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Miniturize Flexible RFID Antenna Design using Metamaterial Structure

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Abstract: Radio Frequency Identification (RFID) is the application of electromagnetic fields to identify and track tags that attached on the objects. It transmits or reads the radio frequency waves in the system. However, due to rapid development of technology in telecommunication, a much more smaller and flexible device is needed. Therefore, in this paper, a new design of flexible RFID antenna using metamaterial structure has been proposed. At first, the basic rectangular microstrip patch antenna with resonant frequency of 900MHz is designed. Then, the CSRR metamaterial structure is introduced at the ground plane to reduce the size of the antenna while the polydimethylsiloxane (PDMS) material is being use as the antenna substrate for flexibility. All the simulation designs were done using CST software. The antenna performances such as resonant frequency, return loss, radiation pattern, gain and bandwidth are then be analyzed and presented. The results show good performances and can be applied for future application.

Keywords: Complementary spit ring resonator (CSRR); Polydimethylsiloxane (PDMS); patch antenna, metamaterial.

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1. INTRODUCTION

Radio Frequency Identification (RFID) technology had been discover since 1939 when it was called Identify Friend or Foe (IFF) consist of tags and track technique by British allies to identify airplanes. Then, this system continuously being used in military application such as personnel and equipment tracking. Starting at year 80s, this technology widely used in the industries and UHF RFID being employed in the distribution and chain supply industries [1]. RFID tag and reader system consist of three main part, which is reader, tag and the host computer to store all the data received and reader programming. The antenna is located at both the reader and tag as it can convert electric power into radio waves and vice versa. Therefore, it can be both transmitter and receiver for the system [2-3].

As the technology widely used in variety fields and industries, there is a high demand for it to be low cost, small in size, easily fabricated and fit into the applications [4]. Thus, the antenna plays the important role in the system. Therefore, in this paper, a new design of flexible RFID antenna with the modification of the ground plane using metamaterial structure and has been proposed and studied.

1.1. Microstrip patch antenna

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side. The characteristic of this antenna is that the radiation can occur from the fringing fields between the patch and the ground plane. The value of effective dielectric constant of the antenna is slightly less than dielectric constant of the substrate due to the fringing fields from the path to the ground not confine in the dielectric only but also spread into air [5]. Figure 1 shows the basic configuration of microstrip patch antenna.

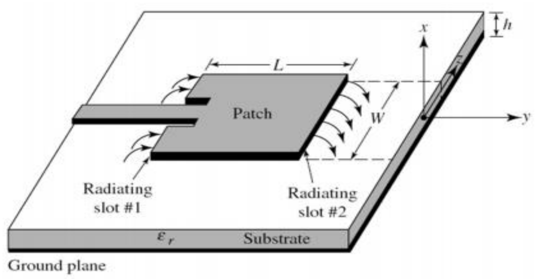

Figure 1: The Radiation of the Microstrip Patch Antenna [5].

1.2. Metamaterial Structure

Generally, metamaterials are some sort of artificial structures which will exhibit unusual electromagnetic properties. The history of metamaterials started in the year of 1968 where it was introduced by a man named V. G. Veselago. This artificial structure can exhibit negative permittivity, negative permeability and a negative refractive index that could not be found in nature [6]. The physical size of the antenna also can be reduced with the metamaterial structures due to that it will be shifted the operating to lower frequency [7]. Bandwidth is the range of frequencies which the antenna radiates and receives energy properly. The metamaterial can increase the bandwidth of the antenna so that it can be used in the wideband operation application. Gain is the relative measurement of the antenna ability to direct the radio frequency energy in the certain direction and pattern [8].

It is predicts that the addition of the structures of metamaterial can improves the performances of the antenna. Thus, the CSRR structure that has been depicted in Figure 2 is used in an array form on the ground plate of the microstrip patch antenna in order to minimize the size of the antenna.

