Frequency-Domain Chipless RFID Transponders: Improvement the Reading Response

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Abstract—*This paper reviews investigations of the authors in the field of frequency-domain chipless RFID transponders. The main issue is to reduce the mutual coupling between adjacent resonant elements in the scatterer array to ensure the robust RCS response for reliable reading of coded information. A major improvement in RCS response of transponders is proposed, using slot-in-plate type transponders. Advantages and drawbacks of the proposed solutions are discussed and several open challenges in the field are emphasized.*

Keywords— ***Chipless RFID, planar scatterer, mutual coupling, monostatic RCS.***

I. INTRODUCTION

Radiofrequency identification (RFID) is widespread technology which is used more and more often in industry, logistics, commerce, health care, etc. Advantage of the RFID technology is in the possibility to read the coded information without necessity of line of sight. Low price of the tag is essential for reaching this goal. Unfortunately conventional tags which contain a chip are about hundred times more expensive than optical barcode [1]. The ultimate reduction the tag cost can be achieved by using chipless RFID tags which provide different methods of storing information without using an electronic chip. Chipless tags based on spectral signature [1-3] are usually composed of resonator/scatterer arrays. Presence or non-presence of each resonator's peak in tag's spectral signature represents logic one or zero, respectively. Sensors represent the promising application of chipless RFID tags [4]. The main issue of this technology that must be solved are both low space bit density and spectral bit capacity.

There are many different types of planar resonators which can be used as basic building units of the tag. There are three important resonator/scatterer quantities, which must be evaluated for each resonator before its use as a building element considered for chipless RFID transponder usage. The first of them is radar cross-section (RCS) which is proportional to the reading distance of the tag. The higher RCS results in the longer reading distance. The second quantity is a bandwidth (BW) of a resonant peak which depends on quality factor Q of the resonator, it can be evaluated from frequency characteristic of the resonator as frequency range of three decibel resonant peak drop, and is important for spectral bit capacity point of view. For example, when bandwidth is, e.g. 200 MHz, only five bits can be stored in each 1 GHz band. Last quantity which is however directly bounded with Q is an electrical size ka where k is wave number and a is radius of circle circumscribing the resonator. Resonators with ka below one are suitable candidates because small scale is essential for purposes of high spectral bit capacity chipless RFID transponders.

The paper reviews the results of authors' investigations in the field of spectral based chipless RFID transponders composed of arrays of uniplanar and planar resonators and slot arrays in the plate scatterers.

II. USED ANALYSIS AND EXPERIMENTS

Investigated tags are analyzed by the method of moments implemented in Zeland IE3D.

To verify the simulated results, we made the monostatic measurement of tags RCS performance in an anechoic chamber; see Fig. 1. It was based on the reflection coefficient evaluation of the double ridge horn antenna DRH20 [5] in front of which a scatterer at distance of 150 mm was placed. The tag's RCS response was calculated with the help relations and modified so that it was applicable to the one-port case described in [6].

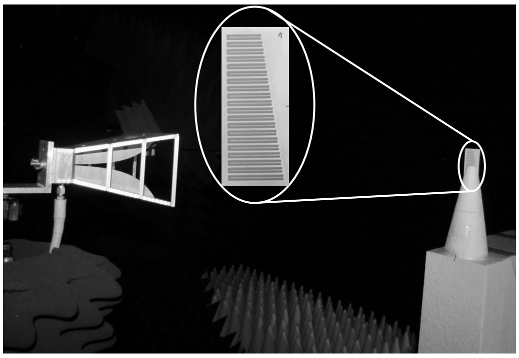

Fig. 1. Measurement setup using monostatic configuration with the detail of the original 20-bit tag.

The simplified analysis was performed using the equivalent circuit of the tag composed of the array of planar resonators. The equivalent circuit of the i^{th} single resonator is composed of a series resonant circuit L_i, C_i, and R_i, see Fig. 2 [7]. This circuit is fed by the source of voltage V_i that corresponds to the incident electric field E irradiating the tag. The missing resonator (logical “0”) is represented in the circuit by choosing resistor equal to 1 MΩ.

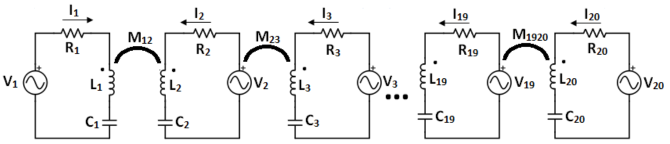

Fig. 2 Equivalent circuit of the tag composed of 20 resonant elements.

