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# Design of Miniaturized Stair Case Fractal Geometry Based Planar Monopole Antenna for Multiband Wireless Communication Applications

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**Abstract**: The compact monopole antenna based on staircase fractal geometry is presented in this paper for multiband wireless communication applications. Initially, a partial ground plane was used to design and explore the rectangular patch. Further, the staircase geometry has been etched from the vertical edges of radiating patch to improve the performance of antenna. Both the antennas radiate only on two frequency bands at 2.49/7.62GHz and 2.60/7.72GHz. The antenna is made of low cost FR4 glass epoxy substrate material with a thickness of 1.6mm and a design frequency of 2.5GHz. As a result, the partial ground plane of the antenna has been adjusted by applying vertical extension as well as staircase design to expand the frequency bands as well as other parameters such as reflection coefficient (S11) and impedance bandwidth. The final geometry of antenna reveals five resonant frequency bands 1.09, 2.38, 4.23, 7.07 and 8.93GHz with corresponding reflection coefficient (S11) of -33.49, -20.96, -17.98, -30.21, -14.35dB. Also, the proposed antenna exhibits the omnidirectional radiation pattern along with the positive value of gain at all the frequency points. It has also been observed that the 1$^{st}$ frequency band of the antenna is shifted towards the lower side from 2.49GHz to 1.09GHz; which plays a dominant role in reduction of size of proposed antenna (almost by 83%). Due to the multiband frequency response and better performance parameters the proposed antenna can be used as a suitable candidate for distinct wireless applications.

**Keywords**: fractal; monopole; rectangular patch; reflection coefficient

## 1. Introduction

In this technological period, substantial changes in communication systems have been noticed, with wired media being unquestionably replaced by wireless media. These revolutionary developments would be impossible to achieve without the proper antenna structure design. Because of its multiband/wideband behaviour as well as size reduction (miniaturisation) due to its space-filling and self-similarity qualities, the fractal antenna is the most essential antenna nowadays[1, 2]. B. Mandelbort was the first technologist to present fractal geometry, demonstrating that it copies itself at a certain scale [3, 4]. As the shapes of fractal are complex in nature so the recursive procedure has been used to design the fractal geometries. The antenna with fractal structures is compact in size, versatile in nature and existing in the numerous forms like Sierpinski Gasket/Sierpinski Carpet [5, 6], Minkowski [7, 8], Koch curves [9, 10], Meander [11, 12], Hilbert [13, 14], Giuseppe Peano [15, 16], etc. These fractal geometries are also used in other structures such as monopole antenna in the form of slots or stubs to generate the multiband and wideband characteristics. The investigators' most difficult problem is to reduce the size of the antenna without affecting the performance criteria [17], to solve this illustrious researcher have explained their procedure for the designing of antenna as; Kundu et al. [18] have designed an antenna with 81.6% size reduction this antenna resonates at 3.5GHz with corresponding bandwidth of 355MHz and is useful for WiMAX frequency band. Similarly, Kumar et al. [19] have investigated a monopole antenna based on hexagonal shaped slot for distinct wireless applications. The designed antenna radiates on dual frequency bands and helps in size reduction up to 75.5%. Also, the 50% reduction in size has been obtained by Fei et al. [20]. In this design authors have used half compact sized monopole antenna with ACS fed and the antenna is useful for UWB application. Likewise, Chen et al. [21] designed a reconfigurable antenna with folded slot which radiates on dual frequency points and also miniature the size almost by 37.5%. Boukarkar et al. [22] created a variable dipole antenna with a dual frequency band. This antenna configuration decreases the original geometry size by 6% and is appropriate for WiMAX and WLAN applications. Similarly, Bekali et al. [23] illustrated the patch antenna with dual frequency band operations for third and fourth generation mobile technologies, the authors have noticed the reduction in size almost by 55.44%. Whereas, 72.17% reduction in size of antenna has reported by Asif et al. [24], in this author have proposed an E-shaped radiating patch of reconfigurable antenna for dual frequency band operations.

