Improvement of Backscatter Properties of C-Shaped Dipole Scatterer for Chipless RFID

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***Abstract* — The paper investigates performance properties of arrays of several different C-shaped folded dipole scatterers that are intended to be used as building units (coding particles) for spectral signature based chipless RFID tags. Frequency resolution and uniformity of radar cross section (RCS) response of single scatterers, its triplets and 10-element arrays are investigated. It is found that array of tapered-arms C shaped folded dipole scatterers provides significantly better uniformity of RCS response of the tag and better frequency resolution than the arrays of C-shaped folded dipoles with parallel arms however at the expense of RCS reduction.**

Index Terms — Chipless RFID, C-shaped folded dipole, microwave backscattering, radar cross section, RFID, scatterer.

I. INTRODUCTION

Chipless RFID technology promises the advantage of simplest and therefore cheapest transponder structure comparing to currently used tags employing silicon chips. An important issue in the design of uniplanar chipless tags based on specific spectral signature response is the attainable surface density of stored information (in bits per unit area) which is if compared with optical barcodes still insufficient. Recent development in the field of fully-printable chipless RFID transponders is summarized e.g. in [1], [2].

Several configurations of printed building units, each of them coding one bit (i.e. coding particle), that operate in low microwave bands (e.g. 2 – 6 GHz) has been proposed, such as dipole strips [3], rectangular and circular split rings resonators (SRR) or C-shaped folded dipole [4]. Each of them provide trade-off between quality factor (bandwidth) and radar cross section (RCS) which is directly determined by electrical size and compactness of the scatterer structure. The vital chipless tag building unit with good performance properties has been found to be C-shaped folded strip dipole [4], [5] that provided 3 dB bandwidth 44 MHz, quality factor 65, and RCS at resonance -29.84 dBsm. Such coding particles has been used to form 20 bit chipless tag of the size 25 × 70 mm operating in frequency band 2 – 4 GHz. RCS response contained 20 resonant peaks which differ in magnitude up to 10 dB, peak-to-valley level changes between 1 dB to more than 10 dB. These parameters illustrate significant non-uniformity of RCS response of investigated tags. Such performance properties might limit the identification reliability of the whole transponder as the maximum achievable read range is given by the lowest RCS level of the used coding particles.

Here we propose geometrical modifications of the individual scatterer which significantly improve uniformity of RCS response of the whole tag including peak-to-valley level, and further improve frequency resolution (increase Q) which may consequently provide higher encoding capacity in unit area. It can be seen that both improvements are at the expense of decreased RCS response of the proposed transponder.

II. C-SHAPED DIPOLE-TYPE SCATTERER

The geometry of improved uniplanar strip scatterers are derived from the C-shaped folded dipole presented by Vena et al. in [4]. In order to correctly compare the performance of original Vena's and our newly proposed particles-scatterers we designed and simulated all of them on the same low loss substrate Rogers RO4003 ($\varepsilon_r = 3.38$, $\mathrm{tg}\delta = 0.002$) of the thickness 0.2 mm which provides lower dielectric loss and higher Q of the scatterers than those manufactured onto 0.8 mm FR-4 substrate used in [4], [5]. The geometrical modifications consist in narrowing the strip width from original 1 mm to 0.25 mm and namely tapering the longitudinal dipole arms toward the open end. This taper shape reduces mutual coupling as the neighboring arms are spatially separated. This coupling significantly affects the RCS response of multi-element tags. The drawback is the smaller RCS as the scatterer area is reduced. The particular scatterers were simulated by MoM software Zeland IE3D and measured in rectangular waveguide R32 (WR284) to prove the validity of the proposed concepts.

The investigated scatterers are shown in Fig. 1. Fig. 1a shows the original C-shaped dipole that has the outer size 20 × 2.5 mm with the strip width 1 mm and gap size 0.5 mm [5]. The newly proposed modified scatterers are depicted in Fig. 1b, c. The narrow-strip C-shaped dipole (NS-CD) has the strip 0.25 mm in width. The tapered narrow-strip C shaped dipole (TNS-CD) has the gap 0.5 mm at the open end of tapered arms. Triplets consist of three scatterers that are 20, 19.5, and 19 mm in length and of the same width. The distance between them is 1 mm as in [5]. This assures the possibility to compare the obtained result with results presented in [5]. All the scatterers are placed on the substrate

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that extends their dimensions about 3 mm at each side of the scatterer; see Fig. 1 showing the layout of all fabricated elements.

