

Near Field RFID Tag for IoT in Sub-Six GHz Band

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Abstract—The present paper introduces the analysis and design of a near field RFID tag for IoT in sub-six GHz 5G frequency band. The proposed radio frequency identification technique is based on the near field interaction between the RFID tag and a wideband antenna reader. This near field interaction adjusts the resonances of the wideband antenna according to the used RFID tag. In addition, the far field RCS of the RFID tag is also investigated to study the relation between the near field and far field responses of the proposed RFID tag. The proposed RFID tag is characterized with adjustable six resonances based on concentric square rings printed on a dielectric slab. For manufacturing and experimental verification, the dielectric slab is assumed to be FR-4. However, the proposed structure can be generalized to other thin and flexible substrates like paper, plastic, and textile.

1. INTRODUCTION

Radio frequency identification (RFID) technology is an automatic recognition system that uses radio waves to identify products and objects. RFID system consists of a tag, a reader, and a processing unit [1–5]. RFID tags can perform tasks such as retrieving, storing, and sending object information such as code, route, and coordinates. By reading the tag placed on the product or objects, the information can be automatically saved or changed. With this information, it is possible to easily determine which product belongs to which order, instantaneous changes can be made in the production schedule, and inventory tracking can be done more easily.

Modern digital solutions are attempting to complement the traditional security features through embedding RFID tags in official paper-work and banknotes [6–8]. On the other hand, wearable RFID tags on flexible substrates have importance in security applications, biomedical applications, structural health monitoring and other logistic applications [9–20]. Although traditional RFID systems based on the use of silicon RFID chips are very common and extensively used in practice, some of their limitations, such as cost and robustness, are driving many researches towards alternative solutions, namely chipless RFID. The most promising way for RFID is to directly print on a product or package like a bar code. The chipless RFID is quite similar in function to the optical bar code, and hence it is also known as RF bar code technology. Chipless RFID system is generally based on multiresonators which perform frequency signature encoding signed in [10–20]. In [11], multiple octagonal shaped resonators are used to present a nine-bit RFID tag on both flexible and non-flexible substrates for Internet of Things (IoT) applications. Depending on the type of the substrate, the range of frequencies was determined. On the other hand, in [12] different resonators of different shapes based on Arabic letters are used as different RFID tags. In this case, each letter corresponds to a unique RF signature which can be used for identification. These multi-resonance configurations can also be implemented by using slot resonators as in [13]. It is found that symmetric configurations of the multi-resonance structure would be more appropriate to make the response of the RFID tag is independent of the polarization of the reader antenna as discussed in [15]. In [19], an RFID tag is introduced consisting of crossed diagonal patches

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combined with L-shaped patches on a dielectric substrate to generate six resonances. It is used to detect cracks and corrosion in metallic structures. In this case, the resonance frequencies of this RFID tag are shifted due to the cracks or corrosion on the metallic structure behind the RFID tag.

In this paper, a simple passive RFID tag based on concentric square ring resonators on a dielectric slab is presented. Two techniques for radio frequency identification are studied. The first technique is based on a resulting radar cross section (RCS) of the designed RFID tag. The other technique is based on near field interaction of the proposed RFID tag with a planar wideband antenna. This near field interaction introduces sharp resonances on the reflection coefficient of the wideband antenna according to the used resonators on the RFID tag. By using a thin substrate, this configuration can be quite useful for paper currency and official papers like passports to increase their security level and facilitate their tracking process. A similar configuration based on a split ring resonator on a plastic film was discussed in [18] for the application of security ID cards.

In the following section, the basic configuration of the proposed RFID tag is presented. The RCS of this tag is studied. In Section 3, we discuss the applicability of using a wideband antenna as a near field reader for this RFID tag. Finally, Section 4 presents the conclusion.