The proposed antenna has been designed and explored in this article based on the above-mentioned state-of-the-art literature, which has been thoroughly analysed and observed. The optimum design of reduced size miniaturized multiband antenna has been proposed; which makes its innovative design among all the antennas as deliberated in literature. The proposed antenna exhibits a greater number of frequency bands and its size is reduced almost by 83%. The suggested multiband antenna's structural geometry, as well as simulated parametric results, will be examined in detail in the following sections.

**2. Antenna Design**

The suggested antenna's design starts with a rectangular radiating patch construction, as shown in Fig. 1. (a). Basic characteristics like as substrate material qualities, substrate thickness, and antenna design frequency are taken into account while designing the initial geometry of the radiating patch. We employed a readily accessible low-cost FR4 glass epoxy substrate with a thickness of 1.6mm and a relative permittivity of 4.4 in our design. The radiating patch of proposed antenna is designed at the frequency of 2.5GHz. The length 'PL' and width 'PW' of the rectangular shaped patch are calculated using these values and found to be 28.2mm and 36.5mm, respectively, using the following equations [25, 26, and 27]. To improve the antenna's performance in terms of impedance bandwidth and S11, the rectangular shaped patch was adjusted by deleting the stair case fractal geometry from both vertical sides of the patch, as illustrated in Fig. 1(c). To study such characteristics, the patch structures are activated using a 50 transmission line feed and a partial ground plane, as shown in Fig. 2(a) and 2(b) . Table 1 lists the parametric dimensions of the planned antenna.

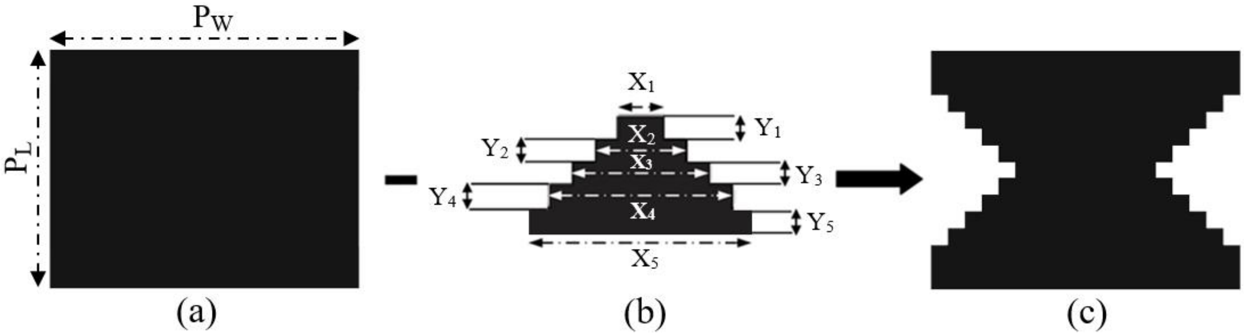


**Fig. 1**: (a) Structure of a rectangular shaped radiating patch, (b) stair case fractal geometry and (c) final structure of radiating patch (proposed)

$$P_W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\right] \frac{1}{\sqrt{1 + 12h / P_W}} \quad (2)$$

$$\Delta P_L = h \times 0.412 \left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{P_W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{P_W}{h} + 0.8\right)}\right] \quad (3)$$

$$P_L = \frac{1}{2 f_r \sqrt{\mu_o \varepsilon_o} \sqrt{\varepsilon_r}} - 2\Delta P_L \quad (4)$$

Where;

