RFID Tags Localization along an axis using a Tunable Near-Field Focused Circular-Phase Array Antenna

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Abstract

A novel concept for RFID tag localization using a tunable near-field focused circular-phase array antenna working at 5.8 GHz is presented. It serves as the reader antenna and focuses the power into a small region, in the tag vicinity. By scanning the focal spot along one axis and monitoring the differential scattered power by a tag, its position along the axis is easily computed with good accuracy. This simple localization scheme is well adapted for specific localization scheme, for example for objects placed over a conveyor belt.

1. Introduction

In less than a decade, radiofrequency identification (RFID) has known an incredible growth, it is now a well known technology used in many industrial applications [1]. To reach the efficiency it has today, the research effort first focused on the tag design to keep it unaffected by the environment and on the base station antenna, often designed to radiate with a high gain in a static direction. But more recently, for security reasons and under the industrial needs, an exciting and new research RFID topic appeared: indoor tag localization [2, 3].

Several tag localization techniques exist for two dimensions (2-D) and fewer for 3-D. All of them use more than one reader antenna [3, 4]. Several different algorithms are proposed, some requiring initial calibration with special reference tags. Each technique is often well adapted to a particular situation. Best accuracy obtained up to now is on the order of 15cm [5]. In all those developments, final cost of a system is always an important key factor in its implementation in industry.

In [6], the authors proposed a tunable near-field focused phased array antenna (FPAA) for RFID systems working at 5.8 GHz. This system provides a dynamically tunable focal length thanks to two phase shifters. In this work, we proposed a novel concept for tag localization: delivering power only close to a tag, where it is needed. We will show that by doing this, in simple situation like a conveyor belt, this lead to a simple and potential efficient localization system. It uses passive tag, two phase shifters and classical envelope detection.

The theory of passive RFID systems is first presented. Then, the overview of the system and the localization algorithm is detailed.

2. Theory of Passive RFID Systems

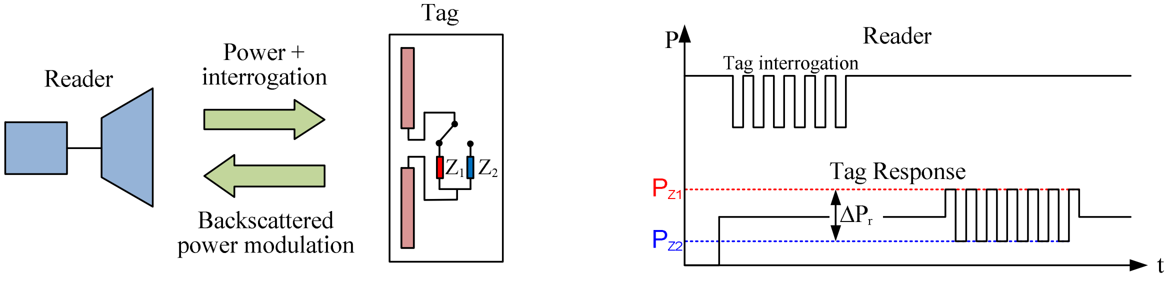
A schematic view of an RFID system is presented in Fig. 1 (a) which shows the two principal components: the reader, also called the base station, and the tag. The reader is the active part of the system: it sends power and information to the tag which is totally passive in most RFID systems. Thanks to the chip included in the tag, the load connected to the tag's antenna is switch between two different impedances: Z_1 and Z_2. The reflected power is thus modified at each switch, producing a modulation of the backscattered power. At first, the reader sends a continuous signal to deliver power to the passive tag. Then, to start the communication, an information frame is sent by the reader as it is shown in Fig. 1(b). Finally, if the power received by the tag is greater than the low-threshold power, called the activation power, the tag responds and the communication between the two elements begins.

From the Friss equation, the power reradiated and scattered by the tag and delivered to the load of the reader, P_{L_reader} is calculated with the following equation [7, 8]:

$$P_{L\_reader} = A_{e\_R} \cdot A_{e\_tag} \left|1-\Gamma_\ell^*\right|^2 S_i \frac{G_{tag}}{4\pi d^2}, \qquad \Gamma_\ell^* = \frac{Z_a^* - Z_\ell}{Z_a + Z_\ell}, \qquad (1)$$

where A_{e_R} and A_{e_tag} are the effective area of the reader antenna and the tag antenna respectively, Γ_ℓ is the modified reflection coefficient that takes into account the tag-load and the tag-antenna impedances, Z_ℓ and Z_a [9], S_i is the power density seen by the tag, G_{tag} is the tag gain and d is the distance between the tag and the reader antenna. This equation assumes that the reader antenna and its load are matched and that the polarizations of both antennas are also matched. The differential scattered power received at the reader load, ΔP_r, is easily obtained from (1) and is:

$$\Delta P_R = A_{e\_R} \cdot A_{e\_tag} \left| \left(1-\Gamma_1^*\right)^2 - \left(1-\Gamma_2^*\right)^2 \right| S_i \frac{G_{tag}}{4\pi d^2} \tag{2}$$



(a) (b)

Figure 1 (a) Passive RFID system. (b) Schematic representation of an RFID communication.

