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REGULAR ARTICLE

Performance Enhancement of Microstrip Circular Ring Dual-Band Patch Antenna with Minimum Reflection for Effective Wireless Communication Applications

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This article proposed a compact dual band circular ring patch antenna designed for wireless communication applications. This novel method improves performance metrics by incorporating a rectangular slot into the patch, which enables operation over two different frequency bands. The addition of the slot significantly increases the return loss of the antenna, which is essential for effective wireless communication. The optimal dimensions of the proposed antenna are 15 × 15 × 2.07 mm³. The FR-4 substrate used in the prescribed design provides a cost-effective, affordable, reliable, and emergency-useful option. The suggested antenna design achieves excellent performance despite its small size by operating effectively at both 6.9 GHz and 12.2 GHz. The prescribed structure offering a bandwidth of 0.5 GHz (6.7-7.2 GHz) at 6.9 GHz and 0.6 GHz (11.9-12.5 GHz) at 12.2 GHz, along with an improved return loss of – 41 dB and – 42 dB, VSWR of 1.02 and 1.01 at resonance. These characteristics enhance the impedance matching at the respective frequencies. The simulated radiation efficiencies are 80 % and 89 %, respectively. In addition, the peak-gain of the prescribed antenna is 9.9 dBi and 9.92 dBi at the desired frequency bands. This design is perfect for wireless communication applications since it is simple, compact, and easy to carry. It also allows seamless operation over two separate frequency bands with minimum reflections.

Keywords: Antenna, Dual band, Gain, VSWR, Radiation efficiency.

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1. INTRODUCTION

There is an increasing need for antennas that provide a combination of high gain, radiation efficiency, low cost, and profile in the present wireless communication environment. An increase in this demand is anticipated. The dielectric resonator antenna is a prominent contender among these several options because to its very desirable characteristics. These antennas can be bought from the commercial sector in a number of shapes and sizes, but the circular ring shape is especially favored for two strong reasons. The ability to precisely regulate the quality factor is the first advantage, as it provides two degrees of freedom. Optimizing this control is necessary to maximize the antenna's performance. The ability of the resonating antenna to handle three different modes is its second benefit. Implementation diversity is provided by these modes, which enable the formation of a broad range of far-field radiation patterns [1]. The resonating antenna is a great choice for satisfying the demands of modern wireless communication due to its versatility and strong performance. For example, an omnidirectional pattern antenna that operates in two bands and is small is shown in [2-3]. To accomplish two transition band operations in [2], a couple of feeds with two parasitic metals inside the antenna box are inserted; however, the antenna gain is not very high. According to research by Song et al. [3], dual-band operation can be covered with the improvement of actual gain using an omnidirectional WLAN loop-slot antenna. A cavity and slot-dipole hybrid construction with array scalability,

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as well as other methods for obtaining an omnidirectional pattern antenna with high gain, are demonstrated in [4]. A 40 × 49 mm² size microstrip patch is proposed in [5] that utilizes a polarization-conversion meta surface through etching the complementary split ring resonator. The overall size of 30 × 40 mm², tiny circular radiating element with two resonating bands covering 2.39-3.75 GHz and 5.39-7.18 GHz was proposed in [7] for various wireless applications [6]. A novel structure with dimensions of 35 × 34 × 1.6 mm³ was developed by Nafis Almas Nafi et al. [8]. This design runs at 4.19 and 4.91 GHz and has a bandwidth ranging from 3.3-4.2 GHz and 4.4-5 GHz. Moreover, flexible antennas are being developed for a broad range applications [9], such as wearable electronics, robotics, IoT [10].

In this article, a novel method for improving dual-band patch antennas' gain, return loss, and compactness using a circular ring and rectangular slot is presented. The ground and radiating planes were constructed using 0.035 mm thick copper and FR-4 as a middle layer with 4.3 permittivity. To assess the performance of the proposed antenna, its dimensions, operating frequencies, gain, VSWR, and return loss are compared with those of earlier studies.

