Low Profile Flexible Metal Mountable UHF RFID Tag Antenna

Adrian-Ioan PETRARIU, Valentin POPA
Stefan cel Mare University of Suceava
Department of Computers, Electronics and Automatics
Suceava, Romania
apetrariu@eed.usv.ro; valentin@eed.usv.ro

***Abstract*—This paper presents a low cost and a low profile flexible microstrip patch tag antenna for UHF RFID systems that can be metal mountable. The simple design that doesn't imply using shorting pins, flexibility and small size (25mm X 50mm X 0.5mm) are a few of the advantages given by this design. The proposed antenna is simulated and the results obtained are compared with measurements performed with Agilent FieldFox N9912A VNA. At ETSI frequency band, the reading distance is up to 2.7m, which shows that the tag achieves good size/performance ratio for flexible metal mountable UHF RFID tags. The gain of the antenna is only -16.25dB, but in order to reach the mentioned reading distance is used an RFID chip having a wake-up power of -20.5dBm. The proposed tag can be easily mounted on metallic objects having various sizes and shapes.**

I. INTRODUCTION

RFID technology is widespread nowadays in various applications, for example ticketing, library inventory, banking, supply chain, traceability of goods and logistics [1]. However, for using this technology for large scale, for other domains than those already mentioned, it's important to solve some gaps that exist, one of the most important one being the functionality of the RFID system in harsh environments [2].

Generally speaking, an RFID system contains an RFID tag (which is attached to the object that needs to be identified), an RFID reader used for tag interrogation and a software application installed on a PC (in most cases) that makes the link between the human operator and the collected information received by the RFID system. The tags can be passive, active or semi-passive, depending on the applications that are used. The common one is the passive tag because it can be used for many years without needing an internal power supply [1]. Other reasons that imply using of passive tags for RFID systems are because they are the cheapest ones and they are simple to manufacture.

In the last few years have been developed applications that imply tagging metallic objects, used on a large scale in supply chain, logistics and traceability of goods. To this end, more and more RFID tag manufacturers have chosen to develop tags that can be easily attached to metal objects.

Thus, in order to identify an object that consists or contain materials with adverse effect for the electromagnetic field, they were created tags with different shapes and sizes, but most of them having a rigid form [3-8]. They were created also tags that can be placed on metallic objects with cylindrical or spherical shapes, known as flexible tags [9-12]. These kinds of tags have large dimensions and can be attached only on big items. The main advantage of large sized tags are a high antenna gain (more than 6dB) that gives a reading distance up to or more than 25m [13].

Nowadays, in order to activate the RFID chip from an RFID tag is needed less than -18dBm [14-15]. Thus, making a tag which has a high antenna gain is not necessary anymore if the distance from the reader antenna to the objects that need to be identified is only a few meters. Furthermore, in applications that are needed short reading distances, the effect of multipath propagation is limited [16]. A low antenna gain can be easily obtained by decreasing the antenna size, but when is using a small antenna, is hard to obtain a high radiation efficiency.

Taking into account all the above mentioned, in this paper the attention is focused on designing and testing a low profile metal mounting RFID tag that has small size and can be used for flexible surfaces.

II. TAG ANTENNA DESIGN

The tag antenna reported in this paper is designed for Higgs-4 EPC Gen2 UHF RFID chip manufactured by Alien Technology [17]. The package of the chip used in the design is SOT-323. This type of package is easy for manual soldering besides other type of package which Higgs-4 chip has (for example die package). The main advantage in using this RFID chip is the minimum RF communication power that can reach the level of -20.5dBm. Thus, in order to obtain an RFID tag that can be identified from a short distance, can be used an antenna with low gain and small size.

If we take into consideration the main components of an RFID tag, the antenna behaves like an energy generator for the chip, having the impedance Z_a and the source voltage V_a. The antenna delivers the power for activating the chip which has impedance Z_{ic}.

