# Embroidered Antenna-Microchip Interconnections and Contour Antennas in Passive UHF RFID Textile Tags

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Galatée Ginestet, Nicolas Brechet, Jeremie Torres, Elham Moradi, Leena Ukkonen, Toni Björninen, Johanna Virkki

*Abstract*—**We studied the possibilities of embroidered antenna-IC interconnections and contour antennas in passive UHF RFID textile tags. The tag antennas were patterned from metal coated fabrics and embroidered with conductive yarn. The wireless performance of the tags with embroidered antenna-IC interconnections was evaluated through measurements and the results were compared with identical tags where the ICs were attached using regular conductive epoxy. Our results show that the textile tags with embroidered antenna-IC interconnections attained similar performance. In addition, the tags where only the border lines of the antennas were fabricated showed excellent wireless performance.**

*Index Terms*—**Electro-textiles, Embroidery, Interconnections, RFID tags, Textile antennas.**

## I. Introduction

EMBROIDERY with conductive yarn is a simple fabrication method with a great potential for example in wearable antenna fabrication due to its compatibility with non-electronic textile processing on various fabric materials [1]-[6]. In addition, it can be a particularly useful approach for embedding electronic interconnections into textile materials [7]-[9].

In this study, we present the possibilities of embroidered antenna-IC (integrated circuit) interconnections in passive UHF (ultra-high frequency) RFID (radio-frequency identification) textile tags. The tag antennas were embroidered with conductive yarn and cut from commercial electro-textile materials, and the tag ICs were attached by embroidery. The wireless performance of the ready-made textile RFID tags was evaluated through measurements and the results were compared to tags with ICs attached by commonly used conductive epoxy.

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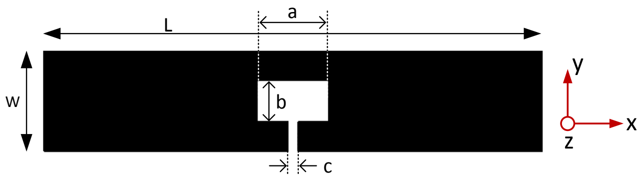
A fundamental challenge of wearable electronics lies in the proximity of the human body. The biological tissues dissipate energy and exhibit high dielectric constants. This restricts antenna radiation efficiency and fundamentally changes the antenna impedance compared with free-space. In this letter, however, we have limited the scope of the investigations to the evaluation of the impacts of novel manufacturing methods on the electromagnetic performance of textile tags and thus the tags are not measured in body-worn configurations, but in air to remove additional sources of uncertainty. In particular, we study embroidered interconnections for the IC attachment and realization of a planar dipole antenna by embroidering only the border line of the antenna. This enables textile RFID tag assembly in a regular textile process and reduces notably the total amount of conductive yarn required to embroider the antenna.

## II. Fabrication of the Tags

The studied tag antenna is shown in Fig. 1. It is a dipole integrating an inductive matching loop and a widely used antenna in UHF RFID tags. The shape of the antenna originates from our previous work, where we studied the stretching durability of electro-textile and screen-printed UHF RFID tags [10]. However, in this work we propose a novel approach to achieve savings in material costs and manufacturing time by creating the antenna by embroidering only its borderlines as shown in Fig. 2. Material saving in embroidered antennas and the effects of the antenna sewing pattern on the tag performance have been previously studied in [11] and [12]. However, to the best of our knowledge, this is the first presentation of a simple and cost-effective contour tag. Overall, we manufactured the antenna in five different ways as indicated in Fig. 2. Firstly, the shape was cut from copper tape and from two different metal-coated fabrics; Copper plated Polyester textile (Less EMF Cat. #A1212) and Copper and Nickel plated Polyester textile (Less EMF Cat. #A1120). Secondly, we manufactured antennas where only the borderline was embroidered on the fabric using Husqvarna Viking with conductive yarn (Shieldex multifilament thread 110f34 dtex 2-ply HC) and finally by cutting a 1 mm wide border line shape from the copper tape. In all cases, the substrate was a thin 100 % cotton fabric.




