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Circular Disc Patched, Dual Polarized and Aperture-Coupled Antenna for 5G mmWave Applications

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ABSTRACT—

As wireless communication technologies have been developing rapidly, the need for high-speed, low-latency connections in 5G networks has put strong focus on the design of compact and efficient antenna structures. Among other challenges, polarization diversity, broad bandwidth, and high feed port isolation have become pressing requirements. In this paper, we introduce a circular disc patch antenna with dual polarization using an aperture-coupled feeding mechanism, especially designed for millimeter-wave 5G applications. The new antenna design includes a radiating layer with a 4×4 circular disc patch array and a feed layer with a common ground plane in between. The ground plane itself is embedded with T-shaped slots acting as the apertures for coupling, allowing energy to be transferred from the microstrip feed lines to the radiating elements without physical contact. The aperture-coupled structure not only improves impedance matching but also provides better isolation between the two orthogonally polarized feeds. With a footprint of only 7 mm × 7 mm, the antenna is small enough to be packaged in dense system packages. The dual-polarized architecture allows signals to be received and transmitted in two orthogonal directions, which is critical to improve channel capacity and lower multipath fading in 5G systems. Simulated results verify broad impedance bandwidth, high gain, and more than 20 dB isolation between the ports, providing robust performance under a range of conditions. The exclusive association of disc geometrical symmetry and aperture coupling constitutes a high-end candidate to design next-generation antenna-in-package (AiP) solutions. It presents a competent and applicable technique for the execution of severe requirements of mmWave 5G communication systems in terms of their performance needs.

***Index Terms*—Dual Polarization, Aperture-Coupled Antenna, Circular Disc Patch, 5G mmWave, Microstrip Antenna, High Isolation, Compact Antenna Design, Antenna-in-Package (AiP), T-Shaped Slot, Wide Bandwidth, Millimeter-Wave Communica- tion**

I. Introduction

THE advent of 5G technology, the demand for compact, high-performance antennas that can support high data rates, low latency, and reliable connectivity has significantly increased. The fifth-generation wireless communication sys- tem introduces substantial advancements over previous genera- tions, particularly in the millimeter-wave (mmWave) frequency range. This spectrum enables higher bandwidth but comes with challenges such as increased path loss and susceptibility to atmospheric absorption. To address these issues, antennas designed for 5G systems must exhibit features like wide impedance bandwidth, high gain, and dual polarization to support multi-directional signal reception and minimize polarization mismatch losses.

To meet the stringent requirements of 5G systems, such as enhanced data throughput, better spectral efficiency, and proven link reliability, antenna structures with wide impedance bandwidth, high gain, and dual polarization capabilities are essential [2], [3]. Dual polarization plays a vital role in mitigating multipath effects, enhancing channel capacity, and supporting multiple-input multiple-output (MIMO) configurations [5], [6]. Among various antenna designs, aperture-coupled patch antennas have gained significant attention due to their superior bandwidth performance, ease of integration with active circuits, and reduced surface wave excitation [4], [17].

The proposed antenna design utilizes a circular disc patch configuration with dual polarization, coupled through an aperture mechanism to enhance its bandwidth and radiation characteristics. The circular disc shape ensures symmetrical radiation patterns and supports both linear and circular polarizations based on the feed mechanism. The aperture coupling technique isolates the feed line from the radiating patch, thereby minimizing spurious radiation and allowing independent optimization of the feed and radiating structures [4], [6].

Several previous works have explored the use of aperture-coupled patch antennas for broadband and dual-polarized applications. For instance, modified H-shaped and C-shaped coupling slots have been proposed to achieve enhanced po- polarization purity and bandwidth [6], [7]. Likewise, proximity coupling and cross-slot feeding methods have also shown promising results in terms of gain and isolation [8], [9]. However, many of these designs either exhibit limited bandwidth, complex fabrication processes, or insufficient polarization discrimination.