Taking into account the above mentioned, the power transferred to the RFID chip (P_{ic}) can be calculated using equation (1).

$$P_{ic} = \frac{1}{2} \cdot \frac{R_e(Z_{ic})}{\left|Z_a + Z_{ic}\right|^2} \cdot V_a^{\ 2} \qquad (1)$$

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It's noted that the maximum power transfer between the antenna and the RFID chip can be performed when the antenna impedance Z_a is equal to the conjugate value of the chip impedance Z_{ic}. The calculated value of the impedance obtained from the manufacturer datasheet for the RFID chip used in this design is Z_{ic}=(20-j191)Ω at 868MHz.

In the real environment, when is used a soldered package for the chip, beside the chip impedance we can find some parasitic impedances that occurs from the soldered joints. In order to find out what is the real impedance of the chip are used the references mentioned in [18] and [19].

Thus, for measurements of the soldered RFID chip is used a VNA from Agilent (FieldFox N9912A). The chip impedance is measured using the Smith Chart and the obtained values are depicted in Fig. 1.

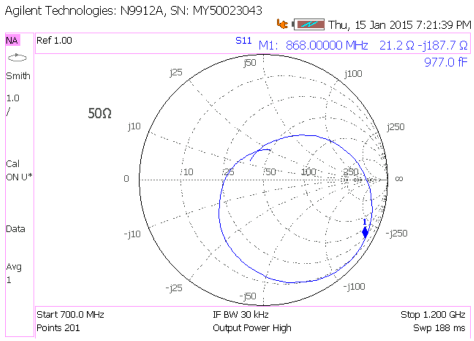

Figure 1. Smith Chart measurement for RFID chip impedance

The measured value of the chip impedance is Z_{icm}=(21.2-j187.7)Ω as shown in the Fig. 1, which is different from the value given by the manufacturer. Thus, in order to maximize as much as possible the power transfer between the antenna and the RFID chip, the antenna impedance Z_a must be equal to the conjugated value of the Z_{icm}, which is Z_{icm}^*=(21.2+j187.7)Ω.

The tag is fabricated using as dielectric Teflon, with a thickness of 0.5mm. The relative permittivity is ε_r=2.1 and the dielectric loss tangent is $tan\delta$=0.002S/m.

For the conductive parts of the antenna is used adhesive copper tape with a thickness of 35µm. The design is simple and hasn't shorting pins for interconnecting the conductive parts, which makes it easy to fabricate. All the dimensions of the antenna are related in Fig. 2.

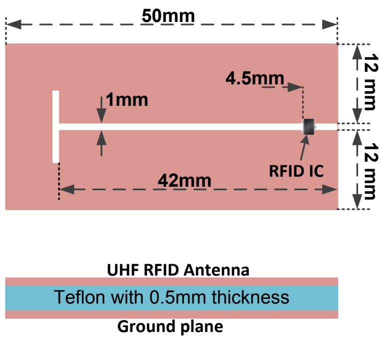

Figure 2. Dimensions of the proposed antenna

A picture with the prototype is shown in Fig. 3. The proposed design is flexible and can easily be attached to any cylindrical or other geometrical shapes of an object because of using the sheet of Teflon as a dielectric substrate.

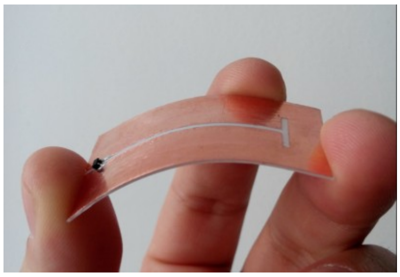

Figure 3. Prototype of the UHF RFID tag

III. Simulated and Experimental Results

In order to obtain the impedance matching for the proposed antenna pattern is used a full wave electromagnetic simulator based on finite element method. The values depicted in Fig. 2 were optimized in a way that the antenna impedance can be matched with the measured values of the chip impedance (Fig. 1).

For simulating the proposed RFID tag is used a square shaped ground plane made from steel with 2mm in thickness and having a dimension of 400mm X 400mm (Fig. 4).

