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

Milan Svanda, Milan Polivka, Jaroslav Havlicek, Jan Machac
Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Electromagnetic Field, Technicka 2, 16627 Prague 6, Czech Republic; Corresponding author: milan.svanda@fel.cvut.cz, fax: +420 233 339 958.

Abstract: *This paper describes properties of a new 20-bit chipless RFID tag of the size 52 × 50 mm², which exhibits an improved magnitude and robustness of the radar cross section (RCS). The tag is based on a novel slots-in-plate array approach, which is complementary to a typical tag consisting of an array of single resonators. In order to eliminate the detuning effect of the missing or shortening slots representing '0' bit information on the resonances of neighbouring slots signifying '1' bit information, the modification of the inter-element arrangement was proposed. Both 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 proliferated into numerous applications, such as logistics of warehouse goods, supply chain management, and tracking and identification of 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 objectives in this research area, which could be solved by transponders that do not use chips – chipless tags; [6-7]. They are typically represented by uniplanar metallic patterns etched on a dielectric or paper substrates. One of the simplest ways to encode the data into a passive metallic structure is to ensure a frequency selective reflection response at the moment 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 utilized to design chipless tags based on the frequency domain detection. The representatives of this group are structures using predominantly various types of LC resonators [8-10]. These transponders can be also employed as chipless sensors [11-13].

Vena et al. [14] proposed a single layer coplanar strip with a short-end on which the quarter wavelength standing mode is excited. The same research group later developed also 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 higher quality factors due to the field concentration between close coplanar strips (showing opposite current flow than the straight strip dipole), whereby they increase the bit density encoded into 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 limited number of these scatterers is collinear with the electric field vector of the incident field usually. Consequently, its RCS is smaller than RCS of straight strip dipole. The chipless tag from [14] exhibits the measured RCS value of about -30 to -34 dBsm, and the bent multi-arm strips tag [15] shows the RCS value between -25 and -30 dBsm.

We have therefore propose a chipless RFID tag that offers a higher RCS at the level of -16 dBsm, which is substantially exceeds the one of the above-mentioned case. The tag is based on a complementary structure composed of coplanar slots etched in a continual metallic layer. This pattern then exhibits a generally larger and typically monotone RCS curve over the selected frequency interval, with dips corresponding to the resonances of individual slots. Further, a technique to reduce the mutual coupling between particular resonators is presented. Two ways of '0' bit information coding via removing or shortening the slots were studied and compared. 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 of 52 × 50 mm² in size chosen with the intention of providing a monotonous RCS curve over the 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 electric field vector of the incident field. The vertical polarization of incident wave excites the electric field in the narrow shorted part of the slot; see Fig. 1.

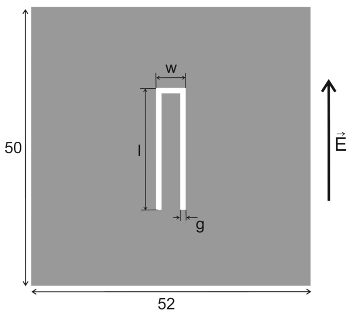


Figure 1. Single coplanar slot introduced symmetrically into rectangle of the size of 52 × 50 mm².

B) RCS peak deepening

The parametric study of single resonator geometry is presented in this section. Fig. 2 clearly shows that the peak depth can be increased by the rise of either the resonator width *w* or gap width *g*. Indeed, the balance between the peak depth and resonator size (bit capacity of the transponder) has to be found.