2. CONCENTRIC SQUARE RINGS PASSIVE RFID TAG

The proposed RFID tag consists of concentric square rings printed on a dielectric slab as shown in Fig. 1. The width of each ring is 0.5 mm, and the spacing between successive rings is also 0.5 mm. The outer length of the greatest ring is 22 mm while the length of the substrate is 26 mm. Thus, the circumference of the outer ring is 88 mm. The difference between the circumferences of each successive two rings is 8 mm. The used substrate in the present analysis is FR-4 of thickness 0.8 mm, dielectric constant $\epsilon_r = 4.3$, and $\tan \delta = 0.025$. This square ring resonates when its circumference is nearly one guided wavelength. For a non-grounded dielectric slab, the effective dielectric constant can be approximated as:

$$\epsilon_e \cong \frac{\epsilon_r + 1}{2} \quad (1)$$

Thus, the guided wavelength would be $\lambda_g = \lambda_0 / \sqrt{\epsilon_e}$. Thus, according to the proposed dimensions and substrate parameters, the analytical six lowest resonances would be 2.094, 2.304, 2.88, 3.291, 3.84, and 4.61 GHz. Effectively, these values would be slightly changed due to the effect of the mutual coupling between the rings as shown in the full wave analysis. In addition, the most inner four concentric rings are added to adjust the effect of the mutual coupling while they resonate at much higher frequencies. The required resonances can be controlled by adding or subtracting the corresponding ring resonator.

Figure 2 shows the radar cross section of this RFID tag for six different configurations obtained by full wave analysis by using finite element analysis based on HFSS. The resonances of the tag with all

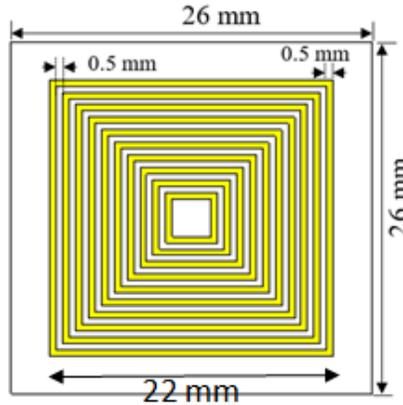


Figure 1. Geometry of the proposed RFID tag composed on concentric square rings on a dielectric slab.

rings are 2.7, 3, 3.4, 3.9, and 4.6 GHz. It can be noted that the resonance frequencies are slightly shifted from the corresponding analytical ones due to the coupling effect as mentioned above. However, this shift is decreased at higher resonances. This can be explained by that the approximation of the effective dielectric constant is more accurate at higher frequency. It can be noted that each ring corresponds to a resonance frequency in the corresponding RCS as shown in Figs. 2(a) to 2(f). Even though the resonances can be clearly discriminated between the different tags from their RCSs, the values of these RCSs for the different tags are very small. Thus, it is required to use high power transmitter combined with a sensitive receiver to discriminate between different tags at a distance more than or around 1 meter. This is the motivation here to introduce a near field reading system instead of using direct RCS measurement.

