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2D Localization using Phase Measurement of Chipless RFID Tags

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Abstract

This paper explores the performance of object localization using chipless tags. We show that it is possible to localize a tag (or an object attached to it) by measuring the phase offset between a known position and the position to estimate. This method provides a better accuracy compared to classical ones based on received signal strength indicator (RSSI). We show that sub-millimeter precision can be achieved for distance measurement with a correct localization probability higher than 99%. These results point the way toward new user interfaces using chipless tags which can be contactless and 3D.

1 Introduction

RFID technology is a mature technology to identity items. A single 0.3 $ RFID chip contains a 96 bits electronic product code used to uniquely identify a tag. However classical RFID technology suffers form its cost which is too expensive for a large number of applications. Chipless RFID technology offers an alternative and a complementary solution to classical RFID and can permit to drastically decrease tag cost. In chipless RFID, tags do not include a chip to store information neither to modulate the backscattered signal. Instead, the information is directly encoded inside the tag structure. A lot of effort have already been done to increase the coding capacity and the robustness of the reading. In this paper, we focus on adding new functionalities to chipless tags. Sensing physical quantities (temperature, material permittivity, location...) is one of the most promising capability. The objective of this paper is to localize an object on a 2D plan using a chipless tag. Since the tag is attached to the object, the problem is equivalent to find the position of a chipless tag on a 2D plan. Localization using chipless tags have already been investigated in the literature. In [1], authors have realized localization by using round-trip time-of-flight and linear least square (LLS) approximation to solve the tri-lateration problem. This approach uses 3 different antennas and is based on the structural mode of the tag to determine the distance information. In [2] author has used the phase of the reflected signal to measure distance variation with sub-millimeter accuracy along a single direction. Moreover, in [3] authors have determined localization of a chipless tag using an attenuation based method. This method provides an absolute positioning but suffers from a relatively low accuracy. In this paper, we propose a new method to localize a chipless tag on a 2D plan. This method uses a single antenna and relies on the phase measurement of the antenna mode of the tag to estimate the distance between a fixed point and all resonators. This information is then used to precisely localize the tag. Finally, this sensing functionality do not come at a price of a loss in coding capacity for the identification functionality (the tag can still be used to identify an item with the same coding capacity). Thus, the results presented in this paper could be apply with any tag.

The following section presents the principle of the Chipless RFID technology. Section 3 introduces the analytical model which permits determining the distance between the tag and the reference position. Measurement bench and results are presented in Section 4 before concluding.

2 Chipless Tag

Chipless tags are classically composed by multiple resonators [4]. Each resonator is a simple structure whose the resonant frequency mainly depends on a simple parameter (typically its length). Combination of multiple resonant frequencies are classically used to identify a chipless tag. Each resonator can backscatter power preferentially at its resonant frequency; so in order to determine the characteristics of a given tag, a reader has to realize two different operations:

- on the emitter side, transmitting power toward the tag (pulse or harmonic sweep);
- on the receiving side, estimating the power spectral density of the received signal to identify the frequencies where the power is higher.

Thus, reading of a chipless tag relies on the magnitude of the backscattered signal. However, the power spectral density does not contain all the information of the backscattered signal. Many characteristics are also included in the phase information. In the proposed solution, we exploit the phase of the backscatter signal to obtain information on the location of the chipless tag.

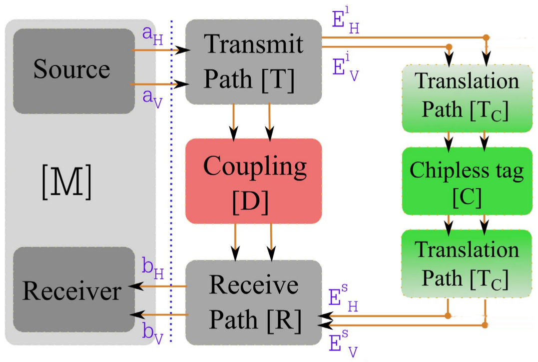

Figure 1. Channel model of the system, accounting for displacement measurements with one chipless tag.