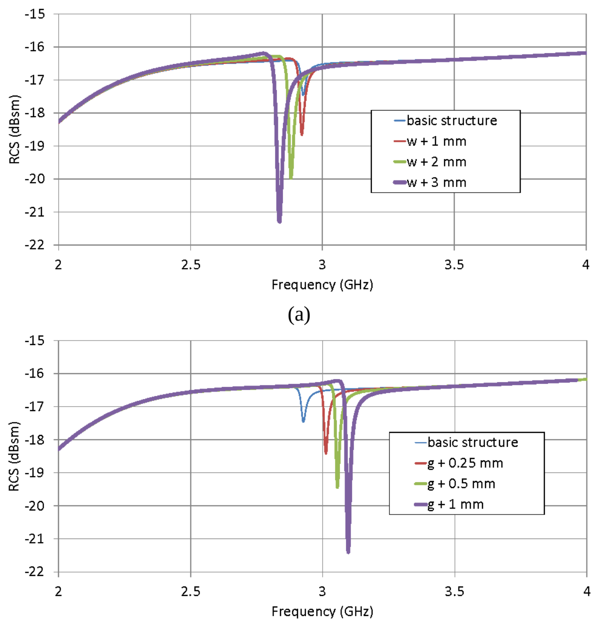


Figure 2. Parametric analysis of simulated RCS response of one resonator with resonator width *w* as parameter (a) and resonator gap *g* as parameter (b).

3. DESIGN OF 20-BITS TAG

The 20-bit tag is based on the structure introduced in section 2. Twenty shorted coplanar slots are situated in the metallic rectangular plate of 52 × 50 mm^2 in size; see Fig. 3.

The slot-arm length *l* ranges from 15.0 to 24.5 mm, with a 0.5 mm length difference between the two neighboring slot couples. The slot gap equals g = 0.25 mm and the shorting slot width is worth 2 mm, so that the metallic gap between the two adjacent slot-arms is equal to 1.5 mm. The coplanar slots in the array are equidistant from each other, at a distance equal to 0.5 mm. The binary information is encoded into the slot array via presence of the slot that represents the notch in the RCS curve, and absence (or short cutting) of the slot that stands for the smooth RCS curve. A 20-element coplanar slot array with the 6^{th} and 18^{th} slots missing thus presents the 20-bit word '11111011111111111011'; see Fig. 3b.

In the basic arrangement with sequent situated resonators (see Fig. 3a - 3c), we can observed a relatively strong mutual coupling of neighbouring resonators, which leads 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 short cutting; see Fig. 3c. However, it can be minimised by the resonators rearrangement, where every fourth resonator is moved to the corresponding quarter of the array. As a result, 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 can observe that the greater the distance, the smaller the mutual coupling of originally neighbouring resonators (and accordingly, the smaller the frequency shift of neighbouring resonances if '0' bit is applied); see Fig. 5. The coding of zero bits by means of short cutting does not offer any further improvement in frequency stability; see Fig. 5b.

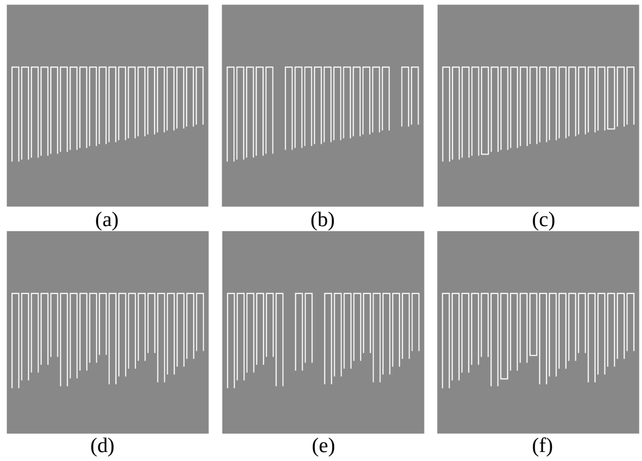


Figure 3. Original arrangement of slots in rectangle, representing 20-bit words '11111111111111111111' (a) and '11111011111111111011' coded by means of removing (b) and short cutting (c). Modified arrangement of slots in rectangle in descending order according to their length, representing 20-bit words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

