REDUCING MUTUAL COUPLING IN CHIPLESS RFID TAGS COMPOSED OF U-FOLDED DIPOLE SCATTERERS

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ABSTRACT: *We propose a novel chipless RFID tag composed of topologically modified uniplanar U-folded dipoles with inclined arms. This topology reduces the interelement mutual coupling and provides a significantly better amplitude uniformity and frequency stability of tag RCS response when logical "0" is coded by removing particular scatterers from the array. Simultaneously, it provides a higher encoding capacity in unit frequency range than the arrays composed of original U-folded dipoles with parallel arms, yet at the expense of small RCS magnitude reduction.*© 2016 Wiley Periodicals, Inc. Microwave Opt Technol Lett 58:2723–2725, 2016; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.30138

Key words: *chipless RFID; U-folded dipole; radar cross section; uniplanar resonator; spectral response coding*

1. INTRODUCTION

In comparison to currently used RFID tags employing integrated chips [1–3], the chipless RFID technology gives an advantage of simpler and therefore cheaper transponder structure. The several configurations of spectral signature-based chipless tags composed of an array of small printed scatterers (coding particles), and operating in low microwave bands have been proposed, e.g.: dipole strips [4], rectangular and circular split rings resonators or U-folded dipoles [5]. Each of them codes one bit in the frequency spectrum by presence/absence of its resonant peak and provides a trade-off between the quality factor (i.e., the bandwidth), and radar cross section (RCS), which is directly determined by the electrical size and compactness of the scatterer structure. The U-folded strip dipole [5,6] that provided a 3 dB bandwidth equal to 44 MHz, the quality factor amounting to 65, and the RCS at the resonance −29.8 dBsm was found to be the chipless tag coding particle with good performance properties. The 20-bit tag of the size 25 × 70 mm operating within the 2–4 GHz frequency band was built, applying twenty of the said resonant particles. The RCS response contained 20 resonant peaks, which differ in magnitude by up to 10 dB, the peak-to-valley level changes from 1 dB up to more than 10 dB. These parameters illustrate a significant nonuniformity of RCS response of the investigated tags that is caused by the mutual coupling of particular resonators. Furthermore, the non-negligible frequency detuning of resonant peaks directly neighboring to missing scatterers coding logical "0" is observed. Such performance properties might degrade the unique recognition of the resonant peaks corresponding to particular scatterers and limit the identification reliability of the whole transponder.

This article proposes a topological modification of the individual scatterer based on our recent work [5,7,8], which improves the amplitude uniformity of RCS response of the whole tag (including the peak-to-valley level), frequency stability and resolution (increased *Q* of scatterers), which may consequently provide a significantly higher encoding capacity within the specified frequency range. The reduction in the resonant frequency of coding particle allows to decrease the size occupied by the scatterer and thus to increase the density of coded information per area unit. As demonstrated the mutual coupling between the resonators is reduced by inclination of their arms so that the adjacent resonators are located effectively at a longer distance. Further, the decreased interelement mutual coupling positively affects amplitude uniformity and frequency stability of resonant peaks in RCS response of tags that code the logical "0" using missing scatterers. Unfortunately, as it was expected, both improvements are at the expense of the RCS response reduction of the proposed transponder. Other ways of improvement in the information reliability has been investigated by means of rearrangement of order of individual scatterers in the array [8,9].

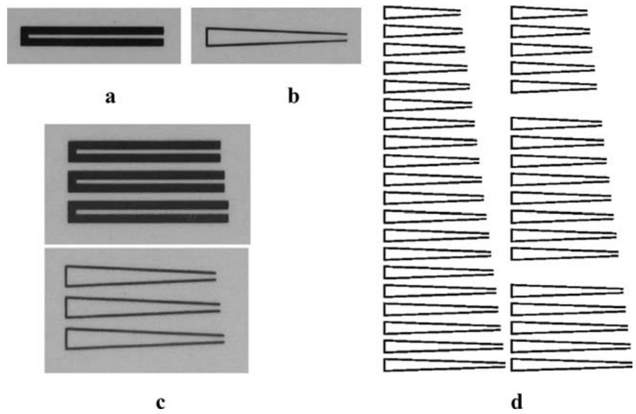

Figure 1 Photograph of investigated modifications of folded-dipole scatterers: (a) U-folded dipole (UD), (b) tapered U-folded dipole (T-UD), (c) their triplets, and (d) 20-element arrays coding information 11111111111111111111, and 11111011111111011111 by missing 6th and 15th elements