$P_W$ = width of patch

$P_L$ = length of patch

$f_r$ = design frequency of patch

$\varepsilon_r$ = relative permittivity of substrate

$h$ = height of substrate

$\varepsilon_{reff}$ = effective dielectric constant

$$\frac{1}{\sqrt{\mu_o \varepsilon_o}} = \text{free space velocity of light}$$

Table 1: The proposed antenna's parametric dimensions (unit in mm)

| $P_W$ | $P_L$ | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $Y_1$ | $Y_2$ |
|---|---|---|---|---|---|---|---|---|
| 36.5 | 28.2 | 2.0 | 6.0 | 10.0 | 14.0 | 18.0 | 2.0 | 2.0 |
| **$Y_3$** | **$Y_4$** | **$Y_5$** | **$S_W$** | **$S_L$** | **$F_W$** | **$F_L$** | **$G_W$** | **$G_L$** |
| 2.0 | 2.0 | 2.0 | 45.6 | 50.0 | 4.0 | 14.8 | 45.6 | 12.0 |

**3. Performance of Designed Antenna**

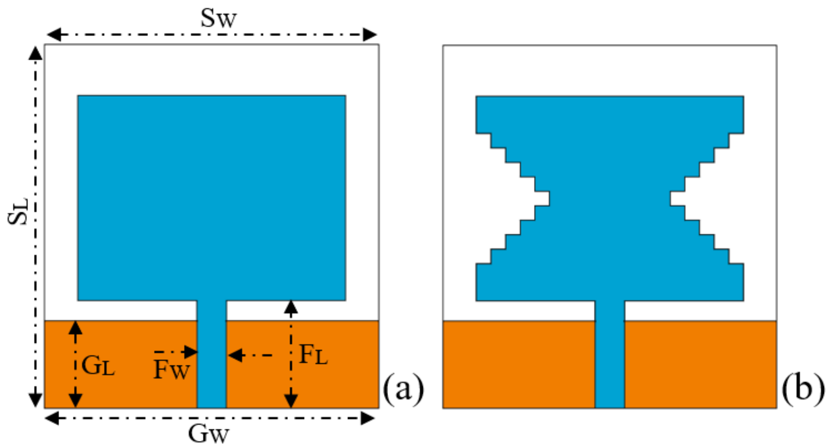


**Fig. 2**: Structures of the designed antenna (a) Antenna-1 and (b) Antenna-2

As shown in Fig. 2 both the antennas are investigated by using partial ground plane, the antenna with simple rectangular patch structure is shown in Fig. 2(a). Furthermore, the structure of the patch has been adjusted to improve performance without affecting other design parameters, as illustrated in Fig. 2. (b). The S11 versus frequency charts are compared to examine the performance of both antennas, as shown in Fig. 3. Antenna – 1 resonates at two frequency points of 2.49 and 7.62GHz, with corresponding bandwidths of 0.88GHz (2.09 – 2.97GHz) and 1.11GHz (7.0 – 8.11GHz), as shown in Fig. 3. After, etching the staircase fractal geometry from the radiating patch the antenna (Antenna – 2) reveals the resonant frequency bands at 2.60 and 7.72GHz with improved S11 of -17.36 and -23.35dB. It is clearly understood from the aforementioned conversation that Antenna-2 reveals improved results in terms of S11 in comparison to Antenna - 1. The ground plane of Antenna – 2 has also been updated to enhance the number of frequency bands while reducing the antenna's size. The process of modification in the geometry and the comparison of various results are discussed in detail in the upcoming section. Ansys HFSS 13, a commercial FEM-based simulator, was used to build, modify, and simulate antenna geometries.