3. RFID Tag Localization System

3.1 General Overview

The general overview of the reader localization system is schematically presented on the Fig. 2. It consists of an FPAA which focuses the incident power into a small region around the focal point [6]. The FPAA produces an E-field linearly polarized. The FPAA is made with 24 dipole antennas radially oriented and equally placed on three concentric rings of radii: 10, 30, and 50cm. The working frequency is 5.8 GHz. The antennas are fed with identical current magnitude but with a phase which is proportional to the off-axis distance. The condition imposed on the different phase delays is that each quasi-isotropic waves produced by individual antennas must interfere constructively at the focal point. The focalization distance is tuned inside a delimited range along the propagation axis (the *z*-one) with the help of phase shifters. Thanks to the circular dispositions of antennas, few phase shifters are required: only two in the present case.

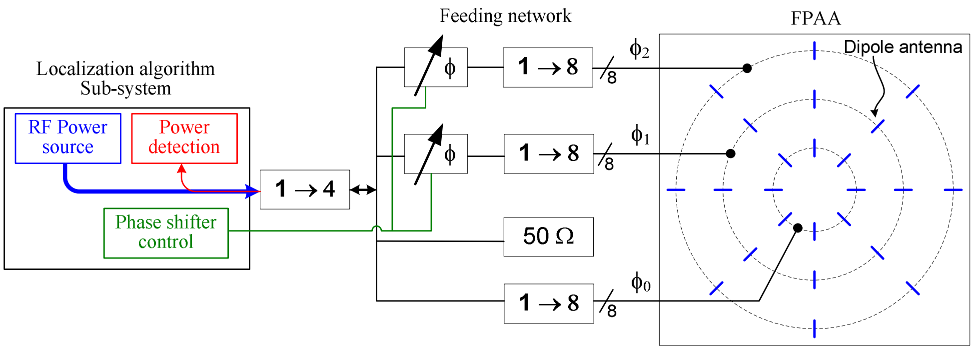


Figure 2 Schematic representation of the FPAA, its feeding network, and of the tag localization algorithm sub-system. Each antenna is fed with a coaxial cable connected to a 1:8 power divider [6].

The focal spot power density, S_i, can be approximated by the following empirical function:

$$S_i(r,z) = Ae^{-\frac{2r^2}{w_B(f)}} e^{-\frac{2(z-f)^2}{w_{FD}(f)}}, \tag{3}$$

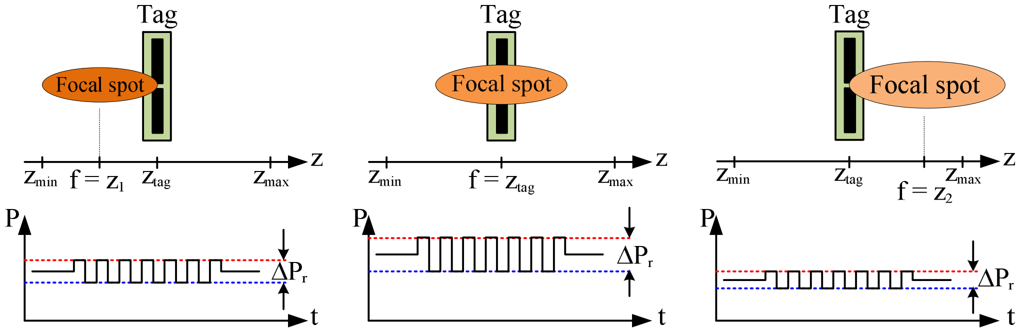
where A is a proportionality constant, r is the off-axis distance, f is the focal length and $w_B(f)$ and $w_{FD}(f)$ are the lateral and the longitudinal half-width power at $1/e^2$ respectively. From measurements published in [6], empirical formulas were found for the latter:

$$\begin{aligned} w_B(f) &= 0.551f + 0.2569 \qquad \text{(in cm; f in m)} \\ w_{FD}(f) &= 30f - 1.3 \qquad \text{(in cm; f in m)} \end{aligned} . \tag{4}$$