2. TAPERED U-FOLDED DIPOLE-TYPE SCATTERERS

The geometry of the proposed uniplanar strip scatterers was inspired by the U-folded dipole presented in [6]. In order to correctly compare the performance of the proposed scatterer with the one investigated in [6], the scatterers were designed and analyzed on the low loss substrate Rogers RO4003 ($\varepsilon_r = 3.38$, tg $\delta = 0.002$) of the 0.2 mm thickness, providing planar resonators with a lower dielectric loss and higher *Q* than those manufactured onto 0.8 mm FR-4 substrate used in [5,6].

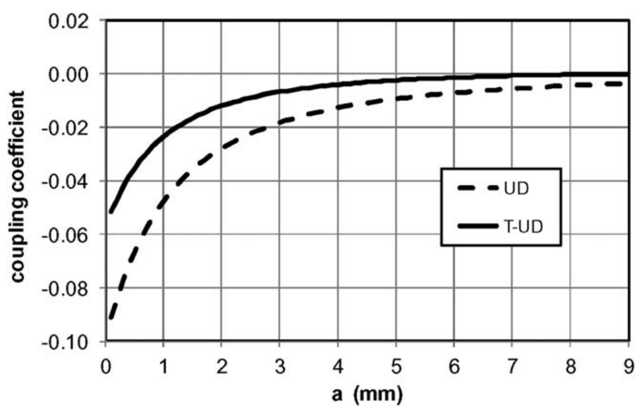

Figure 2 Coupling coefficient of pairs of original UDs, and T-UDs as a function of vertical distance *a*

TABLE 1 Measured Performance Properties of the Highest Resonant Peak of Scatterer Triplets

Scatterer	Resonant frequency (GHz)	3 dB bandwidth (MHz)	RCS lowest (dBsm)
Original UD	3.20	16.7	−46.5
Tapered UD	2.75	17.8	−44.7

Figure 1(a) shows the original U-folded dipole (UD) scatterer of the outer size 20 × 2.5 mm with the 1 mm strip width and the gap size of 0.5 mm, which is in accordance with [6]. The novel tapered U-folded dipole (T-UD) scatterer of the same outer size is depicted in Figure 1(b).

The geometrical modifications consist in narrowing the strip width from original 1–0.25 mm to enable to taper the gap between the longitudinal dipole arms toward the open end to 0.5 mm. This taper shape reduces the mutual coupling between two neighboring coding particles, because their arms are more spatially separated. As it is indicated in Figure 1(c), the fabricated triplets consist of three scatterers that are 20, 19.5, and 19 mm in length and of the same width. The distance among them at short ends is 1 mm, which is the same as in [6]. All scatterers are placed on the substrate that extends their dimensions by about 3 mm at each side of the scatterer.

The mutual inductance M represented by coupling coefficient $\kappa = M/\sqrt{L_1 L_2}$ of pairs of UDs, and T-UDs of the above-described geometry that is 20 mm in length and located at the distance a is plotted in Figure 2. The calculation was done by static definition of M and L using the vector potential of magnetic field [10], p. 234, Fig. 5.3, p. 177

$$M = \frac{\mu_o}{4\pi} \int\int \frac{d\boldsymbol{l}_1 \cdot d\boldsymbol{l}_2}{|\boldsymbol{r}_{12}|}. \quad (1)$$

To simplify the analysis, the T-UD is here approximated by a rectangular current loop where the inclined arms are represented by horizontal segments located at the centers of the tapers. The original folded dipole, Figure 1(a), is substituted by the current loop located at the center of strips. The mutual coupling of T-UDs significantly weakens as the vertical element distance a drops. This phenomenon well documents the reason why of the U-folded dipoles were proposed as suitable building elements of the chipless RFID tags.

3. UNIFORMITY OF RCS RESPONSE OF UD AND T-UD

The scatterer triplets were measured in the R32 waveguide setup, while being fixed on a thin polystyrene stand and located at the transversal position in the centre of the waveguide section that is 37 mm long and inserted between the reference planes. The free space RCS is then extracted from the measured S-parameters by the procedure described in [11]. The performance properties of scatterer triplets that are 20 mm in length are as follows; see Table 1.

