Extremely Low Profile UHF RFID TAG Antennas for Identification of People

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***Abstract*— Three prototypes of the very low-profile TAG antennas for UHF RFID of people were designed, as result of the long-term development. Their performance properties from the wearability point of view were step-by-step improved. The height were decreased from 1.82 to 0.76 mm (0.0022 λ_0 at 869 MHz). The weight were decreased from 38 to 10 g, The gain of antennas measured with enclosed human phantom is in the range of 0.6 ÷ 1.6 dBi. Identification range in real conditions in 4 and 2 m wide buildings corridors reaches 7 and 17 m, respectively, with the NXP Semiconductors chip with the sensitivity of -14 dBm.**

I. Introduction

RFID technology fundamentals are already known for 40 years. However, the completely reliable solution for passive UHF identification of people and metal objects is not provided yet namely due to the negative influence of human body or metals on TAG antenna properties. Several types of metal TAGs can be found in commercially offered solutions, nevertheless the cost of these TAGs is relatively high. As an example the Omni-ID TAGs [1] or Metal TAGs from William Frick & Company [2] can be mentioned. The weight, thickness, and size are the main limiting parameters, which prevent the use of the metal TAGs for RFID of people due to usually unsatisfactory high values.

Previously we have introduced several variants of the very low-profile wearable antennas for UHF RFID of people [3] - [5], see Fig. 1 – 3, as a result of the long-term development where performance of TAG antenna evolutionary variants has been step-by-step improved. Primary purpose for the application of these antennas has been RF identification of people in buildings. However they can be applied also for identification of metal or liquid objects due to the screening effect of inherently present metal plane.

This study compares their performance from the wearability point of view. Their performance properties including identification range are compared in real conditions in two buildings corridors of different widths.

II. TAG Antennas

A. Flatten dual-loop antenna closely spaced over patch array

A dual-loop antenna, placed over a four-element patch array surface represents one of the possible extremely low-profile solutions. The insertion of the patches structure between the metal plate and the dual-loop motive provides a significantly better radiation efficiency than the loop placed over the metallic plate, because the four-element patch array is excited and takes part in the radiation process. However, the drawback of this solution is that the antenna is realized on a high permittivity substrate ($\varepsilon_r = 10$). Consequently, the total weight and the level of production costs make it difficult to use the antenna as a badge TAG. The new antenna total size is $70 \times 105 \times 1.82$ mm (relative size is $0.2 \times 0.3 \times 0.005$ λ_0 at 869 MHz).

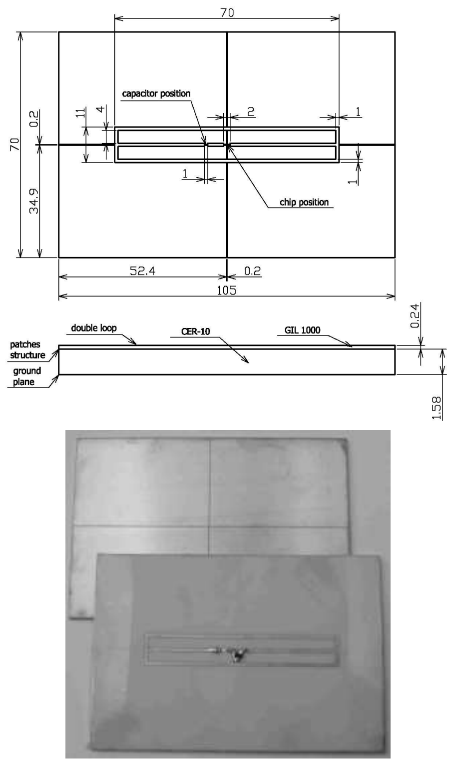

Figure 1: Antenna 1 - Flatten dual-loop antenna closely spaced over patch array [4], a) sketch and b) photograph

B. Dipole excited slot coupled two-element shorted patch

The above-mentioned disadvantages of the antenna 1 can be eliminated using a low permittivity substrate ($\varepsilon_r = 3.2$, $\tan\delta = 0.002$). However, this approach leads to a significantly longer four-element patch size, due to relative long wavelength λ_g. The reduction of the screening four-element patches structure to the two-element structure is the first miniaturization step that does not result in the decrease in the radiation efficiency. The patch array length can be further reduced by the realization of the patches acting as a quarter-wavelength resonators, whose outer edge is conductively connected with the screening metallic plane; see Fig 2. The total size of the antenna is $60 \times 95 \times 1$ mm (relative size is equal to $0.17 \times 0.28 \times 0.003\ \lambda_0$ at 869 MHz). The dipole dimensions are: $la = 28.5$ mm, $lb = 23.5$ mm and $wa = 8$ mm. A planar meanderly folded dipole etched on the superstrate layer (see Fig. 2) is used as an excitation element, whose length is used in order to tune the input impedance so that it is the complex conjugate to the chip impedance value.

