

Chipless RFID Tag with an Improved RCS Response

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Abstract—This paper introduces a new 20-bit chipless RFID tag with an improved radar cross section (RCS), based on a novel complementary approach with the slot-in-plate array with respect to the array of single resonator-based chipless tags. The backscatter pattern is formed by a rectangular metallic plate $52 \times 50 \text{ mm}^2$ in size etched on a thin dielectric substrate in which an array of 20 shorted coplanar slots is introduced. The originally monotonous RCS frequency response of the rectangular plate exhibits dips corresponding to the presence of individual slots, and thus enables binary coding using amplitude shift keying. The tag has been measured in a bi-static arrangement with two double-ridge horn antennas, and provides a significantly improved overall RCS response compared to an array of resonator-based chipless tags. We also propose two modifications to the inter-arrangement of the slots in order to eliminate the detuning effect of the missing slot representing ‘0’ bit information on the resonances of neighboring slots representing ‘1’ bit information.

Keywords—chipless RFID; coplanar slot; radar cross section, RFID; scatterer, strip scatterer.

I. INTRODUCTION

RFID technology for remote identification of goods, animals and people has spread in a range of industrial, business, entertainment and other application areas. Traditional RFID systems operating in the rf and microwave bands use passive transponders with semiconductor chips that enable N-bit information to be stored. Recently, significant efforts have been devoted to research and development of transponders that do not use chips – *chipless* tags – which may further reduce production costs. These chipless tags are typically uniplanar metallic patterns etched on a dielectric, a thin film or a paper substrate. One of the simplest ways to encode the data to a passive metallic structure is to ensure a frequency selective reflection response when the tag is illuminated by an incident electromagnetic wave. This principle is called amplitude shift keying. The bit information is then encoded using an array of uniplanar resonators, where the presence/absence of each of them represents “1” or “0” bit information. Actually, the principle of operation corresponds to a multiple frequency selective surface (FSS) where each element is tuned to its own frequency. However, it is clear that an array of resonators where each of them is tuned to a different specific frequency has a much smaller radar cross

section (RCS) than FSS composed of a large number of the same elements. Various types of resonators have been used to design chipless tags. Jalaly et al. [1] used a microstrip dipole-like strip on an opaque dielectric substrate backed by a metallic plane. Vena et al. [2] proposed a single layer coplanar strip with a short-end that excites the quarter wavelength standing mode. The same group further developed more sophisticated variations of bent multiple-arm coplanar strips [3], and polarization independent arrays of concentric strip rings [4].

These compact uniplanar resonators or scatterers exhibit a higher quality factor, due to the concentration of the field between close coplanar strips with opposite current flow compared to a straight strip dipole. In this way they increase the bit density encoded to the unit area. However, there is a trade-off between the quality factor (directly proportional to the bandwidth and consequently to the bit information density) and RCS, which characterizes the effective reflection properties, which in turn are proportional to the read distance. The magnitude of the reflection of the incident electromagnetic wave at specific resonant frequencies of each resonator is related to its RCS. Individual topologically compact scatterers usually have just a small part of their geometry collinear with the unit polarization vector of the incident field. This makes its RCS smaller than the RCS of a straight strip dipole. 20 coplanar strips from [2] exhibit measured RCS values of about -30 to -34 dBsm, and the bent multi-arm strips [3] have RCS values between -25 and -30 dBsm. However, the read distance in specific chipless RFID applications may be limited due to the low RCS of their tags.

We have therefore proposed a chipless RFID tag that offers higher RCS at the level of -16 dBsm. This substantially enlarges the read distance compared to a value of RCS = -32 dBsm. The tag is based on a complementary structure, coplanar slots introduced in a metallic pattern, unlike the strip-based scatterers presented e.g. in [2], [3]. The basic pattern is a uniplanar rectangle etched on a thin dielectric substrate that has substantially larger 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 a selected frequency interval, with dips corresponding to the resonances of individual slots.

II. DESIGN OF A TAG

First, a metallic rectangular base $52 \times 50 \text{ mm}^2$ in size is chosen to provide a monotonous RCS curve over a frequency range of 2 to 4 GHz. Then 20 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. Vertical polarization of the incident wave excites the electric field in the narrow shorted part of the slot; see Fig. 1a.

