Semi-Platform Tolerant 20-bit Chipless RFID Tag Composed of Dipole Array Closely Coupled to Plate

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***Abstract*— In this paper novel semi-platform tolerant 20-bits chipless RFID tag based on array of dipoles closely coupled to metallic plate of the size 60 × 60 mm is presented. Quality factor of single dipole-plate is analysed to better understand the resonant behavior of the scatterer. RCS response level about 15 dBsm, spectral bit capacity > 15 bit/GHz and good frequency and amplitude stability of the RCS represent promising solution for chipless RFID systems.**

***Index Terms*— chipless RFID, RFID tag, scatterer, mutual coupling, radar cross-section, spectral response coding.**

I. INTRODUCTION

Spectral signature based chipless RFID represents one of the perspective directions of RFID technology for short distance reading. In this concept, presence or absence of each resonant peak or drop in tag's spectral signature represents logic one or zero, respectively. These tags have been intensively investigated recently [1-6], and have a potential to be a microwave frequency equivalent of optical barcodes systems. However, number of issues must be solved such as sufficient spectral bit capacity and space bit density, frequency and amplitude stability of the RCS response in case that the zero bits are coded, radar cross section (RCS) response level and resonance peak or drop depth in the RCS response; [5-6]. The platform tolerance of the transponder is another complex challenge which must be solved before deployment in practical applications.

Majority of the presented chipless RFID transponders have been developed as one-layer printable structures [1-3]. In [7] and [8] authors briefly presents certain one-layer “RF barcodes“ dipole structures detuned by width or gap of the structure. However, the structures must be situated in the close vicinity of large metallic plate for proper operation. The 5-bits RF barcodes are evaluated only by means of s_{21} measurement without presentation of the structure as well as the metallic plane size and consequently evaluation of comparable properties is impossible.

In this paper, novel semi-platform tolerant 20-bits chipless RFID tag based on array of dipoles closely coupled to metallic plate improving our recent design [9] is presented. This concept embodies good RCS response level (about -15 dBsm), relatively high spectral bit capacity (> 15 bit / GHz), good robustness of frequency and amplitude stability of the RCS response and good immunity to dielectric and metallic objects situated below the transponder. On the other hand, double layer substrate and smaller space bit density can be disadvantageous of the presented structure. However, these properties might be acceptable in specific applications with regards to the above mentioned benefits.

II. Q-FACTOR OF A DIPOLE CLOSELY COUPLED TO METALIC PLATE

Unlike in the small antenna design, in chipless RFID technology high quality factor (narrow frequency bandwidth) with sufficient level of RCS response of individual scatterers are prefered to reach maximum spectral bit capacity of the tag. These substantial properties can be realized with the help of the dipole arrays closely coupled above a metalic plane. In order to understand the resonant properties of a lossless dipole-plate scatterer when irradiated by perpendicular incident plane wave frequency dependent quality factor has been calculated numerically from induced currents [10] using matrix form originally proposed by Harrington [11] and further elaborated by Gustafsson et al [12]. Unstructured triangular mesh and RWG basis functions has been applied; see Fig. 1.

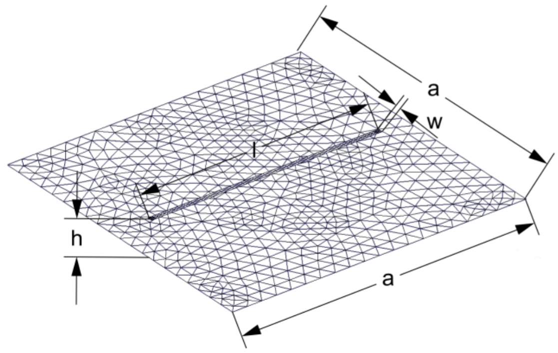

Fig. 1 Dipole closely coupled to a metalic plate.

Quality factor is defined as [12]

$$Q = \frac{2\omega W}{P} \qquad (1)$$

where ω is angular frequency, W is maximum of magnetic W_m and electric W_e stored energies, P is disipated power. Stored energies, and quality factor can be simply calculated from MoM impedance matrix and its frequency derivatives using relations [11]

$$W_m = \frac{1}{4\omega}\mathbf{I}^{\mathrm{H}}\mathbf{X}_m\mathbf{I} = \frac{1}{8}\mathbf{I}^{\mathrm{H}}\left(\frac{\partial\mathbf{X}}{\partial\omega} + \frac{\mathbf{X}}{\omega}\right)\mathbf{I} \quad (2)$$

$$W_e = \frac{1}{4\omega}\mathbf{I}^{\mathrm{H}}\mathbf{X}_e\mathbf{I} = \frac{1}{8}\mathbf{I}^{\mathrm{H}}\left(\frac{\partial\mathbf{X}}{\partial\omega} - \frac{\mathbf{X}}{\omega}\right)\mathbf{I} \quad (3)$$