To overcome these limitations, this work presents a simplified yet high-performance dual-polarized circular disc aperture-coupled patch antenna. The antenna operates efficiently in the mmWave frequency range and is optimized for 5G applications. Its compact profile, broad impedance bandwidth, and high isolation between orthogonal ports make it a suitable candidate for future high-speed communication systems. The simulation and performance evaluation of the antenna validate its effectiveness in achieving desired 5G specifications, including return loss, axial ratio, and radiation pattern stability across the operational band [2], [12], [13]. Given below are the some of the mmWave bands frequencies ranging from 24GHz to 45GHz.

n258: 24.25 GHz – 27.5 GHz

n257: 26.5 GHz – 29.5 GHz ka-Band: 27.5 GHz -28.35GHz

n261(subset of n257): 27.5 GHz – 28.35 GHz n260: 37 GHz – 40 GHz

n259: 39.5 GHz – 43.5 GHz

In summary, this paper introduces a dual-polarized aperture-coupled antenna based on a circular disc geometry. The design aims to address key challenges associated with mmWave 5G communication systems, offering an optimal balance between compactness, performance, and ease of integration. The subsequent sections detail the antenna design process, simulation methodology, and comparative analysis with existing state-of-the-art antenna configurations.

II. Circular disc patched, dual-polarized aperture-coupled antenna Design

The stacked patch structure, the two T-shaped microstrip feed lines, and the two ground plane slots are the constituent components of the stacked patch structure designed for dual polarization. The optimized performance is attained using a high dielectric constant, low-loss, electrically thin feed substrate ($< \lambda/50$) and a thin patch substrate of ($< \lambda/10$) low dielectric constant. Rogers 4350B ($\varepsilon_r = 3.48$), a com- monly employed substrate material for mmWave designs, is selected because of its well-balanced dielectric constant and compatibility with both the feed and patch layers. Substrate thicknesses are chosen as h_p=0.761 mm and h_f =0.254 mm.

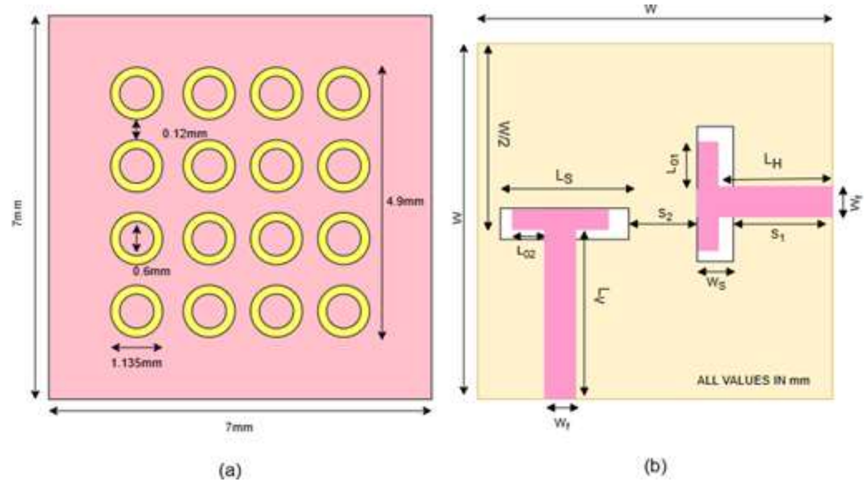


Fig. 1. Circular disc patched antenna (a)Back view (consists of disc patches (b)Front view (consists of feed lines)

The width of the feed line is W_f =0.5 mm. Further, slot dimension plays an important role in antenna's performance, particularly coupling strength as well as back radiation. The length of the slot is selected between 0.1λ to 0.2λ is fixed at 2.5 mm for this design, and the slot width is fixed at 10% of the slot length, making it 0.25 mm. The patch width W_P , derived as 4.9 mm provides efficient resonance at the desired frequency.

The T-shaped aperture-fed structure is utilized to support dual-polarization by allowing orthogonal mode excitation. The symmetrical slot configuration enhances coupling efficiency, and the aperture-coupled feed mechanism isolates the feed and radiating elements on different substrates, minimizing surface wave losses and enhancing bandwidth.

The configuration also provides low mutual coupling between the polarization channels, resulting in improved isolation and overall system performance. Because of its small size and better performance, the T-shaped structure is very appropriate for next-generation wireless communication systems, especially 5G technologies, where high data rates, large bandwidth, and polarization diversity are essential. Due to its optimal design, T-shaped configuration is extremely well-adapted for advanced wireless communication systems that require high data rates, large bandwidth, and polarization diversity, so it is an ideal candidate for future 5G antenna systems.