The slot-arm length l ranges from 15.0 to 24.5 mm, with 0.5 mm length difference between the two neighboring slot couple. The slot width is $w = 0.25 \text{ mm}$ and the width of the shorting slot is $a = 2 \text{ mm}$, so that the metallic gap between the two adjacent slot-arms is $g = 1.5 \text{ mm}$. The coplanar slots in an array are equidistant from each other, at a distance equal to 0.5 mm. The resonant frequency is proportional to length $l + a/2$, while the RCS is proportional to the ratio a/l . In order to encode binary information into the slot array, presence of the slot represents a notch in the RCS curve, and absence of the slot represents a smooth RCS curve. A 20-element coplanar slot array with the 5th and 18th slots missing thus presents the 20-bit word ‘11110111111111111011’; see Fig. 1.

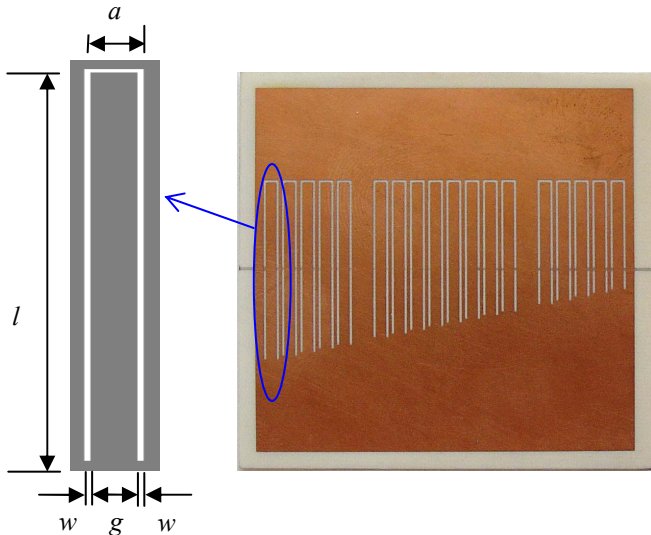


Fig. 1. A single coplanar slot width is etched in the layout of the proposed 20-bit chipless RFID tag consisting of a metallic rectangular plate with 18 shorted coplanar slots representing the bit word ‘11110111111111111011’.

The design of a chipless tag with up to 20 resonant dips has been simulated in Zeland IE3D MoM software to set the resonances within the frequency interval 2 to 4 GHz.

The simulated RCS response of the tag with an array of 18 coplanar slots that are arranged in descending order according to their length (if counted from the left side), see fig. 2a, exhibits an unwanted frequency shift of the neighboring resonances that may deteriorate or even disable the identification of the position of the original resonance; see Fig. 2b. For this reason, we proposed two modified slot array arrangements, which are resistant against a detuning effect of this type.

(i) each second (even) resonator is moved to the second right half of the array, so that the original descending order according to length ‘1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20’, where resonator ‘1’ is the largest one entirely on the left, and ‘20’ is the shortest one entirely on the right, is modified to the order ‘1 3 5 7 .. 19 2 4 6 8 .. 20’; see Fig. 3a,

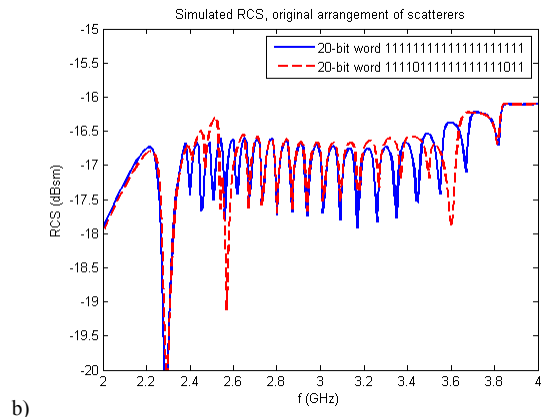
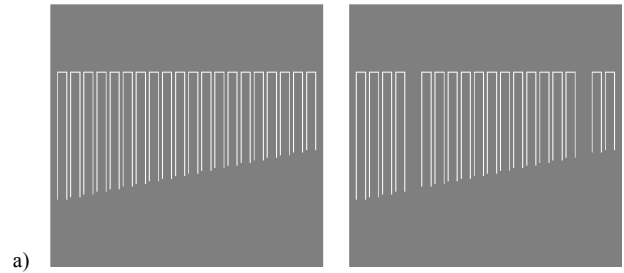


Fig. 2. Original arrangement of the slots in the rectangle representing the 20-bit words ‘11111111111111111111’ and ‘11110111111111111011’ (a), and the corresponding simulated RCS response (b).

