Analysis of RCS Signatures of Chipless RFID Tags Based on Arabic Alphabet Letters with Punctuation

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Abstract **─** In this paper, we investigate chipless RFID (Radio Frequency Identification) tags based on Arabic Alphabets with points, to be used as RF coding particles. First, the tags were designed by considering an Arial font to generate the metallic letters printed on flexible Kapton substrates. Next, the points were connected to form the main bodies of the letters to improve their Radar Cross Section (RCS) signatures when illuminated with incident electromagnetic waves within the frequency band of 2-8 GHz, for both horizontal and vertical polarizations. Good agreement between simulated and measured results has been obtained.

We have found that among all of the similar letters studied, those stripline connections provided us the best way to take into account of the presence of the points and then conveniently distinguish the RCS signals characterizing each letter with a unique RF response.

Finally, a lookup table for the identification of the 18 letters with punctuation that have been studied has been carried out.

Index Terms **─** Arabic letters, chipless, co/cross-polarization, RCS signature, RFID.

I. INTRODUCTION

Radio Frequency Identification (RFID) has been emerging in recent years as a robust technology for wireless data transmission [1]. The technology has several applications, such as asset identification [2], electronic toll collection, vehicle security [2,3], defense systems [4], and security services in the form of personal cards, paper money, access control at short distances [5], and information security [6,7]. Recently, the passive chipless RFID technology has received great research interest [8,9] owing to its lower fabrication cost and smaller size [2,10]. In the passive RFID systems at UHF frequencies, the reader unit and the tag communicate via backscattering of the electromagnetic waves [1]. In fact, the chipless tag can be manufactured by using materials such as plastic or conductive polymers [10,11]. These tags have been envisaged for various types of applications, such as automatic identification, where the natural resonance of the scattered tag is exploited as the identifier [12,13].

Chipless RFID systems are based on generating a unique radio-frequency signature from the tags, which in turn allows the use of cryptographic techniques [14,15] to prevent the counterfeiting of tags. However, such an identification technique highly depends on the geometry of the tag, and several tags based on surface acoustic waves [16], stub-loaded patches [17], stacked multilayer patches [18], and resonators [19] were developed to address the problem.

The tag resonators have attracted a particular interest since the RFID system based on these resonators only requires one antenna which plays the roles of emitter and receiver simultaneously. Many forms and shapes have been explored, such us spirals [19], shorted dipoles [20], Latin letters [21,22], Arab letters [23] to name a few. Recently, Latin letters with improved fonts were proposed for chipless RFID tags [24] and applied for the design of inkjet-printed ones [25].

In a recent work [23], Boularess et al. have investigated the use of Arab alphabet letters as coding chipless RFID particles. The main problem encountered in this approach was the high similarity between many Arab letters, which only differ by the presence (or absence) of one, two or three dots.

In this work, we carry out an in-depth study of the similarity between the Arab letters and investigate the proposed solution in [23] which consists of connecting the main body of the letter to the points with a thin stripline without affecting the visual appearance of the letter. We have also validated our simulations by experiments and have generated a lookup table for studied letters.

The paper is organized as follows: Section II

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describes the working principle of the proposed technique to distinguish between similar letters by adding striplines. In Section III, the design procedure and simulated responses of excited tags under horizontal and vertical polarizations are given. Section IV is dedicated to the experimental validation of the proposed method and comparison between simulated and measured results. Finally, some conclusions are reported in Section V.

II. WORKING PRINCIPLE

In chipless RFID technology, a frequency spectrum is generated when the reader excites a tag based on Arab letters with a linear polarized wave. The above signal is decoded by the reader, which may assign a frequency signature to the tag. This unique RFID depends mainly on the geometry of the letter.

