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Design of a Half-Moon-Shaped Microstrip Patch Antenna With Defected Ground Structure (DGS) for 5G Applications at 26 GHz

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Abstract

A half-moon-shaped microstrip patch antenna is created from circular patch antenna of radius 2.5 mm by removing one side of another circular patch antenna of radius 2.2 mm for 5G applications (high frequency band i.e. 24 GHz and above), which provide faster data transmission but shorter range. When a rectangular notch is removed from the ground side of the proposed antenna, it results in excellent return loss of −44.51 dB and a bandwidth of 3.888 GHz. The novel half-moon-shaped patch antenna is designed using Rogers RT 5880 substrate with a relative permittivity of 2.2 and is fed by 50Ω microstrip line. Defected Ground Structure (DGS)-loaded half-moon-shaped patch antenna obtained an excellent return loss of −44.51 dB with a bandwidth of 3.888 GHz between frequency band of 24.189 GHz and 28.077 GHz, at a resonant frequency of 25.910 GHz, which is close to the desired frequency of 26 GHz. This proposed antenna also can be used for high bandwidth applications requiring precise location tracking and data transmission. The suggested DGS-employed patch antenna yields an acceptable gain of 5.88 dBi at a resonant frequency of 25.910 GHz and voltage standing wave ratio of 1.01, which is very close to the ideal value of 1.

Categories: Microwave and RF Engineering, Wireless Communication Systems
Keywords: half-moon shape patch antenna, dgs, return loss, bandwidth, cst

Introduction

The escalating behest of wireless communication technology made pathway for new technologies such as 5G. 5G, the fifth generation of mobile networks, builds upon the advancements of its predecessors (1G to 4G) which is overcrowded. Using millimeter waves (mmWave), a higher frequency band that can handle substantially larger data speeds than the lower frequency bands utilized in earlier generations, is one of the main characteristics of 5G. The potential speeds of 5G can reach up to 10 Gbps, thanks to these high frequencies, which are usually in the 30 GHz to 300 GHz range. This is far faster than the fastest speeds achieved by 4G LTE. Capacity and Connectivity: 5G can support a much larger number of devices simultaneously, making it ideal for densely populated areas and the growing number of Internet of Things (IoT) devices. It also has much lower latency, meaning the time it takes for devices to communicate with the network is significantly reduced. Different frequency bands, ranging from 24 GHz to 86 GHz in mmWave bands, are defined for 5G communication systems by International Mobile Telecommunications [1] in World Radio Communication in 2019, including 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 GHz and 66-71 GHz for the deployment of 5G networks. Microstrip patch antenna can be designed to operate in these high frequency band due to their small size and lightweight, making them ideal for integration into mobile devices and other compact systems. Due to their low profile, easy fabrication and inexpensive to manufacture, microstrip patch antennas are often used in Global Positioning System, microwave sensors, satellites, radar and other applications.

Microstrip patch antennas consist of a metallic patch on a dielectric substrate with a ground plane on the other side. The patch can be of various shapes, such as rectangular, circular or other geometries. The industry provides a large range of substrates with relative permittivity varying from 2.2 to 12 for the creation of microstrip patch antennas. A substrate with a lower dielectric constant can offer a wide bandwidth and gain at a good efficiency. Numerous researchers have come up with different methods to increase impedance bandwidth, reflection coefficients utilizing different substrate types, feeding methods, various slots, notches in the radiating patch and ground. Hakanoglu et al. [2] reported that an inset-feed square microstrip patch antenna patch with a diamond-shaped slot enhanced the return loss to −44 dB while Imran et al. [3] developed a rectangular patch antenna for dual-band (5G, 54 GHz) 5G cell communication with bandwidths of 1.94 GHz and 2 GHz. Şeker [4] et al. presented a rectangular microstrip patch antenna at a resonant frequency of 26 GHz with a bandwidth of 2.49 GHz, and the proposed antenna was simulated in the High Frequency Structure Simulator (HFSS) module. Kumar [5] et al. presented a circular patch antenna at 28 GHz with a return loss of −43 dB, a 0.792 GHz bandwidth and a gain of 7.69 dBi for 5G and space applications. Kaeib [6] et al. presented a single element slotted microstrip antenna with compact size to operate at 28 GHz for 5G applications having a return loss of −39.37 dB, 2.48 GHz of bandwidth and gain

