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Square RR Loaded Microstrip Patch Antenna for ISM Band Applications

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In this paper, a closed square ring resonator (RR) loaded microstrip patch antenna is proposed for ISM band applications covering a frequency band of 2.2-2.5 GHz. The advantages of microstrip antennas are light weight, low cost, ease of fabrication, and they can be integrated easily with microwave integrated circuits. The presented antenna model is designed by loading it in FR-4 substrate which is sandwiched between the patch and the ground with feedline of 50 Ω. The height of the substrate is taken as 1.6 mm with the dielectric constant of 4.4, and the proposed design is fabricated on 40 × 50 mm² substrate. A square patch with dimensions of 25 × 25 mm² is loaded with closed RRs for the enhancement of gain and radiation pattern. Ansoft High Frequency Structure Simulator which is based on the finite element method (FEM) is used to obtain the simulated parameters of the model for the frequency range of 2.2-2.5 GHz. Parametric analysis is also done to get the optimized parameters for fabrication. Optimized parameters for feed length and width of RR are obtained by increasing and decreasing the dimensions of the above-mentioned parameters. Measurements confirm the characteristics of the fabricated antenna as speculated with the simulation results with a little shift in frequencies. The proposed antenna can be used for WiFi, WLAN and ISM band applications.

Keywords: Dual band, Microstrip, Ring resonator (RR), Square.

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1. INTRODUCTION

In our day-to-day life, wireless communication plays a very important and significant role. The best gift of wireless communication is the connectivity provided to people to communicate with one another [1-3]. In this time of global crisis due to COVID-19 pandemic, telecommunication infrastructure is connecting people and helping necessary data transfer from physical structures to digital platforms. Antennas play a very important part in 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 day by day, microstrip patch antennas prove to be a potential candidate and are preferred over conventional antennas [6]. These antennas have advantages such as light weight, smaller size, low profile, and the ability to manufacture and easily mount to other external devices. The antenna's return loss, reduced dimensions by maintaining its characteristics and promoting the effect of the capacitive filter can be achieved by applying ring resonators (RRs) on a microstrip patch antenna [7]. The main aim of using closed square RR inspired antennas is to minimize the antenna size, enhance the gain, and increase the bandwidth which makes RR desirable for antenna applications.

When RRs are loaded into microstrip antennas, the capacitive filter effect is induced, which works to increase the antenna return loss, reduce the dimensions of the antenna by retaining its main attributes, and other effects [8-10]. The use of various RRs implemented in microstrip antennas is reported by many authors in the literature. Various non-homogenous elementary geometries are used such as split RRs, complimentary split RRs of various shapes like square, circular, triangular etc.

The most common limitations of conventional microstrip patch antennas are low impedance bandwidth, single resonant frequency and low gain. Different techniques have been reviewed in the literature to improve antenna parameters like metamaterials, AMCs, DGS, resonators, etc. [11-14] Ring resonators prove to be a suitable candidate among all the techniques reported for enhancing the antenna parameters due to its simple structural design. In this paper, the use of triple closed square RR has been shown for dual band applications.

The proposed antenna design exhibits advantages in terms of gain, compact size, low fabrication cost, low cross-polarization level, and dual-band operation. Section II illustrates the antenna design, and the simulated and fabricated results are shown in section III.

2. ANTENNA DESIGN

2.1 Model

This section shows the design of the proposed antenna. Fig. 1a and Fig. 1b represent the configuration of the antenna embedded into FR-4 substrate having a relative permittivity of 4.4 and a loss tangent of 0.025, of the fabricated prototype, respectively. The substrate height is taken as 1.6 mm with 25 × 25 mm² patch. Testing of the fabricated prototype was performed with the vector network analyzer, and it shows a satisfactory correlation between the fabricated and simulated results. The geometry of the closed square RR is given in Fig. 1c, and the unit cell electrical equivalent is shown in Fig. 1d. The resonant frequency f_0 of the square RR can be given as:

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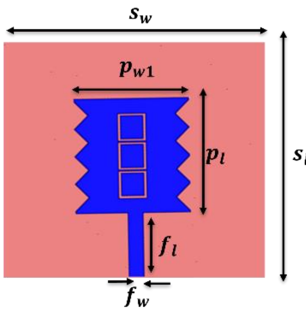
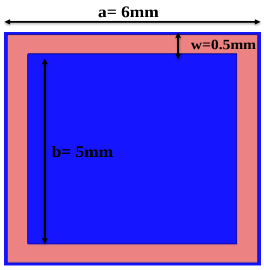
$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}} .$$

