Journal of Engineering Science and Technology
Vol. 20, No. 1 (2025) 336 - 344

DESIGN OF QUADRIC-BAND RESONANT FREQUENCIES WITH PARASITIC STRIPS FOR WIRELESS COMMUNICATION

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Abstract

Multi-band antenna array's development and evaluation for C band, 5 GHz WLAN, and X-band applications is proposed in this publication. . The study can be adapted to higher frequencies for fifth-generation (5G) applications. This unique design is suitable for environments requiring multi-band antennas and IoT devices where smaller size is essential. The antenna is constructed on an RF-4 substrate that has a thickness of 1.4 , permittivity of 4.4. mm. And it is intended to produce four modes at distinct resonant frequencies. The antenna's overall measurements are 25 x 25 x 1.4 mm. According to simulated data, the peak gain ranges from 5 to 7 dB, and the reflection coefficient is less than -10 dB. The radiation efficiency ranges from-0.004 dB to 0.002 dB. The antenna design and results were obtained using CST simulation software. The achievement of quadric-band resonant frequencies in this study is innovative, with performance improved by the use of specially designed parasitic strips. Furthermore, the parasitic strips enabled the quadric-band to be achieved without increasing the antenna size.

Keywords: Multiband antennas, Parasitic elements, Patch antennas, Wireless communication.

1. Introduction

The 5G network has drawn a lot of attention from academia and industry due to the rapid expansion of wireless communications; many reported efforts and research outputs have been made in this area [1, 2]. Even with advancements in mobile communication, the primary function of any antenna remains data collection. The need for low-cost, small, and compact antennas has grown significantly in the last few years. Since multiband antennas resonate at several frequencies, they reduce the requirement for multiple antenna elements in a communication device, which is an improvement in modern multifunctional wireless communication systems [3-5].

The challenge of designing small, multiple-resonant antennas has given many researchers the chance to study a variety of viable solutions. In addition to handling multiband operation, they also deal with the requirement for two or more independent antennas, preventing the isolation issue that could occur from multiple antennas. Many antennas have been proposed for this purpose [6]. The majority of them are made to support two 2.4/5 GHz WLAN frequency bands [7-9].

Simulations have been conducted on patch antennas with triangular slots [10] and antennas utilizing metamaterials [2, 11]. A broad ground plane, featuring various shapes such as squares, rectangles, or circles [12], with protruding parasitic strips has been explored to achieve dual notched bands and increased bandwidth [13]. Reconfigurable technologies are also among the approaches studied for creating multiband antennas [14, 15].

One multiple-input, multiple-output (MIMO) architecture is created by an inventive four-element frequency reconfigurable antenna system that integrates underlay and interweave cognitive radio approaches [16]. Kareem et al. [17] uses a combination of two antennas to create a dual-polarized system to achieve a MIMO antenna. Two antennas are mounted, one on the substrate surface and the other on the outside of the side-edge frame, By placing diodes, the resonance frequency can be dynamic adjusted.

Parasite strips are one of the main methods to create multi-band antennas and increase gain [18]. Compactly printed monopole antennas are used for a range of applications [19]. Their design makes them ideal for direct integration onto communication device circuit boards. Antenna-in-package (AiP) is a good option for compact integration with RF integrated circuits in order to improve the integration of radiofrequency (RF) components for automotive radar. The strips can further increase radiation gain and lower sidelobe level [20]. To accomplish in-phase current distribution, the parasitic strips are set up in a trapezoidal configuration.

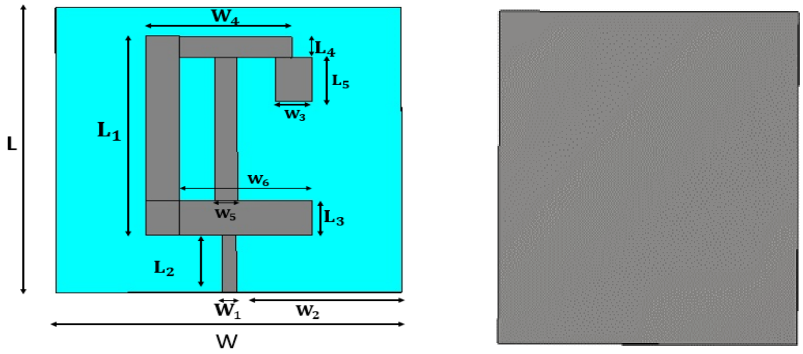
This research presents a study of a multiband antenna operating at four resonant frequencies. The proposed design is based on an inexpensive and widely available FR4 substrate. The antenna dimensions are 25 mm, designed for 5.79 GHz, 8.23 GHz, 11.6 GHz, and 4.3 GHz operating frequencies. The main objective of this research is to develop a multiband antenna with higher gain. The performance of the antenna and its parameters are thoroughly analysed.

