Active UHF Antennas for Demanding RFID Applications

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***Abstract* — The UHF RFID systems are used, on an everyday basis, for identification of millions of different items of goods. Yet there are identification tasks, where a correct and reliable identification is difficult to be accomplished. One of these applications concerns identification of goods equipped with TAGs, densely and randomly accommodated in a larger space. This refers e.g. to the identification of many TAGs fixed on clothes in large cartoon boxes. The TAGs can be located very close to each other, mutually coupled, screened, randomly oriented and placed in an environment with a wide range of wave propagation parameters. The identification of such a set of TAGs represents a difficult problem, because standard configurations are rather prone to fail. The presented paper describes one of the possible solutions. The identification system is equipped with active reader antennas that enable the illumination and the read-out of the TAGs from many different locations as well as angles, and with a wide range of illuminating power. The whole process can be accomplished very fast. In fact, many different scanning procedures can be performed. According to preliminary measurements, such conditions conduce to 100% correct and reliable identification even in case that the tested scenarios include several hundreds of TAGs. The designed RFID system is very likely to be able to work well even in more demanding identification tasks.**

***Index Terms* — active antennas, phased-array, RFID.**

I. Introduction

The employment of RFID systems belong to one of the most widely spread and successful branches of electronics. Applications can be found in various fields, ranging from the identification and counting of goods to the identification of cars or people. The identification is basically very quick; all information can be further processed - in company store systems, for the purpose of the highway billing, for authorization of access to buildings or areas, etc.

Despite the possibility of employment of both, lower and higher operating frequencies, the UHF frequency band remains very popular. In contrast to the usage of the lower (LF, HF) frequency bands, where only a short-distance inductive coupling is used, it shows a potential for identification at longer distances. This is mainly due to the fact that at UHF frequencies, it is possible to carry out the antennas with acceptable dimensions and efficiencies and, at the same time, the propagation of electromagnetic waves as a coupling mechanism can be used. The microwave frequency band, (usually of 2.45 GHz) has the same features and enables the construction of even smaller and more efficient antennas. Yet it is true that merely the active TAGs are available up to now, and the higher propagation loss has to be taken into account.

Standard UHF RFID applications are based on a transmitter (TX) that illuminates the space with TAGs to be identified by the electromagnetic wave of a suitable power density. The antenna of the TAG receives a part of the incident RF power, and the TAG input circuits convert it into a DC power that is capable of activating the coding circuits. The latter modulate the reflection coefficient of the TAG. The modulated reflected wave is received by the receiver (RX) and further processed.

II. System Considerations

Conditions of a correct identification can be described by the following fundamental formulae:

$$P_{rTAG} = P_{TX} + G_{TX} + G_{TAG} - L_0 - L_{k1} \geq P_{rTAG\min} \quad (1)$$

$$P_{rREADER} = P_{rTAG} + G_{TAG} + G_{RX} - L_0 - L_{k2} - L_{conv} \geq P_{rREADER\min} \quad (2)$$

The condition (1) describes the reader-TAG path and states the following: in order to attain the correct identification, the power P_{rTAG} received by the TAG antenna has to exceed the limit value $P_{rTAG\min}$. The P_{rTAG} value is influenced by the TX output power P_{TX}, gain of the transmitting antenna G_{TX}, gain of the TAG antenna G_{TAG}, wave propagation loss L_0 and additional losses L_{k1}. The condition (2) describes the TAG-reader path. For the correct identification, the reflected power received by the reader antenna $P_{rREADER}$ has to be higher than the limit value $P_{rREADER\min}$. Apart from L_0 and L_{k2}, $P_{rREADER}$ also includes the TAG conversion loss L_{conv}. G_{RX} is the gain of the receiving antenna.

