The Design of Closed Square RR Loaded 2-Port MIMO for Dual Band Applications

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Received: 17 January 2022 | Revised: 16 February 2022 | Accepted: 16 February 2022

Abstract-In this paper, a closed square ring resonator loaded 2-port Multi Input Multi Output (MIMO) is proposed for dual-band applications in the S and C band. The presented antenna model is designed by loading it in FR-4 substrate with a feedline of 50Ω and loaded with SRR for the enhancement of isolation and radiation pattern. Ansoft HFSS is used to obtain the simulated parameters of the model for the frequency ranges of 2.2-2.5 and 6-6.3GHz. Measurements confirm the characteristics of the fabricated antenna that were speculated with the simulation results with a little shift in frequencies. The diversity parameter performance analysis justifies the working performance of the 2-port MIMO for WiFi, WLAN, and ISM band applications.

Keywords-dual band; microstrip; RR; MIMO; ECC

I. INTRODUCTION

Wireless communications play a very important and significant part in our daily life [1-3]. In this time of global crisis due to the COVID-19 pandemic, telecommunication infrastructure is connecting people and helping transfer necessary data from physical structures to digital platforms. Antennas play a very important part in the telecommunication network by acting as a transducer in sending and receiving electromagnetic waves [4-5]. As the requirement of compact and portable devices for wireless communication is increasing, microstrip patch antennas prove to be a potential candidate and are preferred over the conventional antennas [6]. These antennas have the advantages of being light weight, smaller in size, they have a low profile, and the potential to be fabricated and incorporate easily on other external devices. However, MIMO antennas have evolved as a potential aspirant in meeting the demands of high data rates and high speed with the significant advantages of decreased fading and link reliability in multipath environments. The use of MIMO antennas results in better spatial and pattern diversity with increased channel capacity [7-10]. The main challenge for the researchers lies in increasing the isolation between the ports so that there is minimum interference between the transmitting and receiving signals. The increased correlation between the ports will affect the antenna efficiency, so mutual coupling needs to be reduced for the better performance of the antenna. Moreover, even in the conventional microstrip patch antennas, the most common limitations are low impedance bandwidth, solo resonating frequency, and low gain. Different techniques have been reported for enhancing the isolation and improving antenna parameters like DGS, resonators, AMCs, meander line, metamaterials, etc. [11-12]. A MIMO antenna with V shaped ground for application in the WLAN band has been presented in [13], whereas in [14], an MIMO antenna loaded with CSRR is proposed. Another MIMO antenna with symmetrically placed patch elements is described in [15].

Ring resonators proved to be a suitable candidate among all the techniques reported for enhancing the antenna parameters due to their simple structural design. In this paper, the use of triple closed square RR has been shown for the reference port antenna and also for the proposed 2-port design. Return loss, reduced dimensions by maintaining its characteristics, and promoting the effect of the capacitive filter can be achieved by the application of ring resonators on the micro strip patch antenna [16]. The main aim of using closed square RR-inspired antennas is to minimize the antenna size, enhance the isolation, and increase the bandwidth making them more desirable for applications. When ring resonators are loaded in microstrip antennas, a capacitive filter effect is induced which works in increasing the antenna return loss, reducing the dimensions of antenna by retaining its main attributes, and other effects [17-

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18]. The use of various ring resonators implemented in microstrip antennas has been reported by many authors in the literature [19-20]. Various non-homogenous elementary geometries have been used like split ring resonators and complimentary split ring resonators in various shapes [21-22].

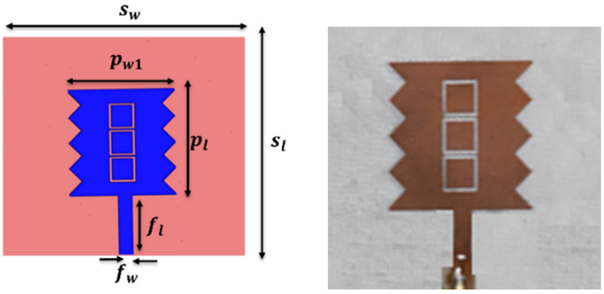
The proposed antenna design loaded with square closed ring resonators exhibits advantages in terms of isolation, compact size, low-fabrication cost, low-cross polarization level, and dual-band operation.