Since some Arabic letters differ from each other only by the presence of one, two, or three dots, the contribution of these points in the backscattered RCS signals is not detectable. For example, when we compare the RCS signals of two letters that are only different in shape by the presence or absence of these points, the retransmitted frequency has a very similar behavior. To address this problem, we connect the dots to the main body of the letter with a thin straight line, and this introduces a significant variation in the RCS as illustrated in Fig. 1. Several tags have been realized, and their signatures measured, to illustrate this phenomenon.

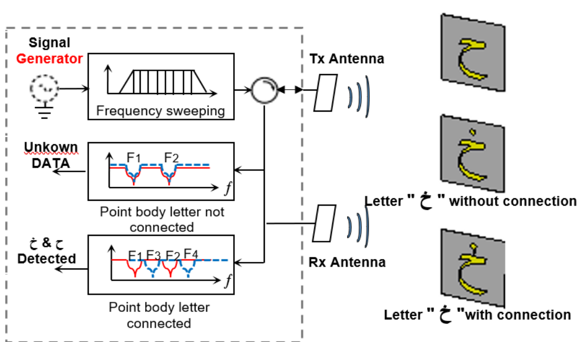


Fig. 1. System description for the modulation resonante frequency of the Arabic alphabet letter tags with and without the dot connections.

For proof-of-concept, we have considered an FSK code which is usually used in chipless RFID systems for coding tag-IDs, owing to its simplicity [12-13]. To apply FSK to the designed tag, when the RFID tag is illuminated with a spectrum of frequencies, a set of resonant frequencies is sent back to the reader. The modulated frequencies determine the EM signatures characterizing the tags based on Arabic letters.

III. SIMULATION METHOD AND ANALYSIS

By nature, the Arabic have complex geometries which can be created by using many fonts. First, we have selected the standard Arial as font for the generation of studied letters, because of its widespread use. Next, we have plotted the Arabic letters with AutoCAD 2016, and have imported them into the electromagnetic simulator CST (Computer Simulation Technology) for numerical analysis. The Arabic letters were illuminated with dual linearly horizontal and vertical polarized plane waves during the simulation process, and two probes were placed orthogonally, close to the tag, in order to record both the co- and the cross-polarized RCS values [6] produced by the tag. Finally, The RCS variation within the frequency band of 2-8 GHz was extracted in the far-field region. Simulations were carried for all the 18 letters of the Arabic alphabet that have similar shapes.

To illustrate the procedure, Fig. 2 presents the results related to selected tags based on letters, which only differ by the presence of a single dot. Figure 2 is dedicated to simulated co-polarized RCS values of chipless tags based on the letters "د" and "ذ". We observe that the RCS responses for letters "د" and "ذ" are quite similar, and the point effect is not significant. This is true for both co- and cross-polarizations. However, if we add a thin strip connecting the dot to the main body of the letter, we realize a noticeable change in value of the RCS, together with a frequency shift, for both co- and cross-polarizations.

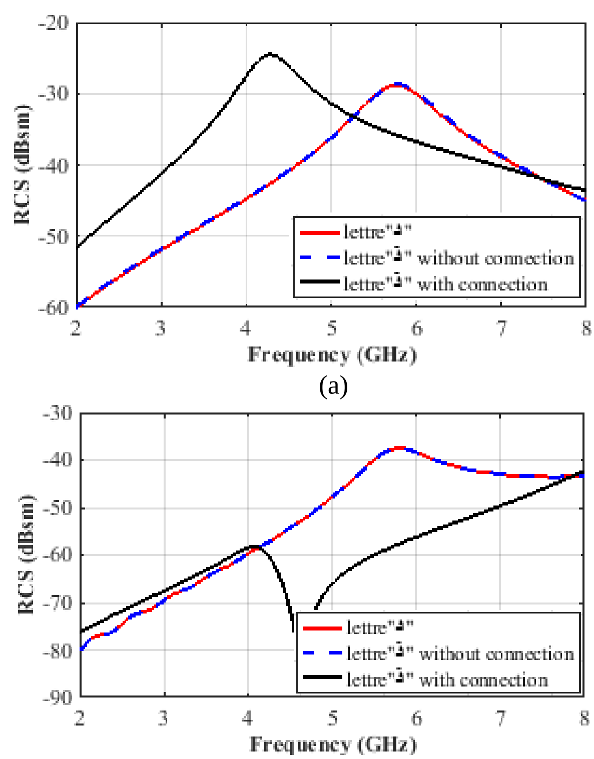


Fig. 2. Simultion of: (a) co- and (b) cross-polarized RCS of Arabic letters "د" and "ذ" with and without the strip connection.