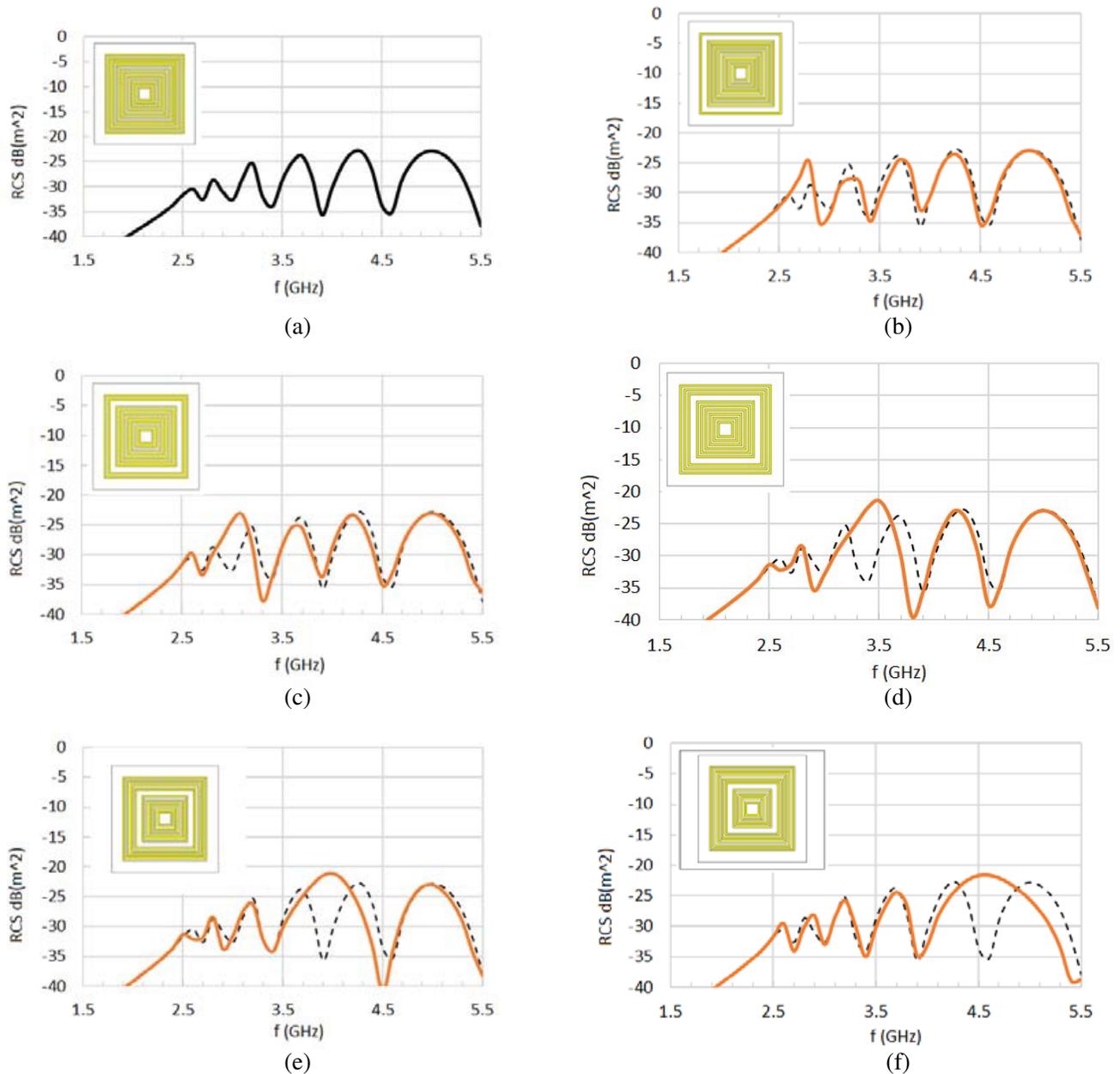


Figure 2. Monostatic RCS with normal incidence of the proposed RFID tag for different six configurations. Dashed line corresponds to the performance of the RFID tag with all rings.

3. NEAR FIELD RFID SYSTEM WITH CONCENTRIC SQUARE RINGS PASSIVE RFID TAG

In this section, a near field identification is proposed by using a wideband antenna as a reader. The proposed antenna is shown in Fig. 3. It consists of a partially grounded patch with a tapered section to be matched with a $50\ \Omega$ microstrip line. The antenna is printed on a substrate RO3003 of thickness $0.25\ \text{mm}$ with $\epsilon_r = 3$ and $\tan \delta = 0.0013$. The total size of the antenna is $(x \times y) = 38 \times 41\ \text{mm}^2$. The dimensions of the patch are $x_p = 21\ \text{mm}$, $y_p = 18\ \text{mm}$, $x_l = 11\ \text{mm}$, and $y_l = 5\ \text{mm}$. The width of the feeding $50\ \Omega$ microstrip line is $w_s = 0.6\ \text{mm}$. Fig. 4 shows the reflection coefficient of this antenna separately. It can be noted that this antenna has a reflection coefficient less than $-10\ \text{dB}$ in the frequency range from 2.2 to $4.5\ \text{GHz}$.

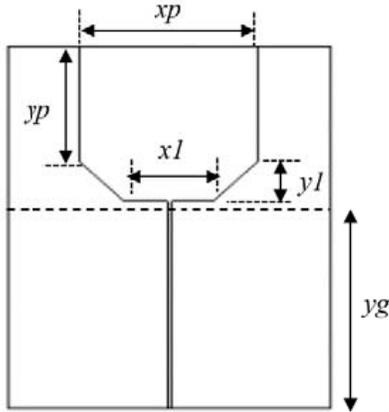


Figure 3. Geometry of the reader antenna.

