Design of a Hexagonal-shaped Split Resonators Based Chipless RFID Tag

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***Abstract*—The main objective behind the design of chipless RFID tags for communication systems is to obtain a compact size, high capacity, and low-cost tag. In this work, a multiresonator based chipless RFID tag is represented. Multiresonators are equivalent to series and parallel LC resonators. A chipless RFID tag with hexagonal-shaped split resonator is proposed. The tag encodes N-data bits using N half-wavelength hexagonal-shaped split resonators operating at different resonant frequencies fi, where i = 1, 2, 3…, N. The split gap in each resonator is rotated by an angle θ=2π/N, where N is the number of resonators. The proposed chipless RFID tag has dimensions of 26 mm × 40.78 mm and operates over a frequency band 0.889 GHz and 2.202 GHz. Each hexagonal-shaped split resonator represents a logic state '1' when interrogated with an incident wave. When the resonator is removed then the logic state will be changed to '0'. The proposed chipless RFID tag is printed on FR-4 substrate with a thickness of 1.6 mm and a dielectric constat (permittivity) of 4.3. The structure design, simulation and analysis are carried out using Microwave Studio CST software.**

***Keywords*—chipless tag, radio frequency identification (RFID), split resonator, capacitance, and inductance.**

I. Introduction

Radio frequency identification (RFID) is a wireless data identification technology used in many applications such as automatic identification of goods, security, supply chain management, etc. [1]. Recently chipless radio frequency identification (RFID) research has been growing and replacing the chipped RFID tags due to low cost, where the integrated circuit (IC) is replaced by a planar encoder printed on flexible substrates, [2]. Chipless RFID tags can be categorized into three types: time-based, frequency-based, and phase-based encoding techniques, [3]. The frequency-based chipless RFID tag can be achieved by the means of LC resonators, [4-6]. In [4], an 8-bit chipless RFID tag based on the complementary split ring resonator (CSRR) is proposed. The chipless RFID tag of a size (25 × 50 mm^2) is printed on Polyethylene substrate with a permittivity of 3, thickness of 0.175 mm, and a loss tangent of 0.002. The structure is fed by 50 Ohm microstrip line. In [5], 8-bit chipless RFID tag consists of monopole disc with eight open-circuited stub is presented. The structure has a size of 23 mm × 31 mm and is fed by two microstrip lines and operates between 4 GHz and 8 GHz. A compact and polarization independent chipless RFID tag is presented in [6]. The proposed tag is a 20-bit tag of dimensions 40 mm × 40 mm and printed on RT Duroid 5880 substrate with a thickness of 1 mm.

For wearable chipless RFID tags, additional features such as light weight, washability, and flexibility have to be considered, [7]. In [8], a fully printable chipless RFID tag on a thin layer of Taconic TF290 laminate was proposed. The tag consists of multiple stop band split resonators in addition to two cross-polarized ultrawide band (UWB) antennas. The advantage of this design is that the TF290 substrate characteristics are similar to thin polymer laminates that makes the design flexible to transfer to plastic and paper.

II. Chipless RFID Tag Design

In this work, a chipless RFID tag is designed based on the hexagonal-shaped split resonator. The hexagonal-shaped split resonator is equivalent to an LC circuit, Fig.1a. The inductive effect is due to the resonator length which is a half-wavelength (λ/2), and the capacitance effect is due to the gap in between the concentric hexagonal-shaped split resonators (coupling effect), Fig.1b. In the proposed chipless RFID tag, in prototype 1, three half-wavelength hexagonal-shaped split resonators are modeled to operate between 0.889 GHz and 2.202 GHz, Fig.2.

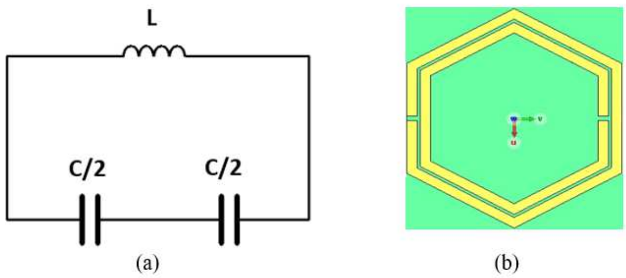


Fig. 1. (a) Equivalent LC circuit, and (b) Hexagonal-shaped split resonator.

