Parametric Study of the Novel UHF RFID Dual-loop Antenna

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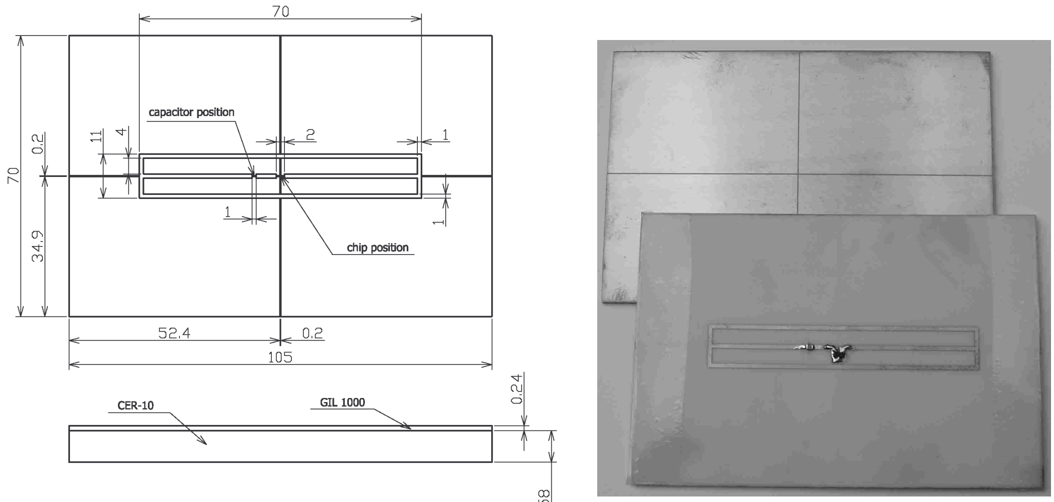
1. Introduction

Currently, UHF RFID systems are increasingly apllied in many areas. They are operated with a decent reliability in free space or are placed on paper-like boxes [1]. The main advantage of this frequency band is represented by a relatively low free-space loss, which enables to read a range of several meters. However, problems arise in case that a TAG antenna is placed in the close vicinity of lossy dielectrics or metal objects. The first case corresponds to the identification of persons and the second one corresponds to e.g. the identification of metallic containers. UHF RFID systems use often shorted dipole type antenna. Unfortunately, the location of this antenna type in the close vicinity of lossy objects causes a substantial detuning of its resonant frequency and, at the same time, a considerable fall in antenna efficiency. This type of antenna is not ideal for the above-mentioned applications. An antenna with a metallic ground plane (serving as a protective shielding) seems to be the best solution of the issues described above. The metallic ground plane increases the front-to-back ratio of the antenna, hence it reduces the influence of an object to be identified to the antenna parameters. However, as the UHF RFID system operates within the frequency range of 860-930 MHz, the TAG antenna resonant size has to correspond to the half-wavelength, which is of about 170 mm at frequency 869 MHz. Such size is inacceptable for TAG antennas - thus they are highly inconvenient for the purposes of identification of persons.

The novel electrically small flatten dual-loop antenna, which is discussed in detail in this paper, represents a promising solution of above-mentioned problems. The antenna has been manufactured and measured. Finally, a parametric study of the antenna parameters change has been undertaken.

2. Novel TAG Antenna

As the measured RFID chip input impedance has the value of $Z_{chip} = 76 - j340\ \Omega$, the antenna input impedance must be the complex conjugate to the chip one. The antenna design results from a loop antenna type, whose input impedance is situated in the inductive area in the Smith chart. According to the above-mentioned reason, the antenna must be situated over a shielding metallic plane. To miniaturize the antenna size and namely to decrease the antenna profile, the substrate with a relatively high permittivity ($\varepsilon_r = 10$) has been used. An acceptable TAG antenna profile seems to be less than 2 mm. It is feasible to increase the radiation efficiency by using a four-element sub-wavelength patch array that is backed by a dielectric substrate, inspired by artificial magnetic conductors [2]; see. Figure 1. If the flatten single loop antenna is set at 1.82 mm (the available thickness of dual-layer substrate) over the shielding metal plane, the radiation efficiency decreases considerably; see Figure 2.



a) b)

Figure 1: Sketch (a) and photograph (b) of designed prototype of loop antenna closely spaced over patch array surface in distance d_1 = 0.24 mm, d_1/λ_0 ~ 0.0007. Antenna is situated over grounded dielectric slab with height d_2 = 1.58 mm, d_2/λ ~ 0.0046. Total relative size is ~ 0.2 x 0.3 x 0.005 λ_0 at 869 MHz.

