Fabrication and Moisture Reliability of Painted and Electro-Textile Tags for Wearable RFID Applications

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***Abstract*—We fabricated flexible antennas for wearable RFID applications by cutting from commercially available electro-textile and by painting with conductive paint on a cotton substrate. The ready tags were coated with a protective encapsulant. The wireless performance of the tags was evaluated initially, after coating, and after moisture testing in tap water. The read ranges of the copper-textile tags and the painted tags were around 10 and 4 meters, respectively. The coated tags were able to maintain the excellent read ranges even after 1 hour in water.**

Keywords—conductive paint; electro-textile; moisture reliability; protective coating; wearable RFID

I. INTRODUCTION

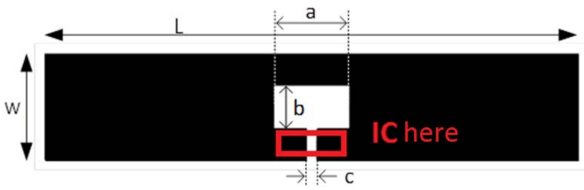
RFID (radio frequency identification) -based wearable solutions provide versatile opportunities for identification, monitoring, and sensing. Possible applications can be found especially from healthcare and welfare sectors, and from sportswear [1-3]. A passive RFID tag is composed only of an antenna and an integrated circuit (IC). When integrated into clothing, these battery-free components offer a cost-effective and maintenance-free platform for versatile body-worn wireless systems.

Wearable components need to be inconspicuous to the user, i.e., light and conformal. The increasing amount of these wireless components has created a need for new types of antenna fabrication methods and materials. Metallized fabrics are a great example technology, which can be used to utilize cost-effective antennas for wearable solutions [3][4]. Also, the use of conductive paint, which can be brush-painted like a traditional paint, has been found to be a potential new approach for fabricating antenna structures [5][6].

In this study, flexible antennas for wearable passive ultra-high frequency (UHF) RFID tags were cut from commercially available copper fabric and painted with conductive paint on a cotton substrate. The fabricated tags were coated with a protective encapsulant. Then, to evaluate their moisture reliability, the ready tags were tested in tap water. The goal of this study was to evaluate the two antenna fabrication solutions, and to find a suitable protective coating material, which is compatible with the used textile antenna materials and does not affect the wireless performance of the tags.

II. FABRICATION

We chose the antennas to be T-matched dipoles with the structure shown in Fig. 1. The electro-textile tag antennas were patterned from Less EMF Pure Copper Polyester Taffeta Fabric (Cat. #A1212), which is a thin and lightweight textile material, and can be easily cut with scissors [7]. The painted tags were fabricated on a thin 100 % cotton fabric. We chose to coat the fabric first, and then paint the antennas on the coated substrate. The selected coating, DuPont PE772 stretchable encapsulant [8], 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 [9]. The tag antennas were brush-painted on the coated fabric through a stencil cut from plastic, by using one layer of paint. Then, the antennas were dried in 70 °C for 30 minutes.



Geometrical parameters [mm]				
L	W	a	b	c
100	20	14.3	8.125	2

Fig. 1. The used tag antenna design.

The tag IC was NXP UCODE G2iL series RFID IC, 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.

Following the attachment of ICs, the coating material was applied on both sides of the electro-textile tags, by dip coating, to completely cover them. The coating was also brushed on top of the painted antennas, and all tags were dried in 100 ºC for 30 minutes. The long drying time and the low drying temperature (recommendation from the coating manufacturer: 100-160 °C for 2-10 minutes) were chosen because of the low temperature endurance of the IC. For comparison, we also fabricated tags where only the IC part of the tag was coated. The coating was brushed on top of the IC with a brush, and also these tags were dried in 100 ºC for 30 minutes. Only one layer of coating was used in each case. Both types of coated tags are shown Fig. 2.