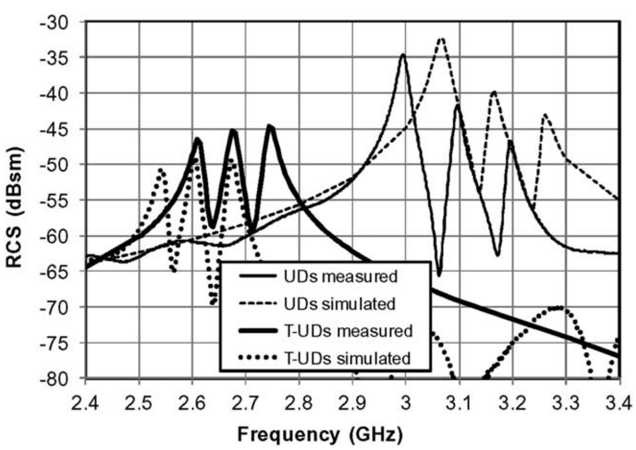

Figure 3 Simulated and measured RCS response of triplets of original UD and T-UD

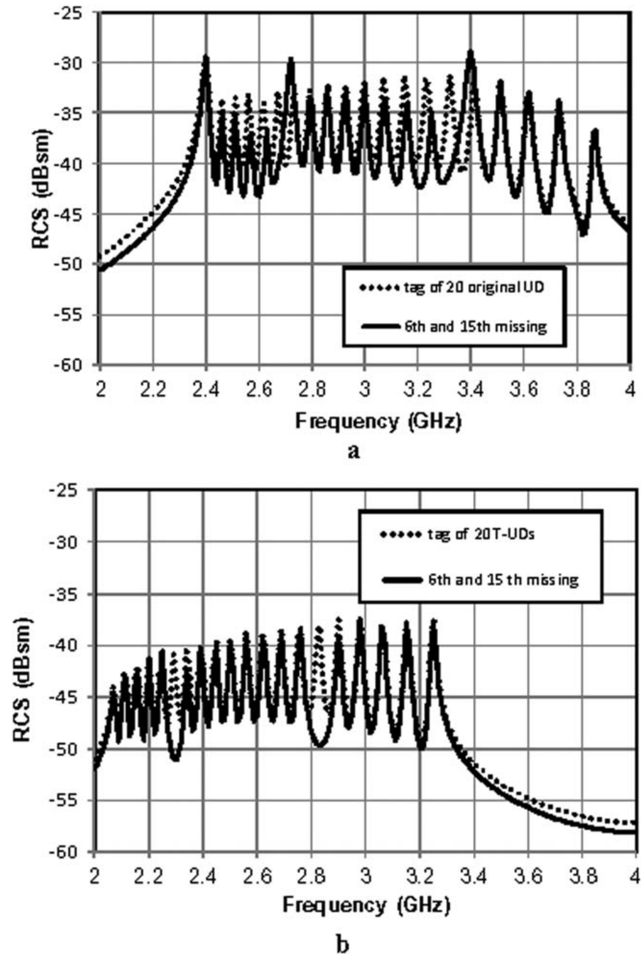

Figure 4 Simulated RCS response of 20-element tag (a) composed of original U-folded dipoles compared with RCS of the version coded by missing 6th and 15th elements and (b) tag composed of tapered U-folded dipoles

The highest resonant peak of the scatterer triplet composed of original dipoles (UD) shows the resonant frequency of 3.20 GHz, which exceeds 2.75 GHz reached in the case of tapered dipole. This means that the proposed T-UDs are relatively smaller and therefore assure a higher density of information per tag unit surface. The lowest RCS peak of scatterer UD triplet is −46.5 dBsm (@ f = 3.2 GHz), which is only about 1.8 dB lower than the lowest RCS peak of T-UD triplet −44.7 dBsm (@ f = 2.756 GHz).

As it can be seen in Figure 3, the arrangement of particular scatterers closely spaced into the triplet detunes the resonant frequencies due to the mutual coupling. Namely in case of UD, we can obviously observe a significant nonuniformity of RCS response magnitude. The tapering of gap between the dipole arms of the T-UD by about 4.5° from the original parallel direction reduces the mutual coupling, see Figure 2. As a result, the amplitude uniformity of RCS response of T-UD is significantly improved.

