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BROAD-BAND DIPOLE FOR RFID APPLICATIONS

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Abstract—A novel planar dipole for Ultra-High-Frequency (UHF) Radio Frequency Identification (RFID) systems is presented here. Referring to a realization based on the use of a chip produced by Texas Instruments, the proposed design approach has been numerically and experimentally investigated. Reported results demonstrate that the proposed antenna exhibits good radiation properties and matching ($|S_{11}| < -10\,\mathrm{dB}$) over the entire UHF RFID bandwidth (860–960 MHz).

1. INTRODUCTION

RFID is an emerging technology gaining growing interest both from scientific and industrial communities [1, 2]. In most applications UHF RFID systems are preferred. The working mechanism is illustrated in Figure 1; its basic components are an interrogator (the reader antenna) and a transponder (a back-scattering tag) [1–5].

A key role is played by the tag whose efficiency strongly influences the system performance. In order to maximize the tag readable range and then the efficiency of the overall system, a great attention must be paid to the tag antenna design [2–15]. The tag should own good radiation properties (high gain and isotropic radiation pattern) and be matched to the tag chip for maximum power transfer:

$$Z_{in,antenna} = Z^*_{in,chip} \tag{1}$$

where $Z_{in,antenna}$ is the input impedance of the antenna, and $Z^*_{in,chip}$ is the complex conjugate of the input impedance of the chip. Referring to Figure 2, where the capacitive behaviour of common commercial

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chips has been highlighted, the following expression can be derived for the antenna impedance:

$$Z_{in,chip} = R_{chip}(\omega) + \frac{1}{j\omega C_{chip}(\omega)} \Rightarrow$$
$$Z_{in,antenna} = R + j\omega L_{antenna} = R - \frac{1}{j\omega C_{chip}} \tag{2}$$

where ω is the angular frequency, R and $\omega L_{antenna}$ are the resistance and the reactance of the antenna, whereas R_{chip} and $-1/\omega C_{chip}(\omega)$ are the resistance and the reactance of the chip.

Condition (2) can be satisfied by adding a matching network between the antenna and the chip or through a proper design of the antenna [2, 3, 9–16]. It is worth underlining that a reasonable impedance match should be guaranteed all over the bands where different world regions locate the spectrum of UHF RFID signals, and consequently in the frequency range 860–960 MHz.

In this paper, a novel tag for UHF RFID systems satisfying the above requirements is presented. The antenna layout has been optimized referring to the input impedance of the UHF Gen 2 Integrated Circuit chip produced by Texas Instruments [17]. Reported numerical results demonstrate that the proposed tag exhibits an excellent impedance matching over the entire UHF RFID bandwidth.

Furthermore, the antenna has been realized and tested; a reading range of 9 m has been measured by using a reader system for the European bandwidth.

The paper is structured as follows: in Section 2 the geometry of the proposed antenna is described, later on numerical and experimental results are given in Section 3. Finally some conclusions are drawn in Section 4.

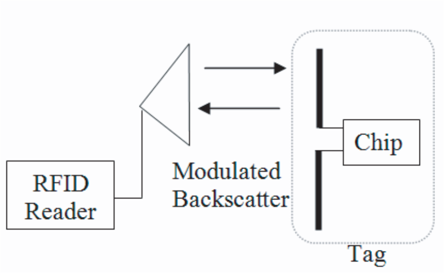


Figure 1. Schematic representation of a UHF RFID system.

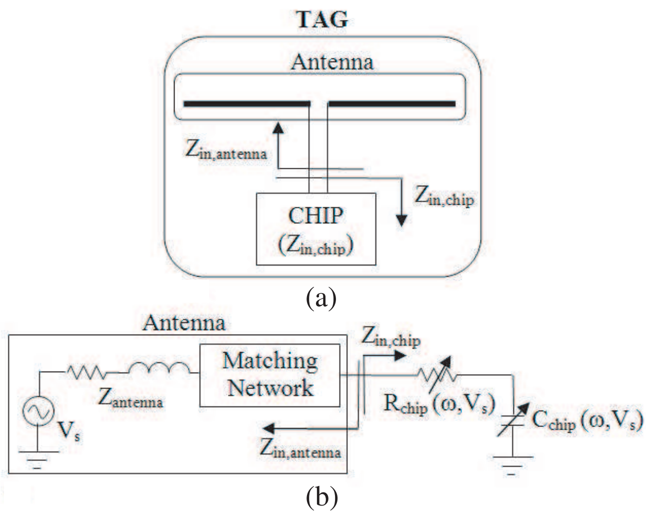


Figure 2. (a) Schematic representation of a UHF RFID tag; (b) Lumped elements equivalent circuit of a UHF RFID tag.

