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Modified D Shaped Dual-Band Microstrip Patch Antenna for 5G Ka Band Application

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***Abstract*—A dual-band microstrip patch antenna is designed and discussed in this article that operates at 28 GHz and 35 GHz frequency band which aligns with the 5G Ka band application. Two resonant cavities are formed by the antenna's modified D-shaped design, which has a half-ring slot and a rectangular slot etched into a rectangular patch. The antenna's return loss is computed within a range of -46.39 dB to -28.14 dB, making it suitable for 5G applications. Impedance matching is evident at 34.64 GHz and 27.68 GHz, where the antenna's voltage standing wave ratios are 1.08 and 1.009, respectively. The suggested dual band antenna provides gains of 3.59 dBi and 6.68 dBi at 34.64 GHz and 27.68 GHz, respectively, and operates in the 5G Ka band applications, which span 26.88 GHz to 28.56 GHz and 34.10 GHz to 35.60 GHz.**

***Keywords*—dual-band, microstrip patch antenna, modified D-shape, return loss, slot patch, 5G application**

I. Introduction

High-speed data transfer and highly stable connectivity are in high demand due to the fast spread of wireless communication and the introduction of fifth-generation (5G) technology [1], [2]. Virtual reality, internet of things (IoT), autonomous vehicles, and telecommunications are just a few of the sectors that 5G wireless technology has the potential to completely transform. With the deployment of 5G technology, several industries are anticipated to experience significant transformations. Microstrip antennas are frequently utilized in this area because, in addition to their affordability, low weight, and conformability, they can cover a large area for connectivity through their emission pattern. Furthermore, microstrip patch antennas have an average frequency range of 1 to 100 GHz, which includes the low, mid, and high 5G frequency spectrum [3].

In the area of 5G communication technology, numerous investigations and studies have been carried out that present dual-band or multiband antennas [4]–[8]. It has been shown that combining helical antennas or integrating them with monopole antennas can provide dual frequency functioning using a variety of helical antenna configurations [9], [10]. In dual-band WLAN settings, various elements such as small rectangular patch, rectangular ring, and fork-like monopole were examined [11]. U slots square patch antennas and Symmetric Slots were employed, yielding gains of 4.37 dBi and 1.37 dBi at 2.45 GHz and 5.8 GHz bands, respectively [12]. The work in [13] presents a dual-band antenna with gains of 2.55 dB and 4.41 dB that operates at 5.8 GHz and 28 GHz frequencies. The aforementioned efforts lack one of these two crucial characteristics desired in 5G systems: higher gain or a low-profile design.

This paper introduces a modified D-shaped microstrip patch antenna that operates in two frequency bands. The radiating patch of the antenna has one rectangular slot and one half-circle slot, which create two resonant cavities. The dimensions and geometry of the slots are tuned to produce the desired frequencies and bandwidth for 5G Ka band applications. Additionally, this paper analyzes the impact of several parameters.

A thorough explanation of the suggested modified D-shaped microstrip patch antenna structure is given in Section II.The Section III of this paper presents an analysis of the various parameter optimizations, while the Section IV discusses the simulated results. The final Section V of the paper presents the conclusion.

