Wideband Circular Patch Antenna with DGS For 5G Applications

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***Abstract*—As a result of 5G wireless communications systems, there is an increased scope for more demanding antenna designs. Examples of these demands include but are not limited to; larger bandwidth requirements, increased antenna gain, smaller form factors and operation within higher frequency bands (e.g., mm Wave). The 28 GHz frequency band has generated a lot of research interest due to its larger frequency spectrum and ability to transmit higher speed data. However, traditional microstrip patch antennas (MPA's), have been used primarily due to their smaller size and ease of integration. However, MPAs have limitations operating in the range of 5G frequency bands due to their inherent lower performance characteristics, e.g., bandwidth and gain. This research will therefore examine the design of a compact, highly efficient, circular microstrip patch antenna with a Defected Ground Structure (DGS). The materials used to construct the antenna include Rogers RT5880LZ due to its low loss and ability to operate consistently at millimeter-wave frequencies. The antenna will have a circular patch shape in order to improve radiation stability. The feed will use a microstrip to achieve impedance matching. The addition of a DGS pattern on the ground plane provides the principal improvement to the antenna compared to previous designs. The DGS enhances the antenna's radiation efficiency, return loss, and bandwidth by introducing additional inductive and capacitive effects into the ground current distribution on the antenna, which modifies how current flows. The DGS achieves this without increasing the physical size of the antenna. The antenna performance was parametrically optimized through a thorough analysis of key design parameters including patch radius, feed inset location, and DGS dimensional values, with simulated results showing the proposed design's validity.**

***Index Terms*—Antenna design, circular microstrip antenna, defected ground structure, fifth-generation systems, millimeter- wave communication.**

I. INTRODUCTION

There has been an increase in demand for ultra-high-speed data rates, low latency, and reliable connections as a result of the rapid development of 5th-generation wireless systems (5th gen). Antennas operating in the millimeter range have been allocated large bandwidths along with reduced spectrum overcrowding to accommodate the abovementioned needs. The 28 GHz millimeter band has been identified as one of the leading frequencies for 5G deployment, specifically for short-distance/high-capacity applications such as small cell sites, base stations, and devices. However, designing antennas at the millimeter-wave spectrum presents many challenges, which include radiation efficiency, impedance bandwidth, surface wave losses, and fabrication tolerance.

Microstrip patch antennas are extensively used in contemporary wireless networks due to their small profile, light weight, simple manufacturing methods, and ability to integrate with radio-frequency (RF) chips. However, there are some disadvantages associated with microstrip antennas that define the antenna's performance when the operating frequency increases to higher frequencies. These disadvantages include a narrow range of impedance bandwidths, a lower gain than would be expected from the same type of structure(s), and a large number of surface waves referenced to the physical size of the dielectric substrate itself. As we enter into the millimeter-wave frequency range, the limitations of microstrip antennas will only worsen, imposing severe limitations on the potential for use of the antenna in multi-band 5G applications.

Many researchers have reported enhancements to the aforementioned limitations in the literature through different methods of substrate enhancement, such as utilizing thick or low-permittivity substrates, using parasitic elements, electromagnetic bandgap (EBG) structures, and modifying feeding techniques. While each of these methods produces marginal improvements, they tend to increase antenna size, structural complexity, or fabrication difficulty. Therefore, it is critical that simple, compact, and efficient antenna configurations be developed that can achieve simultaneously wide bandwidths, good impedance matching, and stable radiation performance.

An effective and fabrication-friendly technique for enhancing microstrip antenna performance is to use defected ground structures (DGSs). The DGS approach causes the surface current distribution to change by adding intentional defects or slots to the ground plane. This changes the way that surface waves travel across the ground plane, reduces the effects of surface wave propagation, creates a better impedance match to the feed line, and increases the amount of bandwidth for a specific application. Unlike complex multilayered or metamaterial-based designs, DGS provides a method for improving antenna performance without significantly increasing antenna size and/or design complexity.