In order to attain the correct identification, both conditions have to be met simultaneously. In the above-described case (i.e. the identification of the set of TAGs fixed on clothes), the satisfaction of conditions is negatively affected by several factors, out of which the majority is included in the additional losses L_{k1} and L_{k2}. They are listed below:

- Additional attenuation of electromagnetic waves, whose exact prediction is very complicated
- Multiple reflections of electromagnetic waves
- Random orientation of TAG antennas

- Changes in parameters of TAG antennas resulting from near dielectric (and frequently also small) metallic objects, such as belt buckles
- Mutual coupling of closely spaced TAG antennas [1]
- Mutual shading of TAG antennas

All the above-mentioned phenomena influence both TX-TAG and TAG-RX paths. Given the conditions (1) and (2), the correct identification predominantly depends on the power levels and reflections. Thus the following solutions should be recommended:

- Enhancement of illuminating power
- Illumination and read-out of TAGs from different positions and angles
- Focusing of power to TAGs

The maximum radiated output power is usually limited by regulations, which are predominantly determined by hygienic standards. Yet a considerable amount of power can be lost in connecting cables. The changes in illuminating and read-out positions and angles can be performed mechanically. However, such solutions are expensive and slow. Many modern readers are equipped with multiple TX outputs and RX inputs (in general, with four or less). Indeed, more TX and RX antennas at different positions can be used. In reality, not all readers provide such a possibility. Accordingly, only rather limited number of different positions and angles can be used.

Mere changes of positions of reader antennas can be substituted by using of phased–array antennas, examples can be found in [2] – [4]. Phased-array antennas are able to focus the electromagnetic power to or from the definite areas and angles. In case they are electronically tuneable, the areas and angles can be shifted. The main disadvantages of the standard phase-array antennas consist in power limitations and attenuation of the electronically controlled phase-shifters. Consequently, in order to find the optimum solution of the above-described identification task, a more robust and versatile tool was designed.

III. Designed System With Active Antennas

Fig. 1 shows the block diagram of the designed RFID system. The system employs a standard RFID reader, in this case the Motorola XR 480. The reader is set to a bistatic operation. Both TX and RX antennas consist of a definite number of active modules. Each TX module includes a RF switch, digitally controlled attenuator, phase-shifter, power amplifier and patch radiator. The RX modules are composed of RF switch, phase shifter, LNA and patch radiator. The active modules can be fixed in different configurations; see Fig. 2.

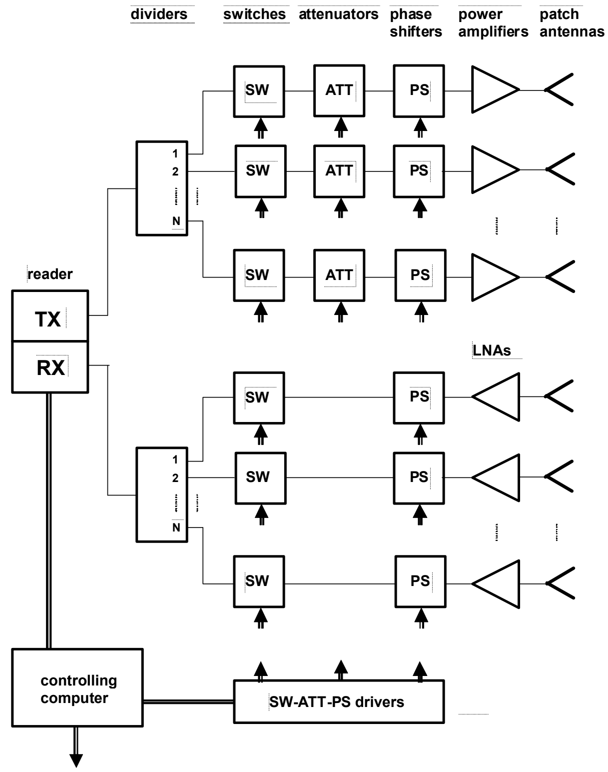

Fig. 1 Scheme of designed RFID system with active antennas.

The aforementioned RFID system, based on active antennas, provides us with the following key advantages:

- The employment of power amplifiers eliminates problems with the attenuation in the TX paths (including cable loss, divider loss, switch loss and phase-shifter loss).
- The set-up enables the utilization of a nearly arbitrary radiated output power. Although limited by hygienic requirements, potentially very high illuminating powers are available, provided that the additional screening is used.
- As the phase-shifters do not experience problems with the high output power from the TX, simpler and low-cost circuits can be used. In order to ensure a wider range of settable phases, the phase-shifters can be easily cascaded.
- LNAs can eliminate the influence of the phase-shifter loss and cable loss on the RX sensitivity. Nevertheless, the possibility of saturation by illuminating power has to be taken into account.
- TX and RX modules can be used in variety of configurations.
- The designed active modules can be assembled using relatively elementary and low-cost components.

