The Optimization of the RFID System for the Identification of Sportsmen in Mass Races

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***Abstract* — The optimization of a standard UHF RFID system for identification of sportsmen in mass races was proposed, realized and verified. The work was based on a system study that identified the main reasons of system failures. The proposed and realized improvements were focused on a development of more efficient and directive antennas for both the reader and the transponder and on an optimization of their location and orientation. The used propagation model turned out to be able to describe the existing fading phenomena and to predict the received signal levels anywhere in a 5 m wide finishing corridor. The optimized RFID system was tested in a standard outdoor operation, the results showed 100% identification reliability.**

***Index Terms* — Patch antennas, RFID, contact-less identification, transponders.**

I. INTRODUCTION

The application of the Radio Frequency Identification (RFID) systems spreads into many fields, such as commercial, industrial, medical, scientific and other areas. In most of the cases, the identification is performed without significant and fast movements of transponders with respect to the reader. However, the identification of fast moving objects (e.g., sportsmen in mass races, cars, components at conveyor belts, etc.) is increasingly demanded. The optimum implementation of any RFID system depends on the geometry of the particular identification task and on the frequency used. The low frequency RFID systems require a relatively strong magnetic coupling and, therefore, usually also a short distance among the reader and transponders. For the identification of a higher number of larger objects, substantially longer distances among the reader and transponders must be taken into account and the usage of higher frequencies can be recommended. In this case, the coupling is ensured by the propagation of the electromagnetic waves.

A basic feasibility study on using a standard commercial RFID system [1] operated in 869 MHz band for identification of moving objects was performed and described in [2]. The study included calculations of the system power budgets, measurements of received signal levels and identification of signal fadings together with their quantification. As a result, the study specified necessary improvements that had to be carried out in order to improve the system for the intended purposes.

II. MAIN MODIFICATIONS OF STANDARD UHF RFID SYSTEM

A. Reader and transponder antennas

The use of standard UHF RFID system for identification of sportsmen resulted in unacceptably low received signal levels, both at the transponders and the reader, and at the same time gave rise to a very low probability of the proper identification at both the start and finish gates. The low gain of the standard reader antenna and the low gain and efficiency of standard transponder antennas were considered as the main cause for this phenomenon. The low received signal levels often fall under the transponder and reader sensitivities and, consequently, the identification fails.

As far as the first optimization step is concerned, the original 8 dBi transmitter/reader patch antennas were substituted by a new 12.5 dBi patch antennas in a collinear arrangement, see reference [3]. In spite of the resulting 2 x 4.5 dB additional gain, the power budget values were still unsatisfactory, which was attributable mainly to a very low efficiency of the standard transponder dipole-type antennas operated in a close vicinity to a human body - it led to an antenna detuning and absorption of the best part of the radiated energy. That was the reason why the second optimization step was concentrated on a design of a transponder antenna that would not be affected by a human body presence. The antennas incorporating a ground plane as an integral part of its structures were considered. From the system point of view, a moderate directivity (5 - 10 dBi) and broad hemispherical radiation pattern were required. Besides, the transponder antennas had to be very light and flexible and had to show a low profile and acceptable surface dimensions. The patch antennas seemed to be a good candidate that could fulfill majority of the above-stated requirements. Since the impedance of the transponder chip Z_{chip} is complex (measured value $Z_{chip} = 76 - j340$), the antenna input impedance Z_{ant} has to represent a complex conjugate $Z_{ant} = Z_{chip}$ *.

Several patch antenna configurations including quarter-wavelength arrangements were modeled and tested. During this design procedure, problems associated with a low efficiency of patch antennas that had a low ratio of their substrate height to a free space wavelength (h/ $_0$) were experienced and solved. Since it was necessary to design a very low profile patch antenna operating at hundreds of MHz, the lower antenna efficiency, analytically described in [4], had to be improved using a low ε_r dielectric, see Fig. 1.

