CHIPLESS RFID TAG WITH AN IMPROVED MAGNITUDE AND ROBUSTNESS OF RCS RESPONSE

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Abstract: This paper describes properties of a new 20-bit 52 × 50 mm² in size chipless RFID tag with an improved magnitude and robustness of the radar cross section (RCS). The tag is based on a novel complementary approach with the slot-in-plate array. A modification of the inter-element arrangement in order to eliminate the detuning effect of the missing slot representing '0' bit information on the resonances of neighboring slots representing '1' bit information was proposed. Two ways of '0' bit information coding were studied and compared.

Keywords: Chipless radiofrequency identification, radar cross section, scatterer.

1. INTRODUCTION
The use of RFID systems has spread into numerous application areas, such as logistics of warehouse goods, supply chain management, and tracking and identifying animals/people in access and monitoring systems; [1]. Most of these applications operate in the UHF band, and require tag antennas tolerant to metallic and dielectric platforms, e.g. metallic boxes, foodstuffs, animal or human bodies; [2-5]. Traditional RFID systems operating in the rf and microwave bands use passive transponders with semiconductor chips that enable N-bit information to be stored.

Further reduction of production costs and potential of the fully printed transponder are important objective in this research area, which could be solved by transponders that do not use chips – chipless tags; [6-7]. These chipless tags are typically uniplanar metallic patterns etched on a dielectric, a thin film or a paper substrate. One of the simplest ways to encode the data to a passive metallic structure is to ensure a frequency selective reflection response when the tag is illuminated by an incident electromagnetic wave. This principle is called amplitude shift keying. The bit information is then encoded using an array of uniplanar resonators, where the presence/absence of each of them represents “1” or “0” bit information. Various types of resonators have been used to design chipless tags based on the frequency domain detection. Representatives of this group are approaches using the most frequently various types of LC resonators [8-10]. These transponders can be also used as chipless sensors [11-13].

Vena et al. [14] proposed a single layer coplanar strip with a short-end that excites the quarter wavelength standing mode. The same group further developed more sophisticated variations of bent multiple-arm coplanar strips [15], and polarization independent arrays of concentric strip rings [16].

These compact uniplanar resonators or scatterers exhibit a higher quality factor, due to the concentration of the field between close coplanar strips with opposite current flow compared to a straight strip dipole. In this way they increase the bit density encoded to the unit area. However, there is a trade-off between the quality factor (directly proportional to the bandwidth and consequently to the bit information density) and RCS (it characterizes the effective reflection properties, which in turn are proportional to the read distance).

Just a small part of these scatterers is collinear with the unit polarization vector of the incident field usually. Consequently its RCS is smaller than the RCS of a straight strip dipole. The chipless tag from [14] exhibits measured RCS value of about -30 to -34 dBsm, and the bent multi-arm strips tag [15] has RCS value between -25 and -30 dBsm. However, the read distance in specific chipless RFID applications may be limited due to the low RCS of their tags.

We have therefore proposed a chipless RFID tag that offers higher RCS at the level of -16 dBsm, which substantially enlarges the above mentioned case. The tag is based on a complementary structure, which consists in coplanar slots introduced in a continual metallic layer, unlike the strip-based scatterers presented e.g. in [14], [15]. This pattern then exhibits a generally larger and typically monotone RCS curve over a selected frequency interval, with dips corresponding to the resonances of individual slots; [16]. Further, a technique to reduce the mutual coupling between particular resonators was presented. The new tag response considerably improves the frequency and amplitude robustness of RCS response without the mean-value of RCS level being decreased. Thereby the reliability of reading the coded information is significantly enhanced.

2. PROPERTIES OF THE COPLANAR SLOT IN A METALLIC PATTERN
A) Coplanar slot design
The tag is based on a metallic rectangular plate 52 × 50 mm² in size chosen to provide a monotonous RCS curve over a frequency range of 2 to 4 GHz; [17]. The shorted coplanar slot forming an inverted letter “U” is introduced symmetrically into the rectangle so that the slot is collinear with the unit polarization vector of the incident field. Vertical polarization of the incident wave excites the electric field in the narrow shorted part of the slot; see Fig. 1.

Figure 1. A single coplanar slot introduced symmetrically into the rectangle 52 × 50 mm² in size.
B) RCS peak deepening

A parametric study of geometry of a single resonator is presented in this section. From Fig. 2 it can be observed that the peak depth can be increased by the resonator width \( w \) or gap width \( g \) increasing. It follows that a trade-off between the peak depth and resonator size (bit capacity of the transponder) has to be found.

3. DESIGN OF 20-BITS TAG

The 20-bits tag is based on the structure introduced in section 2. 20 shorted coplanar slots are situated in the metallic rectangular plate \( 52 \times 50 \text{ mm}^2 \) in size; see Fig. 3.

The slot-arm length \( l \) ranges from 15.0 to 24.5 mm, with 0.5 mm length difference between the two neighboring slot couple. The slot gap is \( g = 0.25 \text{ mm} \) and the width of the shorting slot is 2 mm, so that the metallic gap between the two adjacent slot-arms is 1.5 mm. The coplanar slots in an array are equidistant from each other, at a distance equal to 0.5 mm. The binary information is encoded into the slot array by presence of the slot represents a notch in the RCS curve, and absence (or shorting) of the slot represents a smooth RCS curve. A 20-element coplanar slot array with the 6th and 18th slots missing thus presents the 20-bit word ‘11111011111111011’; see Fig. 3b.