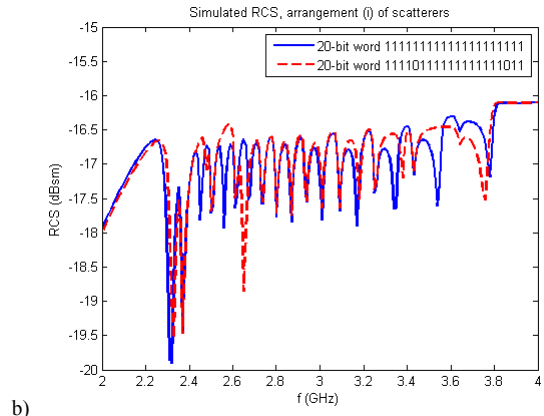
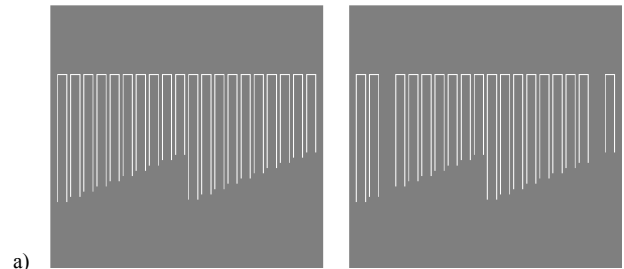


Fig. 3. Modified arrangement (i) of the slots in the rectangle representing the 20-bit words ‘11111111111111111111’ and ‘11110111111111111011’ (a), and the corresponding simulated RCS response (b).

(ii) each fourth resonator is moved to the corresponding quarter of the array so that the original ascending order according to their length ‘1 2 3 4 5 6 7 .. 20’ is modified to ‘1 5 9 .. 2 6 10 .. 3 7 11 .. 4 8 12 16 20’; see Fig. 4a.

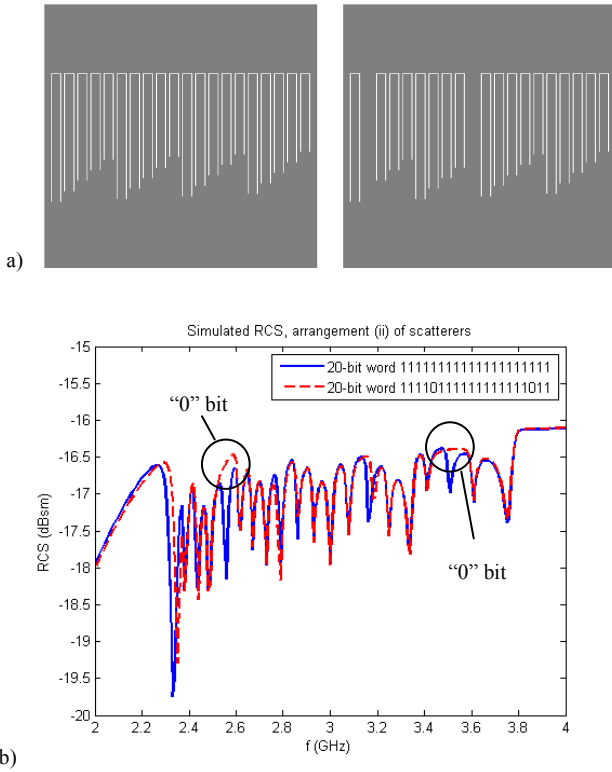


Fig. 4. Modified arrangement (ii) of the slots in the rectangle in descending order according to their length, representing the 20-bit words ‘11111111111111111111’ and ‘111101111111111111011’ (a), and the corresponding simulated RCS response (b).

In arrangement (i), the two neighboring slot resonators differ by at least 1 mm in length, while in arrangement (ii) the difference is at least 2 mm. We may observe that the greater the distance, the smaller is the mutual coupling of originally neighboring resonators, and the smaller is the frequency shift of the neighboring resonance if ‘0’ bit is applied; see Fig. 2b, 3b, and 4b.

It can be seen that removing the slots in 5th and 18th positions (application of a ‘0’ bit) in the case of slot arrangement (ii) does not affect the closest resonances due to the mutual coupling – missing dips can be observed at these positions (dashed red curve) compared to the original 20-bit tag with all 20 slot scatterers (blue curve); see fig. 4b.