IV. TX AND RX MODULES

The designed TX modules consist of the HMC194MS8 RF switches (Hittite), two JSPHS-1000, electronically controlled phase-shifters (Mini-Circuits), MHL98388 39 dBm power amplifiers (Freescale Semiconductor) and patch radiating elements with circular polarization, see Fig. 2. As they were dispensable, the digitally controlled attenuators (enabling an individual setting of radiated power and e.g. control of phase-array radiation patterns) were omitted, up to now.

The designed RX modules consist of the identical air dielectric patch antennas with circular polarization, LNAs, phase-shifters and switches. The antennas gain equals 8.5 dBi. The electronic parts of the modules are fixed on the rear sides of 250 × 250 mm patch antenna substrates.

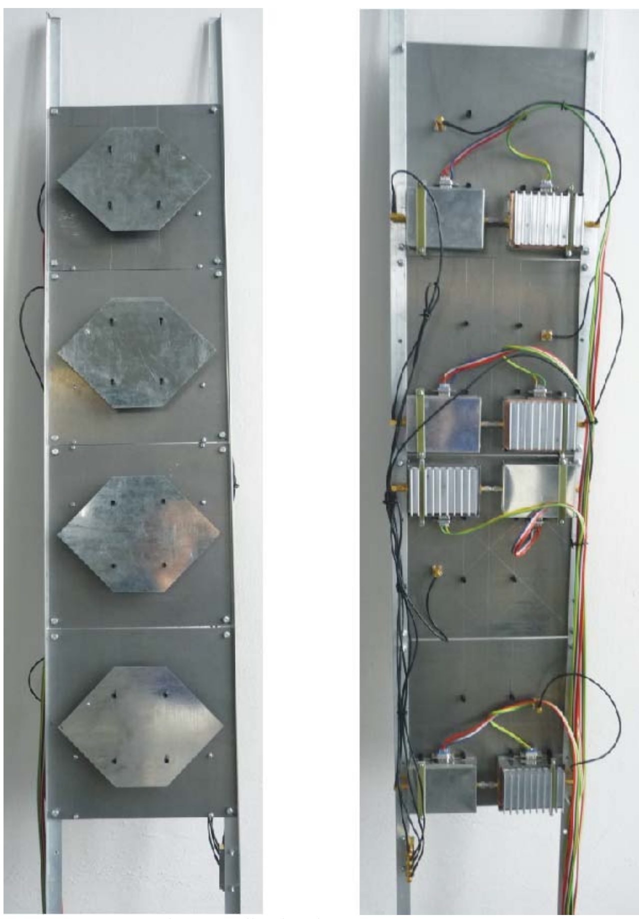

Fig. 2 Realized active antenna array

IV. ANTENNA CONFIGURATIONS, SCANNING PROCEDURES

The active TX and RX active modules in question can be used in many configurations. As far as the above-mentioned identification task is concerned, a linear configuration is employed; see Fig. 3.

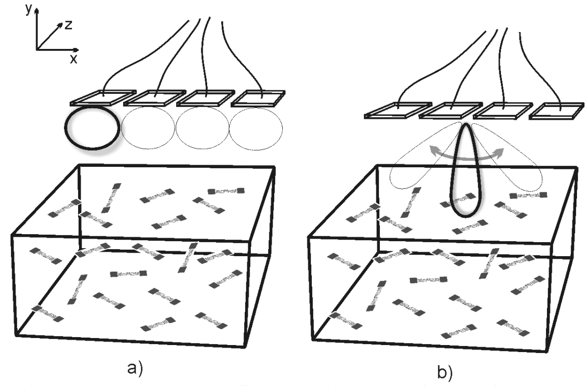

Fig. 3 Linear antenna configuration in a) one-of-N, b) phase-array modes.

Two parallel linear arrays consisting of 4 TX and 4 RX modules are fixed alongside the box with TAGs that are to be identified. Owing to this configuration, a number of different illuminating and read-out procedures can be implemented, namely:

- Both active antennas operate in the one-of-N mode. In one time slot, only one TX and one TX modules are active. This mode enables the illumination and read-out of TAGs at different antenna positions. In addition, for one illuminating position it is also possible to use more read-out positions. As a result, it is possible to preform the identification under different angles between TX-TAG and TAG-RX paths.
- Both antennas operate in the phase-array mode. Apart from the operation under different angles, it is feasible to focus the RF power to a definite area.
- The system employs combined modes, one active module at the output of the TX and phase-array antenna at the RX input (or vice-versa).