The layout of this paper is as follows: Part 2 describes the primary antenna design. Section 3 provides additional details on the parametric analysis, optimization processes, and performance evaluation of the proposed antenna. To enhance gain, a 1-element phased array has been studied and simulated. The final section of this paper presents the conclusions of the research, which may be applicable in 5G and beyond telecommunications.

2. Antenna Design

The desired antenna's geometry and structure are illustrated in Fig. 1, modelled using Computer Simulation Technology (CST). The design employs FR4 as the substrate material, with a perfect electrical conductor applied to both sides. The substrate has a dielectric relative permittivity of 4.4 and a thickness of 1.4 mm. The specified antenna's total dimensions are 25 × 25 × 1.4 mm. A microstrip feed width of 0.8 mm is used to achieve impedance matching and minimize feeding loss, with the antenna designed for an input impedance of 50 ohms.

A rectangular parasitic patch with slots and strips is placed above the conductor to create a capacitive coupling effect. The multiband performance of the antenna is achieved by adjusting specific parameters. The most suitable dimensions for the recommended multiband antenna are provided in Table 1. Figure 1 depicts the final design, which successfully achieves multi resonance frequencies, with Fig. 1(a) showing the top view of the antenna.



(a) Front view **(b) Back view (Ground Plane)**

Fig. 1. Multi-band antenna with parasitic strips.

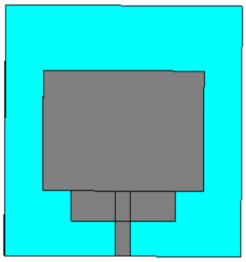
The initial design, shown in Fig. 2(a), is a patch antenna that radiates at 4.77 GHz. Throughout the design process, the antenna width and length remained constant, while modifications were made to the radiating patch and ground plane. These modifications to the radiating patch are illustrated in Fig. 2(b).

The structure resonates at dual bands of 5 GHz and 8.8 GHz due to the modifications, though the lower band exhibits weaker resonance. Figure 2(c) illustrates the creation of parasitic strips that enable multi-frequency band resonance, although these strips result in a lower reflection coefficient of 4.77 dB. Reflection coefficient for the suggested designs plotted against frequency as shown in Fig. 3.

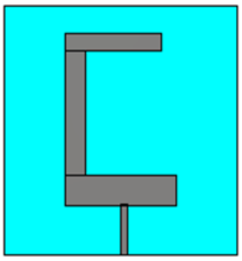
In the final stage of design improvement, a secondary strip is added, allowing the antenna to operate at 4.3 GHz, 5.79 GHz, 8.23 GHz, and 11.6 GHz. This configuration supports WLAN, Sub-6 GHz 5G, X-band, and Ku-band applications. The design operates in a hybrid mode, exciting two modes through a single radiating aperture. Both resonance and anti-resonance frequencies are radiated by the hybrid mode antenna [21-23].

Table 1. Parameters of the Structure for the Considered Design.

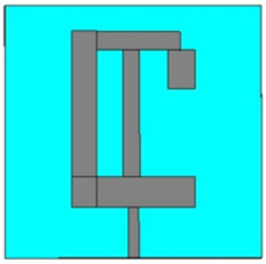
Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	25	L_4	1.8	W_3	2.5
W	25	L_5	4	W_4	10.4
L_1	17	W_1	0.8	W_5	1.3
L_2	5	W_2	14.7	W_6	12



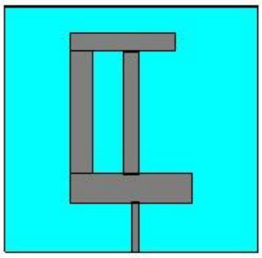
(a) Prototype 1



(b) Prototype 2



(c) Prototype 3



(d) Prototype 4

Fig. 2. The stages for the selected antenna's structure.

