On the Decoding of Equiprobable UWB Chipless RFID Tags Using a Minimum Distance Detector

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Abstract - **In this paper a minimum distance detector is implemented for the first time, to decode equiprobable ultra-wide band (UWB) chipless radio frequency identification (RFID) tags in an additive white Gaussian noise (AWGN) channel. The coding of the UWB chipless tags is performed by changing the position of the resonance dip in order to increase the Euclidean distance (ED) between different codes. Four UWB chipless RFID tags are successfully decoded verifying the viability of this decoding technique and their coding performance is evaluated calculating their detection error probability.**

Index Terms — **Ultra-wide band, UWB, UWB chipless RFID tag, radar cross section, RCS, decoding.**

1. Introduction

UWB chipless RFID systems are a technical solution being investigated for barcode replacement due to their tags low cost of fabrication [1]. In this type of systems, a reader's transmitted signal is sent to interrogate the UWB chipless RFID tag and the modified signal (according to the tag's stored code) is backscattered to the reader where the decoding process should take place [2]. The exchange of signals between the reader and the chipless tag takes places through communication channels, which suffer from different impairments like noise, attenuation, distortion, fading, and interference that contribute to errors in the signal detection. The noise is present in all communications channels and is the one that adds the major impairment in many of them [3]. Therefore, the importance to study the effect of its impairments in the UWB chipless RFID technology detection and coding is evidenced.

In previous works, the decoding is performed by analyzing the signal differences between codes without considering the noise [4]. Another approach, suggest the use of an adaptive direct path cancellation to perform the frequency encoded tag detection [5], which allows extracting the backscattered tag signal and perform the conventional decoding by analyzing the peaks and dips.

In this paper, the decoding of an equiprobable UWB chipless RFID system under the influence of an AWGN channel model is performed. A minimum distance detector is implemented for the first time to estimate the UWB chipless RFID tag code in presence of a noisy channel. The detector calculates the standard ED between the received signal and all stored UWB chipless tags signals templates to select the closest one. Five UWB chipless RFID tags are designed and fabricated to study the effect of the tags coding in the minimum distance detector, furthermore the detection probability error of four tags is calculated.

2. AWGN channel modeling and optimal detection

The AWGN channel can be mathematically described by $r(t) = s_m(t) + n(t)$, where $s_m(t)$ is the m-th UWB chipless RFID tag backscattered signal, $n(t)$ is the zero-mean white Gaussian noise with spectral density of $N_0/2$, and $r(t)$ is the received signal at the detector. The objective of the detector is to analyze $r(t)$ and take the optimal decision of the transmitted message $s_m(t)$ that minimizes the error probability [3].

By using an orthonormal basis, each transmitted signal can be represented by a vector $\vec{s}_m \in \mathbb{R}^N$ and therefore the channel model becomes $\vec{r} = \vec{s}_m + \vec{n}$. The optimal detection rule is the one that maximizes the conditional probability of $\vec{s}_m$ being transmitted given that $\vec{r}$ is received $P[\vec{s}_m/\vec{r}]$. It is described mathematically in (1) using the noise Gaussian probability density function [3].

$$\hat{s}_m = \underset{1 \le m \le M}{argmax} \left[P_m \left(\frac{1}{\sqrt{\pi N_0}} \right)^N e^{-\frac{\|\vec{r} - \vec{s}_m\|^2}{N_0}} \right] \quad (1)$$

P_m is the m-th UWB chipless RFID tag probability of occurrence, since all tags are equiprobable the term can be dropped. After further operation with a natural logarithmic function and leaving only the $\vec{s}_m$ dependent terms, the decision rule becomes (2) [3].

$$\hat{s}_m = \underset{1 \le m \le M}{\arg max} [-\|\vec{r} - \vec{s}_m\|^2] \quad (2)$$

Maximizing the negative value $-\|\vec{r} - \vec{s}_m\|^2$ is equivalent to minimizing its positive $\|\vec{r} - \vec{s}_m\|^2$, and also to its square root $\|\vec{r} - \vec{s}_m\|$. Therefore, after transforming back to the time domain and consider the signals sampling, the minimum distance detection rule is given by (3).

$$\hat{s}_m = \underset{1 \le m \le M}{\arg min} \sqrt{\sum_{i=-\infty}^{\infty} [r(i) - s_m(i)]^2} \quad (3)$$

3. Test procedures and experimental results

(1) UWB Chipless tags

The UWB chipless RFID tags designed and fabricated for this investigation are based on short-dipoles as the ones presented in [1]. The geometry and picture of the fabricated tags are shown in Fig. 1(a), only two dipoles are used to create one resonating dip within the UWB frequency range

