Analysis and Measurement of the RFID System Adapted for Identification of Moving Objects

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Abstract — A system study of ability of using a commercially available 869 MHz RFID system for identification of moving objects has been performed. The study has been focused on a power budget of received signal levels and on identification of main signal fadings and their quantification. Two types of TAG antennas have been used. Comparisons of their radiation properties when operated in the close vicinity of the human body (or a simple phantom of a human body) have been performed. Suitability of their use is discussed. Results of this study provide deeper insight in the given problem and information in which way the system should be improved in order to comply with the intended purposes.

Index Terms — Patch antennas, RFID, system fading, system identification, transponders.

I. INTRODUCTION

The province of Radio Frequency Identification (RFID) systems covers a broad spectrum of commercial, industrial, medical, scientific and other applications. Several EM principles of the RFID operation exist, including usage of a wide frequency spectrum range, starting from tens of Hz up to several GHz [1]. Suitability of particular implementation of the identification system depends on the given application requirements. Generally, each RFID system consists of three main parts: the transponder (TAG, information medium, carrier), the reading device, and the antenna or another coupling device. In most cases, the identification is performed without significant movement of transponders. However, in the recent time, the demand for RFID identification of relatively fast moving objects (such as sportsmen of mass races or cars for road-toll payment purposes) has increased.

The system study of the ability of using a commercial 869 MHz RFID system for identification of moving sportsmen has been performed [2]. It was motivated by a relatively low reliability of identification during initial tests. The study is focused on a system power budget, on identification of signal fadings together with their quantification, and on analysis of performance of transponder antennas operated in the vicinity of a human body. As a result, the study specifies necessary improvements that have to be done in order to adapt the system for the intended purposes.

II. EMPLOYMENT OF RFID SYSTEMS FOR MASS RACES

RFID system requirements for their employment during mass races come from a nature of these races. During identification at the finish line, it is usually necessary to detect racers moving through a 3 to 10 meters wide corridor. The speed of racers (runners, ski-racers, bikers, etc.) is supposed to be up to 100 km/h. Employment of RF or microwave identification can be advantageous with respect to the corridor size, distances among racers, and possible locations of TAGs on their bodies.

System parameters of a definite commercial RFID system (Trollyponder [3], intended namely for warehouse goods identification) were used for performing power budget analysis and determination of signal fadings. Analysis and practical measurements of received (power) signal levels (RSL) and their comparison with TAG and reader sensitivities were also performed.

For all measurements two types of wearable antennas were used: the meander dipole with a reduced length and a quarter-wavelength patch antenna. The main antenna parameters were also measured in a close vicinity of the phantom of a human body.

III. SYSTEM ANALYSIS AND MEASUREMENTS

A. Power Budget

The system power budget has been analyzed with help of a two-ray model, see Fig. 1a. Just two rays, the direct one and the reflected one are taken into account [3]. Trace loss of this model including gain of antennas used can be expressed in dB as:

\[
L = -20 \log\left(\frac{4\pi}{r_1} \sqrt{G_t(\alpha_1)G_r(\beta_1)} \frac{1}{r_1} e^{-jkr_1} + \sqrt{G_t(\alpha_2)G_r(\beta_2)} \frac{1}{r_2} e^{-jkr_2}\right)
\]

(1)

where \( r_1 \), \( r_2 \) are distances of direct and reflected ray, \( G(\cdot) \) is an angular dependence of transmitter/reader antenna gain, \( G(\cdot) \) is an angular dependence of TAG antenna gain, \( R(\theta) \) is a complex reflection coefficient [4] of a wet ground (\( \rho = 10, \gamma = 10^5 \)). The power \( P_{\text{tag}} \) received by the TAG antenna can be expressed in dB as:
where $P_t$ is the transmitted power, $L$ is the trace loss including antenna gains, $L_f$ is the feeder loss. The signal power $P_{\text{READER}}$ received by the reader can be expressed in dB as:

$$P_{\text{READER}} = P_t + L + L_f$$  

The scheme of the model and the real test arrangement with the transmitter/reader antenna placed on the top of the 5 x 3 m finish line port can be seen in Fig. 1. The transmitter/reader 12 dBi collinear patch antenna (CoMPA) [5] was fixed at the height $h_1 = 3$ m above ground with a 45° downtilt. The location of the TAG antenna was on a chest of a racer at the height of approx. $h_2 = 1.3$ m above ground. Both transmitter/reader and TAG antennas had a vertical polarization.

