Small square-shaped slot antenna for wearable passive UHF RFID tags

Small Square-Shaped Slot Antenna for Wearable Passive UHF RFID Tags

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***Abstract*—We present a slot antenna with the footprint size of 4×4 cm^2 (0.12λ×0.12λ at 915 MHz) for wearable passive UHF RFID tags. In addition to the main radiating slot, cuts made into the surrounding conductor increase the antenna radiation efficiency and help to self-match the antenna impedance with the RFID microchip in the body-worn configuration. Antenna structure is uniplanar and optimised for a low-permittivity textile substrate. The measured attainable read range of the tag is 2.5 metres when affixed to the upper back of a test subject.**

Keywords—Wearable antenna, Radio-frequency identification

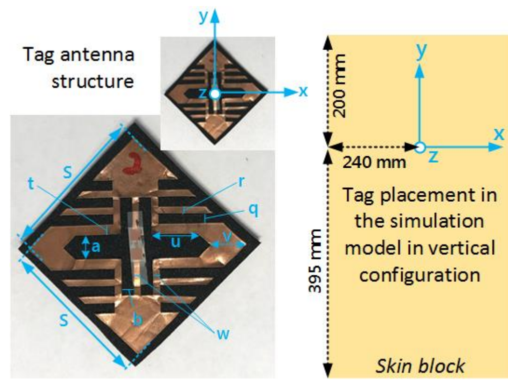
I. Introduction

WBAN (wireless body area network) technologies have gained a lot of research attention during the recent years, as they can offer remarkable benefits for the healthcare and welfare sectors [1]–[4]. Especially passive UHF (ultra-high frequency) RFID (radio frequency identification) inspired technologies have been recognized as a compelling approach to achieve versatile energy- and cost-efficient wireless solutions for future WBANs [1]–[4]. With the help of wearable passive UHF RFID equipment, the remote monitoring of movement and physiological parameters of a person can be achieved unobtrusively. The technology could be utilized in hospitals and used to move healthcare tasks from hospitals to home environments [5]–[8].

The main challenge in wearable antennas comes from the proximity of the human body: the dielectric biological material has notable electrical conductivity and polarizability. This leads to reduction in the antennas' radiation performance through the consumption of energy in the interaction between the antenna's electromagnetic fields and the human body. In this study, we present a small slot antenna for wearable passive UHF RFID tags. It has a footprint of only 4 × 4 cm^2 and uniplanar structure on a thin (2 mm) and low-permittivity textile substrate (Ethylene-Propylene-Diene-Monomer, ε_r=1.26, tanδ=0.007 at 915 MHz).

II. Antenna Structure and Simulation Model

To account for the influence of the human body on the electromagnetic properties of the antenna, we simulated it on a 26 cm × 48 cm × 59.5 cm rectangular cuboid having the dielectric properties of skin given by the four-term Cole-Cole relaxation model [9] (ε_r = 41.3, σ = 0.87 S/m at 915 MHz). We selected the size of this skin block to approximate the dimensions of the torso of an adult male. Fig. 1 presents the antenna structure and simulation model, and indicates the tag placement in the skin block model. It corresponds to the centre of the upper back in between the scapula. The antenna structure was inspired by our earlier study of a slot antenna for general-purpose passive UHF RFID tags [10]. In the present study, we show that a similar structure can be adapted to function well in the proximity of the human body. We also report marked reduction in the size of the antenna and simplifications to its the geometry as compared to [10].



Param.	S	a	b	u	v
Value [mm]	40	6	3	12	9.28
Param.	w	r	q	t	
Value [mm]	2	1.90	2.5	2.80	

Fig. 1. Antenna structure and the simulation model.