Geometrical parameters in millimeters

| L | W | a | b | c |
|---|---|---|---|---|
| 100 | 20 | 14.3 | 8.125 | 2 |

Fig. 1. The studied antenna geometry.

The tag IC utilized in this study is NXP UCODE G2iL series IC (shown in Fig. 3). The manufacturer had mounted the chip on a fixture (copper on a plastic film) with $3\times3$ mm$^2$ pads for easier attachment. We attached the fixture pads to the electro-textile antennas by embroidering a cross over them as shown in Fig. 2 and Fig. 3. In the case of the borderline antennas, we used the cross attachment and as an alternative embroidered the antenna border over the IC pads during the antenna fabrication. Finally, we created another set of identical tags where the IC was attached using conductive epoxy for comparison.

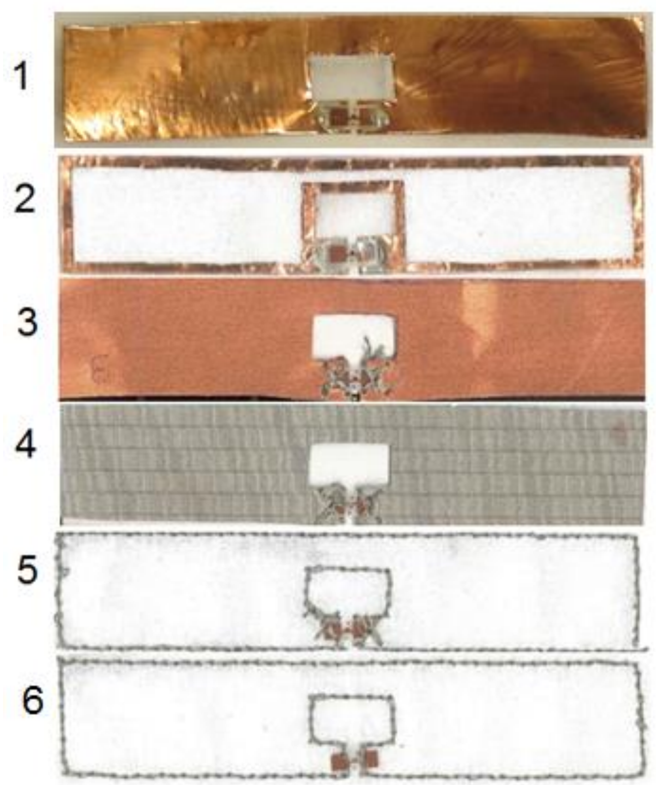



Fig. 2. The ready-made RFID tags: 1. Fully fabricated copper tape tag with a glued IC, 2. Copper tape contour (1 mm) tag with a glued IC, 3. Copper electro-textile tag with an embroidered IC, 4. Nickel/copper electro-textile tag with an embroidered IC, 5. Embroidered contour tag with an embroidered IC, and 6. Embroidered contour tag with IC embroidered together with the antenna.

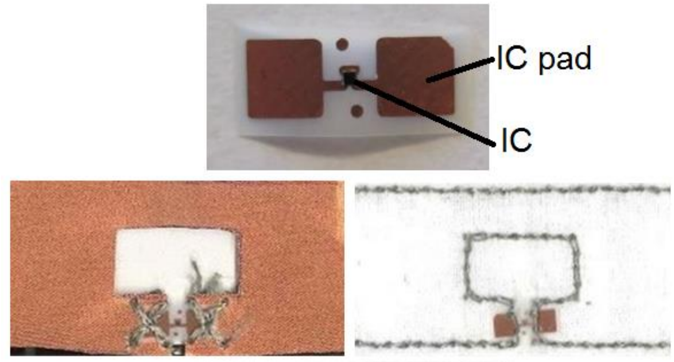



Fig. 3. The used IC strap (up), embroidered cross attachment on copper electro-textile antenna (bottom, left), and antenna embroidered over the IC pads (bottom, right).

