into traditional textiles. Sewing with conductive thread is a versatile manufacturing method, which has great possibilities in textile antennas, due to its compatibility with various textile materials and easily modified conductive patterns [6][7]. Further, conductive paint, which can be brush-painted like a traditional paint, and requires no post-processing, has been found to be a potential new approach for fabricating antenna structures [8][9]. In many applications, the reliability of textile-integrated wireless components is critical, and especially moisture and washing are among the key reliability challenges [10][11].

In this paper, we present textile RFID tag antennas, fabricated by cutting from commercially available electro-textile, as well as by embroidering with conductive thread and painting with conductive paint on a cotton substrate. The ready tags equipped with ICs are coated with a protective encapsulant and the wireless performance of the tags is evaluated after coating, after one hour in tap water, and after five washing cycles in a household washing machine.

2. Tag fabrication

The tag antennas used in this study were T-matched dipoles with the structure shown in Fig. 1. The electro-textile tag antennas were cut with scissors from Less EMF Pure Copper Polyester Taffeta Fabric (Cat. #A1212), which is a thin and lightweight conductive textile material. The painted tags were fabricated on a thin 100 % cotton fabric. We chose to coat the fabric with the protective encapsulant first, and then paint the antennas on the coated substrate. The selected coating, DuPont PE772 stretchable encapsulant, was applied on the fabric, and the substrate was dried in 100 ºC for 60 minutes. The used conductive paint was Bare Conductive's nontoxic, solvent free, and water soluble Electric Paint. The tag antennas were brush-painted on the coated fabric through a stencil cut from plastic, by using one layer of paint. Then, the painted antennas were dried in 70 °C for 30 minutes to maximize their conductivity. Finally, the embroidered antenna contours were sewed on the same cotton fabric with Husqvarna Viking embroidery machine. The used conductive yarn was Shieldex multifilament thread 110f34 dtex 2-ply HC.

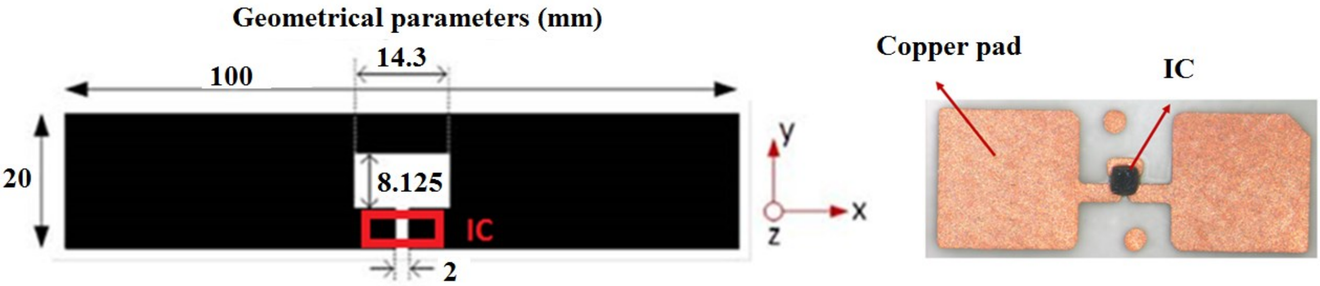

Figure 1. The used tag antenna design (left) and IC strap (right).

The tag IC was NXP UCODE G2iL series RFID IC, which has a wake-up power of −18 dBm (15.8 µW). The IC is attached by the manufacturer in a strap. The strap copper pads were attached to the fabricated antennas using Circuit Works CW2400 conductive silver epoxy. For comparison, in case of the painted tags, the IC strap pads were also attached directly to the paint, when it was still wet. Also, in case of the embroidered tags, the attachment was also fabricated by sewing a cross over the IC pads with conductive thread, as shown in Figure 2.

Following the attachment of ICs, the coating material was applied on both sides of the electro-textile and embroidered tags, by dip coating. The coating was also brush-painted on top of the painted antennas. Next, all tags were dried in 100 ºC for 30 minutes. The extended drying time and the low drying temperature (recommendation from the coating manufacturer was 100-160 °C for 2-10 minutes) were chosen because of the low temperature endurance of the IC component and the relatively thick coating layer protecting the IC. For each tag type, four tags were fabricated and these ready tags are presented in Figure 2.

