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REGULAR ARTICLE

Compact Semicircle CSRR- Loaded Antenna for Triband Applications

A. Ambika[1,*], C. Tharini[1], P. Chakraborty[1], S.S. Prabhu[1], S. Priyadarsini[2], Y.J.N. Ahamed[3]

[1] *Department of Electronics and Communication Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai 600 048, India*
[2] *Department of Computer Science and Engineering, PSR Engineering College, Sivakasi, India*
[3] *Department of Computer Science and Engineering, Sreenivasa Institute of Technology and Management Studies, Chittoor, India*

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This manuscript presents the analysis as well as the design of a compact size 3 semicircle CSRR (Complementary Split-Ring Resonator) loaded multiband antenna. The proposed antenna has 18 mm × 20 mm dimensions and resonates at three frequency bands, namely 2.7 GHz, 3.75 GHz, and 6.5 GHz, making it suitable for Wi-Fi (802.11a), mid-band 5G band, and WLAN applications. The design includes a rectangular finite ground plane that is longer than $\lambda/4$, which enhances performance. The semicircle CSRR structure is etched from a semicircle monopole antenna, which provides additional resonant modes and also contributes to a reduction in the overall size of the antenna. The antenna has a height of 1.6 mm and is printed on an FR4 dielectric substrate with a dielectric constant of 4.4. The designed antenna has been both simulated and fabricated. The results show that all three frequency bands have achieved stable radiation patterns and acceptable return losses (<– 10 dB). The measured gain averages 2.028 dBi, indicating effective performance. The findings indicate that the antenna exhibits a bidirectional radiation pattern in the E-plane and a uniform distribution in the H-plane for lower frequency bands. This work highlights the antenna's compact design and its potential for efficient operation in modern wireless communication systems, providing a promising solution for future applications.

Keywords: Compact antenna, CSRR (Complementary Split-Ring Resonator), Tri-band, 5G, Wi-Fi, WLAN, Miniaturization, Surface current distribution, Return loss, Radiation pattern, FR4 Substrate.

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1. INTRODUCTION

The rapid evolution of wireless communication systems has led to an increasing demand for compact and efficient antennas capable of supporting multiple frequency bands. Multiband antennas are essential for next-generation wireless technologies, such as 4G, 5G, Wi-Fi, and WiMAX, as they enable the operation of various communication standards within a single device. [1] Highlighted the significance of multiband antennas in enhancing wireless communication systems by offering compatibility across diverse frequency bands, making them indispensable for modern multi-service networks The miniaturization required for multi-band support often compromises efficiency, and achieving optimal performance without interference across multiple bands remains a key limitation. Various techniques have been proposed to achieve multi-band performance, such as the incorporation of metamaterials, complementary split-ring resonators (CSRRs), and defected ground structures (DGS) [2-4, 5] proposed a triband microstrip antenna incorporating a hexagonal complementary split-ring resonator (CSRR). This design effectively achieved triband operation, targeting wireless communication systems. The use of hexagonal CSRR contributed to the compact size and enhanced frequency selectivity. However, the performance of this design in highly congested communication environments and its suitability for higher-order applications remain areas for further exploration. Similarly, [6] proposed a compact triband antenna design incorporating advanced loading techniques to achieve high performance for wireless applications. Their approach successfully minimized the antenna's size while ensuring excellent multiband operation. Similarly, [7] developed a triband slot antenna integrated with an asymmetric split-ring resonator (SRR), demonstrating enhanced frequency selectivity and compactness. Despite these achievements, scalability to other frequency bands and fabrication complexities were identified as limitations requiring further exploration. [8] introduced a multiband antenna design tailored for advanced wireless applications, such as Wi-Fi 6E and Wi-Fi 7. This design utilized optimized complementary

* Correspondence e-mail: ambika@crescent.education

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split-ring resonators (CSRRs) to achieve significant size reduction without compromising performance.