Parameter	W	Wp	g	W_f	Ws	Ls
Size (mm)	7	4.9	0.12	0.5	0.6	2.53

Parameter	L_H	L_V	LO1	LO2	S_1	S_2
Size (mm)	2.25	3.3	0.91	0.8	2.2	0.7

TABLE I

Design Parameters for the proposed Antenna

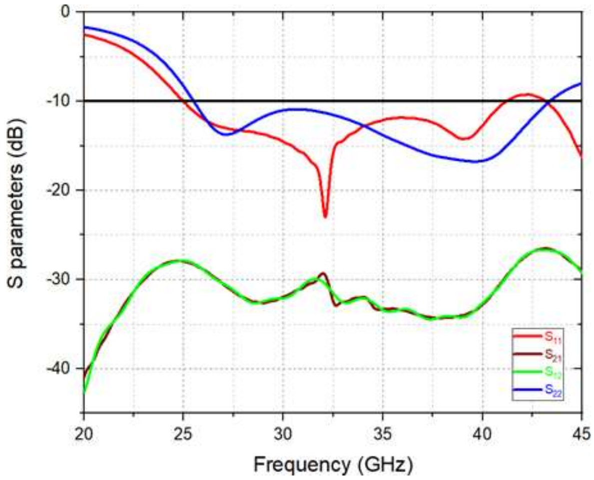


Fig. 2. S-parameters of the proposed antenna

The simulated S-parameters of the presented dual-polarized antenna are shown in Figure 2 with a frequency range of 20 GHz to 45 GHz. The reflection coefficients S11 and S22 are below –10 dB from 24 GHz to 44 GHz, which shows excellent impedance matching and broad operating bandwidth for both ports. The transmission coefficients S12 and S21 are always less than –25 dB throughout the whole band, verifying a high degree of port isolation between the two ports of polarization. Such high isolation is important to reduce mutual coupling and provide optimal performance in MIMO and dual-polarized systems. The findings verify the antenna's ability for 5G mmWave applications with wideband operation and high isolation.

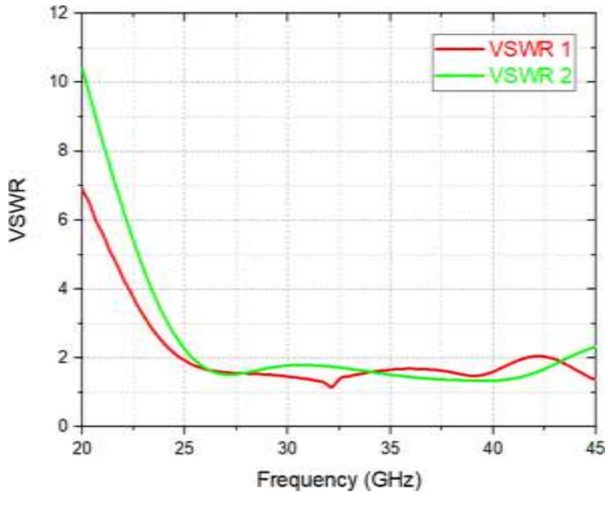


Fig. 3. VSWR of the proposed antenna

Figure 3 illustrates the VSWR characteristics of the proposed dual-port antenna for both ports (VSWR 1 and VSWR 2) across the frequency range of 20–45 GHz. It can be observed that the VSWR values for both ports remain well below 2 from 24 GHz to 44 GHz, indicating excellent impedance matching within the operational band. A VSWR below 2 corresponds to a return loss better than –10 dB, which confirms the efficient transmission of power and minimal reflections at the antenna input. The stable and low VSWR values across the desired frequency range validate the antenna's suitability for wide band 5G mmWave applications and ensure reliable dual-polarized performance.