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of 6.37 dB. Colaco [7] et al. proposed a rectangular patch antenna with a return loss of −33.4 dB, good bandwidth of 3.56 GHz and gain of 10 dBi. Przesmycki et al. [8] proposed a rectangular microstrip patch antenna that resonates at 28 GHz with a return loss of −22.51 dB, gain of 3.6 dBi and a decent bandwidth of 5.57 GHz. Fante et al. [9] published a rectangular microstrip patch antenna operating at 28 GHz with a bandwidth of 1.062 GHz and a return loss of −54.49 dB using Rogers RT/Duroid 5880 substrate material. Punith et al. [10] proposed a multi-band microstrip patch antenna operating at 23.9 GHz, 35.5 GHz and 70.9 GHz. Ghazaoui [11] et al. reported a slotted E-shape microstrip patch antenna at 28 GHz with a return loss of −39.70 dB, bandwidth of 4.1 GHz and a gain of 5.32 dBi. Singh [12] et al. introduced a simple rectangular antenna resonates at 29.87 GHz and 39.02 GHz with a return loss of −17.16 dB and −20.35 dB, respectively, having bandwidth of 1.24 GHz and 2 GHz. Kamal et al. [13] proposed a single-band hook-shaped antenna with a gain of 3.59 dBi and a low return loss of approximately −36 dB. Gemeda et al. [14] proposed a inset-feed rectangular microstrip patch antenna with return loss of −38.86 dB, bandwidth of 1.046 GHz and a gain of 7.587 dBi at a resonant frequency of 28 GHz. Hussain et al. [15] designed a circular microstrip patch antenna with two rectangular slots, a resonance frequency of 28 GHz, a bandwidth of 3.52 GHz and a return loss of around −29 dB. Gaid et al. [16] proposed a rectangular microstrip patch antenna with a resonance frequency of 28 GHz, a return loss of −45 dB and a bandwidth of 1.43 GHz using HFSS software and Computer Simulation Technology (CST) validation.

In this effort, a half-moon-shaped microstrip patch antenna is created from circular patch antenna by removing another circular patch antenna for 5G application (high frequency band i.e. 24 GHz and above), which provide faster data transmission but shorter range. Due to the size reduction at higher frequencies, microstrip patch antennas can be integrated into small devices, making them suitable for mobile phones, base stations and IoT devices. When a rectangular notch is removed from the ground side of the proposed antenna, it results in an excellent return loss of −44.51 dB and a bandwidth of 3.888 GHz at a resonant frequency of 25. 910 GHz, which is close to the desired frequency of 26 GHz. This proposed antenna also can be used for high bandwidth applications requiring precise location tracking and data transmission.

Materials And Methods

A half-moon-shaped microstrip patch antenna with notch in the ground is loaded using the CST studio suite version 2022. The suggested antenna's substrate, known as Rogers RT 5880/Duroid, has a loss tangent (tanδ) of 0.0010 and a relative permittivity of 2.2. Both the feedline and the ground are made of copper-containing material. The presented antenna is feeding with 50Ω microstrip line. The measurements of patch and ground for the proposed patch antenna, which is intended to be developed at a resonant frequency of 26 GHz, are found using equations (1) through (7) below. These calculations may be used to determine the width and length [17] of the patch antenna.

$$W = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \qquad ...(1)$$

where c is speed of light, f_0 is the resonant frequency, ε_r is the relative permittivity of the substrate

$$L = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} - 2\Delta L \qquad ...(2)$$

where ϵ_{eff} is the effective relative permittivity given as follows:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \qquad ...(3)$$

and ΔL is the length extension given as follows:

$$\Delta L = 0.412h\frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad ...(4)$$

Radius(a) of the circular patch antenna can be determined using following equation:

$$a = \frac{F}{\left[1+\frac{2h}{\pi F\varepsilon_r}\left(\ln\left(\frac{\pi F}{2h}\right)+1.7726\right)\right]^{0.5}} \qquad ...(5)$$

where $F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$

The length and width of the ground is calculated as

$$L_g = 6h + a \quad ...(6)$$

$$W_g = 6h + a \quad ...(7)$$

The thickness of the metal patch is taken as 0.035 mm and width and length of the ground taken as 7.5 mm and 7 mm. The different parameters for the proposed microstrip patch antenna are given in the Table 1.