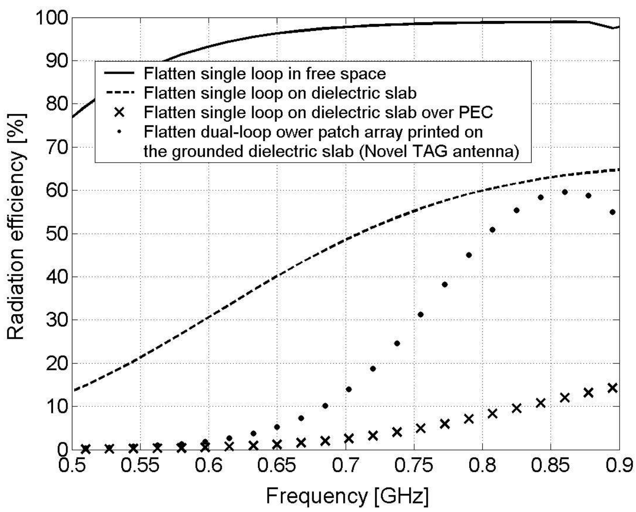


Figure 2: Comparison of simulated radiation efficiency for flatten single and dual-loop antennas placed in free space and over dual-layer substrate; layer 1 thickness 0.24 mm (d_1/λ_0 ~ 0.0007), layer 2 thickness 1.58 mm (d_2/λ ~ 0.0046).

The antenna properties were measured by Wheeler cap method [3] for a half-loop modification (equivalent to the monopole) in free space and for the case that the antenna is placed in the close vicinity of an agar phantom. The half-loop input impedance is, in comparison to the loop impedance, of a half value. Thus $Z_{\text{half-loop}} = Z_{\text{loop}}/2 = 38 + j170\ \Omega$ is considered for further evaluation. The comparison of the simulated and measured antenna efficiency and gain is indicated in Table 1.

Table 1: Efficiency and gain of loop antenna, evaluated by Wheeler cap method

	Frequency [MHz]	Radiation efficiency [%]	Antenna efficiency [%]	Directivity [dBi]	Gain [dBi]
Simulated	869	53	39	5.3	1.3
Measured, free	869	68	38	5.0	0.8
Measured, agar	869	70	33	5.4	0.6

The comparison of the simulated and measured radiation patterns can bee seen in Fig. 3. The radiation patterns were measured for the loop antenna, fed by a coaxial cable with a non-perfect symmetrisation. Therefore the E-plane pattern shows about 15° tilt embodies. This tilt is not expected to be present in case of the real TAG antenna-chip arrangement. In the simulation data the tilt is not considered (see Figure 3b), because the ideal discrete feed port has been used.

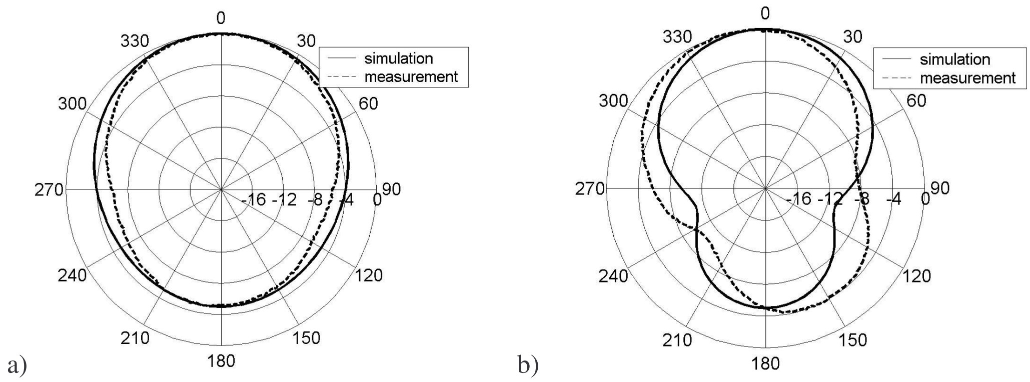


Figure 3: Simulated and measured radiation patterns of novel flatten dual-loop antenna
a) H-plane, b) E-plane

3. Parametric Study

The parametric study of the radiation efficiency dependence on the patch array, backed by the dielectric slab properties (substrate thickness, the patch size and the gap among the patches), has been performed. The following figures depict the influence of variations of the aforementioned parameters on the radiation efficiency. It is the crucial parameter affecting the antenna gain. The corresponding resonant frequency detuning and impedance mismatching can be corrected by tuning the loop length.

