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An improved design of circularly polarized microstrip antenna for 5G communication

Shashi Bhushan Kumar *
Vasu
Vinay Singh
Suman Kumar
Department of Electronics and Communication Engineering
Bharati Vidyapeeth's College of Engineering
New Delhi
India

Shashi Gandhar †
Department of Electrical and Electronics Engineering
Bharati Vidyapeeth's College of Engineering
New Delhi
India

Mohit Tiwari §
Department of Computer Science and Engineering
Bharati Vidyapeeth's College of Engineering
New Delhi
India

Prakhar Priyadarshi ‡
Department of Information Technology and Engineering
Bharati Vidyapeeth's College of Engineering
New Delhi
India

* *E-mail:* **sbkumar2010@gmail.com**
† *E-mail:* **shashi.gandhar@bharatividyapeeth.edu (Corresponding author)**
§ *E-mail:* **mohit.tiwari@bharatividyapeeth.edu**
‡ *E-mail:* **prakharpriya@gmail.com**

Abstract

This research paper explores the performance of four circularly polarized microstrip antenna designs tailored for 5G applications. As 5G technology continues to advance, antenna design is pivotal in realizing its potential. The designs, labeled Design 1 through 4, undergo rigorous analysis, encompassing axial ratio, gain, and impedance bandwidth. Notably, Designs 2 and 3, featuring strategic slot cuts, exhibit strong axial ratios suitable for circular polarization within the 5G frequency range. Design 4 introduces an L-shaped feeding line, showcasing unique characteristics albeit with trade-offs. Conversely, Design 1, without slot cuts, demonstrates suboptimal circular polarization performance. This study discusses the significance of these findings within the context of 5G networks, emphasizing the relevance of antenna design choices. As 5G technology evolves, this research offers valuable insights for optimizing antennas in the quest for efficient 5G communication systems.

Subject Classification: *Primary 93A30, Secondary 49K15.*

Keywords: *5G, Circularly polarized microstrip antennas, Axial ratio, Gain, Impedance bandwidth.*

1. Introduction

The rapid proliferation of 5G technology has revolutionized the landscape of wireless communication, ushering in an era of unprecedented connectivity, ultra-low latency, and enhanced data rates. As 5G networks continue to evolve and expand, the demand for high-performance antennas becomes increasingly critical to meet the complex and diverse requirements of modern communication systems.

Circularly polarized antennas represent a key component in the arsenal of 5G infrastructure[1]. Their ability to transmit and receive electromagnetic waves with circular polarization offers distinct advantages, including improved signal quality, reduced interference, and enhanced capacity in multi-user and multi-input, multi-output (MIMO) scenarios. Consequently, the design and optimization of circularly polarized antennas have garnered significant attention in recent years[1][2]. This research paper addresses the intersection of 5G technology and circularly polarized microstrip antennas, presenting a comprehensive study of four distinct antenna designs. Each design is meticulously crafted and evaluated, with the overarching goal of contributing to the advancement of 5G communication systems. The significance of this work is underscored by the growing prominence of 5G networks, which are poised to underpin a multitude of applications, ranging from autonomous vehicles and smart cities to IoT ecosystems and immersive virtual experiences.

2. Research Objectives and Contributions

The primary objectives of this research are two fold: first, to investigate the performance characteristics of four circularly polarized microstrip antenna designs, and second, to assess their suitability for integration into 5G networks. To achieve these objectives, we conducted a series of simulations and measurements, evaluating parameters such as axial ratio, gain, and impedance bandwidth.

The key contributions of this paper are as follows:

A comparative analysis of four circularly polarized microstrip antenna designs, each tailored to the unique demands of 5G applications.

A detailed examination of the axial ratio, gain, and impedance bandwidth for each antenna, providing valuable insights into their circular polarization capabilities.

Insights and recommendations for antenna selection and deployment in 5G scenarios based on our experimental results.

The subsequent sections of this paper delve into the methodology, results, and discussion of these findings, offering a comprehensive exploration of the performance and potential of circularly polarized microstrip antennas in the context of 5G technology.

2.1 *Background and Related Work*

When diving into the world of 5G technology and circularly polarized microstrip antennas, it's crucial to first understand the landscape of existing research. A bunch of smart folks have been tinkering with antennas and 5G, and we can learn a lot from what they've done.