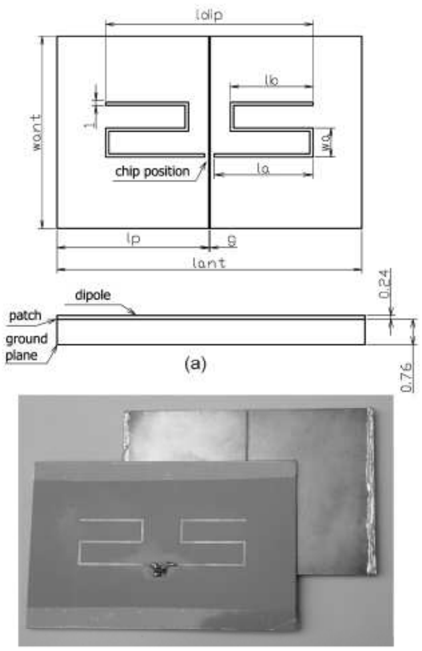

Figure 2: Antenna 2 - slot coupled two-element shorted patch with meanderly folded excitation dipole closely spaced above [3], a) sketch and b) photograph

C. *Directly excited two-element shorted patch*

The removal of the upper substrate represents another possibility how to simplify the structure of the antenna. The shorted two-element patch structure can be excited directly by the chip, inserted into the slot situated between the inner patch edges; see Fig. 3. Unfortunately, this structure does not involve the capability of impedance tuning. By the insertion of two slots (as reactive elements that are, from both sides, symmetrically close to the inner slot), by setting of its distance, length and width the impedance matching can be achieved. The total size of the directly excited antenna is $60 \times 100 \times 0.76$ mm (relative size is $0.17 \times 0.29 \times 0.0022\ \lambda_0$ at 869 MHz). The dimensions of the impedance slots are: $ls = 40$ mm, $ws = 6$ mm and $p = 3$ mm. The antenna is realized on the low-permittivity substrate $\varepsilon_r = 3.2$.

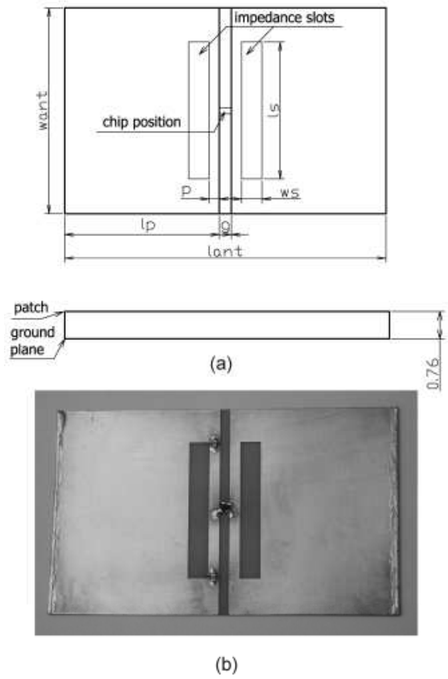

Figure 3: Antenna 3 - two-element shorted patch with tuning slots and RFID chip [3], a) sketch and b) photograph. SMD capacitors act as galvanic separation for used chip.

III. The Tag Antennas Performance Comparison

The following tables compare the main properties of the above described antennas. Antennas are identified by shorted name in this section. Antenna 1 represents flatten dual-loop antenna closely spaced over patch array, Antenna 2 represents dipole excited slot coupled two-element shorted patch and Antenna 3 represents directly excited two-element shorted patch.

Table I illustrates significant weight and thickness reducing in the above described evolution development steps. Due to the single layer substrate, the Antenna 3 embodies the most important improvement from the cost product point of view.

TABLE I
Physical Parameters of the RFID Badge Antennas

Antenna	Substrate	ε_r [-]	Dimension / Relative wavelength size	Weight [g]
Antenna 1	2 layer	10	$105 \times 70 \times 1.82$ mm $0.3 \times 0.2 \times 0.005\ \lambda_0$	38
Antenna 2	2 layer	3.2	$95 \times 60 \times 1$ mm $0.28 \times 0.17 \times 0.003\ \lambda_0$	14
Antenna 3	1 layer	3.2	$100 \times 60 \times 0.76$ mm $0.29 \times 0.17 \times 0.0022\ \lambda_0$	10

Figures 4 - 7 depict real and imaginary part of the input impedance of the antennas measured in free space and with enclosed agar phantom ($\varepsilon_r \sim 55$, $\mathrm{tg}\,\delta \sim 0.5$ and $80 \times 110 \times 15$ mm size).

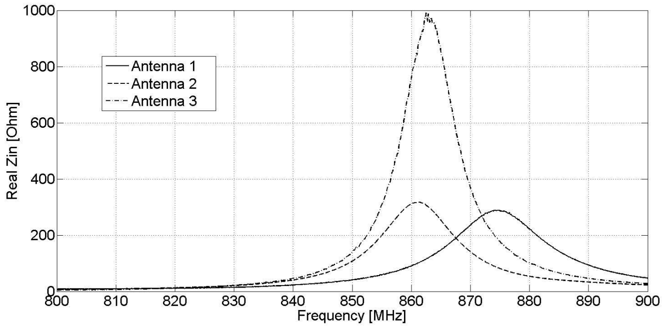

Figure 4: Comparison of the real part of input impedance of the tested antennas in free space.