In addition, according to the research, circular microstrip patch Geometries provide smoother current distribution and improved resonant characteristics than a rectangular patch Geometries provide a smoother current distribution and improved resonant characteristics compared to rectangular patch antennas, making them particularly well-suited for millimeter-wave applications. Wave applications. Using these considerations to guide our research, this paper describes the development and analysis of a compact circular microstrip antenna with integrated dual-stage defected ground structure designed for operation at 28 GHz. The design incorporates a method of reducing the size of the ground plane through controlled methods followed by the application of a thin circular ring defect that was shown to provide increased control over the surface currents and improve the electromagnetic characteristics of the antenna.

The antenna was designed utilizing a low-loss RT5880LZ. substrate and was verified through full-wave electromagnetic simulations providing detailed parametric analysis of surface currents and performance to demonstrate increased bandwidth, decreased return loss, increased radiation efficiency and increased gain through the use of the dual-stage DGS technique compared to previous designs, substantiating that the dual-stage DGS technique is an efficient method to achieve wide bandwidth design at the millimeter-wave frequency range providing design opportunities for compact 5G wireless communications systems.

II. DESIGN AND ANALYSIS

The beginning of this antenna configuration is based on a traditional circular microstrip patch antenna operating at 28 GHz in the mm-wave frequency range. The reason for using Circular microstrip antennas have a compact size. a relatively even distribution of electric field current along their length, and a stable resonance at high frequency operation. The resonant radius is determined using analytically derived equations between the resonant frequency of a patch antenna with a given relative permittivity of the substrate and the thickness of the substrate and effective radius of the antenna.

Therefore, these equations provide an excellent basis for beginning the antenna geometry and thus produce a patch antenna with resonance close to its operating frequency. The Rogers RT5880LZ substrate was selected for use in the antenna, being a low-dielectric loss and low-relative permittivity ($\varepsilon r=2.0$) material, which has ideal properties to Use when working with millimeter-wave technologies. Lower relative permeability results in less surface wave excitation and greater radiating efficiency, both of which are important at the higher frequency ranges. A 0.5 mm thick substrate provides a balanced combination of mechanical support and EM performance. Thinner substrates will reduce the surface-wave losses; however, they will not Provide enough mechanical support for practical fabrication.

A microstrip feed line with a 50-ohm impedance excites the patch antenna, with dimensions selected to achieve the best possible match between the feed network and the circular radiating patch of the antenna. Full-wave electromagnetic Analysis of the antenna was completed using CST Studio. Suite, allowing for analysis of the impedance characteristics, radiation performance and current distribution of the antenna. The conventional antenna exhibited a resonant frequency of about 27.9 GHz, which is nearly at the desired operating frequency band. The antenna model exhibits simulation results showing that its impedance bandwidth is limited to around 0.75 GHz. which does not meet the requirements of wide- band fifth-generation (5G) millimeter-wave communications.

The narrow impedance bandwidth is mainly due to the strong propagation of surface waves and the restricted current path variation of conventional microstrip antenna designs. To solve this issue caused by conventional designs, aA modification technique of the ground plane is proposed, which consists of the two-phase (DGS) technique. In the In the case of a conventional design, the width and length of a Ground planes are reduced symmetrically by 2Ax.

During Phase 1 to create controlled discontinuities directly below the radiating patch, thus changing the surface current arrangement of the ground plane in a major way. Consequently, the effective electrical path length of the antenna is increased, and along with better matching of impedance; this ultimately results in an increase in the impedance bandwidth. The modification of the original ground plane is coarse. Tuning adjustment that expands the bandwidth and preserves the resonance close to the desired frequency. Additionally, the modifications reduce the amount of surface waves. Propagation, which reduces losses due to energy and improves radiation efficiency, thus providing a good starting point for additional refinement through the next phase of the DGS work.

