



Wearable passive UHF RFID tag based on a split ring antenna

Citation

Waris, B., Ukkonen, L., Virkki, J., & Björninen, T. (2017). Wearable passive UHF RFID tag based on a split ring antenna. In *Proceedings of 2017 IEEE Radio and Wireless Symposium* (pp. 55–58). IEEE. <https://doi.org/10.1109/RWS.2017.7885944>

Year

2017

Version

Peer reviewed version (post-print)

Link to publication

[TUTCRIS Portal \(http://www.tut.fi/tutcris\)](http://www.tut.fi/tutcris)

Published in

Proceedings of 2017 IEEE Radio and Wireless Symposium

DOI

[10.1109/RWS.2017.7885944](https://doi.org/10.1109/RWS.2017.7885944)

Copyright

© 2017 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

Take down policy

If you believe that this document breaches copyright, please contact cris.tau@tuni.fi, and we will remove access to the work immediately and investigate your claim.

Wearable Passive UHF RFID Tag based on a Split Ring Antenna

Bilal Waris, Leena Ukkonen, Johanna Virkki, Toni Björninen

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

Abstract — We present the development and performance evaluation of a wearable passive UHF RFID tag based on a split ring antenna that is electromagnetically optimized for operation in the close proximity of the human body. The antenna is composed of a single conductor layer and created on a light-weight textile substrate. Our results show that the split ring antenna provides stable performance for the tag placed at different distances from the body, as well as in air. This is an advantageous feature for cloth-integrated tags with generally unspecified antenna-body separation.

Index Terms — Split ring antenna, wearable antenna, RFID

I. INTRODUCTION

Wireless body area networks (WBAN) are an increasingly important area of research and offer a great potential for monitoring and communication in versatile application areas, such as in healthcare, welfare, and public safety [1–3]. The passive UHF (ultra-high frequency) RFID (radio frequency identification) technology based on battery-free ultra-low-power tags is a compelling approach for tracking people and for the development of wireless sensors in WBANs. Further, the RFID enabled sensor tags are envisioned to provide remote monitoring of physiological parameters in assisted living and bedside applications in hospitals [4–5].

In the applications of wireless technology in body-centric systems, the fundamental challenge for antenna development raises from the proximity of the human body, which is composed of highly dissipative biological tissues with high dielectric constants. This generally limits the antenna radiation efficiency and prompts the need for the optimization of the antenna impedance in the body-worn configuration. In comparison with single-layer antennas, multi-layer structures, such as microstrip patches, achieve improvement in performance through the antenna-body isolation provided by the ground plane. However, for cloth-integration, simplistic conformal structures based on antennas made of single conductor layer are preferred. Previously, it has been shown that in a body-worn configuration, single-layer magnetic antennas based on slot-type radiators outperformed electrical dipoles [6].

In this work, we focus on studying the performance of another fundamental single-layer antenna, the split ring antenna in a body-worn configuration. To our knowledge, this is the first time a split ring tag has been studied for

wearable RFID tags. As an advantageous feature, it maintains its performance at various antenna-body separations down to two millimeters, as well as in air. This is a novel characteristic for wearable antennas based on a single conductor layer. Another benefit of this antenna type for RFID tags is that it exhibits inductive input impedance below the self-resonance. This enables the direct complex-conjugate impedance matching with RFID microchips, which have capacitive inputs [7].

II. DEVELOPMENT OF THE WEARABLE SPLIT RING TAG

The antenna development was initiated by considering the split ring antenna structure made of two concentric rings, as shown in Fig. 1. The smaller ring is the feed loop, where we mount the RFID IC (integrated circuit) and the larger one is the main radiating body, where the split gap is introduced.

The principle of operation of the split ring antenna is that a time varying magnetic field polarized perpendicular to the plane of the split ring resonator (SRR) induces circulating current on the feeding part, resulting in the magnetic field that goes out from the inside of the feeding loop to the outside of the feeding loop. Finally, in order to cancel this magnetic field, new magnetic field is induced near the radiating part. Hence, due to the split gap in SRR an opposite directional current is generated in the radiating part. It is actually the source to radiate into the free space [8]. The SRR gap provides rather larger capacitance and together with the inductance of the ring, resonates at a wavelength much longer than the size of the resonator.

We used copper tape (thickness 35 μm) as the antenna conductor and EPDM (Ethylene-Propylene-Diene-

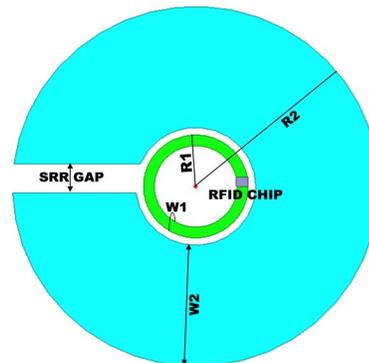


Fig. 1. Structural diagram of the studied split ring RFID tag.