To evaluate the performance of a larger structure, we simulated and measured 20-element arrays of both the original UD and the

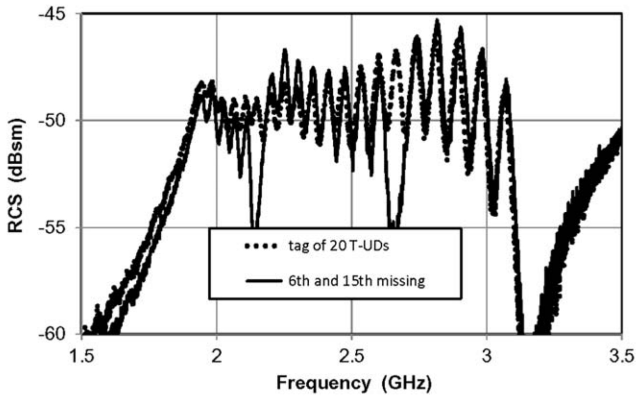

Figure 5 Measured RCS response of 20-element tags composed of tapered U-folded dipoles coding information 11111111111111111111–tag with 20 elements, and 11111011111111011111–tag coded by missing 6th and 15th elements

proposed T-UD. Both of them were sequentially detuned by changing their lengths by 0.5 mm from 16 to 25.5 mm so that the outer sizes of the arrays were 69 × 25.5 mm^2. The evaluation of RCS of the fabricated tags was performed by one-port vector measurement of monostatic RCS in a free space. The horn antenna and scatterer array lied at the distance of approx. 19 cm. The tag RCS was evaluated using the method similar to that described in [6]. The simulations were performed by Zeland IE3D software.

The frequency range between the lowest and highest resonant peaks of UD and T-UD are ∼1.5 and 1.2 GHz, respectively; see Figure 4(b). This means that the proposed 20-element T-UD array provides ∼1.25 times higher information capacity per unit frequency range.

To verify the influence of bit coding on the shape of the spectra, we removed the 6th and 15th scattereres; see Figure 1(d). We have found that the spectra of the original U-folded 20-element array exhibit an extensive change, namely in the case of resonant peaks neighbouring the removed one. These two peaks significantly alter their magnitudes; the lower one decreases, while the upper one increases by about 2–3 dB. Furthermore, their resonant frequencies are detuned to the position of original resonance; see Figure 4(a). The same effect is presented in the results of Vena et al.; see Figure 4 in [6].

Consequently, the “0” bits are nearly invisible in the tag spectral response. On the other hand, such unwanted behaviour has not been observed in case of 20-element T-UD array; see Figure 4(b) showing the simulation results, and Figure 5 indicating the measured data. The resonant peaks neighbouring the missing peaks remain exactly at the same frequency position and their magnitude change is considerably smaller than in the case of UD array. Moreover, a better amplitude uniformity and frequency stability of the RCS response of T-UD compared with UD array is apparent.

The T-UDs have smaller effective area due to the tapering than the UDs. These results in smaller RCS in comparison to the UDs by ∼7–10 dBsm, see Figure 4 and Table 1. As a consequence, the sensitivity of the proposed tag is lower than the original.

4. CONCLUSION

Proposed novel chipless RFID tag composed of topologically modified uniplanar U-folded dipoles with inclined arms requires about 20% lower frequency range for coding 20-bit information in the same unit area than the reference scatterer array composed of original U-folded dipoles with parallel arms.

The topology is designed to reduce the inter-element mutual coupling and thus provides a better amplitude uniformity and frequency stability of tag RCS response when logical “0” is coded by removing particular scatterers from the array. However, both improvements are achieved at the expense of small RCS magnitude reduction.

The presented uniplanar resonators are of a very simple structure, and therefore their fabrication costs are very low. A certain drawback is that the tags cannot be placed on conducting walls.

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DESIGN OF A 75–110-GHz MILLIMETER-WAVE 90-nm CMOS HIGHLY ISOLATED TRANSMITTER/RECEIVER SWITCH BY LEAKAGE-CANCELLATION TECHNIQUE

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