TABLE I Dimensions of the Antenna Design

Antenna Component	Symbol	Value (mm)
Patch radius	r	2.3
Substrate length	Sy	8
Substrate width	Sx	8
Substrate height	h	0.5
Ground depth	Gd	0.035
Feed-line length	Fy	3.8
Feed-line width	Fx	1.6453
Inset length	Iy	1.84
Inset width	Ix	0.25

- Values calculated based on the standard circular patch radius equation that were optimized for use at 28 GHz.
- Initial substrate and ground dimensions are equal to provide for a symmetric design.
- The feed-line width (Fx) was selected for the purpose of producing a 50-characteristic impedance.
- The conventional design was used as the basis for the antenna before making any modifications due to the Defective Ground Structure (DGS)

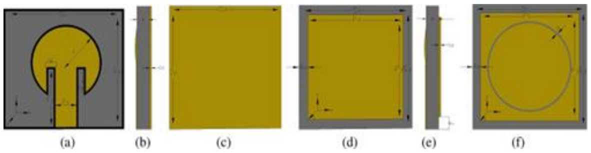

Fig. 1. Conventional circular patch antenna design: (a) front View, (b) side view, (c) back view. Proposed antenna with DGS of: (d) back view with first step (e) side view, and (f) back view with second step of DGS

Radius: -

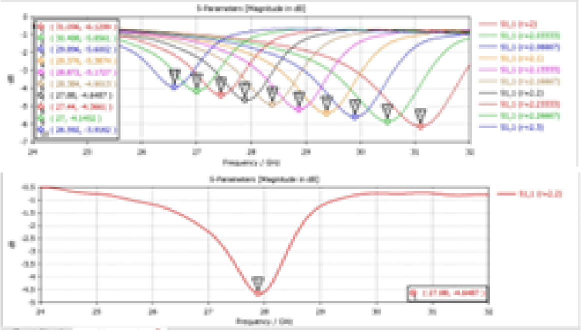

Fig. 2. S-Parameter (S11) variation for different radii and S-Parameter (S11) for patch radius r = 2.2 mm values (r = 2.0 mm – 2.3 mm)

Inset feed length

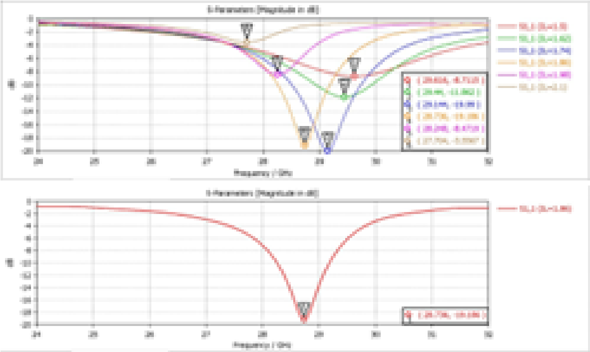

Fig. 3. shows the simulated S-parameter (S11) variation for different inset feed lengths, showing the effect of inset length values ranging from IL = 1.5 mm to 2.1 mm, with the optimum impedance matching achieved at an inset feed length of IL = 1.84 mm.

Ax length

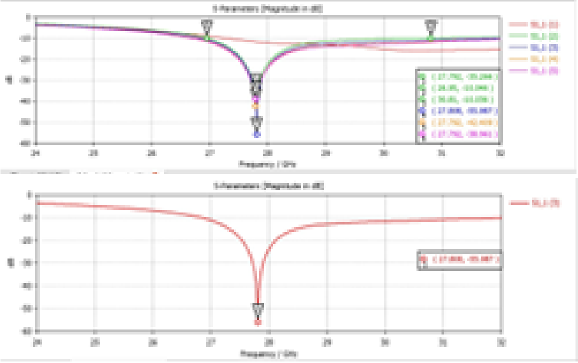

Fig. 4. S-Parameter (S11) variation for different slots and S-Parameter (S11) result for slot dimension AX = 0.133 mm.

a length

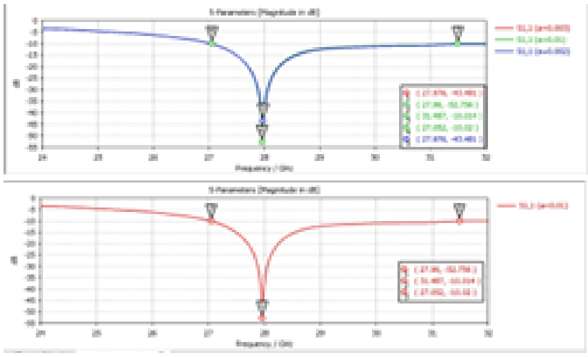

Fig. 5. S-Parameter (S11) variation for different and S Parameter (S11) result for parameter values of parameter ‘a’.a = 0.015 mm