[9] presented a compact tri-band antenna specifically designed for wireless communication and fifth-generation (5G) applications. Their approach leveraged advanced loading techniques to achieve high-performance multi-band operation while maintaining a small form factor.

[10] developed a triband compact antenna aimed at wireless applications. Their design demonstrated enhanced miniaturization and operational efficiency across multiple bands, contributing to the growing body of work on compact multi-band antennas. [11] proposed a tri-band slot antenna integrated with an asymmetric split-ring resonator (SRR), specifically tailored for wire-less applications. The asymmetric SRR configuration enabled the antenna to achieve tri-band operation with enhanced frequency selectivity and compactness. Despite these advancements, there is still a need for innovative approaches to address the limitations of existing methods.

This work presents three new, enhanced compact semi-circular monopole antenna designs featuring a CSRR- based patch structure. These designs are intended for Wi- Fi (802.11a), mid-band 5G, and WLAN services, offering good antenna parameters. The proposed antenna designs aim to overcome the drawbacks of previous methods by providing a compact solution without altering the shape and size of handheld devices. Implementing CSRRs allows for unique antenna characteristics, including multiband performance and size reduction, making these antennas well-suited for modern wireless communication systems.

2. PROPOSED DESIGN OF ANTENNA

The proposed antenna design consists of monopole antennas in a semicircle shape. The rectangular finite ground plane's length is slightly more than $\lambda/4$, Here, λ represents the wavelength of the frequency being used. The monopole antenna is printed on the top side of a FR-4 dielectric substrate, while the ground plane is printed on the opposite side.

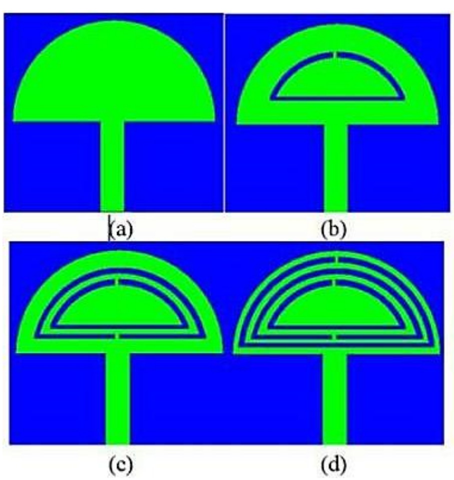

Fig. 1 – Refinement of Semicircle SRR antenna

Figs. 1a, 1b, 1c, and 1d illustrate different configuration phases of a semicircle split-ring resonator (SRR)-based monopole antenna designed for tri-band applications. The proposed design improves the conventional semicircle monopole antenna with an insert feed. The antenna is integrated onto an FR-4 substrate ($\varepsilon_r = 4.4$) with dimensions of $(20 \times 18 \times 1.6)$ mm^3. To achieve three bands with a partial ground plane, a single, double, and triple CSRR ring was formed in the conventional monopole antenna while maintaining the same semicircle shape. The antenna specifications are shown in Table 1.

The following design equations were used to design the antenna [12]

$$f_r = \frac{X_{mn}}{h_{cm}+B_m} \tag{1}$$

Where $a = 9$ mm and $h = 1.6$ mm

$$a_e = a\left\{1 - \frac{2h}{\pi a}\left(ln\frac{\pi a}{2h} + 1.7726\right)\right\}^{0.5} \tag{2}$$

$$f_r = \frac{1.8412\times3\times10^8}{4\times3.14\times9.3\sqrt{4.4}} \tag{3}$$

Table 1 – Proposed antenna dimensions

Parameters	Dimensions(mm)
Width, W	18
Length, L	20
Radius, R	9
Ground length, g_l	8.2
1st CSRR radius, r_1	6
2nd CSRR radius, r_2	7.5
3rd CSRR radius, r_3	8.5
1st CSRR width,	0.3
1st CSRR Split gap, Ws_1	0.3
2nd CSRR Split gap, Ws_2	0.4
3rd CSRR Split gap, Ws_3	0.25