Although the proposed analysis is approximate it predicts the amplitude level and frequency positions of resonant peaks of predicted RCS response fast and quite well. This is a very fast and efficient tool that is capable to pre-evaluate a suitability of the particular scatterers for implementing in the chipless RFID tags.

III. PLANAR RESONANT SCATTERERS FOR CHIPLESS RFID

Particular resonators are presented in Fig. 3 – 5 together with their performance. Examples of this category are half-wavelength planar dipole (length 37 mm, 1 mm in width), circular ring (diameter 10 mm, line width 1 mm, split length 2.3 mm), rectangular loop (side 10 mm, line width 1 mm, split length 2.5 mm), meander dipole (total length 56 mm, meander length 6 mm, line width 1 mm, distance between meanders 1 mm) and thick U dipole (arm length 20.5 mm, line width 1 mm, distance between arms 0.5 mm), proposed in [8]. There are another three scatterers which are based on the thick U dipole. It's thin dipole (arm length 20.5 mm, line width 0.25 mm, distance between arms 2 mm) which was proposed in [9], U dipole with skew arms (arm length 20.5 mm, line width 0.25 mm, distance between skew arms at their open ends 0.5 mm) which was also proposed in [9] and meander U dipole (arm length 20.5 mm, line width 0.25 mm, meander length 5 mm, distance between meander arms 0.2 mm, distance between dipole arms 2 mm). Analogical scatterer was proposed in [10]. Last group of scatterers are represented by several capacitive loaded dipoles and one inductively loaded dipole (ILD). All these scatterers occupy a rectangle area 20.5 mm by 2.5 mm. ILD consists of 18 skew parts. Spacing between them and arms 9.25 mm in length is 0.23 mm, line width is 0.25 mm and length of straight part in the middle of scatterer is 2 mm. Basic capacitive loaded dipole (CLD 1) consists just dipole part and four ending arms 9.25 mm in length each. Spacing between dipole part and arms is 0.88 mm and width of all lines is 0.25 mm. Version labeled as CLD 2 is based on CLD 1 and four inner arms were added (length 8.75, spacing between dipole part and inner arms is 0.38 mm, spacing between outer and inner arms is 0.26 mm). Capacitive loaded dipoles can be divided into two groups. The difference is in mutual linking of terminating arms which can be either mender or spiral shaped. There are three arm versions labeled as 'M 3 arm' and 'S 3 arm' which are an extension of CLD 2 (arms width as well as spacing between them was reduced to 0.18 mm), Fig. 3 [11]. Thin versions (M 5 arm and S 3 arm v2) have five and three arms respectively and their line width as well as spacing between arms is 0.1 mm. Layouts of all proposed scatterers are shown in Figs. 4 and 5. All scatterers were designed on RO4003 substrate (ε_r = 3.38, tan δ = 0.002, 0.2 mm in thickness).

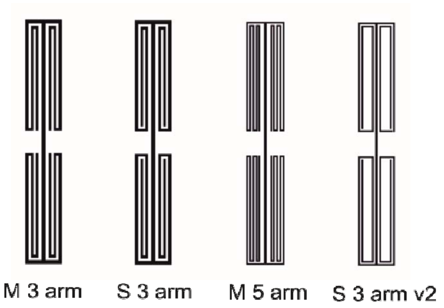

Fig. 3 Detail of proposed scatterers geometry [11].

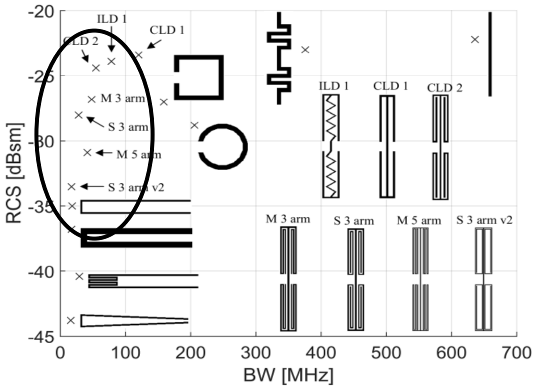

Fig. 4 Comparison of scatterers according the RCS and resonance bandwidth.