II. ANTENNA DESIGN

A. Model

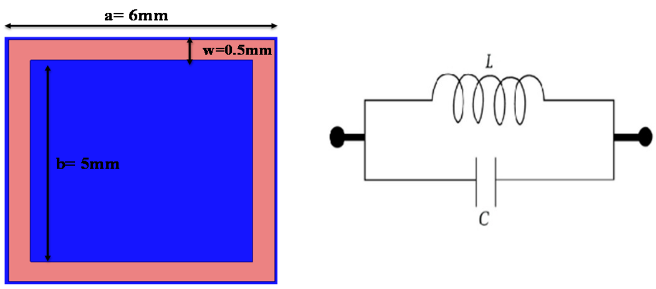
The present section illustrates the design of the single antenna element taken as a reference. Figure 1 represents the configuration of the antenna embedded on a FR-4 substrate having relative permittivity of 4.4 and a loss tangent of 0.025 along with the fabricated prototype. The substrate height is taken as 1.6mm with a 25×25mm^2 patch. The antenna dimensions are mentioned in Table I. Testing of the fabricated prototype has been conducted with the Vector network analyzer and it shows satisfactory correlation among the fabricated and the simulated results. The geometry of the closed square RR is given in Figure 2(a) and the unit cell electrical equivalent is shown in Figure 2(b). The resonating frequency f_o of the square RR is given as:

$$f_o = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (1)$$



(a) (b)

Fig. 1. Geometry of the reference antenna. (a) Simulated design, (b) fabricated antenna.



(a) (b)

Fig. 2. (a) Ring resonators, (b) equivalent circuit.

TABLE I. ANTENNA DIMENSIONS

Antenna dimensions	Size in mm
p_{w1}	40
p_l	50
s_w	25
s_l	25
a	6
b	5
f_l	16
f_w	3

B. Design Specifications

The parameters of the antenna are obtained from the conventional formulas given below [15].

The width (W) is calculated as:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (2)$$

where c is the free space velocity of light and ε_r the dielectric constant of the substrate. The effective dielectric constant of the microstrip patch antenna is:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \quad (3)$$

The actual length of the patch (L) is:

$$L = L_{eff} - 2\Delta L \quad (4)$$

where

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (5)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (6)$$

The simulated and fabricated return loss for this antenna is shown in Figure 3 which shows that this single element antenna is operating at 2.4GHz for ISM band applications.

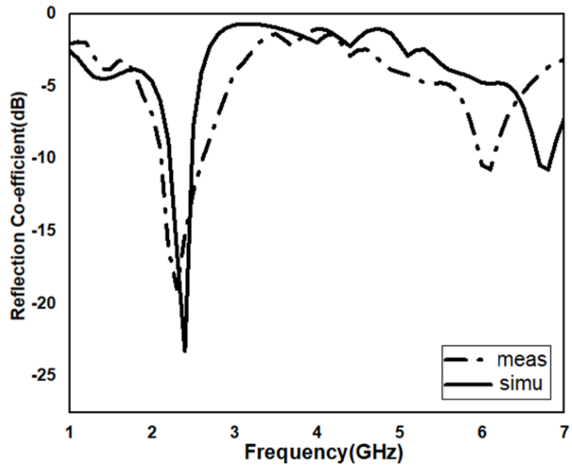
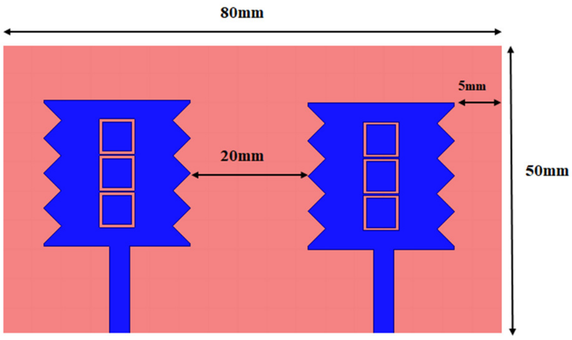


Fig. 3. Measured and simulated reflection coefficient for the single element antenna.

Figure 4 shows the proposed MIMO antenna. Testing of the fabricated prototype has been conducted with the Vector network analyzer and it shows satisfactory correlation among the fabricated and the simulated results. The electrical equivalent circuit for one element is shown in Figure 5. A tank circuit of inductor L and capacitor C is formed by each unit cell of the resonator. L_f is resulted due to the current flow through the main feedline. The shunt capacitances C_{g_1} and C_{g_2} are formed due to the gap in the ground plane and patch.