III. PARAMETRIC ANALYSIS

Detailed analysis of the design parameters has been per- formed to determine the characteristics of various geometric parameters on the performance of the 28 GHz circular microstrip antenna. Because of how susceptible millimeter- wave antennas are to minor changes in size, the emphasis was placed on identifying the major parameters that affect the following:(1) resonant frequency, (2) impedance matching, and (3) bandwidth of a circular microstrip antenna. The primary two parameters that were determined were ground plane reduction parameter Ax, antenna component symbol value (mm), patch radius r (2.2), substrate length Sy (8), substrate width Sx (8), substrate height h (0.5), ground depth Gd (0.035), feed-line length Fy (3.8), feed-line width Fx (1.6453), inset length Iy (1.84), inset width Ix (0.25), and trimming thickness (a) of the circular ring that was introduced in the DGS second stage. Other geometric design parameters, such as patch radius, feed line dimensions, and slot size was also evaluated in order to fine-tune the overall performance.

A. *Effect of Ground Plane Reduction (Ax)*

While reducing the ground area to 2Ax in Stage 1 of the DGS process causes a change in the direction of current flow under the patch and adds more inductive-capacitive Loading, it also expands the range of impedance bandwidths available from the patch. The change in impedance bandwidth that occurs with the varying Ax Values can be summarized as follows: Reducing the Size of Ax on the patch: the first and third boundaries of Ax (0.15 mm and 0.20 mm) provide a substantial improvement in matches and broadened operational bandwidth.

Most likely, the closest value to the ideal value of Ax is 0.133 mm, where:

- The resonant frequency is approximately 28.7 GHz.
- A bandwidth of approximately 3.9 GHz is available
- Return loss on the patch is approximately -55 dB.

dBLarge reductions of Ax of 0.25 mm create a poor match due to added inductive-capacitive loading; added resonances also cause undesirable degradation of DGS effectiveness. The above data and results indicate that the proper ground area reduction must be maintained for maximum bandwidth. enhancement while continuing to maintain stable resonances.

B. *Effect of Circular Ring Thickness (a)*

The optimal Ax was followed by a thin circular ring. etched into the reduced ground plane, thus providing fine- tuning capabilities for the resonance of the antenna due to the thin-ring structure behaving as a precise perturbation element on the reactive performance of the antenna. From the simulation results, the following conclusions may be drawn:

- Very small A values (0.001 - 0.01 mm) result in large shifts in resonant frequency and return loss.
- The ideal value of 0.015 mm results in the following performance:
  - ○ Resonant Frequency (Fr) 28.00 GHz

  - Return Loss (RL) -57 dB
  - Excellent wideband stability across the full 26 - 32 GHz frequency range
- Values greater than or less than 0.003 mm shift Fr away from 28 GHz and reduce the amount of time the antenna will be in a matched condition for its lowest null point. Therefore, the thin-ring DGS is the primary means for aligning the resonance of the antenna.

C. Influence of Other Geometric Parameters

The antenna characteristics were defined predominantly by Ax and a, but the following parameters were optimized as well:

- The patch radius (r) - Increasing r moves the resonance lower; the optimal radius for 28 GHz was found to be r = 2.3 mm.
- Feed-line width (Fx) – The optimum feed-line the width for a stable 50 Ω match is 1.645 mm.
- Inset feed length – The inset feed length should be between 1.5 and 2.1 mm for improved impedance matching.
- Slot dimension – Minor slot-width variations may assist in fine-tuning the impedance match; however, the effect of small slot-width variations is significantly less than that of Ax and a.

These additional parameters provided a method to improve the input matches without negatively impacting the wideband attributes of the DGS.

D. Final Optimized Parameter Combination

The optimized parameters resulting from both the thesis and Journal papers are combined for maximum performance. and their characteristics are: -

- Ground-plane widths (A, where A=0.133 mm).
- Thickness of the rings (where a = 0.015 mm).
- Patches: Radius=2.3 mm.
- Material: RT5880LZ ($\varepsilon r = 2.0$, h = 0.5 mm).
- Feed width: 1.645 mm.