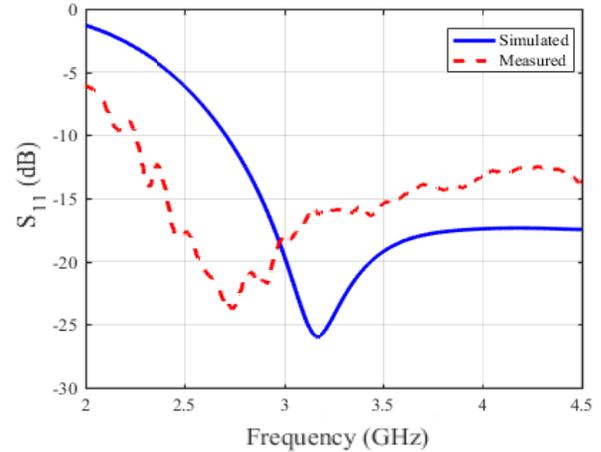


Figure 4. Simulated and measured S_{11} of the reader antenna.

This wideband antenna is used as a near field reader for the designed RFID tag. The effect of the tag appears as resonance frequencies. Due to the presence of the conducting patch and the additional substrate of the antenna, the effective dielectric constant of the RFID tag is increased. Thus, the corresponding resonance frequencies are slightly shifted down from the free space RCS resonances of the RFID tag mentioned in the previous section. Fig. 5 shows the proposed RFID reader configuration. In this case, the proposed RFID tag is placed in the proximity of the reader antenna as shown in Fig. 5.

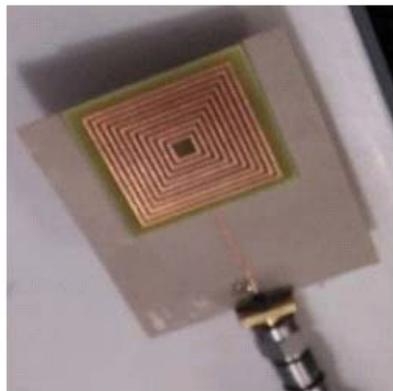


Figure 5. The proposed near field RFID tag identification configuration consisting of a wideband antenna in proximity of the RFID tag.