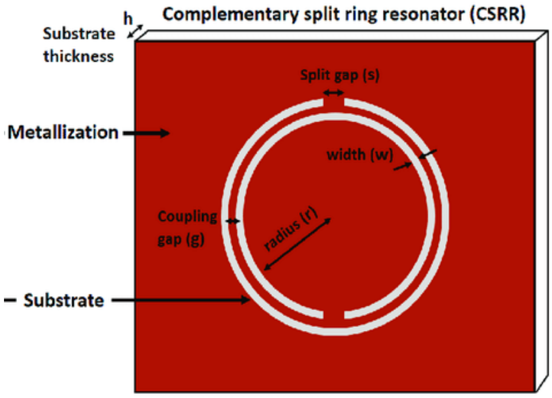

Figure 2: Complementary split ring resonator (CSRR) structure.

1.3. Polydimethylsiloxane (PDMS) substrate

The polydimethylsiloxane (PDMS) is an ultra-flexible polymer that can be used as a substrate as shown in Figure 3. PDMS has useful features which are low-cost, lightweight, biocompatible and chemically resistant [9]. It can be formed to any size or thickness by spin coating or replica molding. Its flexibility enables it to be conformed to any shape and to fabricate multilayered structures by simple bonding techniques [10]. The characteristics of PDMS are it has very low Young's modulus, $E_{young} = 2MPa$ that compatible with many silicon micromachining techniques and its dielectric properties are $\varepsilon_r = 2.68$ $tan\delta = 0.04$ [11].

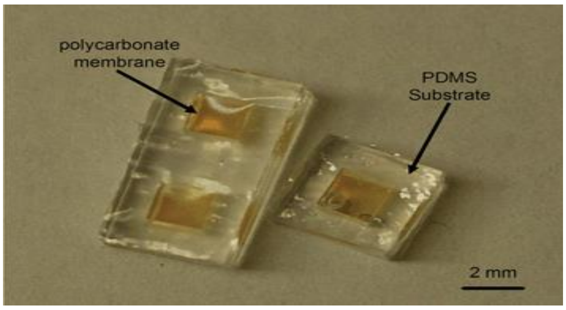

Figure 3: PDMS substrate and polycarbonate membrane [9]

2. ANTENNA DESIGN

In this paper, the design of rectangular microstrip patch antenna with microstrip line feeding and CSRR ground structure has been proposed. The CSRR is implemented at the ground plane of the antenna. In this project, microstrip patch antenna is set to operate at the frequency of 900MHz. As known, the metamaterial structure will be able to decrease the size of the antenna by shifting the resonant frequency to the lower frequency.

The followings section explained the design specifications of the rectangular microstrip patch antenna, CSRR structure and the antenna with CSRR ground. All of the designs are constructed on a PDMS substrate with the relative permittivity of 2.68 and thicknesses of 1.6mm while the conductor ground and patch with thickness of 0.0035mm.

2.1 Rectangular Microstrip Patch Antenna

The equation to calculate the parameters of the rectangular patch antenna are listed as below [12]:

Width of the patch,
$$w = \frac{c}{2fo\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

Effective dielectric constant,

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}(1+12\frac{h}{W})^{\frac{-1}{2}} \tag{2}$$

Effective length,
$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = \frac{0.412h(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}-0.8)} \tag{4}$$

Thus, length of the patch, $L = L_{eff} - 2\Delta L$ (5)

The length of the ground, $L_g = 2L$ (6)

The width of the ground, $w_g = 2w$ (7)

The length of the feedline, $Fi = \frac{6h}{2}$ (8)

Where,

$c = 3 \times 10^8 m/s$

f_o is the operating frequency

h is the height of the substrate

ε_r is the permittivity of the substrate

Zin = 50Ω

Figure 4 and Table 1 shows the complete dimensions of the rectangular patch antenna.

