The Effects of Added Clothing Layers on the Performance of Wearable Electro-Textile UHF RFID Tags

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Abstract

In this paper, we study the effects of added clothing layers on the performance of wearable electro-textile passive UHF RFID tags. The electro-textile tag antennas were ironed on the upper back of cotton T-shirts with hot-melt glue and coated with a stretchable protective encapsulant. The wireless performance of the tags was evaluated on-body in office conditions. We tested the effects of wearing two types of winter coats on top of the T-shirts. Based on our measurement results, adding a thick coat on top of the T-shirt does not stop the tag from working but reduces the peak read range from 7 meters to 5 meters. The fabricated electro-textile tags remained readable from distances of 2-5 meters, throughout the global UHF RFID frequency band, even when a thick winter coat was worn on top of the T-shirt.

1. Introduction

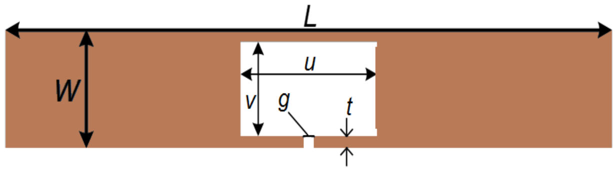
Antennas are critical enabling parts of wearable wireless solutions and thus an active research area. Conductive fabrics, i.e., electro-textiles, are a great example technology, which can be used to utilize cost-effective antennas for clothing-integrated solutions. Electro-textile materials are easy to cut and can be unnoticeably embedded into traditional textiles, for example by using hot-melt glue [1-2].

Passive ultra high frequency (UHF) radio-frequency identification (RFID) technology, which is the focus of this study, has gained a lot of interest as a versatile wearable wireless platform [3-6], mostly due to the simple structure and low cost of the passive UHF RFID tags. The battery-free and remotely addressable electronic tags, composed only of an antenna and an integrated circuit (IC), are readable from distances of several meters, which is extremely suitable for wearable applications. The simple structure also makes it easy to integrate these tags into clothing.

In this paper, we study the effects of added clothing layers on the performance of wearable electro-textile UHF RFID tags. We first introduce the simple fabrication method of the electro-textile tags integrated into T-shirts. Next, we evaluate their wireless performance on-body in an office environment. Finally, we test the effects of wearing two types of winter coats on top of the T-shirts, on the tags' wireless performance.

2. Fabricated Tags

Figure 1 presents the used antenna and antenna dimensions. This wearable dipole antenna design has been originally presented in [8]. It has been optimized to perform near the human body by using a human body model in ANSYS HFSS version 15.



t	*g*	*L*	*W*	*u*	*v*
2	2	120	20	27	16

Figure 1. The design and dimensions of the UHF RFID tag antenna in [mm].

The RFID tags were fabricated on the upper back of a 100 % cotton T-shirt. The electro-textile tag antennas were utilized from nickel plated Less EMF Shieldit Super Fabric (Cat. #A1220), which has a layer of hot-melt glue on the backside. These antennas were cut from the electro-textile material with scissors and then ironed directly on the cotton T-shirts. The electro-textile material has a sheet resistance of approximately 0.16 Ω/□.

The used IC is NXP UCODE G2iL RFID IC, provided in a strap that has copper pads on a plastic film, which we attached to the electro-textile antennas using conductive epoxy (Circuit Works CW2400). The used IC has a wake-up power of −18 dBm (15.8 μW) and the strap structure is presented in Figure 2.

Finally, to protect the fabricated RFID tags from their harsh use environment, especially considering the effects of moisture and the need for continuous washing cycles, both sides of the tags were coated with a stretchable protective encapsulant (DuPont PE772). This flexible coating has previously been found to be an effective way to protect copper-textile and embroidered RFID tags from the effects of moisture and machine washing [2]. As our goal is also to make these T-shirt tags reliable in normal use, the coating is essential. The coating was brush-painted to fully cover the tags and the coated tags were dried in 100 ºC for 60 minutes. An example of a ready passive UHF RFID tag attached into a T-shirt is shown in Figure 2.