Parameters	Values (mm)
Width of ground (W_g)	7.5
Length of ground (L_g)	7
Width of feed (W_f)	0.69
Length of feed (L_f)	1.35
Height of substrate (h)	1.1
Outer radius of circle (r)	2.5
Width of notch in the ground side (a)	7
Length of notch in the ground side (b)	0.90

TABLE 1: The parameters for proposed microstrip patch antenna

The frequency selection, appropriate substrate material selection and patch dimension selection are critical components in the design of microstrip patch antennas. A half-moon-shaped microstrip patch antenna with outer radius of 2.2 mm using Rogers RT 5880 substrate is designed initially and implemented using CST studio suite. The desired frequency for the proposed modeling is 26 GHz. A notch in the ground side is applied to improve the return loss and bandwidth of the proposed antenna. Figure 1 depicts the proposed antenna geometry design. Initially, a circular patch antenna of 2.5 mm radius is designed using CST studio suite version 2022. Later, another circular patch of radius 2.2 mm is removed at one side from the original circular patch antenna. To increase return loss and bandwidth, a rectangular notch is cut out from ground side of the proposed antenna.

As illustrated in Figure 1(a), half-moon-shaped microstrip patch antenna is designed by taking a circular patch initially of radius 2.5 mm. Using another circular patch of radius 2.2 mm, a notch is removed from initial circular patch to make a half-moon-shaped patch antenna. The bandwidth of the half-moon-shaped antenna is 3.591 GHz, with the frequency band lying between 24.517 GHz and 28.108 GHz and its return loss is −20.53 dB. In the next phase, a rectangular portion (as dimensions given in Table 1) is removed from the ground side and provides a return loss of −44.51 dB, with the frequency band lying between 24.189 GHz and 28.077 GHz.

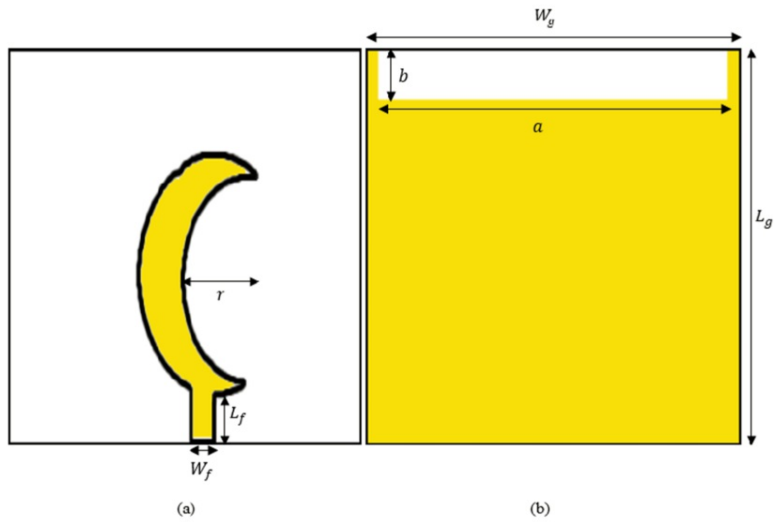

FIGURE 1: Geometry of proposed antenna: (a) half-moon-shaped patch, (b) half-moon-shaped patch antenna with DGS