Theory of electrically small antennas says that resonant structures with small ka have high quality factor Q which implicates low bandwidth which is beneficial for high spectral bit capacity and low RCS which is inappropriate for reading range. Therefore there is always a trade-off between spectral bit capacity and reading range of the tag. Results of simulations in IE3D software are shown in Figs. 4 and 5 confirm this theory. The best candidates for tags with small size, high RCS, and low BW are marked in Figs. 4,5.

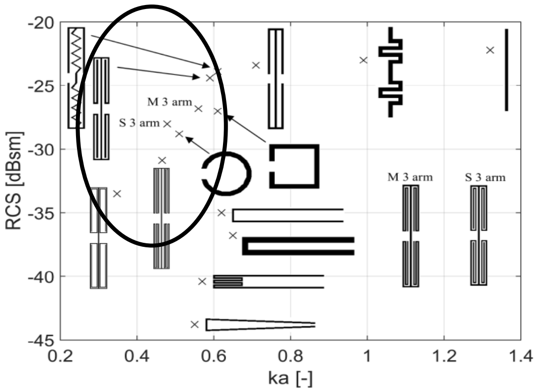

Fig. 5 Comparison of scatterers according the RCS and *ka* product.

IV. TAGS WITH REDUCED COUPLING BETWEEN RESONATORS

The paper further compares measured RCS response of the tag composed tapered U-folded dipoles (T-UD) [12] and with the tag composed of resonators rearranged in their positions [6]. Based on that, the advantage of the tags with reduced mutual coupling between neighboring resonators is shown. All scatterers were designed on the low loss substrate Rogers RO4003 ($\varepsilon_r = 3.38$, $\mathrm{tg}\delta = 0.002$) of the thickness 0.2 mm.

Weak mutual coupling in case of an array of T-UD resonators of Fig. 6a assures stable amplitude level and frequency positions of adjacent resonant peaks. Consequently it enables their reliable identification as shown in Fig. 7 where the measured RCS is plotted as the response of the tag composed of 20 resonant elements and the tag with missing 6th and 15th elements.

Another way to reduce the mutual coupling between planar resonators has been obtained by using an array with rearranged positions of resonators [6]. Tags with rearranged positions of resonators are shown in Fig. 6b. Measurement RCS of the tags from Fig. 6b are plotted in Fig. 8. Coded "0" by missing 6th and 15th resonators are clearly visible in the response. Similar geometry of the tag that is composed of electrically small spiral capacitive loaded (C-loaded) dipole scatterer is presented in Fig. 6c [13]. The tag was fabricated on the low-loss dielectric substrate Rogers RO4350 ($\varepsilon_r = 3.66$, $\tan\delta = 0.003$) with the thickness of 0.254 mm. Measured RCS response is plotted in Fig. 9. Comparison of plots in Fig. 9 shows the good stability of the RCS response.

Measured RCS responses in Figs. 7, 8, and 9 show that the presented tags assure reliable reading the coded information.

Fig. 6 Layouts of investigated modifications of folded-dipole scatterers: a) arrays of 20 T-UDs [10], coding information 11111111111111111111, and 11111011111111011111 by missing 6th and 15th elements, b) rearranged resonators in the array [9] coding the same information, c) half spiral capacitive loaded dipoles [12].

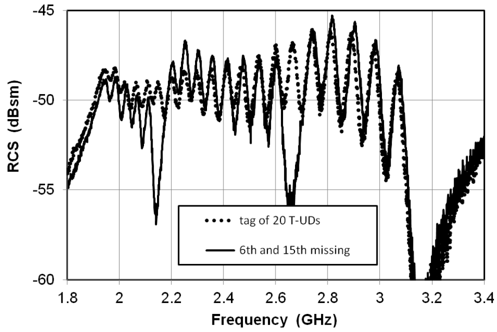

Fig. 7 Measured RCS response of 20-element tags composed of tapered U-folded dipoles, and tag coded by missing 6th and 15th elements, [11].

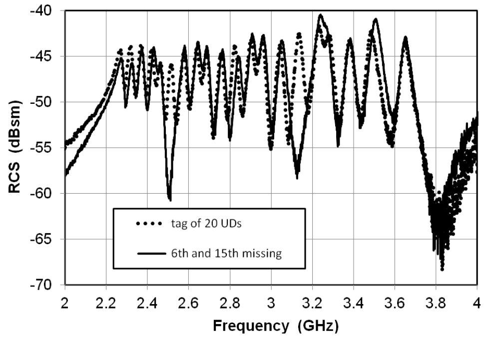

Fig. 8 Measured RCS response of 20-element tag with rearranged resonators, and 18-element tag coded by missing 6th and 15th elements from Fig. 6b, [6].