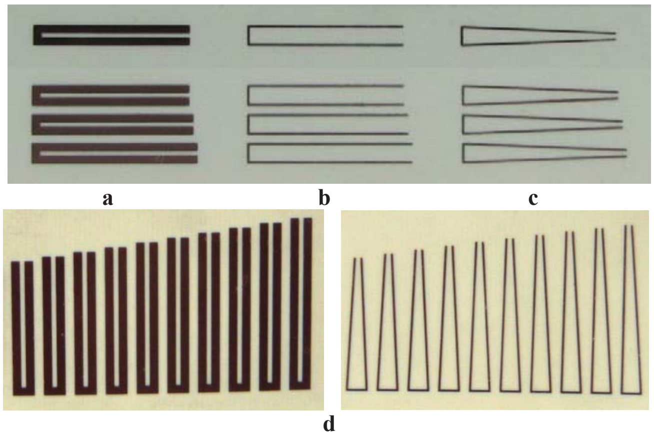


Fig. 1 Photograph of investigated modifications of C-shaped folded-dipole scatterers: a) C-shaped dipole (CD), b) narrow-strip C-shaped dipole (NS-CD), c) tapered narrow-strip C-shaped dipole (TNS-CD), and their triplets, d) 10-particles tag arrays.

The performance properties of particular single scatterers such as resonant frequency, 3 dB bandwidth, and RCS magnitude at resonance of individual scatterers obtained by measurement are shown in Table I.

TABLE I
MEASURED PERFORMANCE PROPERTIES OF INDIVIDUAL SCATTERERS

Scatterer	**Resonant frequency** (GHz)	**3 dB bandwidth** (MHz)	**RCS** (dBsm)
original CD	3.19	16.7	-41.4
NS-CD	3.02	19	-39.4
TNS-CD	2.72	17.8	-51.5

III. Influence of Mutual Coupling on the Uniformity of RCS Response and Frequency Resolution

A. Measurement Set-ups and Determination of RCS

The single scatterers and their triplets were measured in the R32 waveguide setup. The used waveguide line was calibrated by the TRL calibration method at the two reference planes. Measured scatterers were fixed on thin polystyrene stand and located at the transversal position in the center of the measurement waveguide section 37 mm in length inserted between the reference planes. Scattering parameters were measured and de-embedded to the center of the measurement section. The RCS in free space is then extracted from measured S parameters by the procedure described in [6]. This procedure is calibrated by measuring S parameters of a metal disk and a metal sphere with polarizabilities that can be determined analytically. Then free space polarizabilities of the scatterers are extracted. The RCS is calculated from the free space polarizabilities according to [7].

The simulated and measured RSC of designed triplets of particular scatterers detuned by reducing their length sequentially by 0.5 mm serve to evaluate the behavior of the tags designed as arrays of the scatterers.

Measurement of RCS of fabricated tags composed of 10 elements has been performed in free space using two-port vector measurement of bistatic RCS using two double ridge horn antennas DRH20 and vector network analyzer Agilent E5071C. The horns, and scatterer array lied in the vertices of isosceles triangle of the edge size of approx. 55 cm. The evaluation of tag RCS is the same as used in [5].