## III. Measurement and Simulation Results

The tags were tested wirelessly using Voyantic Tagformance measurement system. It contains an RFID reader with an adjustable transmission frequency (0.8…1 GHz) and output power (up to 30 dBm) and provides the recording of the backscattered signal strength (down to −80 dBm) from the tag under test. We conducted all the measurements with the tag suspended on a foam fixture in an anechoic chamber.

During the test, we recorded the lowest continuous-wave transmission power (threshold power: $P_{th}$) at which the tag remained responsive. Here we defined $P_{th}$ 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. In addition, 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. As explained in [10], this enabled us to estimate the attainable read range of the tag ($d_{tag}$) versus frequency 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 sensor tag, $\Lambda$ 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. We present all the results corresponding to $EIRP$ = 3.28 W, which is the emission limit for instance in European countries. Based on the calibration data provided by the manufacturer of the measurement system, we have estimated that the combined static uncertainty in $d_{tag}$ due to variability in the system reference tag ($\Lambda$) and the output power meter of the reader ($P_{th}$, $P_{th*}$) is less than 5% throughout the studied frequency range.

The attainable read ranges of the fabricated tags are presented in Figs. 4–6. As can be seen, the reference tag, i.e., tag fabricated from copper tape and the IC attached with conductive epoxy, shows peak read ranges of approximately 12 meters.

TABLE I. IMPEDANCE OF THE ANTENNA AND RFID MICROCHIP.

| **Frequency (MHz)** | **Antenna impedance (Cu contour) [Ω]** | **Antenna impedance (Cu, full) [Ω]** | **RFID microchip impedance [Ω]** |
|---|---|---|---|
| 800 | 5.02 + *j*161i | 3.75 + *j*124 | 16.7 − *j*217 |
| 825 | 6.82 + *j*172i | 5.05 + *j*131 | 15.7 − *j*211 |
| 850 | 9.43 + *j*183i | 6.87 + *j*139 | 14.8 − *j*204 |
| 875 | 13.3 + *j*196i | 9.44 + *j*148 | 13.9 − *j*199 |
| 900 | 19.0 + *j*211i | 13.1 + *j*157 | 13.2 − *j*193 |
| 925 | 27.6 + *j*227 | 18.4 + *j*167 | 12.6 − *j*188 |
| 950 | 40.7 + *j*244 | 25.9 + *j*178 | 11.8 − *j*183 |
| 975 | 60.2 + *j*260 | 36.4 + *j*188 | 11.2 − *j*178 |
| 1000 | 87.8 + *j*273 | 50.5 + *j*197 | 10.8 − *j*174 |

Both electro-textile tags patterned from metal plated fabrics show attainable peak read ranges of approximately 11 meters (cross embroidered ICs) and around 10 meters (glued ICs). Thus, in both cases the read ranges of the tags with the embroidered ICs are slightly longer than the read ranges of the tags with the glued ICs. This may be due to imperfect compatibility of the conductive epoxy and the textile materials. These read ranges are also very close to the read ranges of the copper tape reference tags, which indicates highly conductive antenna-IC interconnection using the embroidery approach that is fully compatible with textile processing.

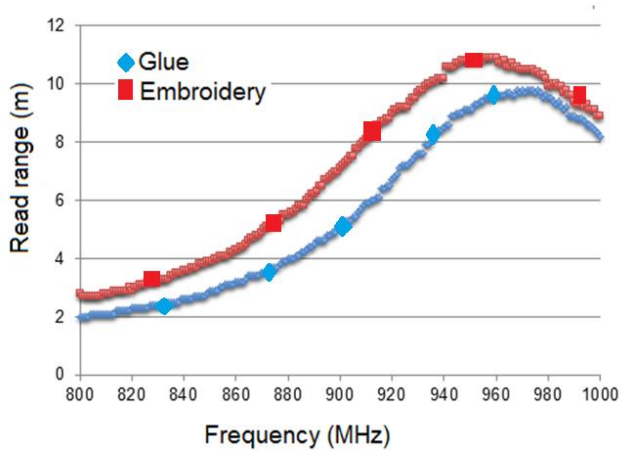



Fig. 4. The attainable read ranges of the copper electro-textile tags with glued and embroidered ICs.