DGS, Defected Ground Structure

Results

A half-moon-shaped microstrip patch antenna with a Defected Ground Structure (DGS) is designed to enhance the return loss and bandwidth to −44.51 dB and 3.888 GHz. In this effort, return loss, bandwidth and gain of microstrip patch antenna are being enhanced, as it provides low bandwidth and gain. Using the CST studio suite of tools, all simulations and analyses for the design of this microstrip patch antenna are performed. Modeling of the proposed antenna is done between 22 GHz and 30 GHz. The proposed half-moon-shaped patch antenna with DGS antenna is modeled at a resonant frequency of 25.910 GHz, with achieved bandwidth of 3.888 GHz and a return loss of −44.51 dB, compared to standalone half-moon-shaped antenna, which provides a return loss of −20.53 dB at resonant frequency of 26.106 GHz. The return loss of two different stages of antennas is compared as shown in Figure 2. How much power is reflected back from the load to the source is shown by return loss (dB). Voltage standing wave ratio (VSWR) of two stages of antenna is also compared as shown in Figure 3. The VSWR indicates how well the antenna fits the transmission line. The half-moon-shaped patch antenna provides VSWR of 1.2 at resonant frequency of 26.106 GHz while half-moon-shaped patch antenna with DGS registers itself good matching device with VSWR of 1.01. Figure 4 represents the comparative gain graph among two different stages of antennas. The half-moon-shaped patch antenna with DGS outperforms the standalone antenna and provides good gain of 5.88 dBi at a resonant frequency of 25.910 GHz, whereas the half-moon-shaped patch antenna yields a gain of 5.37 dBi at a resonant frequency of 26.106 GHz. Efficiency of half-moon-shaped patch antenna with DGS is obtained as 83% while the half-moon-shaped patch antenna yields 75% at a resonant frequency of 25.910 GHz and 26.106 GHz, respectively, as displayed in Figure 5. Directivity of DGS-loaded half-moon-shaped patch antenna achieved 7.13 dBi at a resonant frequency of 25.910 GHz as shown in Figure 6.

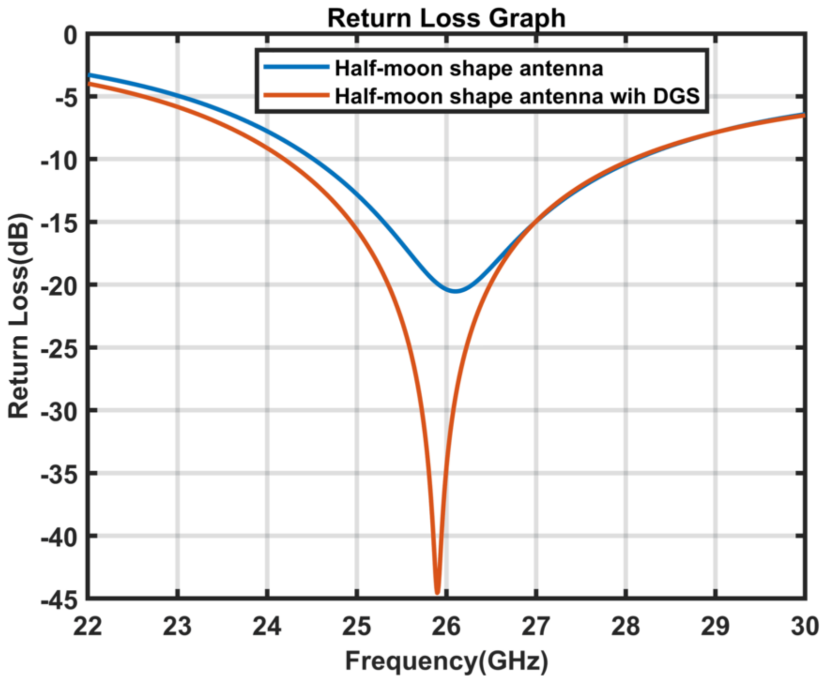

FIGURE 2: Comparative return loss between half-moon-shaped antenna and antenna with DGS

