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Research Article

Small-Size Wearable High-Efficiency TAG Antenna for UHF RFID of People

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This paper introduces a small-size, low-profile wearable radiator based on the coupled patches and vertically folded patches techniques for application as a tag antenna for identification of people in the European UHF RFID band. The electric field distribution comes out dominantly from the central coupling slot, and thus the electric properties of the radiator are almost unaffected by the human body to which the antenna is intended to be attached. Accordingly, with the relative size $0.14 \times 0.12 \times 0.009\ \lambda_0$ at 866 MHz ($50 \times 40 \times 3.04\ mm^3$), the antenna exhibits total efficiency better than 50 %, even if it is attached directly to a person.

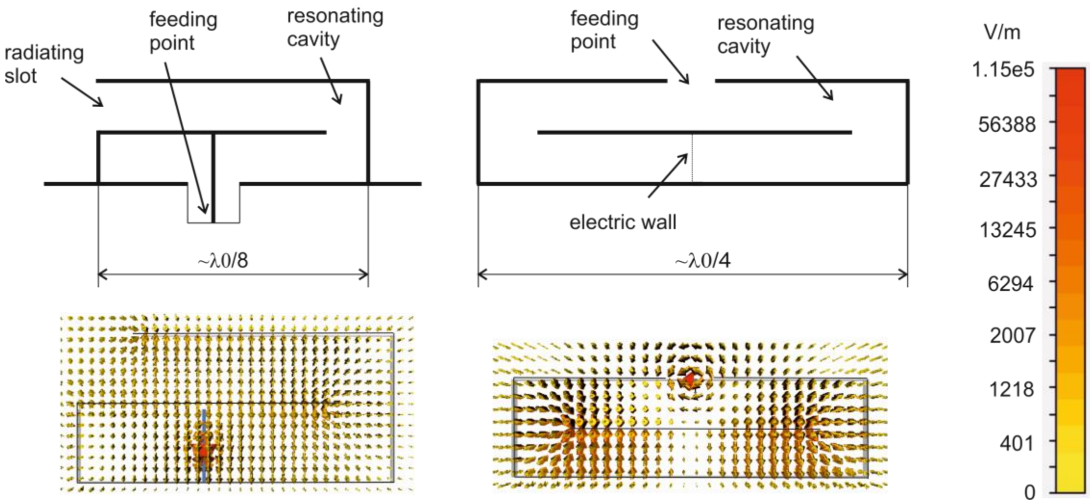
1. Introduction

Modern body area network (BAN) communication systems [1 - 5], and also radiofrequency identification systems (RFID) [6 - 12] require small-size, low-weight, inexpensive radiators, which can be easily integrated into electronic devices or e.g. on human clothes.

The coupled patches technique, introduced and employed in [13 - 15], developed especially for screening the influence of the human body, enables the design of wearable antennas with an extremely low profile (typically lower than $0.003\ \lambda_0$) and at the same time sufficient radiation efficiency typically better than 50 %. This is a significantly better value than the radiation efficiency of the common half or quarter wavelength patch antenna of the same size and height [16]. However, this technique does not enable the resonant length of the antenna to be smaller than approximately $0.3\ \lambda_0$ [14]. Thus, further miniaturization of antenna footprint size is a challenge for researchers.

Capacitive loading of a shorted patch antenna and its generalization, a vertically folded patch technique, which enables a half or quarter wavelength patch antenna to be minimized by means of repeat folding of the patch cavity, was presented in [17 - 18], see Fig. 1.

In this paper, we present a novel small-size high-efficient UHF RFID tag antenna of overall electrical size $ka = 0.58$ combining both of the techniques mentioned above. The coupled patches technique, which excites the maximum electric field magnitude in the central coupling slot, enables high radiation efficiency to be achieved with a very low profile, together with good immunity from the human body as opossite sides are formed by metallic walls; see Fig. 1b, which reduce the interaction of electric field with the base material. At the same time, the vertically folded patch technique enables a smaller footprint size of the structure to be achieved together with an acceptable increase in antenna height.