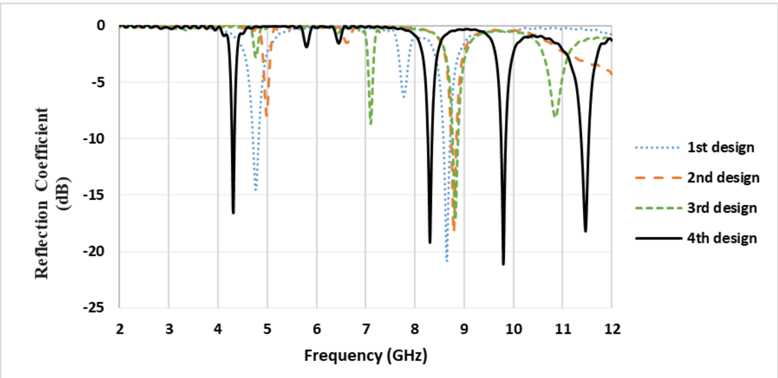


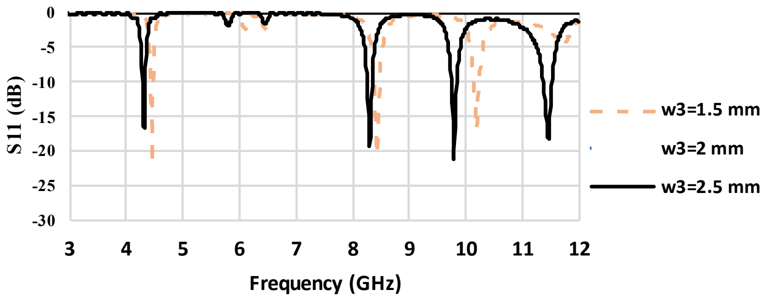
Fig. 3. Reflection coefficient for the suggested designs plotted against frequency.

3. Impact of Antenna Parameter's on Reflection Coefficient

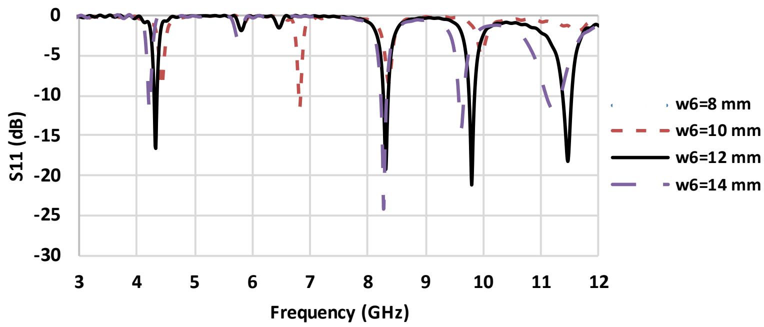
The optimization of antenna parameters is evaluated using CST electromagnetic simulation technology. The reflection coefficient characteristics of the proposed antenna are shown in Figs. 4(a) and (b). The results indicate that resonant frequencies can be produced, modified, and overlapped by adjusting parameters. Specifically, shifting the resonant frequency around 11.3 GHz leads to improvements, although it results in a slight shift. As resonant frequencies increase, they are slightly shifted, and the reflection coefficient drops below 10 dB. Increasing the parameter to 14 mm further lowers the reflection coefficient.

Increasing the dimension of the parameter from 2 mm to 4 mm causes a slight shift in the resonant frequencies and an increase in the reflection coefficient, as shown in Fig. 4(c). The resonant frequencies between 9 GHz and 12 GHz are affected by this parameter change. When the parameter is set to 4 mm, the reflection coefficient remains below 10 dB.

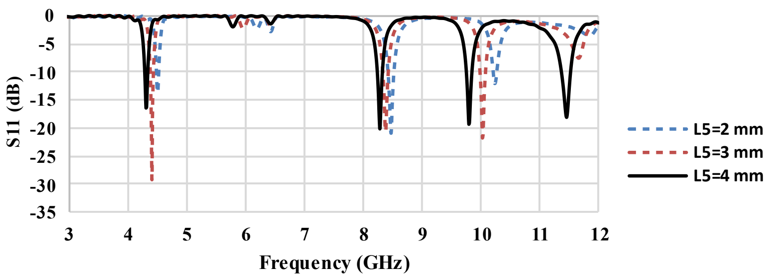
As seen in Figs. 2 and 3, the findings are compared with common projectile configurations to verify the validity and accuracy of the calculations. Table 1 provides a thorough description of the model and test conditions.