In the basic arrangement with sequent situated resonators see Fig. 3a - 3c, we can observed relatively strong mutual coupling of the neighbouring resonators, which can lead to the frequency shift of particular peaks in the RCS response; see Fig. 4a. As it can be seen in Fig. 4b, this phenomenon cannot be eliminated even by coding of the zero bits by shorting; see Fig. 3c.

However, this phenomenon can be minimised by the resonators rearrangement that each fourth resonator is moved to the corresponding quarter of the array so that the original ascending order according to their length ‘1 2 3 4 5 6 7 .. 20’ is modified to ‘1 5 9 .. 2 6 10 .. 3 7 11 .. 4 8 12 16 20’; see Fig. 3d.

We may observe that the greater the distance, the smaller is the mutual coupling of originally neighboring resonators, and the smaller is the frequency shift of the neighboring resonance if ‘0’ bit is applied; see Fig. 5. Coding of the zero bits by shorting doesn’t offered next improving of the frequency stability; see Fig. 5b.

Figure 2. Parametric analysis of simulated RCS response of one resonator with resonator width \( w \) as a parameter (a) and resonator gap \( g \) as a parameter (b).

Figure 3. Original arrangement of the slots in the rectangle representing the 20-bit words ‘11111111111111111111’ (a) and ‘11111011111111011’ coded by removing (b) and shorting (c). Modified arrangement of the slots in the rectangle in descending order according to their length, representing the 20-bit words ‘11111111111111111111’ (d) and ‘11111011111111111011’ coded by removing (e) and shorting (f).

Figure 4. Simulated RCS response of 20-element coplanar slot array with sequent arrangement of inter-elements representing comparison of a bit words ‘11111111111111111111’ and ‘11111011111111011’ for (a) encoding by resonator removing and (b) encoding by resonator shorting.
4. MEASUREMENT OF TAG PERFORMANCE

To verify the simulated results, we performed the monostatic measurement of tag RCS performance in an anechoic chamber; see Fig. 6. It was based on the evaluation of reflection coefficient of a double ridge horn antenna DRH 20 [18] in front of which a scatterer at a distance of 0.25 m was placed. The calculation of RCS response of the tag was performed by the relation used in [14] and modified so that it was applicable to the one-port case

$$\sigma^{tag} = \left(\frac{s_{11}^{tag} - s_{11}^{iso}}{s_{11}^{iso} - s_{11}^{ref}}\right)^2 \sigma^{ref},$$

where $s_{11}^{tag}$ is the reflection coefficient, when the measured tag is used as a scatterer. $s_{11}^{ref}$ represents the reflection coefficient, when the reference plate is used as a scatterer. $s_{11}^{iso}$ is the reflection coefficient of antenna itself in case that no scatterer is used and comprises the residual reflection from the experimental surroundings. $\sigma^{tag}$ is the RCS of the measured tag, $\sigma^{ref}$ is the RCS of the reference scatterer, which is the rectangular metal plate 50 × 52 mm² in size (corresponding with the measured tags) and 0.3 mm in thickness. Its analytical formula for RCS is as follows:

$$\sigma^{ref} = 4\pi \frac{a^2 b^2}{\lambda^2}.$$  

The monostatic measurement arrangement enables to avoid the use of angular dependent formula for reference scatterer and eliminates the influence of mutual coupling of the transmitting and receiving antennas in case of bistatic measurement. The measured data are smoothed to suppress the noise caused by a number of residual reflections.

Fig. 7 illustrates the measured RCS response of two variants of scatteres arrangement in 20-bit chipless RFID tags, i.e. with sequent arrangement and with re-arrangement of inter-elements representing comparison of bit words ‘11111111111111111111’ and ‘11111011111111111011’ for encoding by resonator removal. Significant improvement consisted in inter-element mutual coupling minimisation and frequency stability of the peaks can be observed.

5. CONCLUSION

20-bit 52 × 50 mm² in size chipless RFID tag based on a novel approach with the slot-in-plate array has been proposed. This approach is complementary to the chipless tag composed of an array of individual U-dipole scatterers. The overall RCS response is significantly improved provided that the...
interrogating signal reflected from a larger radar target contains band-notched resonators, such as slot-type elements placed in the planar rectangular element. The overall response of the plate-scatterer itself is almost 20 dB higher than the response of the tag composed of an array of U-folded dipoles.

A modification of the inter-element arrangement in order to eliminate the detuning effect of the missing slot representing ‘0’ bit information on the resonances of neighbouring slots representing ‘1’ bit information has been proposed and verified. Frequency stability and consequently reliability of reading was significantly improved.

Two ways of ‘0’ bit information coding have been studied and compared. Significant difference between encoding of the “0” bits by resonator removing and the encoding by resonator shorting was not observed. Consequently both ways can be used for encoding of zero bits.

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REFERENCES


