

# Improvement of RCS Response of U-Shaped Strip-Based Chipless RFID Tags

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**Abstract**—We present a modification of an arrangement of 20-bit chipless tag composed of 20-element array of U-shaped strip scatterers that significantly improves radar cross section response in terms of uniformity and amplitude robustness over the operational frequency range 2 to 4 GHz. This modification is based on the inter-arrangement of array elements in order to eliminate the strong coupling between neighboring resonance elements. The tag has been measured in a mono-static arrangement with one double-ridge horn antenna, and provides a significantly improved homogeneity of the RCS response compared to an original array of folded dipole resonators. The reliability of the reading of coded information is highly improved.

**Keywords**—*chipless radiofrequency identification; radar-cross section; scatterer*

## I. INTRODUCTION

Although RFID technology has been known for more than three decades, it did not start to be used extensively until the last decade. Now, it has a broad field of applications in commerce, industry, medicine, science and other areas [1]. Recently, significant effort has been devoted to investigation and development of RFID transponders that do not use chips - *chipless* tags, which may further reduce production costs. An important problem in the design of chipless tags is the attainable surface volume density of stored information (in bits per  $\text{cm}^2$ ). In this field, RFID chipless tags still cannot compete with optical barcodes at present. A disadvantage of optical barcodes, however, is the need for direct unscreened contact between the code holder and the reader. In the case of RFID tags, the reader can be screened, since detection is performed by radio waves.

Uniplanar metallic arrays of resonant elements, scatterers, etched on a thin dielectric film or a paper substrate represent one of the most widely spread kind of spectral signature-based chipless tags [2, 3]. The way to encode the data to such passive metallic structure is to ensure a frequency selective reflection when the tag is illuminated by an incident electromagnetic wave. The bit information “1” or “0” is encoded using presence/absence of resonance peaks in frequency response of tag radar cross section (RCS). This principle corresponds to amplitude shift keying.

Several topologies of frequency-based scatterers, has been proposed, among them, e.g., C-shaped [4], multiple C-shaped

[5] strips, concentric strip rings forming polarization independent tags [6], or complementary slots-in-plate [7]. The arrangement of individual scatterers in descending order according to their resonance frequencies, i.e., scatterers with the closest dimensions placed side-by-side, affects negatively the uniformity of their RCS response due to the mutual coupling of neighboring elements. The largest and smallest RCS resonance peaks may differ in amplitude level up to 8 dB [4]. This mutual coupling can be reduced, e.g., using modified scatterer topology as the use of tapered arms of U-shaped dipole [8]. The negative accompanying effect of this solution is the overall reduction of RCS level of the transponder.

Here, we propose different approach to reduction of mutual coupling using modification of the inter-arrangement order of individual scatterers in the array that results in improved uniformity and amplitude robustness of RCS response without decreasing of the mean-value of RCS level and without detuning frequencies of remaining resonance peaks. Particular resonators are rearranged so that resonators with neighboring resonance frequencies are not neighbors in the array. This reduces substantially their mutual coupling. The new tag response by this way substantially improves reliability of reading the coded information.

## II. CHIPLESS TAG ARRANGEMENTS

The layout of original and rearranged 20-bit chipless tag is depicted in Fig. 1. The topology of single U-shaped strip element is inspired by that used in [4]. The outer size of the largest element is  $25.5 \times 2.5$  mm and the smallest one  $16 \times 2.5$  mm with the strip width 1 mm and the gap size 0.5 mm so that all the RCS resonance peaks match the frequency range from 2 to 4 GHz. The distance between the two neighboring elements is 1 mm. The tag motif was etched on a low-loss dielectric substrate Rogers RO4003 ( $\epsilon_r = 3.38$ ,  $\tan \delta = 0.002$ ) of 0.2 mm in thickness. The incident excitation field is oriented parallel to shortening strip stub placed at one end of each scatterer, i.e. horizontally to the tag presented in Fig. 1. These chipless tags were simulated by MoM software Zeland IE3D.

To reduce mutual coupling between directly neighboring scatterers with neighboring resonance frequencies we have proposed a modification of inter-element arrangement. The

resonators are subdivided into four sub-arrays. In these sub-arrays now each resonator is next to the originally fourth in length resonator from it. Consequently, the original ascending order according to the resonator length ‘1 2 3 4 5 6 7 .. 20’ is modified to ‘1 5 9 13 17, 2 6 10 14 18, 3 7 11 15 19, 4 8 12 16 20’; see Fig. 1b. The resonators with neighboring resonance frequencies are now located far away and their coupling is substantially reduced in this layout.