Normally, the forward link operation, i.e., the efficiency of the wireless power transfer from the reader to the tag IC (integrated circuit) limits the read range of passive tags. Assuming free-space conditions for site-independent comparison, the attainable tag read range at the spatial observation angles φ and θ of a spherical coordinate system centred at the tag is given by

$$d_{tag}(\phi,\theta)=\frac{\lambda}{4\pi}\sqrt{\left\{\frac{4\,\mathrm{Re}(Z_A)\mathrm{Re}(Z_{IC})}{|Z_A+Z_{IC}|^2}\right\}\frac{e_r D(\phi,\theta) EIRP}{P_{ic0}}}, \qquad (1)$$

where λ is the wavelength of the carrier tone emitted by the reader, *EIRP* is the regulated equivalent isotropic radiated power, P_{ic0} is the wake-up power of the tag IC, e_r is the tag antenna radiation efficiency, D is the tag antenna directivity, and the factor in the curly brackets is the antenna-IC power transfer efficiency (τ) determined by the antenna and IC impedances Z_A and Z_{IC}, respectively.

The software package we used in antenna modelling and optimisation was ANSYS HFSS. Our target was maximising the product $\tau \cdot e_r$ as both factors were influenced strongly by the geometrical parameters in Fig. 1, whereas D was approximately independent of them. Below, we present all the read range results corresponding to $EIRP$ = 3.28 W (emission limit e.g. in European countries) in the direction of the positive z-axis in Fig. 1. The RFID IC we used is NXP UCODE G2iL RFID IC, provided in a fixture made of copper on a plastic film with 3×3 mm^2 contact pads. We attached the pads to the antenna using conductive epoxy (Circuit Works CW2400). The chip has the wake-up power of −18 dBm (15.8 μW) and we modelled it as a parallel connection of the resistance and capacitance of 2.85 kΩ and 0.91 pF, respectively.

III. Results and Discussion

In the simulations, we noted that antenna self-matching within the 4×4 cm^2 footprint was not possible by optimising the main slot (params. a, b, u, v, w in Fig. 1) alone. To elevate both Re(Z_A) and Im(Z_A) to the appropriate levels shown in Fig. 2, we found the additional cut-outs (params. r, q, t in Fig. 1) to be an effective strategy. This also improved e_r. Initially, we optimised the antenna in vertical configuration shown in Fig. 1. Here its electric field oscillates vertically along y-axis. If the antenna is rotated 90° in the xy-plane to a horizontal configuration, its impedance matching and radiation efficiency remain unaffected (τ=93%, e_r=1.1%), but its radiation pattern changes. The directivity towards the positive z-axis in Fig. 1 is 6.1 dBi and 4.6 dBi at 915 MHz in the vertical and horizontal configurations, respectively. Consequently, d_{tag} is different in the two configurations as shown in Fig. 3.

We tested the tag 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}) 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 tag under test was characterised using a system reference tag with known properties. As explained with details in [11], this enabled us to estimate the attainable read range of the tag. Fig. 3 shows the results. The simulations and measurements are in good agreement and the peak read range of 2.5 metres verifies a compelling size-performance ratio for small wearable tags.

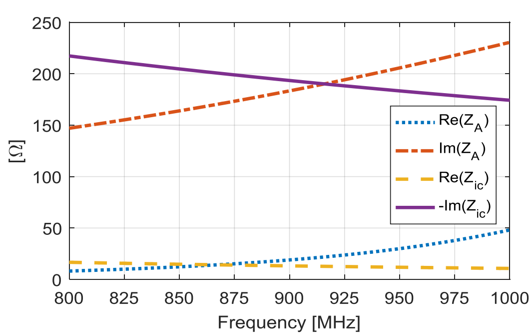


Fig. 2. Simulated antenna impedance and the complex conjugate of the RFID microchip impedance.

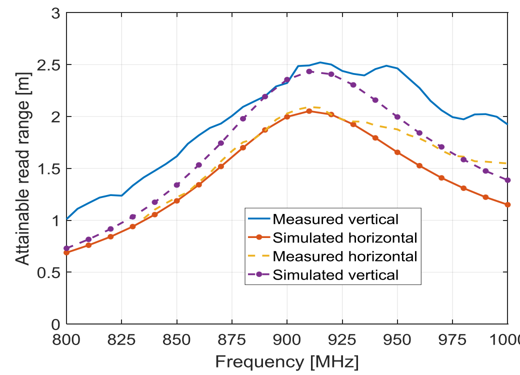


Fig. 3. Simulated and measured d_{tag} toward the positive z-axis in Fig. 1.

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