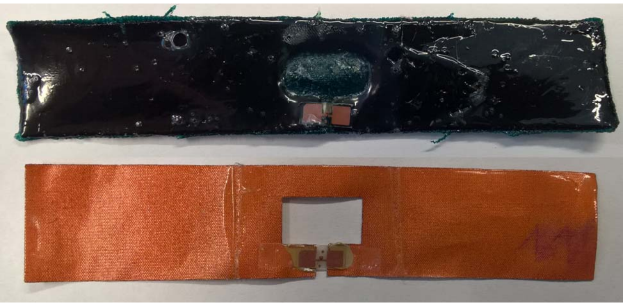


Fig. 2. A painted tag (top) and an electro-textile tag (bottom) fully coated.

III. MEASUREMENTS

The performance of the components was evaluated wirelessly using Voyantic Tagformance measurement system. It contains an RFID reader and provides the recording of the backscattered signal strength of the tested tag. All the measurements were conducted with the tag suspended on a foam fixture in an anechoic chamber. First, the wireless channel from the reader antenna to the location of the tag was characterized using a reference tag. During the test, we recorded the threshold power, at which a valid 16-bit random number from the tag was received as a response to the query command in ISO 18000-6C communication standard. This enabled us to estimate the achievable read range of the tag (d_{tag}) versus frequency as given in (1):

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

where λ is the wavelength transmitted from the reader antenna, P_{th} is the measured threshold power of the tag, Λ is a known constant describing the sensitivity of the reference tag, and P_{th*} is the measured threshold power of the reference tag. Finally, EIRP is the emission limit of an RFID reader, as equivalent isotropic radiated power (Here EIRP = 3.28 W, which is the emission limit in European countries).

After the initial performance measurements, where the tags were measured before and after coating, the tags were placed into tap water for 1 minute, 10 minutes, and 1 hour, and measured immediately after each testing time.

IV. RESULTS

Fig. 3 presents the measured read ranges of the non-coated painted and copper-textile components in air, through a frequency range of 800-1000 MHz, which covers the global UHF RFID frequency bands. As can be seen, all tags showed excellent wireless performance: The electro-textile tags attained read ranges of around 10 meters, while the maximum read ranges of the painted tags were around 4 meters. The IC attachment method (attached directly to wet paint / attached with conductive glue after antenna drying) did not affect the wireless performance, i.e., the read ranges of the painted tags.

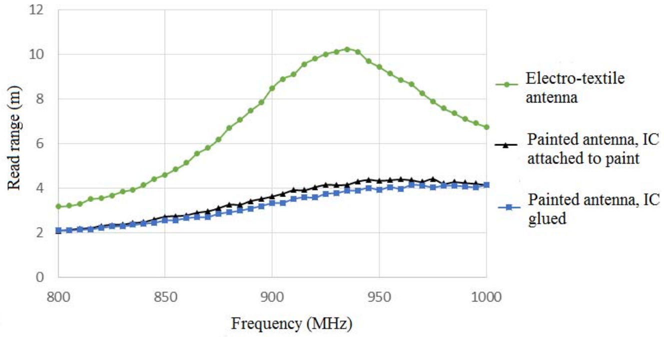


Fig. 3. Read range results of all types of tags before coating.

During the first minute of the moisture test, it came clear that the painted tags need to be fully coated in order for them to withstand moisture. Fig. 4 shows a painted tag, where only the IC is coated, when the tag is placed into water. As can be seen, the paint starts to spread into the water immediately. Thus, these tags cannot be considered to be moisture reliable without a protective coating. Moisture did not seem to have any visible effect on the electro-textile tag antennas.

Fig. 4. A painted tag in water.

The measurement results of a fully coated painted tag are shown in Fig. 5. The measured read ranges of a fully coated and an only IC-coated electro-textile tag are shown in Fig. 6 and Fig. 7, respectively. Four tested and measured tags of each type showed similar performance.