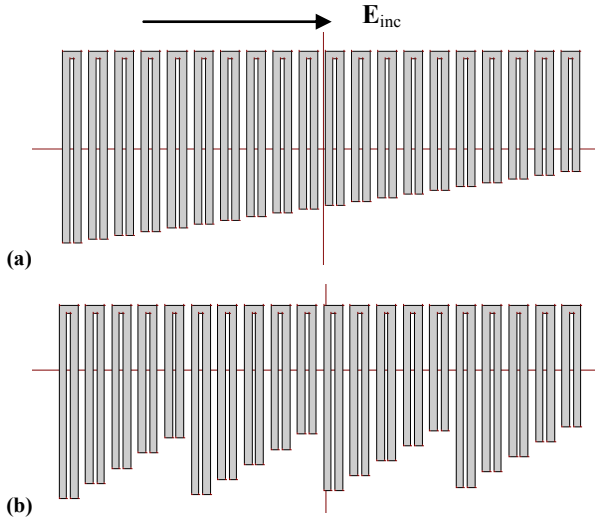


Fig. 1. Layout of 20-bit chipless tag representing the word ‘11111111111111111111’ composed of an array of the U-shaped strip scatterers: (a) original, and (b) modified configuration. The arrow denotes the orientation of incident electric field vector.

### III. MEASUREMENT OF TAG PERFORMANCE

The monostatic measurement of tag performance in an anechoic chamber, see Fig. 2, was based on evaluation of reflection coefficient of double ridge horn antenna DRH20 [9] in front of which a scatterer in the distance of 0.75 m was placed. The calculation of RCS response of the tag was done by the relation used in [4] modified to one-port case

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

where  $\sigma^{tag}$  is the RCS of the measured tag,  $\sigma^{ref}$  is the RCS of the reference scatterer which is rectangular metal plate  $100 \times 100 \text{ mm}^2$  in size and 0.3 mm in thickness. Its well-known analytically given formula for RCS is

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

$S_{11}^{tag}$  is the reflection coefficient when the measured tag is used as a scatterer,  $S_{11}^{ref}$  is the reflection coefficient when the reference plate is used as a scatterer.  $S_{11}^{iso}$  is the reflection coefficient of antenna itself if no scatterer is used and comprises residual reflection from the experimental

surroundings. Measured data are smoothed to suppress noise by Matlab function “smooth” using a method “rloess” with the coefficient 0.015.

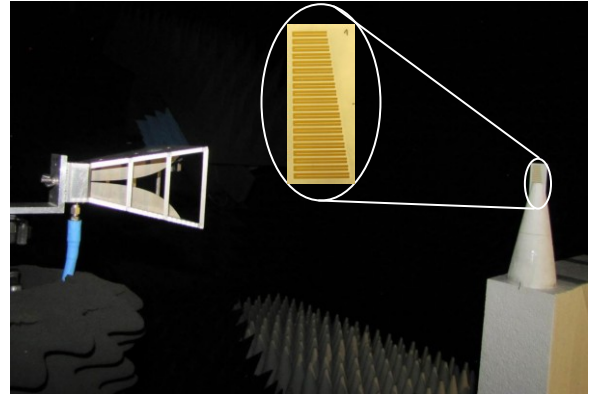
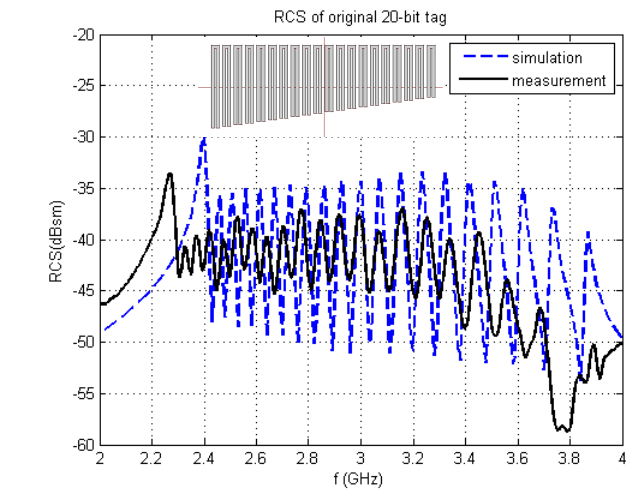


Fig. 2. Measurement setup using monostatic configuration with the detail of the original 20-bit tag. Vertical tag orientation and corresponding vertical polarization of incident electric field was used here.