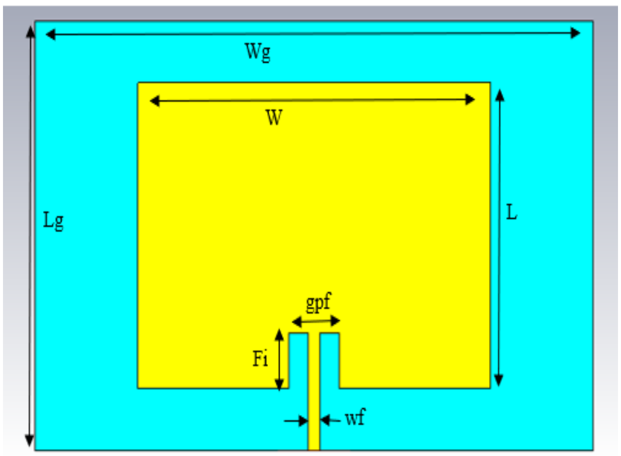

Figure 4: Design of the rectangular patch antenna.

Table 1. Dimension of the antenna

Parameter	Calculated Value (mm)	Optimized Value (mm)
W	122.87	145
L	101.32	99.5
Fi	4.8	18
Wf	4.375	4.5
Wg	245.74	230
Lg	202.64	140
gpf	6.375	8

2.2 CSRR metamaterial unit cell

In this project, the circular CSRR structure has been chosen. The parameters of the CSRR are calculated so the unit cell resonates at 900MHz. Figure 5 and Table 2 shows the optimized dimension of the unit cell.

The equation to calculate the parameters of the circular CSRR structure are shown as below [13]:

As the resonant frequency of the CSRR can be obtained as

$$f_{o,CSRR} = \frac{1}{2\pi\sqrt{L_C C_C}} \quad (9)$$

Thus,

$$L_c C_c = \frac{1}{(2\pi f_0)^2} \quad (10)$$

The capacitance C_C can be approximated by that of a slot of radius, r_0 and width, d.

The resulting inductance, $L_c = L_0/4$ (11)

While, the total inductance, $L_0 = 2\pi r_0 L_{pul}$ (12)

Where, L_{pul} is the per-unit-length inductance of a CPW transmission line.

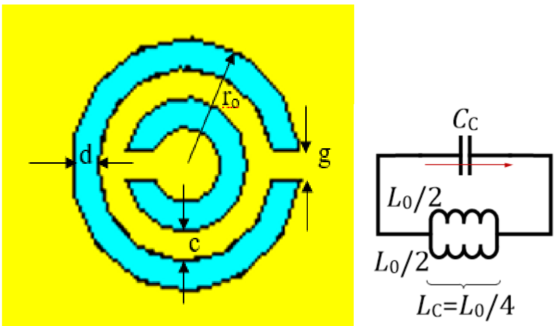

Figure 5: (a) Design of the circular complementary split ring resonator (CSRR) (b) Equivalent circuit.

2.3 Rectangular Microstrip Patch Antenna with CSRR ground plane

Finally, the rectangular microstrip patch antenna is combined with circular CSRR structure at the ground plane. After optimization, the size of the patch has been reduced to 95mm x 85mm. There are nine CSRR unit cell use at the ground plane. The complete dimensions of the antenna are shown in Figure 6, Figure 7 and Table 3.

Table 2. Dimension of the Circular Complementary Split Ring Resonator (CSRR)

Parameter	Value(mm)
Radius, r_o	17
Gap, g	4
Gap of ring, d	4
Gap between ring, c	4

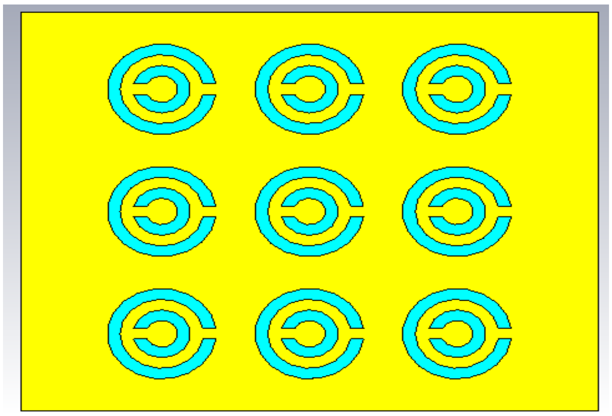

Figure 6: Ground plane of the antenna.