III. MEASUREMENT OF TAG PERFORMANCE

Measurements of the RCS of the proposed tag with arrangement (ii) of the slots encoding the word “111101111111111111011” were made using two-port vector measurement of bistatic RCS, using two double ridge horn antennas DRH20 [5] and the Agilent E5071C vector network analyzer; see Fig. 5. The horn antennas and the chipless scatterer array were placed in the vertices of the isosceles triangle of edge size of approx. 55 cm. The evaluation of tag

RCS uses the same procedure as in [2], and is made by the relation

$$\sigma^{tag} = \left(\frac{S_{21}^{tag} - S_{21}^{iso}}{S_{21}^{ref} - S_{21}^{iso}} \right)^2 \sigma^{ref}, \quad (1)$$

where σ^{tag} is the RCS of the measured tag, σ^{ref} is the RCS of the reference rectangular plate $52 \times 50 \text{ mm}^2$ in size and 0.3 mm in thickness with the analytically given formula valid for approx. $\theta < 20^\circ$

$$\sigma^{ref} = 4\pi \frac{a^2 b^2}{\lambda^2} \left(\frac{\sin(ka \sin(\theta) \cos(\varphi)) \sin(kb \sin(\theta) \sin(\varphi))}{ka \sin(\theta) \cos(\varphi) kb \sin(\theta) \sin(\varphi)} \right)^2. \quad (2)$$

S_{21}^{tag} is the transmission coefficient when the tag is used as a scatterer, S_{21}^{ref} is the transmission coefficient when the reference sphere is used as a scatterer. S_{21}^{iso} is the transmission coefficient if no scatterer is used and represents the mutual coupling of the horns. It includes the effect of interferences as the rf signal is spread from the phase center which, in addition, vary with frequency, and is at the same time reflected and diffracted from the rods that form the lateral wall of the horns. As the result of this complicated mutual coupling, the S_{21}^{iso} curve is rippled over the tracked frequency interval. Although the mechanical distance of the horns, and of each horn and scatterer, can be measured, the electrical distance, i.e. the distance of their phase center, is difficult to evaluate. The close mechanical distance of the horns and the scatterer result in angle θ reaching about 25° , so that eq. (2) provides limited precision. As a result of the issues mentioned here, a comparison between the simulated and measured RCS response provides limited agreement, with a slight frequency detuning of resonances and superimposed ripples, even at frequencies where there are no resonances; check the curves below 2.3 GHz and above 3.8 GHz in Fig. 5. However, removal of the slot in 5th and 18th positions is noticeable, i.e. the resonant dip is missing.

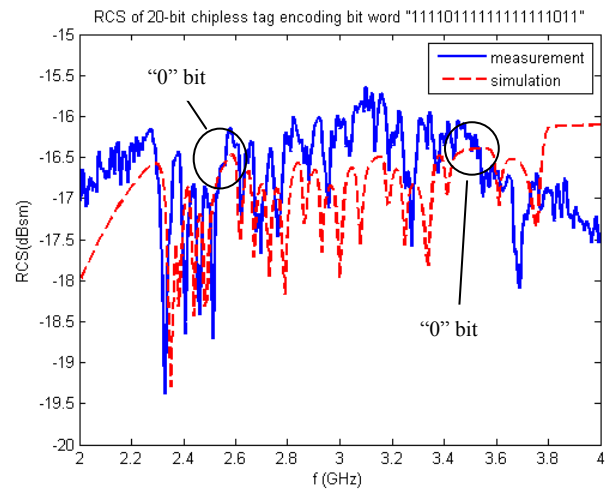


Fig. 5. Simulated and measured RCS response of the 20-bit chipless tag encoding bit word “111101111111111111011”, “0” bit is represented by absence of the resonance.

IV. CONCLUSION

A new kind of chipless uniplanar tag, using 20 U-slot resonators introduced in a rectangular metallic plate, has been proposed, designed, fabricated and measured. This approach is complementary to the chipless tag composed of an array of individual U-dipole scatterers. The frequency response of this tag is represented by dips in the RCS smooth curve of the basic metallic plate without slots. The overall response of the plate-scatterer itself is almost 20 dB higher than the response of the tag composed of an array of U-folded dipoles. It therefore potentially has a large read distance. However this type of slot array located in a row with descending length of each slot is tightly coupled. This results in a deteriorated response of the tag, and particular dipoles that correspond to '0' bits are missing. It is therefore not possible to read the encoded information. This problem has been solved by re-distributing the resonators so that each second (even) resonator has been moved to the second right half of the array, and finally each fourth resonator was moved to the corresponding quarter of the array. In this way, the mutual coupling between neighboring resonators has been significantly reduced. Correspondingly, the response of the tag can be properly read, including all '0-s' representing missing notches of absent resonators. However this "slots-in-plate" chipless tag approach is still in its infancy, as the depth of the dips corresponding to an individual slot are relatively small compared to the level of interference noise superimposed on the RCS curve. In a real environment it might

be difficult to discriminate them. Further experimentation on higher Q "slots-in-plate" resonators is therefore required.

ACKNOWLEDGEMENT

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