2. DESIGN METHODOLOGY

The proposed design consists of a circular ring with a rectangular slot type antenna as shown in Figure 1. The conventional three-layer structure uses copper for the ground layer, which has total measurements of 15 × 15 × 0.035 mm³. The middle FR-4 layer has a total size of 15 × 15 × 2 mm³. A radiating patch made of copper with an overall size of 13 × 13 × 0.035 mm³ is utilized. The dimensions (mm) of the prescribed structure are $R_1 = 10$, $R_2 = 9$, $R_3 = 7$, $R_4 = 6$, $R_5 = 3$, $a = 5$, $b = 3$, $c = 2$, $x = y = 0.5$.

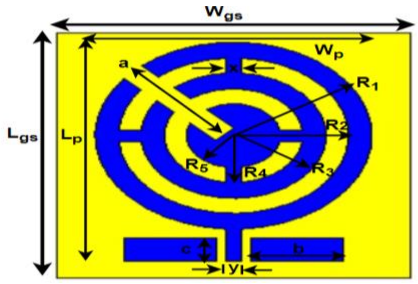


Fig. 1 – Top view of the proposed antenna

Electromagnetic challenges that need accurate and quick simulation results are solved with the CST tool. The key advantage of this tool is its straightforward requirements for linear resource scaling with respect to the number of mesh nodes. This allows for the simple and efficient control of huge radiating structures.

2.1 Step by Step Design Approach

Figures 2 (a-d) depict the methods that were taken into consideration for constructing the proposed antenna. The basic design (Step-1) employs a circular ring as a radiating patch, as seen in Fig. 2(a). In the second stage of design (Step-2) involves inserting a second circular ring inside the first ring with two small square patches as depicted in Fig. 2(b). In the third step (Step-3), a circular ring is added inside the second ring with two small square patches, as shown in Figure 2(c). The last fourth stage (Step-4) involves inserting a rectangular slot within the three rings and inserting two patches at both sides of feeding, as shown in Fig. 2(d). Figure 3 shows the return loss plot for different parts of constructing the proposed design. The last stage (Step-4) yields the highest return loss.

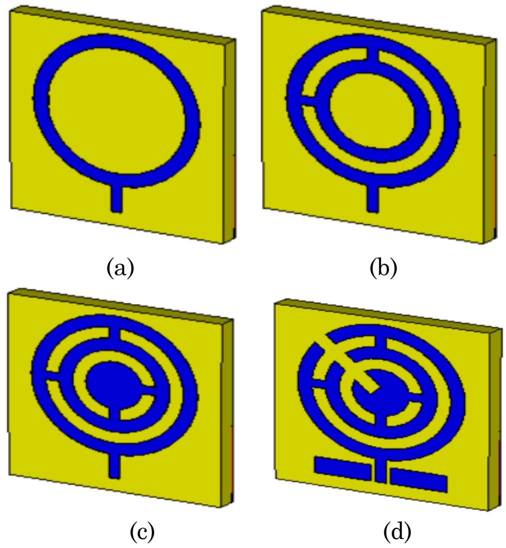


Fig. 2 – Construction of the suggested antenna using various design stages (a) Step-1 (b) Step-2 (c) Step-3 (d) Step-4

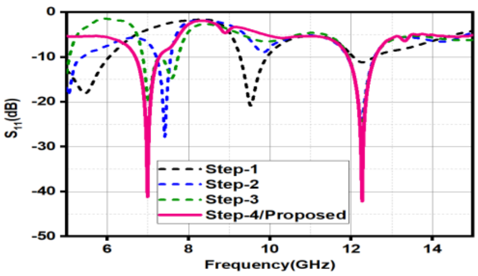
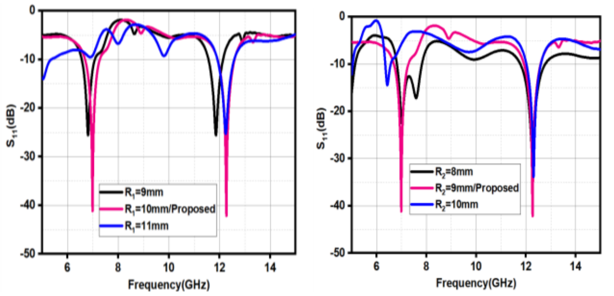