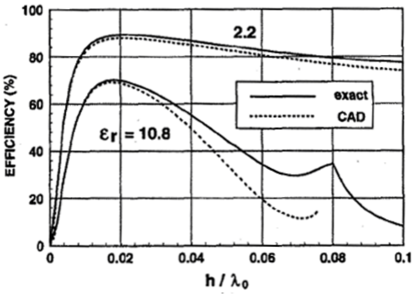

Fig. 1 Radiation efficiency of rectangular patch antenna with dimensions *W/L*= 1.5 versus electrical thickness of substrate at frequency of 5.0 GHz. Loss tangent 0.001 is assumed for both substrates, from reference [4]

A new patch antenna with the required input impedance $Z_{ant} = Z_{chip}{}^* = 76 + \mathrm{j}\,340\Omega$, based on a foam dielectric (G3 9568 foam $h = 4.8$ mm, $h/\ _0 \sim 0.014$) and conductive fabric was designed and realized, see Fig. 2. The conductive fabric was used for a creation of both the ground plane metallization and the top plane radiating patch. The antenna structure was modeled in the IE3D EM simulator, its $W/L \sim 0.3$ and operating frequency is slightly below its half-wavelength resonance. The ground plane dimensions are 165 x 74 mm, the measured gain of an antenna placed on a human body equals 5.0 dBi. The weight of the antenna is equal approx. to 20 g – which is considered to be very flexible and is supposed to be integrated within sportsmen number labels.

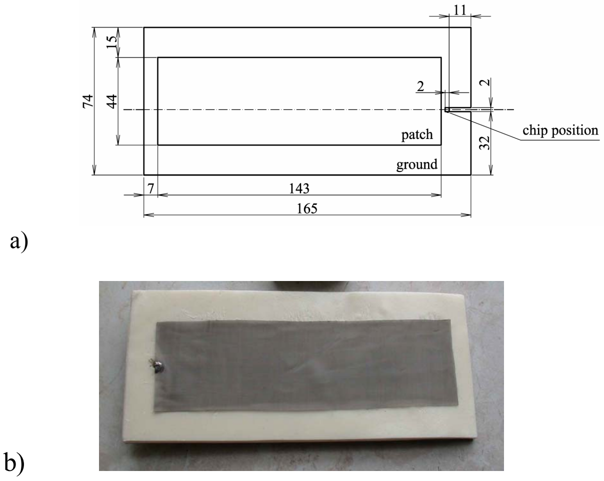

Fig. 2 Transponder patch antenna with chip, a) schematic view,
b) photograph of designed prototype

The comparison of the measured gains of the standard meander dipole used in [2], the λ/4 patch antenna used in [2], and the new designed patch antenna is presented in Tab. I. The *b* parameter represents the distance between the antenna under test and the phantom (a tank of 5litres of salt water) which stands for a substitute for a human body.

TABLE I
MEASURED GAINS OF ANTENNAS TESTED

Antenna type	G [dBi]
Meander dipole, free space	2.2
Meander dipole, *b* = 20 mm	-5.72
λ/4 patch, free space	-3.02
λ/4 patch, *b* = 10 mm	-1.12
λ/4 patch, *b* = 0 mm	-0.12
New patch, free space	6.3
New patch, *b* = 0 mm	5.0

The above-presented values of the measured gains show that the new patch antenna can bring substantial improvements in the system power budget. The new antenna parameters are nearly independent off the presence of a human body. Moreover the component is also a very good candidate for a RFID antenna that can be fixed directly on large metal objects (containers, cars, etc.).