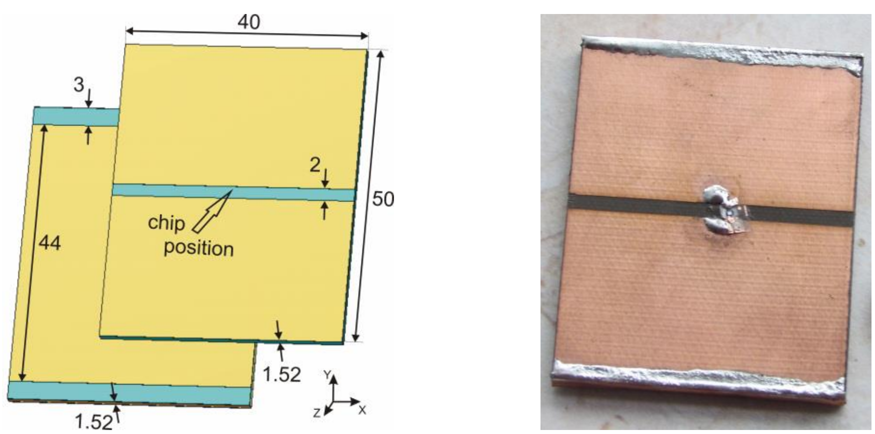


(a) (b)

Figure 1: The side cross section and electric field distribution of the vertically folded quarter wavelength patch antenna (a) and the proposed vertically folded coupled patches antenna (b).

2. Design, realization and measurement

Fig. 2 depicts a sketch and a photograph of the manufactured vertically folded coupled patches UHF RFID antenna. The antenna is manufactured on a low-permittivity substrate Taconic RF-30 with $\varepsilon_r = 3.0$ and loss tangent $\tan\delta = 0.002$. The total size of the proposed antenna is 50 × 40 × 3.04 mm3, which gives a relative size of $0.14 \times 0.12 \times 0.009\ \lambda_0$ at 866 MHz, i.e. $ka = 0.58$, where a is the diameter of the sphere completely circumscribing the antenna, including the mirror currents. The antenna is fed by the NXP G2X2 RFID chip with input impedance $Z_{in} = 22 - j195\ \Omega$ and power sensitivity -15 dBm. The weight of the antenna is approximately 15 g.



(a) (b)

Figure 2: Sketch (a) and photograph (b) of a folded coupled patches RFID antenna (dimensions stated in mm).

The performance properties of the antenna were verified in a monopole-type arrangement [14] in order to avoid the use of a balun situated between the antenna and the coaxial connector; see Fig. 3. The monopole-type input impedance then accounts for a half of the value compared to the dipole-type impedance. Consequently, $Z_{monopole} = Z_{dipole}/2$ is considered for further evaluation (where $Z_{dipole} = Z_{chip}^* = 22 + j195\ \Omega$.

The transmission coefficient; see Fig. 4, between the antenna and the chip input impedance was evaluated from the standard reflection coefficient measurement. The measurement was performed with and without a human body phantom (manufactured from agar with $\varepsilon_r \sim 55$ and $\tan\delta \sim 0.5$ of $80 \times 110 \times 15\ mm^3$ size) which was enclosed directly in the back of the antenna.

The above-mentioned monopole-type arrangement enables to measure the radiation and the total efficiencies by the Wheeler cap method [19]. A cap size of $122 \times 122 \times 122\ mm^3$ was used. The simulation was performed in a full arrangement; according to Fig. 2a. The measurement was performed with and without the human body phantom; see Fig. 5, Fig. 6 and Table 1. Very good immunity from the phantom as well as sufficient radiation and total efficiency can be observed at operation frequency 866 MHz.