MoM IE3D software has been used to simulate radiation patterns of a single patch radiator and 4 element linear phase array, see Fig 4-7. Distance of the radiators is one wavelength. Linearly increasing phase shift is used: 0°, 90° and 180°. Distribution of excitation amplitudes is uniform.

Beside the linear arrays, the matrix arrays can also be set together and used.

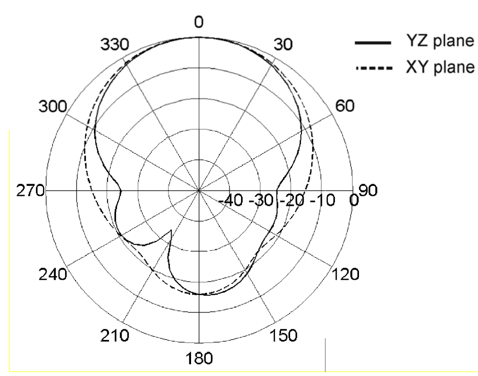

Fig. 4 Simulated radiation patterns of the single patch radiator.

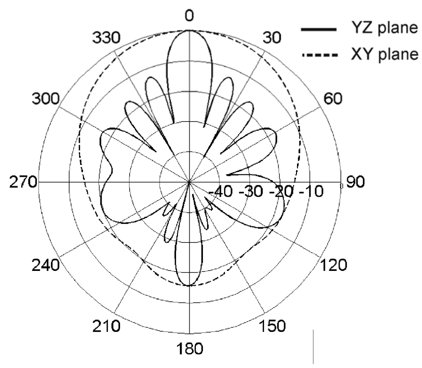

Fig. 5 Simulated radiation patterns of the linear phased-array with the phase shift 0°.

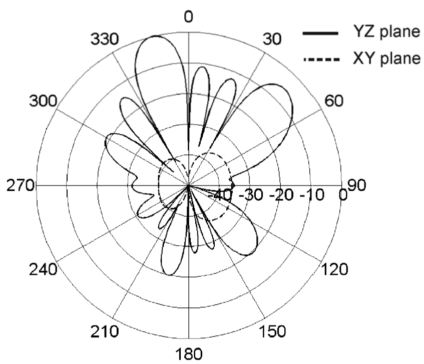

Fig. 6 Simulated radiating patterns of the linear phased-array with the phase shift 90°.

V. Practical Results

So far, merely limited number of tests has been conducted. Since the digital controlling unit (DCU) still shows definite problems, tests were performed with a simple manual control. All of them show a positive influence of changes of positions and angles on the correct and reliable identification. After finishing the DCU and SW capable of performing all the above described identification procedures, a new set of tests will be performed. A simulator of the discussed set of TAGs was carried out by fixing 200 TAGs to randomly shaped pieces of foam and throwing all pieces randomly into a $2 \times 1 \times 1$ m cartoon box. For more demanding tests, pieces of absorbing foam and a small metallic object will also be inserted. The test using DCU will include the steps listed below:

- The evaluation of identification reliability on the scanning procedures and configurations analyzed above. Four TX and four RX antennas are used in the beginning.
- All the mentioned scanning procedures will be performed using different values of the radiated output power (from low to higher values).
- For each type of the scanning procedure, the measurement determines the value of the minimum radiated power that corresponds to the correct identification of all TAGs in the simulator.
- Scanning procedures with the minimum power required can be recommended for practical operation.

V. Conclusion

The discussed RFID system has been designed for the identification of hundreds of clothes equipped with UHF RFID TAGs stuffed in large cartoon boxes. The preliminary test indicated difficulties with identification using standard reader and standard antennas. With the help of the developed active antennas, it is possible perform successfully the identification using antennas at different positions or phase-array operation. The very high and focused power densities can be created in order to illuminate the TAGs while ensuring the read-out from numerous positions and angles. All up to now performed tests show a positive influence on the accuracy and reliability of the identification. The designed RFID system can be successfully employed in similar identification tasks.

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