Design And Analysis of Circularly Polarized Microstrip Patch Antenna with Enhanced Bandwidth For C- Band Frequencies

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Abstract:

This paper presents the design and characterization of a circular microstrip patch antenna with enhanced bandwidth. The antenna, fabricated on an FR-4 substrate with dimensions of 23 mm x 23 mm x 0.8 mm, utilizes a partial ground plane configuration to achieve the desired performance. Through careful design and optimization, the proposed antenna achieves a bandwidth of 4 GHz, with a peak resonating frequency of 6.2 GHz. Additionally, the axial ratio bandwidth is measured at 700 MHz. The antenna exhibits a constant gain of 2.69 dBi across its bandwidth, ensuring consistent performance. Furthermore, the antenna demonstrates good radiation patterns, making it suitable for a wide range of applications requiring reliable wireless communication.

Keywords: ***Circular microstrip patch antenna, Enhanced bandwidth, Partial ground plane configuration, Bandwidth optimization.***

I. INTRODUCTION

The C-band spectrum, ranging from 4 GHz to 8 GHz, offers valuable real estate for wireless communication due to its favorable propagation characteristics and regulatory compliance. This band underpins various applications like satellite communication, radar systems, and wireless networks. However, the ever-increasing demand for high-speed data transmission necessitates the design and analysis of antennas with wider bandwidths to meet these growing needs.

Microstrip patch antennas, known for their compactness, lightweight structure, and ease of integration, are particularly well-suited for harnessing circularly polarized (CP) wave radiation within the C-band. This research introduces a novel design for a circularly polarized microstrip patch antenna specifically tailored for C-band applications.

This innovative design leverages a strategic combination of cutting-edge elements to achieve exceptional CP performance. A meticulously engineered rectangular stub forms the core of the design, playing a critical role in enabling CP wave radiation and ensuring optimal functionality across the desired frequency range. Furthermore, a strategically integrated parasitic strip facilitates dual-band CP operation, significantly enhancing the antenna's versatility and adaptability for various communication scenarios.

The subsequent sections of this paper delve deeper into the proposed design. We begin by exploring the significance of C-band communication and the advantages of microstrip patch antennas. Following this, we meticulously dissect the proposed antenna design, explaining the rationale behind each element and its contribution to achieving CP radiation and enhanced bandwidth. The paper then progresses to a detailed analysis of the antenna's performance through simulations and measurements. Finally, we conclude by summarizing the key findings and highlighting the potential applications of this innovative design in C-band communication systems.

II. COMPACT DESIGN AND ANALYSIS OF ANTENNA

The groundbreaking antenna design exemplified in this research epitomizes a sophisticated amalgamation of state-of-the-art components, including a parasitic structure, rectangular stub, partial ground, and an "L"-shaped microstrip radiator. Each element has been meticulously optimized to fully exploit the potential of circularly polarized (CP) wave radiation, resulting in a dual-band CP operation that guarantees exceptional performance. At the heart of this innovation lies the rectangular stub, a crucial component enabling CP wave radiation and ensuring peak functionality across the frequency spectrum. Furthermore, the incorporation of a parasitic strip facilitates dual-band CP operation, elevating the antenna's versatility and adaptability in diverse scenarios.

This final antenna design, depicted in Figure 1, showcases

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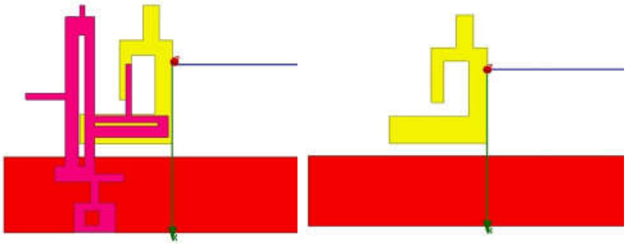
a compact and efficient form factor measuring 23 x 23 x mm on a widely used FR4 epoxy substrate. With its strategic integration of essential elements like the parasitic structure, rectangular stub, partial ground plane, and L-shaped microstrip radiator, this antenna promises unparalleled performance and reliability in signal transmission and reception.