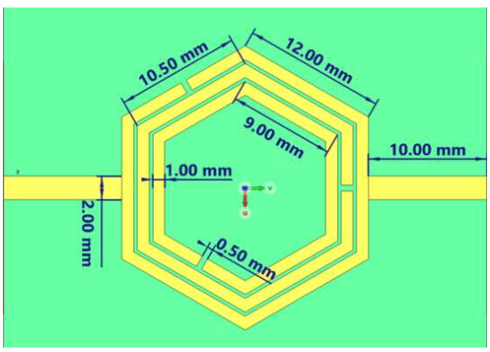


Fig. 2. Hexagonal-shaped split resonator based chipless RFID tag (prototype 1).

The corresponding resonant frequencies are calculated by:

$$f_i = \frac{c}{\lambda_i\sqrt{\varepsilon_r}}, \qquad i = 1,2,3\ldots,N \tag{1}$$

where, f is the resonant frequency, c is the speed of light, λ is the wavelength, ε_r is the dielectric constant of the substrate, and N is the number of resonators. The proposed chipless tag is printed on FR-4 substrate with a thickness of 1.6 mm and a dielectric constant of 4.3. The design, simulation, and optimization are carried out using Microwave Studio CST software. The prototype 1 shown in Fig.2 consists of three hexagonal-shaped split resonators corresponding to three resonant frequencies with a split gap periodically rotates by an angle $\theta = \frac{2\pi}{N}$, where N is the number of hexagonal-shaped split resonators. The calculated resonant frequencies by Eq.1, for isolated hexagonal-shaped split resonators, excluding the coupling effect and the microstrip feed lines, are f_1 = 0.973 GHz, f_2 = 1.159 GHz, and f_3 = 1.354 GHz.

III. Results and Discussion

The simulated transmission coefficient S21, that describes how much electromagnetic waves pass through the transmission medium, of the prototype 1 is presented in Fig.3 with three resonant frequencies operating at f_1 = 0.923 GHz, f_2 = 1.733 GHz, and f_3 = 2.118 GHz over a frequency band between 0.889 GHz and 2.202 GHz. Figure 3 shows three nulls used to encode incident wave required for RFID tag application. Each resonator represents a logic state '1' when interrogated with an incident wave. When the resonator is removed then the logic state will be changed to '0'. Three different combinations for three data bits are represented. Combination 1: the three resonators exist, Fig.2, this combination encodes a data bit '111', Combination 2: the most inner resonator is removed, Fig.4a, this combination encodes a data bit '110', Combination 3: the resonator in between is removed, Fig.4b, this combination encodes a data bit '101'.

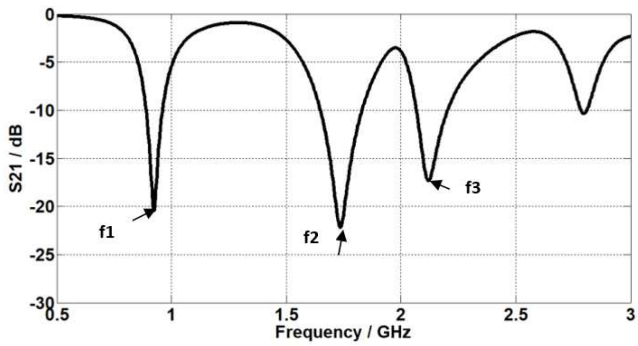
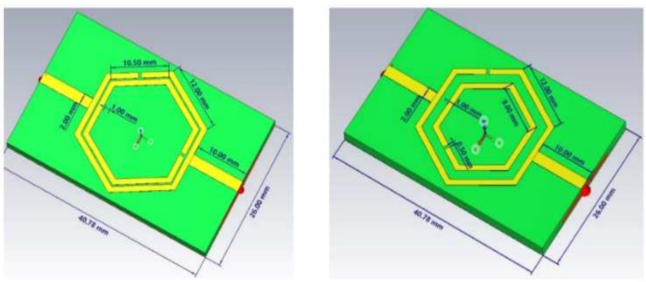


Fig. 3. Simulated transmission coefficient S21 of the prototype 1 shown in Fig.2.



(a) (b)

Fig. 4. (a) The most inner resonator in Fig.2 is removed, and (b) the resonator in between in Fig.2 is removed.

The transmission coefficient S21 of the three different combinations is shown in Fig.5.