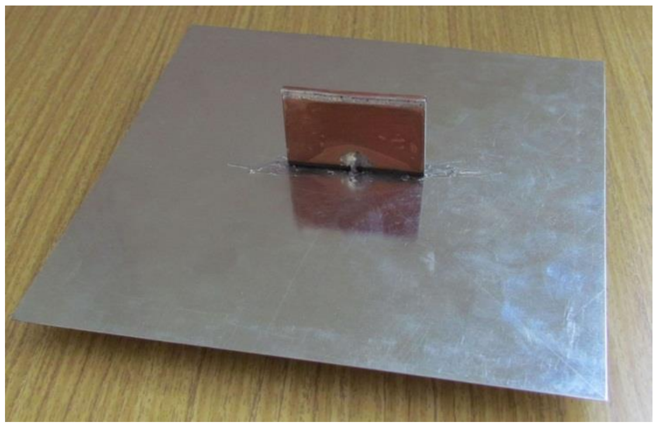


Figure 3: Photograph of a manufactured prototype of a folded coupled patches RFID antenna in the monopole-type arrangement with the ground plane $130 \times 130\ mm^2$.

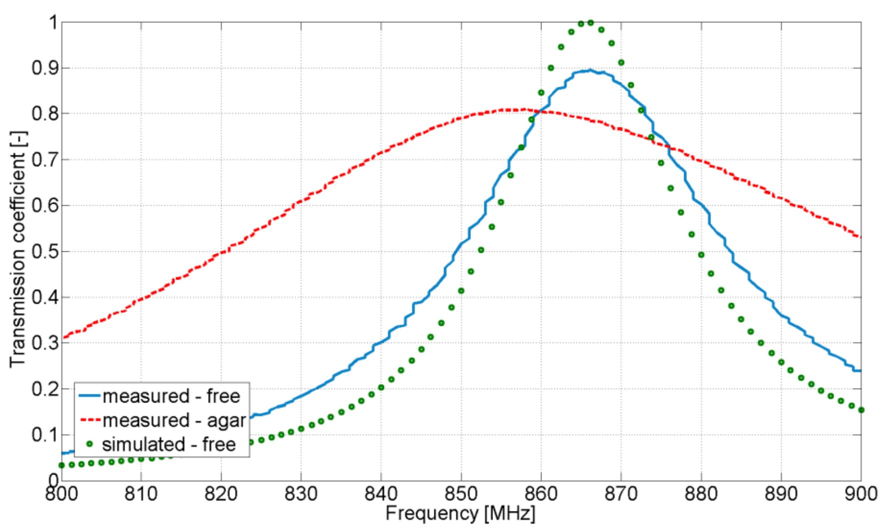


Figure 4: Simulation and measurement of the transmission coefficient of the vertically folded coupled patches tag antenna.

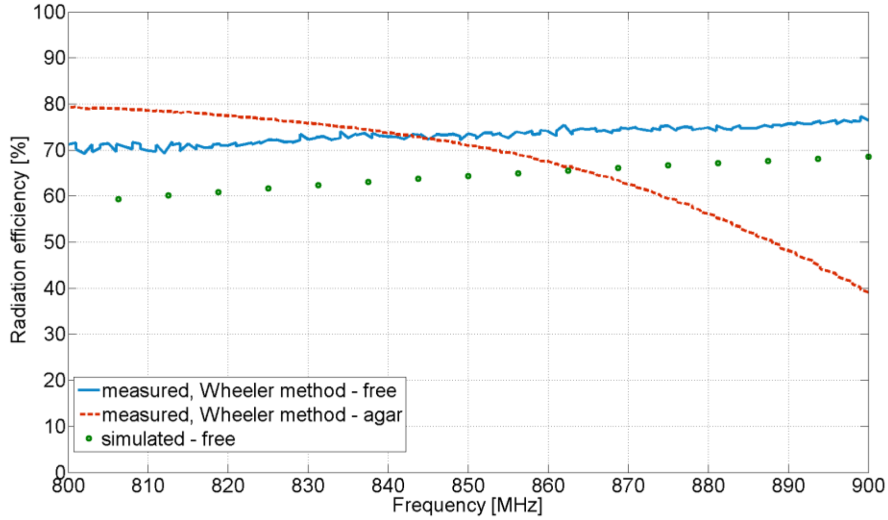


Figure 5: Simulation and measurement of the radiation efficiency of the vertically folded coupled patches tag antenna.