This overall configuration gives acceptable performance at the mm-level for:

- Resonance frequency: 28.00 GHz.
- Bandwidth: 27.07-31.36 GHz.
- Return Loss: -62 dB.
- VSWR: 1.001.
- Gain: 6.4dBi.

IV. RESULTS AND DISCUSSION

Using CST Studio Suite, the antenna's performance was simulated employing full-wave electromagnetic modelling, and these simulation results were used to evaluate the DGS-based Circular Microstrip Antenna. This Project was then evaluated against the Antenna's most important parameters, Reflection Coefficient, impedance Bandwidth, Voltage Standing Wave Ratio, Surface Current Distribution, Gain, Radiation Efficiency, and how it compared against currently available 28 GHz Antennas. It was found that by systematically designing and optimizing the DGS, the Antenna's performance is significantly improved within the millimetre-wave range.

A. Reflection Coefficient

Using CST Studio Suite, the antenna's performance was simulated using full-wave electromagnetic modeling, and these simulation results were used to evaluate the DGS-based circular microstrip antenna. This project was then evaluated against the antenna's most important parameters, Reflection Coefficient, Impedance Bandwidth, Voltage Standing Wave Ratio, Surface Current Distribution, Gain, Radiation efficiency and how it compared against current available 28 GHz antennas. It was found that by systematically designing and optimizing the DGS, the antenna's performance is significantly improved within the millimeter-wave range.

Reflection Coefficient and Impedance Bandwidth The reflection coefficient (S11) is a critical parameter that quantifies the degree of impedance matching between the antenna and the feeding transmission line. A lower S11 value indicates better impedance matching and reduced power reflection. The standard circular microstrip antenna, without any changes to its ground plane, has a resonance frequency of about 27.9 GHz. However, the antenna exhibits a very narrow impedance bandwidth of less than 1 GHz, which severely limits its applicability for wideband 5G millimeter-wave communication systems. This limitation arises due to strong surface-wave propagation and restricted current-path variation inherent to conventional microstrip structures. To address this limitation, a two-stage defective ground structure is introduced. In the first stage, the ground plane is symmetrically reduced by a factor of 2Ax. Creating purposeful breaks beneath the radiating patch.

This modification alters the surface current distribution and effectively increases the electrical length of the antenna, resulting in noticeable improvement in impedance matching and bandwidth. A thin circular ring was etched onto the reduced ground planes in the second stage, further enhancing impedance matching. Due to this fine structure, precise tuning of the antenna resonance occurs. Impedance matching is now deeper due to the finely tuned structure. The antenna, which has optimized parameters of Ax = 0.133 mm and a = 0.015 mm, has a maximum return loss of -62 dB at exactly 28.00 GHz. The corresponding -10 dB matching performance is from 27.07 to 31.36 GHz. Therefore, the antenna has a usable bandwidth of roughly 4.3 GHz. A substantial increase in bandwidth confirms the dominant effect of the dual-stage ground plane engineering method in enhancing an antenna's electromagnetic performance.

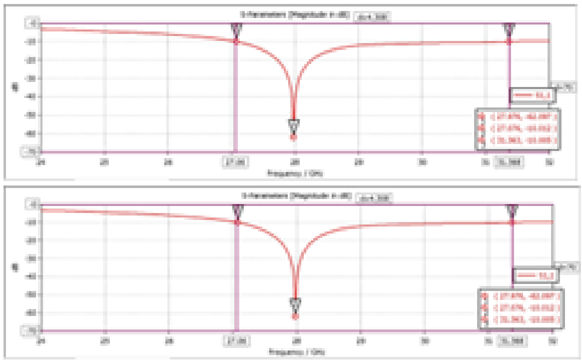

Fig. 6. Return loss comparison of the conventional antenna and the proposed DGS antenna

B. Voltage Standing Wave Ratio (VSWR)

The Voltage Standing Wave Ratio (VSWR) is a different more intuitive way of saying whether or not an antenna's Impedance can be adjusted to work with that of its feed line. (Typically, 50 Ω). Ideally, the VSWR of any antenna Operating efficiently at its design frequency will always be less than 2.