3 Analytical Model

Figure 1 presents the model of the transmission between the reader and the tag [2]. The detection system is represented by the block M. T and R represent respectively the transmitting and the receiving path. Coupling between emitting and receiving antenna is noted D and block C represents the chipless tag. Since the tag can be located at a given distance d form the antenna, blocks T_C represent the phase offset due to propagation.

From [2], a distance variation can be extracted by using only 2 measurements $M_{vh}^{'(d_0)}$ and $M_{vh}^{'(d_1)}$ at 2 different locations d_0 and d_1, and a background measurement I_{vh}. Distance variation $d_1 - d_0$ can thus be extracted and is equal to:

$$d_1 - d_0 = -\frac{1}{2k}\text{angle}\left(\frac{M_{vh}^{'(d_1)} - I_{vh}}{M_{vh}^{'(d_0)} - I_{vh}}\right) \quad (1)$$

Note that this equation holds in cross-polarisation and only at a resonant frequency. Moreover if one distance is known (for example d_0), absolute distance d_1 can thus be determined In the following, this position at which the distance is known is called the reference position. Finally, if the tag contains more than one resonator, the distances can also be determined independently for each resonator. The following section describes the measurement bench used to localize a chipless tag.

4 Results

In order to validate the model, measurements have been done in real environment and are presented in figure 2. For this, response of the tag has been captured using a 2 port antenna (cross-polarization measurement). This dual-access dual-polarization Satimo QH2000 antenna is connected to the VNA ports 1 and 2 in the horizontal and vertical polarization, respectively. The reference position has been taken when the tag is straight upward the antenna at a height of 10 cm (see figure 2). Tag is then moved on a horizontal square of 20cm side length (red square in figure 2), centered on the reference position by step of 1 cm on both axis.

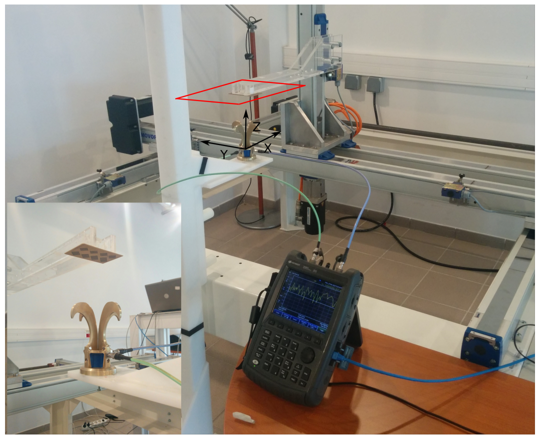

Figure 2. Measurment bench in real environment for 2D localization

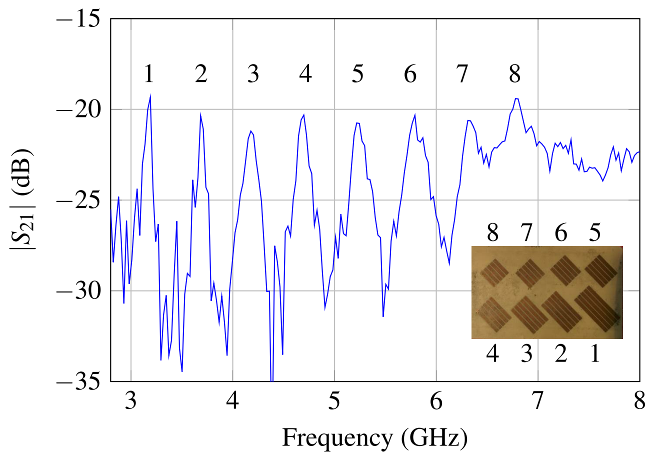

Figure 3. Response of the measured tag in magnitude at the reference position (0,0).