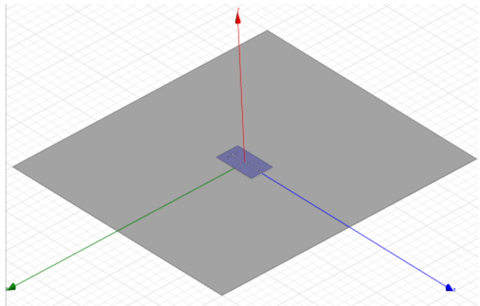

Figure 4. Simulation of the tag antenna

The antenna impedance can be easily changed by moving the feed point. Some of these values for the simulated impedances are related in Table 1. At 868MHz the antenna impedance is Z_{am}=(23.4+j190)Ω taking into account the feed point like in the Fig. 2.

TABLE I. Simulated Antenna Impedance with the Change of the Feed Point Location

Distance of the feed point [mm]	$Re(Z_{11})$ [Ω]	$Im(Z_{11})$ [Ω]
1	26.2	208,4
3	25	203,1
5	23	190,6
7	22,7	263,2
9	27	230
11	21,4	185,7
13	19,2	186,4
15	18,3	183,1

In Fig. 5 and Fig. 6 respectively, are depicted the reactance and the resistance of the antenna with the frequency sweeping from 800MHz to 900MHz. Both, simulated and measured values are compared.

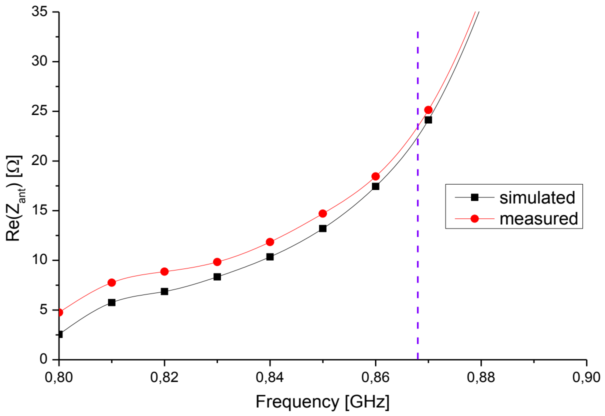

Figure 5. Compared values for resistance of the antenna

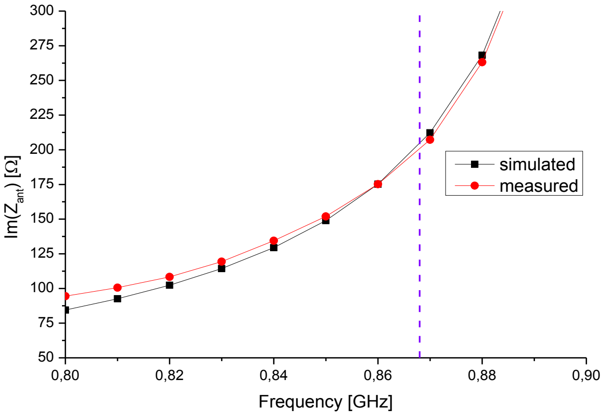

Figure 6. Compared values for reactance of the antenna

Another important parameter that must be taken into account is the power reflection coefficient (S_{11}).

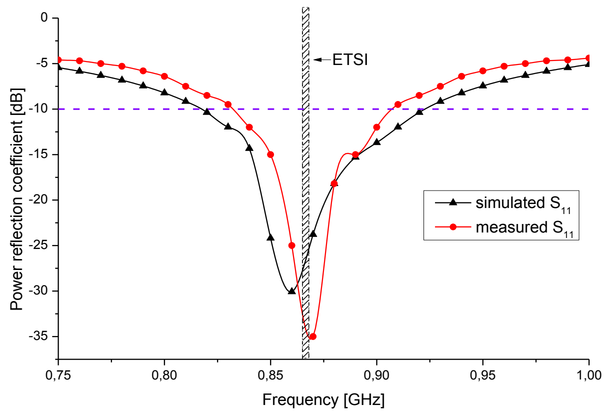

Figure 7. Power reflection coefficient of the proposed antenna

The values measured with the same VNA are compared with the simulated ones and the results are depicted in Fig. 7. For the proposed antenna pattern at 868MHz is obtained a value of -33dB. The -10dB bandwidth is 80MHz, from 830MHz to 910MHz, which covers the ETSI frequency band.

