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Design of a Resistant Circularly Polarized Tag Antenna with high performances in the EU UHF RFID band

Khodor JEBBAWI^{*,1}, Matthieu EGELS², Philippe PANNIER³

Abstract—In this study, a novel resistant Radio Frequency Identification (RFID) tag with high performances is presented. The proposed tag consists of two antennas. The first one is an inductive antenna used for matching the imaginary part of the chip impedance at the target frequency. The second antenna is coupled with the first one in order to increase the gain and improve the tag performances. The tag antennas are designed to operate in the EU Ultra-High Frequency (UHF) RFID band. The crossed dipole antennas technique is used to achieve the Circular Polarization (CP) in the operating band. Many prototypes have been manufactured, and good agreement between simulations and measurements has been achieved. The band covered for an Axial Ratio (AR) < 3 dB is from 863 to 869 MHz. The Read Range (RR) of the tag has been measured in a standard anechoic chamber. From the measured results in EU RFID band, the tag has a maximum RR of about 16.35 m at 868 MHz.

Index Terms—RFID, UHF, Resistant Tag, CP, Antenna, Crossed-Dipole Antennas, Loop Antenna, Wireless.

I. INTRODUCTION

Nowadays, RFID wireless communication is used in various applications such as tracking, identifying objects, supply chain management [1, 2] and so on. As the RFID technology is employed in several domains, the RFID components (reader, tag) especially the tag should be able to operate in complex and hostile environments. The tag antenna acts as a power receiver for the chip and as radiating source that sends out information to the reader. Therefore, the role of the tag antenna in the RFID system is so important. For that, the high performances of the antenna are requested.

The state of art on the tag antenna illustrates that a CP antenna can be improve by 3 dB the power received by a tag, as well the maximum reading range can be increased by approximately 41%. Thus, the design of CP UHF tag antenna which able to resist to a harsh environments is actually one of the challenging topics in the RFID community. Many studies have been carried out on the CP RFID tags. The CP radiation can be achieved by the majority of the antenna types: dipoles, patch, loop and so on [3, 4, 5]. Crossed dipole antennas are attractive because they are simple, planar, easy to fabricate and easy to integrate into devices.

The proposed tag of this study is more specifically dedicated to the ETSI (865-868 MHz) band. This tag will be useful for

recovering the statistics of a football match through the following functional scenario: a wearable RFID reader antenna is placed on the ankle of the football player and it communicate with a RFID tags inserted inside the ball to get data that can be used to compute the match statistics. So, the aim of this study is to present a novel compact resistant UHF RFID tag with high performances. To increase the tag performances, the proposed design should be CP with high read range values. To make tag resistant to mechanical shocks, the tag chip is protected by wrapping it with epoxy resin.

II. TAG ANTENNAS

A. Description of the Structure

Fig. 1 shows the material composition of the tag. The RFID module consists of two components, chip Monza R6 [6] fixed on a small loop antenna (first antenna). Both are wrapped in a disk of epoxy resin ($\epsilon_r = 4.4$, $\tan \delta = 0.02$) with a thickness of 1 mm. Epoxy is used due to its good features such as high mechanical strength, resistance to heat and chemical properties of insulation [7]. These features of epoxy protect the chip and make the tag more resistant to mechanical shocks. As the first antenna is electrically very small ($\ll \lambda/2$), so it didn't have a good performances and couldn't be considered as a radiated antenna in the UHF band. In order to achieve a resistant tag with high performances, another antenna is added and coupled with the first one. The second antenna is etched on a semi-flex Taconic RF-35 substrate with a dielectric constant (ϵ_r) of 3.5 and thickness (h) of 1.52 mm.

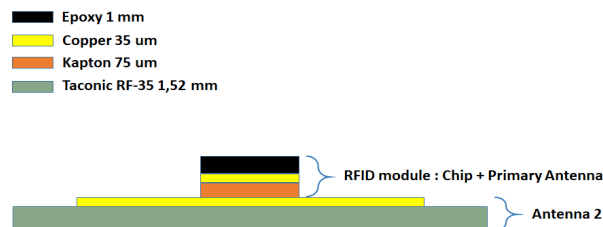


Fig. 1. Material composition of the tag.