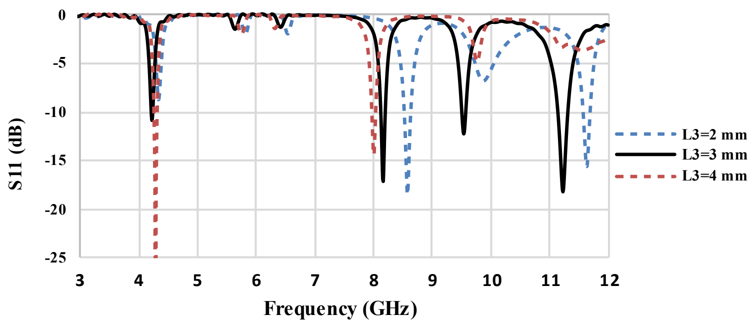
(a) Effect W_3



(b) Effect W_6



(c) Effect L_5



(d) Effect L_3

Fig. 4. The effect of parameters W_3, W_6, L_5, L_3 on reflection coefficient.

4. Radiation Pattern and Gain

Figure 5 displays a reflection coefficient as an indicator of frequency. After adjusting each design parameter, the resonant frequencies are observed at 4.3 GHz, 8.3 GHz, 9.7 GHz, and 11.45 GHz. The reflection coefficient for each resonant frequency is below 10 dB. Figure 6 illustrates that the gain between 5 GHz and 6 GHz drops to below 4 dB. Beyond 6 GHz, as the resonant frequency increases, the gain rises by up to 7 dB.

At 4.3 GHz, the radiation efficiency and gain is -0.58 dB and 5.3 dB respectively, The radiation efficiency and gain at 8.3 GHz are -0.04 dB and 5.79 dB. The radiation efficiency and gain at 9.79 GHz are -0.02 dB and 6.46 dB, respectively. Lastly, the radiation efficiency and gain at 11.45 GHz are 0.02 dB and 6.89 dB, respectively. In contrast to the other resonant frequencies, there are greater sidelobes between 8.3 GHz and 11.45 GHz.

Figure 7 illustrates the distribution of surface current for the quadric antenna. At 4.3 GHz and 8.3 GHz, the current is concentrated near the right strips of the patch, as shown in Figs. 7(a) and (b). At 9.7 GHz, the current is distributed more uniformly across the patch, as depicted in Fig. 7(c). For the final resonant frequency of 11.45 GHz, the current is primarily distributed across the patch's middle section, as seen in Fig. 7(d).