B. Improved propagation model

In order to predict the received signal levels (RSLs) in the whole area of the finishing gate corridor, the new trace loss formula describing more precisely signal propagation paths and including angular dependences of antenna gains, was derived and used for the power budget calculations. The entire signal path attenuation can be expressed as follows:

$$L = -20\log\left(\left(\frac{\lambda}{4\pi}\right)\left|\sqrt{G_{tV}(\alpha_d)G_{rV}(\beta_d)G_{tH}(\gamma)G_{rH}(\delta)}\cdot\frac{1}{r_1}e^{-j\cdot k\cdot r_1} + \right.\right. \qquad (1)$$

$$\left.\left. + \sqrt{G_{tV}(\alpha_r)G_{rV}(\beta_r)G_{tH}(\gamma)G_{rH}(\delta)}\cdot \mathrm{R}(\vartheta)\cdot\frac{1}{r_2}\cdot e^{-j\cdot k\cdot r_2}\right|\right)$$

,where r_1, r_2 stand for distances of direct and reflected rays, $G_{rV}(\ )$, $G_{rH}(\delta)$ represent angular dependences of transmitter/reader antenna gains in a vertical/horizontal planes, $G_{tV}(\alpha)$, $G_{tH}(\gamma)$ are angular dependences of the transponder antenna gains in a vertical/horizontal planes and $\overline{R}(\vartheta)$ indicates a complex reflection coefficient of a wet ground ($_r = 10$, $= 10^{-2}$ S/m).

Fig. 3 and 4 show the plots of the simulated and measured TAG input power P_{rTAG} at the gate axis $p = 0$ and at the $p = 2.5$ m offset. Both figures include results corresponding to the meander dipole antenna and the new patch antenna. Fig. 5 shows the values of the simulated reader input power $P_{rREADER}$ at the same configuration. All plots compare measured and simulated data with the corresponding sensitivity values.

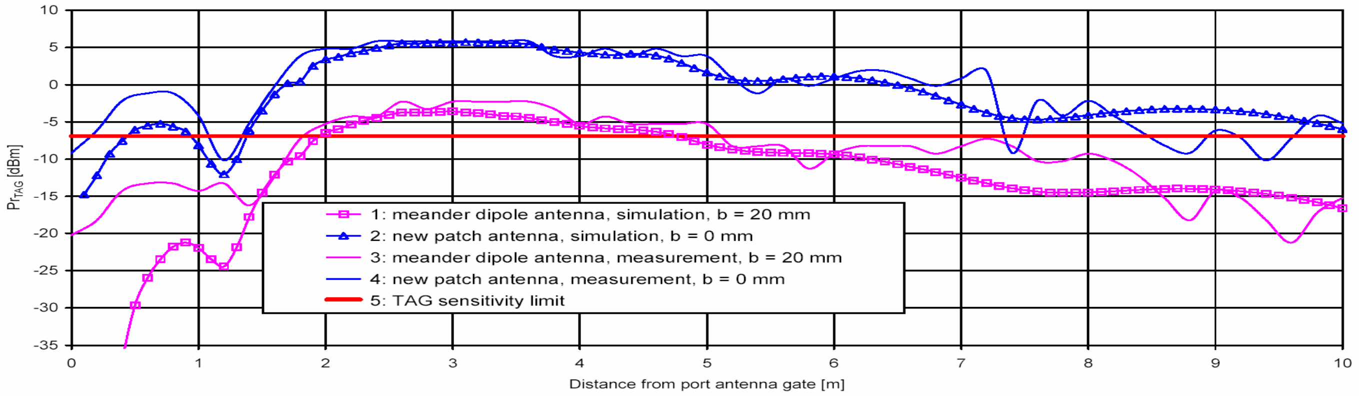

Fig. 3 Simulated and measured TAG input power P_{rTAG} (tilt of gate antennas $\psi = 30^{o}$, P_t = 3.5 W, h_1 = 3 m, h_2 = 1.3 m, p = 0 m)