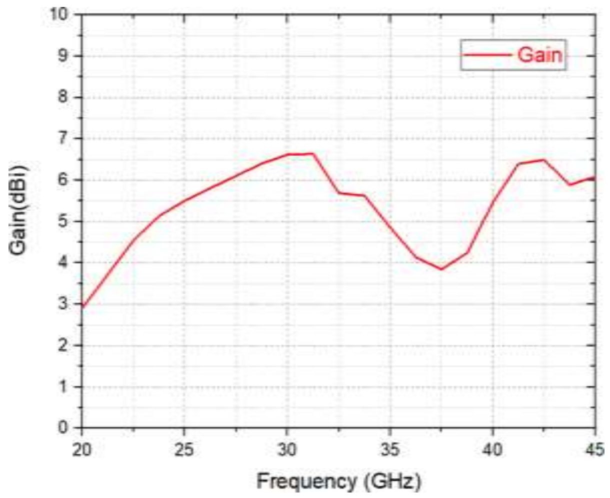
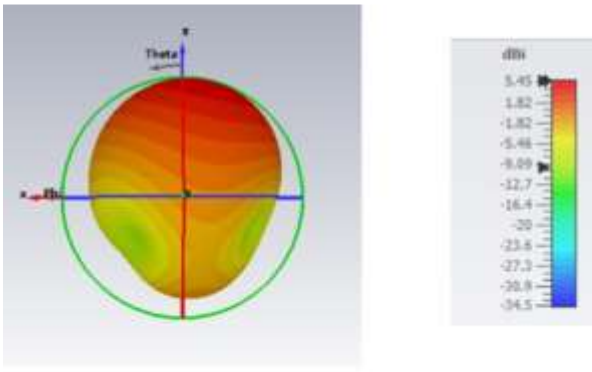
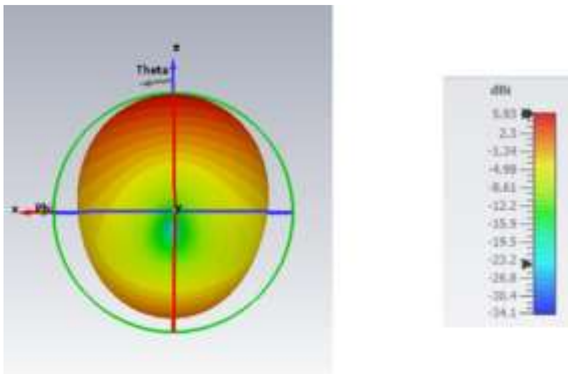


Fig. 4. Gain of the proposed antenna

Figure 4 shows the simulated gain response of the designed antenna over the frequency range of 20–45 GHz. The antenna has a peak gain of about 7 dBi and a relatively stable gain profile across the operating band. The gain increases slowly from about 3 dBi at 20 GHz to its peak at about 30 GHz, with minor variations after this frequency. In spite of small fluctuations noted between 35 GHz and 40 GHz, the gain is still over 4 dBi over the whole band. The gain over the 24–44 GHz band is about 7 dBi, which is adequate for 5G mmWave applications involving moderate-to-high directivity. The results validate the ability of the antenna to efficiently radiate in a vast frequency band with good stability.



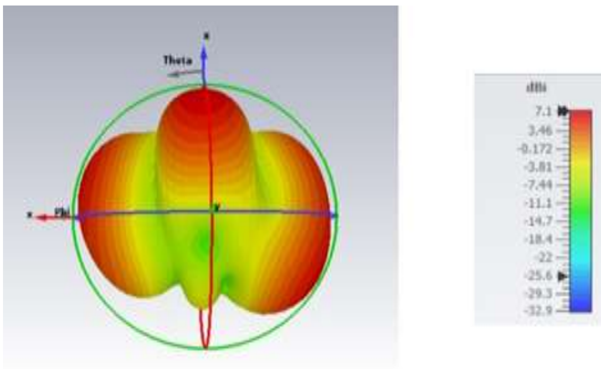
(a) (b)



(a) (b)

