Miniaturized Patch Antenna for the Radio Frequency Identification of Metallic Objects

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Abstract — **The growing interest in the Radio Frequency Identification (RFID) technology is giving rise to new applications, in particular for the identification of metallic objects. This interest has initiated the development of new designs for RFID tag antenna. This paper presents a UHF miniaturized patch antenna aimed at this application. The patch antenna is fed by a balanced feed to avoid a cross-layered construction and matched with a stub. Its miniaturization is achieved by inserting a u-shaped slot in the radiating patch.**

Index Terms — **Radio Frequency Identification (RFID), metallic object, balanced feed, u-slotted antenna.**

I. INTRODUCTION

A Radio Frequency Identification (RFID) system consists of: tags on each object to be tracked; a reader that requests/receives information from the tags; and a database that gathers the information to be processed.

This paper introduces the design of a passive UHF RFID tag, i.e. one that doesn't possess any kind of internal energy source. A passive UHF RFID tag consists of an antenna and a microchip containing the Identification Data (ID). It is activated and powered by the electromagnetic waves radiated or coupled by the reader. It responds via the modulation of its backscattering aperture. A detailed description of the physical concept can be found in [1]. General considerations for the design of passive UHF tags are described in [2].

Today the challenge for RFID systems is to perform in complex environments containing water based or metallic items. The radio frequency identification of metallic objects such as containers, trucks, cars, compressed gas cylinders etc. is particularly challenging. On the one hand, the surrounding metallic objects affect the RFID system and can create destructive interference. On the other hand the RFID tag antenna should be designed to perform in the vicinity of metallic objects. In close proximity, a conducting plane affects antenna properties including radiation efficiency, resonance frequency, and input impedance [3], [4]. Therefore, a tag antenna should be designed either by considering the coupling that exists within the metallic plane and the antenna or by choosing a design that includes a ground plane, resulting in a tag antenna that is unaffected by any object behind its ground plane. The second solution takes advantage of the metallic surface of the object to be tagged by increasing the antenna ground plane and therefore increasing the antenna gain, thus, improving the tag performances [5].

Many antenna structures consist of a ground plane like Inverted-F Antennas (IFA) [3], [4] or like microstrip patch antenna [6]. In this paper a patch antenna was preferred for its manufacturing simplicity, low cost, and low profile. The material used as a substrate is a low cost 1.58 mm thick FR4 having a relative permittivity of $\varepsilon r = 4.2$ and a loss tangent parameter $\tan\delta = 0.01$. The CST Microwave Studio® is used to perform the antenna structure. The original design is introduced in [6]. In this work, we put our efforts in its miniaturization. Size reduction diminishes the amount of material needed and therefore decreases one of the biggest manufacturing cost factors. Besides, smaller tags are more aesthetic for users.

This paper presents the input impedance measurement of the RFID chip mounted on strap before introducing the original RFID tag patch antenna and its miniaturization achieved by inserting a u-shaped slot. Simulation and measurement results are then introduced.

II. INPUT IMPEDANCE MEASUREMENT OF THE RFID CHIP

The RFID chip mounted on the tag antenna should be activated with low power at a maximum range. To improve the power transfer to the chip, the antenna input impedance Za has to be the complex conjugate of the chip impedance Zc. For this reason, the measurement of the chip input impedance is crucial.

RFID chips exist in many package formats. The EPCglobal Class 1, Generation 2 standard chip considered for this design is mounted on a strap and then fixed to the antenna through a Pressure Sensitive Adhesive (PSA). The presence of the strap and the PSA change the input impedance. The chip impedance was measured using the method proposed in [6]. Fig. 1 shows a picture of the test board that was designed on the FR4 substrate. The chip input impedance was measured with a HP8720D Vectorial Network Analyser (VNA) using a user-defined calibration kit consisting of the three loads shown on

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Fig. 2: an open circuit, a short circuit and a 50 Ω load. A 22 Ω surface mount resistance was also measured to validate this method. Using this setting an average value of Zc = 28 - j148 Ω at 915 MHz for the chip on strap impedance was measured in contrast with the value of Zc = 20 - j255 Ω specified for the chip without the strap. Fig. 3 shows the Smith chart with the measurement results.

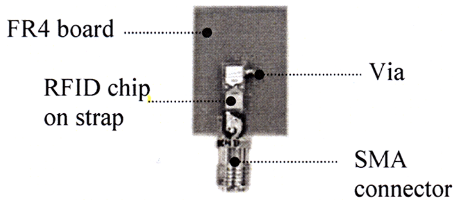

Fig. 1. The test board used for the input impedance measurement of the RFID chip mounted on strap.