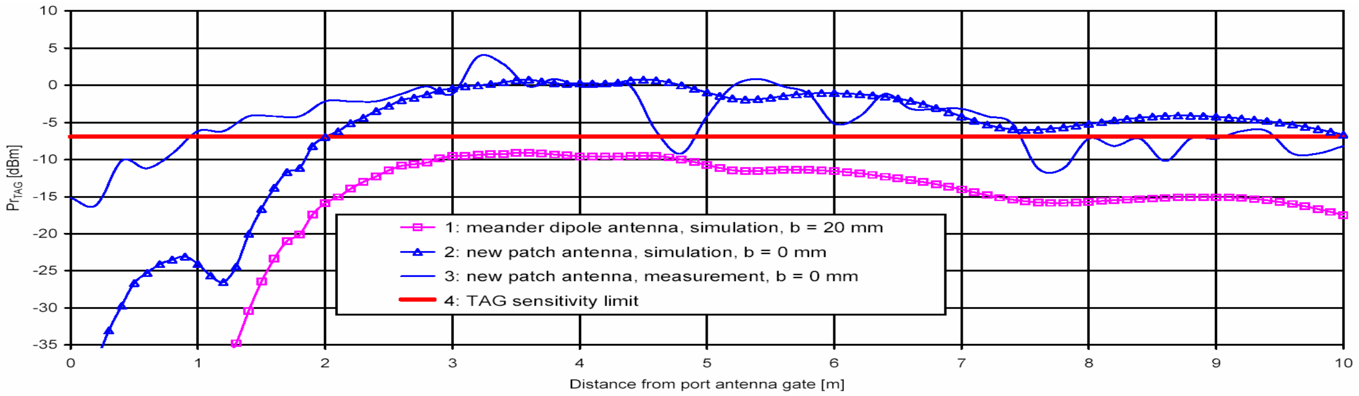

Fig. 4 Simulated and measured TAG input power P_{rTAG} ($\psi = 30^{o}$, P_t = 3.5 W, h_1 = 3 m, h_2 = 1.3 m, p = 2.5 m)

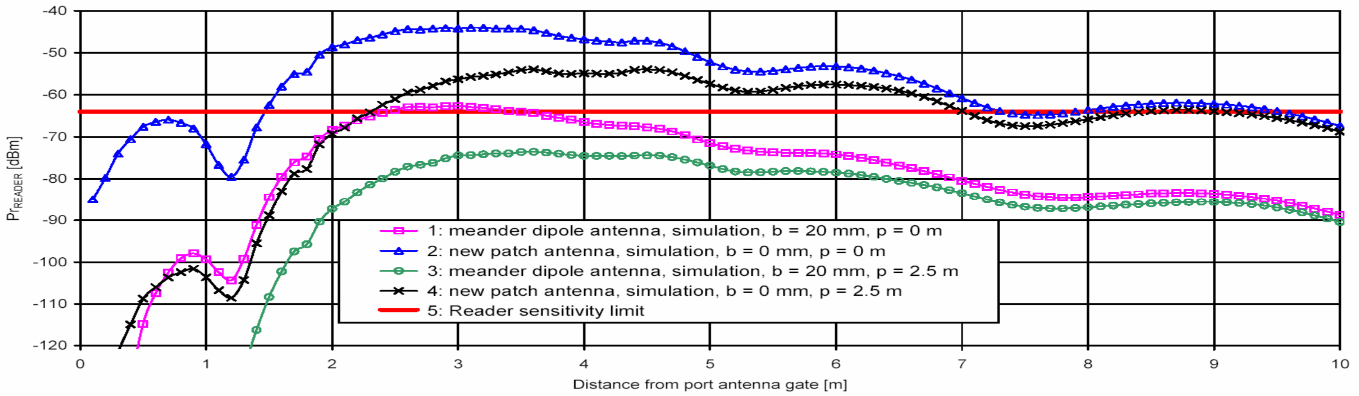

Fig. 5 Simulated reader input power $P_{rREADER}$ ($\psi = 30^{o}$, P_t = 3.5 W, h_1 = 3 m, h_2 = 1.3 m)