B. RFID module: Chip with Loop Antenna

Fig. 2 shows the geometry of the loop antenna. This antenna is printed on a single metallic layer of a flexible dielectric substrate kapton ($\epsilon_r = 3.5$, $\tan \delta = 0.008$) which has a thickness of 0.075 mm. As shown in Fig. 2, the antenna is planar and consists of a multi-turn spiral coil. The perimeter of the first antenna is less than $\lambda/10$ in order to keep a constant current inside. The RFIC used is Monza R6 from Impinj. Monza R6 requires -20 dBm of wake-up power to activate itself. This chip has an impedance of $16 - j141$ at 868 MHz. As the first antenna is a small loop, so its impedance is inductive (positive imaginary part). The dimensions of loop is tuned so that its impedance matched the imaginary part of the chip impedance.

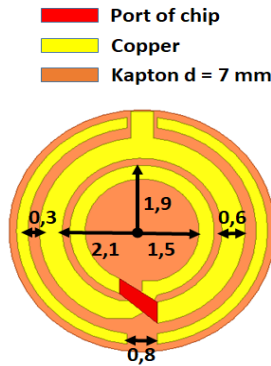


Fig. 2. Geometry of the loop antenna (units: mm).

C. Radiated antenna: Crossed dipole antennas

The main reason of adding a second antenna to the loop antenna is to amplify the RF signals radiated from the tag in the EU UHF RFID band (865 to 868 MHz). Circularly polarized antennas are usually recommended for wireless communication systems [6, 7] especially for RFID. Therefore, the second antenna is designed to achieve a CP radiation. As noted in [8], a conventional crossed dipole is used to produce CP radiation in the $\pm z$ direction. In this study, the approach of [8] is applied for designing the second antenna of the tag. Fig. 3 shows the structure of the proposed antenna. It is observed that the second antenna is formed of two-perpendicularly crossed dipole antennas. These dipoles are meandered in order to reduce the size of the antenna. All detailed parameters of the second antenna are summarized in Table I.

The parameters of the proposed antenna are tuned to achieve a CP at the resonance frequency which is 868 MHz. An antenna is CP when the profile of its surface current rotated at the resonant frequency. The surface current distribution on the antenna at 868 MHz for four different phase angles, from 0° to 270° respectively with an interval of 90° are shown in Fig. 4. As phase increases, the surface current vector \vec{J}_s rotates mainly clockwise as shown in Fig. 4. Therefore, the Left Handed Circulation Polarization (LHCP) is achieved at 868 MHz.

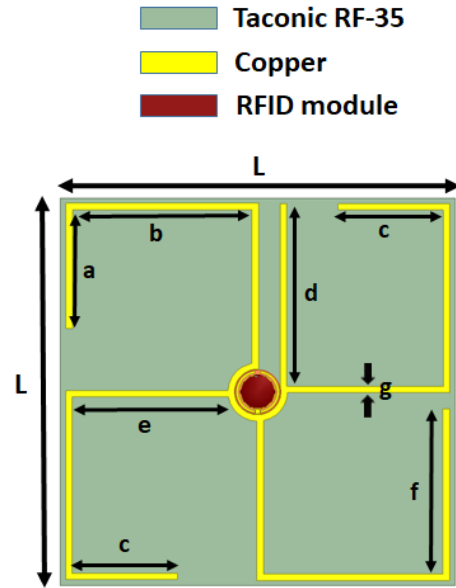


Fig. 3. Geometry of the proposed tag antennas.

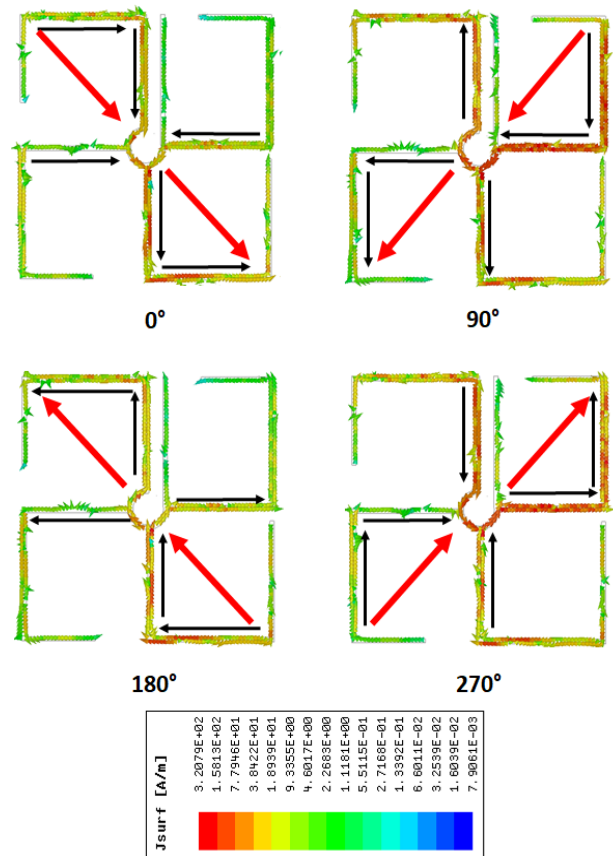


Fig. 4. Surface current distribution at 868 MHz.

