Embroidered Antennas and Antenna-Electronics Interfaces for Wearable RFID Tags

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***Abstract*—We summarize the possibilities of embroidery with conductive yarn in the fabrication of antennas and antenna-electronics interconnections for wearable RFID tags. Based on our results, both fabrication time and amount of conductive yarn used in fabrication of a dipole antenna can be saved by selecting dense or parse stitching for different regions of the antenna, or by sewing only the antenna borderline. Moreover, we fabricated the antenna-IC interconnection by sewing through the pads of the fixture carrying the IC during the antenna fabrication. Our wearable prototype tag showed excellent wireless performance, and was detectable at distances of 6 and 2 meters, in air and on the human body, respectively.**

Keywords*—*antennas; embroidery; interconnections; wearable RFID tags

I. Introduction

Clothing-integrated radio frequency identification (RFID) applications offer endless opportunities, especially in automatic identification and sensing. With the help of wearable RFID equipment, remote monitoring of movement or physiological parameters of a person can be achieved inconspicuously.

Embroidered structures have a high potential in wearable applications, as they are cost-effective, lightweight, and easy to integrate with clothes [1–3]. In addition, sewing has been found to be a useful method for embedding interconnections into textile structures [3–6]. The performance of a sewed antenna depends on the electrical properties of the conductive yarn, the structure of the sewed pattern, and on the used stitch and thread density [7]–[10].

In this paper, we overview our previous results related to embroidery in fabrication of antennas and antenna-IC interconnections. First, we study the effects of reducing the amount of conductive yarn and the impact of the sewing pattern on the wireless performance of RFID tags [11]. In addition, we investigate two types of sewed antenna-IC interconnections [3]. Finally, we present a simple wearable UHF RFID tag, where we have realized the both the antenna and antenna-electronics interconnection in a single-step process by embroidering with conductive yarn [12].

II. Antenna Pattern and IC Attachment Study

First, we studied the impact of the embroidery pattern on the wireless performance of passive UHF RFID tags with sewed antennas. The tags were embroidered on 100 % cotton fabric, by using five different embroidery patterns. The embroidery was done by using Husqvarna Viking embroidery machine, and 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.

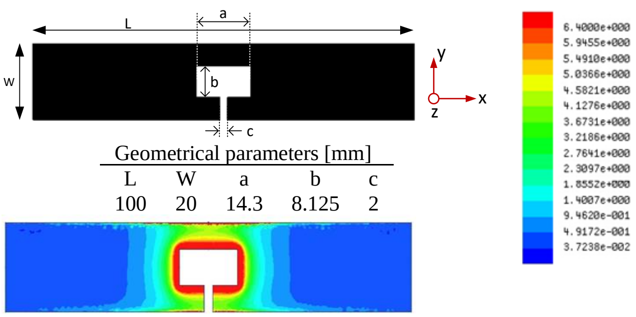


Fig. 1. The tag studied in the first part of the work (top) and the simulated surface current density [A/m] at 915 MHz (bottom).

Fig. 1 shows the antenna that we used in the first part of the work reviewed in this article. It is a dipole with an embedded inductive loop matching. Two of the tested sewing patterns were dense stitching with the thread aligned vertically (x-axis of Fig. 1) and horizontally (y-axis of Fig. 1). Based on the simulated density of the surface current [A/m] in Fig. 1, we also fabricated two antennas with dense stitching only in the central area of the antenna that carries a high current, compared with the rest of the structure that we embroidered with sparse stitching, as shown in Fig. 2. Lastly, we fabricated also an antenna where we sewed only the borderlines, i.e., the contour

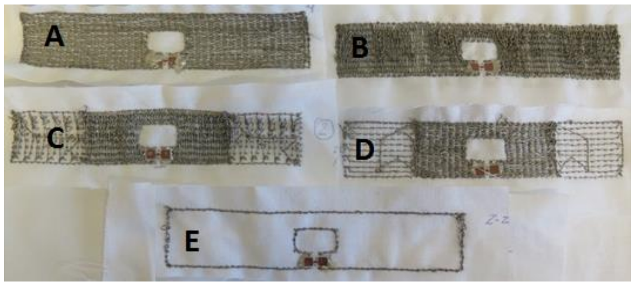


Fig. 2. The studied sewing-patters: antenna with A) full horizontal stitching, B) full vertical stitching, C) partial vertical stitching, D) partial horizontal stitching and E) only borderline sewed.