$$P = \frac{1}{2}\mathbf{I}^{\mathrm{H}}\mathbf{R}\mathbf{I} \quad (4)$$

where $\mathbf{X}_{\mathrm{m}}$, $\mathbf{X}_{\mathrm{e}}$, and $\mathbf{R}$ are components of Z-matrix. $\mathbf{I}$ and $\mathbf{I}^{\mathrm{H}}$ are surface current vector and its Hermitian transponse, resp. and impedance matrix has the following form

$$\mathbf{Z} = \mathbf{R} + j\mathbf{X} = \mathbf{R} + j(\mathbf{X}_m - \mathbf{X}_e). \quad (5)$$

A quality factor of half-wavelength dipole of the length 46 mm and 1 mm in width in a free space exhibit flat curve around free space resonant frequency f = 3.0 GHz and and reaches low value of $Q \sim 4.0$. If the same dipole is situated in the close vicinity above PEC plate of the size 60 × 60 mm in the height from 1.0 to 2.0 mm (~ 0.01 to 0.02 λ_0 at resonant frequency) its $Q(f)$ is significantly heigher. The curve $Q(f)$ exhibits narrow resonant peak with the Q value of several hundred; see Fig. 2. It worth noticing the smaller is the dipole height above plate the higher is the quality factor value and the narrower is the $Q(f)$ curve which consequently increases spectral bit density.

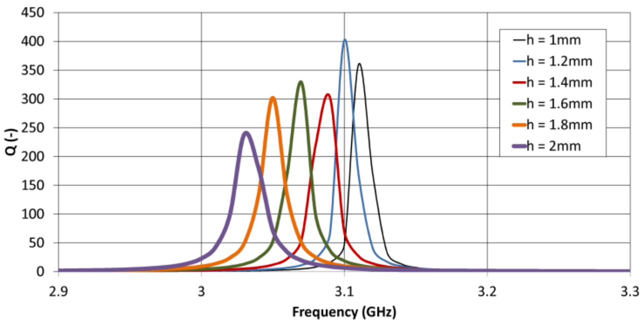

Fig. 2. Simulated quality factor of the 46 mm dipole placed in the height h above 60x60 mm PEC plate according to Fig. 1.

III. TOPOLOGY OF 20-BIT CHIPLESS RFID TAG

Further we present compact chipless RFID tag composed of an array of detuned planar dipoles backed by rectangular metallic plate of the size 60 × 60 mm operating in frequency range 2.2 to 3.5 GHz; see Fig. 3. The length of the dipole strips varies from 37 to 56 mm with the length increment of 1 mm. Width and transverse distance are 1.5 mm. The distance between the dipole array and a plate is 1.1 mm. The motif was designed on a Rogers RO4350 substrate with relative permittivity $\varepsilon_r = 3.66$, loss tangent $\tan\delta = 0.003$, and thickness of 0.1 mm. Foam layer with relative permittivity $\varepsilon_r = 1.3$, loss tangent $\tan\delta = 0.02$, and thickness of 1 mm is inserted between the plate and the substrate.

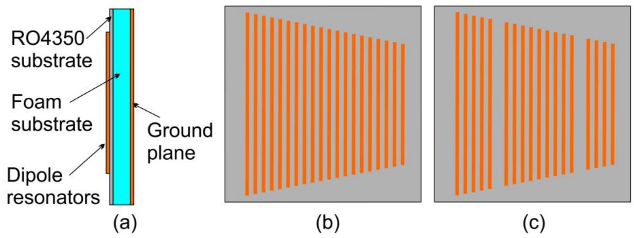

Fig. 3. Cross-section (a) and layouts of investigated 20-bit tags constituted by dipoles closely coupled to rectangular plane coding information (b) 11111111111111111111, (c) 11111011111111101111 by missing 6th and 16th elements.

IV. SIMULATION AND BIT WORDS CODING

The behavior of designed detuned strip dipole arrays was simulated by EM simulator Zeland IE3D. RCS responses of bit words '11111111111111111111' and '11111011111111101111' are compared in Fig. 4. RCS curve of the level of about -15 dBsm is notched by narrow resonant dips representing of the individual dipole resonances. Their good uniformity and frequency stability was confirmed. In case of the arrays with zero bits; see Fig. 9c we may notice that due to removing of 6th and 16th scatterers, corresponding resonant peaks are missing without the effect of distortion of magnitude and frequency interval uniformity of RCS curve. Furthermore the RCS level is relatively high (about -15 dBsm) and the resonance dips are about 2 - 5 dB deep.