According to the measured values, the impedance of the antenna is approximately equal to the measured impedance of the chip. The power transfer efficiency τ, which can be calculated with the equation (2), tells us how well matched is the tag. In our case, the value of τ is 0.9 which is a reasonable value taking into account that for maximum impedance matching the value for τ is 1.

$$\tau = \frac{4 \cdot R_e(Z_a) \cdot R_e(Z_{ic})}{|Z_a + Z_{ic}|^2} \quad (2)$$

The theoretically read range of the tag can be calculated using equation (3).

$$d_{tag} = \frac{\lambda}{4\pi}\sqrt{\frac{P_r \cdot G_r \cdot G_t \cdot \tau}{P_t}} \quad (3)$$

In equation (3), d_{tag} is the maximum calculated read distance of the proposed tag, P_r is the output power of the reader, G_r is the reader antenna gain that is used for measurements, G_t is the gain of the tag antenna, τ is the power transfer efficiency calculated with equation (2) and P_t is the RFID chip sensitivity which is provided by the manufacturer. In order to determine this empirical value, we must find out all the values for the parameters implied in the equation.

The antenna gain for the tag will be obtained from the simulation values. Those values are depicted in Fig. 8 and for 868MHz we can achieve a maximum value of -16,25dB.

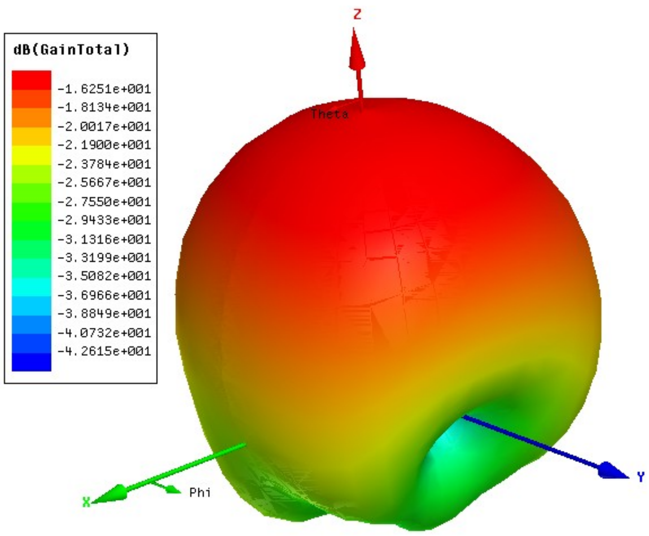

Figure 8. Simulated gain of the UHF tag

A commercial ALR-9900+ EMA RFID reader with the operating frequency of 866-868 MHz, an output power of 31.6dBm, and a circular polarized antenna with a gain of 5dBi was used to determine the maximum reading range of the proposed tag antenna pattern. So, the mathematical determination of the maximum reading range for the proposed tag is 2.8m, taking into consideration P_t as -20.5dBm. Measuring this distance with the above mentioned RFID system is obtained a maximum reading distance of 2.7m.

IV. Conclusions

A low profile flexible UHF RFID tag that can be attached by metallic objects is designed and fabricated using a flexible Teflon substrate. Was outlined the simulation results obtained compared with the measured ones. Both, the simulation and the experimental work verified the proposed prototype. Using only 0.5mm thickness of the dielectric was achieved a reading distance of 2.7m and a bandwidth of 94MHz in the ETSI frequency band. This UHF RFID tag can be used for curved metal surface with good performances.

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