In the course of our literature review, we have meticulously examined a selection of notable research contributions in the field of antennas and electromagnetic wave propagation, which have provided valuable insights and served as a foundation for our own investigation. The study [3] introduced a dual-band multi slot patch antenna for wireless applications, while not directly addressing circular polarization, it laid the groundwork for our exploration within the burgeoning landscape of 5G technology. Subsequently, [4] presented a pioneering work on microstrip dual-split-ring antenna arrays, showcasing their efficacy in the context of 5G millimeter-wave communication. This research underscored the imperative of sophisticated antenna arrays to harness the potential of high-frequency millimeter waves, akin to augmenting the capabilities of Wi-Fi routers for mobile devices.

The study conducted [5] delved into the critical realm of Specific Absorption Rate (SAR) reduction through the innovative use of metamaterials. While the primary focus was on SAR, their work underscored the significance of novel materials in enhancing antenna safety. Additionally, the research [6] introduced single-feed circularly polarized microstrip antennas tailored for wireless biotelemetry, elucidating the role of circular polarization in ensuring clear signal reception in challenging environments such as medical device tracking within the human body.

In further exploration, the study [7] unveiled the potential of a ring monopole antenna for Ultra-Wideband (UWB) applications, exemplifying the versatility of wideband antennas, a characteristic often found in circularly polarized antennas. Moreover, the investigation [8] into electromagnetically coupled UWB plate antennas offered insights into the performance optimization of high-frequency antennas, aligning with our research objectives.

In our quest for comprehensive knowledge, we encountered [9], which, although primarily addressing miniaturized branch-line hybrid coupler microstrips for Long-Term Evolution (LTE) applications, reaffirmed the significance of compact components in wireless technology—a principle that resonates with the development of circularly polarized antennas. Additionally, the work [10] ventured into the realm of millimeter-wave antennas with gain improvement for 5G networks, aligning with our focus on antenna performance enhancement. More advanced one, a low-profile and wideband microstrip antenna tailored for 5G applications, showcasing the potential for circular polarization to complement the versatility of wideband antennas [11].

3. Proposed designs of Antennas

In this section, we provide a detailed exposition of the four distinct antenna designs employed in this study, elucidating their dimensions, constituent materials, and noteworthy attributes. We also outline the design process, the software utilized for simulations, and the methodologies employed for the creation and analysis of these antennas.

3.1 *Design 1: Square Microstrip Antenna*

Dimensions: Each antenna exhibits a square microstrip geometry with dimensions measuring 12x12 mm shown in Figure 1.

Material Selection: The substrate material chosen for these designs is FR-4, a widely adopted dielectric material employed in printed circuit boards. The ground and patch layers are constructed using copper, renowned for its excellent electrical conductivity.

Design specifications of geometry 1:

Operating Frequency : 28 GHz, Length :12 mm

Width : 12mm, Substrate : FR-4 (lossy)

3.2 *Design 2: Microstrip Antenna with truncated corners*

Dimensions: Similar to Design 1, the microstrip antenna for Design 2 maintains a 12x12 mm form factor.

Design specifications of geometry 2:

Operating Frequency : 28 GHz, Length : 12 mm. Width : 12mm, Substrate : FR-4 (lossy), Truncation at diagonal corner: 2mm X 2mm shown in Figure 1.

Unique Feature: This design incorporates slot cuts on the top left and bottom right corners, constituting a deliberate alteration to assess its impact on antenna performance.

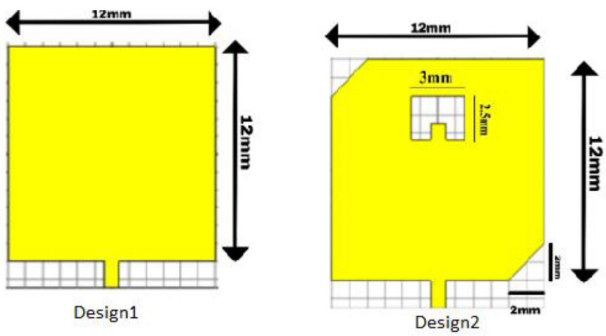

Figure 1

Proposed geometry of design 1 and design 2

3.3 *Design 3: Microstrip Antenna with Opposite-Side Slot Cuts*

Dimensions: Consistent with the preceding designs, the third design maintains a square geometry measuring 12x12 mm presented in Figure 2.