DGS, Defected Ground Structure

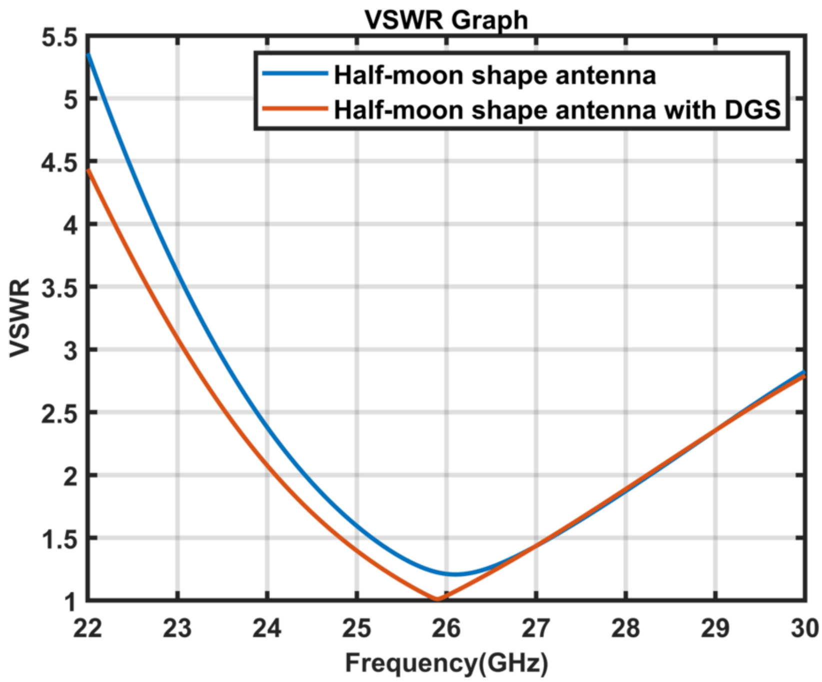

FIGURE 3: Comparative VSWR between half-moon-shaped antenna and antenna with DGS

VSWR, voltage standing wave ratio; DGS, Defected Ground Structure

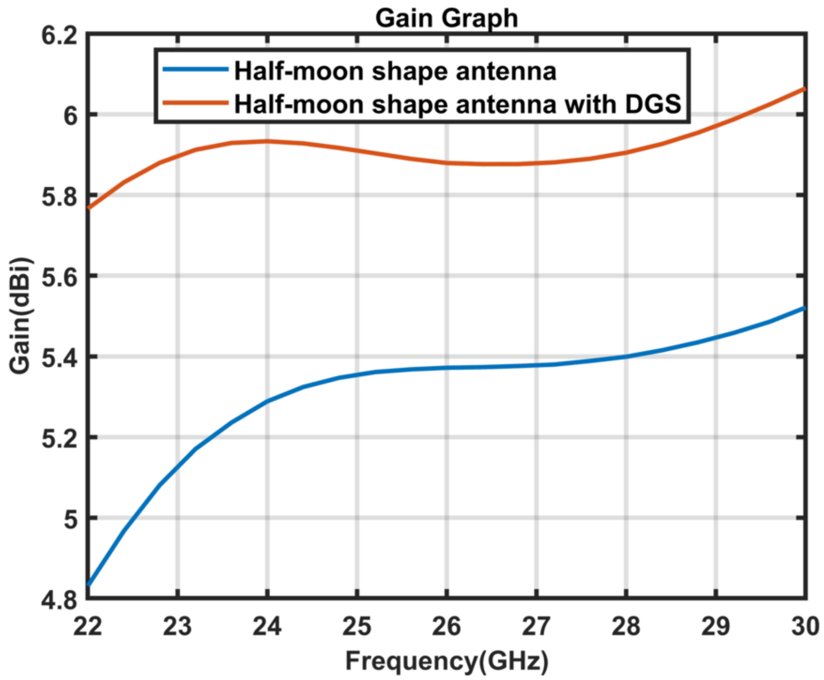

FIGURE 4: Comparative gain between half-moon-shaped antenna and DGS-loaded antenna