II. Design Procedure of the Antenna

A. Basic Structure of the Antenna

The design of the proposed antenna is shown in Fig. 1

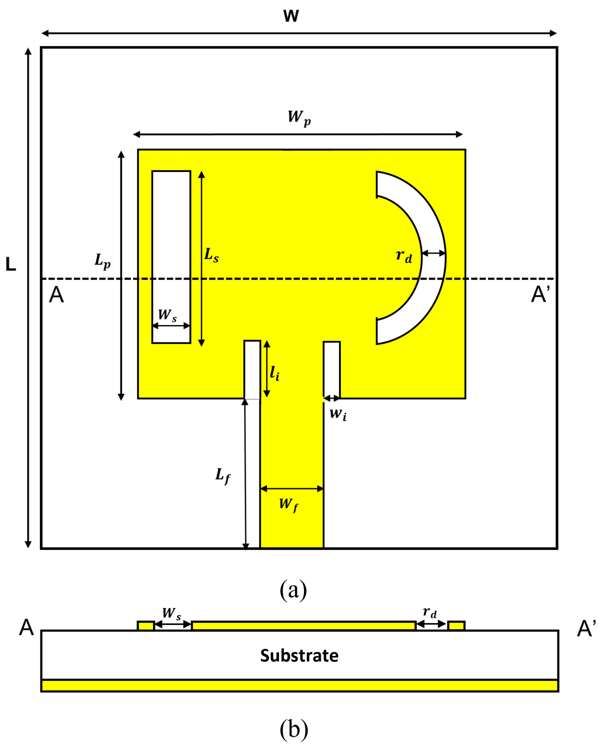


Fig. 1: Geometrical structure of the proposed modified D-shaped antenna. (a) Top view, (b) Cross-Section view.

The proposed antenna includes three layers including a single substrate layer. The middle layer is the substrate that is made up of the Rogers RT Duroid 5880 material ($\varepsilon_r = 2.2$, and $tan\delta = 0.008$). There are two metal layers: one is the ground layer, which is located beneath the substrate layer, and the other is the radiating patch printed on the substrate layer.

In the antenna design, the length and width of the element are denoted by L and W respectively. The length and width of the radiating patch is expressed as L_p and W_p that are located on the top metal layer. Among the two slots etched on the patch, the rectangular-shaped slot having the height of L_s and width of W_s and the other slot having the shape of half ring is separated by a distance r_d. The impedance of the line is 50Ω for the feeding line having width and length W_f and L_f respectively. The height and width of the inset fed line is denoted by l_i and w_i, respectively. To assess this design concept, the parameters are tuned using the software CST Studio Suite.

After optimizing the antenna length and width values, the best output have been selected first. The value with the lowest S-parameter were selected as the optimal one after the patch length and width have been selected and optimized. The patch is then positioned at a distance of roughly 50Ω from the feed line length. The slot's width and length were optimized initially, and then the best return loss was determined. At $3 \times 4.7mm^2$, the patch's maximum gain was found to be about 7.8 dBi. The values of the optimized parameters of the designed antenna are listed in Table I

TABLE I: Parameters of the designed modified D-shaped Antenna

Parameter	Value
Substrate dimension, L × W	6.7 × 6 mm^2
Slot width, W_s	0.50 mm
Patch length, L_p	3.04 mm
Slot length, L_s	2.06 mm
Patch width, W_p	4.23 mm
Inset feed length, L_i	0.67 mm
Feed width, W_f	0.80 mm
Inset width, W_i	0.20 mm
Feed length, L_f	1.83 mm
Half ring slot width, r_d	0.3 mm

III. Parametric Analysis of Proposed Microstrip Patch Antenna

A. Optimization of Microstrip Patch Length and Width

A detailed parametric study was carried out in an effort to optimize the antenna parameters. Our primary focus was on improving the antenna's return loss, voltage standing wave ratio, gain, radiation pattern, and bandwidth. Our strategy was to build and optimize a dual-band microstrip patch antenna using a methodical process that was based on theoretical concepts. Moreover, this theoretical analysis provides some characteristics that help to tune the antenna for the best performance.

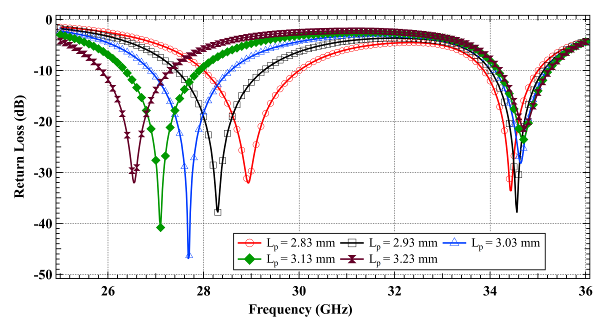


Fig. 2: Return loss (dB) for various Patch length (L_P).

A study is being conducted on the impact of changing the Microstrip patch width (W_P) and length (L_P). Fig. 2 shows how the S-Parameter varies for various patch lengths (L_P) when both slots are included in the proposed antenna. Two well-matched frequency bands, one ranging from 26 to 30 GHz and the other from 34 to 35.5 GHz, are displayed in Fig. 2. This optimization yields the two frequency bands at the ideal locations for the value of 3.04 mm (L_P).