(a)



(b)

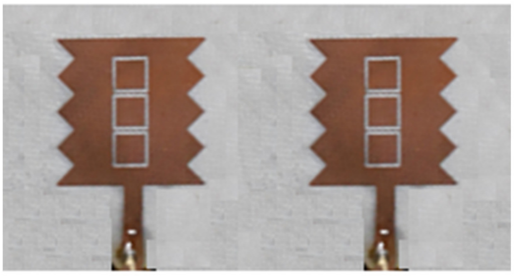


Fig. 4. Geometry of the proposed antenna. (a) Simulated design, (b) fabricated antenna.

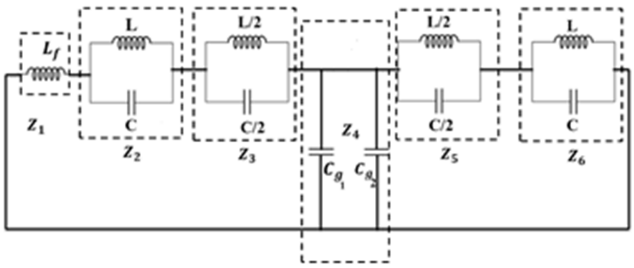


Fig. 5. Equivalent circuit of one patch element.

III. PARAMETRIC ANALYSIS

For the best probable performance of the proposed antenna, its dimensions have been optimized and this is evident from the following observations. The variations in the return loss have been observed by varying several parameters as discussed below.

A. Outcome of Changing Length of Feed

The proposed line fed antenna's return loss is observed by changing the length to 15mm and 17mm. The feed length f_l (16mm) of the proposed design is giving the optimum results as shown in Figure 6.

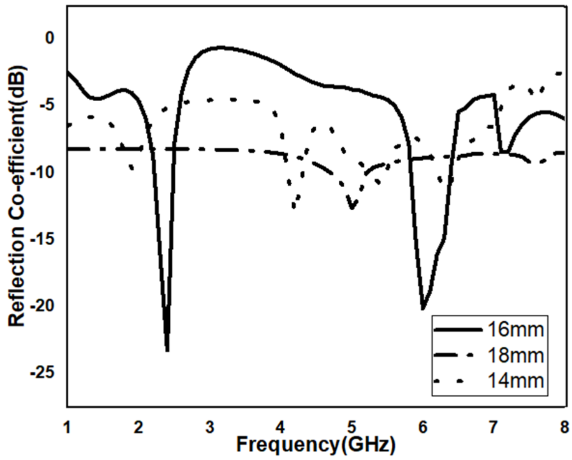


Fig. 6. Reflection coefficient by varying feed length.

B. Outcome of Changing Width of Feed

Return loss variations have been observed by increasing and decreasing the feed width to 2.8mm and 3.2mm. Optimum return loss is observed for the feed width of 3mm as designed in this paper.

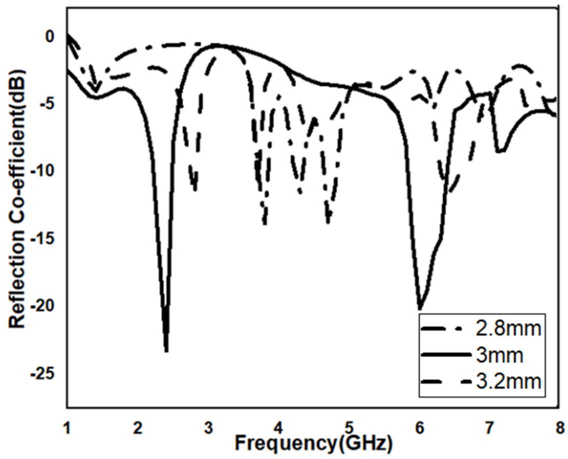


Fig. 7. Reflection coefficient by varying feed width.

C. Outcome of Changing the Width of the Ring Resonator

Slot width of the ring resonators was varied to 0.5mm and 1.5mm to obtain the variations in return loss characteristic as shown in Figure 8. It is noticed that slot width of 1mm is providing the best results.