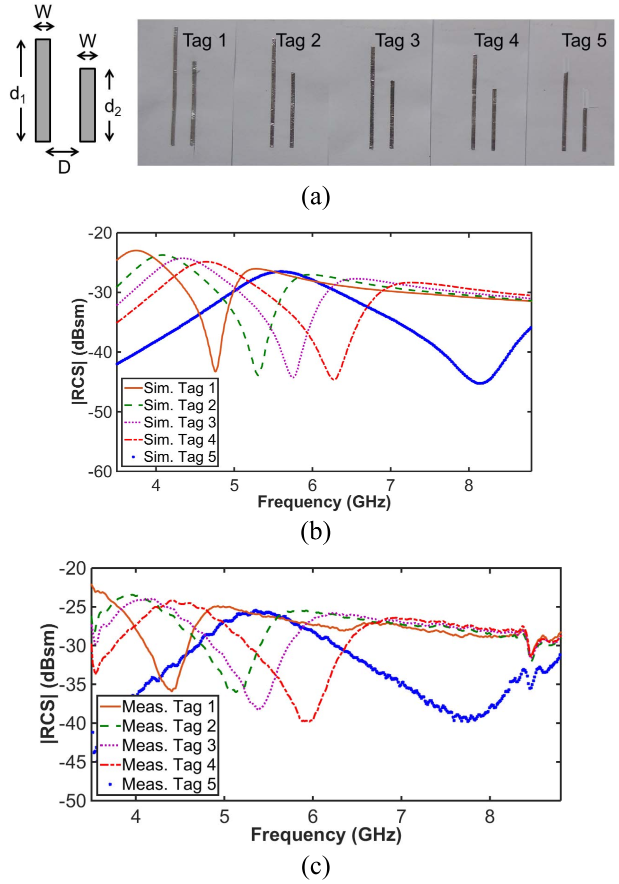

Fig. 1: UWB chipless RFID tags (a) geometry and prototypes picture, where W = 0.5 mm and D = 50 mm for all tags, Tag 1: d_1 = 35 mm, d_2 = 25 mm, Tag 2: d_1 = 32 mm, d_2 = 22 mm, Tag 3: d_1 = 30 mm, d_2 = 20 mm, Tag 4: d_1 = 28 mm, d_2 = 18 mm, and Tag 5: d_1 = 23 mm, d_2 = 13 mm. (b) Simulated |RCS|, (c) Calculated |RCS| from measurements.

from 3.5 to 8.8 GHz. The five different chipless tags are fabricated using aluminum strips on bond paper following the procedure described in [6]. Fig. 1(b) shows the UWB chipless tags |RCS| simulated with CST Microwave Studio, and Fig. 1(c) presents the results of the UWB chipless RFID tags measurements conducted with the set up and calculation method explained in [6], at a distance of 30 cm and a power control of -9 dBm. Tags 1, 2, 4, and 5 are designed in a way that the dips between tags have a larger frequency separation than the one from tag 3, which dip is placed between the dips of tags 2 and 4 to study its influence in the detection.

(2) UWB chipless RFID tag detection

The received signal from the UWB chipless RFID tags, capture from the vector network analyzer is processed using a MATLAB® script based on equation (3) and the distance to all five different possibilities is calculated. The results without removing the path loss are summarized in Table I, as can be seen, by selecting the minimum value, the UWB chipless RFID tags 1, 4, and 5 are correctly identified, tags 2 and 3 present the same values, and furthermore tag 3 is detected as tag 4. If tag 3 is removed from the table, all four tags are successfully identified, reinforcing the importance of ED between codes. The plot of tags 1, 2, 4 and 5 detection's error probability against the signal-to-noise ratio (SNR) is shown in Fig. 2, the ED among signal templates is calculated using the error probability equation and Q-function in [3].

TABLE I
Minimum Distance Detector Results

Euclidean distance calculations					
Received signal	Tag comparison template				
	Tag 1	Tag 2	Tag 3	Tag 4	Tag 5
Tag 1	**0.0836**	0.0982	0.0982	0.0921	0.0985
Tag 2	0.0951	**0.0874**	0.0874	0.0892	0.0945
Tag 3	0.0957	0.0835	0.0835	**0.0827**	0.0949
Tag 4	0.1085	0.1029	0.1029	**0.0836**	0.104
Tag 5	0.1174	0.1165	0.1165	0.1078	**0.0836**

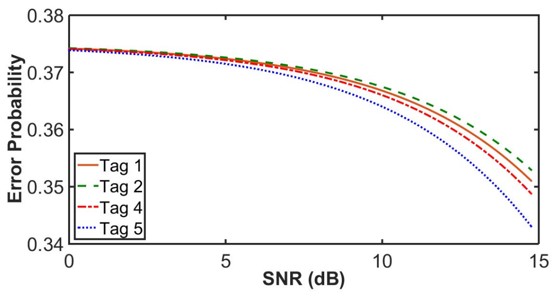

Fig. 2: UWB chipless RFID tags detection's error probability

4. Conclusion

The minimum distance detector is successfully implemented for UWB chipless RFID tags. The results show that the ED between tags codes has a direct impact on the detection capabilities of the UWB chipless RFID system.

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