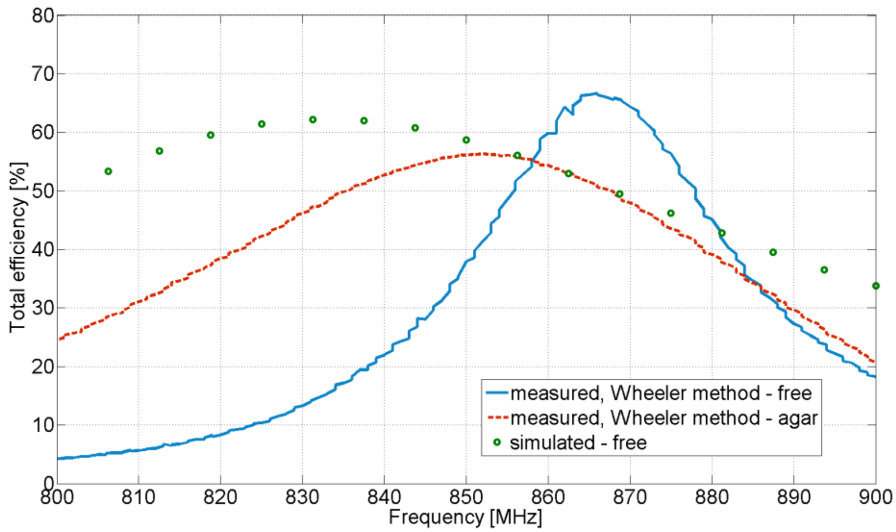


Figure 6: Simulation and measurement of the total efficiency of the vertically folded coupled patches tag antenna.

Table 1: Impedance and radiation properties of the vertically folded coupled patches RFID antenna at frequency 866 MHz.

	Transmission coefficient (-)	Radiation efficiency (%)	Total efficiency (%)
Measurement, free space	0.9	75	66
Measurement, agar phantom	0.8	65	51
Simulation, free space	1.0	66	51

3. Read range and identification tests

In order to evaluate the performance of the TAG antenna in real operational conditions, read range tests were performed with transmitted power of 30 dBm and standard 8 dBi reader antennas, which gives 6.3 W of effective isotropic radiated power (EIRP). The tag antenna with the chip was fixed at a height of 1.3 m in free space and on a person’s chest over about 2 mm thin shirt. The standard commercial RFID system (see Table 2) was used for the evaluation of the read distance as well as the reliability of person identification in corridors.

The read range evaluated in 4 m width corridor in a free space is 7.5 m, and for the antenna attached to a human chest the read range is 7.0 m; see Fig. 7. The read range evaluated in 2 m width corridor in a free space is 11 m, and for the antenna attached to a human chest the read range is 9.7 m; see Table 3.

Table 2: Standard used UHF RFID system parameters.

System components	Parameter	Values
	Operating frequency (Europe)	866 MHz
Reader	Transmitted power	30 dBm
	Receiver sensitivity	-64 dBm
	Reader antenna gain	8.0 dBi
	Reader antenna polarization	linear
Transponder (TAG)	Chip sensitivity	-15 dBm
	Chip impedance	22 – j195 Ω
	TAG conversion loss	approx. 6 dB

(a) (b)

Figure 7: Photograph of a test configuration: general view (a) and detail (b) of a person with the chest-fixed TAG in 4 m wide corridor.

Table 3: Identification tests of the folded coupled patches antenna in free space as well as on the human chest in buildings corridors.

Corridor width	Read range, free space (m)	Read range, human chest (m)
4 m	7.5	7
2 m	11	9.7

4. Conclusion

A novel small footprint size and extremely low profile wearable antenna based on a combination of coupled patches and vertically folded patch techniques has been introduced, and a sample has been developed for European UHF RFID band. The size of the tag antenna without a chip was $50 \times 40 \times 3.04$ mm^3, which is $0.14 \times 0.12 \times 0.009$ λ_0 at 866 MHz. The antenna exhibits total efficiency better than 50 %, irrespective of whether it is placed in a free space or enclosed on a human body phantom. The read range of the antenna placed on a person's chest tested was better than 7 m, while showing negligible influence of the human body to which the antenna was attached.

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