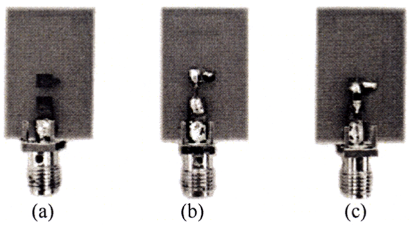

Fig. 2. The boards used for the VNA calibration. (a) open circuit, (b) short circuit, (c) 50 Ω load.

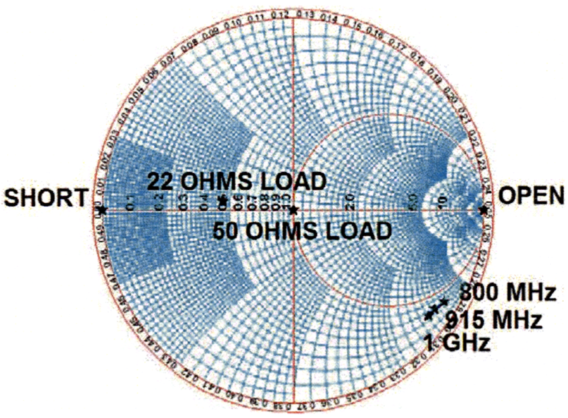

Fig. 3. Smith chart of the measured loads and the RFID chip impedances.

The measurement of the chip input impedance as a function of the input power (from -30 dBm to 5 dBm) was accomplished, however, no significant variation of the input impedance was observed.

III. Design of the Original RFID Patch Antenna

Based on [6], the original patch antenna on the FR4 substrate with a balanced feed was designed and optimized. Using a balanced feeding, the expense of cross-layered structures is avoided. Fig. 4 shows the antenna structure. The antenna design parameters are: W_{sub} = 145.5 mm, L_{sub} = 83.8 mm, W_p = 84 mm, L_p = 83.8 mm, L_f = 31.5 mm, L_{f1} = 15.8 mm, L_{f2} = 10 mm, L_{f3} = 20.1 mm, W_f = 1 mm, W_{st} = 2.7 mm, W_{pt} = 3 mm.

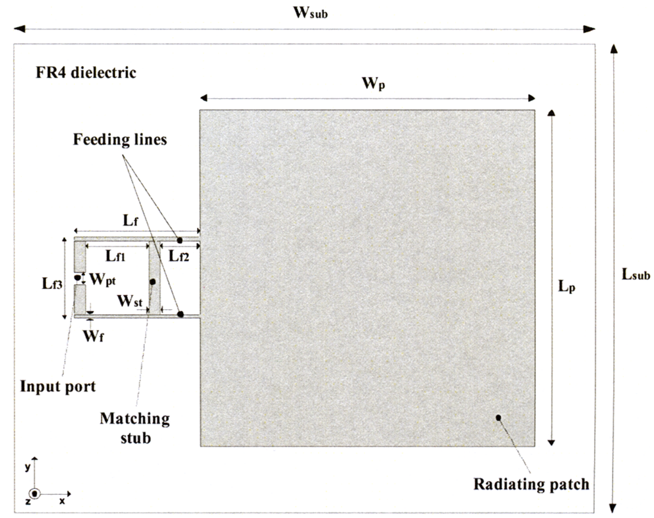

Fig. 4. Geometry of the original patch antenna.

In Fig. 5, the excitation of the TM_{01} mode is illustrated with a conventional one-port unbalanced feeding (port 1) on the edge on a maximum of the electric field and the two-port balanced feeding (port 2 and 3) obtained by feeding the patch symmetrically to the middle of the y axis with a phase inversion of 180°.

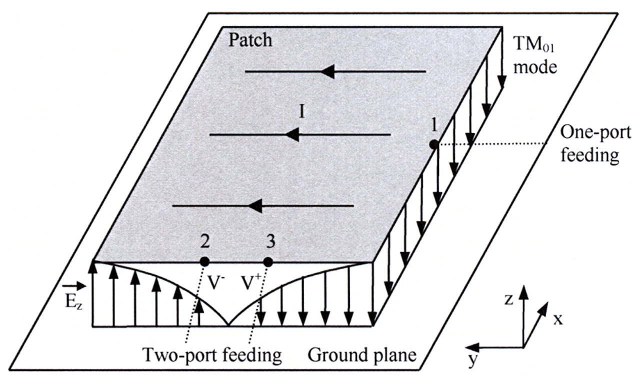

Fig. 5. Illustration of the TM01 mode excitation with a one-port unbalanced feeding and with a two-port balanced feeding.