TABLE I

BIOLOGICAL TISSUES PROPERTIES AT 915 MHz

Tissue	Skin	Fat	Muscle
ϵ_r	41.33	5.46	55.00
$\tan \delta$	0.414	0.185	0.339

Monomer) cell rubber foam as a substrate (thickness: 2 mm, $\epsilon_r=1.26$, $\tan\delta=0.007$ at 915 MHz). To approximate the impact of the human body on the antenna, right beneath the substrate, we stacked three large rectangles representing the dielectric properties of skin, fat, and muscle. Thickness of 2 mm, 2 mm, and 60 mm, respectively, were assigned to these layers. In the simulation, the dielectric properties of all of the biological tissues were based on the frequency-dependent four-term Cole-Cole dispersion model with the parameters provided in [9]. Table I lists the dielectric properties of the tissues at 915 MHz, which was the targeted frequency of operation.

This geometrically simplified body model enabled us to estimate the antenna impedance and radiation efficiency in the proximity of the body, as well the radiation properties of the antenna, when mounted on relatively large flat area of the body, such as the upper back. The development of the structure was based on electromagnetic (EM) modelling in ANSYS High Frequency Structure Simulator (HFSS) with the target of maximal tag read range at 915 MHz.

Normally, the read range of passive tags is limited by the forward link operation, i.e., the efficiency of the wireless power transfer from the reader to the tag IC. 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 centered at the tag is given by

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

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 determined by the antenna and IC impedances Z_A and Z_{IC} , respectively [4]. Equation (1) is a direct implication of Friis' equation combined with simple circuit analysis where a generator (representing the tag antenna) with internal impedance of Z_A is loaded with the RFID IC.

The RFID IC we used in this study was NXP UCODE G2iL series RFID IC with the wake-up power of -18 dBm ($15.8 \mu\text{W}$) and we modelled it as a parallel connection of the resistance and capacitance of $2.85 \text{ k}\Omega$ and 0.91 pF , respectively. In this work, we present all the read range results corresponding to $EIRP = 3.28 \text{ W}$ (emission limit e.g. in European countries) in the direction perpendicular to the

antenna surface away from the body.

Since the directivity of the split ring antenna remains relatively constant regardless of the exact antenna geometry, the goal in the antenna optimization was good complex-conjugate impedance matching between the antenna and IC

TABLE II

GEOMETRICAL DIMENSIONS OF THE ANTENNA IN [mm]

R1	R2	W1	W2	SRR gap	Chip gap
11.5	40	2.4	26.9	6.5	2

TABLE III

SIMULATED EM PROPERTIES OF THE TAG AT 915 MHz

	Z_A [Ω]	τ	e_r	D [dBi]	d_{tag} [m]
On body	$36+j196$	0.76	0.023	4.85	2.75
In air	$96+j35$	0.14	0.769	1.52	4.50

and as high as possible radiation efficiency in the body-worn configuration. The dimensions of the developed antenna are listed in Table II and the simulated EM properties on 2 mm EPMD substrate on body and in air at 915 MHz are given in Table III. The simulated d_{tag} versus frequency is presented along with the measured results in Section III.

Overall, the results in Table III show that in the body-worn configuration, the antenna-IC power transfer efficiency is high, because the antenna impedance was optimized for this scenario. However, the radiation efficiency is low due to the energy dissipation in the biological tissue. In comparison, in air the antenna-IC power transfer efficiency is low due to mistuned antenna impedance, but this negative impact is compensated by the elevated radiation efficiency. Finally, it can be noted that the presence of the body increases the antenna directivity by approximately 3.3 dB, which enhances d_{tag} in the body-worn configuration.

III. RESULTS FROM SIMULATIONS AND WIRELESS TESTING

A. 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}) 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 [4], this

enabled us to estimate the attainable read range of the tag in

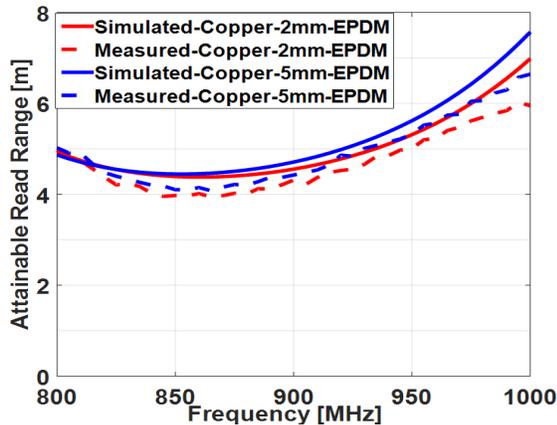


Fig. 2. Comparison of the simulated and measured attainable read ranges in air.

free-space.