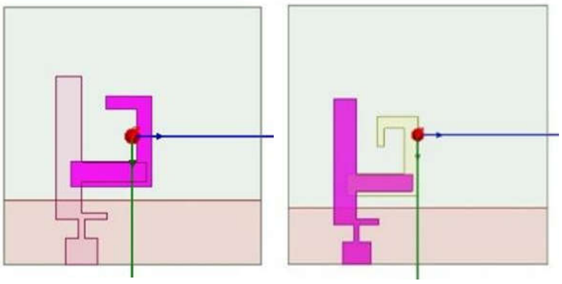


(a) (b)

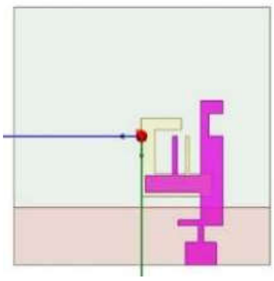
Figure 1: (a) Front View (b) Back view of the antenna

Revealing the Evolutionary Phases

The journey of antenna development unfolded through a captivating progression of stages, each building upon the foundation laid by its predecessor:



(a) (b)



(c)

Figure 2: (a), (b) & (c) Evaluation of stages

The antenna design process unfolded in stages, each building on the previous one [Figure 2]. The initial stage (a) used a basic monopole radiator with a full ground plane, resulting in a narrow bandwidth (0.11 GHz) and linear polarization around 9.5 GHz. Stage 1 (b) introduced a rectangular patch on the monopole radiator, likely accompanied by ground plane modifications, to broaden the bandwidth and lay the groundwork for circular polarization in later stages. Specific performance details for this stage are unclear. Stage 2 (c) incorporated a parasitic structure, likely an additional strip element, to achieve dual-band operation by introducing new resonant frequencies. However, details about the new bands, bandwidth expansion, and polarization are unknown.

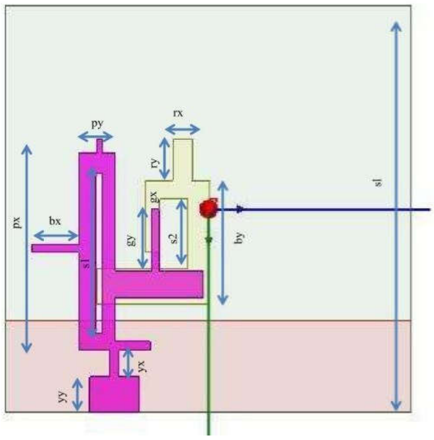


Figure 3: Final design of the antenna.

The final stage, called the "Ultimate Iteration" (Figure 3), combined all the elements from previous stages: the rectangular patch, partial ground plane, parasitic structure, and a rectangular stub for phase control. This stage achieved single-band circular polarization within a specific frequency range with a gain of 2.69 dBi. There appears to be a discrepancy between the text suggesting dual-band CP and the actual design, which seems optimized for single-band CP in the C-band spectrum.

The Table 1 represents how the different developed stages of the antenna design vary with one another.

TABLE 1: The development stages analysis

Antenna Stage	Operating Band/B.W(GHz)	Peak Gain(dbi) in the operating band	Applications
0	(9.54-9.65)/0.11	1.09	Single band with no CP
1	(4.91-5.51)/0.6 (6.61-7.5)/0.89	2.05 2.19	Dual-band with CP
2	(3.41-4.27)/0.86 (6.9-7.96)/1.06	2.20 2.22	Dual-band with no CP
3 (Final)	(4.01-10.22)/5.9	2.69	Single band with CP

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To achieve peak performance and enhanced bandwidth, a detailed examination and refinement of antenna geometry and feeding methods were meticulously carried out. Utilizing advanced simulation tools was pivotal in ensuring that the design met the desired criteria. A thorough performance assessment, covering aspects such as impedance bandwidth, peak gain, axial ratio bandwidth, and radiation pattern analysis, was conducted to affirm the antenna's suitability for C-band applications. Additionally, real-world performance was verified through experimental testing.

