Erroneous Reading of Information in Chipless RFID Tags

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Abstract— Chipless RFID tags are designed as arrays of planar or uniplanar resonators. These tags should be as small as possible to increase their attraction. On the other hand the closer are particular resonators located the tighter is their coupling. This coupling prevents the reader from proper reading the coded information. This is due to detuning of particular resonant frequencies of resonators and due to changing levels of the resonant peaks. Finally some compromise must be done in the tag design. For error-less reading of information coded by the presence/absence of resonant peaks in the RCS response the proper choice of scatterer topology and their arrangement has significant importance. Simple and efficient way of checking the suitability of particular resonators is presented.

1. INTRODUCTION

Chipless RFID tags working with the spectral signature are composed of arrays of small planar or uniplanar (printed) scatterers (coding particles), each of them codes one bit in frequency response of the tag. Presence of the resonant peak corresponding to presence of particle represents logical "1", absence represents logical "0" [1]. These tags have been intensively investigated recently [1–9], and have a potential to be a microwave frequency equivalent of optical barcodes systems. The advantage of microwave tags is that they can be somewhere hidden or screened (by a dielectric material), and therefore there is no need of direct sight as in optical range. The size of microwave tags is however proportional to wavelength causing a drawback comparing to optical barcodes. The designed microwave tags must be, therefore optimized with the aim to reduce the taken area and to increase the amount of coded information.

This paper uses the results of works [8, 9] that present two ways of reducing the mutual coupling between resonators in chipless RFID tags. The coupling was effectively reduced by increasing the distance between resonators by tapering their arms [8], and rearranging positions of resonators in tag [9]. This paper presents a simple equivalent electric circuit used to analyze tags and to evaluate their normalized radar cross section (RCS). Analysis of this circuit is very fast and resulting RCS corresponds well to measured values. This analysis could serve namely as a tool to check up the suitability of particular scatterers to be used in RFID tags.

2. TAG EQUIVALENT CIRCUIT

The layouts of tags presented in [8, 9] are shown in Fig. 1. They are composed of arrays of 20 folded dipoles (FD) resonators. Each of these resonators can be represented by a series resonant circuit. These circuits are coupled together by mutual inductances. Consequently the tag equivalent circuit, Fig. 2, is composed of 20 series resonant circuits fed by particular voltage sources. These circuits are coupled dominantly by magnetic field. The coupling coefficient decreases with distance. So it is sufficient to consider only coupling of neighboring resonators. The equivalent circuit of the ith single resonator is composed of a series resonant circuit L_i, C_i, and R_i, see Fig. 2. This circuit is fed by the source of voltage V_i that corresponds to the electric field E of the electromagnetic wave irradiating the tag

$$V_i = El_{ieff}, \tag{1}$$

where l_{ieff} is effective length of the ith resonator working as a receiving antenna. Changing amplitudes and phases of V_i we can simulate oblique incidence of the wave, or its different forms — planar, cylindrical, spherical. The presented analysis is done for the perpendicular incidence of the plane wave, so all voltages are taken $V_i = 1$ and are in-phase. Magnetic field of the reflected wave that is excited by dipoles corresponds linearly to the current flowing along these dipoles [10]. In the case of the perpendicular incidence of the plane wave the tag response that defines radar cross section (RCS) is therefore proportional to the power of sum of currents in particular resonators of the equivalent circuit [11]

$$\mathrm{RCS} \sim \left(\Sigma_{i=1}^{20} I_i\right)^2 . \tag{2}$$

The missing resonator that in the tag codes bit with logical “0” is represented as a circuit with resistance $R = 1\,\mathrm{M\Omega}$ that assures nearly zero value of the passing current and consequently no (or negligible) contribution to the response.

