RFID Tag Design Using Spiral Resonators and Defected Ground Structure

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Abstract. *This paper presents a simple generalized approach to design a compact chipless radio frequency identification tag. The proposed chipless tag encodes data into the spectral signature using a set of spiral resonators on both sides of substrate. Transmission amplitude component of the tag is used for data encoding. For miniaturization purpose, defected ground structure is used to reduce the circuit size by half compared to the conventional cascading technique. The proposed chipless tag operates between 4 GHz and 6 GHz and produces 256 different binary strings through eight encoded bits. Measurement and simulation results verify the authenticity of this design.*

Keywords

Defected Ground Structure (DGS), microstrip line, multi-resonator, Radio-Frequency Identification (RFID), spiral resonators

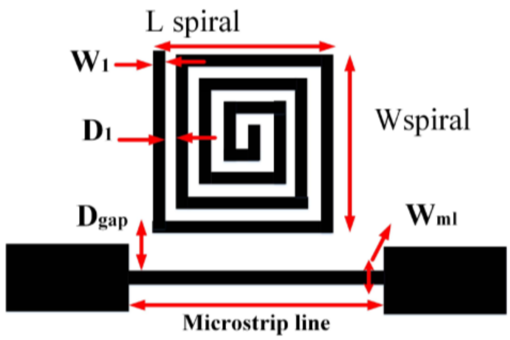
1. Introduction

Radio Frequency Identification (RFID) can be utilized to replace the barcode in the area of contactless data capturing. RFID system consists of three major components: a reader or interrogator, which sends the interrogation signals to a RFID tag that is to be identified; an RFID tag, which contains the identification code; and middleware software, which maintains the interface and the software protocol to encode and decode the identification data from the reader into a mainframe or personal computer. The reader is commonly connected to a host computer, which performs additional signal processing and has a display of the tags' identity. Chipless RFID tags use the electromagnetic (EM) properties of materials using various layouts to achieve a particular EM behavior. The chipless RFID tag encodes into the spectral signature in both magnitude and phase of frequency response. In [1], [2] and [3] fully printable chipless RFID system on a 90-µm thin Taconic TF-290 laminate were presented. The data encoding was performed in the multi-resonating circuit, which was comprised of multiple-stopband spiral resonators [1–3]. The tag design can then be easily transferred to plastic and paper. Microstrip technology is a trusted candidate to be used for resonators implementation as it provides a high level of versatility [4]. A chipless RFID tag including receiver and transmitter antennas was presented in [5]. The tag comprises of a microstrip multi-resonating circuit with 35 spiral resonators. The data can be encoded with a possible 1.3 billion different IDs using the "shorted spiral" technique, which is performed by minimal layout modifications. In [6], a tag consisting of a UWB monopole antenna loaded with multiple cascaded spiral electromagnetic band gap structures was presented. In [7] and [8], Pythagorean tree geometry and split-wheel resonators are used to accomplish the spectral signature, respectively. In [8] differences in phase values of scattering parameters created by different coupling positions of spiral resonators were used to code bits at the frequency of transition zero. In a similar method both phase and amplitude were used for spectral signature accomplishment [9]. A method for data coding which is solely based on transmission phase was presented in [10], resulting in a simple encoding technique. In a similar method, data is encoded through quantized values of the difference between the TE and TM phase responses, requiring less bandwidth [11]. A two-layer printed chipless RFID tag was realized on Teslin paper in [12], where inkjet printing technique was used to achieve a high data capacity. Two element-rearranged 20-bit spectral signature based chipless tags composed of U-shaped strip scatterers have been investigated in [13] to reduce mutual coupling between resonators.

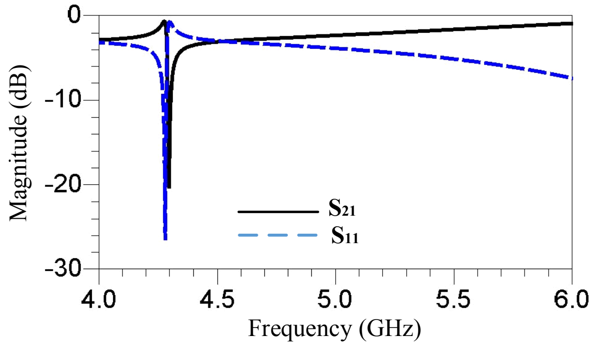
In this paper, a generalized method is proposed to miniaturize RFID tags using Defected Ground Structure (DGS) and spiral resonators. Eight spiral resonators are designed to create eight transmission nulls used to code eight bits in a compact area by taking advantage of DGS technique.