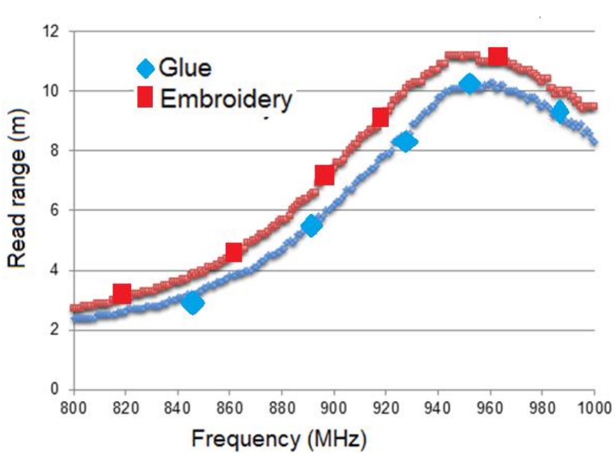



Fig. 5. The attainable read ranges of the nickel/copper electro-textile tags with glued and embroidered ICs.

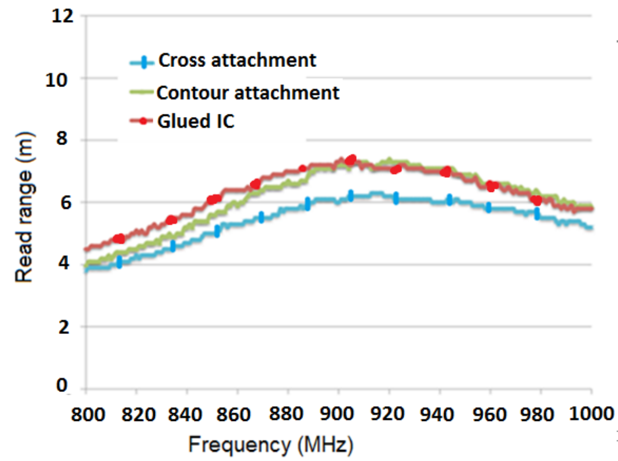



Fig. 6. The attainable read ranges of the embroidered contour tags with different types of IC attachments.

In case of the embroidered contour tag, the tag IC was sewed to the antenna with the cross embroidery and by sewing the contour over the IC strap pads. As can be seen from Fig. 7, the read ranges of these tags are very close to the embroidered tags with the glued ICs. The tag with the antenna-IC interconnection embroidered together with the antenna and the tag with the glued IC both show attainable read ranges of approximately seven meters. The read range of the tag with a cross embroidered IC attachment is slightly shorter, i.e., approximately six meters. All contour tags achieved their peak read range at a lower frequency (around 910 MHz) than the electro-textile tags with fully fabricated antennas. In these tags the downward frequency shift was likely due to the change in the electrical length of the antenna as the current was forced to flow at the exterior boundary of the antenna.

We fabricated a copper tape contour tag with a 1 mm thick contour and attached the IC with the conductive epoxy. The read range of this reference contour tag can be seen in Fig. 4b. As can be seen, the resonance frequency of this tag is around 890 MHz, which supports the earlier findings of the downward shift in frequency. As Fig. 7d shows, the gain of the contour dipole is only 0.5 dB lower than the gain of the conventional dipole, hence the radiation characteristics of the contour tag are almost the same as the full dipole's. However, the contour shape has a significant effect on the input impedance (Table 1 presents the impedances of the fully fabricated and contour copper antennas and the microchip at different UHF frequencies), changing the antenna matching to the IC (Fig. 7c and Fig. 7e). This change can be compensated, e.g., by modifying the t-match dimensions. As Fig. 7a shows, most of the current in the copper reference antenna is in the borders, revealing the reason why the contour antenna works like a normal dipole antenna. The copper tape contour tag achieved a peak read range of 9.5 meters. This is approximately two meters longer than the read ranges of the embroidered contour tags (Fig. 6).