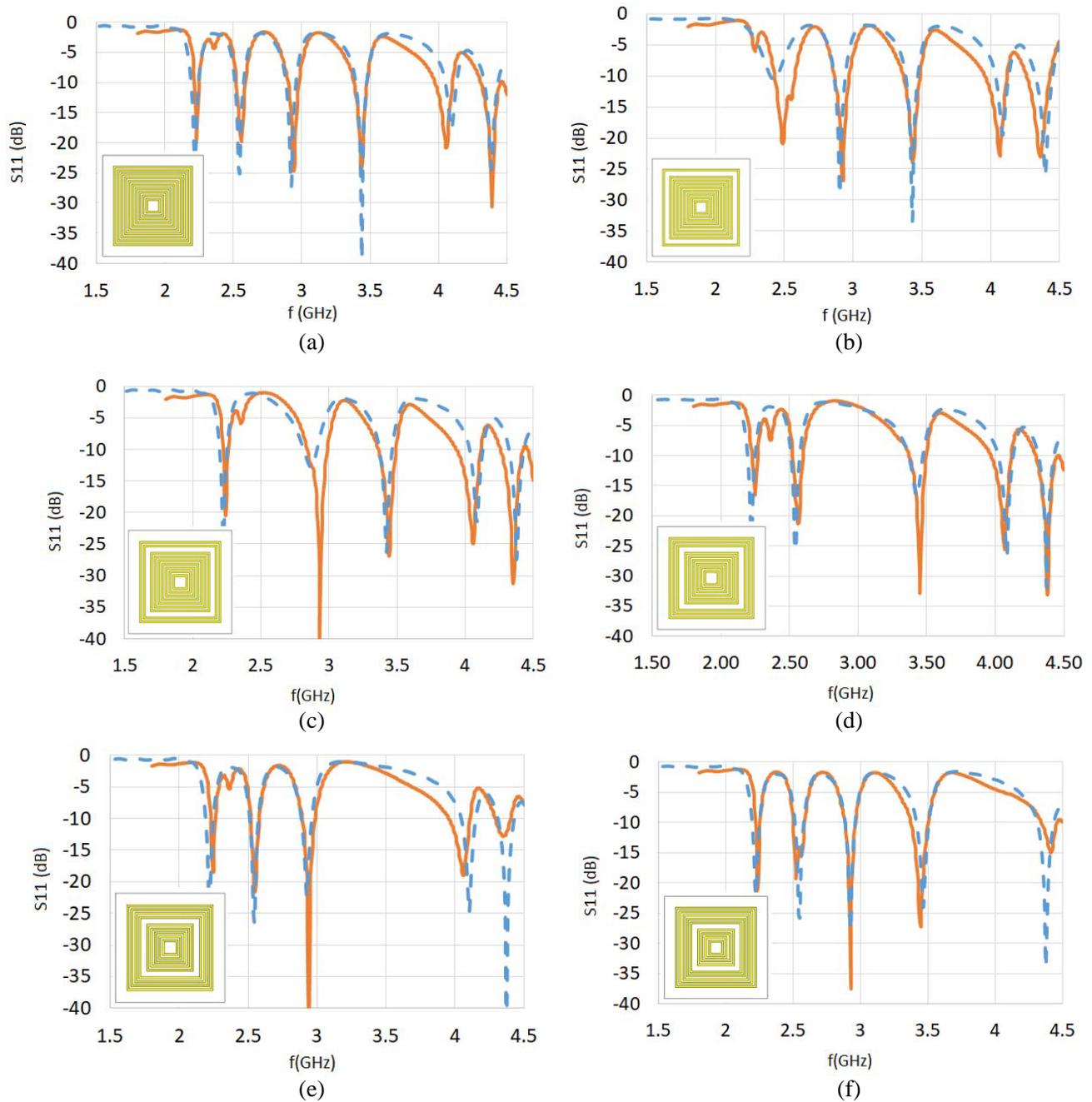


Figure 6. Measured and simulated reflection coefficients of the reader antenna for different RFID tag configurations. Dashed lines corresponds to the simulation results and solid lines corresponds to the measured results.

Fig. 6 shows the simulated and measured reflection coefficients of the reader antenna for different RFID tags as discussed in Section 2. It can be noted that the RFID tag with all square rings has resonances at 2.12, 2.54, 2.92, 3.43, 4.09, and 4.39 GHz. It can be noted that these resonance frequencies are shifted toward lower frequencies due to the increase of the effective dielectric constant as mentioned before. Fig. 6 also shows the effect of removing rings on the resonances of the reader antenna. It is quite clear that each ring corresponds to a specific resonance frequency which can be classified as digital bit in the corresponding RFID tag. Based on these results, it can be concluded that this multi-ring resonator

structure can be used as a six-bit RFID tag for a near field RFID system. The advantage of this simple configuration is that it has a significant difference more than 10 dB in the reflection coefficient between the presence and absence of the corresponding ring resonator. This significant difference can be easily detected by a simple wideband receiver system. Although the sample in the present case is printed on an FR-4 substrate, the basic theory of the proposed multi-ring resonator is valid for other dielectric substrates. Thus, it is expected that this configuration is also valid for other substrates like paper, plastic, and textile substrates.

4. CONCLUSION

In this paper, we present a multi-ring resonator on a dielectric substrate without a ground plane. We studied the RCS of such multi-resonators for different numbers of rings. The RCS shows very small values which require high power transmitter and a sensitive receiver to discriminate between the different tags. We presented another more practical approach based on a near field reader. This near field reader is simply a wideband antenna. The RFID tags introduce different resonances in this wideband antenna which can be easily discriminated for the different tags. The present configuration in this paper is based on six resonances corresponding to six bits in the frequency range between 2 and 5 GHz. This configuration is quite suitable to be integrated with IoT and 5G applications in the sub-six GHz band. Although the present RFID tag is based on a rigid FR-4 substrate, the basic idea of this configuration is also applicable to flexible substrates like paper and plastic. This property makes this RFID tag suitable for other applications like wearable RFID and RFID for official papers and banknotes.

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