DGS, Defected Ground Structure

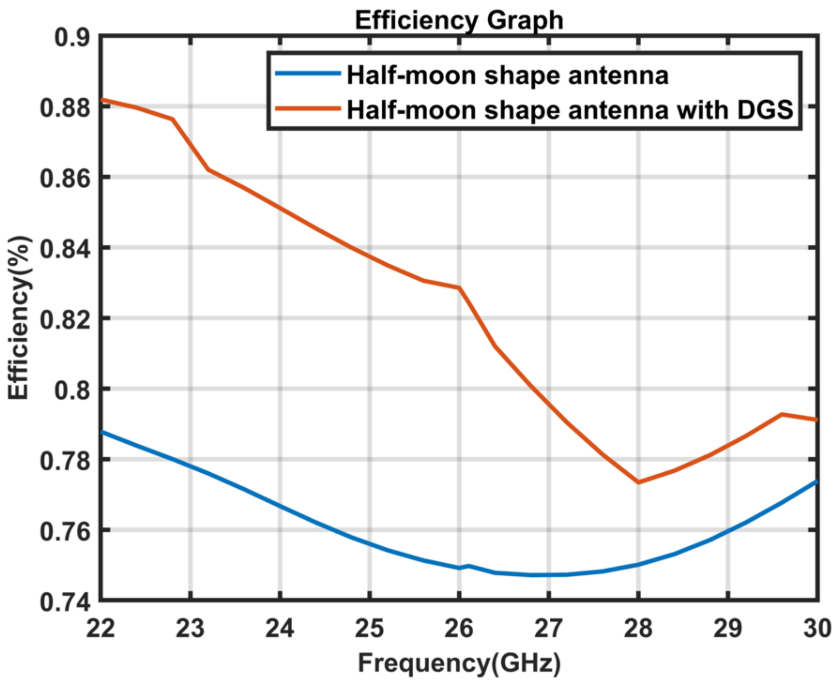

FIGURE 5: Comparative efficiency between half-moon-shaped antenna and DGS-loaded antenna

DGS, Defected Ground Structure

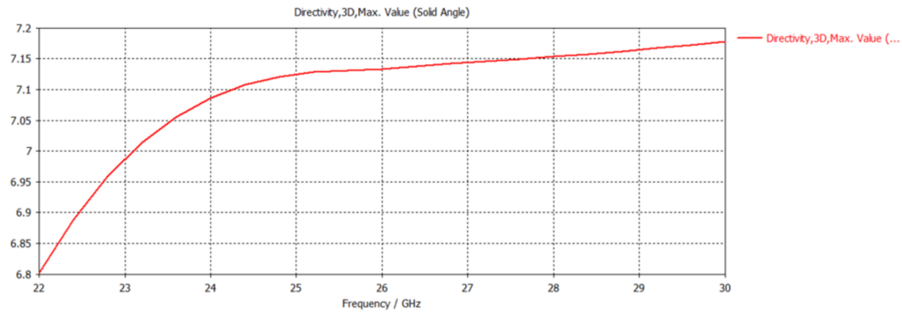

FIGURE 6: Directivity of DGS-loaded half-moon-shaped antenna

DGS, Defected Ground Structure

Figures 7 and 8 display the 2D radiation characteristics of the half-moon-shaped patch antenna at φ= 0° and φ= 90° and Figures 9 and 10 show DGS-employed proposed antenna at φ= 0° and φ= 90°. DGS-loaded proposed antenna have a 3 dB beamwidth of 76.7° and 91.7° at resonance frequencies of 25.910 GHz and a 3 dB beamwidth of 76.5° and 82.5° for half-moon-shaped patch antenna at resonance frequencies of 26.106 GHz. Figure 11a-b displays the surface current distribution of half-moon-shaped patch antenna and DGS-employed proposed antenna. The surface current of the half-moon-shaped microstrip patch antenna is 232 A/m, whereas the DGS-loaded patch antenna has a surface current of 244 A/m.