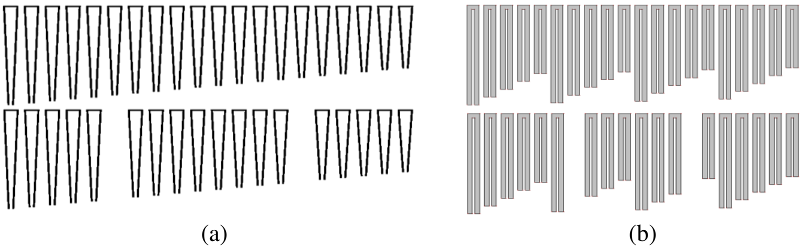

Figure 1. Layouts of investigated tags (a) 20-element arrays tapered U-folded dipoles (T-UD) [8] coding information 11111111111111111111, and 11111011111111011111 by missing 6th and 15th elements, (b) re-arranged resonators in the array [9] coding the same information.

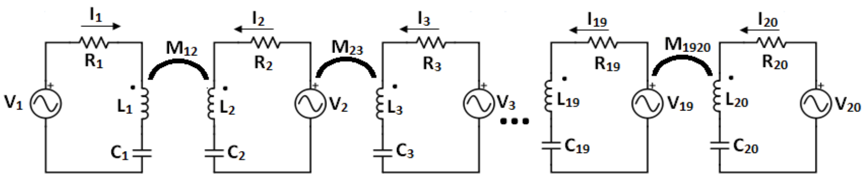

Figure 2. Equivalent circuit of the tag composed of 20 resonant elements.

Table 1. Elements of the equivalent circuit presented in [12].

i	f_{oi} (GHz)	l_i (mm)	L_i (nH)	κ_i	R_i (Ω)
1	2.074	25.5	16	−0.024	0.3
2	2.110	25	15.7	−0.0238	0.295
3	2.159	24.5	15.4	−0.0236	0.29
4	2.200	24	15.1	−0.0234	0.285
5	2.252	23.5	14.8	−0.0232	0.28
6	2.296	23	14.5	−0.023	0.275
7	2.342	22.5	14.2	−0.0228	0.27
8	2.390	22	13.9	−0.0226	0.265
9	2.447	21.5	13.6	−0.0224	0.26
10	2.500	21	13.3	−0.0222	0.255
11	2.559	20.5	13	−0.022	0.25
12	2.624	20	12.7	−0.0218	0.245
13	2.692	19.5	12.4	−0.0216	0.24
14	2.763	19	12.1	−0.0214	0.235
15	2.833	18.5	11.8	−0.0212	0.23
16	2.903	18	11.5	−0.021	0.225
17	2.985	17.5	11.2	−0.0208	0.22
18	3.067	17	10.9	−0.0206	0.215
19	3.157	16.5	10.6	−0.0204	0.21
20	3.254	16	10.3	−0.0202	0.205

Equations for each loop in the circuit from Fig. 2 read

$$-V_1 + (R_1 + X_{L1} + X_{C1})I_1 + X_{M12}I_2 = 0 \quad (3a)$$
$$-V_2 + (R_2 + X_{L2} + X_{C2})I_2 + X_{M12}I_1 + X_{M23}I_3 = 0 \quad (3b)$$
$$\ldots$$
$$-V_{19} + (R_{19} + X_{L19} + X_{C19})I_{19} + X_{M1819}I_{18} + X_{M1920}I_{20} = 0 \quad (3c)$$
$$-V_{20} + (R_{20} + X_{120} + X_{C20})I_{20} + X_{M1920}I_{19} = 0 \quad (3d)$$

where $X_{Li} = j\omega L_i$, $X_{Mij} = j\omega M_{ij}$, and $X_{Ci} = 1/(j\omega C_i)$. Solution of (3) determines the particular currents and therefore the tag response (2).

3. MAKE ERRONEOUS READING OF THE TAG RESPONSE RELIABLE

The analysis of the chipless tags composed of 20 T-UD [8] was performed applying parameters of particular circuit elements determined in [12] as listed in Table 1.