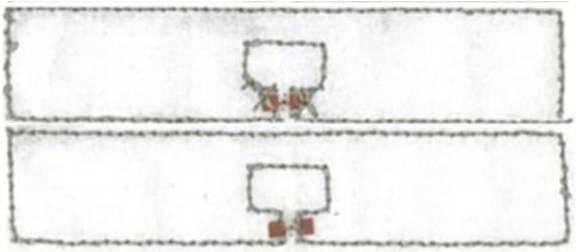


Fig. 3. Contour tags with IC strap attachment by an embroidered cross (top) and embroidered antenna borderline over the pads (bottom).

of the initial solid antenna shape.

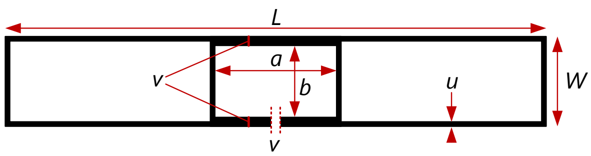
The RFID IC (integrated circuit) we used in all tags presented in this article is NXP UCODE G2iL series RFID IC. It is provided by the manufacturer in a strap where the IC is attached to a thin fixture with large 3×3 mm^2 copper pads. In the first part of this study were attached the pads to the embroidered structures using Circuit Works CW2400 conductive silver epoxy. Fig. 2 shows the ready tags.

Next, we studied sewing as a method for IC attachment. For this purpose, we attached the IC strap pads to the contour type antenna by embroidering a cross over them and embroidering the antenna borderline over the pads simultaneously with the antenna fabrication. Fig. 3 shows the outcomes of both approaches.

Finally, we modified the contour type tag to function in the proximity of the human body, manufactured it using the sewn antenna-IC interconnection, and carried out on-body testing. Fig. 4 shows the structural diagram of the wearable tag. In the fabrication process, we first placed the IC strap on the fabric substrate with the metallized side facing up, and then sewed the antenna borderline and antenna-IC interconnection with conductive yarn, by placing two single-line tracks immediately next to each other, as shown in Fig. 5. Finally, the wearable tags were adhered to a 5-mm layer of ethylene propylene diene monomer (EPDM) cell rubber foam, which simulates the use of clothes, and separates the antennas from the body so that adequate body-worn performance can be maintained. The ready wearable tag and a magnification of the antenna-IC interconnection are shown in Fig. 5.

III. Measurements

The performance of the fabricated tags was evaluated 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 tested tag. The measurements of



Parameter	L	W	a	b	u	v
Value [mm]	120	20	16	27	1	2

Fig. 4. The structural diagram of the wearable contour tag.

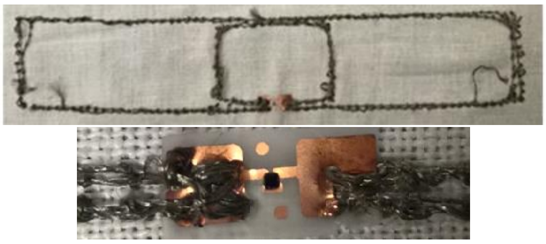


Fig. 5. Wearable contour tag (top) and a magnification of the antenna-IC interconnection (bottom).

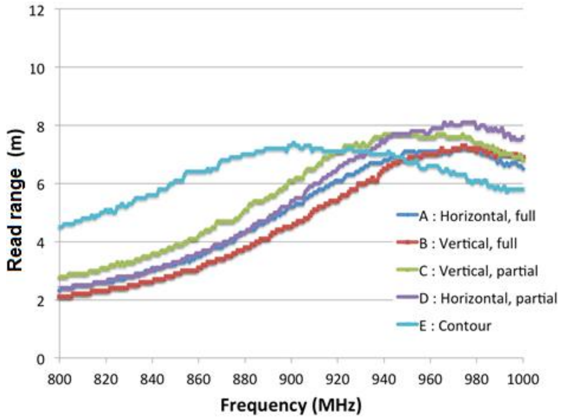


Fig. 6. Attainable read ranges of the tags with different sewing patterns.

the tags with differed sewing patters and with different IC attachment methods were conducted with the tag suspended on a foam fixture in an anechoic chamber. The fabricated wearable tag was attached vertically to the upper back between the shoulder blades of a male test subject.

