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Comparison of Wearable Passive UHF RFID Tags based on Electro-Textile Dipole and Patch Antennas in Body-Worn Configurations

Zhigang Wei[1], Aruhan Liu[1], Xiaochen Chen[2], Bilal Waris[2], Leena Ukkonen[2], Toni Björninen[2], Johanna Virkki[2]

[1]Department of Electronic Engineering
City University of Hong Kong
83 Tat Chee Avenue, Kowloon, Hong Kong

[2]Department of Electronics and Communications Engineering
Tampere University of Technology
Tampere, FI-33101, Finland

***Abstract* — We compare wearable passive UHF RFID tags based on dipole and patch antennas comprising electro-textile conductor on a light-weight and conformal textile substrate. The tags' wireless performance was evaluated when attached to the upper back of a test subject. Despite the fundamentally different structures and electromagnetic operation mechanisms of the antennas, both tags attained read ranges of several meters. In the optimized configuration, the patch tag achieved slightly higher performance, but was found to be more sensitive toward variable antenna-body separation.**

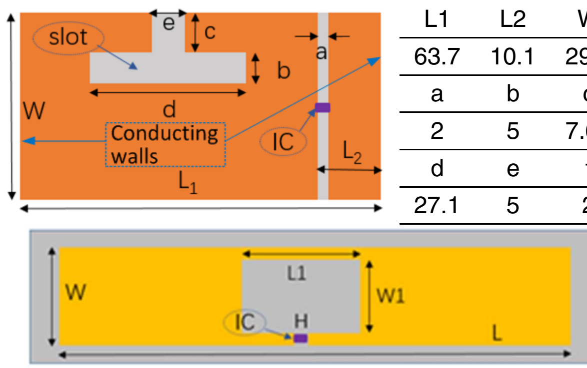
***Index Terms* — Wearable antenna, dipole antenna, patch antenna, electro-textile, RFID.**

I. Introduction

Passive UHF (ultra-high frequency) RFID (radio-frequency identification) tags are a compelling approach for the development of low-power wireless monitoring and communication devices in the internet of things and wireless body area networks (WBAN) [1–2].

Wearable antennas are enabling blocks in WBANs, but a fundamental challenge 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. These phenomena are more pronounced for single-layer antennas [3], such as dipoles and slot-type radiators as compared with common multi-layer antennas, such as microstrip patch [4] and planar inverted-F antenna [5], which benefit from the antenna-body isolation provided by the ground plane. However, the cloth-integration of stacked interconnected conductor layers is generally more challenging.

In this work, we compare the performance of wearable passive UHF RFID tags based on dipole and microstrip patch antennas. The tags are worn at various separations from the body and their read range coverage around the subject is evaluated through wireless measurements.



L1	L2	W
63.7	10.1	29.8
a	b	c
2	5	7.68
d	e	t
27.1	5	2

L	W	L1	W1	H
120	20	27	16	2

Fig. 1. Structural diagrams of PT (top) and DT (bottom). Dimensional parameters are given in millimeters.

II. Structure of the Compared Tags

Fig. 1 shows the structural diagram of both studied tags. The studied dipole tag (DT) is based on a straight dipole antenna with an embedded inductive matching loop and the microstrip patch tag (PT) comprises a slotted radiating patch that is connected to the ground plane from the two opposite edges, as indicated in Fig. 1. Structure of PT originates from [6–7] where it was first developed for a metal mountable tag implemented on regular circuit board and then re-optimized as a wearable electro-textile antenna.

The shape of DT has been previously used in an electro-textile strain sensor tag [2]. As a part of the current work, we re-optimized its dimensions through full-wave electromagnetic simulation to achieve maximal tag read range in the body-worn configuration. The simulation process was identical to that described with details in the case of PT in [7] .

To achieve a light-weight and conformal structures compatible with textile manufacturing, both antennas were manufactured using nickel- and copper-plated Less EMF Shieldit Super Fabric (Cat. #A1220) as the electro-textile conductor and EPDM (Ethylene-Propylene-Diene-Monomer) cell rubber foam as the substrate. The electro-textile exhibits a sheet resistance of approximately 0.16 Ω/sq and the dielectric constant and loss tangent of EPDM are 1.26 and 0.007, respectively, at the targeted operation frequency of 915 MHz. The tag antennas were optimized on 2 mm EPDM with the body directly beneath them.