TABLE I
PARAMETERS OF THE PROPOSED ANTENNA (UNITS: MM).

L	a	b	c	d	e	f	g
60	18.7	27.7	16.2	28.7	24.2	26	1

III. RESULTS AND DISCUSSION

The photograph of the manufactured tag is shown in Fig. 5. The maximum power transfer from the antenna to the RFIC is achieved when the reflection coefficient is the lowest in the target band. The expression of the reflection coefficient is shown in equation (1) [9].

$$\Gamma^* = \frac{Z_{ant} - Z_{chip}^*}{Z_{ant} + Z_{chip}} \quad (1)$$

Z_{ant} and Z_{chip} are respectively the antenna and chip impedances.

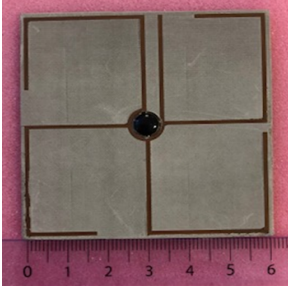


Fig. 5. Photograph of the tag.

Fig. 6 shows the simulated reflection coefficient of the tag antenna. Very good conjugate matching ($|\Gamma^*|_{dB} \ll -$) between the input impedances of the antenna and the chip was achieved especially in the EU RFID band (865–868 MHz). The axial ratio versus frequency is shown in Fig. 7. It is observed that a CP is attained with an AR < 3 dB at all the EU RFID frequencies.

The simulated gains of the tag are shown in Fig. 8. The circular gain is calculated from the linear gain by using the equation (2) [10]. As shown in Fig. 8, the higher circular gain (3.41 dBic) is achieved in the target band at 868 MHz.

$$G_{tag}[dBic] = G_{tag}[dBiL] + 3dB + 20 \cdot \log\left(\frac{1 + 10\left(\frac{-AR}{20}\right)}{2}\right) \quad (2)$$

The simulated read range (RR) is computed by using the following equation of [10]:

$$RR = \frac{\lambda}{4\pi} \sqrt{\frac{W_{EIRP} \cdot G_{tag}}{P_{min}}} \quad (3)$$

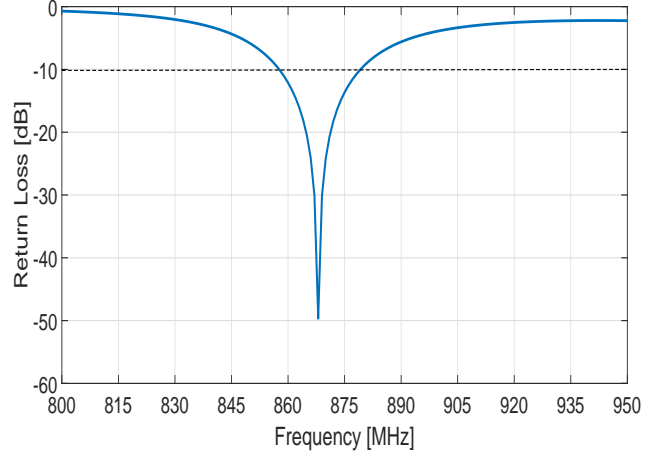


Fig. 6. Reflection coefficient of the proposed antenna.

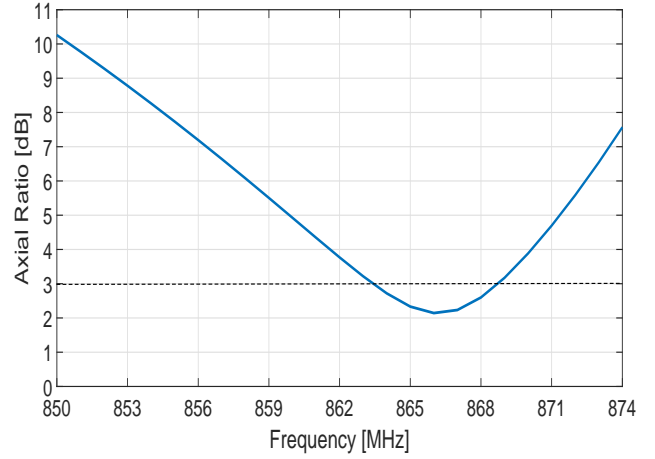


Fig. 7. Axial ratio of the antenna.