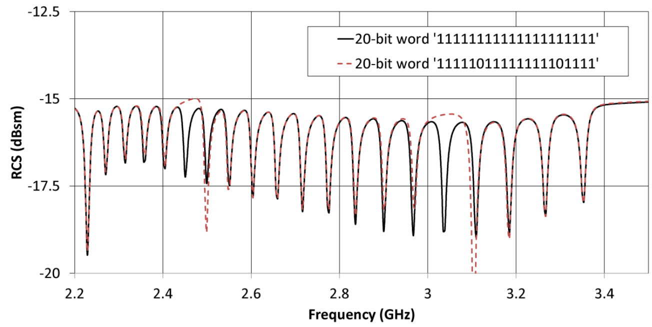

Fig. 4. Simulated RCS response of bit words '11111111111111111111' in comparison with in a free space.

V. MEASUREMENT

Performance properties of the tags were verified by monostatic measurement of tag RCS in an anechoic chamber. The measurement was based on the evaluation of a reflection coefficient of the double ridge horn antenna DRH 20 [14] in front of which the transponder at the distance of 0.5 m was situated. The calculation of RCS response of the tag was performed by the equation used in [1] and modified so that it was applicable to the case of the one-port measurement.

$$\sigma^{tag} = \left(\frac{S_{11}^{tag} - S_{11}^{iso}}{S_{11}^{ref} - S_{11}^{iso}}\right)^2 \sigma^{ref}, \quad (6)$$

where S_{11}^{tag} is the reflection coefficient of the measured tag. S_{11}^{ref} represents the reflection coefficient of the reference plate used as a scatterer. S_{11}^{iso} symbolizes the reflection coefficient of the antenna itself in case that no scatterer is used, and comprises the residual reflection from the experimental surroundings. σ^{tag} stands for the RCS of the measured tag, σ^{ref} embodies the RCS of the reference scatterer, which is the rectangular metal plate 60 × 60 mm² in size and 0.3 mm in thickness. Its analytical formula for RCS can be expressed as follows:

$$\sigma^{ref} = 4\pi \frac{a^4}{\lambda^2}. \qquad (7)$$

For verification of the transponders immunity to the objects situated below this one measurement on 150 × 200 mm in size rectangular plate from plastic was performed.

Figs. 4 and 5 contain two curves corresponding to the tag configurations from Fig. 2b and c. The solid black line represents the full 20-bit word ‘11111111111111111111’, whereas dashed red line symbolizes the bit word, where two ‘0’ bits are coded. In case of the plastic plate the radar cross section response has very similar character as in free space measurement; see Fig. 5 – 6 and the recognition of the bit word can be performed on the basis of the same criteria. Good frequency and amplitude stability of the RCS response in case that the zero bits are coded in the bit word was confirmed.

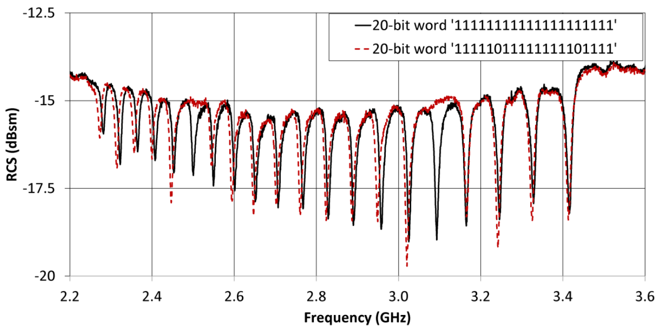

Fig. 5. Measured RCS response of bit words ’11111111111111111111’ in comparison with ’11111011111111101111’ in a free space.

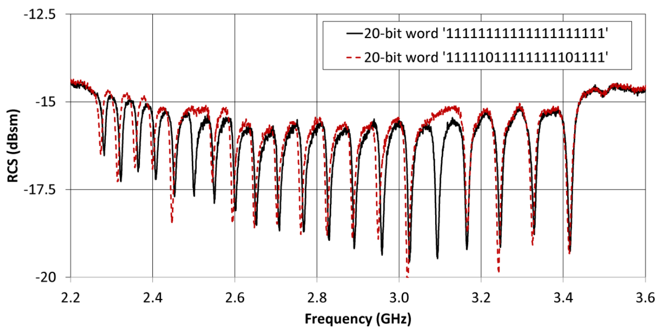

Fig. 6. Measured RCS response of bit words ’11111111111111111111’ in comparison with ’11111011111111101111’ on a plastic plate.

VI. Conclusion

Novel semi-platform tolerant chipless RFID transponder based on array of dipoles closely coupled to metallic plate was analysed, developed, manufactured and verified in free space and over plastic plate. Relatively high RCS response level about -15 dBsm and good spectral bit capacity better than 15 bit/GHz as well as good frequency and amplitude stability of the radar cross section response in case that the zero bits are coded mae it a good candidate for specific chipless RFID applications.

Acknowledgment

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