The RFID IC used in both tags was NXP UCODE G2iL RFID IC (wake-up power: −18 dBm or 15.8 µW), which was provided in a fixture made of copper on a plastic film with 3×3 mm^2 pads. Circuit Works CW 2400 conductive epoxy was used to attach the fixture pads to the electro-textile.

III. Wireless Testing Procedure

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. 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 with details in [2], this enabled us to estimate the attainable read range of the tag (d_{tag}) versus frequency from

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

where d_{tag} 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* = 3.28 W is the emission limit of an RFID reader e.g. in European countries.

All measurements were conducted with the studied tag attached to the upper back of a male test subject as shown in Fig. 2. In the measurements, P_{th} was recorded from 0.8 GHz to 1 GHz with the steps of 2 MHz. To assess the spatial coverage of the tag, the subject rotated 360° with steps of 45° with respect to the stationary transmitting/receiving antenna and the frequency sweep was repeated at each rotation step. Prior to measurement the channel characterization was conducted in the absence of the test subject as the measurement system reference tag is not platform-tolerant, i.e. Λ is not valid if the tag is placed near the body. However, the multipath contribution due to the scattering from the test subject is readily identified as fluctuations in d_{tag} versus frequency graphs which are not characteristic to the radiation properties of neither of the studied tag antennas.

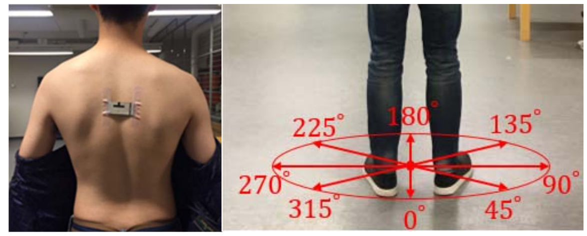


Fig. 2. Tag under test attached to a test subject's upper back during the measurements.

IV. Results and Discussion

The result for DT worn directly on the body as well as on additional 5 mm and 10 mm EPDM separators are presented in Figs. 3–4, respectively. When worn directly on the body, the tag achieves d_{tag} of approximately three meters when it is facing the reader antenna (direction of 0°) and maintains d_{tag} above two meters at the directions of 45° and 315°. As expected, at directions where either the dipole axis is pointing toward the reader (directions 90° and 270°) or the body is in between the tag and the reader antenna, d_{tag} is reduced. However, it still remains above one meter. Overall, the addition of separating EPDM layers is seen to have little impact on d_{tag} although it improves d_{tag} in the line-of-sight directions 0°, 45°, and 315° slightly.

Fig. 4 presents the results for PT worn directly on the body. It achieves the peak d_{tag} of 4.7 meters near 890 MHz from directions of 0° and 45°. In other directions, expect for 180° and 270°, the tag maintains the peak d_{tag} above 2.6 meters. The measurement results on different antenna-body separations follow the same trend, but d_{tag} reduces as the separation increases. Consequently, the tag fails to respond from directions between 135° and 225°, but maintains d_{tag} above 2.5 meters from the line-of-sight directions, i.e., from the directions of 0°, 45°, 90°, and 315°.

Based on the results, the main differences between the studied tags is that d_{tag} of DT remains stable with different antenna-body separations with slight improvement with increased separation, whereas d_{tag} of PT reduces more with the increasing separation. Moreover, the frequency response of DT is relatively flat due to its inherently broader bandwidth and lower efficiency compared with PT. This reduces the impact of uncertainty in the antenna frequency tuning and manufacturing on its operation. Overall, from line-of-sight directions, both tags achieved read ranges above 2.5 meters, which enables many practical applications. In terms of the size and shape, DT provides a simpler single-layer structure, whereas PT comprises interconnected conductor layers. On the other hand, the footprint of DT is larger compared to PT.