Figure 2 (a) shows that the maximum peak values of the simulated co-polarized RCS signals for both the letters "د" and "ذ" is -29 dBsm; however, by connecting the dot to the main body the RCS increases to -25 dBsm with a frequency shift of about 2 GHz. For cross-polarization results shown in Fig. 2 (b), we note also a clear difference in terms of the RCS level and the resonance frequency in the electromagnetic response of the studied letter due to the presence of the connecting metallic strip.

To better analyze the effect of the added connection, we have simulated the surface current distributions for the previous letter with and without the metallic strip, and we present the results in Fig. 3. We observe that the addition of the connecting strip improves the coupling between the dot with the main body of the letter and increases in the localized current induced on the dot, which may explain the increase in the RCS value of the "connected" letter, and the downward of the resonating frequency, because of an increase in the resonating current path.

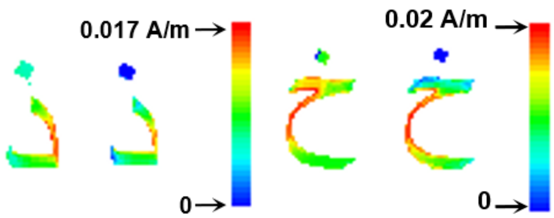


Fig. 3. Surface current distribution at the resonance frequencies of letters "ذ" and " and "خ" with and without the connection.

IV. RESULTS AND DISCCUSION

A. Prototypes

The Arabic alphabetic shapes were realized by etching copper on a flexible Kapton substrate of thickness 0.1mm, relative permittivity 3.5 and a loss tangent of 0.004. The size of each chipless tag is 37×37mm^2. All the letters written with the standard Arial font, have a height of 24mm, and they generate resonating frequencies within the 2-8GHz band. We can classify Arabic letters into two groups: 10 letters with different shapes and 18 letters with similar shapes which may be regrouped into sub-groups of two or three letters, as shown in Fig. 4.

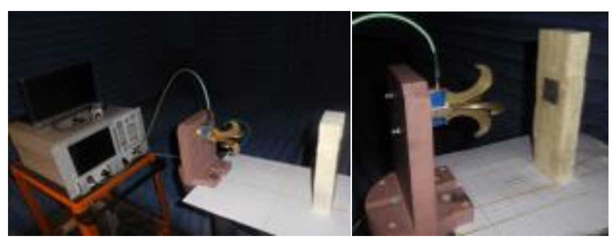
Fig. 4. Prototypes of the 18 similar letters which differ only by the presence or absence of dots.

As mentioned previously, similar letters that differ from each other only by the presence of the dots, have similar electromagnetic responses. To mitigate this problem, we need to connect the body of the letters with the dots using a 0.1mm width copper line as shown in Fig. 5.

Fig. 5. Photograph of the chipless tag based on the connected Arab letter "خ".

B. Measurement setup

The measurement set-up is based on a bi-static radar approach, and is used to obtain the co- and cross-polarized RCS from the tags under test. As shown in Fig. 6, the experimental set-up includes an Agilent vector analyzer PNA-N5222A, which provides an incident power of 0 dBm within the frequency range 2 to 8 GHz, a dual-polarized wideband Vivaldi antenna with a maximum gain of 12 dBi covering the band 0.7-18 GHz, which acts both as a transmitter and a receiver, and a chipless tag (device under test) backed with absorbing materials and placed at 15 cm from the antenna to ensure that the tag is in the near-field region. The antenna detects the backscattered RCS signals from the tag when excited with both horizontally and vertically polarized incident electromagnetic waves. The far-field values are deduced from the near-field measurements by using an appropriate code.



