Textile-Integrated Stretchable Structures for Wearable Wireless Platforms

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Abstract— **In this study, antennas for passive UHF RFID tags were created from a carbon-based stretchable conductor on a stretchable elastic band by brush-painting. The antenna-microchip interconnections were fabricated by two different ways: 1) by using already commonly reported gluing with conductive silver epoxy and 2) by sewing the IC with conductive yarn. In addition to wireless evaluation of the fabricated RFID tags before and after stretching, we evaluated the effects of the interconnection type on tag performance and reliability. The achieved read ranges of around 1.5 meters are suitable for versatile textile-integrated RFID applications. Stretching causes permanent decrease to the tag read range but they remain functional even after 100 stretching cycles. In addition, the tags with the embroidered interconnections were found to be more reliable towards harsh stretching, compared to the tags with glued ICs. These initial results are very encouraging, considering the current trend towards more eco-friendly and cost-effective materials in electronics.**

Keywords—antennas, passive UHF RFID, stretchable conductor, interconnections.

I. Introduction

The trend towards stretchable electronics is fundamentally changing the way we fabricate and use electronics [1][2]. In wearable applications, stretchability enables seamless integration of comfortable electronics into clothes. Antennas are the critical enabling components of wireless wearable applications and they operate in an extremely challenging environment. Wearable antennas must be an integral part of clothing and to endure different environmental stresses, such as repeated stretching. During daily movement, the human skin may already stretch up to 15 %-20 %. This leads to the challenge of implementing textile-embedded antennas that function well under harsh elongations [3].

Passive ultra high frequency (UHF) radio-frequency identification (RFID)-based solutions have gained a lot of interest as wearable wireless platforms [4]-[7], mostly due to the simple structure and low cost of passive UHF RFID tags. These tags are composed only of an antenna and an IC (integrated circuit). In wearable applications, mechanical stresses are always involved. The major reliability challenges of textile-integrated electronics lie in electric and mechanical interconnections and in wireless performance of antennas. In addition to the required high reliability, the current trend requires more eco-friendly materials, at the same time demanding more cost-efficient solutions.

In this study, antennas for passive UHF RFID tags were created from a carbon-based stretchable ink on a stretchable elastic band by brush-painting. Two different IC attachment methods were used. Finally, the wireless performance and stretching reliability of the fabricated RFID tags were studied and analyzed.

II. Fabrication of RFID Tags

A basic dipole RFID tag antenna was brush-painted on a stretchable elastic band using a carbon-based stretchable conductor (DuPont PE671). The dimensions on the antenna are shown in Fig. 1. This is a widely used antenna type in UHF RFID tags and has been previously used e.g. in [8][9]. The brush-painted carbon-based antennas were cured in an oven, in 120 °C for 1 hour.

Next, in order to establish fully functional passive UHF RFID tags. NXP UCODE G2iL series RFID ICs, provided by the manufacturer in a strap with copper pads, were attached to the antennas. The antenna-microchip interconnections were fabricated by two different ways. The first method was a commonly used way, where the IC is attached on top of the antenna with conductive silver epoxy (Circuit Works CW2400). This method has been used, e.g., in [8][9]. It is proved that this epoxy glue shows good conductivity and establishes a well-working electric interconnection between antenna and IC. In the second method, the IC pads were embroidered on the tag antenna using Husqvarna Viking embroidery machine and conductive yarn (Shieldex multifilament thread 110f34 dtex 2-ply HC). The DC linear resistivity of the yarn is 500 ± 100 Ω/m, and the

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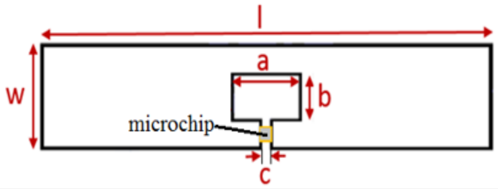
diameter is approximately 0.16 mm. This type of embroidered antenna-IC interconnection has been previously utilized with embroidered and electro-textile antennas [7][9]. Both types of tags studied in this paper are shown in Fig. 2.



a	b	c	W	L
14.3 mm	8.125 mm	2 mm	20 mm	100 mm

Fig. 1. Used RFID tag design.

Fig. 2. Ready RFID tags: Embroidered (top) and epoxy-glued (bottom) interconnections.

III. WIRELESS MEASUREMENTS

The wireless performance of the tags was evaluated using Voyantic Tagformance RFID measurement system. It contains an RFID reader with an adjustable transmission frequency (800-1000 MHz) 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.

During the test, we recorded the lowest continuous-wave transmission power (threshold power: Pth) of the fabricated tags. Here we defined Pth as the lowest 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. In addition, the wireless channel from the reader antenna to the location of the tested tag was first characterized using a system reference tag with known properties. This enabled us to estimate the attainable read range of the fabricated carbon-based passive UHF RFID tags (dtag) 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 measured 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 the RFID reader given as equivalent isotropic radiated power. We present all the results corresponding to EIRP = 3.28 W, which is the limit in European countries.

IV. MEASUREMNT RESULTS

The initial read ranges of the tags with epoxy-glued and embroidered antenna-IC interconnections were measured and they are presented in Fig. 3 and Fig. 4, respectively. As can be seen, initially all tags showed similar wireless performance and read ranges of 1.5 meters throughout the global UHF RFID frequency band of 860-960 MHz.

Next, the manufactured tags were stretched to 110 % of their initial length by hand for 100 and 200 stretching cycles. After continuous stretching, the read ranges of tags with embroidered antenna-IC attachments could still reach 1 meter. However, it was discovered that the epoxy-glued antenna-IC interconnections were easily broken during the stretching cycles, which is shown in Fig. 5.