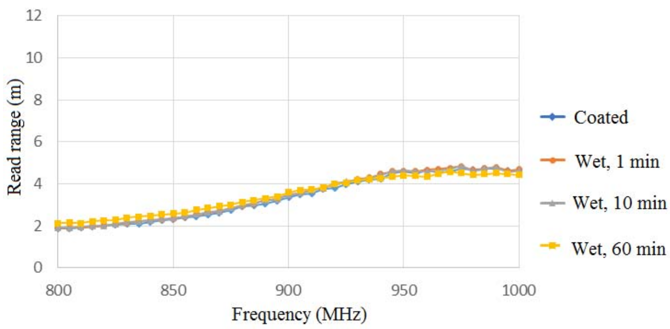


Fig. 5. Read range results of a fully coated painted tag.

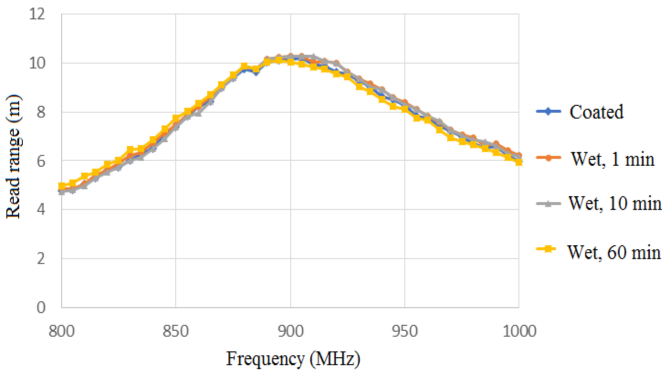


Fig. 6. Read range results of a fully coated electro-textile tag.

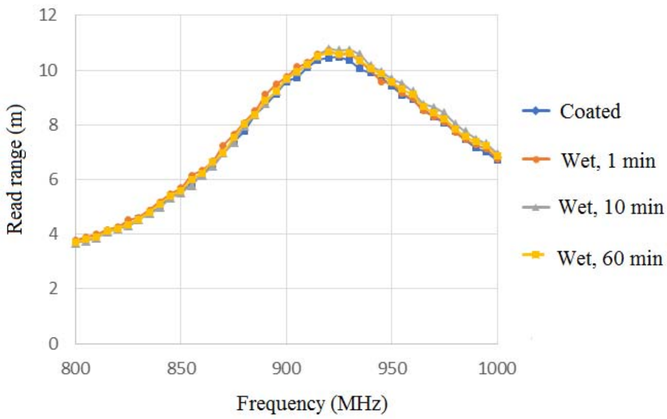


Fig. 7. Read range results of an only IC-coated electro-textile tag.

When compared to the initial read range results, it can be seen that in case of the electro-textile tags, the coating caused a downward shift in the frequency of the peak read range. This shift was more severe for the fully coated tags (from 940 MHz to 900 MHz) than for the tags where only the IC was coated (from 940 MHz to 920 MHz). However, this shift did not have an effect on the maximum read range itself, both types of coated tags showed peak read ranges of around 10 meters. The coating had no effect on the performance of the painted tags.

As can be seen, moisture did not have any effect on any of the tested tags. The read ranges measured immediately after one hour in water were the same as before moisture testing. Thus, we can consider the encapsulant be a potential future coating material for wearable components against moisture, enabling also the use of conductive paint as an antenna material in high humidity conditions.

The achieved results are very promising for future wearable applications. However, the effect of the coating on the optimal performance frequency shift needs to be studied further, also with other textile antenna materials. Another future step is to start washing tests in a household washing machine. The washing reliability of electro-textile tags coated with versatile materials has been studied before, but no suitable coating material to make the tags washable was found [3]. In case of the painted tags, the mechanical stress during washing can be damaging for the tags, as the painted conductor can crack, which is another major reliability challenge, and a reason for further coating studies.

V. Conclusions

RFID-based wearable components are among the key technologies to support the future of wearable wireless networks. We studied the fabrication and moisture reliability of flexible painted and electro-textile RFID tags. The fabricated tags were coated with a protective, flexible encapsulant, and their reliability was studied in tap water. The tags were wirelessly measured before coating, after coating, and after the moisture tests. The initial read ranges of the copper-textile tags and the painted tags were around 10 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 all moisture tests. Future research includes washing studies, and also the needed amount of the protective coating will be optimized, in order to minimize its effects on the tags' wireless performance.

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