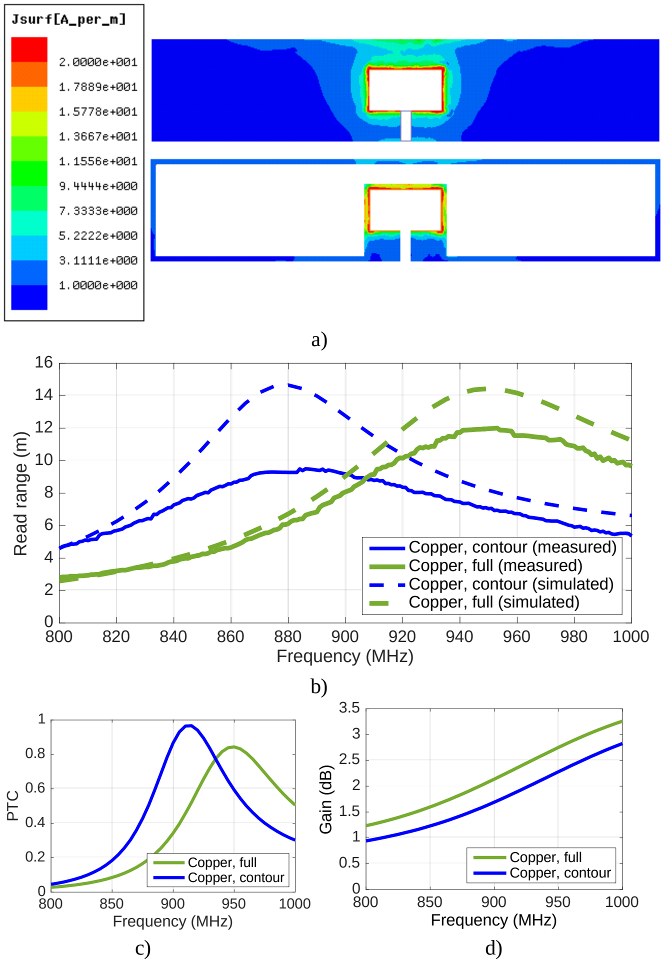



Fig. 7. Simulation of result of (a) amplitude of the surface current [A/m] at 900 MHz. In the simulation, 100 mW is delivered to both antennas, (b) antenna gain toward the positive z-axis in Fig. 1, (c) power transfer efficiency between the antenna and the RFID microchip which was modeled as a parallel connection of resistance and capacitance of 2.85kΩ and C = 0.9 pF, respectively, and (d) attainable tag read range under reader's emission limit of EIRP = 3.28 W in the direction of positive z-axis in Fig. 1.

Based on the results, we conclude that significant amounts of time and conductive yarn can be saved in the embroidering by only sewing the borderline of the RFID tag antenna. The shift in the frequency of the peak read range can be compensated by modifying the dimensions of the integrated matching loop.

However, textile antennas are the critical enabling components of future wireless body area networks and they operate in an extremely challenging environment. Wearable applications require the antennas to be an integral part of clothing and to endure different environmental stresses, such as repeated bending, crumpling, and wrinkling. Thus, reliability testing of these embroidered antennas and textile-electronics interconnections will be the next research topic.

## IV. Conclusion

We studied embroidered antenna-IC interconnections in passive UHF RFID electro-textile tags and the possibility of creating a planar dipole tag by only embroidering the border lines of the full antenna shape. According to our results, the tags with the embroidered interconnections showed similar or superior performance in comparison with identical tags with ICs attached with conductive epoxy. Also, based on the measurement results, tags where only the border lines of the antennas were fabricated showed excellent wireless performance, which indicates that significant amounts of time and conductive materials could be saved with this manufacturing approach.

Future work includes evaluation of the reliability of the embroidered antennas and textile-electronics interconnections and electromagnetic optimization of the contour type antennas.

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