The radius of the monopole is denoted as a_e, while the resonant frequency is represented as f_r. In this design, the parameters were selected as $a = 9$ mm, $h = 1.6$ mm, and $a_e = 9.82$ mm to achieve a resonant frequency of approximately 2.13 GHz. To introduce additional electrical resonance at 3.6 GHz, a semicircular split-ring complementary split-ring resonator (CSRR) was etched from the monopole antenna. This resonance was achieved by carefully designing the dimensions of the CSRR, including its width and length. Further, additional semicircular CSRRs were etched along the outer edges of the monopole antenna. This modification was implemented to create resonance at 2.4 GHz while simultaneously enhancing the impedance matching at 3.8 GHz, which corresponds to the upper resonant frequency of the band. The top and bottom geometries of the proposed antenna, designed for tri-band operation, are illustrated in Fig. 2. Fig. 3 shows the experimental antenna. In Fig. 4, a comparison is made between the simulated return loss (S_{11}) characteristics of a monopole antenna with and without CSRR configurations. When a single semicircle CSRR is employed, the antenna has a band that resonates at 3.6 GHz. On the other hand, using dual semicircle CSRR results in resonances at 3.5 GHz and 7 GHz but with poor impedance matching. However, by implementing a triple semicircle CSRR, the antenna demonstrates several resonances at frequencies of 2.2 GHz, 3.8 GHz, and 6 GHz, while also achieving enhanced impedance matching.

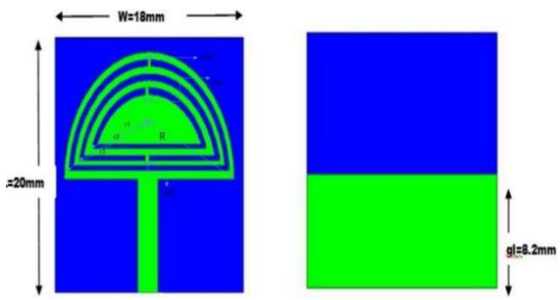

Fig. 2 – Displays the suggested shape of the antenna (a). Overhead perspective (b). View from the bottom

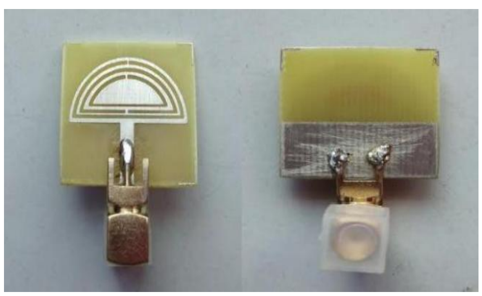

Fig. 3 – Front View and Back view

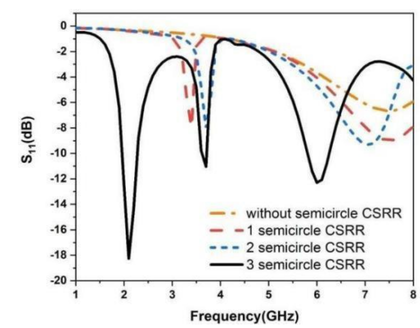

Fig. 4 – Displays the simulated S_{11} characteristics for the proposed antenna both with and without CSRRs

3. SURFACE CURRENT DISTRIBUTIONS

The surface current distribution of the proposed monopole antenna was analyzed to understand its operating mechanism across three frequency bands: 2 GHz, 3.6 GHz, and 6 GHz. This analysis is critical for identifying the role of various antenna parameters in performance across these bands. The results reveal that in the three-slot circular antenna structure, the center and outer slots are primarily responsible for resonance at the lower frequency band (2 GHz), while the inner slot contributes to resonance at 3.6 GHz. Through a coupled effect, the three circular slots collectively enable resonance at the higher frequency band of 6 GHz. In the semicircular CSRR-loaded monopole antenna, the outer semicircular CSRR is primarily responsible for the resonance at the 2 GHz frequency band. The results of this analysis are illustrated in Fig. 5.