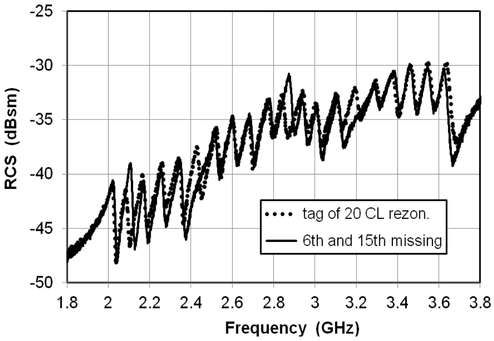

Fig. 9 Measured RCS response of 20-bit chipless tags using rearanged half-spiral capacitive loaded dipoles, representing bit words '11111111111111111111', and '11111011111111011111'.

V. TAGS WITH FREQUENCY NOTCHED RESPONSE

The read distance in specific chipless RFID applications may be limited due to the low RCS of their tags. Therefore a chipless RFID tag that offers a higher RCS at the level of -16 dBsm was proposed [14]. The tag is based on a complementary structure; coplanar slots are introduced in a metallic pattern, unlike the strip-based scatterers presented in [6]. The basic pattern is a uniplanar rectangle etched on a thin dielectric substrate that displays a substantially higher RCS due to its large size relative to the wavelength that is used. An array of coplanar slots shorted at the one end is introduced into the surface of the rectangle. 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.

The tag is based on a metallic rectangular plate 52×50 mm^2 in size chosen to provide a monotonous RCS curve over the frequency range of 2 to 4 GHz. Twenty shorted coplanar slots forming an inverted letter “U” are introduced symmetrically into the rectangle so that the slots are collinear with the unit polarization vector of the incident field. The vertical polarization of incident wave excites the electric field in the narrow shorted part of the slot. Slots are arranged in same manner as U-folded dipoles in Fig. 6 in order to improve resonant dips uniformity by reducing mutual coupling.

The slot-arm length ranges from 15 to 24.5 mm, with 0.5 mm in length difference between the two neighboring slot couple. The slot width is 0.25 mm and the metallic gap between the two adjacent slot-arms equals g = 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 symbolizing a notch in the RCS curve, and by absence of the slot representing a smooth RCS curve. A 20-element coplanar slot array with the 9th and 17th slots missing thus presents the 20-bit word ‘11111011111111111011’, see Fig. 10. Fig. 11 illustrates the measured *RCS* responses of the tags from Fig. 10.

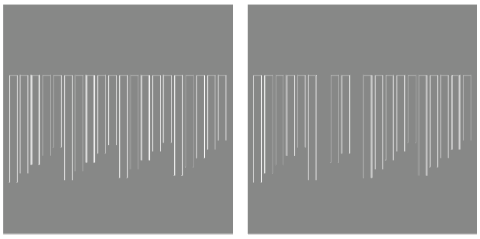

Fig. 10: Two 20-bit tags using UD shaped slots [13].

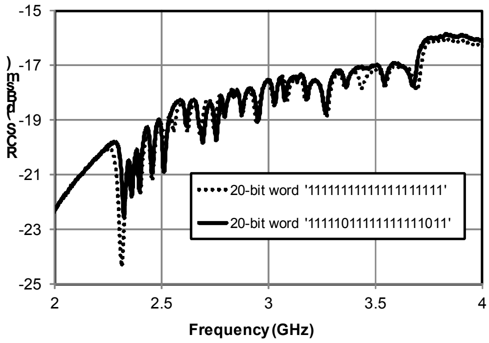

Fig. 11 Measured RCS responses of the 20-bit tag using UD shaped slots

VI. CONCLUSION

The paper presents a review of authors’ investigations in field of frequency-domain chipless RFID transponders. The performance comparison of various types of scatterers recently proposed by the authors is presented. The issue of proper location of adjacent resonant elements in the scatterer array to reduce the mutual coupling and consequently ensure the robust RCS response for reliable reading of coded information is addressed. The system composed by U-shaped slots etched into a metallic patch has been proposed and provides RCS higher by 20 dB then the tags composed of dipoles which is beneficial for the increase of read distance. The simple equivalent circuit method has been set up for fast preliminary analysis of investigated tags composed of arrays of planar and uniplanar resonators.

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