B. Measured Results

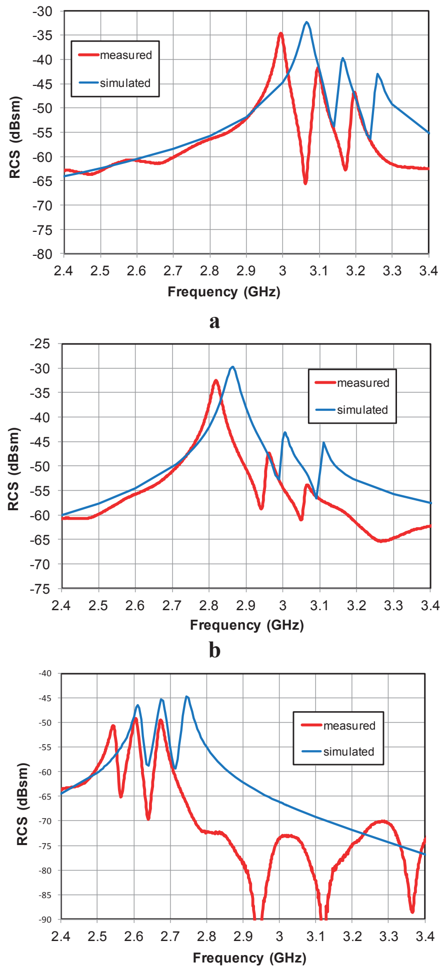
Arrangement of single scatterers closely spaced into the triplet detunes resonant frequency and changes magnitude of each resonant peak in RCS response due to the mutual coupling as it can be seen in Fig. 2. Namely in case of original C-shaped dipole and its thin-width strip modification the significant non-uniformity in RCS response is apparent. On the other hand tapering of each dipole arms about 4.5° from the original parallel direction decreases mutual coupling. Due to this the uniformity of the RCS response is significantly improved, see Fig. 2c. This result is verified in Fig. 3, where RCS of the tags composed of 10 particular dipoles from Fig. 1d are plotted.

Plots of RCS in Figs. 2 and 3 show another important effect. The particular scatteres both in triplets and 10-particles tag arrays are tuned in the same way by reducing sequentially their length by 0.5 mm. However the triplet and the tag composed of C-shaped folded dipoles with tapered arms show more homogeneously spread maxima of RCS with their closer spacing. This means that this scatterer is more suitable as a building block of tags as it can provide higher information density in a defined frequency band.

Measured RCS differs from and calculated RCS as it can be seen in Figs. 2 and 3. However both measurement and simulation verify the influence of the coupling to the tag behavior and its significant elimination in the case of proposed dipoles with tapered arms. Differences between measurement and simulation are caused namely by the measurement in the waveguide of relatively big transversal dimensions. Due to this the wave propagating along the waveguide in only loosely coupled to the scatterer and the measurement precision is reduced. The preciseness of free space measurement is limited by extreme requirements of the sensitivity, reproducible positioning of measured particles and spherical targets used as reference scatterers.

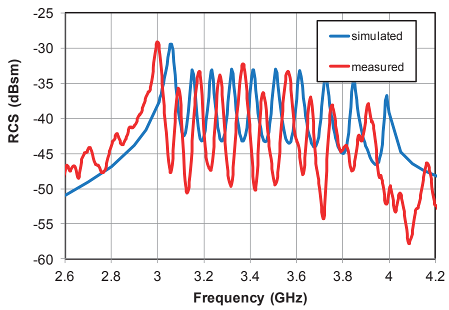
IV. Conclusion

The tags composed of the C-shaped folded dipole with tapered arms exhibit significantly better uniformity of RCS response and nearly constant peak-to-valley distance of individual resonances than application of original C-shaped folded dipoles with parallel arms at the expense of slight reduction of RCS. This is significant result which improves an identification reliability of RCS response. Further, the narrower RCS frequency bandwidth of the scatterer with tapered arms increases frequency resolution and enables higher information density in unit area.



c

Fig. 2 Simulated and measured RCS response of triplets of: a) C-shaped dipole, b) narrow-strip C-shaped dipole, c) tapered narrow-strip C-shaped dipole.



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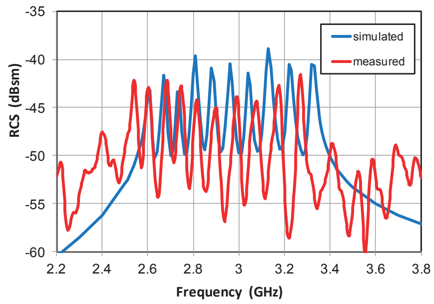

b

Fig. 3 Simulated and measured RCS response of 10-element tags composed of: a) original C-shaped dipoles, b) tapered narrow-strip C-shaped dipoles.

The scatterers composed of single units, triplets, and tags of 10 elements were designed, fabricated and measured. Measured RCS verifies the character of the proposed scatterers behavior. The presented uniplanar resonators are of a very simple structure, and therefore their fabrication costs are very low.

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