Fig. 6 shows the cracking of the tag antenna after stretching cycles, which causes the decrease of the tag performance. Further, due to the reliability problems of the epoxy-glued interconnections, the tags with the embroidered interconnections were found to be more reliable towards harsh stretching.

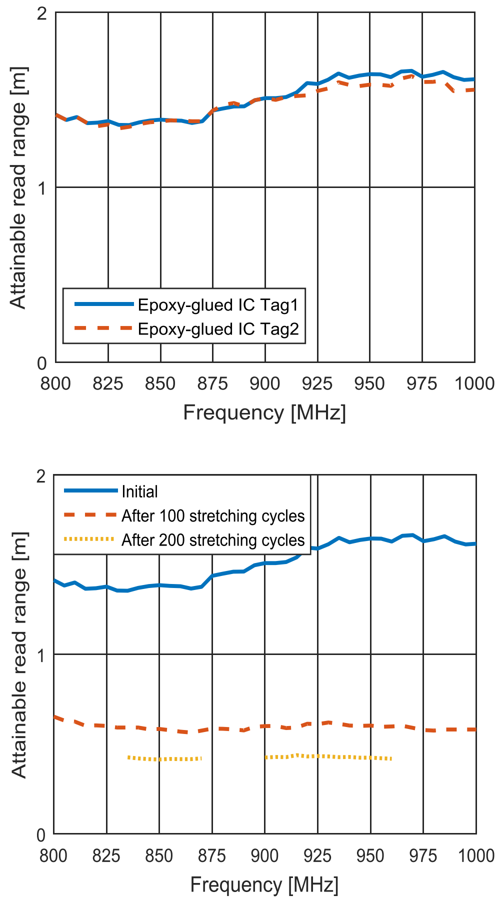


Fig. 3. Read ranges of tags with epoxy-glued interconnections: Two tags initially (top) and a tag after stretching cycles (bottom).

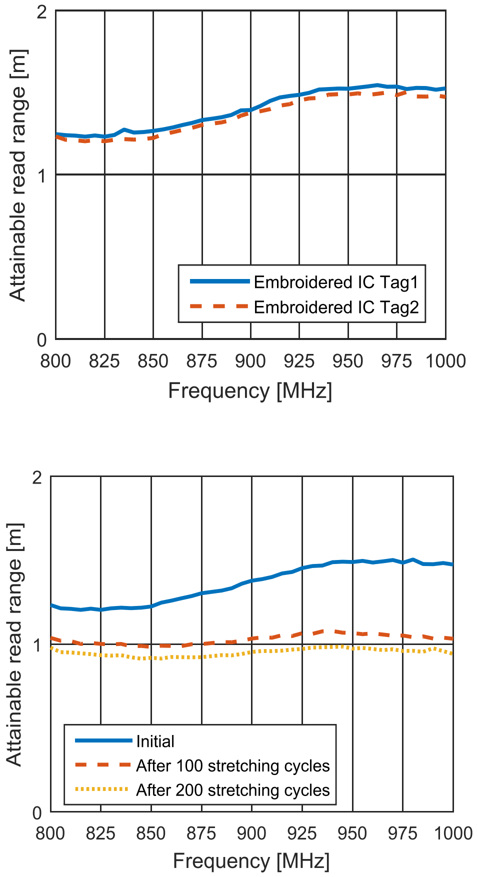


Fig. 4. Read ranges of tags with epoxy-glued interconnections: Two tags initially (top) and a tag after stretching cycles (bottom).

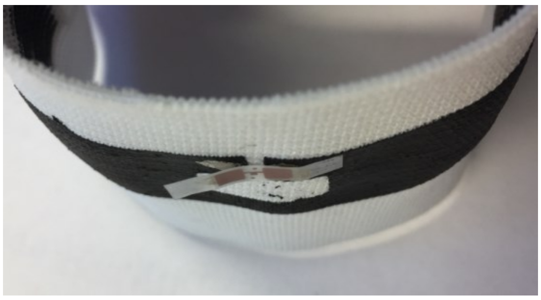


Fig. 5. Broken epoxy-glued antenna-microchip interconnection.

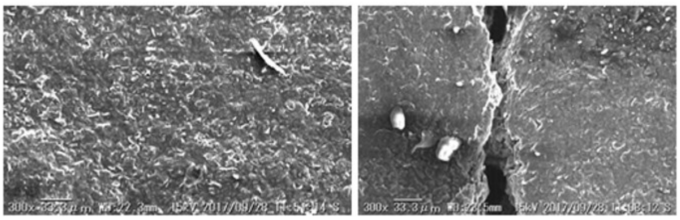


Fig. 6. Conductor layer on a textile substrate: Before any stretching (left) and cracked after 100 stretching cycles (right).

CONCLUSION

This paper presents new type of carbon-based stretchable antennas for passive UHF RFID tags. The tag antennas were brush-painted on a stretchable elastic band and their strain reliability was evaluated. Further, two types of antenna-IC interconnection methods were compared in this study: We established the IC attachment with conductive glue and by embroidering with conductive yarn. Both types of tags showed similar initial read ranges of around 1.5 meters, which are suitable for versatile textile-integrated RFID applications. In addition, it was concluded that tags with embroidered antenna-IC interconnections are more robust towards continuous stretching. Future research work will include additive fabrication methods for the carbon-based conductor, especially 3D direct write dispensing will be studied. Further, we will study more ways to combine embroidered structures into conductive ink-based antennas.

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