2. Design of the Proposed RFID Tag

Spectral signature-based chipless tags encode data into the spectrum using resonant structures. Each bit is associated with the presence or absence of a resonant peak



(a)



(b)

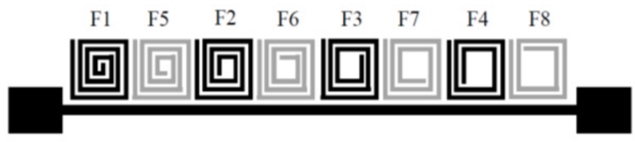
Fig. 1. (a) First order proposed tag on a RT /DURIOD 5880 substrate ($\varepsilon_r = 2.2$, $\tan\delta = 0.0009$) with the thickness of 0.381 mm. (b): Simulated S-parameters results. ε_r and $\tan\delta$ are permittivity and loss tangent of the substrate, respectively. $L_{spiral} = 3$ mm, $W_{spiral} = 3$ mm, $W_1 = 0.2$ mm, $D_1 = 0.2$ mm, $D_{gap} = 0.2$ mm, $W_{m1} = 0.2038$ mm.

at a predetermined frequency in the frequency spectrum. Such structure can be implemented using a microstrip transmission line closely exposed to one or several resonators, as shown in Fig. 1.

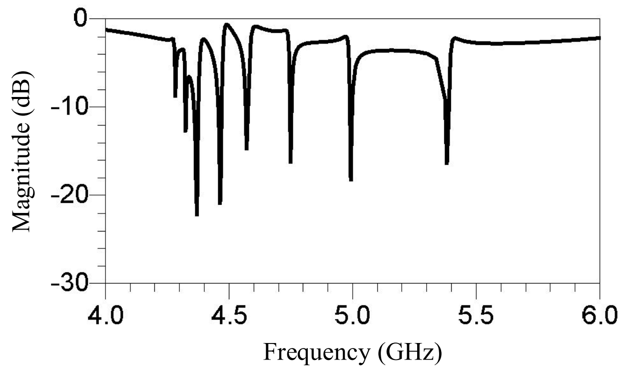
Each resonator is designed to resonate at a certain frequency, which can be used to code a bit of data. In this work, spiral resonators are proposed to be embedded in the tag due to their ability to produce deep transmission zeros with sharp skirt performance. The presence of each transmission null in the frequency response is assigned to '0' in binary logic. The first spiral resonator is designed to resonant at 4.3 GHz, introducing a transmission zero with transmission loss well higher than 10 dB, which is easy to be detected. To increase the number of bits and achieve a quite practical tag, the number of spiral resonators operating at different frequencies should be increased. To do so, seven more spiral resonators are designed to operate in the frequency range from 4 to 6 GHz, as shown in Fig. 2. The resonators are named F1, F2, …, F8.

The eight well-tuned spiral resonators are cascaded with an equal distance of 0.8 mm from each other to create a RFID tag providing eight resonant frequencies, shown in Fig. 2 and Tab. 1.

Despite of very good performance of the depicted RFID tag, the total dimension of the tag is 0.75 $\lambda_g \times 0.08$ λ_g (λ_g is guided wavelength at 5 GHz) equals to 32 mm×3.4 mm, which may not be suitable for some appli-



(a)



(b)

Fig. 2. (a) Layout of a multi-resonator with series eight resonators. (b) S_{21} Simulated parameter.

cation. Therefore, a miniaturization technique should be adopted to reduce the proposed RFID tag size. There are various fractal geometries, effectively used for this purpose [14–16]. Such techniques, however, need more elaboration for spiral resonators due to narrow gaps in the structure. Therefore, to reduce the size of the circuit to half, every second spiral resonators in the RFID tag, shown in Fig. 2(a), which are labeled by F5, F6, F7, F8, are realized on the back of substrate by etching metallic layer of the ground plane of the circuit. This technique is known as defected ground structure [17–19] and in addition to the size reduction, it has been used for harmonics and unwanted coupling suppression. Here, DGS technique has not only significantly reduced the circuit size, but it also does not need any optimization or re-tuning, as it has no considerable effects on the magnitude and frequency of the transmission nulls as shown in Fig. 4. Table 1 shows the transmissions zeros' characteristics for both proposed tags.