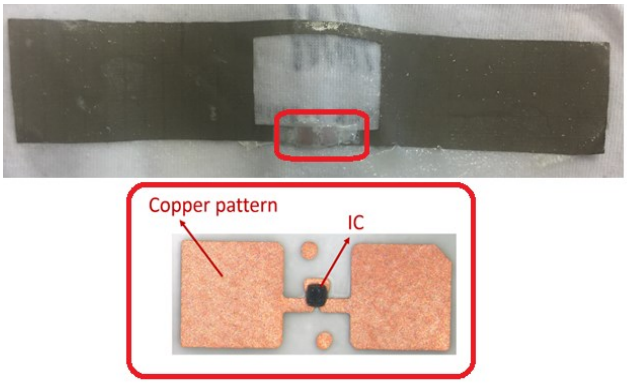


Figure 2. A ready electro-textile RFID tag attached into a T-shirt (top) and the used IC strap structure (bottom).

3. Wireless Measurements

The wireless performance of the tags was evaluated using Voyantic Tagformance RFID measurement system. This system contains an RFID reader with 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: P_{th}) of the fabricated T-shirt tags. Here we defined P_{th} 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 T-shirt tag under test was first characterized using a system reference tag with known properties. 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, Pth is the measured threshold power of the T-shirt tag, Λ is a known constant describing the sensitivity of the system reference tag, $Pth*$ 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.

The backscattered signal power is the time-average power detected from T-shirt tag's response at the receiver. It was measured by using the threshold power as the reader transmitted power. The backscattered power of the tag at the receiver $P_{backscattered}$ is:

$$P_{backscattered} = P_{th} G_{tag}^2 G_t^2 \left(\frac{\lambda}{4\pi d}\right)^4 \alpha|\rho_1 - \rho_2|^2 \qquad (2)$$

where P_{th} and λ are as in (1), G_{tag} is the gain of the tested tag antenna, G_t is the gain of the reader (transmit/receive) antenna, d is distance from the tag, ρ_1 and ρ_2 are the power wave reflection coefficients of the tag in two different chip impedance states (used for modulating the backscattered signal) and α is a coefficient that depends on the specific modulation details.

For the wireless measurements, a male test subject wore the T-shirt and stood in a distance of 1 meter from the RFID reader antenna. Initially, the subject wore the T-shirt with the attached RFID tag on top of a thin long sleeve shirt, as presented in Figure 3.

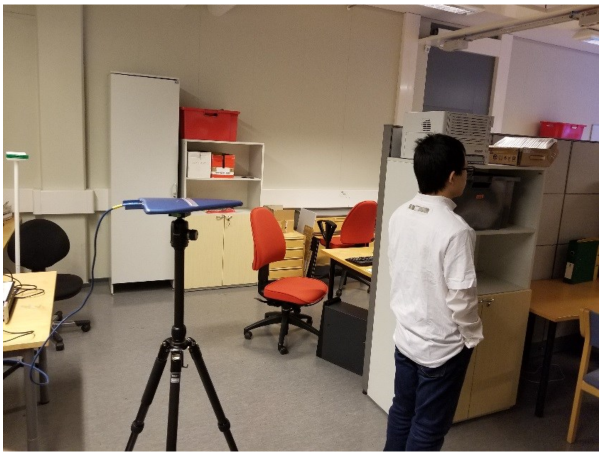


Figure 3. The initial measurement setup: T-shirt on top of a thin long sleeve shirt.

Figure 4. The second measurement setup, where a thin winter coat is worn on top of the T-shirt.

Next, a thin coat, which was a 3 mm thick down jacket, was added on top of the T-shirt, as shown in Figure 4, and the performance of the tag was measured again. Finally, a thick coat, which was a 10 mm thick down jacket, was added on top of the T-shirt and the tag was measured. All the on-body measurements were completed in a normal office environment, including office furniture, as shown in Figures 3-5.