2. GEOMETRY OF THE PROPOSED TAG ANTENNA

The proposed tag antenna is illustrated in Figure 3. The main radiating body consists of two monopoles realized as a strip closed over a pseudo-circular area designed as a composition of three circles.

In order to obtain an inductive behaviour of the input impedance of the antenna so to satisfy (2), the geometry of Figure 3(a) has been modified by adding two inductive loops. The layout obtained this way is illustrated in Figure 3(b).

The two circular areas have been placed at a distance of $\lambda/4$ from the antenna port, and the parameters given in Figures 3(b) and 3(c) have been optimized in order to satisfy the matching condition with respect to the tag chip over the entire UHF RFID systems bandwidth.

More specifically, a numerical optimization has been performed by using the commercial full-wave simulator CST Microwave Studio.

As highlighted in Figure 3(c), in order to take into account the capacitive behaviour of the chip, numerical analysis have been performed by using a lumped capacitor in series with the input port of the antenna and by using R_{chip} as normalization impedance of the reflection coefficient.

The value of the lumped capacitor has been set referring to the UHF Gen 2 Integrated Circuit produced by Texas Instruments (Part Number RI-UHF-11111-01, RI-UHF-00001-01) and to the European

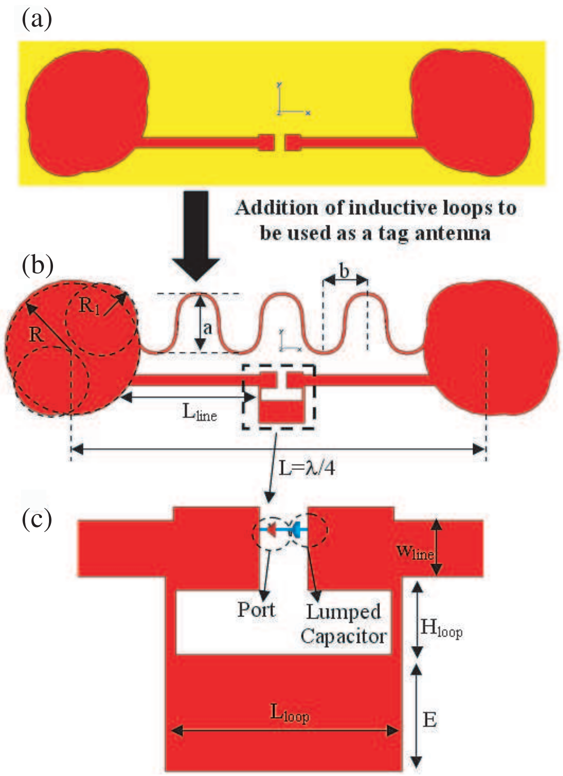
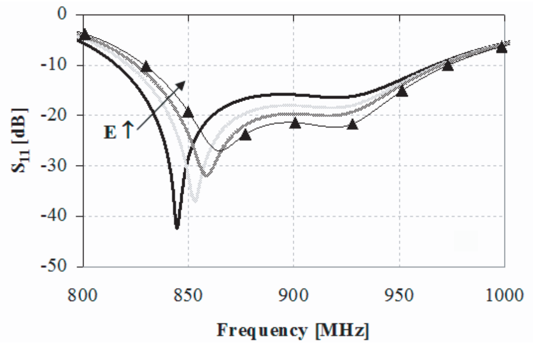


Figure 3. Geometry of the tag proposed in this paper. (a) Main Radiating body, (b) layout of the proposed tag and geometrical parameters. (c) Strategy adopted to model the chip: A lumped capacitor has been used to take into account the imaginary part of the chip input impedance.