Figure 3 shows the response of the tag composed of 18 and 20-element UDs from [1] where the resonators are coupled relatively strongly. The first and the last resonators have neighbors only from one side, so RCS at maximum of the first resonator is higher than in the case of others, RCS at maximum of the last resonator is lower. If particular UD resonators are removed from the array to code logical zero bit information peaks adjacent to missing resonances are strongly distorted both in amplitude level and frequency position. Strong element coupling thus makes difficult, or even impossible, to read properly the coded information and predicts that such kind of element is not suitable for implementing chipless RFID tags.

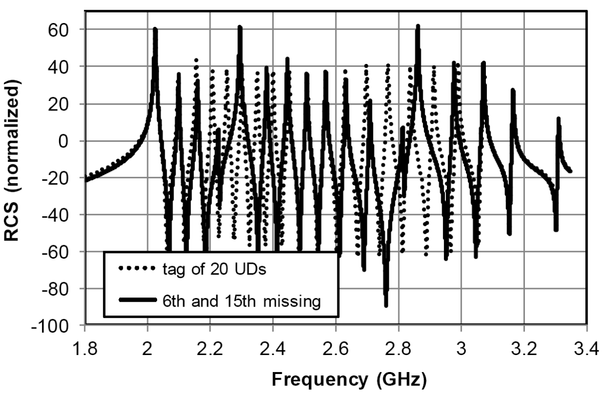

Figure 3. RCS response of the equivalent circuit of 20-element tag composed of U-folded dipoles [1] compared with the 18-element version coded by missing 6th and 15th elements.

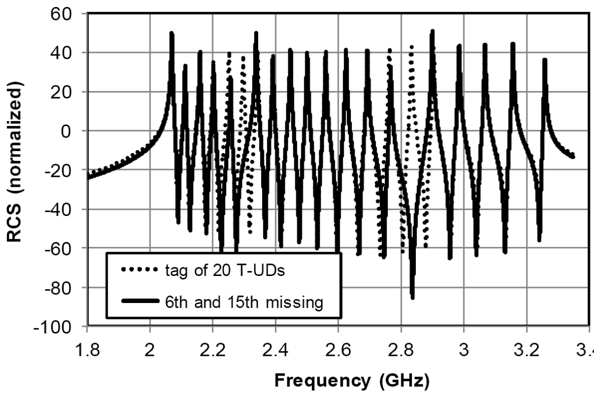

Figure 4. RCS response of the equivalent circuit of 20-element tag composed of tapered U-folded dipoles [8] compared with the 18-element version coded by missing 6th and 15th elements.

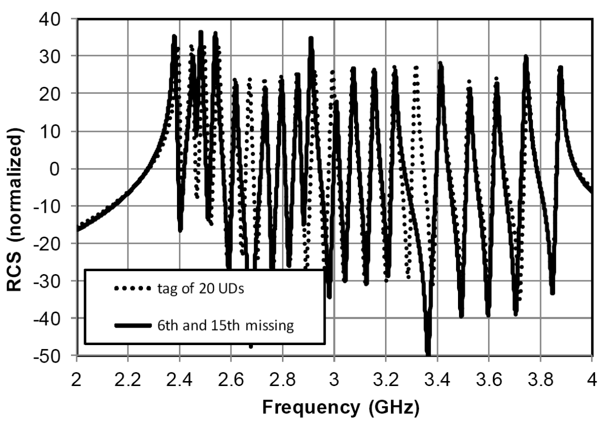

Figure 5. RCS response of the equivalent circuit of 20-element tag with rearranged resonators [9], compared with the 18-element version coded by missing 6th and 15th elements from Fig. 1(b).