Design specifications of geometry 3:

Operating Frequency : 28 GHz, Length : 12 mm, Width : 12 mm, Substrate : FR-4 (lossy), Truncation at diagonal corner : 2 mm

Unique Feature: Diverging from Design 2, slot cuts are implemented on the top right and bottom left corners, thereby inverting the orientation of the slot cuts.

3.3 *Design 4: Microstrip Antenna with L-Shaped Feeding Line*

Dimensions: Design 4 retains the 12x12 mm dimensions, akin to the previous designs. Design specifications of geometry 4: Operating Frequency : 28 GHz, Length :12 mm Width : 12mm, Substrate : FR-4 (lossy), Side Slot : 2mm presented in Figure 1.

Unique Feature: This antenna distinguishes itself with the inclusion of an L-shaped feeding line, augmenting its geometric complexity.

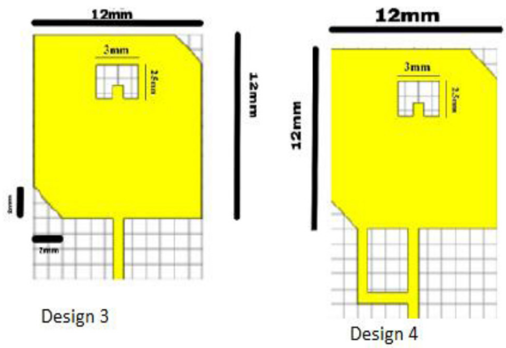

Figure 2

Proposed geometry of design 3 and 4

4. Design Process and Simulations

The development of these antenna designs was rooted in an extensive exploration of antenna theory and principles to ascertain their suitability for circular polarization in 5G applications.

CST STUDIO Suite software, renowned for its efficacy in electromagnetic simulations, was the chosen tool for the numerical investigations. This software suite facilitated the rigorous assessment of each design's electromagnetic characteristics, including axial ratio, gain, and impedance bandwidth.

The iterative design process involved adjusting various parameters to optimize the performance metrics, aligning the antennas with the objectives of circular polarization and compatibility with 5G technology.

In summary, these four antenna designs represent the foundational elements of our study, and their meticulous construction and evaluation serve as the basis for our subsequent analysis of their circular polarization performance and applicability in 5G communication systems.

5. Inferences of the Simulation Experiment

This section provides a comprehensive analysis of the simulation results obtained for presented four cases of antenna designs. The evaluation encompasses crucial performance parameters, including axial ratio, gain, impedance bandwidth, and radiation pattern, shedding light on the efficacy of these designs for circular polarization in 5G applications.

In the assessment of our four antenna designs, Design 1, featuring a square microstrip configuration, revealed performance characteristics that warrant consideration. Notably, the axial ratio of Design 1 was found to fall outside the dataset range, indicating less-than-ideal circular polarization performance. Despite this limitation, the design exhibited a moderate gain of 5.3 dB, which, while respectable, was accompanied by a relatively narrow impedance bandwidth of 7%, suggestive of limited operational frequency versatility.