In addition, Fig. 3 demonstrates the variation of return loss for different patch width (W_P) when both slots exist in the proposed antenna. Fig. 3 shows two well-matched frequency bands, one of which is the same for all W_P values and has a bandwidth of 2 GHz extending from 26.8 to 28.8 GHz and the other band spans from 33.2 to 36.6 GHz. The result of this optimization is the two frequency bands at the optimal positions for the 4.23 mm (W_P) value.

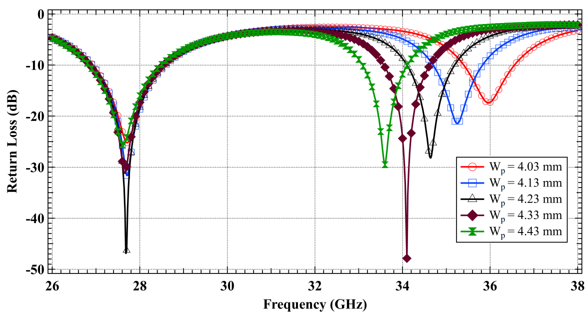


Fig. 3: Return loss (dB) for various Patch width (W_P).

B. Optimization of Microstrip Patch slot Length

After designing the rectangular slot into a patch, the length of the rectangular slot is optimized as shown in Fig. 4. It offers optimum performance at rectangular slot length and width at L_s = 2.06 mm and W_s = 0.50 mm respectively.

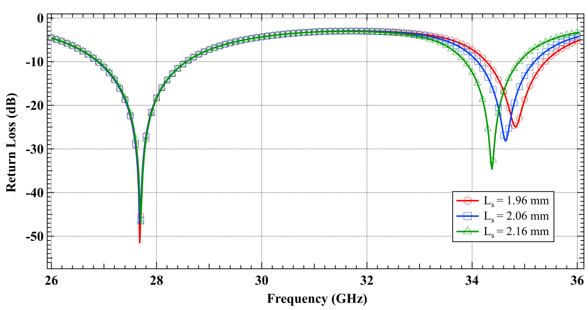


Fig. 4: Return Loss for the optimization of Slot length (L_s).

C. Optimization of distance between rectangular slot and half ring slot

One of the important parameter analyses that needs to be mentioned is the space difference between the rectangular slot and the half-ring slot that makes the patch modified D-shaped in our designed antenna. In Fig. 5, return loss for various distance variances between two slots is shown. When the half-ring and rectangular slots are spaced 0.75 mm apart, a D-shaped single slot forms, producing a single frequency band. The antenna is better matched the more space we provide to separate the two slots. Two well-matched frequency bands with respective centers at 27.68 GHz and 34.64 GHz were found for a distance difference of 3.1 mm.

D. Optimization of the half-ring slot width

Return loss for different half-ring slot widths is displayed in Fig. 6. Two well-matched frequency bands operate in the

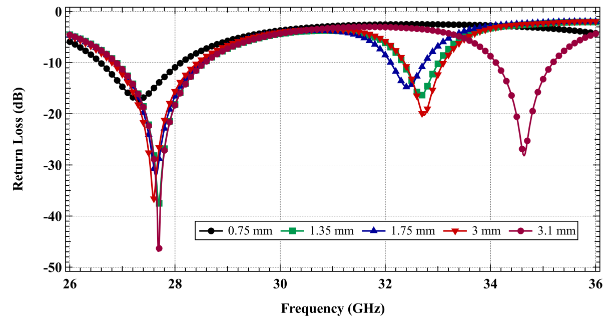


Fig. 5: Return loss (dB) for various distance differences between rectangular slot and half ring slot.

Ka-band and are observed for varying half-ring slot widths. Following this modification, the two frequency bands for the 0.3mm (r_d) value are in the most optimal locations at our desired centered frequencies of 27.68 GHz and 34.64 GHz.