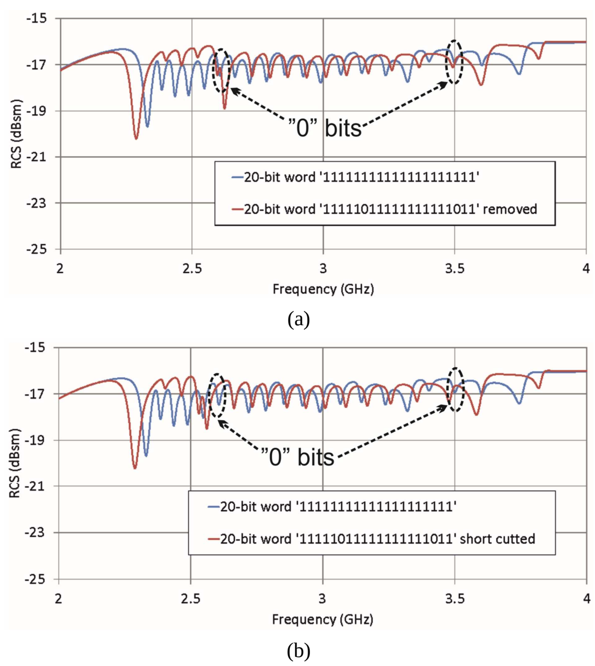
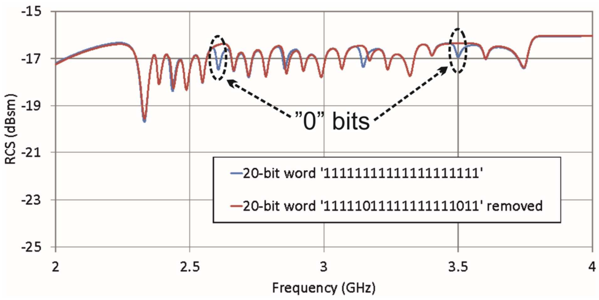
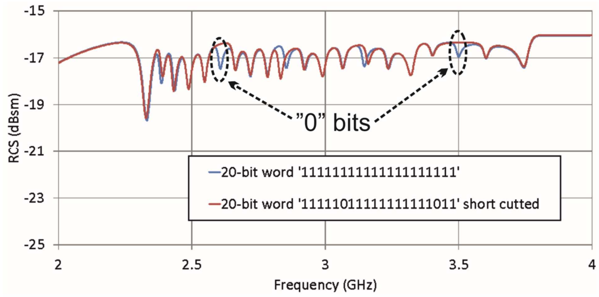


Figure 4. Simulated RCS response of 20-element coplanar slot array with sequent arrangement of inter-elements representing comparison of bit words '11111111111111111111' and '11111011111111111011' for (a) encoding by means of resonator removing and (b) encoding by means of resonator short cutting.



(a)



(b)

Figure 5. Simulated RCS response of 20-element coplanar slot array with rearrangement of inter-elements representing comparison of bit words '11111111111111111111' and '11111011111111110111' for (a) encoding by means of resonator removing and (b) encoding by means of resonator short cutting.

4. MEASUREMENT OF TAG PERFORMANCE

To verify the simulated results, we performed the monostatic measurement of tag RCS performance in the anechoic chamber; see Fig. 6. The verification 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 [19] and modified in a way that made it applicable to the one-port case

$$\sigma^{tag} = \left(\frac{S_{11}^{tag} - S_{11}^{iso}}{S_{11}^{ref} - S_{11}^{iso}} \right)^2 \sigma^{ref} , \qquad (1)$$

where s_{11}^{tag} is the reflection coefficient in case that the measured tag is used as a scatterer, whereas S_{11}^{ref} represents the reflection coefficient in case that 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 experimental surroundings. σ^{tag} symbolizes the RCS of measured tag, while σ^{ref} stands for the RCS of reference scatterer, which is the rectangular metal plate with dimensions of 50 × 52 mm^2 (corresponding to the measured tags) and of the thickness of 0.3 mm. Its analytical formula for RCS is as follows:

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

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 the case of bistatic measurement.