IV. RESULTS AND DISCUSSION

For simulating the antenna parameters, finite element based Ansoft HFSS is used and for the fabricated results and the Vector network analyzer manufactured by ANRITSU is utilized. The model number is MS2073C offering a frequency range from 5kHz to 15GHz and 350μs/data point sweep speed.

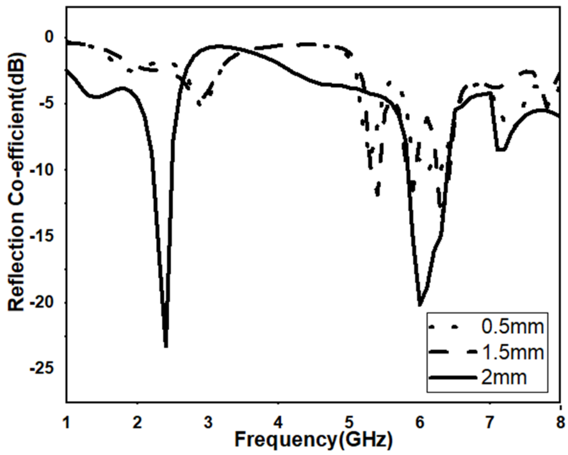


Fig. 8. Reflection coefficient by varying resonator width.

A. Reflection CoEfficient and Radiation Patterns

Figure 9 shows the measured and simulated reflection coefficient for the proposed MIMO antenna. The antenna provides return loss> –20dB and isolation of more than 20dB to tune over frequency bands between 2.3–2.4GHz and 5.9–6.3GHz.

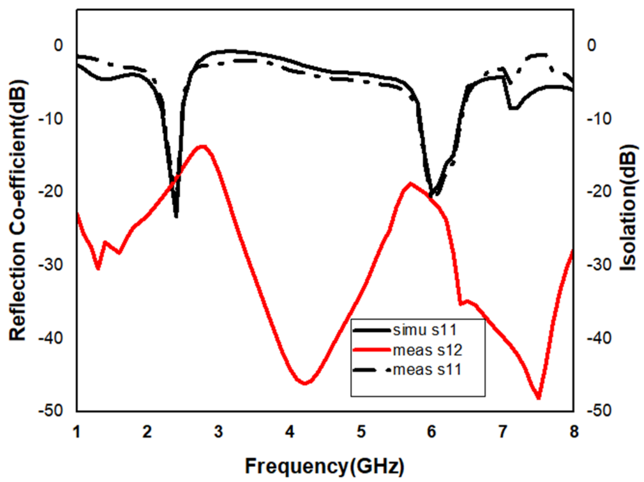


Fig. 9. Measured and simulated reflection coefficient of the proposed antenna.

The radiation patterns for the E plane and H plane of the proposed antenna for both operating frequencies are shown in Figure 10. It is observed that the proposed design shows good radiation performance and cross polarization is less compared to the co-polarization in both planes.

B. Gain

Figure 11 shows the gain of the proposed antenna. It can be observed that the proposed design has a maximum gain of 7dBi at 2.4GHz resonating frequency and a gain of 4.5dBi at 6.1GHz frequency.

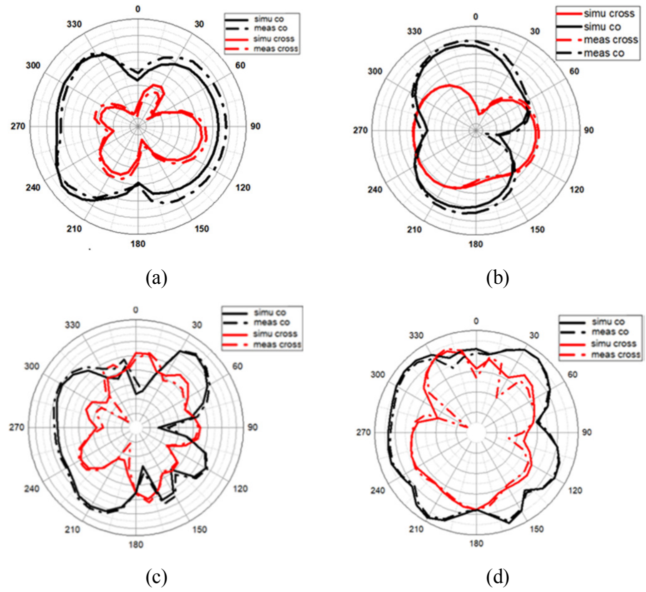


Fig. 10. Radiation patterns of the proposed antenna: (a) 2.4GHz E plane, (b) 2.4GHz H plane, (c) 6.1GHz E plane, (d) 6.1 GHz H plane.