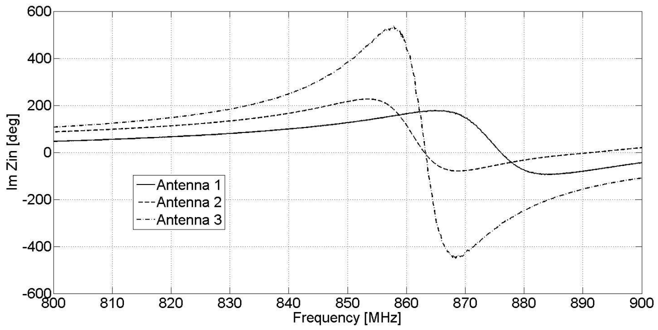

Figure 5: Comparison of the imaginary part of input impedance of the tested antennas in free space.

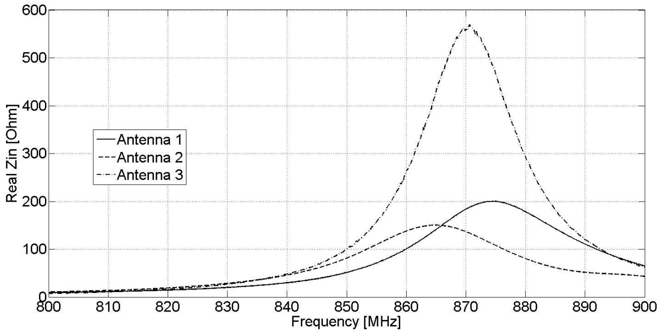

Figure 6: Comparison of the real part of input impedance of the tested antennas on the agar phantom.

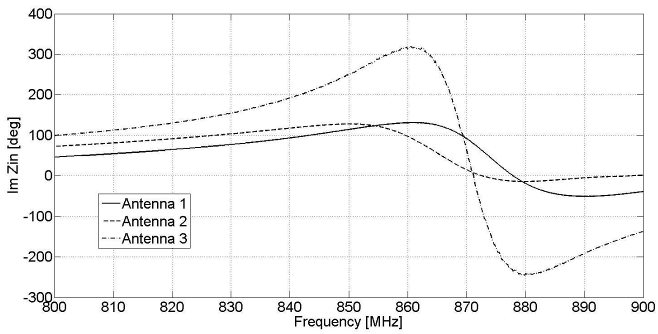

Figure 7: Comparison of the imaginary part of input impedance of the tested antennas on the agar phantom.

In table II and table III antenna efficiency and antenna gain is compared, respectively. Both parameters are simulated for antennas placed in free space and measured in free space and enclosed on the agar phantom.

TABLE II
ANTENNA EFFICIENCY OF THE RFID BADGE ANTENNAS

Antenna	Simulated, free space [%]	Measured, free space [%]	Measured, agar [%]
Antenna 1	39	38	33
Antenna 2	54	47	64
Antenna 3	56	52	60

TABLE III
GAIN OF THE RFID BADGE ANTENNAS

Antenna	Simulated, free space [dBi]	Measured, free space [dBi]	Measured, agar [dBi]
Antenna 1	1.3	0.8	0.6
Antenna 2	1.0	1.3	1.7
Antenna 3	1.1	1.0	1.6

IV. READ RANGE TESTS

Finally, identification tests of the antennas with chips have been performed in 4 m and in 2 m wide buildings corridors. The antennas have been fixed on the people chest as a badge in the height of 1.25 m, since the identification of persons is the expected antenna application. The height of the reader antennas has been 1.5 m. The antenna 1 and 2 were fed by the Trolley Scan chip [6] and tested by the Trolley Ponder reader. The antenna 3 was fed by the NXP Semiconductors chip UCODE G2XM [7] and tested by the Motorola reader XR 480. The both readers transmitted power was 1 W. The identification range of this RFID configuration is expressed in Table IV. The waveguide effect has significantly influence to the read range increasing in the 2 m wide corridor.

TABLE IV
IDENTIFICATION RANGE OF THE RFID BADGE ANTENNAS (ON CHEST) IN 4 M AND 2 M WIDE CORRIDOR, P IS READER AND TAG ANTENNA AXIS OFFSET

Antenna	4 m corridor			2 m corridor	
	p = 0 m	1 m	1.8 m	0 m	0.8 m
Ant. 1	6	4	5.5	13.5	10
Ant. 2	3	2.8	3.6	9	8.5
Ant. 3	7	6.8	6	17	10.2

V. CONCLUSIONS

Three variants of the very low-profile TAG antennas for UHF RFID of people were designed, as a result of the long-term development. All of the antennas embody good antenna efficiency and positive gain independently on a close presence of human body. The directly excited two-element shorted patch seems to be the most suitable for badge TAG antenna. Single layer configuration and low weight (10 g) are the main advantages. It exhibits as far as 7 m read distance in 4 m wide corridor and up to 17 m in the narrower 2 m wide corridor. Utilization of the low-cost substrate (e.g. FR 4) can be the next development step for practical application of the developed antennas.

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