Cost- and Time-effective Sewing Patterns for Embroidered Passive UHF RFID Tags

Nicolas Brechet, Galatée Ginestet, Jeremie Torres
Institute of Technology
University of Montpellier
Montpellier, France
{nicolas.brechet , galatee.ginestet} @etu.umontpellier.fr
jeremie.torres@umontpellier.fr

Elham Moradi, Leena Ukkonen, Toni Björninen,
Johanna Virkki
Department of Electronics and Communications Engineering
Tampere University of Technology
Tampere, Finland
{elham.moradi , leena.ukkonen , toni.bjorninen ,
johanna.virkki}@tut.fi

***Abstract*—Embroidery is an efficient method for the fabrication of textile antennas. We studied the effects of reducing the amount of conductive thread to achieve savings in material costs and the effects of the sewing pattern on the wireless performance of embroidered passive UHF RFID tags on two different fabric substrates. The antennas were sewed on cotton and polyamide fabrics, the ICs were attached to the embroidered antennas with a conductive adhesive, and the wireless performance of the ready-made textile RFID tags was evaluated through measurements. The fabric parameters were found to have a major effect on the tag performance. Based on our results, significant amounts of time and conductive yarn can be saved in the embroidery of RFID tag antennas by only partially sewing the tag antenna.**

Keywords—conductive yarn; embroidery; passive UHF RFID technology; textile antennas;

I. INTRODUCTION

The growing interest towards wearable radio frequency identification (RFID) tags is based on their endless opportunities in identification, monitoring, and sensing applications, especially in the healthcare and welfare sectors. The increasing amount of these wearable wireless components has created a need for fast and low-cost textile antenna manufacturing.

Embroidery with conductive yarn is a simple manufacturing method with a high potential in this application due to its compatibility with non-electronic textile processing on various fabric materials [1] [2]. In addition, it can be a particularly useful method when embedding interconnections into textiles [3] [4]. A look at the current state-of-the-art of embroidery and related manufacturing techniques is presented in [1]. In embroidery, we have the full control of the conductive pattern: shape, stitch density, and stitch type. In antenna fabrication, cost-savings can be achieved by manufacturing larger solid conductor areas by using parse sewing patterns. At the same time, this reduces the time spent on sewing. Therefore, it is important to investigate the effect of the sewing pattern, along with the geometry of the antenna, on the performance of textile tags.

In this work, we study the effects of reducing the amount of conductive yarn and the impact of the sewing pattern on the wireless performance of passive ultra high frequency (UHF) RFID tags based on sewed antennas. We focus on evaluating the performance of the tags in air, in absence of environmental stress factors and the effects of the proximity of the human body on wearable tags. This way, the source of any observed performance variation is limited to the antenna fabrication parameters.

II. FABRICATION OF THE TAGS

A. Fabrication Parameters

The conductivity of a sewed antenna depends on the electrical properties of the conductive thread, the structure of the sewed pattern, and stitch and thread density of the sewed pattern [5]–[8]. The studied tag antenna (shown in Fig. 1) is a straight dipole integrating an inductive matching loop, which is a widely used antenna in UHF RFID tags. Its shape originates from our previous work, where we studied the stretching durability of electro-textile and screen-printed tags [9].

The tags were fabricated on two different fabrics, 100 % cotton and 100 % stretchable polyamide, by using five different embroidery patterns. The used thread was multifilament silver plated thread (Shieldex multifilament thread 110f34 dtex 2-ply HC). The DC lineal resistivity of the thread is 500±100 Ω/m, and the diameter is approximately 0.16 mm. Two of the studied sewing patterns were fully embroidered antennas, sewed vertically (x-axis of Fig. 1) and horizontally (y-axis of Fig. 1) to fill up the solid conductor area completely with the thread. We also fabricated two dipoles with using full vertical and horizontal patterns in places with highest surface current density, and the rest of the antenna was only partially embroidered. In the fifth antenna, only the borders, i.e., the contour of the antenna was sewed. Two samples of each antenna type were fabricated on both fabric substrates.

It was quickly discovered that the stretchable polyamide fabric is a challenging substrate for embroidery. In order to help the needle to pass through the fabric, the fabric needed to be strained, which resulted in the sewed pattern to shrink from

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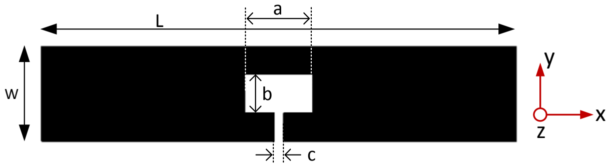
its original length. Thus, on the stretchable polyamide fabric, an initial length of 105 mm was chosen for the pattern to obtain an antenna with the realized length of 100 mm.