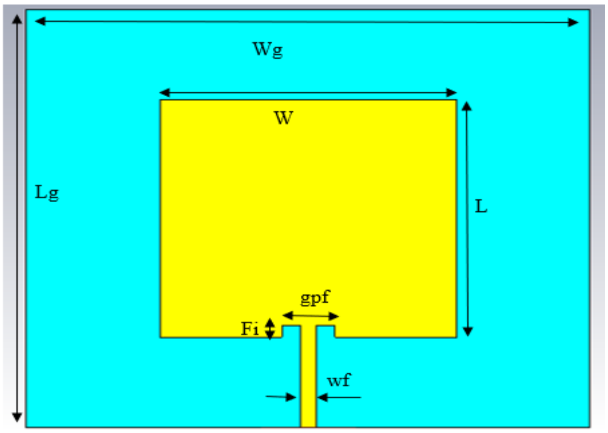

Figure 7: Font plane of the antenna.

Table 3. Optimized Dimension of the Antenna with CSRR Ground Plane

Parameter	Optimized Value (mm)
W	95
L	85
Fi	4
Wf	5
Wg	180
Lg	150
gpf	6

3. SIMULATION RESULTS AND DISCUSSION

All the designed is simulated using the CST Studio software and the simulation the results are shown in the following section

3.1 Rectangular Microstrip Patch Antenna

Figure 8 shows the S_{11}-parameter response of the antenna. The output response shows the antenna operates at 900.6MHz with the return loss of -12.6dB. While, the impedance bandwidth of the antenna is calculated as 5.5MHz at -10dB.

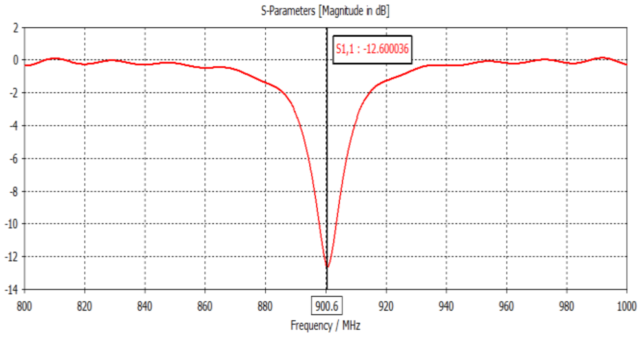

Figure 8: S_{11} parameters of the rectangular microstrip patch antenna.

In the following, Figure 9 shows the 3D radiation pattern of the antenna. The results depict that the antenna gain is 6.715dB with the radiation efficiency of -0.9106dB and total efficiency of -1.167dB.

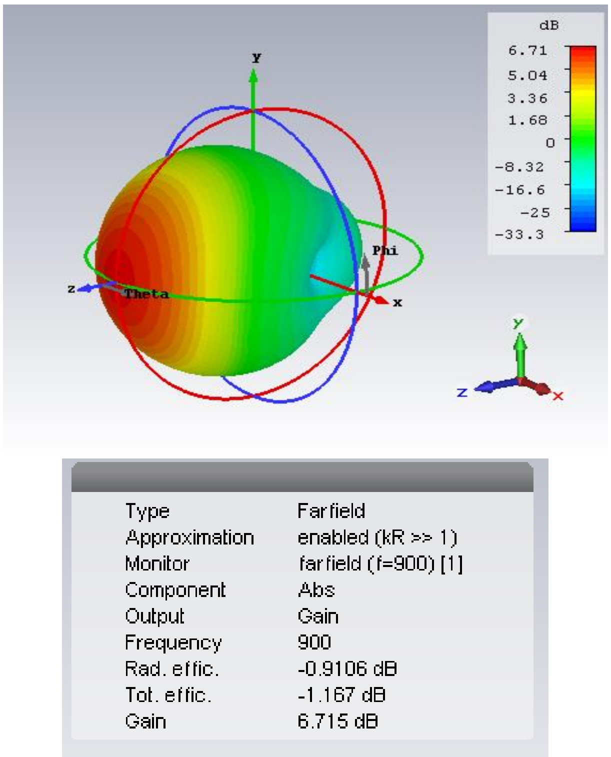

Figure 9: 3D radiation pattern of the optimized antenna at 900MHz.