The wireless channel from the reader antenna to the location of the tag was first 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 versus frequency as

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

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, which in our case is 3.28 W, according to the emission limit in European countries.

IV. Results

Fig. 6 presents the measured read ranges of the tags with different antenna patterns in air, through a frequency range of 800-1000 MHz, which covers the global UHF RFID frequency bands. As can be seen, the read ranges of the tags with fully and partially stitched antennas range from 7 to 8 meters, with the partially stitched antennas providing slightly better results than the fully stitched versions. Thus, placing 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, is a promising approach. The contour type tag, on the other hand, shows a significant shift in frequency of the peak read range, but also achieves a high read range of approximately 7 meters, due to the minimized conduction loss. As the shift in frequency could be easily compensated by adapting the inductive matching loop shape (params. *a* and *b* in Fig. 4), and the contour pattern requires minimal amount of thread and sewing time, we considered this tag the most promising candidate for the continuation of the study [3][11].

Fig. 7 presents the read range results of the contour tags with different IC attachments methods. As can be seen, the tags with the IC attached by embroidering over the IC strap pads during antenna fabrication show similar performance as the tags with the ICs attached by conductive epoxy. This confirms that sewing also provides a highly conductive antenna-IC interconnection. Importantly, it is fully compatible with regular textile processing.

Finally, Fig. 8 presents the measured read ranges of the body-worn contour type tag through a frequency range of 800-1000 MHz. The read range of the embroidered tag in air and near the human body was around 6 meters and around 2 meters, respectively. Overall, the performance of the embroidered tag combined with the benefits related to the materials, manufacturing, and integration, is compelling for wireless identification and other electronics devices in future body-centric wireless systems.

V. Conclusions

RFID-based wearable components are among the key technologies to support the future body-centric wireless systems. We reported the effects of reducing the amount of conductive yarn, and the effects of the sewing pattern on the wireless performance of embroidered passive UHF RFID dipole tags, to achieve savings in fabrication time and material costs. Especially, sewing only the borderline of a fully metallized planar dipole yielded an excellent tradeoff between performance and manufacturing complexity. Moreover, we found that sewed antenna-IC interconnections yielded high

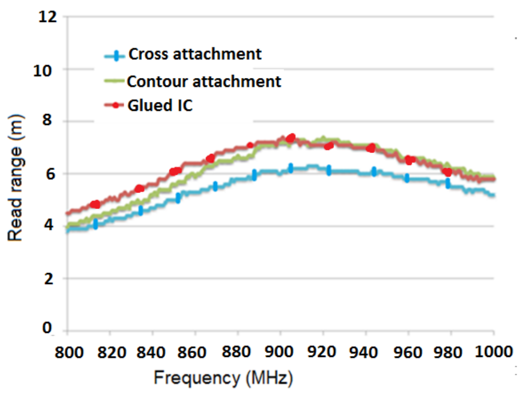


Fig. 7. Attainable read ranges of the tags with different IC attachment methods.

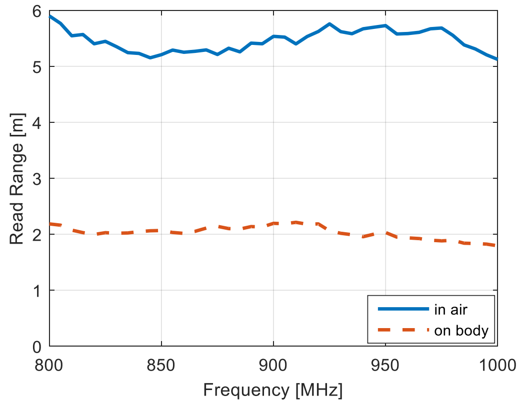


Fig. 8. Attainable read ranges of the body-worn embroidered tag.

performance similar to that achieved with conductive epoxy. The embroidered contour tags showed on-body read ranges of around 2 meters, which is a very promising result, and supports the use of embroidery in fabrication of textile electronics.

Acknowledgements

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