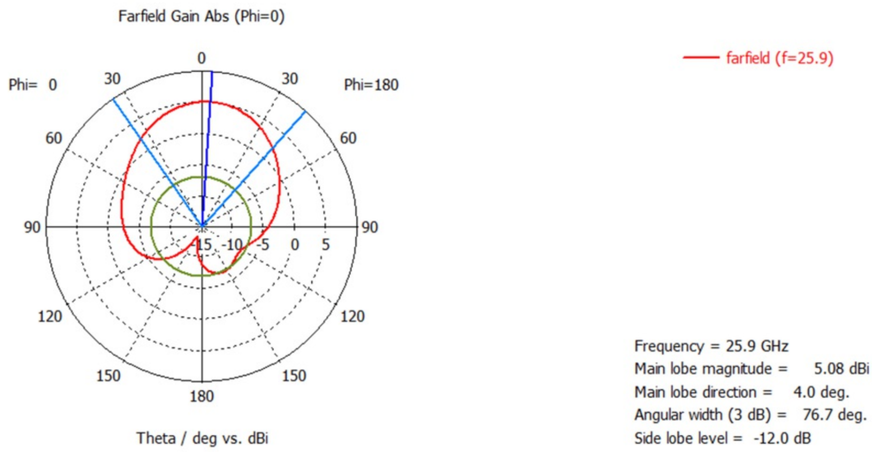

FIGURE 7: 2D radiation pattern of half-moon-shaped patch antenna at φ= 0°

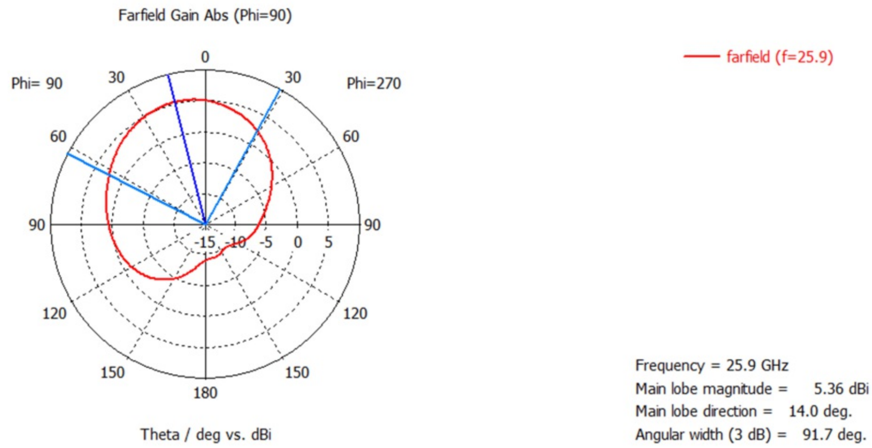

FIGURE 8: 2D radiation pattern of half-moon-shaped patch antenna at φ= 90°

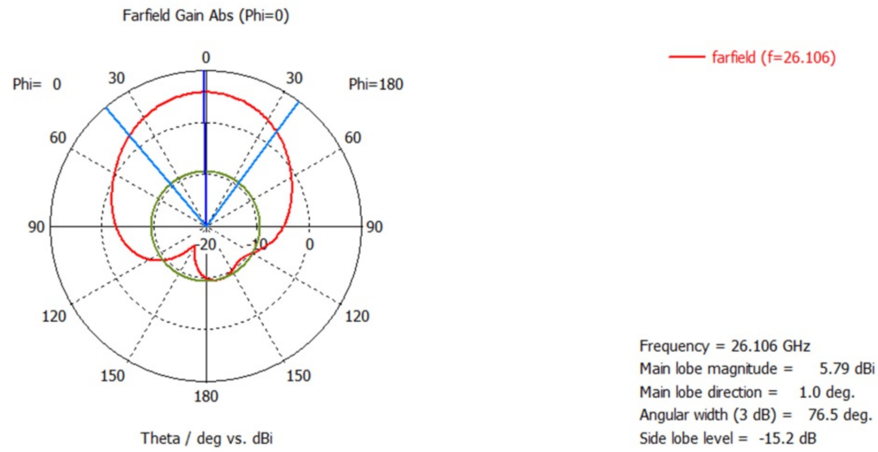

FIGURE 9: 2D radiation pattern of DGS-loaded half-moon-shaped patch antenna at φ= 0°

DGS, Defected Ground Structure

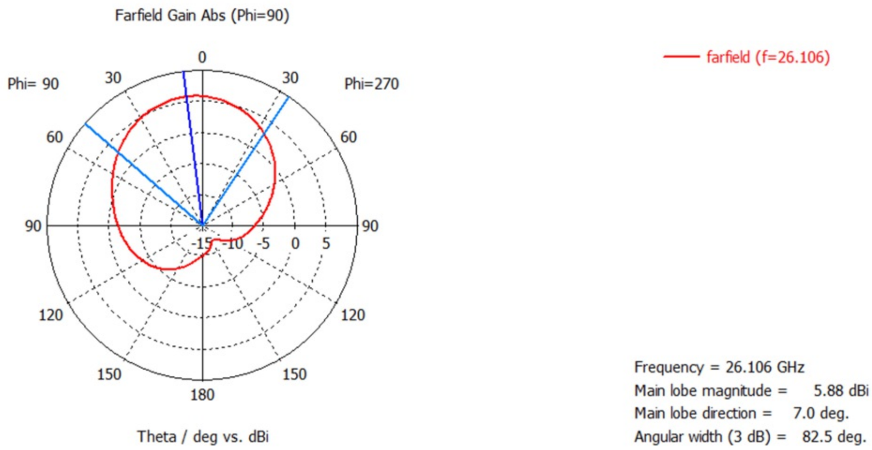

FIGURE 10: 2D radiation pattern of DGS-loaded half-moon-shaped patch antenna at φ= 90°