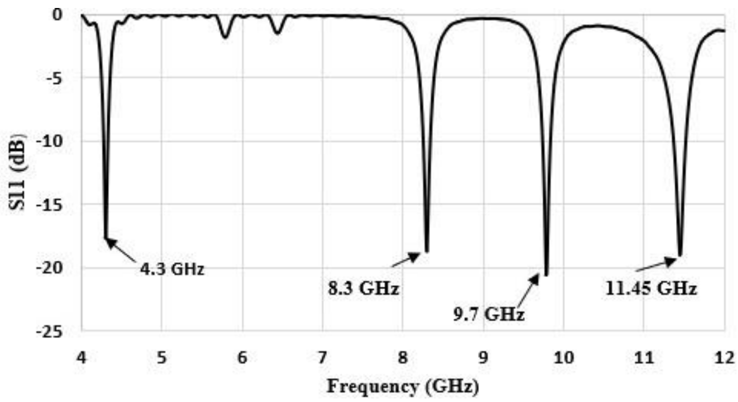
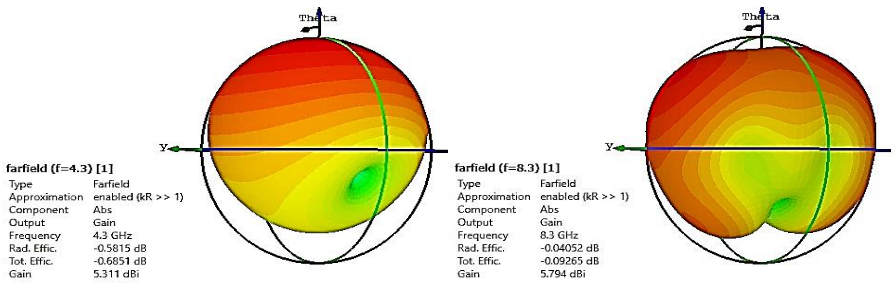
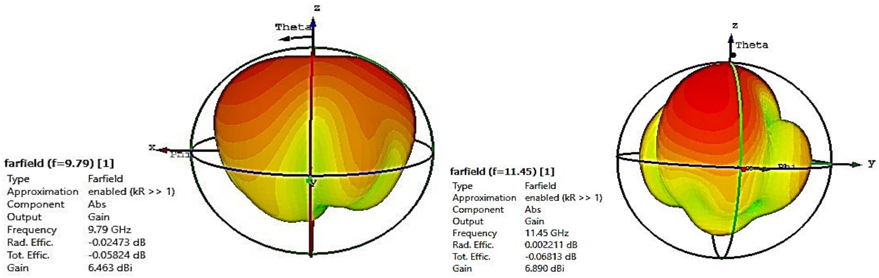


Fig. 5. Reflection coefficient against frequency.

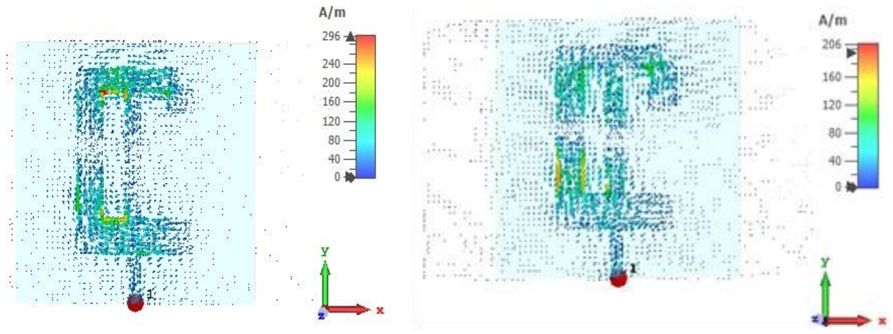


(a) 4.3 GHz **(b) 8.3 GHz**

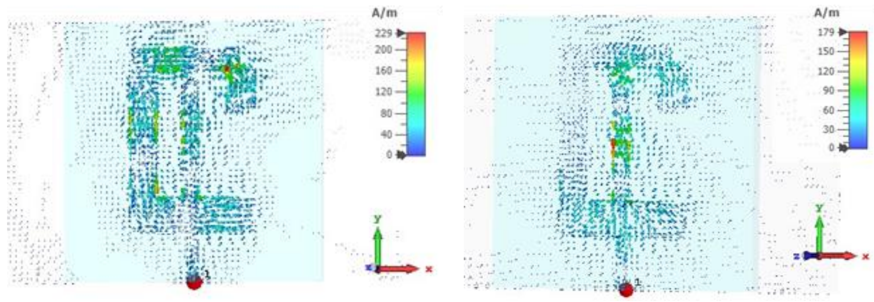


(c) 9.79 GHz **(d) 11.45 GHz**

Fig. 6. radiation pattern at different frequencies.



(a) 4.3 GHz. **(b) 8.3 GHz.**



(c) 9.7 GHz. **(d) 11.45 GHz.**

Fig. 7. Current distribution at different frequencies.

5. Conclusion

A Quadric-band antenna is presented, utilizing parasitic strips to excite the resonant modes . The resonant frequencies are 4.3 GHz, 8.3 GHz, 9.79 GHz, and 11.45 GHz. The radiation efficiency ranges from -0.004 dB to 0.002 dB, while the gain varies between 5.3 dB and 6.8 dB. The resonant frequencies exhibit a reflection coefficient below 10 dB and an impedance matching of 50 ohms. Rescaling the multiband antenna to higher frequencies makes it potentially suitable for 5G applications.

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