The antenna excitation with the two-port balanced feeding results in the surface current distribution shown on Fig. 6.

We can see that the surface current in one feeding line flows opposite the other feeding line to excite the TM_{01} mode and obtain a linear polarization along the y axis. A stub used to achieve the impedance matching connects the two feed lines. The matching procedure considers a transmission line model presented in [6].

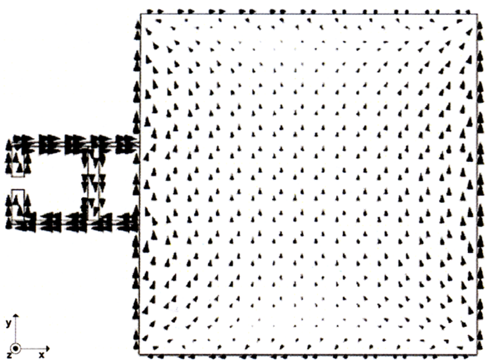

Fig. 6. Simulated surface current distribution on the original patch antenna.

IV. MINIATURIZATION OF THE RFID PATCH ANTENNA

Inserting a U-slot on the patch, as described in [7], the miniaturization of the initial patch antenna is performed. The use of a slot insertion for size reduction was considered because compared to shorting-pin-loaded, planar inverted-*L* or folded miniaturized patch antenna, it achieves an easy fabrication for mass production and low cost [7]. The miniaturized antenna is represented on Fig. 7. A 57 % area reduction compared to the original design is achieved.

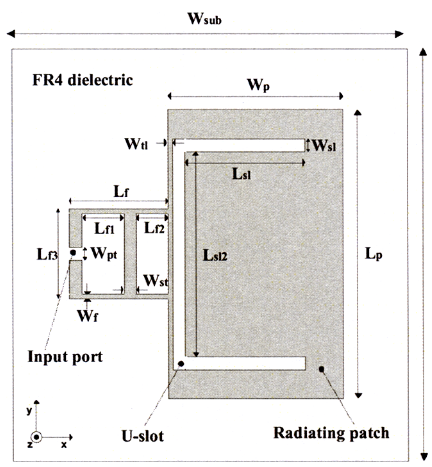

Fig. 7. Geometry of the miniaturized patch antenna.

The antenna design parameters are: W_{sub} = 99.6 mm, L_{sub} = 99.5 mm, W_p = 42.7 mm, L_p = 69.5 mm, L_f = 23.9 mm, L_{f1} = 10.2 mm, L_{f2} = 8 mm, L_{f3} = 21.5 mm, W_f = 1 mm, W_{pt} = 3 mm, W_{st} = 2.7 mm, W_{sl} = 3 mm, L_{sl} = 29 mm, L_{sl2} = 49.6 mm, W_{tl} = 1.3 mm. The slot increases the electrical length of the antenna by lengthening surface current on the radiating patch. Therefore, the antenna size can be reduced to achieve the desired resonance frequency. Fig. 8 shows the surface current distribution on the miniaturized patch. A linear polarization along the *y* axis is achieved.

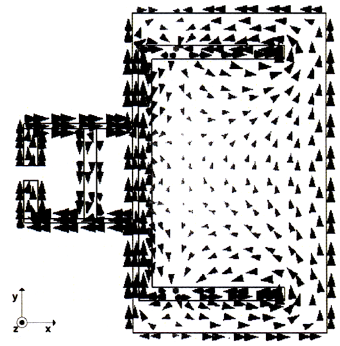

Fig. 8. Simulated surface current distribution on the miniaturized patch antenna.

V. SIMULATION AND MEASUREMENT RESULTS

A. The Miniaturized Patch Antenna Simulation Results

The miniaturized patch antenna is designed in simulation to operate at the resonance frequency of 915 MHz. The antenna input impedance *Za* has a good impedance matching to the chip input impedance, *Za* = 25.5 + j145 Ω (Fig. 9).

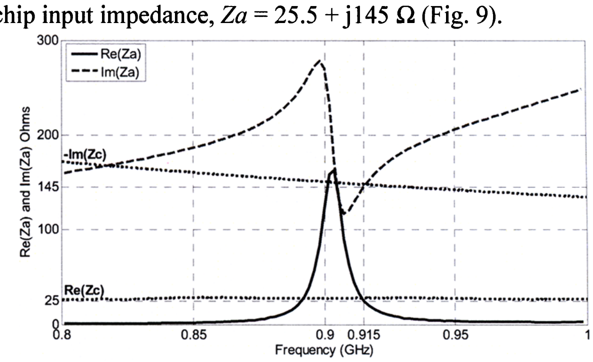

Fig. 9. Simulated complex input impedance *Za* of the miniaturized patch antenna and measured complex conjugate RFID chip input impedance *Zc*.