![Fig. 1](image1.png)

**Fig. 1** Scheme of a) the two-ray model and b) photograph of a real arrangement of transmitter/reader and TAG antennas at the finish line port

### B. Tested TAG Antennas

Two types of TAG antennas were designed and tested. The meander line shorted dipole (30 x 98 mm) made of conductive cloth, see Fig. 2a, and the quarter-wavelength patch antenna fed by a microstrip line with a transition to a SMA connector, see Fig. 2b. The gain of the dipole antenna fixed 20 mm in front of a chest phantom (101 tank with a salt water) was approx. -3.9 dB and -5.7 dBi when placed on a human body.

Dimensions of the patch manufactured on a 3 mm thick dielectric substrate (ε = 3.05, tg ~ 0.003) are 121 x 51.5 mm, and the ground plane dimensions are 141 x 61.5 mm. Its gain was approx. -0.1 dBi when placed on a human body and -0.6 dBi fixed 10 mm in front of a phantom. Radiation patterns (see Fig. 2) were measured in an anechoic chamber.

![Fig. 2](image2.png)

**c) Fig. 2** Photographs of TAG antennas: a) the meander dipole 20 mm in front of the phantom, b) the patch antenna 10 mm in front of the phantom, c) radiation pattern of the meander dipole radiation pattern in a free space and with a 10 and 20 mm spacing in front of a phantom, and the patch antenna radiation pattern with a 10 mm spacing in front of the phantom

Both antennas can be fixed on a sportswear, for example on a number label. The patch antenna used has still unpractical dimensions. However, attempts are performed to manufacture it from soft and light materials.

### C. Simulated and measured RSLs

Values of RSLs of both types of TAG antennas simulated and measured under different conditions (taking into account real shapes of antenna radiation patterns, detuning and energy absorption in the closely spaced body phantom) can be seen in Fig. 3 and 4.
Fig. 3  Simulated and measured RSLs at the TAG antennas, including mechanisms of system fadings: a) meander dipole placed 20 mm in front of the body, b) patch antenna both placed on a body 1.3 m high. Transmitter antenna placed at height of 3 m, downtilt 45°, transmitted power 1 W, vertical polarization.

Fig. 4  Simulated RSL values at the transmitter antenna, including mechanisms of system fadings with a) meander dipole, b) patch antenna. Transmitter/reader antenna has been placed at height of 3 m, downtilt 45°, transmitted power 1 W, vertical polarization.
IV. CONCLUSIONS

Analysis and measurement of the power budget of the RFID system intended for the detection of moving objects were performed, two different antenna types were used. Except of influences of shadowing by another racers, which is not included in this paper, the results show two main reasons of low RSLs at the TAG receiver. The first reason is given by radiation patterns of the TAG and transmitter/reader antennas, especially in elevation angles close to 90°, see Fig. 3a and 3b. The second reason is a drop of efficiency of the meander line antenna by detuning and energy absorption caused by the placement in the immediate vicinity of the racer body. The basic TAG sensitivity is around –6.9 dBm, see Fig. 3. In the case of the dipole antenna (placed 20 mm in front of the racer body), there is a backup of only 3 dB over the TAG sensitivity in the 1.5 to 2.5 m range from the port antenna base. In the case of the patch antenna, the system backup is higher and the range is wider. In the 1 to 3.5 range, there is a backup up to 8 dB over the TAG sensitivity. When both antennas are placed directly at the body, the difference is substantially bigger (the meander antenna gain drops, while the patch antenna gain is approximately the same).

Investigated RFID system detects TAGs each 1/70 s. With a speed of a racer about 100km/h, 0.4 m with a RSL above the TAG sensitivity is needed for correct detection and identification. Outside the specified ranges, the RSL values are bellow the sensitivity of TAG or a reader and identification will not be performed. The results show that for the given purposes standard dipole antennas cannot be used, they are too much influenced by a human body even when it is placed 20 mm in front of a racer body. In order to improve the power budget, another types of antennas have to be developed. Tested patch antenna provides very good results but suffers from unsuitable dimensions and weight. Soft and light version of the patch antenna is being prepared. Power budget can also be improved by increasing the transmitted power. The Trolleyponder system can operate with up to 4 W, which represents additional 6 dB improvement when compared with the 1 W transmitted power used.

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