Weak mutual coupling in case of an array of recently proposed T-UD resonators of Fig. 1(a) presented in [8] assures stable amplitude level and frequency position of adjacent resonant peaks and thus enables their reliable identification in comparison with the RCS response of the full 20-bit tag; see Fig. 4. The another way of reducing the mutual coupling in arrays of planar resonators was proposed in [9] by rearranging positions of resonators in the array, see Fig. 1(b). Fig. 5 plots RCS of this tag calculated with the help of the equivalent circuit. The plot documents again the suitability of that simple solution to predict the tag behavior. The behavior of the tags shown in Fig. 1 is verified by measured RCS plotted in Fig. 6 [8, 9]. More over the obtained results were verified by simulations performed by the Zeland IE3D software [8, 9]. Measured and simulated data show similar shape to results of the equivalent circuit analysis. What can not be compared is the level of the RCS response. The RCS calculated from the equivalent circuit response represents only some normalized values. It is due to the fact of taking all voltages equal to 1 and due to the substitution of RCS by currents in Eq. (2).

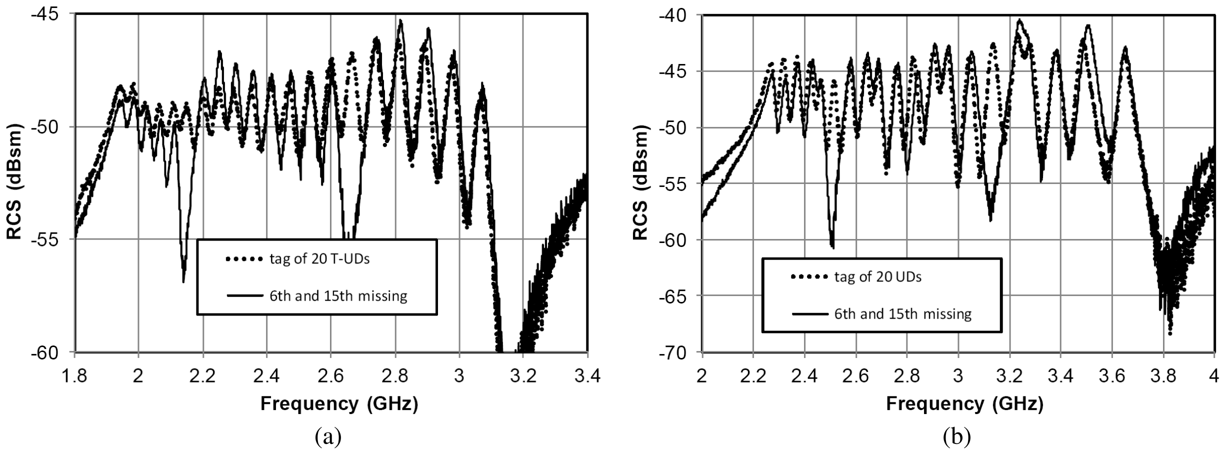

Figure 6. Measured RCS response of 20-element tags composed of tapered U-folded dipoles, and tag coded by missing 6th and 15th elements Fig. 1(a) [8], and of 20-element tag with rearranged resonators, and 18-element tag coded by missing 6th and 15th elements from Fig. 1(b) [9].

4. CONCLUSIONS

Presented analysis of the influence of mutual coupling using simplified equivalent circuit model of the array of planar resonators predicts quite well the shape of RCS response for investigated layouts of chipless RFID scatterers. It has been found that the removing of particular resonators from the array to code logical "0" bit information in case of strong inter-element mutual coupling causes significant distortion of the amplitude level and frequency position of adjacent resonant peaks. Such behavior makes difficult to read coded information and predicts that elements with strong mutual coupling are not good candidates for chipless RFID scatterers. Rather it is recommended to use scatterers with reduced mutual coupling and/or rearrange the scatterers in the array in such a way that frequency neighboring resonators are placed further apart to reduce coupling.

Generally, the proposed simplified analysis method is capable to pre-evaluate a suitability of the particular scatterers for implementing in the chipless RFID tags and predicts quite well the shape of RCS response.

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