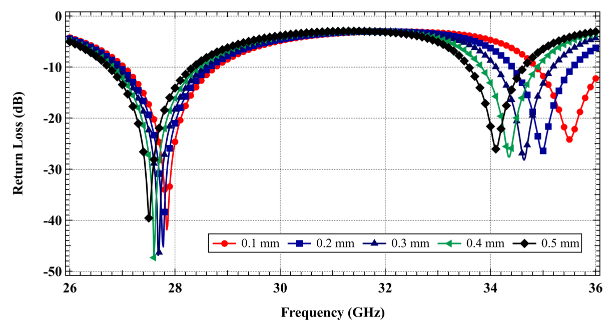


Fig. 6: The return loss (dB) is assessed across different widths of the half-ring slot (r_d).

E. Optimization of the rectangular slot width

Fig. 7 shows the return loss for various widths of the rectangular slot. For different rectangular slot widths, well-matched dual bands operating in the Ka-band frequency ranges are seen in Fig. 7. The result of this optimization is the two frequency bands at the intended center frequency positions for the 0.5mm (W_s) value.

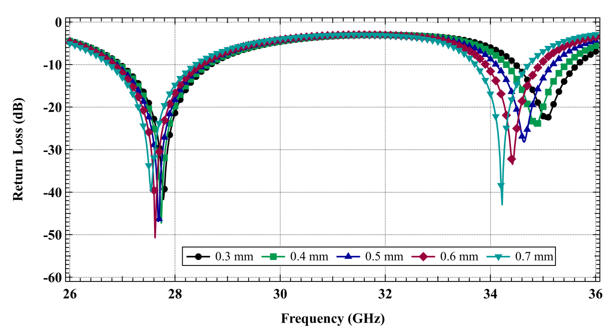


Fig. 7: The return loss (dB) is assessed across different widths of the rectangular slot (W_s).

IV. RESULTS ANALYSIS

A. Analysis the performance of the antenna with different slot scenarios

The proposed modified D-shaped microstrip antenna results were performed using CST having several slot scenarios. Firstly the antenna is simulated without any slots to observe if it is properly matched. At 29 GHz, it shows a single frequency band with a return loss of -25 dB. It demonstrates that the suggested antenna matches perfectly without any slots. The designed antenna is also analyzed with the presence of only rectangular or half-ring slots. But it exhibits significantly good performance with the presence of both slots. The resonances were roughly at 27.68 GHz and 34.64 GHz with a return loss of -47 dB and -28 dB respectively with the presence of both rectangular and half-ring slots. The S(1,1) results of different slot scenarios are shown in Fig. 8.

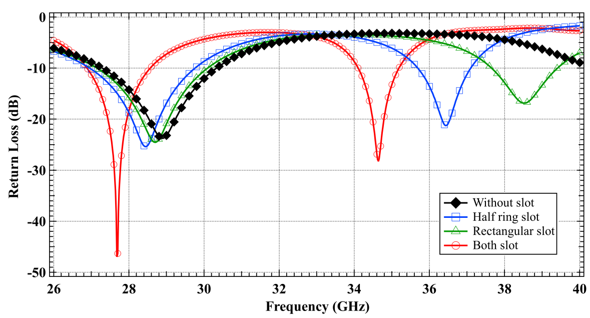


Fig. 8: Return loss (dB) of the antenna for various slot scenarios.

B. Voltage Standing Wave Ratio (VSWR) of the designed antenna

The VSWR of the proposed modified D shaped antenna is 1. 009 at 27.68GHz and 1.08 at 34.64 GHz respectively. The value was found below 2 and in the range of 1 to 2 which is expected for a well performed antenna.