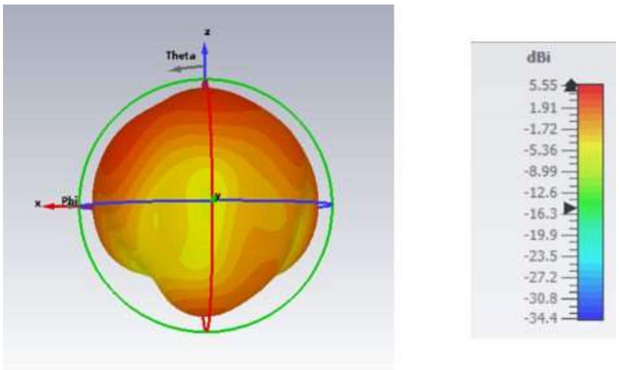
Fig. 5. (a)Farfield field for 24GHz at port 1 (b)scale Fig. 6. (a)Farfield field for 24GHz at port 2 (b)scale

The antenna's Far-Field radiation pattern consists of the main, minor, and neighbouring lobes. Far-field is used to determine antenna performance in terms of gain (dB). We measured far-field at frequencies of 25 GHz, and 45 GHz for both ports, port 1 and port 2 and the gains of respective frequencies are 5.45 dBi, 5.93 dBi, 7.2 dBi, and 5.55 dBi, respectively. The maximum far-field gain is distributed at a



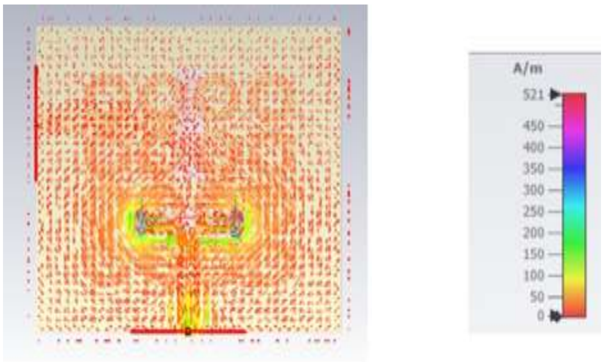
(a) (b)

Fig. 7. (a)Farfield field for 45GHz at port 1 (b)scale



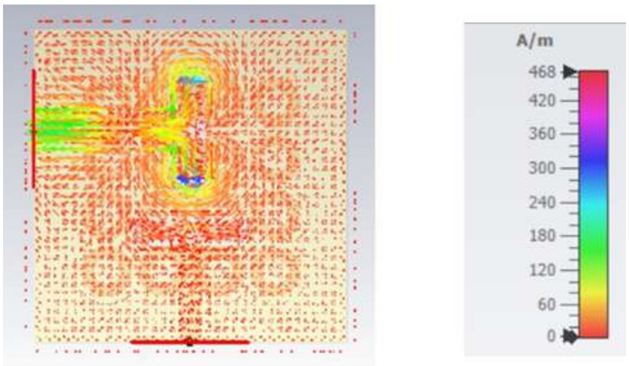
(a) (b)

Fig. 8. (a)Farfield field for 45GHz at port 1 (b)scale frequency of 45GHz for port 1. As seen in Figures5 6 7, 8.



(a) (b)

Fig. 9. (a)Surface current distribution for 24GHz at port 1 (b)scale



(a) (b)

Fig. 10. (a)Surface current distribution for 24GHz at port 2 (b)scale

The far-field radiation patterns of the designed antenna at various frequencies in the operating band were investigated to assess its directionality. From the 3D radiation plots, the antenna is quasi-omnidirectional as well as directional based on the frequency. For low frequencies, the radiation pattern is relatively flat, but at higher frequencies, the radiation pattern tends to become highly directional with well-defined main lobes. The measured maximum gain ranges from 5.45 dBi to7.1 dBi, showing effective radiation performance throughout the band. These radiation features verify that the antenna is suitable for use in 5G, with both wide-area coverage and directional concentration as required.

Surface current is received by the antenna at the bottom of the feed line, the center of the T-shaped line, and the point where the T-shaped and feed line join. The maximum surface current is distributed at a frequency of 24 GHz. We detected surface current at frequencies for 25 GHz, 45 GHz at both port, port 1 and port 2 as 525 A/m, and 468 A/m, 310 A/m, and 320 A/m as shown in Figures 9101111.