Fig. 3 – The prescribed design S_{11}(dB) vs frequency plot for various iteration steps

3. PARAMETRIC ANALYSIS

3.1 Impact of R_1 and R_2 Parameters

The split gap in the design determines the capacitance value, whilst the metal's length, width, and thickness determine the inductance value. The relative return loss plot is depicted in Figure 4(a) following parametric analysis, by varying R_1 from 9-11 mm with 1 mm step size. The return loss is decreased at $R_1 = 9$ mm and 11 mm. According to Figure 4(a), the maximum return loss for two resonant bands attained only at $R_1 = 10$ mm. Similarly, R_2 is varied with an increment of 1 mm from 8 to 10 mm, the relative return loss plot is displayed in Figure 4(b). Figure 4(b) illustrates that at two resonant bands, $R_2 = 9$ mm produces the highest return loss, whereas $R_2 = 8$ mm and 10 mm produces the lowest return loss.

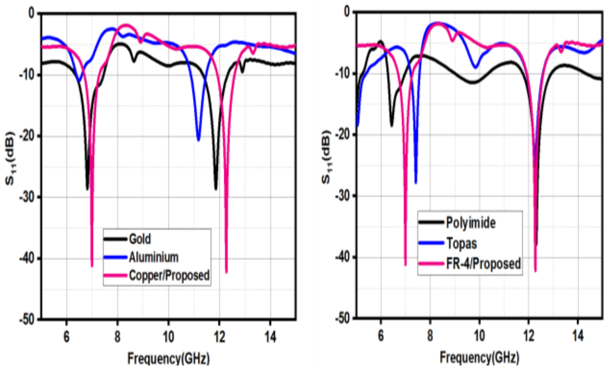


(a) (b)

Fig. 4 – S_{11}(dB) plots obtained through parametric analysis by varying (a) R_1 and (b) R_2 parameters

3.2 Influence on Various Types of Conductive and Dielectric Materials

Analyzing the impacts of various conducting and dielectric materials has revealed differences in return loss. The utilization of suitable material alternatives is essential for the development of an effective structure in the proposed design. While designing the uppermost layer of the design, three conductive materials were considered: gold, aluminium and copper. The copper material may yield the highest S_{11} of the conductive materials investigated in Figure 5(a). The pink spectrum indicates that copper has been selected as the conducting material. Furthermore, parametric analysis is carried out for a several dielectric materials. The dielectric materials considered in the study include polyimide, Topas and FR-4. Figure 5(b) shows that the FR-4 substrate material design yields the highest return loss based on the analysis.

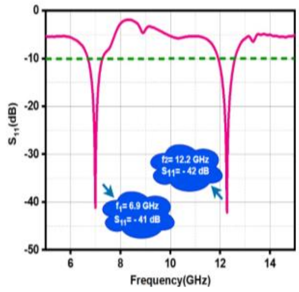


(a) (b)

Fig. 5 – S_{11}(dB) Plot for different materials utilized in the design analysis (a) conductive and (b) dielectric

4. RESULTS AND DISCUSSIONS

Figure 6 depicts the proposed design's return loss plot. Initial resonance of the proposed antenna occurs at 6.9 GHz with 0.5GHz bandwidth (6.7-7.2 GHz) with return loss of – 41 dB, while the proposed design also resonates at 12.2 GHz with 0.6 GHz bandwidth (11.9-12.5 GHz) with return loss of – 42 dB. The VSWR of the suggested design is illustrated in Fig. 7. This figure shows that throughout the whole operational bands' resonant frequency, the VSWR values are below 1.1. To effectively couple electromagnetic (EM) energy into the suggested antenna, a detailed analysis of the microstrip feed with a circular ring is conducted, and the feed length is optimized. In addition, the rectangular slot's implementation results in a higher return loss for the resonating bands. As seen in Figure 7, the VSWR values at resonance are 1.02 and 1.01. Which represents, the proposed antenna has a minimum reflection at two resonant bands.