B. Performance of the Tag in Air

As explained in Section II, the antenna was optimized for the maximal read range of the tag in the body-worn configuration. However, as shown by the results in Fig. 2, the tag exhibits very broad operation band and high read range also in air. This platform tolerance is a novel feature for wearable antennas based on a single conductor layer. Moreover, the simulated and measured results are in excellent agreement with the small deviations explained by the uncertainty in the hand-craft construction of prototype tags.

C. On-Body Performance of the Tag

To confirm the performance of the tag in body-worn configuration, measurements were conducted with the tag attached to the upper back of a male test subject. The results are presented in Table IV. Comparison with the simulation results in Fig. 3 confirms a good match between the measurement and simulation. Moreover, the tag achieved a high read range, above four meters, in the body-worn configuration. This correlates with the fact the tag antenna was optimized on the 2 mm substrate in body-worn configuration. However, it should be noted that good performance was maintained also on the 5 mm substrate, as well as in air, as explained earlier. This indicates that the tag can be integrated to clothes with variable thickness.

IV. CONCLUSION

We presented a wearable passive UHF RFID tag based on a split ring antenna. The antenna was optimized for operation in the proximity of the body. Measurements were conducted both in air and with the tag affixed in the upper back of a test subject. It was found to operate well both in air and body-worn at different antenna-body separations.

This is a new and a highly beneficial property for wearable

TABLE IV
MEASURED ATTAINABLE READ RANGE ON BODY [m]

Freq. [MHz]	800	820	860	880	900	920	940	1000
2mm EPDM	1.5	2	2.3	2.7	3.8	4	4.1	3
5mm EPDM	1.2	1.9	2.5	2.9	3	2.8	2.3	1.9

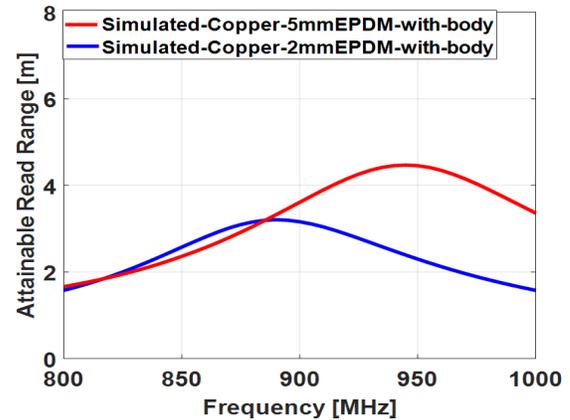


Fig. 3. Simulated attainable read ranges on body.

tags. Thanks to its single-layer structure, the developed tag is readily integrated into clothing for the use in various WBAN applications.

REFERENCES

- [1] P. Van Daele, I. Moerman, P. Demeester, "Wireless body area networks: status and opportunities," in *Proc. 2014 URSI GASS*, Beijing, P. R. China, 4 pages.
- [2] Ya-Li Zheng, Xiao-Rong Ding, Yuan-Ting Zhang, et al., "Unobtrusive sensing and wearable devices for health informatics," *IEEE Trans. Biomed. Eng.*, vol. 61, no. 5, pp. 1538–1554, May 2014.
- [3] S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, A. Jamalipour, "Wireless body area networks: a survey," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 3, pp. 1658–1686, Third Quarter 2014.
- [4] Feiyan Long, Xiaodong Zhang, T. Björninen, J. Virkki, L. Sydänheimo, Yan-Cheong Chan, L. Ukkonen, "Implementation and wireless readout of passive UHF RFID strain sensor tags based on electro-textile antennas," in *Proc. 2015 European Conf. Antennas Propag.*, Lisbon, Portugal, 5 pages.
- [5] S. Amendola, G. Boveseccchi, P. Coppa, G. Marrocco, "Thermal characterization of epidermal RFID sensor for skin temperature measurements," in *Proc. 2016 IEEE AP-S Intl. Symp. Antennas Propag.*, Fajardo, Puerto Rico, USA, pp. 461–462.
- [6] R. M. Mäkinen, T. Kellomäki, "Body effects on thin single-layer slot, self-complementary, and wire antennas," *IEEE Trans. Antennas Propag.*, vol. 62, no.1, pp. 385–392, Jan. 2014.
- [7] M. Polivka, A. Holub, M. Vyhnalik, M. Svanda, "Impedance properties and radiation efficiency of electrically small double and triple split ring antennas for UHF RFID applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 221–224, Feb. 2013.
- [8] J. B. Pendry, A. J. Holden, D. J. Robbins, W. J. Stewart "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microw Theory Techn.*, vol. 47, no. 11, pp. 2075–2084, Nov. 1999.
- [9] S. Gabriel, R. W. Lau and C. Gabriel, "The dielectric properties of biological tissues: III. parametric models for the dielectric spectrum of tissues," *Phys. Med. Biol.*, vol. 41, no. 11, pp. 2271–2293, Nov. 1996.