TABLE 2 OPTIMIZATION PARAMETERS

Optimized Parameter	Value (mm)
SL	23
Space	4.8
h	0.8
RX	2
ry	2.8
yy	0.5
yx	1.5
xx	0.5
by	4
px	10.7
py	2
by	1.5
by	5
sd	3

The compact and efficient design of the proposed antenna not only simplifies implementation but also highlights its versatility. This foundational design serves as a robust platform for various circularly polarized (CP) antennas, showcasing its adaptability across diverse configurations.

In summary, this study introduces a groundbreaking advancement in CP antenna technology. The innovative design offers a compelling blend of performance, versatility, and adaptability. Through meticulous optimization and rigorous analysis, this research sets a new benchmark in antenna design, opening doors for significant advancements in wireless communication technology.

III. Result and Discussion

S11 PARAMETER

Assessing antenna performance involves evaluating the S11 parameter, which indicates signal reflection efficiency at a specific connection point. In ideal conditions, minimal signal reflection is preferred for efficient power transfer between the antenna and the connected system. The analysis focuses on the S11 plot, particularly at 6.2 GHz in the C-band spectrum. A significant dip at this frequency suggests strong resonance, making the antenna suitable for C-band applications. Additional analysis is recommended to gain a thorough understanding. Key considerations include the depth of the dip indicating impedance match quality, the presence of other resonances denoted by extra dips, and the importance of achieving substantial dip coverage across the entire C-band for optimal performance.

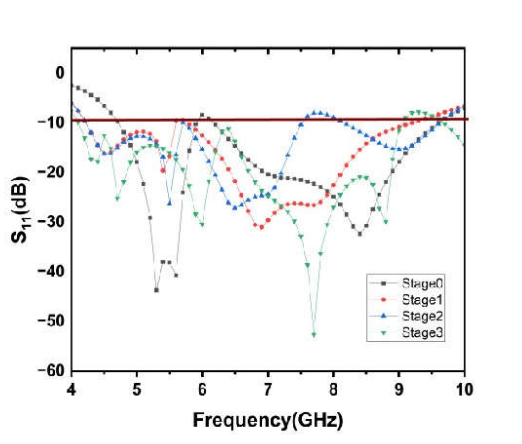

Fig.4(a). The Optometric Analysis Plot

Figures 4(a) and 4(b) likely represent the S11 parameter for the development stages (4a) and the final design (4b). A thorough analysis of the S11 responses, encompassing the entire C-band spectrum, provides valuable insights into the antenna's impedance matching with the feeding system. This matching is crucial for efficient power transfer and minimizing signal reflection. By examining these responses, we gain a deeper understanding of the antenna's ability to function seamlessly within C-band communication systems.

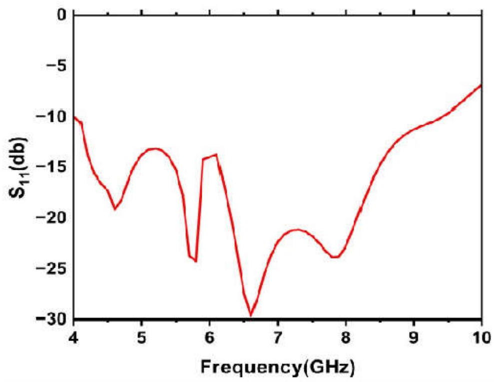

Fig. 4(b) The S_{11} Responses of proposed antenna

Furthermore, analyzing S11 responses throughout the design process allows for parameter refinement, ultimately

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leading to optimized performance. The consistent and predictable behavior of the S11 parameter validates the antenna's robustness and suitability for C-band applications. This comprehensive analysis underscores the antenna's reliability and compatibility with modern communication systems, making it a compelling choice for efficient C-band communication.