(a) (b)

Fig. 6. Photograph of the experimetal setup: (a) measurment setup, and (b) tag under test.

We have estimated the RCS value of the investigated tags by using the following equations [14]:

$$\sigma_{Co-Pol}^{tag} = \frac{R^4\,(4\pi)^3}{G_t\,G_r\,.\lambda}\left|S_{11/22}^{co\_tag} - S_{11/22}^{co\_no\ tag}\right|, \qquad (1)$$

$$\sigma_{Cross-Pol}^{tag} = \frac{R^4\,(4\pi)^3}{G_t\,G_r\,.\lambda}\left|S_{11/22}^{cross\_tag} - S_{11/22}^{cross\_no\ tag}\right|, \qquad (2)$$

where, R is the distance between the tag and the antenna, and λ the wavelength. G_t and G_r are the gain of the transmitting antenna and receiving antennas, respectively. $\sigma_{Cross-Pol}^{tag}$ and σ_{Co-Pol}^{tag} are the RCS values for co- and cross-polarizations, obtained when the transmitting and the receiving antennas are positioned along the parallel (horizontal or vertical) and the perpendicular directions, respectively.

In (1) and (2), we have supposed that the RCS of tag can be directly extracted from the measured S-parameter. However, before measuring the letter's electromagnetic signature, a calibration procedure should be performed to remove the static environment effect [13]. During the calibration process, we first measure and record the received signal without the tag, take it as a reference, add the tag to be tested, and then perform the measurements of the backscattered signals.

C. Experimental results and discussion

We began by measuring the RCS of 4 tags corresponding to the letters "ش" and "غ" (co-pol.), and letters "ث" and "ج" (cross pol.) and compare the results to the simulations to validate the measurement procedure. The obtained results of this preliminary study are given in Fig. 7. The results presented in Fig. 7 show that we have good agreement between the simulation and the measurements. We add that the acceptable difference between the simulated and the measured RCS levels is due to losses which cannot totally be accounted in our simulations, such as losses during the calibration procedure and polarization losses due the misalignment of the antenna with the tag.

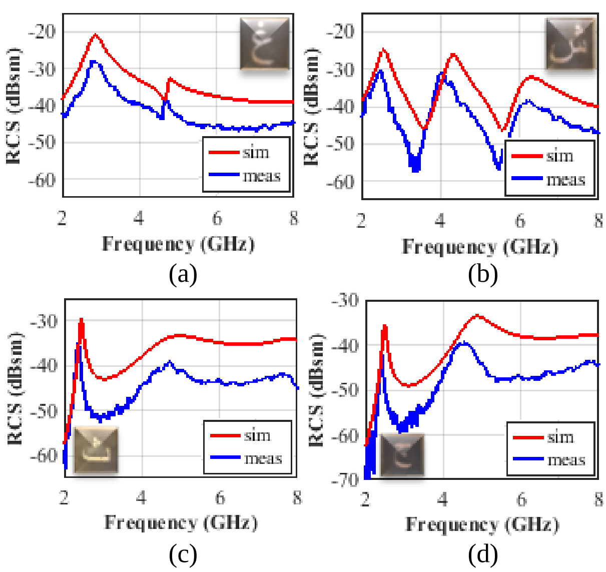


Fig. 7. Simulated and measured tags RCS versus frequency for: (a) letter " غ " letters (co-Pol. VV), (b) letter " ش " (co-Pol. HH), (c) letter " ج " (cross-Pol. HV), and (d) letter " ث " (cross-Pol. VH).

Having validated of our simulated (CST) results with the experiments, we will now focus on the measured results alone here on.