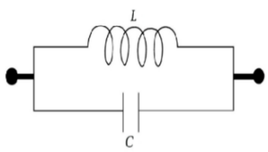


a – Simulated design

b – Fabricated antenna



c – Ring resonators (RRs)



d – Equivalent circuit

Fig. 1 – Geometry of the proposed antenna and the equivalent circuit of a unit cell

Table 1 – Antenna dimensions

Antenna dimensions	p_w	p_l	s_w	s_l	a	b	f_l	f_w
mm	25	25	40	50	6	5	16	3

2.2 Design Specification

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

1. Calculation of the width (W):

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} ,$$

$$P = \lambda^{1}_{\max}/n ,$$

where c is the free space velocity of light; ε_r is the dielectric constant of the substrate,

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

where ε_{eff} is the effective dielectric constant of the microstrip patch antenna.

2. The actual length of the patch (L):

$$L = L_{eff} - 2\Delta L, \quad \text{where} \quad L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} ,$$

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

3. PARAMETRIC ANALYSIS

For the best probable performance of the proposed antenna, the antenna dimensions have been optimized, as evident from the following observations. Changes in return loss are observed by varying several parameters as discussed below.

The return loss of the proposed line fed antenna is observed by changing the length to 15 mm and 17 mm. The feed length f_l (16 mm) of the proposed design gives optimum results, as shown in Fig. 2.

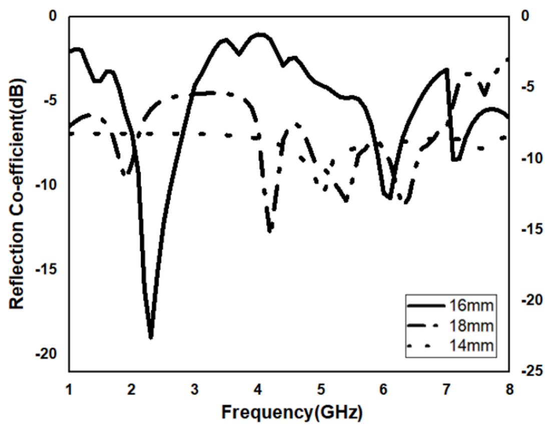


Fig. 2 – Reflection coefficient by varying feed length

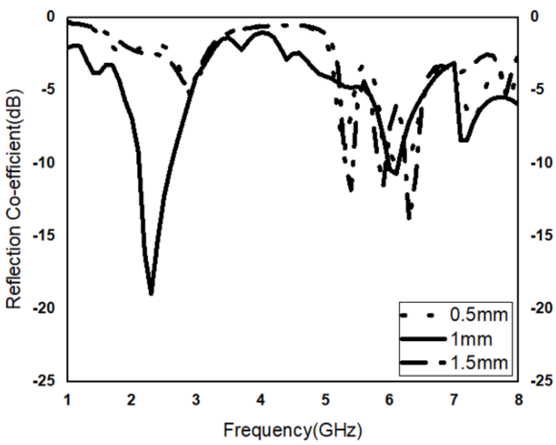


Fig. 3 – Reflection coefficient by varying resonator width

Slot width of the ring resonators is varied to 0.5 mm and 1.5 mm to obtain the variations in return loss characteristic as shown in Fig. 3. It is noticed that slot width of 1 mm is providing better result.

4. RESULTS

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

The following figure shows the measured and simulated reflection coefficient for the proposed antenna. The antenna provides a return loss > – 20 dB to tune in frequency range of 2.3-2.5 GHz.

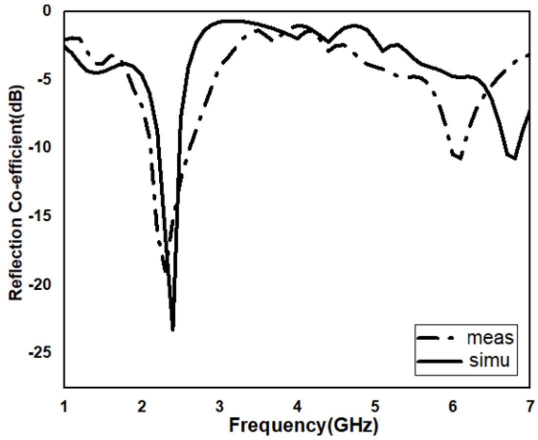
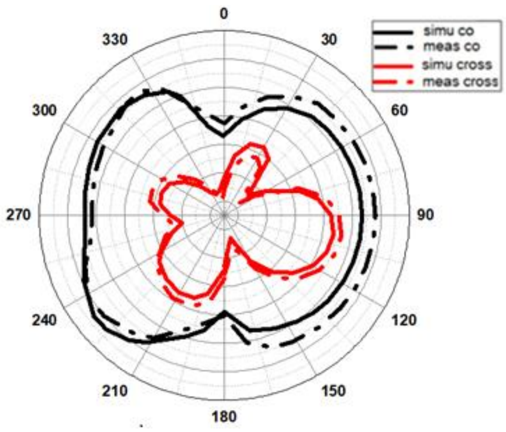