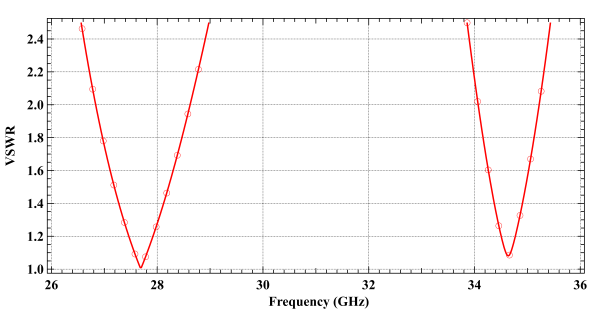
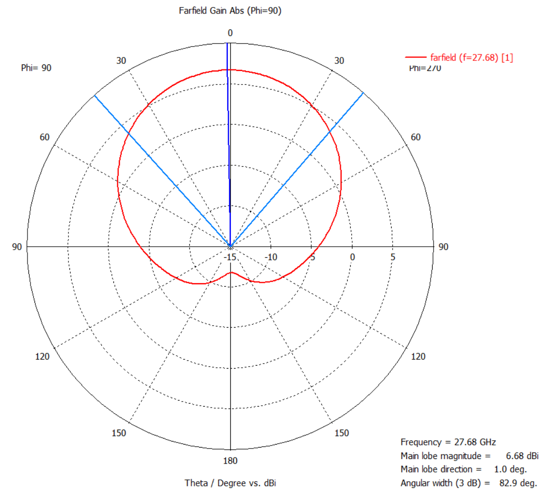


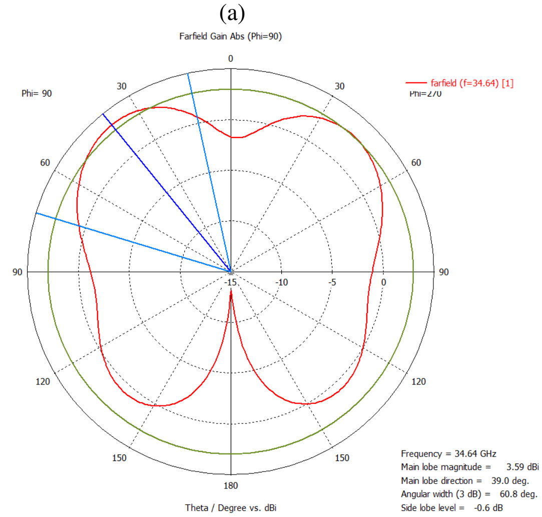
Fig. 9: VSWR of the proposed modified D shaped dual band antenna.

C. Gain of the designed antenna

The illustrated antenna gain and directivity curve display a peak gain of 6.68 dBi in the broadside direction (0 degrees).



(a)



(b)

Fig. 10: 2D Radiation Pattern at (a) 27.68GHz and (b) 34.64GHz.

Notably, the antenna exhibits gains of 6.68 dBi and 3.59 dBi at frequencies of 27.68 GHz and 34.64 GHz, respectively. Fig. 10 presents the two-dimensional radiation pattern of the proposed antenna.

Table II outlines the return loss, gain, and bandwidth values for the dual frequency bands. The comparative analysis of the performance of our proposed antenna with other studies is presented in Table III. The Table III reveals that our modified D-shaped dual-band antenna is not only compact but also exhibits superior bandwidth performance in comparison to other referenced works.

TABLE II: A summary of the proposed modified D-shaped antenna's simulation outcomes.

Frequency (GHz)	Return Loss (dB)	Gain (dBi)	Bandwidth (GHz)
27.68	-46.97	6.68	2.01
34.64	-28.246	3.59	1.46

TABLE III: The modified D-shaped antenna's performance in comparison to previous works.

Refences	Antenna Dimensions (mm^2)	Frequency (GHz)	Bandwidth (GHz)
[5]	5.3×5.35	28	0.47
[8]	11×5	28	0.82
[6]	19×19	28	1
[14]	55×110	28	1.06
[7]	5×5	28	1.44
This Work	6×9.4	27.68	**2.01**

V. Conclusion

This study presents the design of a modified D-shaped microstrip patch antenna with two slots: a rectangular slot and a half-ring slot. To get the best outputs, a parametric analysis is carried out. The optimized antenna produced two bands, with frequencies between 26.8 -28.8 GHz and 34.1-35.6 GHz. The antenna is well matched, as evidenced by the -46.97 dB and -28.24 dB return loss at the frequency of 27.68 GHz and 34.64 GHz, and the obtained gain is 6.68 dBi, 3.59 dBi respectively. The obtained results make the designed antenna operate in dual band covering the Ka band used for 5G applications.

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