3.2 Rectangular Microstrip Patch Antenna with CSRR ground plane

Figure 10 shows the S_{11}-parameter response of the antenna. The output response shows the antenna operates at 900MHz with the return loss of -11.7dB. In addition, the calculated antenna bandwidth is slightly reduced to 2.78MHz.

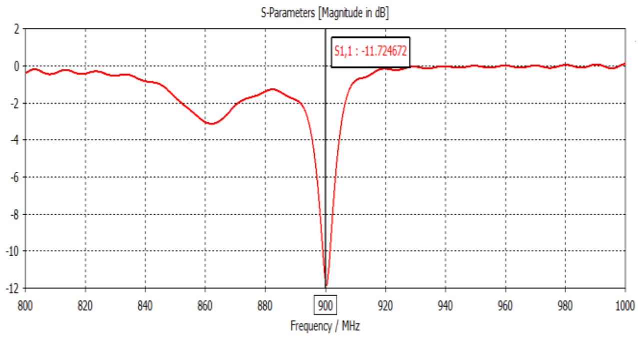

Figure 10: S_{11} parameters of the optimized rectangular microstrip patch antenna after adding the CSRR structure.

Figure 11 shows the 3D radiation pattern and gain of the antenna. The results show gain of 4.358dB with the radiation efficiency of -0.9403dB and total efficiency of -1.243dB have been obtained.

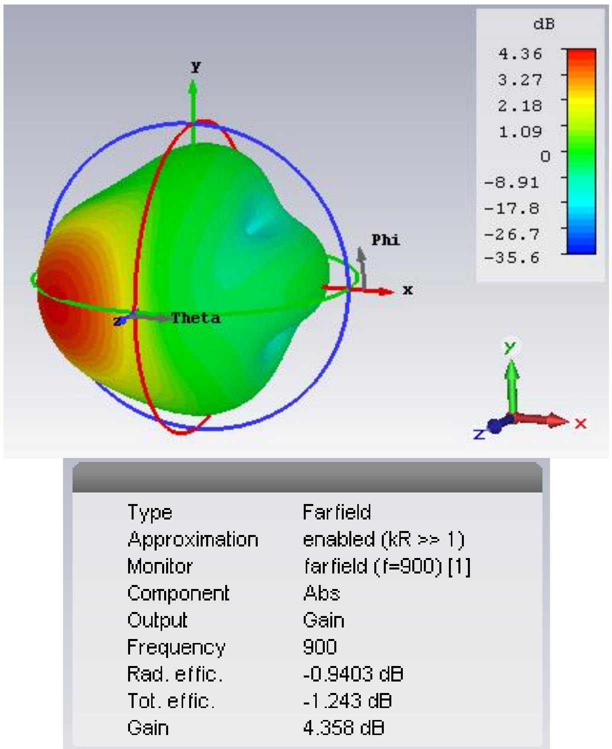

Figure 11: 3D radiation pattern of the optimized antenna at 900MHz after the addition of CSRR structure.

From the simulation results, it is shows that the antenna size has been successfully reduced by 44.03%. The slight lower gain of the antenna is actually due to the smaller size of the rectangular patch antenna structure. The complete comparison of the both antenna performances were summarized in Table 4.

Table 4. Comparison between Basic Rectangular Patch with and without CSRR Ground Plane.

Parameter	Rectangular Patch	Optimized Value After adding CSRR
Patch Size (W x L)	145mm x 99.5mm	95mm x 85mm
Operating Frequency	900.6MHz	900MHz
Bandwidth	5.5MHz	2.78MHz
Gain	6.715dB	4.358dB

4. CONCLUSION

As a conclusion, the rectangular microstrip patch antenna with CSRR ground has been successfully designed to operate at resonant frequency of 900MHz. It can also be seen that size of the rectangular patch antenna has been reduced by 44% compared to conventional structure. However, the gain of the antenna is slightly reduces to 4.35dB. For future works, the antenna can be simulated in the bending condition so that the flexibility of the antenna can be analyzed whether it will affect the performances of the antenna.

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