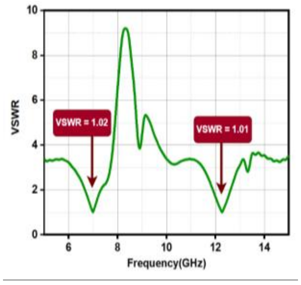
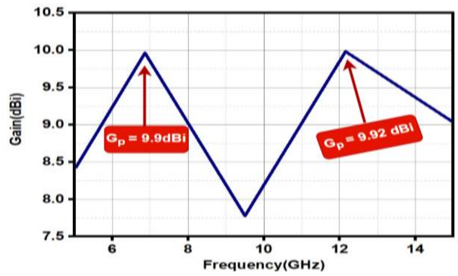
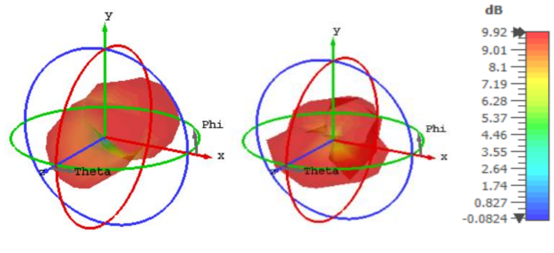


Fig. 6 – Return loss Plot **Fig. 7** – VSWR Plot

The proposed design operates at two resonant frequencies 6.9 and 12.2 GHz produces an excellent peak gain of 9.9 and 9.92 dBi at resonance as depicted in Figure 8(a-c), produces a high radiation efficiency of 80 and 89 % at resonance as shown in figure 9 respectively.



(a)



(b) (c)

Fig. 8 – Gain plot of proposed antenna (a) Simulation (b) At 6.9GHz (c) At 12.2 GHz

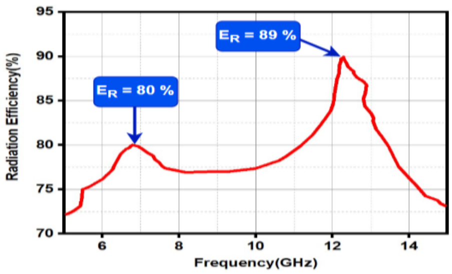
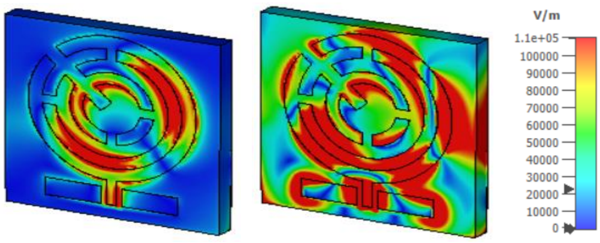


Fig. 9 – Radiation efficiency plot

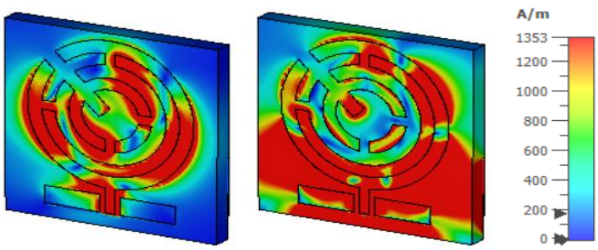
4.1 Various Distributions and Analysis

According to Figure 10(a), the inner circular ring of the radiating patch exhibits the lowest electric field intensity at 6.9 GHz along the antenna's vertical direction. The electric field is stronger at 12.2 GHz in the inner and outer circular rings, as well as on the left and right side of the feed point, as seen in Figure 10(b). In Figure 11(a), a minimum magnetic field is shown in and around the circular ring, which spreads horizontally along the antenna at 6.9 GHz. The magnetic field is stronger at 12.2 GHz, as seen in Figure 11(b). Consequently, the directions of propagation of the electric and magnetic fields are opposite. Figure 12(a-b) illustrates that the feed line displays the maximum current distribution when operating at 12.2 GHz. The inner and outer ring radiating patch has the lowest distribution of current at 6.9 GHz when compared to 12.2 GHz.