4. RADIATION PATTERNS AND GAINS

This antenna has been fabricated, and its E- and H-plane radiation patterns were measured at frequencies of 2.7 GHz, 3.75 GHz, and 6.5 GHz in an anechoic chamber. Fig. 7 presents the measured radiation parameters of the proposed antenna across these three frequency bands. The results indicate an average gain improvement of 2.028 dB at the measured frequencies. The findings show that the antenna exhibits a bidirectional radiation pattern in the E-plane and a uniform radiation distribution in the H-plane for the lower frequency bands. However, at 6.5 GHz, deviations from the expected pattern are observed, likely due to manufacturing inaccuracies or measurement errors.

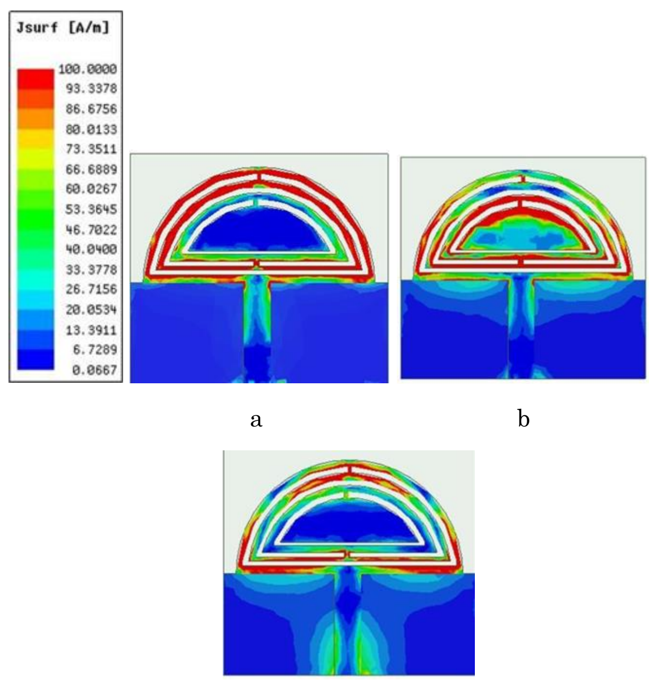

Fig. 5 – Surface current distribution of semicircle CSRR for respective frequency band, (a) 2 GHz, (b) 3.6 GHz, (c) 6 GHz

5. SIMULATED VS MEASURED RESULT DISCUSSION

The fabrication and measurement of this antenna have been completed. Fig. 9 displays the $|S_{11}|$ results obtained from simulations and measurements within the frequency range of 2 to 7 GHz. The experimental results suggest that the lower band has a functional range ($|S_{11}|$ 10 dB) of 150 MHz (2.6 – 2.75 GHz), the middle band has a functional range of 100 MHz (3.7 – 3.9 GHz), and the higher band has a functional range of 500 MHz (6.2 – 6.7 GHz). These bandwidths allow the antenna to provide LTE band, WiMAX, and WLAN operations, as requested. The differences between the modeled and tested curves might be caused by a manufacturing fault, the substrate's relative permittivity tolerance, or a mismatch in the particular impedance be-tween the SMA connection and the micro strip feed line.