For each position, 10 measures between 2.8 GHz and 8 GHz with 201 points are recorded. The chipless tag we have chosen for this study is a cross-polarization tag composed of 8 resonators. In [5], authors have shown that this tag has a coding capacity of 19 bits. Classical response in magnitude of this tag is presented in figure 3. This response has been obtained after removing the environment response I_{vh} (*i.e.* without the tag) and without using time gating. The eight resonant frequencies, corresponding to the eight resonators are clearly visible on the magnitude response. Shorter resonators correspond to higher resonant frequencies. The location of these peaks is used to realize the identification function of the tag.

We have shown from the previous section that it is possible to determine theoretically the distance variations between two positions and also the absolute distance form the antenna (by using the reference position). In this part, the phase at the resonant frequency of the first resonator (3.19 GHz) and last resonator (6.78 GHz) of the received signal is determined for each position (x and y). The reference position $(0,0)$ has been chosen at the origin (above the

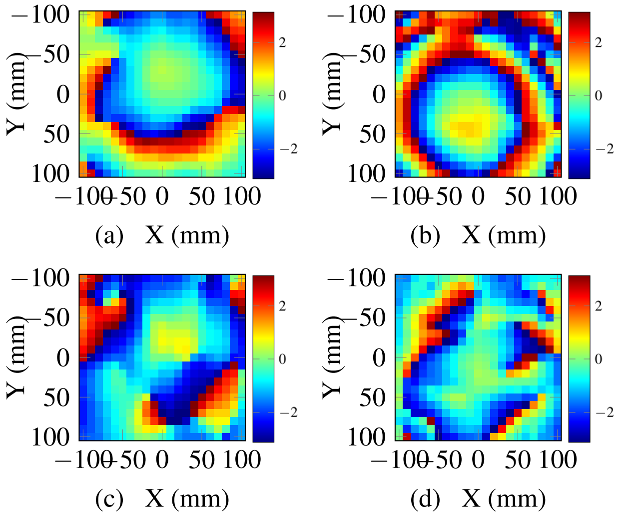

Figure 4. Phase variation as a function of the position on the plan, (a) for the first resonant frequency (3.19 GHz), (b) for the 8th resonant frequency (6.78 GHz), (c) between first and second peak (3.39 GHz), (d) after the 8th peak (7.70 GHz).

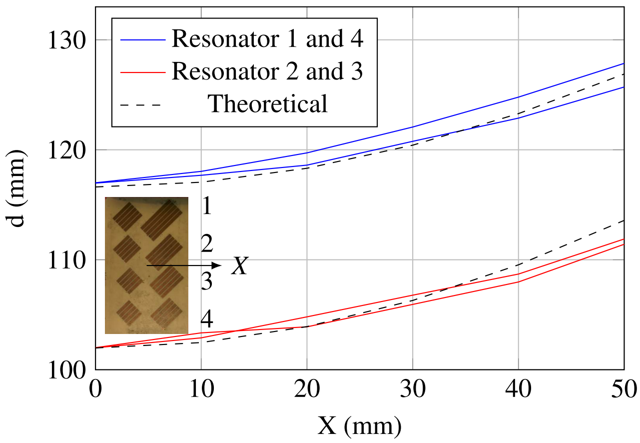

Figure 5. Distance estimation for 4 resonators (plain) and theoretical distance (dashed) as a function of X.

antenna). Results are shown in figure 4. For comparative purpose, the plot has been also realized for frequencies outside the peak apex (3.39 GHz and 7.70 GHz). For the two resonant frequencies, phase exhibits concentric patterns due transitions between $\pm\pi$ (phase wrapping) whose period depends on the wavelength. Moreover, pattern center corresponds to the position where the given resonator is the closest to the antenna (positions are different because resonators are not located at the same place, see figure 3). On the other side, phase for non-resonant frequencies presents unpredictable behavior (but remains deterministic).