Figure 5. The last measurement setup, where a thick winter coat is worn on top of the T-shirt.

4. Measurement Results

The wireless measurements results of an example T-shirt tag in the frequency range of 800-1000 MHz are presented in Figures 5 and 6. Firstly, Figure 5 shows the measured backscattered signal power from the tested tag. Next, Figure 6 presents the attainable read range results of the tag.

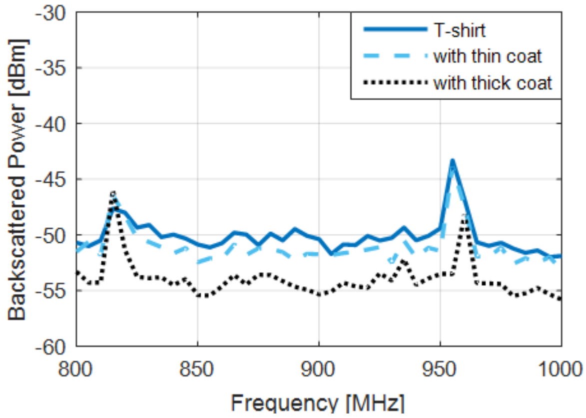


Figure 6. Wireless measurement results: backscattered signal power.

As can be seen, the peak read range and the best wireless performance of the tag is originally placed between 860-870 MHz, which is around the European center frequency. The initial peak read range of the tag, when measured on-body in normal office conditions, is around 7 meters. Further, the tag is readable from a distance of around 4 meters in the frequency range of 800-1000 MHz. Thus, the tag works in a suitable way all over the global UHF RFID frequency band.

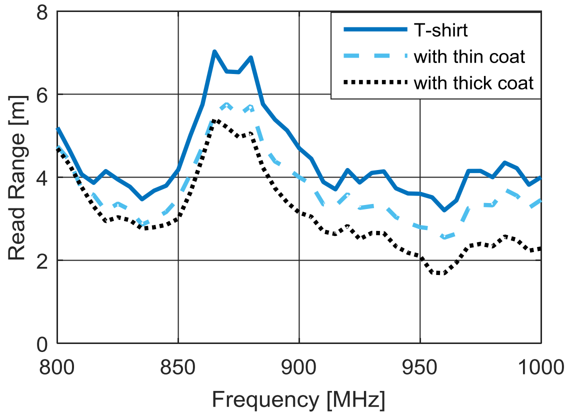


Figure 7. Wireless measurement results: read range.

Based on these measurement results, the winter coats have an effect on the tag read range: Adding the thin coat on top of the T-shirt drops the read range to slightly below 6 meters, to around 5.8 meters. Further, adding the thick coat over the T-shirt drops the read range further, to slightly over 5 meters. However, the tags remain readable from distances of 2-5 meters, throughout the global UHF RFID frequency band. These read ranges are more that suitable for many practical applications and thus using these passive UHF electro-textile RFID tags under thick clothing layers should not be a problem. However, for further conclusions, measurements need to be carried out from different directions and with different materials worn on top of the T-shirts.

5. Conclusions

We fabricated electro-textile passive UHF RFID tags integrated into T-shirts. The ready tags were coated with a protective encapsulant and their on-body wireless performance was evaluated initially as well as under two types of winter coats. The initial read ranges of the tags, when measured on-body, were around 4-6 meters in the global UHF RFID frequency band, while the peak read range was 7 meters. Adding a thick coat on top of the T-shirt did not stop the tags from working but reduced the peak read range to 5 meters. Throughout the UHF RFID frequency range, the tags remained readable from distances of 2-5 meters. In our next paper, we will present washing reliability results of these T-shirt tags. Following, we will test integration of these electro-textile tags into different types of clothing and evaluate the tag performance under different types of clothing layers. Further, the plan is to evaluate the wireless performance of several wearable tags in one T-shirt at the same time.

6. Acknowledgements

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7. References

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