(a) (b)

Fig. 10 – Distribution of *E*-field at (a) 6.9 GHz (b) 12.2 GHz



(a) (b)

Fig. 11 – Magnetic field distribution at (a) 6.9 GHz (b) 12.2 GHz

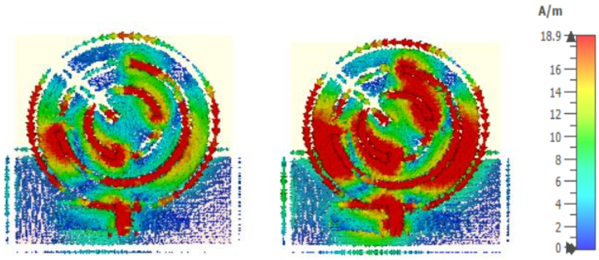


Fig. 12 – Distribution of Surface Current at (a) 6.9 GHz (b) 12.2 GHz

4.2 Performance Comparison with Other Reported Works

The performance of the suggested antenna is contrasted with the presented literature in Table 1. This proposed square-shaped multi-slot defective ground structure patch antenna offers superior radiation efficiency and gain while maintaining compact size.

Table 1 – Comparison with recently reported work

Ref.	Year of Pub.	Ant.Size (mm^2)	S_{11}(dB)	VSWR	Gain (dBi)
[6]	2022	55.5 × 52.9	– 19.4	1.12	7.15
[9]	2023	6.25 × 7.4	– 31.9	1.03	4
[10]	2024	6 × 6	– 17 and – 23	1.21 and 1.09	7.4 and 7.9
This Work	–	15 × 15	– 41 and – 42	1.02 and 1.01	9.9 and 9.92

5. CONCLUSION

This article presents a circular ring shape microstrip patch antenna designed for wireless communication application. The total dimensions of the proposed antenna are 15 × 15 × 2.07 mm^3, and a FR-4 dielectric substrate material has been used for simulation. An antenna designed with optimal dimensions produces superior outcomes, resulting in satisfactory antenna performance. The proposed antenna achieves 9.9 dBi and 9.92 dBi of peak gain, and 80 % and 89 % radiation efficiency at 6.9 and 12.2 GHz frequencies, respectively. Hence, the suggested antenna is strongly recommended for effective wireless communication applications.

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Покращення продуктивності мікросмужкової круглої кільцевої дводіапазонної патч-антени з мінімальним відбиттям для ефективних застосувань бездротового зв’язку

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У цій статті запропоновано компактну дводіапазонну круглу кільцеву патч-антену, призначену для бездротового зв'язку. Цей новий метод покращує показники продуктивності шляхом включення прямокутного слота в патч, що дозволяє працювати в двох різних діапазонах частот. Додавання слота значно збільшує втрати на відбиття антени, що є важливим для ефективного бездротового зв'язку. Оптимальні розміри запропонованої антени становлять 15 × 15 × 2,07 мм^3. Підкладка FR-4, що використовується в запропонованій конструкції, є економічно ефективним, доступним, надійним та корисним в надзвичайних ситуаціях варіантом. Запропонована конструкція антени досягає чудових характеристик, незважаючи на свій невеликий розмір, ефективно працюючи як на частотах 6,9 ГГц, так і на 12,2 ГГц. Запропонована структура пропонує смугу пропускання 0,5 ГГц (6,7-7,2 ГГц) на частоті 6,9 ГГц та 0,6 ГГц (11,9-12,5 ГГц) на частоті 12,2 ГГц, а також покращені втрати на відбиття – 41 дБ та – 42 дБ, КСХН 1,02 та 1,01 на резонансі. Ці характеристики покращують узгодження імпедансу на відповідних частотах. Модельована ефективність випромінювання становить 80 % та 89 % відповідно. Крім того, піковий коефіцієнт посилення заданої антени становить 9,9 та 9,92 дБ в потрібних діапазонах частот. Ця конструкція ідеально підходить для бездротового зв'язку, оскільки вона проста, компактна та зручна для перенесення. Вона також дозволяє безперебійну роботу у двох окремих діапазонах частот з мінімальними відбиттями.

Ключові слова: Антена, Дводіапазонна, Коефіцієнт підсилення, Ефективність випромінювання.