The surface current distribution patterns depicted in the above figures9101111 are the magnetic field intensity (in A/m) in different antenna configurations or geometries. Figures (a) Fig. 10. (a)Surface current distribution for 24GHz at port 2 (b)scale in each figure are the vector plots of the magnetic field, and figures (b) are the corresponding color scale employed to represent the field intensity. The direction of the magnetic field is shown by the arrows in the vector field, and the color gradient (red for low intensity to blue/purple for high intensity) depicts the strength.

In the figure 9, the current is denser near the bottom center of the structure and is creating a clear directional flow downwards, which implies a dipole-like distribution with heavy activity close to the feed or excitation point. The second image, figure 10, has a more spread field with concentration on the left, which may show a directional radiation pattern or asymmetrical structure. The third and fourth figures 1112 images have higher field intensity with more symmetric distribution patterns, particularly around the central axis, suggesting stronger coupling or greater input power. Interestingly, the maximum field strengths differ in each instance (e.g., 310 A/m, 220 A/m, 521 A/m, and 468 A/m), which reflects varying levels of excitation or structural changes. These plots are critical in assessing antenna performance, such as impedance matching, radiation behavior, and total field confinement.

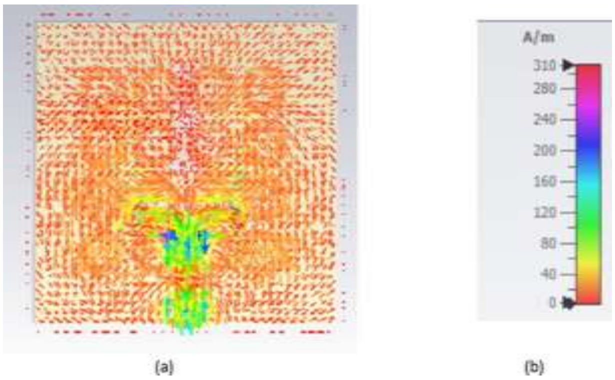


Fig. 11. (a)Surface current distribution for 45GHz at port 1 (b)scale

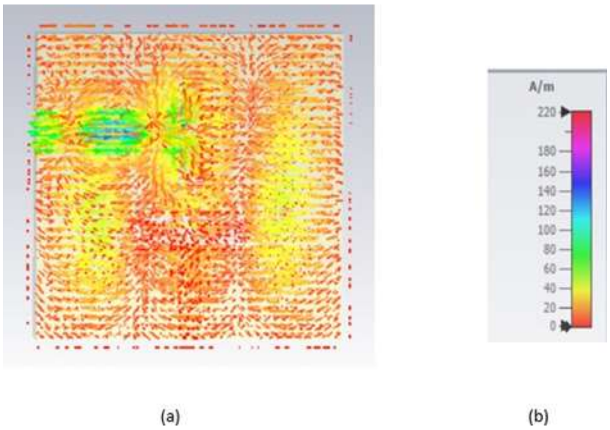


Fig. 12. (a)Surface current distribution for 45GHz at port 2 (b)scale

III. Conclusion

This paper introduces a compact, circular disc patched, dual-polarized T-shaped antenna with aperture-coupled feed, tailored for use in 5G millimeter-wave applications. The presented design efficiently responds to the increasing need for high-gain, wideband antennas with high polarization isolation. Simulation results validate a wide bandwidth of impedance with S11 always less than –10 dB, referring to good impedance matching, whereas a VSWR of less than 2 guarantees effective

power transmission with small reflection. The antenna realizes a maximum gain of around ∼ 7 dBi and has low mutual coupling of –20 dB, and thus it is very much apt for use in po- polarization diversity in dense urban areas with multipath propagation. Current distribution analysis further reveals efficient excitation of desired modes with little unwanted radiation. In comparison with current state-of-the-art implementations, the presented antenna provides competitive performance in a smaller footprint of 0.56 × 0.56 λ_0, as illustrated in Table II. Its ease of manufacturing, cost-effectiveness, and scalability are also supported by its low-profile, planar shape and ability to be fabricated with common PCB fabrication techniques. Generally, the antenna being proposed is an ideal candidate to be integrated in future 5G base stations and mobile platforms, with high system capacity, increased reliability, and extended coverage.

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