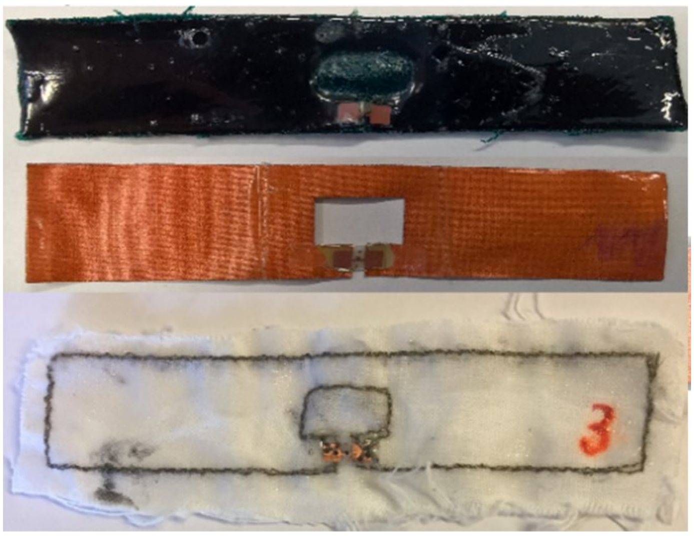

Figure 2. Ready tags with painted (top), electro-textile (middle), and embroidered (bottom) antennas.

3. Measurements and reliability testing

The wireless performance of the fabricated and coated textile tags was evaluated in an anechoic chamber, using Voyantic Tagformance RFID measurement system. The system contains an RFID reader with an adjustable transmission frequency (0.8…1 GHz) and output power (up to 30 dBm), and the recording of the backscattered signal strength (down to −80 dBm) from the tag under test is provided.

First, the wireless channel from the reader antenna to the location of the tag under test was characterized using a system reference tag with known properties When evaluating the tags, the lowest continuous-wave transmission power (threshold power: P_{th}) at which the tag remained responsive, was recorded. P_{th} is defined as the lowest power at which a valid 16-bit random number from the tag is received as a response to the *query* command in ISO 18000-6C communication standard. The attainable read range of the tag (d_{tag}) versus frequency can be calculated from

$$d_{tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{\Lambda}\frac{P_{th*}}{P_{th}}}, \qquad (1)$$

where P_{th} is the measured threshold power of the tag, Λ is a known constant describing the sensitivity of the system reference tag, P_{th*} is the measured threshold power of the system reference tag, and *EIRP* is the emission limit of an RFID reader given as equivalent isotropic radiated power. All the results are corresponding to *EIRP* = 3.28 W, which is the emission limit in European countries.

The reliability of the tags was evaluated with a moisture test, where the tags were placed into room temperature tap water for 1 hour. After the moisture test, the same tags were washed in a household washing machine, by using a normal 40 °C washing cycle with detergent and spinning. The tags were measured after the moisture test and after each washing cycle. Altogether five washing cycles were done.

4. Results

The read ranges of the coated electro-textile, embroidered, and painted tags were around 10, 6, and 4 meters, respectively. All the read range results are presented in Figure 3. The IC attachment method (glued compared to painted/sewed) in case of the painted and embroidered tags did not have an effect on the read range results. As can be seen from the results, all types of tags were able to maintain their read ranges after the moisture test. Thus, the protective coating was very effectively protecting the tags from moisture.

However, washing was found to be detrimental for the tags: The painted conductor was found to crack because of the mechanical stress during washing, and thus the painted tags cannot be considered suitable for wearable applications requiring washing in a washing machine. Figure 3 shows the wireless performance of a painted tag: after the first washing cycle, the read range was slightly decreased and there were some cracks on the tag antenna. However, already after the second washing cycle, the tag did not respond at all, and the surface of the antenna showed serious cracking.

The electro-textile tags and the embroidered tags survived all five washing cycles, but also their read ranges slightly decreased after each washing cycle. Also, in further washing tests, some of the tested electro-textile and embroidered tags broke due to the mechanical stress harming the antenna-IC joint. Tags with both types of IC attachment method were found to break during washing. Thus, based on the results, the tested encapsulant can be considered a potential protective coating for textile-integrated wireless components, as they were able to maintain the excellent read ranges after 1 hour in water. The coating seems to also protect the components during washing, to a certain degree, but the mechanical stress has a major effect on the tags' reliability.

In the next step of this research, further support material is needed around the antenna-IC attachments, in order to make these tags truly washable. Further work also includes studying different textile substrates and conducting washing tests with more washing cycles.