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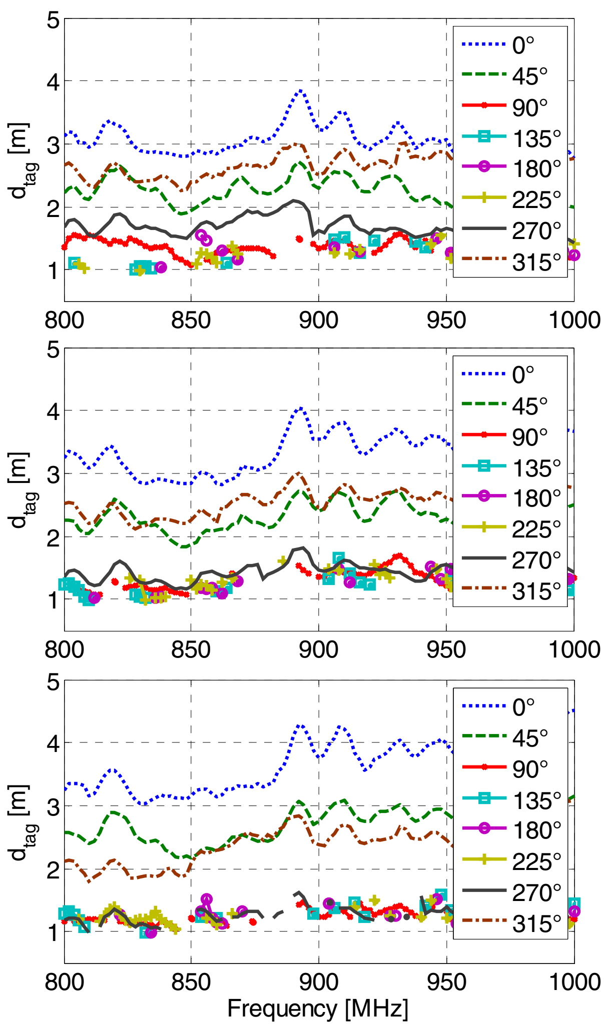

Fig. 3. d_{tag} of DT worn directly on body (top) and at 5 mm (center) and 10 mm separations (bottom).

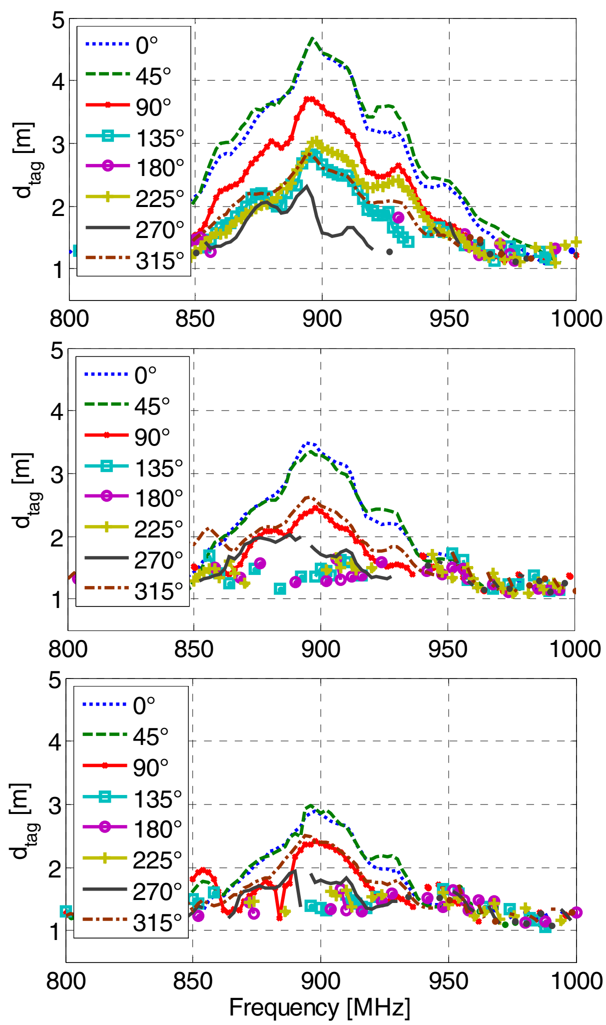

Fig. 4. d_{tag} of PT worn directly on body (top) and at 5 mm (center) and 10 mm separations (bottom).