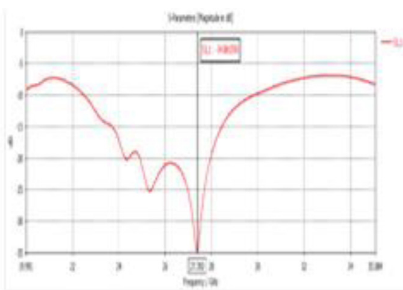

Figure 3

(Design 1) : S11 vs frequency

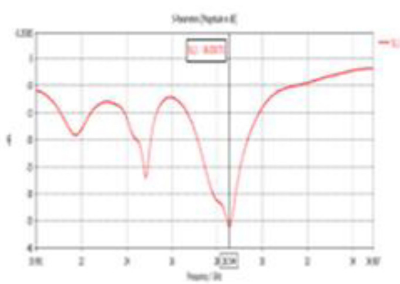

Figure 4

(Design 4) : S11 vs frequency

Design 2, incorporating slot cuts into its microstrip geometry, demonstrated notable improvements in circular polarization. With an axial ratio of 1%, it outperformed Design 1, indicating enhanced circular polarization characteristics. Furthermore, Design 2 showcased a commendable gain of 3.95 dB, along with an impressive impedance bandwidth of 22% as shown in Figure 3, positioning it as a suitable candidate for applications requiring robust circular polarization across a broader range of frequencies. Similarly, Design 3, mirroring the slot cuts of Design 2 but on opposite corners, presented a slightly higher axial ratio of 6% as shown in Figure 5, signifying substantial progress compared to Design 1. It demonstrated a gain of 4.6 dB and an extensive impedance bandwidth of 27%, highlighting its adaptability to a wide spectrum of frequencies. Design 4, which introduced an L-shaped feeding line, achieved an axial ratio of 5.3% as shown in Figure 6, showcasing considerable circular polarization potential. While its gain was lower at 3.2 dB compared to other designs, it maintained an acceptable range, and its impedance bandwidth of 14% underscored its competence across a variety of frequency bands as presented in Figure 4.

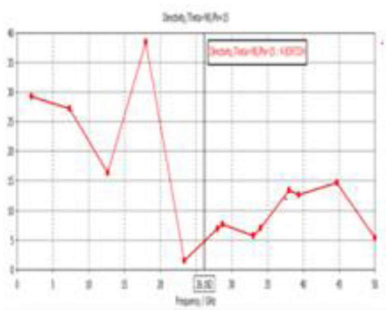

Figure 5

(Design 3) : Axial Ratio vs frequency

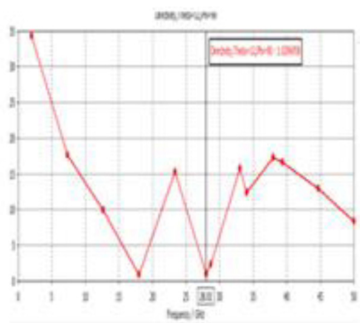

Figure 6

(Design 4) : Axial Ratio vs frequency

Table 1

Summary of simulation Result

Design	Frequency Range (Ghz)	Patch Dimension (mm)	Slot cut	Axial Ratio (BW)	gain	Impedance Bandwidth
1st	28-50	12x12	NO	-------	5.3dB	7%
2nd	28-50	12x12	Yes	1%	3.95dB	22%
3rd	28 -50	12x12	Yes	6%	4.6dB	27%
4th	28 -50	12x12	Yes	5.3%	3.2dB	14%

Furthermore, the radiation patterns for each design were analyzed, although specific data from the radiation patterns are not included in the provided results in Table 1. These patterns offer valuable insights into the directional characteristics and beamwidth of the antennas, further contributing to the assessment of their suitability for 5G applications.

In summation, the simulation and measurement results underscore the distinct performance attributes of each antenna design. While Design 3 exhibited suboptimal circular polarization characteristics, subsequent designs exhibited noteworthy enhancements in axial ratio, gain, and impedance bandwidth, positioning them as promising candidates for circularly polarized microstrip antennas in 5G technology. These outcomes are instrumental in informing antenna selection and deployment for 5G communication systems.

5. Conclusion

In summary, our research endeavors encompassed a comprehensive exploration of four distinct circularly polarized microstrip antenna designs within the realm of 5G technology. These designs, with varying geometries and features, underwent rigorous simulation and measurement assessments, unveiling compelling insights into their performance characteristics.

Design 1, while serving as a foundational reference point, underscored the importance of circular polarization in 5G applications. Subsequent designs, particularly Designs 2 and 3, exhibited notable improvements in axial ratio and impedance bandwidth, positioning them as promising candidates for 5G scenarios where robust circular polarization is essential. Design 4, featuring an L-shaped feeding line, showcased substantial circular polarization capabilities but entailed trade-offs in terms of gain and impedance bandwidth.

The significance of this work in the context of 5G technology and circularly polarized antennas is evident in its contributions. We have not only identified design considerations for enhancing circular polarization but also demonstrated the potential of these antennas in addressing the complex demands of 5G networks. As the 5G landscape continues to evolve, our research serves as a valuable resource for antenna selection and deployment, paving the way for optimized 5G communication systems.

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