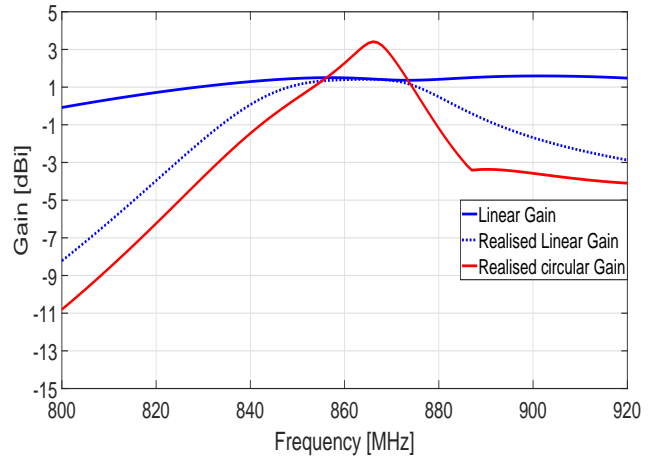


Fig. 8. Simulated gains against frequency.

Where, W_{EIRP} is the Equivalent Isotropic Radiated Power ($W_{EIRP} = 2$ W), λ is the wavelength, G_{tag} is the gain of the tag and P_{min} is the sensitivity of the chip (-20 dBm).

The reading distance of the tag is measured using an RFID bench. The bench is developed by National Instruments (NI-100 [11]) for RFID characterization especially for the tag. It can be used for measuring the maximum read range of an RFID tag in the free space.

The RR is measured for two polarizations, RR_{D1} and RR_{D2} are respectively the reading distances of the tag in the horizontal and vertical planes. Fig. 9 (c) shows the photograph of the RFID bench used for measuring the reading distance in horizontal (Fig. 9 (a)) and vertical (Fig. 9 (b)) orientations.

The simulated and measured results of RR for the two orientations (D1 and D2) are presented in Fig. 10. As shown in this figure the reading ranges measured for D1 are between 16.1 and 16.35 m at all CP frequencies (863 to 869 MHz). For D2, the values of RR are between 11.3 and 11.78 m. To insure the matching between the simulated and measured AR, the equation (4) is used to calculate the measured AR through the measured RR_{D1} and RR_{D2} [12].

$$\sqrt{AR_{measured}} = \sqrt{\frac{G_{tag,D1}}{G_{tag,D2}}} = \frac{RR_{D1}}{RR_{D2}} \quad (4)$$

At 868 MHz:

From Fig. 10: $AR_{measured} = (16.35/11.78)^2 = 1.92$

So $AR_{measured, dB} = 10 \cdot \text{Log}(1.92) = 2.84$ dB

From Fig. 7: $AR_{simulated} = 2.6$ dB

The results of the comparison between simulated and measured AR are in good agreement at the target frequency. The difference between RR for D1 and D2 is due to the non-zero value of axial ratio. The AR is the ratio between the minor (D1) and major (D2) axes of the polarization ellipse. So if the AR is equal to one (0 dB), the minor and major axes are the same. As the $AR_{measured}$ at 868 MHz is 2.84 dB ($\neq 0$ dB), the RR_{D1} and RR_{D2} are not equal but the polarization still circular ($AR_{measured} = 2.84$ dB < 3 dB).

Fig. 11 shows the simulated 3D radiation patterns of the tag antenna at 868 MHz. The radiation patterns of the antenna exhibit 8-shaped patterns which are due to the designed antenna made of dipoles.

To compare the performances of the proposed antenna to the CP tag antennas from literature, a metric called Figure Of Merit (FOM) is defined. The FOM is the ratio of the reading distance by the volume occupied by the tag. The FOM can be computed by:

$$FOM = \frac{\text{Read Range (m)}}{\text{Antenna volume (dm}^3\text{)}} \quad (5)$$

Table II shows the comparison between the antenna of this study and those from literature. All antennas literature operate in the UHF RFID frequency bands and having similar properties to the proposed one.