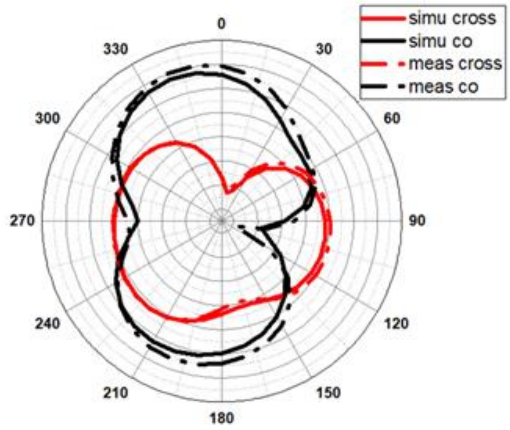
Fig. 4 – Measured and simulated reflection coefficient for the proposed antenna

The radiation patterns for the *E*- and *H*-planes of the proposed antenna for both operating frequencies are shown in Fig. 5. It is observed that the proposed design shows good radiation performance, and cross polarization is less compared to co-polarization in both planes.

Fig. 6 shows the gain of the proposed antenna, and it can be observed that the proposed design has a maximum gain of 7 dBi at 2.4 GHz resonant frequency.



(a) 2.4 GHz, *E*-plane



(b) 2.4 GHz, *H*-plane

Fig. 5 – Radiation patterns of the proposed antenna

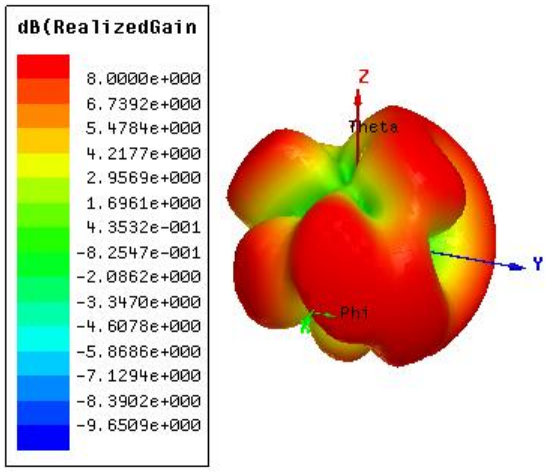


Fig. 6 – Gain of the proposed antenna at 2.4 GHz

5. CONCLUSIONS

A triple closed RR of square shape embedded on microstrip patch antenna for ISM band is presented in this work. The resonant frequency band at return loss > 20 dB is 2.3-2.4 GHz with good impedance matching and a gain of 7.5 dB at 2.45 GHz is obtained. The proposed antenna model is suitable for applications in ISM band covering WiFi, and WiMAX applications.

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Мікросмужкова патч-антена з RR у формі квадрата для додатків діапазону ISM

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У роботі мікросмужкова патч-антена із замкненими кільцевими резонаторами (RR) у формі квадрата пропонується для застосування в діапазоні ISM, що охоплює смугу частот 2,2-2,5 ГГц. Перевагами мікросмужкових антен є невелика вага, низька вартість, простота виготовлення, а також їх легко інтегрувати з інтегральними НВЧ схемами. Представлена модель антени розроблена шляхом нанесення її на підкладку FR-4, яка затиснута між патчем і землею з лінією живлення 50 Ом. Висота підкладки складає 1,6 мм, її діелектричні проникність дорівнює 4,4, а розмір підкладки, на якій виготовлена запропонована конструкція, становить 40×50 мм². Квадратний патч розміром 25×25 мм² нанесений із замкнутими RR для покращення підсилення та діаграми спрямованості. Для отримання змодельованих параметрів моделі для діапазону частот 2,2-2,5 ГГц використовується Ansoft High Frequency Structure Simulator, заснований на методі скінченних елементів (FEM). Параметричний аналіз проводиться для отримання оптимізованих параметрів виготовлення. Оптимізовані параметри довжини та ширини RR отримують шляхом збільшення та зменшення розмірів вищезгаданих параметрів. Вимірювання підтверджують характеристики виготовленої антени, що передбачаються результатами моделювання, з невеликим зсувом частот. Запропонована антена може бути використана для додатків WiFi, WLAN та ISM.

Ключові слова: Дводіапазонний, Мікросмужковий, Кільцевий резонатор (RR), Квадрат.