

Compact Chipless RFID Metamaterial Based Structure Using Textile Material

M. E. Jalil, Noor Asmawati Samsuri, Mohammad Kamal A Rahim and R. Dewan

UTM -MIMOS CoE in Telecommunication

Communication Engineering Department, Faculty of Electrical Engineering, University Technology Malaysia, 81310 Johor Bahru, Johor, Malaysia

ezwanjalil@gmail.com, asmawati@fke.utm.my, mkamal@fke.utm.my, raimidewan@gmail.com

Abstract—A novel multi-resonator using rectangular slotted complementary split ring resonator (CSRR) on planar transmission line is proposed for the design of chipless RFID tag. The chipless design consists of 4 rings resonator which etched on the back of the substrate and is connected to 50 ohm planar transmission line. Each resonator enables to code in four different allocations (00, 01, 10, 11) with bandwidth allocation of 200 MHz. The 8 bits chipless tag with low insertion loss (below -13 dB) operates from 2.5 to 6.5 GHz. The 25 mm × 20 mm flexible chip-less RFID tag is designed on the fleece substrate ($\epsilon_r=1.35$, thickness=1mm, $\tan \delta=0.025$). At the end, the effects of orientation of split ring resonator, number of elements and substrate types are studied and analyzed.

Keywords—component; chipless RFID tag, complementary filter, resonator, split ring resonator, transmission line.

I. INTRODUCTION

Chip-less RFID has attracted vast interest among researchers for the past few years. The chip-less RFID has a tremendous potential for low cost identification application to replace the conventional RFID such as in supply chain management, human identification and monitoring, cyber centric monitoring and space application [1, 2]. Efforts attempted to investigate the potential of chip-less RFID design and technique have been blooming ever since the discovery of the various improvement techniques for RFID performance.

In chip-less RFID technology, there is a significant interest to design a low cost, flexible and light weight chip-less RFID in order to reduce fabrication cost, enhance mobility and provide convenience to the consumers. Apart from that, the textile material such as fleece, flannel and denim are recommended for the design of chipless RFID especially for on-body operation in wearable application. Furthermore, textile material are ergonomical and selected as chosen substrate as it is easily conformable to any surfaces [3, 4]

A 6 bits chip-less RFID tag utilizing spiral resonator operates between 5-11 GHz on flexible Taconic [5] and a 10 bits chip-less RFID tag multiple L-C resonator operates between 0-110MHz on polyamide material [6] have been reported. However, the dimension of reported tag is too large.

Compact size and high density data are the main criteria in designing the chip-less RFID tag.

One of the methods to fulfil the chip-less RFID's criteria is by using metamaterial structure. The metamaterial is described as an artificial material with extraordinary properties that is not available in nature. The metamaterial structure offers numerous potential benefits such as in the enhancement of performance and minimization of the overall dimension. Most of the metamaterial types such as split ring resonator (SRR) have high Q factor which is suitable to produce narrowband resonator. The narrowband resonator is capable to enhance data capacity of chip-less RFID by maximizing the number of resonators in specific frequency range. A complementary split ring resonator (CSRR) is introduced which have the negative image of typical SRR. In contrast with SRR, the CSRR structure orientated in such a way it is perpendicular with respect to the electric field for producing electric coupling.

In this paper, two designs of different geometry of 8 bits chip-less RFID tag based on modified complementary split ring resonator (MCSRR) have been proposed: 1) circular (CMCSRR) and 2) rectangular (RMCSRR) [7,8]. The conducting parts of tag (i.e transmission line and ground plane) are constructed using Shieldit TM Super, polyester with nickel and copper with thickness of 0.17 mm. The tags are designed on homogenous and flexible fleece substrate 1.35, ($\epsilon_r=1.35$, $h=1$ mm, $\tan \delta=0.025$). The tags operate between 2.5 - 12 GHz which covers Ultra Wideband (UWB).

II. CHIPLESS RFID DESIGN

The proposed design is simulated by using Computer Simulation Technology (CST) Microwave Studio 2015. In the proposed chip-less tag, four half wave length SRRs located on the ground plane are connected to the center of 50 Ω micro strip transmission line to design an 8-bits tag ID. Frequency shifting technique is introduced for the tag ID encoding by allocating each ring resonator to represent specific frequency as shown in Fig 1[9]. Each half-wavelength rectangular ring structure represents two bits which resonates at certain frequency (1st ring = 2.5-3.5 GHz, 2nd ring=3.5-4.5 GHz, 3rd ring=4.5-5.5GHz and 4th ring=5.5-6.5GHz).

The CSRR has two split rings with different gap sides. The inner ring is the loading element for outer ring to generate single band operating frequency. The MCSRR is introduced by placing the same side of gap to generate multiple stop bands.