3. Simulation and Experimental Results

As discussed in Sec. 2, each spiral resonator can produce a transmission zero at a certain frequency, which corresponds with a zero in binary logic. So, if all eight spiral resonators are in the circuit, eight transmission nulls will be detected in the frequency response, generating {00000000}. As a result, the proposed tag can produce 256 different binary strings, which is equal to 2^8=256 different statuses. For instance, to generate the following binary string {11110000} only four resonators with higher resonance frequencies must be engaged to produce four transmission zeros acting as four digital zeros in the string, while the other four resonators having lower resonance frequencies are not participating in this particular coding.

To verify the accuracy and reliability of the presented technique, here as an example case, three scenarios of all

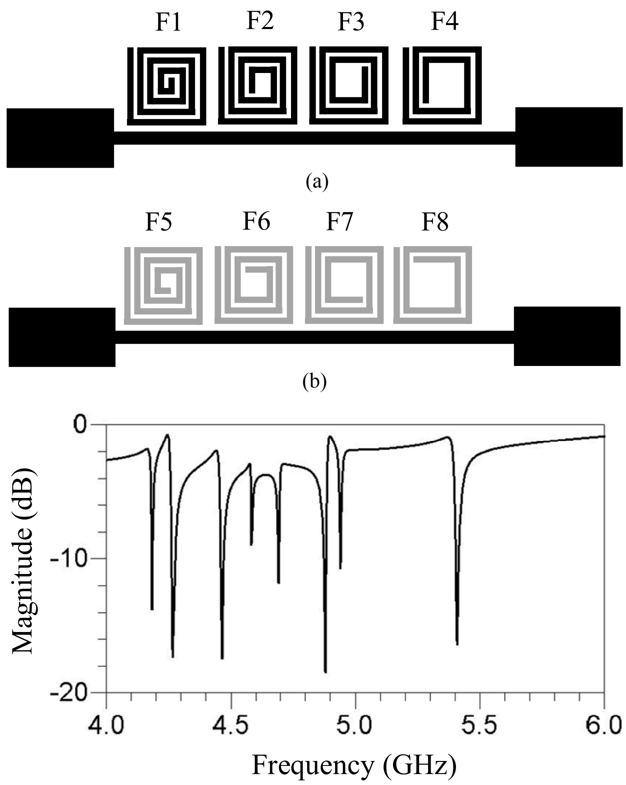


Fig. 3. An example of the proposed chipless RFID tag. (a) Top view, showing the four main resonators with black color. (b) Back view, showing the four DGS resonators with gray color. (c) Magnitude of the simulated insertion loss.

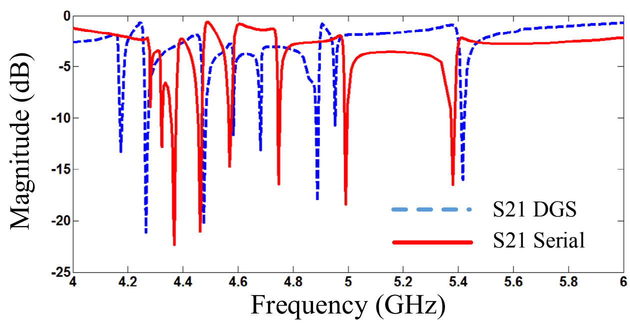


Fig. 4. $|S_{21}|$ comparison of tags with serial and DGS spiral resonators.

possible 256 scenarios are considered to show the ability of the presented tag to produce binary strings.

Scenario I: To generate a binary string of {00100111}, four resonators, which are F1, F2, F5 and F6 needed to take part in the circuit, while the rest of the resonators which are the defected ones (F3, F4, F7 and F8) are not used. The layout of such a tag and the associated S-parameters are shown in Fig. 5.

Scenario II: To generate {11011000}, based on the positions of the zeros in the string and the frequency of the transmission nulls, as reported in Tab. 1, resonators (F3, F4, F7 and F8) should only be used in the circuit. Figure 6 shows the layout and S-parameters of this tag.

Scenario III: To generate {10110100}, the second and fourth main resonators on top of substrates (F2 and F4) and the last two defected ground resonators (F6 and F8) are engaged to introduce the required transmission zeros to create the required string, as shown in Fig. 7.

Finally, one prototype of the tag including all eight resonators was fabricated on a RT /DURIOD 5880 substrate to verify the concept. Figure 8 and 9 show photographs and results of the fabricated tag. There is only a negligible frequency shift in the measurement results, which did not affect the accuracy, because it has not changed the order of the transmission nulls representing zeros in the binary string.