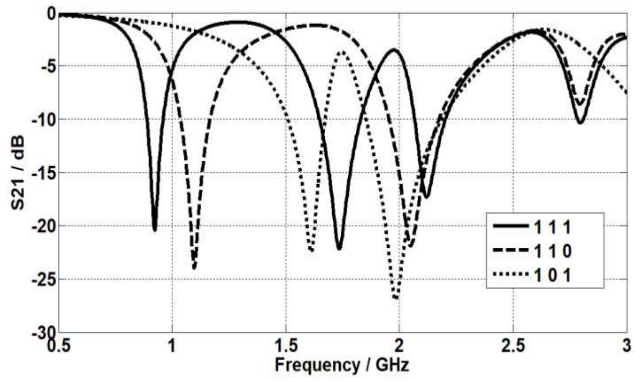


Fig. 5. Simulated transmission coefficient S21 of the three different combinations of the prototype 1.

The hexagonal-shaped split resonator based chipless RFID tag is expanded to consider 6-bits. To achieve that, the prototype 1 modeled in Fig.2 is expanded by inserting additional three hexagonal-shaped split resonators (prototype 2), Fig.6. The corresponding transmission coefficient S21 is shown in Fig.7. The resonant frequencies for both prototypes are summarized in Table I.

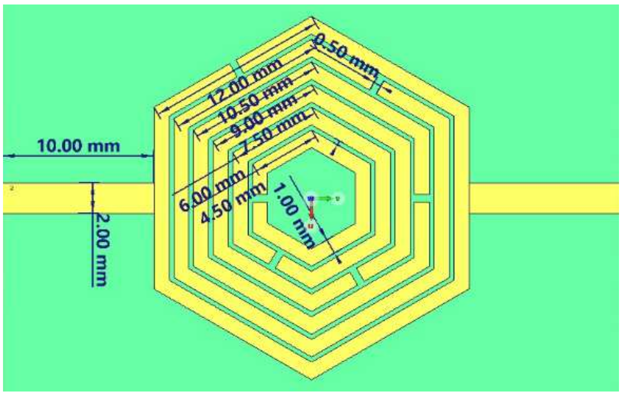


Fig. 6. Hexagonal-shaped split resonator based chipless RFID tag (prototype 2).

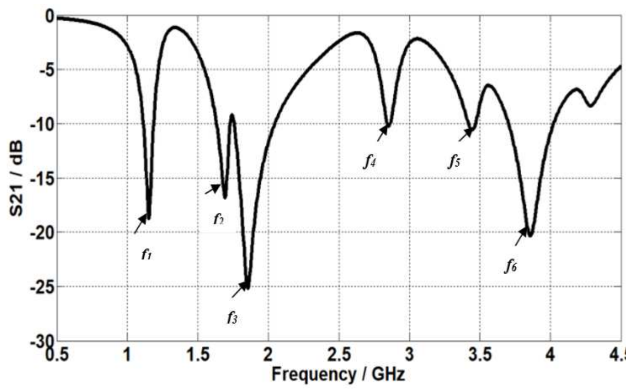


Fig. 7. Simulated transmission coefficient S21 of the prototype 2 shown in Fig.6.

IV. Conclusion

A hexagonal-shaped split resonators based chipless RFID tag is presented. Encoding capacity of N bits is proportional to the number of hexagonal-shaped split resonators. In this work, in prototype 1, a 3-bit chipless RFID tag is modeled in an area of 26 mm × 40.78 mm and analyzed. Then the concept of hexagonal-shaped split resonators based chipless RFID tag is expanded to consider a 6-bit chipless tag, Prototype 2. Both prototypes are printed on FR-4 substrate of thickness 1.6 mm. The resonator lengths are calculated as half-wavelength resonators. Table II shows the proposed 6-bit hexagonal-shaped split resonator tag in comparison with the previous chipless RFID tag designs.

TABLE I. THE RESONANT FREQUENCIES FOR BOTH PROTOTYPES.

Prototype 1 (*N* = 3 resonators)			**Prototype 2 (*N* = 6 resonators) all frequencies are in GHz**					
f_1	f_2	f_3	f_1	f_2	f_3	f_4	f_5	f_6
0.92	1.73	2.12	1.17	1.68	1.86	2.85	3.46	3.86
S21 in dB			**S21 in dB**					
-20	-22	-17	-19	-16	-25	-10	-10	-20

TABLE II. THE RESONANT FREQUENCIES FOR BOTH PROTOTYPES.

Ref.	**Size mm^2**	**Nr. of bits**	**Substrate**	**Geometry**
[4]	25 × 50	8	Polyethylene	CSRR
[5]	23 × 31	8	RO4003C	monopole disc
[6]	40 × 40	20	RT Duroid 5880	cross loop resonator
This work	26 × 40	6	FR-4 substrate	Hexagonal - shaped split resonators

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