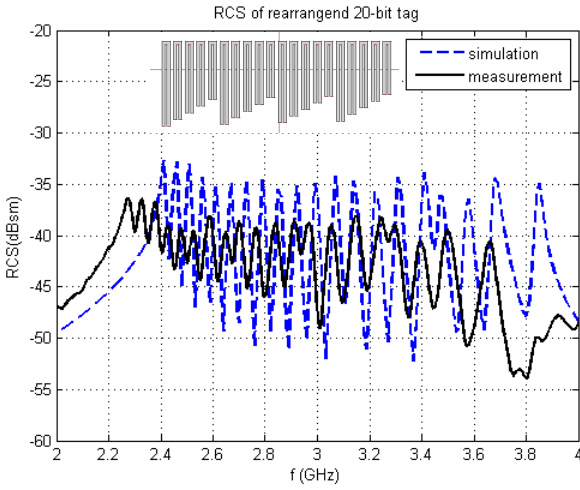
### IV. RESULTS

Simulated and measured RCS response of original 20-bit chipless tag is depicted in Fig. 3a. We may notice that the amplitudes of RCS levels of the highest and lowest resonance peaks differ by about 9 dBsm and even more than 12 dBsm for simulated and measured data, respectively. Further, we may notice that the measured RCS amplitude of the highest resonance peak is about -46.5 dBsm, and it is just only 3.5 dBsm above the closest parasitic noise peak at 3.88 GHz. This response is clearly not suitable for reliable detection of particular bits.

In case of rearranged tag the difference between the highest and lowest resonance peaks is just about 4 dBsm for both simulated and measured data; see Fig. 3b. This represents significant improvement of uniformity of RCS response. Measured RCS amplitude of the highest frequency resonance peak is about -40.5 dBsm, and it is about 8 dBsm above the closest parasitic noise peak at 3.90 GHz.



(a)



(b)  
Fig. 3. Simulated and measured RCS response of (a) original and (b) rearranged chipless tag representing the 20-bit word '11111111111111111111'.

Further we verify tag performance in both configurations for 20-bit word '1111101111111011111' where 6<sup>th</sup> and 15<sup>th</sup> elements are missing; see Fig. 4, and represent bits "0", by simulation.

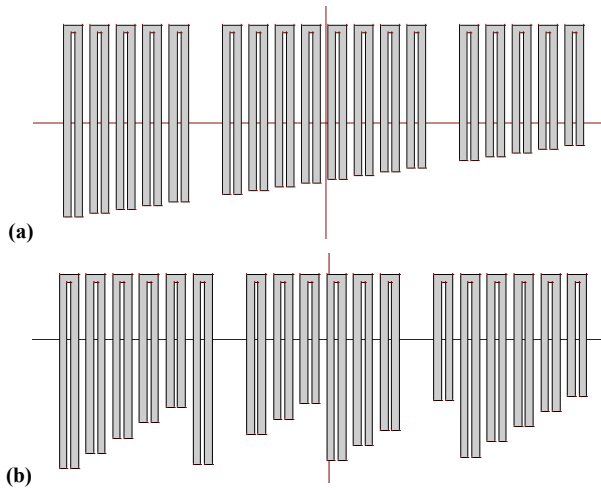
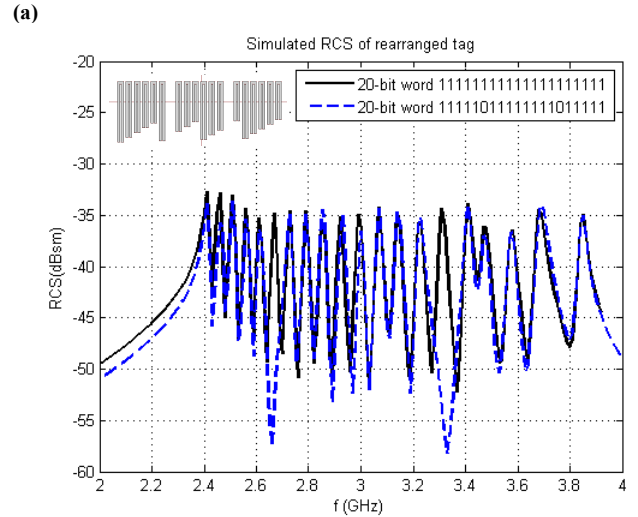
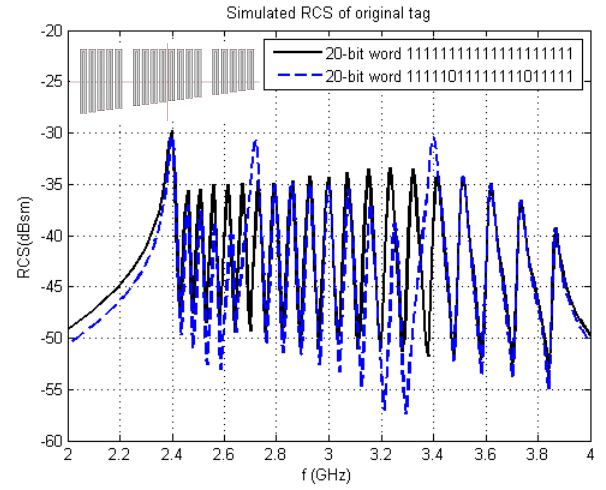