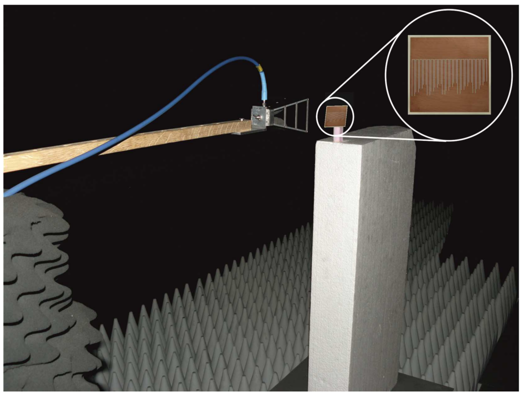
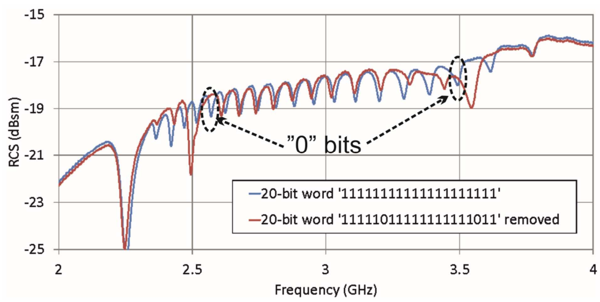
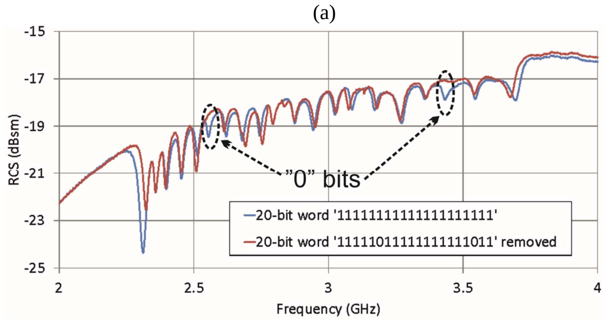


Figure 6. Measurement setup using monostatic measurement configuration with detail of element-rearranged 20-bit tag.

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 re-arrangement of inter-elements, representing comparison of bit words '11111111111111111111' and '11111011111111111011' for encoding by means of resonator removal. A significant improvement consisted in the inter-element mutual coupling minimisation. In addition, the frequency stability of peaks can be observed.



(a)



(b)

Figure 7. Measured RCS response of 20-element coplanar slot array with sequent arrangement (a) and with re-arrangement of inter-elements (b) representing comparison of bit words '11111111111111111111' and '11111011111111111011' for encoding by resonator removal.

5. CONCLUSION

The novel 20-bit chipless RFID tag (whose dimensions are 52 × 50 mm^2) with the slots-in-plate array has been proposed.

The applied novel 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 is reflected from a larger metallic structure, such as a planar rectangular plane with slot-type elements. The overall response of plate-scatterer itself is almost by 20 dB higher than the response of tag composed of an array of U-folded dipoles.

We proposed and verified the modification of inter-element arrangement in order to eliminate the detuning effect of the missing slot representing '0' bit information on the resonances of neighbouring slots signifying '1' bit information. The frequency stability and thus also reliability of reading were significantly improved.

Two possibilities of '0' bit information coding were studied and compared. A significant difference between the encoding of '0' bits by means of resonator removal and the encoding via resonator short cutting was not observed. Consequently, it can be stated that both ways can be used for encoding of '0' bits.

ACKNOWLEDGEMENTS

This work was supported by Czech Science Foundation under the project GA15-08803S.