Two new chip-less RFID tags using MCSRR are proposed as shown in Fig 1. The first design consists of four slotted circular split ring resonator with the diameter of 13, 10, 8 and 5 mm respectively. The second design consists of four rectangular slotted split ring resonators with the length of 13, 10, 8 and 5 mm. The split ring resonator will be placed on the back of the substrate under the slot to achieve high magnetic coupling between the transmission line and the rings. The substrate dimension is 25 × 20 mm. The tag design is connected by 1 mm width planar transmission. Subsequently, two 50 ohm SMA connectors are connected at the each end of the transmission line.

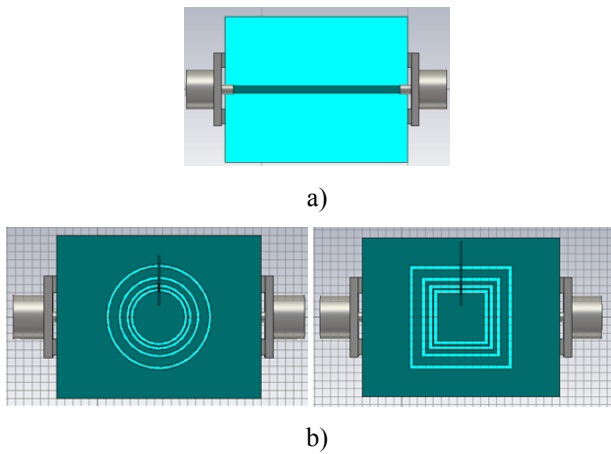


Fig 1. Layout of metamaterial split ring resonator structure a) Front, b) backside

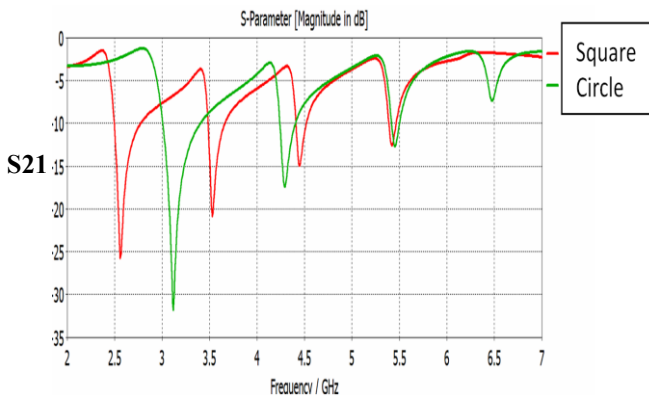


Fig 2. S_{21} , Simulated Insertion Loss for Rectangular (SMCSRR) and Circular (CMCSRR) Split Ring Resonator

Simulated performances of both circular and rectangular slotted complementary split ring resonator with similar substrate dimension are shown in Fig 2 which clearly displays

all resonance frequencies of rectangular complementary split ring resonator that are lower than the resonance frequency of the circular split ring resonator at various band. The total length of ring resonator will influence both of the split ring resonators. The total length of rectangular loop can be estimated as $L_{no} = (4 \times Length) - Gap - (4 \times Width)$. However, the total length of circular ring can be estimated from $L_{no} = 2 \pi \times (Diameter/2) - Gap$. The resonant frequency can be derived from Equation 1. Table 1 shows the simulated result of resonant frequency of both complementary split ring resonators

$$f_1 = \frac{c}{2 L_{no} \sqrt{\epsilon_{eff}}} \quad (1)$$

f = Resonant frequency

c = Speed of light

L_{no} = Length of no element

ϵ_{eff} = Effective permittivity substrate.

TABLE 1. LENGTH AND RESONANCE FREQUENCY OF COMPLEMENTARY SPLIT RING RESONATORS

Types	Circular			Rectangular			
	Bit	Diameter (mm)	Total (mm)	Freq (GHz)	Length (mm)	Total (mm)	Freq (GHz)
1 st		13.0	40.8	3.43	13.0	52.0	2.56
2 nd		10.0	31.4	4.39	10.0	40.0	3.53
3 rd		8.0	25.1	5.40	8.0	32.0	4.45
4 th		5.0	15.7	6.4	5.0	20.0	5.43

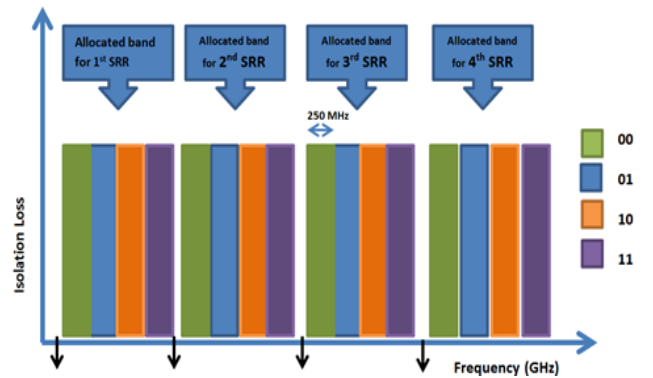


Fig 3. Illustration of frequency shifting technique for data encoding

From previous research, a single ring resonator encodes only a single bit has been reported in [7]. However, the frequency shifting approach as shown in Fig 3 is introduced to improve the amount of bit generated by a single resonator.