From this result, we can now estimate the distance variations between the reference position and the unknown position. But, before applying (1), phase need to be unwrapped by adding multiples of $\pm 2\pi$ to compensate the variations observed in figure 4. This unwrapping has to be done

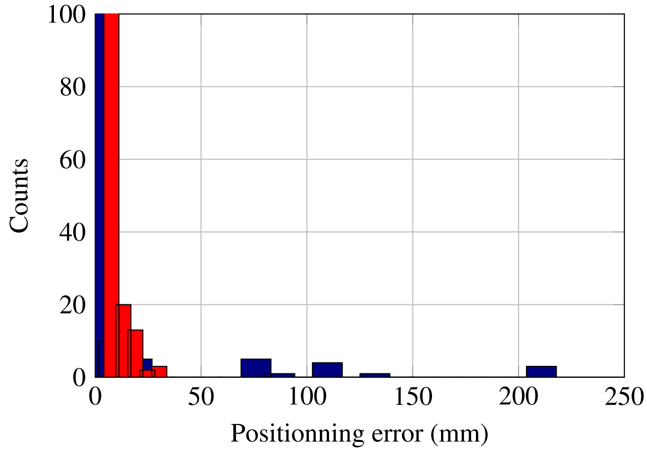

Figure 6. Histogram of the distance error considering ML estimator extracted form resonant frequencies (red) and non-resonant frequencies (blue)

jointly along x and y axis. Absolute distance for each resonator can thus be estimated by adding the distances obtained from the reference position (which are known) and the distance variations. Figure 5 presents the distance between resonators 1, 2, 3, 4 and the antenna when we move the tag along x axis form $x = 0$ to $x = 50$ mm. Theoretical distance is also presented on the same plot. The two lower curves correspond to the two inner resonators which are closer in distance form the antenna and the two upper curves correspond to the two outer resonators. We can also see that the distance predicted with (1) is very close to the theoretical distance. In order to estimate the accuracy of our measure, we have computed the variance of the error between different measurements for the same location. This variance for all resonators is less than 20μm (this result do not take into account error due the position of the reference).

Since distance measurement has been validated, we can now use these results to estimate the location of the chipless tag on a 2D plan. As the relative positions between resonators are known (see figure 5), and distances between resonators and the antenna can be extracted as previously shown (from measurement), it is possible to localize the tag using multilateration algorithms. Solutions have been developed in [6] and [7] but remain relatively complex. In the following, we consider a simpler approach based on Maximum Likelihood (ML) estimator over a discrete set $\mathscr{A}_P$ of locations:

$$\hat{P} = \arg\min_{\mathscr{A}_P} \sum_{i=1}^{8} (d_{ui} - d_{ki})^2 \tag{2}$$

where $\hat{P}$ is the estimated coordinates, d_{ui} and d_{ki} are respectively the distance between the antenna and the ith resonator for the unknown location (u) and for a known location (k) stored in a database (for example (0,0)). This database is composed by the eight distances between the resonators and the antenna for all measured positions. Then, we select a random location (considered as unknown) and we estimate the distances from the antenna. Finally, we compare these eight distances to our database to select the location which is closest (in term of mean square error) to the unknown one . Figure 6 presents the histogram of distance error considering the ML estimator. Red bars corresponds to the case where distances are computed at the resonant frequencies. In this case, we can see that the position is correctly estimated in 99.04% of the cases (which represent 441 different positions). When estimation fails, errors are located near the exact position (1 cm apart). On the other case, blue bars present the error location when distances are computed on non-resonant frequencies (as explained in [2], this is due to the fact that the validity range of (1) is limited in the neighborhood of the tag resonance frequency). We can see that, the error is higher in probability and values.

5 Conclusion

In this paper we have shown that we can successfully localize a chipless tag using phase measurement. This localization can be realized without loosing the coding capacity since the same resonators are used for identification and sensing. Moreover, we have shown that the accuracy of our proposed method is very good since distances are measured with a millimeter precision. Finally, we have developed a simple maximum likelihood estimator to localize a tag on a plan. The estimator performance can return the correct location in more than 99% of the cases. Finally, this methods can easily be extended to determine 3D positioning and/or orientation.

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