3.2 The Tag Localization Principle

The localization technique proposed here is meant to find the *z*-position of an RFID tag with respect to the reader. The physical principle of localization is the following. Due to the focusing nature of the FPAA, there is sufficient power to wake up the tag only in the vicinity of the focal point. In a coarse description, this region could be assimilated to an ellipsoid, later called the *power-ellipsoidal volume* (PEV). If a tag is outside the PEV, the reader do not return modulated power to the reader. Inversely, when the tag is inside the PEV, the tag power is above the activation power and a scattered modulated signal is now received by the reader. A first rough estimate of the tag z-position, z_{tag}, is therefore: $z_{tag} = f \pm FD$, where f is the focal length of the FPAA and FD is the *effective focal depth* defined as the distance from the focal spot center for which the tag activation power is reached. FD is proportional to w_{FD}, and, in fact, defines the front and back limits of the PEV.

This precision can be improved by performing a scan of the focal spot. This can easily be done with simple dedicated electronics added to the reader. Its role is double: 1) to feed the electronic phase shifters for the scan process from z_{min} to z_{max}, and 2) to monitor the magnitude of the scattered differential power, ΔP_r, received by the reader. For a tag positioned at z_{tag}, ΔP_r, is null until the PEV reaches the tag. From that moment, the tag will start responding to the reader with a low magnitude ΔP_r because the activation power is just above the threshold limit. This situation is illustrated in Fig. 3(a). For increasing values of f, the power density seen by the tag will increase rapidly until it reaches a maximum. From equation (2), we see that ΔP_r will also increase up to a maximum which occurs when $f = z_{tag}$. This second situation is illustrated in Fig. 3(b). For $f > z_{tag}$, the magnitude of ΔP_r will rapidly decrease until f reaches z_3, the position for which the PEV leaves the tag, see Fig. 3(c). Above that point, activation power is not reached at the tag and ΔP_r becomes null once again. A schematic representation of ΔP_r and of its absolute magnitude during the scan is represented in Fig. 4. The tag actual *z*-position thus corresponds to the focal spot position for which the maximum magnitude of ΔP_r is recorded. With the scan, the precision of the measurement is improved. It depends on the signal-to-noise-ratio (SNR) of the whole RFID system.



(a) (b) (c)

Figure 3 Three different situations encountered during the scan of the focal spot along z. The tag position is z_{tag}. Focal length is: (a) $z_1 < z_{tag}$, (b) z_{tag}, (c) $z_2 > z_{tag}$. Schematic graph of the backscattered power for the three focal lengths.

For this new localization concept, a simple situation was assumed: the tags are quasi-static during the scanning process and they are all placed at a height such that the PEV will indeed pass through them. It is also assumed that at all times, only one tag is present in the power-ellipsoid volume.

Finally, it is important to mention that the above discussion is qualitative and relies on equation (2) which is valid in the far-field approximation: effective areas are indeed defined for plane waves [7]. In the present situation, the tag cannot be considered as illuminated with a single plane wave. The exact power that will be received cannot be simply calculated from (2). However, only relative value of the power is pertinent in the localization technique. Also, any field can be decomposed on the basis of plane-waves and evanescent fields [10]. The latter do not carry power and equation (2) can be considered valid and evaluated for each plane-wave of the decomposition. The total power can be obtained by summation of all those contributions. Very small biases come from the decomposition because of the static position of the tag during the scan. Even though the effective areas and G_{tag} are functions of the plane-wave directions, the plane-wave spectrum will change very slowly during the scan process at a given z_{tag}.

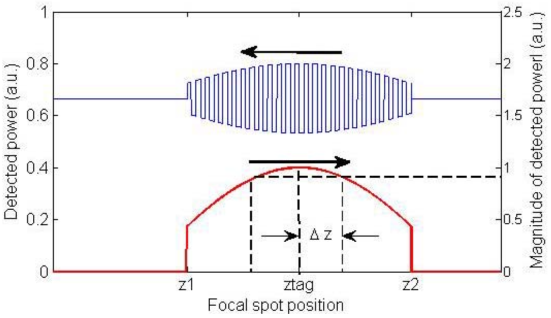


Figure 4 Schematic representation of the differential scattered power by the tag and measured at the reader load and of the envelope magnitude of the signal. The tag *z*-position corresponds to the envelope maximum value.

5. Conclusion

A novel concept of an RFID tag localization was proposed. It is based on a reader dynamic Focused Circular-Phase Array Antenna capable of rapidly modifying its focal length. It was shown that a scan of the focal spot leads to tags localization along the z-axis. More analysis of the system is underway.

6. References

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