From the analysis, the length of resonator has inverse relationship with resonant frequency. The addition of gap size reduces the length of resonator and increases the resonant frequency. A single resonator can generate different states of a data bit. For example, a single resonator is capable to resonate at four different conditions (00, 01, 10, 11) in different frequency band allocation.

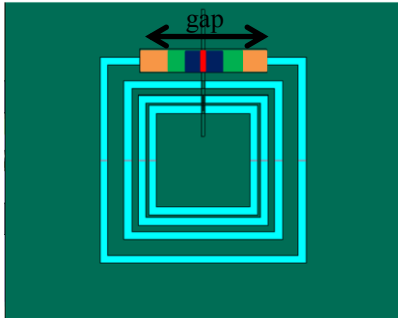


Fig 4. Gap variation between resonator for encoding data, (red=00, green=01, blue=10 and red=11)

The chip-less tag encode bits of 00,01,10 and 11 by varying the gap between ring resonators from 0.25, 2.00, 5.00 and 8.00 mm as shown in Fig 4. The relationship between gap and resonance frequency are shown in Fig 5. The gap of 0.25mm, 2.00mm, 5.00mm and 8.00mm resonate at four different bands allocation which are 2.5-2.7 GHz (00), 2.75 – 2.95 GHz (01), 3.00-3.20 GHz (10) and 3.25-3.45 GHz (11). Each bit has the same bandwidth allocation of 200 MHz. For example; the insertion loss of orange line which resonates at 3.3 GHz provides ID information of 11000000. The second resonator is severely affected when the gap of 1st resonator is equal to 8 mm. However, the second resonator positions still remain at 1st allocation band (00) in the range between 3.5-3.7 GHz. To improve the amount of bit per single resonator, the allocation bands with different condition are added in specific frequency range. However, mutual coupling between resonator and fabrication error are considered to avoid the overlap of resonant frequency between multiple resonators.

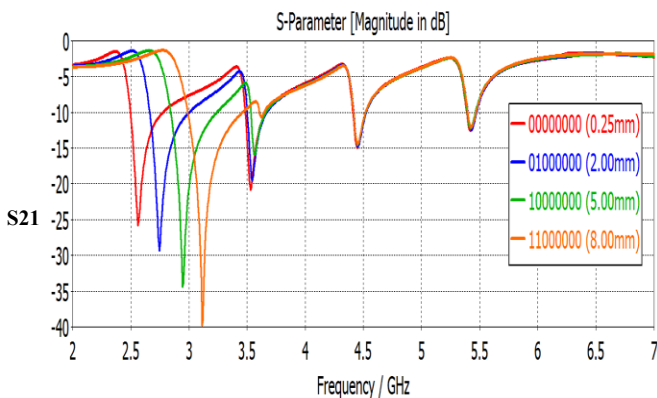


Fig 5. S_{21} , Gap vs Resonance Frequency for tag 1(00000000), tag 2 (01000000), tag 3(10000000) and tag 4 (11000000) by changing 1st SRR

III. RESULT AND DISCUSSION

A. Effect of Orientation Gap of Split Ring Resonator

The main objective of this analysis is to investigate the effect of different gap orientation of split ring resonator on the insertion loss behavior. The good chip-less RFID tag is insensitive to the polarization and position of transmission line [10]. From Fig 6, the circular split ring resonator maintains its resonance at fixed frequency for 2nd, 3rd and 4th SRR and slightly shifted at 1st frequency band. The rectangular split resonator has more stabilized resonant frequency compared to circular split ring resonator with different orientation as shown in Fig 7. The shifting in frequency of rectangular split ring of about 200 MHz is still acceptable.