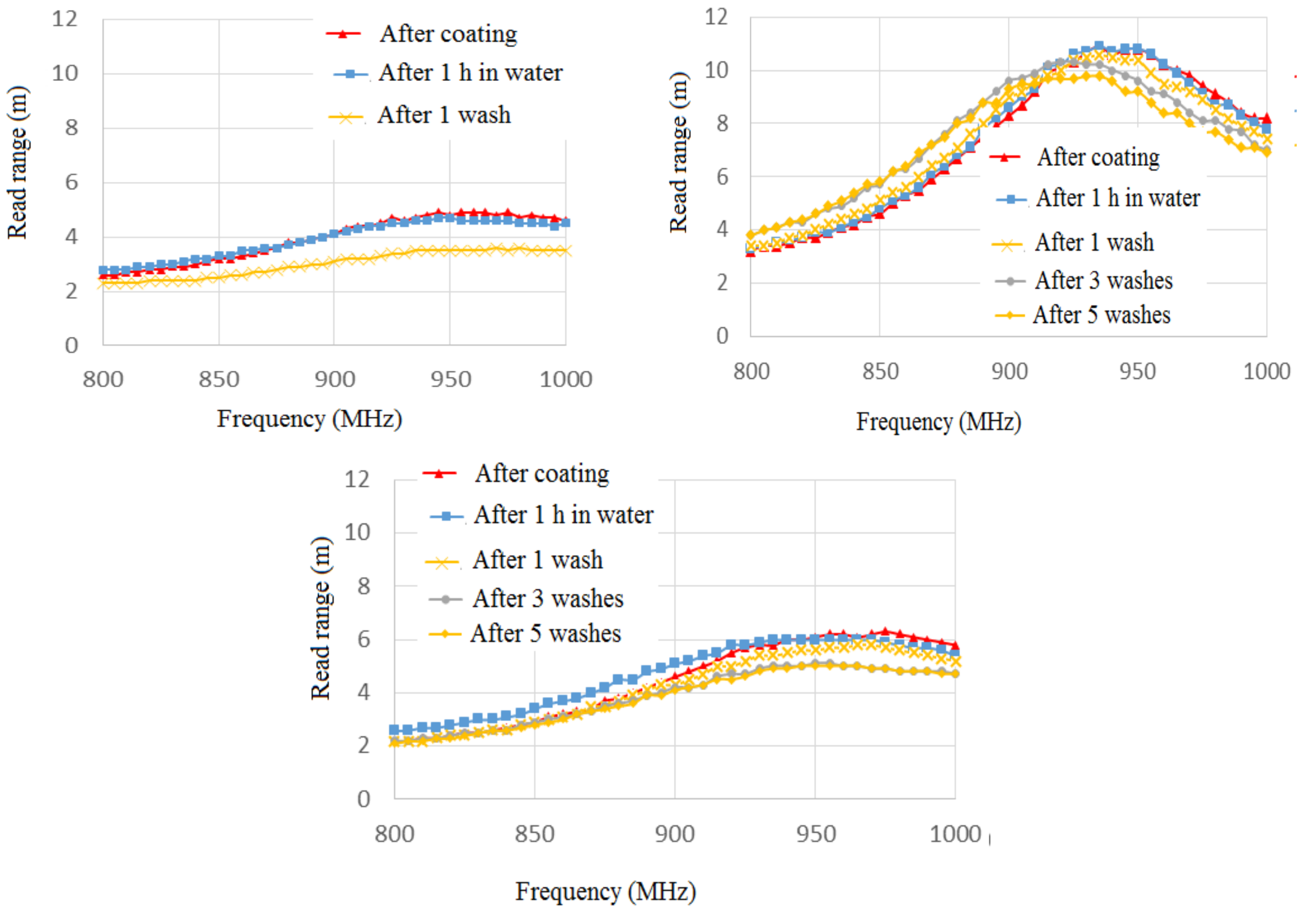

Figure 3. The read range results of painted (top left), electro-textile (top right), and embroidered (bottom) tags.

5. Conclusions

RFID-based wearable platforms are among the key technologies to build the future of wearable wireless networks. We studied the fabrication and washing reliability of RFID tags with painted, embroidered, and electro-textile antennas. The fabricated tags were coated with a protective, flexible encapsulant, and their reliability was studied in tap water, as well as after five washing cycles. The initial read ranges of the electro-textile tags, embroidered tags, and the painted tags were around 10, 6, and 4 meters, respectively. The encapsulant was found to be a potential protective coating for these textile tags, as they were able to maintain the excellent read ranges after the moisture test. However, washing in a washing machine was found to be damaging for the tags. The painted antennas were found to crack and break due to the mechanical stress. In addition, the antenna-IC interconnections were found to be easily breakable in a normal household washing machine.

Ackowledgements

This research was done as part of the European Commission Marie Curie IRSES project "AdvIOT". The research work was supported by the Academy of Finland and TEKES.

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