TABLE II

BACKUP OF POWER BUDGETS WITH RESPECT TO READER AND TRANSPONDER SENSITIVITIES

Antenna	Power budget backup			
	Transmitter – transponder path		Transponder - reader path	
	Corridor axis	p=2.5 m	Corridor axis	p=2.5 m
Meander dipole b = 20 mm	3.3	-2.1	1.3	-10.5
$\lambda/4$ patch b = 0 mm	9.8	3.7	14.4	2
New patch b = 0 mm	12.5	7.2	19.8	9

Tab. II includes the calculated values of the backup of both the reader-transponder and transponder-reader power budgets with respect to the transponder and reader sensitivities (the minimum values of the transponder and the reader input powers that ensure the proper identification). The backup values correspond to a distance between 2.5 to 3.5 m (i.e. the distance between the transponder from the reader). All other geometrical and power parameters correspond to [2]. Both power budgets based on the new patch antenna provide reserves high enough to guarantee a correct identification. Theoretical simulations were verified by means of the practical system testing.

C. Testing of optimized UHF RFID system

The identification reliability of the improved RFID system was tested under practical conditions. Seven racers in an in-line configuration passed several times through the finish gate corridor, see Fig. 6.

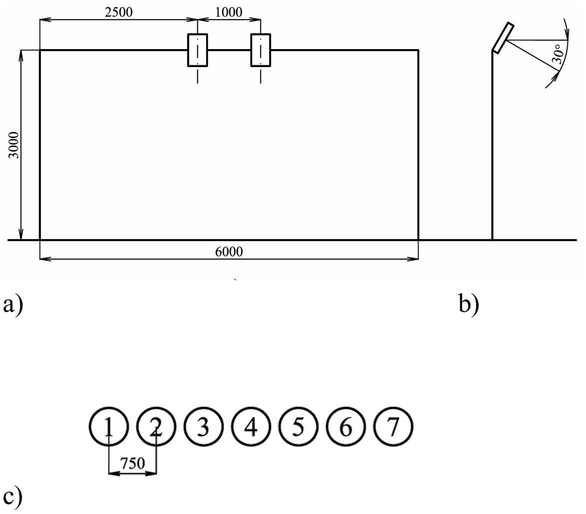

Fig. 6 Finish gate corridor configuration with two transmitter/reader antennas, a) front view, b) side view with $\psi = 30°$ antennas tilt, c) sportsmen configuration

Two speeds of sportsmen were tested – the first one corresponded to a faster walk (approx. 6 km/h) and the other one equated a long-distance run (approx. 15 km/h). The reliability of the identification of the optimized RFID system can be seen in Tab. III.

TABLE III

COMPARISON OF RELIABILITY OF IDENTIFICATION OF STANDARD VERSUS OPTIMIZED RFID SYSTEM

Speed of movement	**Reliability of identification**	
	Standard RFID system	**Optimized RFID system**
walk	66.7 %	100 %
run	52.4 %	100 %
totally	59.6 %	100 %

IV. CONCLUSION

The standard UHF RFID system was adapted for the identification of sportsmen in mass races. The system optimizations were performed with the help of the system study and identification of main signal fadings. For the substantial improvements of the power budgets, it was necessary to use the new transmitter/reader antennas with additional 4.5 dB of gain. Furthermore, it was crucial to find their proper alignment, develop a new wearable low profile and also a low weight transponder antenna. The patch antenna structure was used in order to ensure that the antenna parameters are not affected by a close presence of a human body. In comparison to the original dipole-type antenna, the gain of the new patch transponder antenna placed on a human body is more than 10.5 dB higher. The above-described changes increased the reader-transponder power budget by approximately 15 dB (direct path) and the total power budget by about 30 dB (direct + return paths). The resulting power budget backup amounts to about 7 dB (in the case of the direct path) and to approx. 9 dB (in case of the direct + return path). The aforementioned power budget backups refer to a location in a 5 meter wide finishing corridor in the range approx. 2.5 - 3.5 m from the gate. On the corridor axis, the power backup values reach approx. 12.5 and 20 dB respectively. The optimized RFID system was tested in a standard outdoor operation, the results showed 100% identification reliability.

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