Figure 7 shows the VSWR performance characteristics of the new proposed antenna reveals that the VSWR was less than two for all frequencies tested (in the range between 27.07 GHz to 31.36 GHz). This indicates that there was good impedance matching over the wideband frequency range. At 28 GHz (the resonant frequency), the antenna's VSWR was equal to 1.001, which is an excellent indicator of the compatibility of the antenna's impedance and that of the 50 Ω feed line. The low VSWR also confirms that the use of both a dual-stage, and Dual-Stage DGS is an effective method of tuning antennas and providing stable wideband operation.

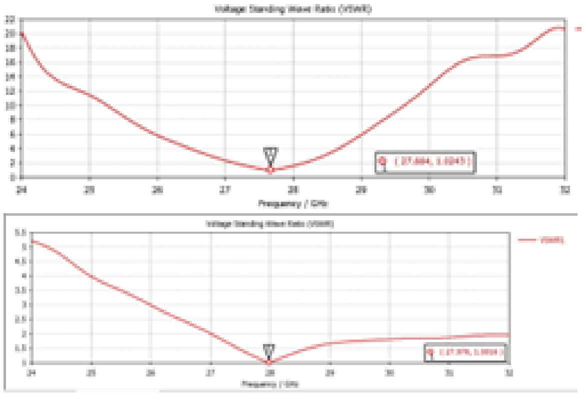

Fig. 7. VSWR with & without DGS

C. Surface Current Analysis

This section will explain how the use of a DGS in the Construction and operation of antennas affect energy. Transfer efficiency through surface current. The DGS affects where on the antenna's surface current is distributed, which in turn affects its performance. The antenna that was used as a control for this study had an area of surface current that mostly was concentrated on the lower middle section of the circular-shaped aperture.

This caused the DGS antenna to have low efficiency in terms of radiation, and it could only operate over a very narrow bandwidth. Comparatively speaking, a DGS-driven antenna will exhibit a much higher density of surface current in the area of damage to the printing on the ground plane as opposed to being concentrated in the corners of the ring. This has resulted in the DGS providing an overall increase in the surface current channel length by as much as four times, resulting in a corresponding increase in both efficiency of output-radiated power and bandwidth of operation. The DGS has also increased the bandwidth of operation by acting to reduce the amount of surface-wave propagation from the last loop to the edge of the circular patch through the use of a DGS structure.

D. 2D Polar Plot Representation

The two-dimensional (2D) polar graphs are graphical. representations that depict the radiation properties of the antenna in its principal planes, specifically at its operating frequency of 28 GHz. They illustrate how the radiated power is distributed with respect to the angle from the antenna and provide insight into how stable, well-defined, and directed the radiated energy pattern of the antenna is the E-plane (φ = 0°) and H-plane (φ = 90°) radiation diagrams were compared between the conventional antenna and the newly developed antenna with the defected ground structure (DGS). In both the E-plane and H-plane, the newly developed DGS-based antenna shows stable and well-defined main lobes with little distortion. This shows that using a faulty ground structure does not affect the radiation pattern. The characteristics of the antenna are also enhanced, and the bandwidth is increased. DGS at φ = 90 DGS at φ = 90.

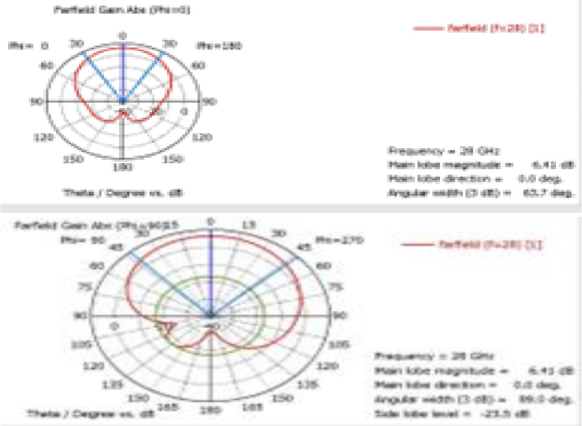

Fig. 8. Polar plot without DGS and Polar plot with DGS at φ = 0 & φ = 90

E. Gain and Efficiency

The amount of electric power that the antenna emits and directs toward sources and targets, providing an important measurement of the quality of the antenna based on its antenna gain characteristics. The antenna is able to attain maximum gain, which is 6.4 dBi at 28 GHz.