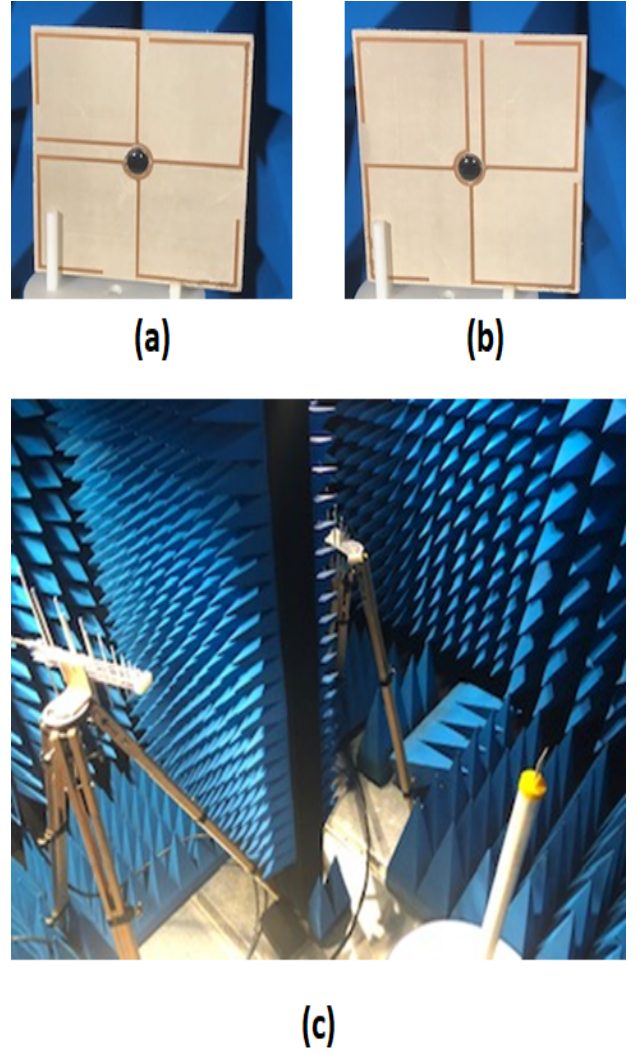


Fig. 9. Measurement setup of the RR in (a) horizontal (b) vertical plane.

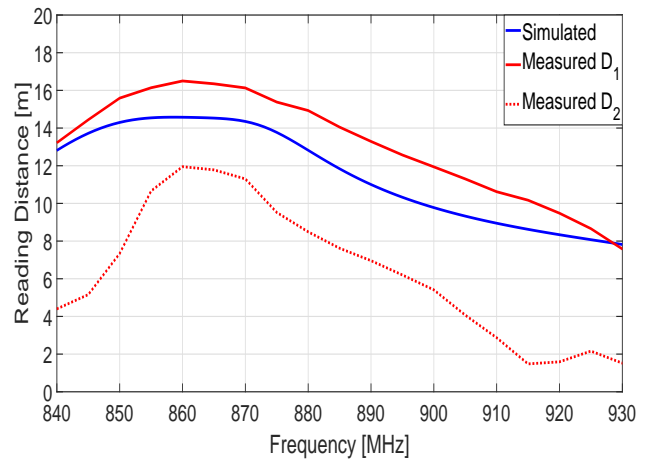


Fig. 10. Simulated and measured reading distance.

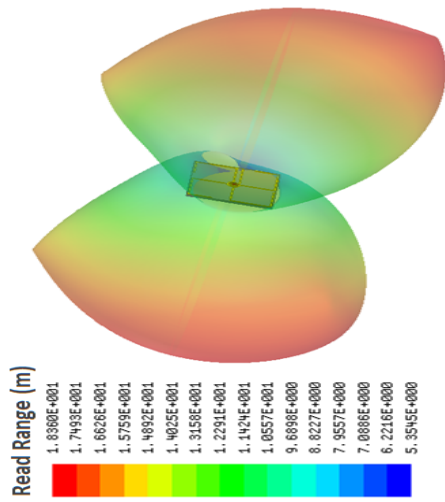


Fig. 11. Simulated 3D reading range pattern of the proposed antenna at 868 MHz

TABLE II
COMPARAISON TO STATE OF THE ART OF CP UHF-RFID TAGS

Antenna	Size (mm ³)	RR (m)	FOM
[13]	68 x 68 x 1	6.5	1.4
[14]	40 x 40 x 2	3.5	1
[15]	74 x 74 x 1.6	1.92	0.21
[16]	80 80 1.6	2.3	0.22
Proposed tag	60 x 60 x 1.52	16.35	3

IV. CONCLUSION

In this paper, a compact resistant UHF RFID tag with high performances is proposed. The proposed design uses two antennas coupled together. Crossed-dipole technique is applied to produce the CP radiation. The measured results are in good agreement with the predicted simulated ones. Measurement results of the read ranges in the vertical and horizontal orientations of the tag show that the AR < 3 dB from 863 MHz to 869 MHz. The tag is CP at all EU UHF RFID frequencies. The higher values of the circular gain and read range were respectively 3.41 dBiC and 16.35 m at 868 MHz.

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