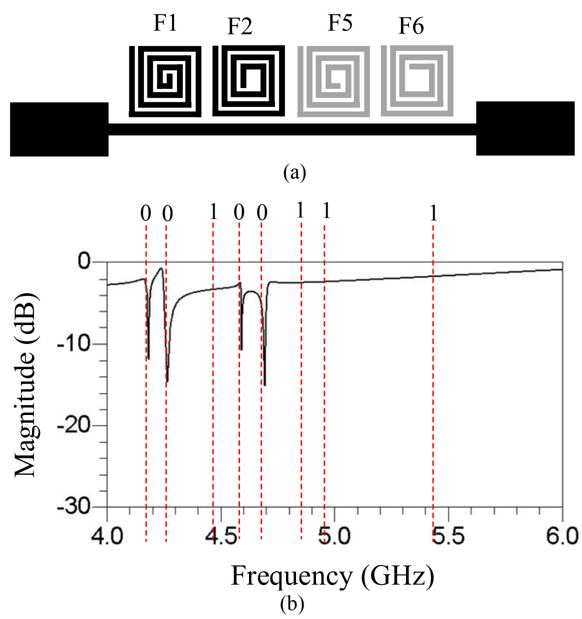


Fig. 5. Layout of a tag generating the binary string of {00100111}. Four resonators which are F1, F2, F5 and F6 active to introduce four transmission nulls acting as zeros in binary logic. (a) Layout. (b) Insertion loss.

4. Frequency and Magnitude Stability

In order to verify how the frequency and magnitude stay unchanged in the event of absence of some resonators (the same analysis as [13]), two hypothetical states are considered, and corresponding insertion losses are compared to the RFID tag having all resonators (i.e. {00000000}). In other words, performance of the proposed RFID tag, in terms of frequency and magnitude stability, is evaluated for two scenarios when F2 and F8, shown in Fig. 3, do not exist in the circuit. These states result in two different binary strings which are {01000000} and {00000001}. The reason why F2 and F8 are chosen is that the stability versus both non-defected and defected resonators to be shown.

As it can be seen from Fig. 10, frequencies and magnitude of the transmission nulls, which are created as a result of presence of spiral resonators, are not affected by

	Resonator	F1	F2	F3	F4	F5	F6	F7	F8
Magnitude (dB)	Serial	–8.903	–22.377	–14.781	–18.419	–12.807	–21.607	–16.404	–16.489
	DGS	–13.294	–21.189	–20.399	–10.699	–11.607	–13.101	–18.190	–15.986
Frequency (GHz)	Serial	4.281	4.369	4.569	4.991	4.323	4.462	4.784	5.380
	DGS	4.185	4.268	4.477	4.954	4.584	4.682	4.890	5.418

Tab. 1. Comparison between the series and defected spiral resonators.

Type	L (mm)	W (mm)	S (mm^2)
Serial	32	3.4038	108.9216
DGS	16	3.4038	54.4608

Tab. 2. Area comparison between the serial and DGS.

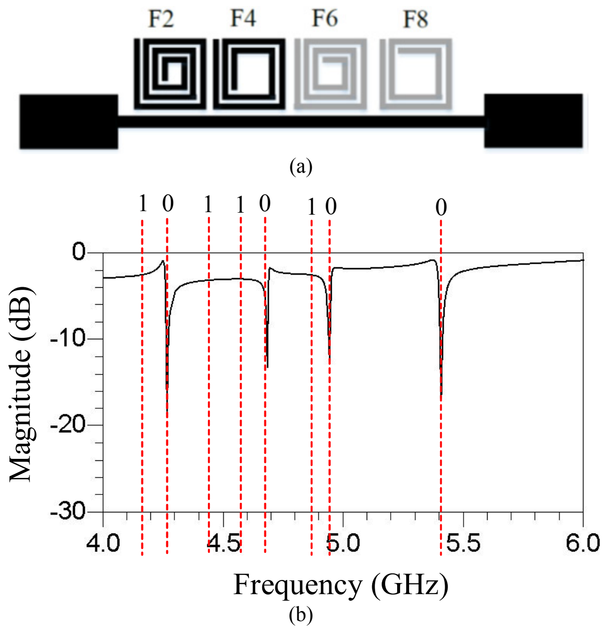


Fig. 6. Layout of the tag producing {11011000}. (a) Layout. (b) Insertion loss.