This is ideal for compact 5G millimeter-wave electronics, where there are size constraints.The antenna has a radiating efficiency of approximately 70%, meaning less than one-third of the input electrical power has been dissipated as dielectric and conductor losses this achievement is incredible for a compact millimeter-wave antenna, as the losses associated with poorly designed antennas tend to increase because of the relatively tiny mechanical [physical] sizes of the antennas during very high frequency operation. Additionally, the antenna retains relatively consistent gain. across its entire operating frequency range; therefore, the radiation characteristics of the antenna are expected to be the same at all frequencies that would fit within the defined range of the 5G antenna.

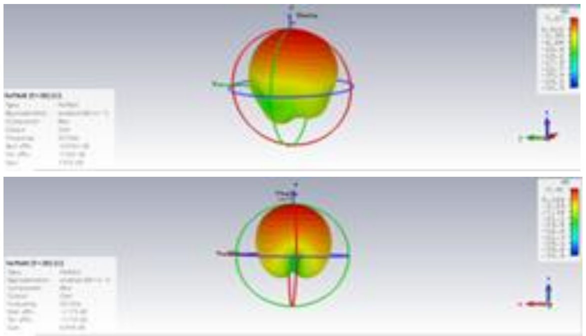

Fig. 9. Radiation pattern comparison of the proposed antenna with and without DGS

TABLE II Comparative Performance Analysis of the Proposed Antenna with Existing Works

Reference	Antenna Dimensions (mm^3)	Resonant Frequency (GHz)	Bandwidth (GHz)	Peak Gain (dBi)	Return Loss (dB)	Efficiency (%)
[1]	5 × 3 × 1.6	28	4.41	4.49	-27	89
[2]	6.2 × 8.4 × 1.57	28	5.57	5.06	-23	—
[3]	30 × 30 × 0.508	28	5.00	5.80	-30	80
[4]	1.2 × 1.2 × 0.018	28	6.40	5.60	-33	87
[5]	7.43 × 3.8 × 0.79	28	2.10	7.41	-30	—
[6]	5.16 × 3.44 × 0.55	28	1.95	6.14	-27	—
[7]	10 × 10 × 1.575	28	4.00	7.10	-28	—
[8]	18.85 × 24 × 0.254	28	2.90	3.45	-35	88
Proposed Work	8 × 8 × 0.5	28	4.3	6.4	-62	70

V. CONCLUSION

In this research work, we reported on the design and evaluation of a compact circular microstrip antenna for use with a 28 GHz millimeter-wave 5G system, which includes a dual-stage, deflated ground. The antenna uses a low-loss RT5880LZ substrate, and systematic engineering techniques were employed to optimize the antenna through controlling the amount of ground reduction and placing a thin circular ring defect on the surface of the microstrip board. In effect, these two approaches improved the level of electromagnetic performance exhibited by the antenna.

The proposed antenna achieves a wide impedance range. bandwidth of 4.3 GHz (27.07–31.36 GHz), an ultra-low return loss of -62 dB, the minimum voltage-standing-wave ratio of 1.001 and a stable peak gain of approx. 6.4 dBi. The radiation patterns produced by the proposed antenna are stable within the operating band, indicating that the antenna is suitable for use in practical 5G millimeter-wave systems. A comparison with recently reported antennas also demonstrates that the proposed antenna exhibits better bandwidth enhancement performance, improved impedance matching performance, compact size, and simple design compared to other designs.

Due to disadvantages, and the fact that the antenna has an efficient fabrication process, the proposed antenna is a strong candidate for use with compact 5G transceivers and millimeter-wave systems and for future development. of wireless communications.

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