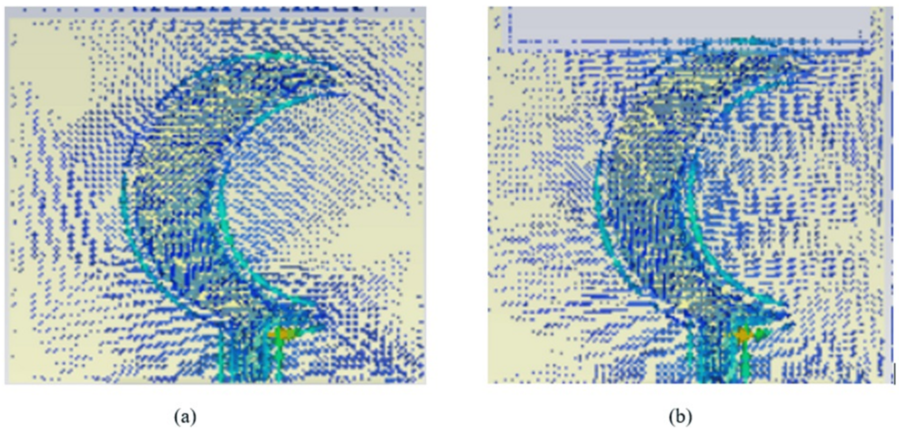

FIGURE 11: Surface current distribution of (a) half-moon-shaped patch antenna and (b) DGS-loaded proposed antenna

Discussion

The proposed half-moon-shaped microstrip patch antenna with DGS is modeled using CST studio suite version 2022. The suggested patch antenna with DGS offers a high return loss of −44.51 dB with an excellent bandwidth of 3.888 GHz, with the frequency band lying between 28.077 GHz and 24.189 GHz, which is essential for 5G applications like streaming of real-time audio/video and so on. The proposed antenna also provides good gain of 5.88 dBi at a resonant frequency of 25.910 GHz and acceptable efficiency of 83%. The VSWR of suggested antenna is 1.01, which is so close to ideal value of 1. In Table *2*, a comparative result of both stages of antennas is displayed.

Antenna	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz)
Half-moon patch antenna	26.106	–20.53	3.591
Half-moon patch antenna with DGS	25.910	–44.51	3.888

TABLE 2: Comparative results of different stages of antenna modeling

DGS, Defected Ground Structure

The results of the suggested DGS-loaded unique half-moon-shaped microstrip patch antenna are contrasted with those of earlier studies. In terms of bandwidth, resonant frequency, gain and return loss, Table 3 contrasts the recommended antenna with the alternative. The recommended patch antenna offers a very high bandwidth, acceptable gain, and a great return loss based on the comparison data.

References	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz)	Gain (dBi)
[2]	26	−33.40	3.56	10
[3]	26	Not specified	2.49	Not specified
[8]	30.216	−44.059	1.008	Not specified
[11]	28	−43	0.792	7.69
[14]	28	−38.86	1.046	7.58
[15]	28	−39.37	2.48	6.37
[16]	28	−39.70	4.1	5.32
Proposed work	25.910	−44.51	3.888	5.88

TABLE 3: Compares the suggested patch antenna design to earlier patch antenna designs

Conclusions

A novel half-moon-shaped microstrip patch antenna is designed by restructuring a circular patch antenna, cutting away another circular patch antenna. The half-moon-shaped microstrip patch antenna provides a return loss of −20.53 dB with a bandwidth of 3.591 GHz at a resonant frequency of 26.106 GHz. A rectangular notch is removed from the ground side of the proposed antenna to enhance the return loss and bandwidth. The half-moon-shaped patch antenna with DGS achieved a return loss of −44.51 dB with a bandwidth of 3.888 GHz, which is favorable for 5G applications at a resonant frequency of 25.910 GHz, close to the desired frequency of 26 GHz. VSWR of the proposed DGS-loaded antenna is 1.01, very near the ideal value of 1, and the gain of the suggested antenna is 5.88 dBi at a resonant frequency of 25.910 GHz.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Dipankar Saha, Sudip Mandal, Kabita Purkait

Acquisition, analysis, or interpretation of data: Dipankar Saha

Drafting of the manuscript: Dipankar Saha

Critical review of the manuscript for important intellectual content: Sudip Mandal, Kabita Purkait

Supervision: Sudip Mandal, Kabita Purkait

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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