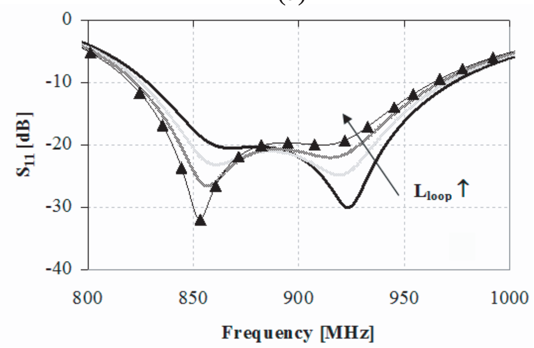
frequency band of UHF RFID (865 MHz–867 MHz).

Figure 4 highlights the dependence of the antenna reflection coefficient on the geometrical parameters of the loop illustrated in Figure 3(c); it is evident that the loop strongly influences the level of the impedance matching between the antenna and the chip. As for the dipole working frequency and its relative impedance bandwidth, they are mainly determined by the dimensions (absolute value of R and R_1) and the shape of the pseudo-circular area (R-to-R_1 ratio).

Referring to Figure 3, the combination of the antenna parameters resulting in the desired behaviour for the antenna input impedance is given in Table 1.



(a)



(b)

Figure 4. Dependence of the reflection coefficient on the geometrical parameters of the inductive loop added in a parallel configuration to the chip. Results obtained with CST Microwave Studio: the chip impedance has been set to the value reported in the Texas Instruments data sheet for the European band and an input power of −13 dBm.

Table 1. Parameters of the realized tag antenna. All dimensions are in millimetres.

R	R_1	L	L_{line}	L_{loop}	E	W_{line}	H_{loop}	a	b
12.6	7	88	26.7	9.8	4.8	2.3	3.1	11	7.8

3. NUMERICAL AND EXPERIMENTAL RESULTS

According to the geometrical parameters calculated in the previous section, a prototype of the proposed UHF tag has been realized. In order to comfortably test the prototype in practical applications, the antenna has been realized by using adhesive copper. The soldering

Figure 5. Photograph of the realized tag antenna.

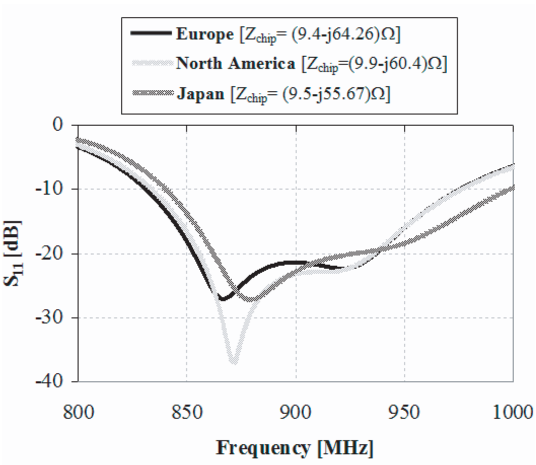


Figure 6. Reflection coefficient of the proposed antenna. Results calculated by CST Microwave Studio by using for the chip impedance the values reported in the Texas Instruments data sheet respectively for the UHF RFID band of Europe, North America and Japan. The values used for R_{chip} and C_{chip} are those corresponding to an input power of $-13\,\text{dBm}$ (minimum typical read).

between RFID chip and antenna has been realized through conductive tape. In Figure 5, a picture of the prototype is reported.

The reflection coefficient calculated by CST Microwave Studio is illustrated in Figure 6; this result has been obtained referring to the value of Z_{chip} reported in the Texas Instruments data sheet for the European bandwidth:

$$Z_{in,chip}\left(\omega = 2\pi 866.5\,\text{MHz}\right) = (9.4 - j64.26)\,\Omega \Rightarrow$$
$$R_{chip}\left(866.5\,\text{MHz}\right) = 9.4\Omega,\ C_{chip}\left(866.5\,\text{MHz}\right) = 2.86\,\text{pF} \quad (3)$$

These results have been verified by using a reader UHF RFID systems for the European bandwidth (see Figure 7). More specifically, experimental measurements demonstrate that the proposed tag guarantees a reading range of 9 m.