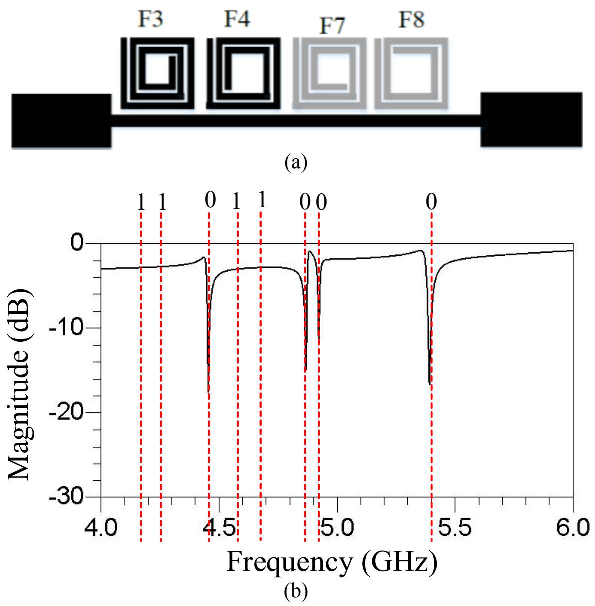


Fig. 7. Layout of the tag producing {10110100}. Two main resonators and two DGS resonators are engaged. (a) Layout. (b) Insertion loss.

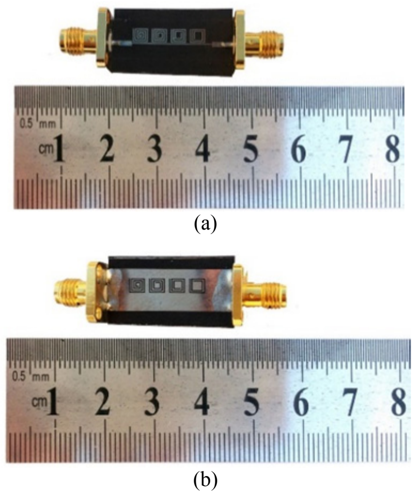


Fig. 8. Fabricated chipless RFID tag. (a) Front view. (b) Back view.

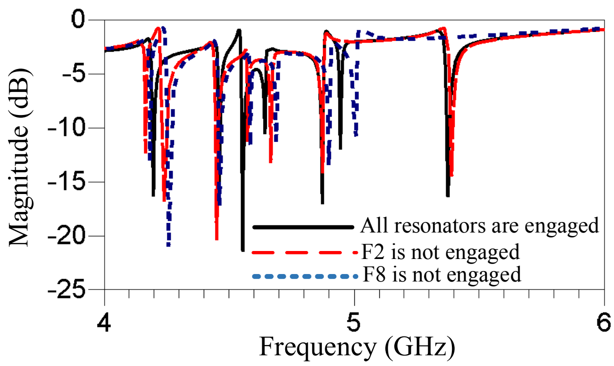


Fig. 9. Frequency and magnitude stability of the proposed chipless RFID tag.

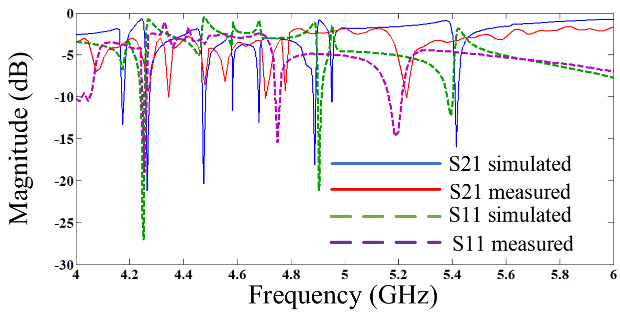


Fig. 10. Measurement and simulation insertion loss results of the RFID tag.

removing resonators F2 and F8. There is, however, a negligible discrepancy, which does not disturb the RFID tag's performance as the order of transmission zeros are not affected.

5. Conclusion

In this paper, a straightforward method to design a chipless RFID tag is presented. The presented approach consists of designing spiral resonators on both sides of a readily available commercial substrate to introduce 8 independent transmission nulls used to encode eight bits. Defected ground structure is utilized for realization of 4 defected spiral resonators, resulting in 50% reduction in the length of the tag. The chipless RFID tag is designed to operate at 4–6 GHz of the UWB spectrum, showing very good agreement between the EM simulation and fabrication measurement results. This technique can be used in a practical RFID system. In order to improve the performance of the presented tag, appropriate fractal geometry can be applied to fit more independent resonators in the same space.

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