Geometrical parameters in millimeters.

	L	W	a	b	c
Cotton	100	20	14.3	8.125	2
Polyamide	105	20	14.3	8.125	2

Fig 1. The studied tag antenna geometry.

The tag chip we used was NXP UCODE G2iL series RFID IC with the wake-up power of −18 dBm (15.8 μW). It was provided by the manufacturer in a fixture patterned from copper on a plastic film. We attached the 3×3 mm^2 pads of the fixture to the antenna with conductive silver epoxy (Circuit Works CW2400).

B. Ready Tags

In order to establish the performance of the sewed UHF RFID tags relative to other known textile antenna technologies, we also fabricated and tested a reference tag made of copper and three other electro-textile tags with the same antenna geometry and tag IC. The copper tag antenna was patterned from copper tape. The three electro-textile tags were made of Less EMF Pure Copper Polyester Taffeta Fabric (Cat. #A1212), Less EMF Stretch Conductive Fabric (Cat. #321), and from a conductive nickel and copper-plated Less EMF Shieldit Super Fabric (Cat. #A1220).

The ready electro-textile tags and the reference copper tape tag are presented in Fig. 2. The embroidered tags on cotton and polyamide are shown in Fig. 3 and Fig. 4, respectively.

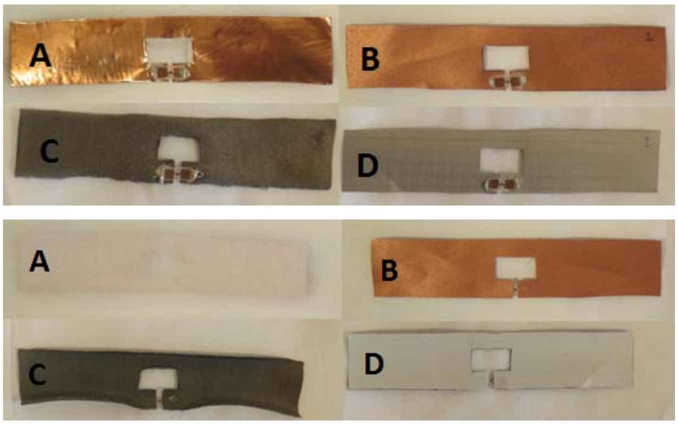


Fig. 2. Front side (top) and back side (bottom) of A) Copper tape reference tag, B) Copper electro-textile tag, C) Stretchable electro-textile tag, and D) Nickel/Copper electro-textile tag.

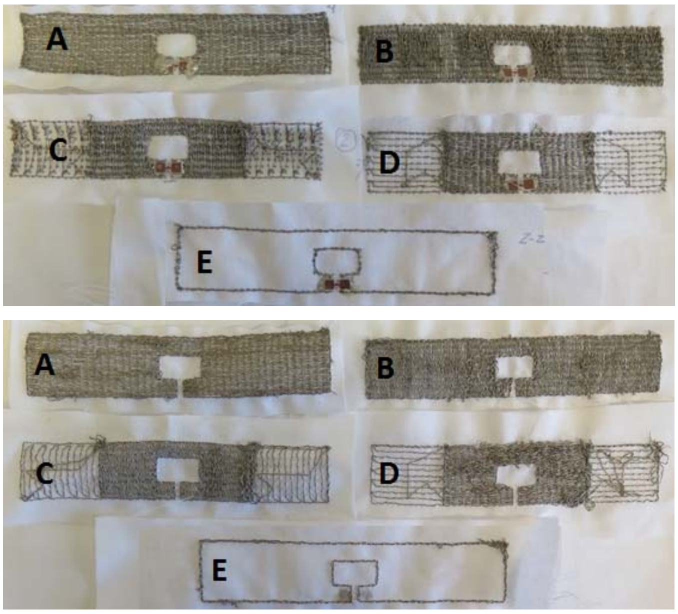


Fig. 3. Front side (top) and back side (bottom) of A) Fully horizontally embroidered antenna, B) Fully vertically embroidered antenna, C) Partially vertically embroidered antenna, D) Partially horizontally embroidered antenna, and E) Antenna with only the outside boarders on the cotton fabric.