In order to verify the behaviour of the antenna over the entire UHF RFID bandwidth, numerical simulations have been also performed by using the Z_{chip} value reported in data sheet for the band of North America (915 MHz) and Japan (953 MHz):

North America

$$\begin{aligned} & Z_{in,chip}\,(\omega = 2\pi 915\,\mathrm{MHz}) = (9.5 - j60.4)\,\Omega \Rightarrow \\ & R_{chip}\,(915\,\mathrm{MHz}) = 9.9\Omega,\ C_{chip}\,(915\,\mathrm{MHz}) = 2.88\,\mathrm{pF} \end{aligned} \tag{4}$$

Japan

$$\begin{aligned} & Z_{in,chip}\,(\omega = 2\pi 953\,\mathrm{MHz}) = (9.5 - j55.67)\,\Omega \Rightarrow \\ & R_{chip}\,(915\,\mathrm{MHz}) = 9.5\Omega,\ C_{chip}\,(915\,\mathrm{MHz}) = 3\,\mathrm{pF} \end{aligned} \tag{5}$$

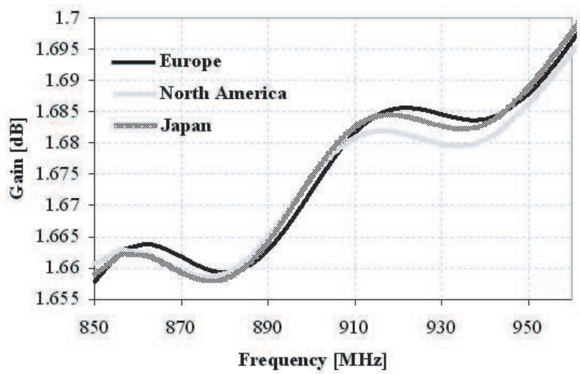
Results obtained this way are compared in Figure 6 and resumed in Table 2; it is evident that a reflection coefficient smaller than −15 dB has been calculated in all cases.

As for the radiation properties, the gain and radiation efficiency are given in Figure 8. In all the three analyzed situations, the proposed tag exhibits a gain of about 1.7 dB and a radiation efficiency greater than 89%.

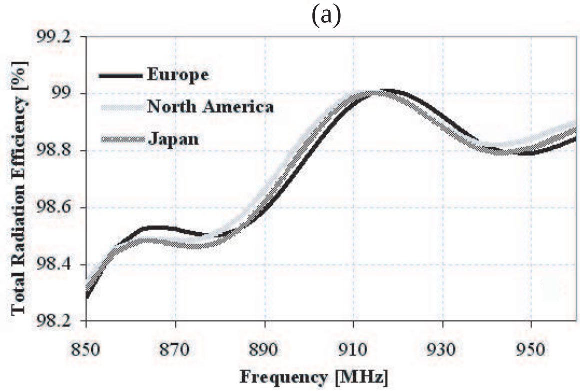
Table 2. Performance of the proposed tag antenna. Results obtained by using the full-wave simulator CST Microwave Studio. The values of R_{chip} and C_{chip} are those corresponding to an input power of −13 dBm (minimum typical read).

	EUROPE (866.5 MHz)	NORTH AMERICA (915 MHz)	JAPAN (953 MHz)
R_{chip} (Ω)	9.5	9.9	9.5
C_{chip} (pF)	2.86	2.88	3
S_{11} (dB)	-27	-23	-18
Gain (dB)	1.66	1.68	1.69
Total Radiation Efficiency (%)	98.5	99	88.8

Figure 7. UHF RFID reader system adopted to experimentally verify the reading range of the proposed tag.



(a)



(b)

Figure 8. Gain (a) and radiation efficiency (b) of the proposed tag. Results calculated by CST Microwave Studio.

It is worth underlining that the values adopted in simulations for Z_{chip} are the ones reported in data sheet for an input power of -13 dBm, corresponding to the minimum power for the chip activation. This has been done to verify the matching quality in the most critical case.

4. CONCLUSION

A novel tag for UHF RFID systems has been presented. The tag has been designed and realized by using the UHF Gen 2 Integrated Circuit produced by Texas Instruments. The proposed design approach allows to easily customize the antenna bandwidth by acting on its geometrical parameters. Reported numerical results demonstrate that the proposed tag exhibits good performance over the entire band of UHF RFID systems. Furthermore, by using a reader system working in the European bandwidth, a reading range of 9 m has been experimentally measured.

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