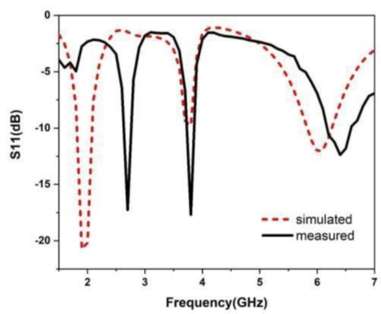

Fig. 6 – Simulated and measured S_{11} parameters

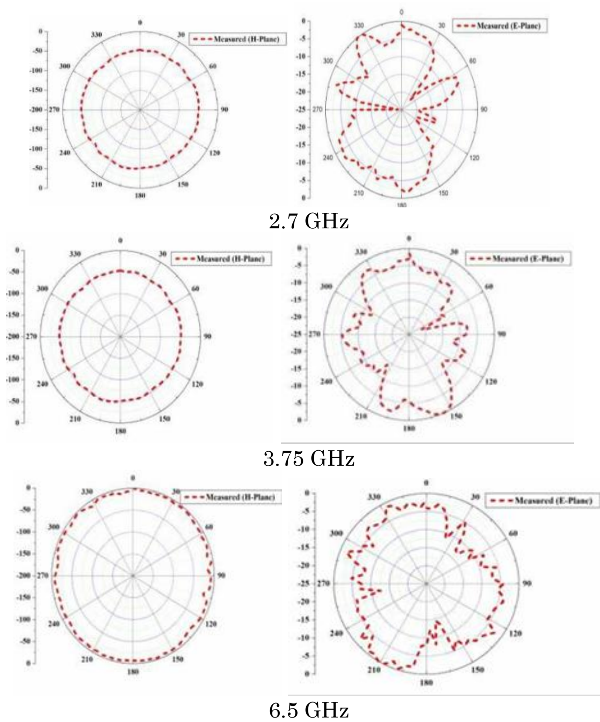

Fig. 7 – *H*-plane and *E*-plane patterns

A comparison of the recommended performance parameters for the proposed triple-band antenna and existing multi-band antennas designed for WLAN and WiMAX applications is provided in Table 2. The table offers detailed insights into the antenna dimensions, resonant frequencies, advancements, radiation patterns, and frequency ranges utilized by each design. The antennas described in references [6, 11, 12] exhibit relatively large dimensions, and their suboptimal ground structures contribute to reduced gain. In contrast, the triangular split-ring resonator (SRR) demonstrates a notably low gain performance.

Table 2 – Comparison of the performance characteristics

Ref	**Antenna**	**Antenna dimensions**	**Resonant Frequencies (GHz)**	**Gain (dBi)**
[13]	Triangular SRR resonator	30 × 50 × 1.6	3.5, 4.1, 5.6 & 9.7	1.24, 0.62, 0.69
[14]	Defected ground structure	50 × 50 × 1.5	1.2 GHz, 2.45 GHz and 5.6372 GHz	NA
[15]	Hilbert fractal slot and DGS	24 × 34 × 1.6	2.45, 3.6, 5.7	1.7, 2.1, 4.02
[Proposed]	Tri Semicircle antenna design	18 × 20 × 1.6	2.7GHz, 3.75GHz, and 6.5GHz	Avg gain of 2.028

6. CONCLUSIONS

The analysis reveals that the antenna proposed in this study provides adequate gain, a reliable omnidirectional radiation pattern, and sufficient bandwidth to cover the desired Mid-Band 5G and WLAN frequency ranges. Additionally, these benefits are achieved within a compact form factor, making the proposed antenna a highly efficient and practical solution.