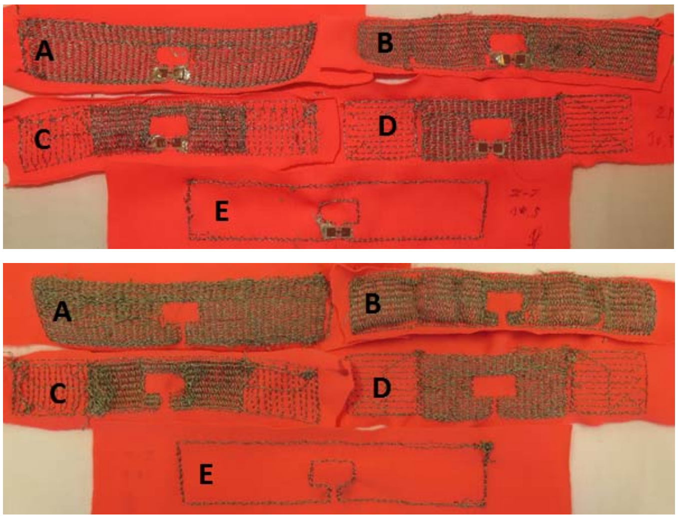


Fig. 4. Front side (top) and back side (bottom) of A) Fully horizontally embroidered antenna, B) Fully vertically embroidered antenna, C) Partially vertically embroidered antenna, D) Partially horizontally embroidered antenna, and E) Antenna with only the outside boarders on the polyamide fabric.

III. EVALUATION OF THE TAGS

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}). 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 [9], 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 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 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.

IV. MEASUREMENT RESULTS

Figures 5 and 6 show the estimates of the attainable read ranges for the tags on cotton and polyamide substrates, respectively, based on the measured threshold power. Fig. 7 presents the attainable read ranges of the reference copper tag and the three different electro-textile tags.

As can be seen from Fig. 7, the reference copper tape tag shows the best performance and a peak read range of about 12 meters around 950 MHz. Also the Nickel/Copper textile and Copper textile tags achieved peak read ranges of over 9 meters.

As can be seen from Fig. 5, the read ranges of the partially and fully fabricated antennas on cotton vary from 7 to 8 meters. The small differences in the read range are most probably caused by reproducibility issues. Thus, a promising way to optimize the embroidery pattern of the antenna on cotton fabric is using more threads in places with high current density to keep the imaginary part of impedance near that of an antenna with regular solid metallization, and embroider sparsely the parts carrying low current density to decrease conduction losses.

As can be seen from Fig. 6, the fabric parameters had a major effect on the performance of the polyamide tags. Here the peak read ranges of the tags varied as much as 3.5 meters compared with 1 meter in the case of the cotton fabric tags. The large variability was most probably due to the major reproducibility challenges in embroidery caused by the elasticity of the polyimide material. Based on these results, the polyamide substrate is not considered suitable for antenna embroidery.

We also tested dipoles with only borders embroidered (patterns E in Figs. 3–4). In these cases, a visible shift in resonance frequency was observed, but the tag achieved high read ranges due to the minimized conduction loss. The shift in the resonance frequency shift could be easily compensated by shortening the dipole length or by adapting the geometrical parameters a and b in Fig. 1. Thus, this pattern not only requires minimal amount of thread and sewing time, but also achieves very high read ranges (See Fig. 5 and Fig. 6). On polyamide, the best performance was achieved with the tag that had only the contour of the tag embroidered. This tag showed a peak read range of about 9 meters at around 930 MHz. Thus, the peak read range was achieved at a much lower frequency than with the other tags on polyamide. The contour antenna was the only antenna on the polyamide substrate that did not cause fabrication challenges.

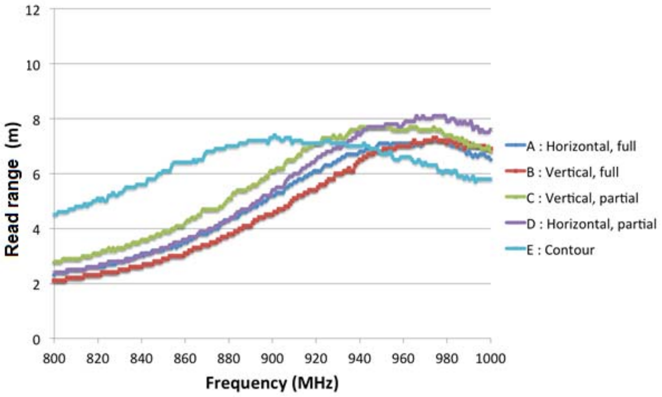


Fig. 5. The attainable read range of the tags on the cotton substrate.