The simulated reflection coefficient Γ, the -10 dB bandwidth and the directivity of the miniaturized patch antenna are compared on Table I for two configurations: the miniaturized antenna standing alone and fixed on an infinite ground plane to simulate the effect of a metallic object.

The obtained bandwidth is relatively small and do not meet the 2.8 % US UHF bandwidth requirement (902 MHz to 928 MHz). But a design in the European band, covering the 0.3 % bandwidth at 868 MHz, is achievable.

The principal difference between the two models is an increase in the directivity when the antenna is fixed to a ground plane over its directivity when standing alone as expected as the ground plane of the patch antenna is increased. No significant change in the matching or bandwidth of the antenna is observed. This shows that the tag is not affected by the presence of the metallic plane.

TABLE I
SIMULATED RESULTS FOR THE MINIATURIZED PATCH ANTENNA STANDING ALONE AND POSITIONED ON AN INFINITE GROUND PLANE

Antenna configuration	Frequency (MHz)	Γ (dB)	Bandwidth (MHz)	Directivity (dB)
Standing alone	915	-20.65	7 (0.77 %)	4.74
On an infinite ground plane	915	-21.57	7 (0.77 %)	6.08

B. The Miniaturized RFID Tag Measurement Results

1. The performance measurements

First, the miniaturized RFID tag performances including the number of reads per second at a distance of 50 cm from the reader's antenna and reading range were measured. The experiment was realized in an anechoic chamber with a 30 dBm UHF RFID reader ALR 9780 from Alien Technology connected trough a 8 dB loss cable to a G_T = 4.3 dBi gain linearly polarized horn antenna (0.42W equivalent Isotropically Radiated Power, EIRP). The Table II compares the results for the miniaturized RFID tag standing alone and fixed on a 25 cm x 25 cm metallic sheet.

TABLE II
THE MEASUREMENT RESULTS OF READS PER SECOND AND READING RANGE FOR THE MINIATURIZED RFID TAG

Tag configuration	Reads per second at 50 cm	Reading range (cm)
Standing alone	212	93
Fixed on a metallic sheet (25 cm x 25 cm)	212	133

As expected, these results confirm that the metallic sheet improves the RFID patch antenna performances. This surface is being used as an extension of the antenna's ground plane, thus improving the reading range.

2. The tag's radar cross section measurement

The Radar Cross Section (RCS) of the miniaturized antenna can be measured in an anechoic chamber. The procedure is described in [10]. First, the complex reflection coefficient Γ_1 of a horn antenna with a gain G_T placed in front of the tag holder located at a distance of R = 50 cm is measured to take into account reflections from the measurement setting. Then, the miniaturized tag is placed on the stand and the complex reflection coefficient Γ_2 is measured. The contribution of the tag Γ_{tag} is obtained from (1).

$$\Gamma_{tag} = \Gamma_1 - \Gamma_2 \quad (1)$$

Then, using (2) the tag RCS σ is obtained [10].

$$\sigma = \left|\Gamma_{tag}\right|^2 \frac{(4\pi)^3 R^4}{G_T^2 \lambda^2} \quad (2)$$

Fig. 10 shows a photo of the miniaturized tag RCS measurement.

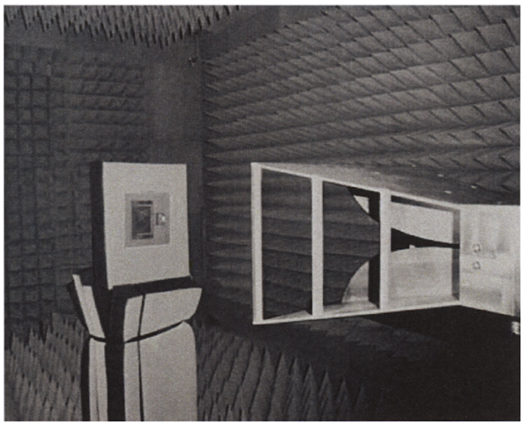

Fig. 10. Photo of the miniaturized tag's RCS measurement.

VI. CONCLUSION

This paper concerns a U-slotted RFID patch antenna for the radio frequency identification of metallic objects that achieved a size reduction of 57 % in area with respect to the initial patch design.

The measurements show that the tag performances are enhanced as fixed on a conducting plane as expected from simulation results.

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