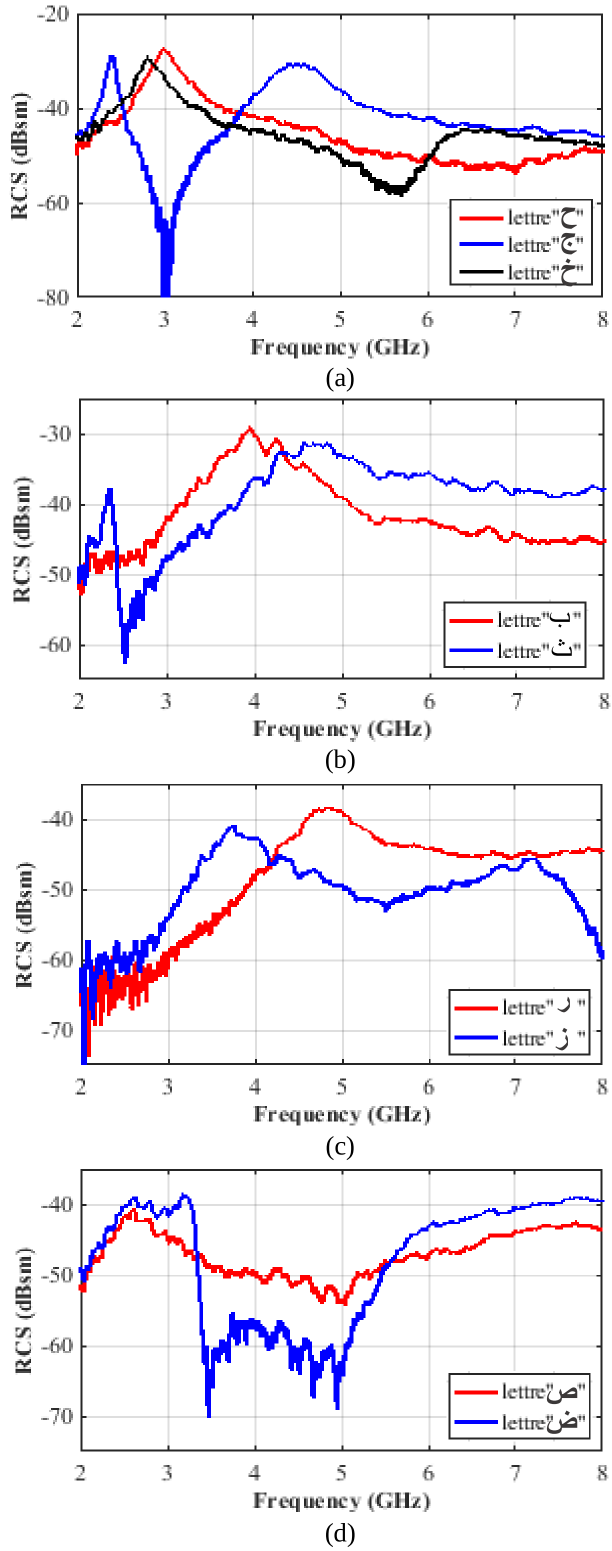


Fig. 8. Measured RCS versus frequency for tags tags based on: (a) letters "ح" ,"خ" and "ج" a (co-Pol. VV), (b) letters "ب" and "ث" (co-Pol. HH), (c) letters "ر and "ز" (cross-Pol. HV), and (d) letters " ص" and "ض" (cross-Pol. VH).

We have studied a few selected tags based on the letters that have a high level of shape-similarity to demonstrate that our proposed solution of connected dots to the main body of the letter is efficient. The results of this study are presented in Fig. 8.