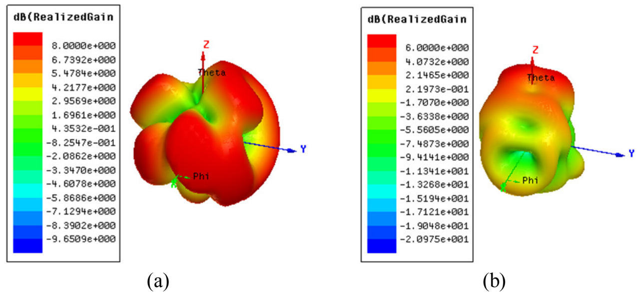


Fig. 11. Gain of the proposed antenna. (a) 2.4GHz, (b) 6.2GHz.

C. Diversity Parameters

The various performance metrics for justifying the performance of the proposed MIMO antenna, like Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and Group Delay (GD) were computed. It is observed from Figure 12 that the proposed MIMO antenna is having good performance metrics as ECC is below 0.05 with DG of more than 9.98, and GD less than 2ns.

ECC defines the amount of correlation between an antenna and the others and can be expressed as:

$$\rho_e = \frac{|\sum_{n=1}^{N} S^*_{a,n} * S^*_{b,n}|^2}{\prod_{k=(a,b)}^{n}[1-\sum_{n=1}^{N} S^*_{a,n} S_{n,k}]} \quad (7)$$

where N is the number of antenna elements, and a, b are the antenna elements.

The measured ECC for the proposed antenna is below 0.05 which justifies its use for practical applications. The proposed design provides a maximum GD of 2ns which is well within limits. Another important performance parameter in MIMO antennas is DG which defines the amount of obtained improvement in MIMO compared to SISO and can be expressed as:

$$DG = 10\sqrt{1 - ECC^2} \quad (8)$$

DG should be more than 9.95 for any practical applications and the computed results shows that DG is more than 9.96 as can be seen in Figure 12. A comparison of some of the existing works for isolation enhancement is presented in Table II for different applications.

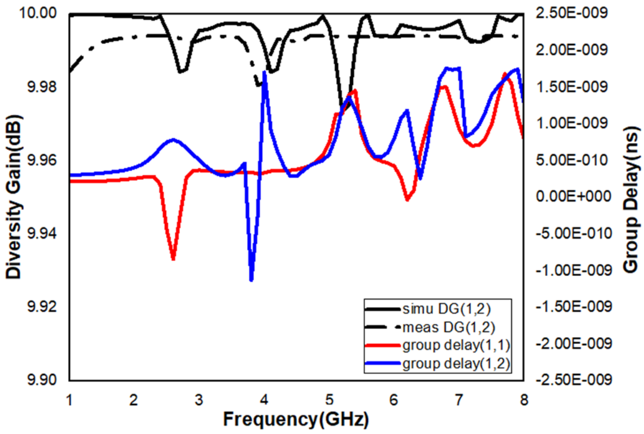


Fig. 12. Diversity gain and group delay of the proposed antenna.

TABLE II. COMPARISON WITH EXISTING WORKS

Ref No.	Size (mm)	Minimum Isolation (dB)	Resonant frequency (GHz)
[19]	100×50	15	1.73, 2.8
[20]	100×50	10	2.4-2.5
[21]	80×40	15	2.9-3.3, 3.2-3.6
[22]	100×60	10	2.4-2.6, 3.4-3.6
This paper	80×50	20	2.2-2.5, 6-6.3

V. CONCLUSION

A triple closed RR of square shape, embedded on a microstrip patch antenna for S and C band applications is presented in this work. The resonating frequency band at return loss >20dB is 2.3-2.4 GHz and 5.9-6.3 GHz with good impedance matching and gains of 7.5dB and 5dB respectively. The proposed antenna model is befitting for applications in S and X bands covering WiFi, WLAN, and ISM band applications with isolation of more than 20dB in the operating bands. The performance parameters of the proposed MIMO antenna are satisfactory with ECC < 0.1, DG > 9.93dB and a maximum GD of 2ns.

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