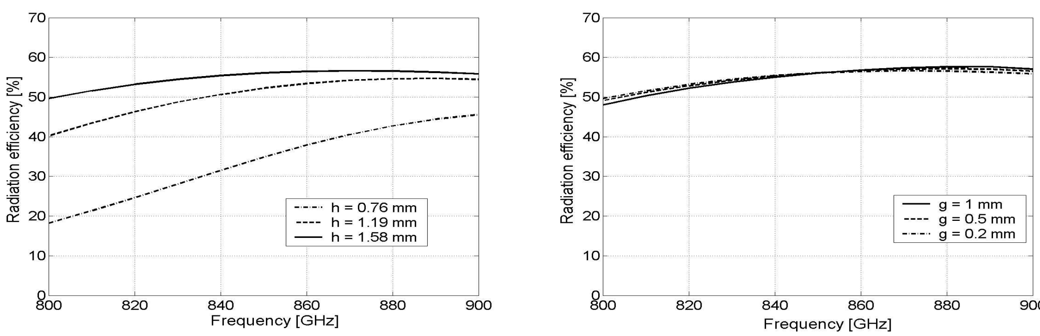


Figure 4: Simulation of influence of substrate thickness *h* (a) and gap size *g* (b) on radiation efficiency of novel flatten dual-loop antenna

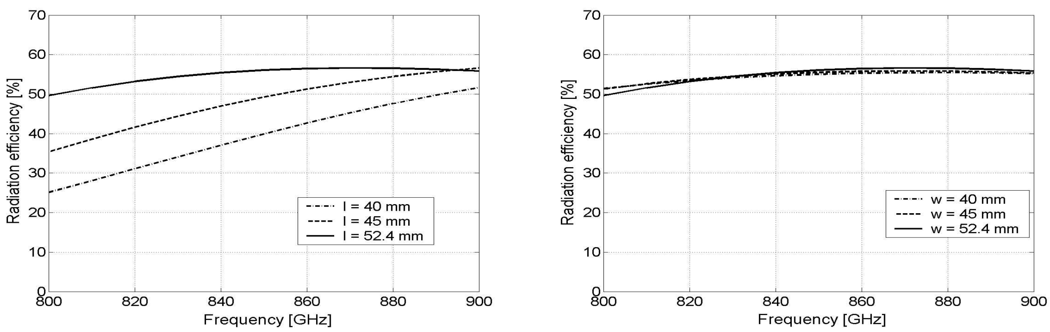


Figure 5: Simulation of influence of patch length *l* (a) and patch width *w* (b) on radiation efficiency of novel flatten dual-loop antenna

5. Conclusion

The developed electrically small low-profile (~ 0.2 x 0.3 x 0.005 λ_0) dual-loop TAG antenna seems to be a satisfactory solution for the RFID of either persons or dielectric objects. The designed UHF RFID TAG antenna operates in a close vicinity of the tested dielectric object (agar human phantom) with the radiation and antenna efficiencies better than 70 and 40 %, respectively, whereas its height over shielding metal plane is smaller than 2 mm. Consequently, the badge-sized antenna embodies the positive gain of about 1 dBi. The main disadvantage of this solution is represented by the higher production costs caused predominantly by the dual-layer performance.

The parametric study of the radiation efficiency dependence on the patch array surface variations shows a significant influence of the substrate thickness and the patch length on the radiation efficiency. On the contrary, the impact of the gap and the patch-element width on the radiation efficiency is insignificant. Hence the reduction of the antenna width (at the expense of directivity decreasing) is possible. All parameters affect the antenna input impedance, which can be tuned by the loop length.

Acknowledgments

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