VSWR

Achieving a VSWR below 2 across the entire C-band spectrum (4 GHz - 8 GHz) stands as a significant achievement in antenna design, indicating a strong alignment between the antenna and connected systems like transmitters or receivers. This favorable impedance matching offers two key advantages, making the antenna well-suited for C-band communication applications. Firstly, by reducing signal reflection within the C-band, well-matched impedance enables efficient power transfer and minimizes signal loss, ensuring high-quality signal transmission crucial for reliable communication in satellite and radar systems operating in this frequency range. Secondly, the antenna's low VSWR indirectly supports effective circular polarization by minimizing signal reflection due to impedance mismatch, allowing for the efficient radiation of circularly polarized waves throughout the C-band.

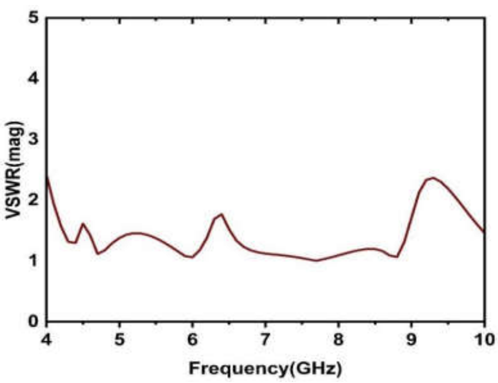

Fig. 5. VSWR of the designed antenna

AXIAL RATIO

The axial ratio plays a critical role in the C-band antenna design, determining its ability to achieve circular polarization and reduce signal fading in specific communication applications. While an ideal circularly polarized antenna would exhibit a 0 dB axial ratio, real-world designs typically aim for values below 3 dB. The antenna design excels by achieving a wide axial ratio bandwidth (7.2 GHz to 8.3 GHz) within the C-band, offering two key advantages: effective circular polarization across a substantial C-band range (7.2 GHz to 8.3 GHz) and a broad bandwidth ensuring consistent circular polarization within the frequency band. This impressive axial ratio bandwidth showcases antenna's capability to emit circularly polarized waves efficiently over a significant portion of the C-band, making it a compelling solution for diverse C-band communication applications.

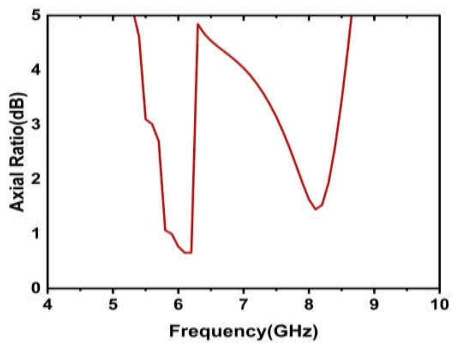

Fig. 6. Axial ratio frequency response for the proposed antennas.

TOTAL GAIN

The 2.69 dBi peak gain in the C-band antenna design is pivotal for its performance. Gain measures how well the antenna concentrates radio waves compared to an isotropic radiator, akin to focusing a flashlight beam. This higher gain enhances signal strength and coverage, enabling stronger signals and broader coverage within the C-band, beneficial for satellite communication and radar systems. Additionally, by reducing interference and focusing energy directionally, the antenna ensures reliable communication crucial for mobile and satellite applications. The attained gain aligns with modern C-band communication standards, meeting signal strength and coverage requirements. Ultimately, the 2.69 dBi gain allows the antenna to focus radio waves effectively, resulting in stronger signals, improved coverage, and enhanced communication reliability essential for successful C-band communication applications.