First, we compare in Fig. 8 (a), the responses of the tags based on the letters "خ","ح" and "ج". We were able to distinguish between them where connecting the point of letters "خ" and "ج" permitted to allow the presence of only one point in their structure. Similarly, letters "ب" and "ث" (Fig. 8 (b)), letters " ر " and " ز " (Fig. 8 (b)) and letters " ص " and " ض " (Fig. 8 (c)) can be easily distinguished, after connecting the dots to the main bodies of the letters, by using the co- and/or cross-polarization measurements.

A thorough analysis of the RCS values for all the letters we have studied show that following the connection of the dots, all the letters are charcterized with unique electromagnetic signatures characterized by two unique resonance frequencies corresponding to both the horizontal and vertical polarizations. These results lead us to conclude that we can use similar arabic letters, that are only slightly different, by coding the particles in the RFID technology to generate the RF codes.

Table 1: Measured RCS lookup table for 24mm-height Arab letters with punctuation using both horizontal and vertical polarization excitations

Arabic Letters	Co-Polar		Cross-Polar	Arabic Letters	Co-Polar		Cross-Polar
	HH	VV	HV and VH		HH	VV	HV and VH
ر	4.85	4.83	4.84	د	5.62	5.65	5.68
ز	3.74 7.27	3.76	3.74 7.20	ذ	7.9	4.11	4.14 7.9
ب	3.95	7.81	3.95 7.88	ت	3.96	3.09	3.09
ث	4.84 2.35	2.35	2.35 4.71	ع	3.07 5.38	3.14 5.56	3.16 5.54
ش	2.49 4.03 6.26	2.52 4.01	2.50 4.00 6.26	غ	2.67 4.30 7.59	2.79 4.68	2.84 4.67 7.67
س	3.19 3.64	3.09 6.25	3.19 6.51	ظ	3.71 4.67	3.65 4.73	3.74 4.71
ج	2.40 4.27	2.40 4.53	2.41 4.56	ط	3.95	4.00 6.04	6.04 4.00
ح	7.84	2.99	2.99 7.80	ص	2.62 5.50	2.60 7.56	2.60 7.60
خ	6.18 774	2.80 6.42	2.89 6.45	ض	2.63 3.37	3.23 6.04	2.62 3.21

By the end of our study, we have generated a lookup table (see Table 1) for all the 18 similar letters, and have provided their resonant frequencies within the 2-8 GHz band, for both the horizontal and vertical polarizations of the incident electric field. The obtained results confirm that each of the tags based on an Arab letter can generate a unique electromagnetic signature.

Table 2: Main published works on chipless RFID tags based on alphabets

Ref.	Alphabet	Letter Font	Letter Police	Freq. Band (GHz)	Letter Height (mm)	Max. RCS (dBsm)
[22]	Latin	Arial	15	6-13	15	-22
[25]	Latin	Calibri with slots	48, 150, 275	0.1-20	33.65	-20
[23]	Arab	Arial	24	1-10	24	-
This work	Arab	Arial with connected dots	24	2-8 GHz	24	-20

In Table 2, we have regrouped the main published results related to chipless RFID tags based on alphabets. Only Latin and Arab letters were investigated until now, with few fonts such as Arial and Calibri. Usually, each alphabet has its own geometry, and then its own limitations when applied to design of chipless RFID tags. So, no unique solution can be proposed for all alphabets, e.g., with Latin tags [25]; thin slots were added within letters to increase their backscattered RCS, whereas in this work, we propose to connect the dots to the main body of the letter to better differentiate between similar ones.

V. CONCLUSION

In this paper, we have carried out both numerical and experimentally studies on the design of chipless RFID tags based on Arabic alphabet letters with dots. We have studied the RCS responses of these similar letters when illuminated with incident electromagnetic waves polarized both horizontally and vertically for better recognition. We have found that, for all the letters we have studied, connecting the dots to the main bodies of the letters with a thin metallic stripline enable us to endow each letter with a unique RF response that has a single resonance frequency; consequently, similar Arabic letters that are very similar each other can still be be coded in the context of chipless RFID technology, as though they are quite different.

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