REFERENCES

1. Finkenzeller, K., RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, 2nd edition, John Wiley & Sons, 2005.
2. S. Manzari, S. Pettinari, and G. Marrocco, "Miniaturised Wearable UHF-RFID Tag with Tuning Capability", Electronic Lett., 2012, vol. 48, issue 21, pp. 1325–1326.
3. P. H. Yang, Y. Li, L. Jiang, W. C. Chew, and T. T. Ye, "Compact Metallic RFID Tag Antennas with a Loop-Fed Method", IEEE Trans. Antennas Propag., 2011, vol. 59, issue 12, pp.4454-4462.
4. M. Svanda and M. Polivka, "Matching Technique for an On-Body Low-Profile Coupled-Patches UHF RFID Tag and Sensor Antennas", IEEE Trans. Antennas Propag., vol. 63, No. 5, pp. 2295 - 2301, May 2015
5. M. Polivka and M. Svanda, "Stepped Impedance Coupled-Patches Tag Antenna for Platform-Tolerant UHF RFID Applications," IEEE Trans. Antennas Propag., vol. 63, No. 9, 2015, pp. 3791-3797
6. S. Preradovic, N. C. Karmakar, "Chipless RFID: Bar Code of the Future", IEEE Microw. Mag., Vol.11, No.7, pp.87-97, Dec. 2010.
7. S. Preradovic, N. C. Karmakar, "Advanced Radio Frequency Identification Design and Applications", Fully Printable Chipless RFID Tag (chapter 7), InTech, 2011.
8. S. Preradovic, N. C. Karmakar, "Multiresonator-Based Chipless RFID", Springer, 2012.
9. F. Costa, S. Genovesi, A. Monorchio, "Chipless RFIDs for Metallic Objects by Using Cross Polarization Encoding", IEEE Trans. Antennas Propag., vol.62, no.8, 2014, pp.4402-4407.
10. R. Rezaiesarlak, M. Manteghi, Design of Chipless RFID Tags Based on Characteristic Mode Theory (CMT), IEEE Trans. Antennas Propag., vol.63, no.2, 2015, pp.711-718.
11. A. Guillet, A. Vena, E. Perret, S. Tedjini, "Design of a Chipless RFID Sensor for Water Level Detection", Antenna Technology and Applied Electromagnetics (ANTEM), Toulouse, 2012, pp. 1-4.
12. E. M. Amin, N. Karmakar, "Partial Discharge Monitoring of High Voltage Equipment Using Chipless RFID Sensor", Asia-Pacific Microwave Conference, Melbourne, VIC, 2011, pp. 1522-1525.
13. Y. Feng, L. Xie, Q. Chen, L. R. Zheng, Low-Cost Printed Chipless RFID Humidity Sensor Tag for Intelligent Packaging, IEEE Sensors Journal, vol. 15, no. 6, pp. 3201-3208, 2015.
14. A. Vena, E. Perret, S. Tedjini, "A Fully Printable Chipless RFID Tag With Detuning Correction Technique", IEEE Microw. Wireless Comp. Lett., Vol. 22, No. 4, April 2012, pp. 209-211.
15. A. Vena, E. Perret, S. Tedjini, "Design of Compact and Auto-Compensated Single-Layer Chipless RFID Tag", IEEE Trans. on Microw. Theory Techn., vol.60, no.9, Sept. 2012, pp. 2913-2924.
16. A. Vena, E. Perret, S. Tedjini, "High-Capacity Chipless RFID Tag Insensitive to the Polarization", IEEE Trans. Antennas Propag., vol.60, no.10, Oct. 2012, pp.4509-4515.
17. M. Polivka, M. Svanda, J. Machac, "Chipless RFID Tag with an Improved RCS Response", Proc. of European Microw. Conf. (EuMC), 2014 44th, Rome, Italy, pp.770-773, 6-9 Oct. 2014
18. Model DRH20 - Double ridge waveguide horn. RFspin s.r.o., 6.11.2015. [Online]. Available at http://www.rfspin.cz/en/antennas/drh20.php.
19. M. Polivka, J. Havlicek, M. Svanda, J. Machac, "Improvement in Robustness and Recognizability of RCS Response of U Shaped Strip-Based Chipless RFID Tags", *IEEE Antennas Wireless Propag. Lett.*, 2016, DOI: 10.1109/LAWP.2016.2549638, in press.