Fig. 4. Layout of tags representing 20-bit word '1111101111111011111' in (a) original, and (b) rearranged configuration. "0" bit is represented by the absence of 6<sup>th</sup> and 15<sup>th</sup> elements.

It can be seen that removing the two tag elements from the original tag affects the RCS amplitude of the closest neighboring resonance peaks. The lower peak response is reduced and the higher peak response is risen so that their difference is about 9 dBsm; see Fig. 5a. Moreover resonance frequencies of these two peaks are shifted closer to each other, so the required frequency gaps partially disappear. In case of rearranged tag, Fig. 4b, the removing of the two elements does not affect the closest neighboring resonance peaks both in response level and in frequency position; see Fig. 5b. This assures reliable detection of bits "0".



(a)  
Fig. 5. Simulated RCS response of (a) original and (b) rearranged chipless tags representing the 20-bit words '11111111111111111111' and '11111011111111111011111'. "0" bit is represented by the absence of the corresponding resonance peak.

Simulated and measured RCS response of rearranged tag encoding 20-bit word '1111101111111011111' is depicted in Fig. 6 where the positions of missing resonance peaks corresponding to missing 6<sup>th</sup> and 15<sup>th</sup> elements are clearly visible. Frequency shift approx. 150 MHz and amplitude difference from about 2 to 3 dBsm between simulated and measured data is presented. This is namely due to the limitation in simulated data where infinite substrate in MoM implementation is used while the real footprint size of supporting dielectric plate is  $76 \times 33 \text{ mm}^2$ .

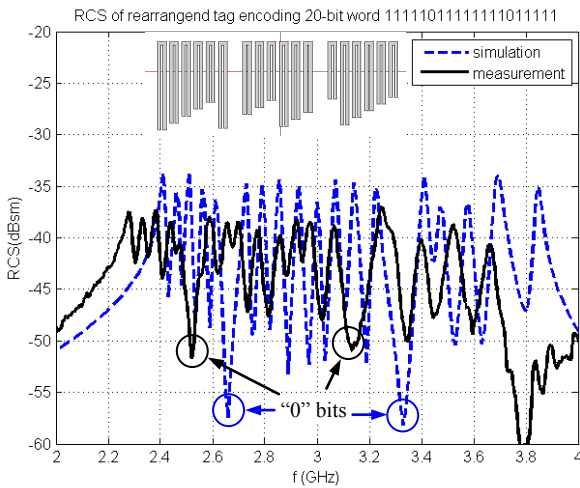


Fig. 6. Simulated and measured RCS response of rearranged chipless tag representing the 20-bit word '11111011111110111111'.

## V. CONCLUSION

We proposed a modification of a layout of 20-bit chipless tag composed of 20-element array of U-shaped strip scatterers that significantly improved uniformity and amplitude robustness of RCS response over the operational frequency range 2 to 4 GHz. The array layout was rearranged so that the neighboring resonators in the original array of resonators with descending length were subdivided into four sub-arrays. Resonators with neighboring resonance frequencies were now located in different sub-arrays and therefore were placed far away to be coupled. The proposed modification significantly improved recognition of individual resonance peaks in spectrum signature of chipless tag and increased reliability of its reading including reliable recognition of bits "0".

## ACKNOWLEDGMENT

This work has been supported by the Czech National Foundation under project No. 15-08803S, by the Czech Technical University in Prague under project No. SGS13/198/OHK3/3T/13, and partially by COST project No. LD 14122 WiPEELMAG "Electromagnetic Structures and Circuits for Wireless Power Transmission", which form a part of COST project No. IC 1301 WiPE "Wireless Power Transmission for Sustainable Electronics".

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