REFERENCES

1. J. Smith, E. Johnson, R. Davis, *IEEE Trans. Antennas Propag.* **60** No 4, 1789 (2022).
2. Mishra, S. Thakur, S. Pandey, *IEEE Access* **7**, 93753 (2019).
3. N.K. Mallat, A. Iqbal, *Prog. Electromagn. Res. Lett.* **84**, 39 (2019).
4. T. Osklang, C. Phongcharoenpanich, P. Akkaraekthalin, *Int. J. Antennas Propag.* **4**, 1 (2019).
5. M. Aminu-Baba, M.K.A. Rahim, F. Zubir, M.F.M. Yusoff, A.Y. Iliyasu, M.M. Gajibo, H.A. Majid, K.I. Jahun, *Bull. Electr. Eng. Inform.* **9** No 5, 1916 (2020).
6. R. Rajkumar, U.K. Kommuri, *IEEE Xplore* **66** No 6 (2018).
7. S.M. Verulkar, A. Rochkari, M.A. Trimukhe, V. Bodade, R.K. Gupta, *Prog. Electromagn. Res. C* **142**, 1 (2024)
8. L. He, S. Yi, H. Yang, *J. Electromagn. Waves Appl.* **36** No 1, 69 (2022).
9. M. Raja Kumar, M. Meena, *J. Electr. Syst.* **20-6s**, 2857 (2024).
10. D. Allin Joe, T. Krishnan, *Int. J. Antennas Propag.* **2023**, 5344999 (2023).
11. V.K.S. Rajanna, T.V. Venkatesh, P.K.T. Rajanna, M.S. Shambulinga, *Prog. Electromagn. Res. Lett.* **117** (2024).
12. D.R.S. Daniel, R. Pandeeswari, S. Raghavan, *AEU-International J. Electron. Commun.* **75**, 8 (2017).
13. K. Mahendran, R. Gayathri, H. Sudarsan, *Microprocess. Microsyst.* **80**, 103400 (2021).
14. M. Mabaso, P. Kumar, *J. Commun.* **14** No 8, 684 (2019).
15. O. Benkhadda, M. Saih, K. Chaji, S. Ahmad, A. Reha, *Prog. Electromagn. Res. C* **133**, 167 (2023).

Компактна антена з напівциркулярним CSRR-резонатором для тридіапазонних застосувань

А. Амбіка[1], Ч. Тхаріні[1], П. Чакраборті[1], С.С. Прабху[1], С. Пріядарсіні[2], Й.Дж.Н. Ахамед[3]

[1] *Кафедра електроніки та зв'язку, Інститут науки й технологій B.S. Abdur Rahman Crescent, Ченнаї, Індія*
[2] *Кафедра комп'ютерних наук та інженерії, Інженерний коледж PSR, Сівакасі, Індія*
[3] *Кафедра комп'ютерних наук та інженерії, Інститут Sreenivasa, Чіттур, Індія*

У даній роботі представлено аналіз та проєктування компактної тридіапазонної антени, навантаженої напівциркулярною структурою CSRR (Complementary Split-Ring Resonator). Запропонована антена має розміри 18 × 20 мм і працює на трьох резонансних частотах: 2.7 ГГц (підходить для Wi-Fi 802.11a), 3.75 ГГц (для середньочастотного діапазону 5G), 6.5 ГГц (для WLAN-застосувань). Конструкція антени включає прямокутну обмежену опорну площину, довжина якої перевищує 1/4 довжини хвилі (λ/4), що сприяє покращенню робочих характеристик. CSRR-структура витравлена з напівциркулярного монопольного елемента, що створює додаткові резонансні моди та дозволяє зменшити розміри антени. Антена має висоту 1.6 мм і виготовлена на діелектричній підкладці FR4 з діелектричною сталою $\varepsilon_r = 4.4$. Усі три діапазони мають стабільні характеристики випромінювання та зворотні втрати нижчі за – 10 дБ, Середній коефіцієнт підсилення: 2.028 дБі. В *E*-площині спостерігається двонапрямна діаграма випромінювання, а в *H*-площині – рівномірний розподіл на нижчих частотах. Це дослідження демонструє ефективність мініатюрної конструкції антени, придатної для сучасних бездротових комунікаційних систем, зокрема 5G, Wi-Fi та WLAN, і становить перспективне рішення для майбутніх компактних пристроїв.

Ключові слова: Компактна антена, CSRR, Тридіапазонність, 5G, Wi-Fi, WLAN, Мініатюризація, Розподіл поверхневого струму, Зворотні втрати, Діаграма випромінювання, Підкладка FR4.