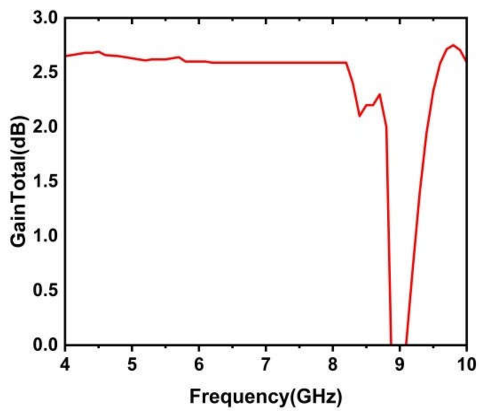

Fig. 7. The graph illustrating gain as a function of frequency

RADIATION PATTERN

Understanding an antenna's radiation pattern is crucial as it illustrates how radio waves propagate from the antenna

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in all directions, indicating signal directionality and coverage. While the provided radiation pattern pertains to a dipole antenna at 400 MHz, not within the C-band range, the principles apply to C-band antennas. Analyzing the radiation pattern of the C-band antenna design is vital for evaluating its directionality, gain, coverage, and polarization characteristics. Assessing these aspects ensures the antenna meets the specific requirements of the C-band application. For instance, a narrow beamwidth signifies focused signal transmission ideal for long-distance communication, while a wider beamwidth offers broader coverage with lower gain. By examining the radiation pattern, you can tailor the antenna design to optimize signal strength and coverage for effective communication within the C-band spectrum.

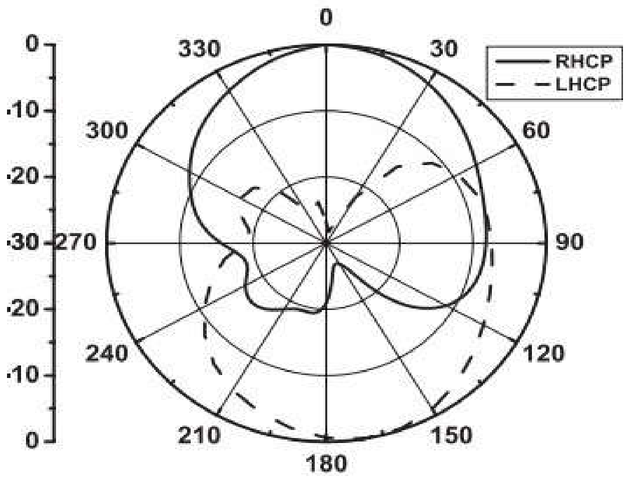

Fig 6.Radiation Pattern

Several key parameters drive the advancement of a high-performance C-band antenna design. Achieving a low S11 value and maintaining VSWR below 2 ensure efficient power transfer, minimal signal reflection, and effective circular polarization across the C-band spectrum. The peak gain of 2.69 dBi enables directional concentration of radio waves, enhancing signal strength, coverage, and communication reliability within the C-band.

Analyzing the radiation pattern provides insights into directional characteristics, coverage area, and polarization properties, optimizing the antenna design for specific C-band communication requirements. By iteratively refining design parameters based on these factors, a sophisticated antenna solution can be developed to excel in transmitting and receiving signals seamlessly within the C-band spectrum, offering unparalleled communication capabilities.

TABLE 3: THE TABULATED COMPARISON OF THE PROPOSED ANTENNA WITH ANTENNAS REPORTED IN THE LITERATURE.

Antenna Literature	Operating Frequency (GHz)	Axial Ratio bandwidth	Gain (dBi)	Radiating Element
[1]	5.95-8.82	6.65-8.82	1.9	T-shaped monopole antenna with a parasitic strip
[2]	5.8	5.51-13.1	2.8	parasitic strip
[13]	5.5	4.2 -7.6	3.5	C-shaped monopole
Proposed	4.01-10.22	7.22-8.3	2.69	L shaped microstrip radiator

IV. Conclusions

In summary, this study introduced an innovative circular microstrip patch antenna design that achieves a broad bandwidth of 4 GHz and a peak resonating frequency of 6.2 GHz. The antenna, constructed on an affordable FR-4 substrate with compact dimensions (23 mm x 23 mm x 0.8 mm), employed a partial ground plane configuration to enhance its performance. This approach led to a consistent gain of 2.69 dBi across the bandwidth and a satisfactory axial ratio bandwidth of 700 MHz. Moreover, the antenna demonstrated favorable radiation patterns, indicating its potential for various wireless communication applications that require dependable signal transmission.

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