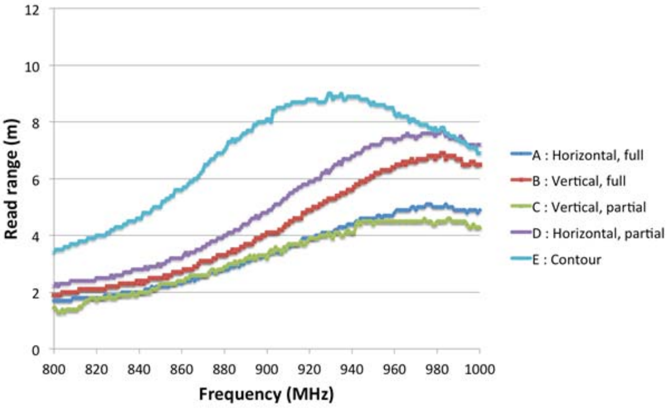


Fig. 6. The attainable read range of embroidered tags on the polyamide substrate.

For comparison, a tag with a 1 mm wide copper tape contour was fabricated and measured (See Fig. 8). As can be seen, the peak read range of the copper contour tag is around 9.5 meters around 890 MHz. This peak read range frequency is similar to the embroidered contour tag on the cotton fabric, and thus supports our findings.

Based on the achieved results, the read ranges of the embroidered RFID tags on cotton are very comparable to the other types of textile RFID tags. Significant amounts of time and conductive yarn can be saved in RFID tag antenna fabrication by only partially sewing the tag antenna. In this case, the optimized fabrication method is to only embroider the tag antenna contour.

However, textile antennas need to endure extremely challenging environments, such as repeated bending, crumpling, and wrinkling. Thus, reliability testing of these embroidered antennas will be the next research topic.

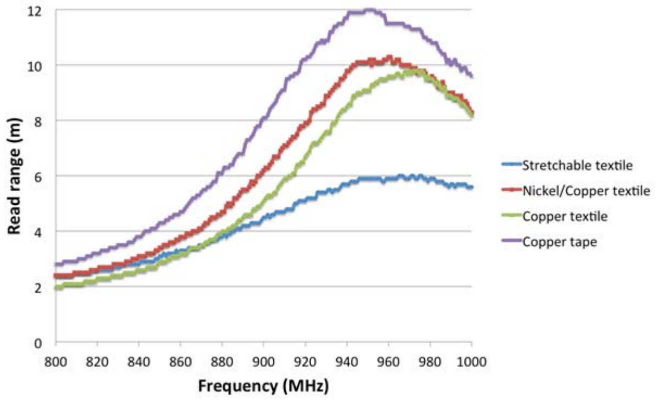


Fig. 7. The attainable read range of the reference copper tag and the three other electro-textile tags.

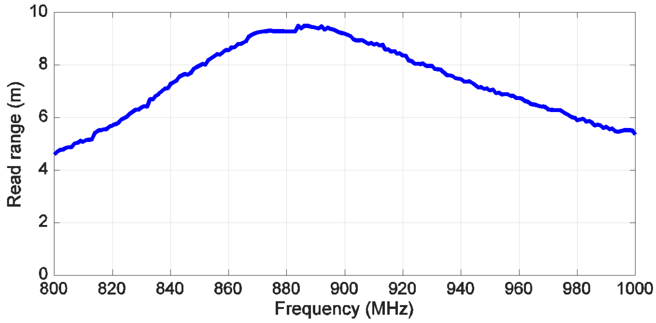


Fig. 8. The attainable read range of a copper tape contour (width: 1 mm) tag.

V. CONCLUSIONS

We studied the effects of reducing the amount of used conductive yarn and the effects of the sewing pattern on the wireless performance of embroidered passive UHF RFID dipole tags on a stretchable polyamide and on a cotton fabric. Based on the wireless measurement results, significant amounts of time and conductive yarn can be saved in the embroidery of RFID tag antennas by only partially sewing the tag antenna. Especially the tags where only the border line of the antenna was sewed, showed excellent wireless performance and thus have a high potential for future wireless applications. However, it was discovered that the structure and material of the fabric substrate has a major effect on the fabrication of the antennas and their wireless performance.

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