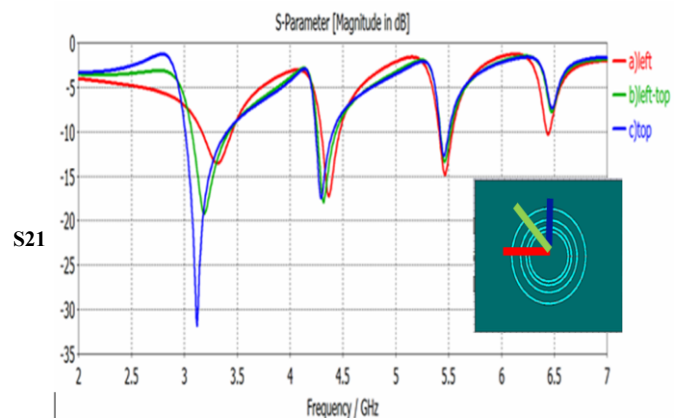


Fig 6. S_{21} , Simulated Insertion Loss for Circular Split Ring Resonator

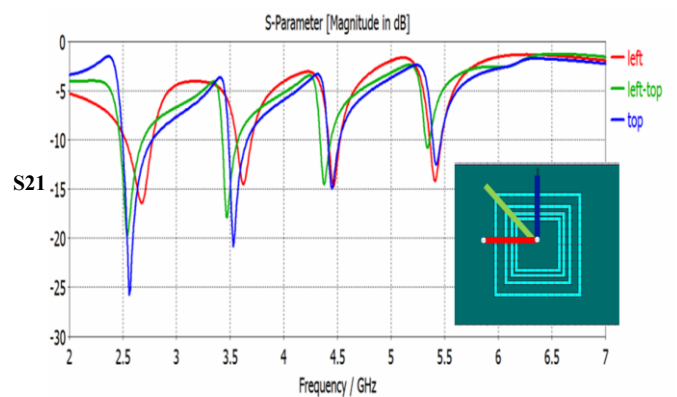


Fig 7. S_{21} , Simulated Insertion Loss for Rectangular Split Ring Resonator

B. Effect of No of element of Split Ring Resonator

The repetition of the element of the CSRR structure with same dimension improves the insertion loss of split ring resonator as shown in Fig 8. From Fig 8, it is clear that all of the rings are coupled transmission line using duplication element to increase attenuation of about 5-25 dB at their resonant frequency without any frequency shifting. However, the entire size of the chip-less tag depending on the number of element used.

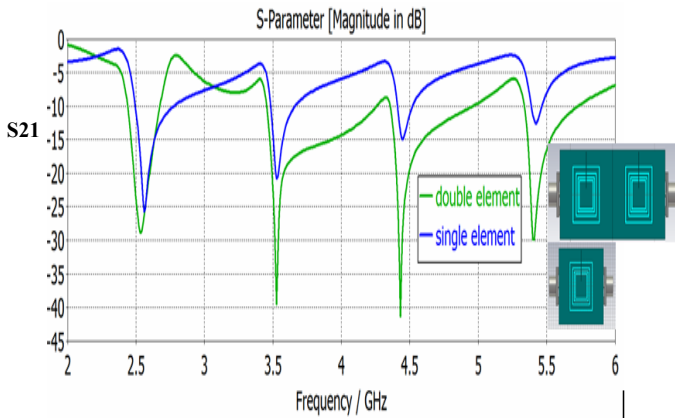


Fig 8. S_{21} , Simulated Insertion Loss for Rectangular Split Ring Resonator with Different Number of Element

C. Material of element of Split Ring Resonator

From Fig 9, it is clear that insertion loss of split ring resonator using Taconic board is between -25 and -42 dB, which is significantly higher than -15 dB obtained on fleece fabric with same dimension. The Taconic board ($\epsilon_r=1.35$, $h=1\text{mm}$, $\tan \delta=0.0011$) provides good performance of insertion loss because it has low loss. However, the fleece fabric still provides good performance and potential solution for designing flexible chipless RFID tag.

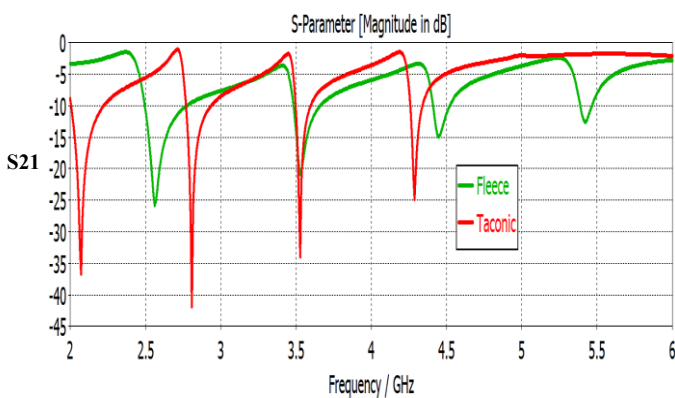


Fig 9. S_{21} , Simulated Insertion Loss for Rectangular Split Ring Resonator with Different Material.

CONCLUSION

A novel chip-less RFID tag using modified complementary split ring resonator on fleece substrate operates between 2.5 to 6.5 GHz with 8 bits of data have been designed and analyzed. The concept of modified complimentary rectangular split ring resonator is proposed to miniaturize the size and reduces the space consumption for chipless RFID application. Two optimization techniques were used to improve the S_{21} of chipless RFID tag: material with low loss tangent and addition number of element. The compact, flexible and lightweight chip-less RFID based on MCSRR has the potential to be produced for wearable application

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