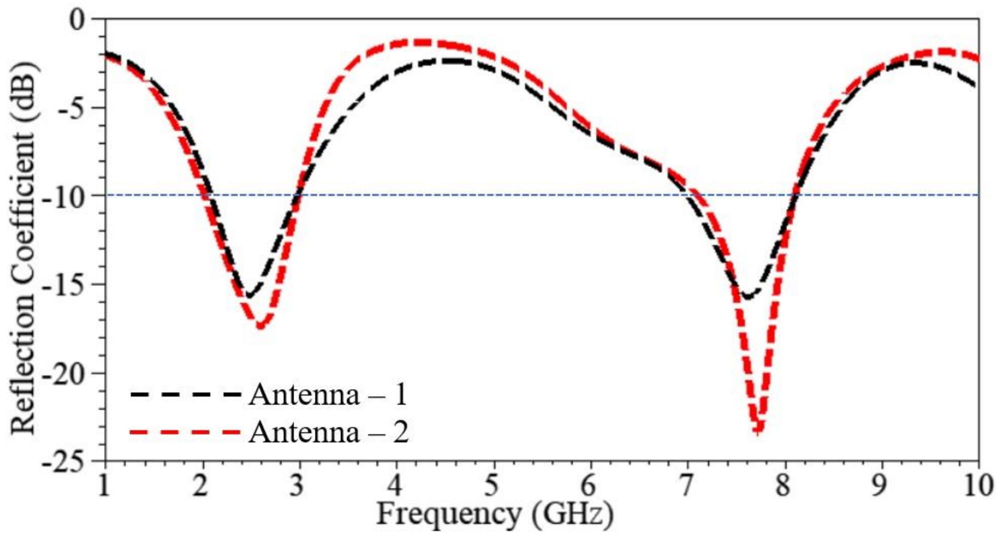


**Fig. 3**: Comparison of S11 curves of different structures of the designed antenna

### *3.1 Effects of ground plane*

In this section, the two types of modified ground plane have been introduced on the structure of antenna (Antenna – 2) as shown in Fig. 4. Initially, the vertical extension with dimension $E_1$ = 37.5mm and $E_2$ = 2.0mm is being attached to the partial ground plane of Antenna – 2, to obtain the new geometric structure named as Antenna – 3 as shown in Fig. 4(a). This extension has been added to improve the performance parameters and reduce the size of antenna by shifting the initial frequency bands towards the lower side. Further, to get the more improvement in antenna performance the staircase structure with dimension $S_1$ = 6.5mm, $S_2$ = 2.0mm and $S_3$ = 2.0mm is etched from the ground plane of Antenna – 3 to generate the final structure of proposed antenna named as Antenna – 4 as shown in Fig. 4(b). Now, to study the difference between the performance of both the antennas (Antenna – 3 and 4), their S11 curves are compared in Fig. 5.

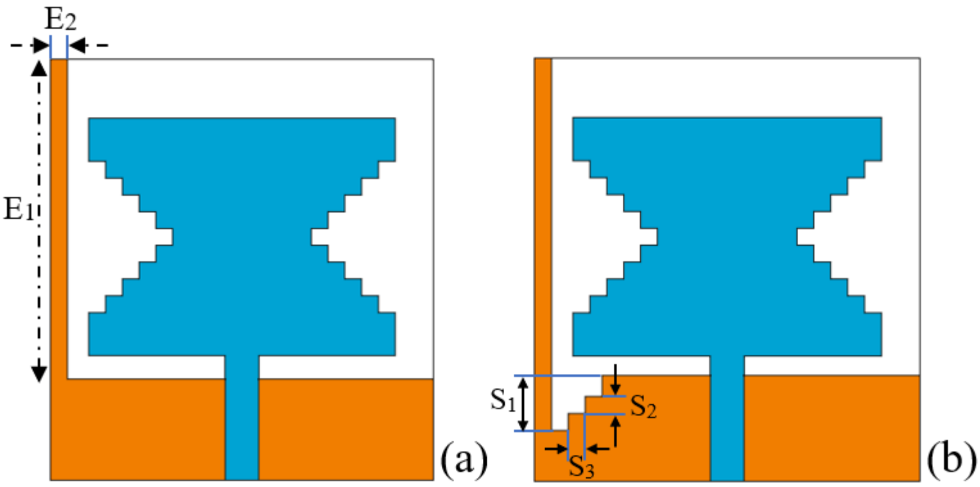


**Fig. 4**: Modified ground plane structure on Antenna – 2; (a) Antenna – 3 and (b) Antenna – 4 (proposed antenna)

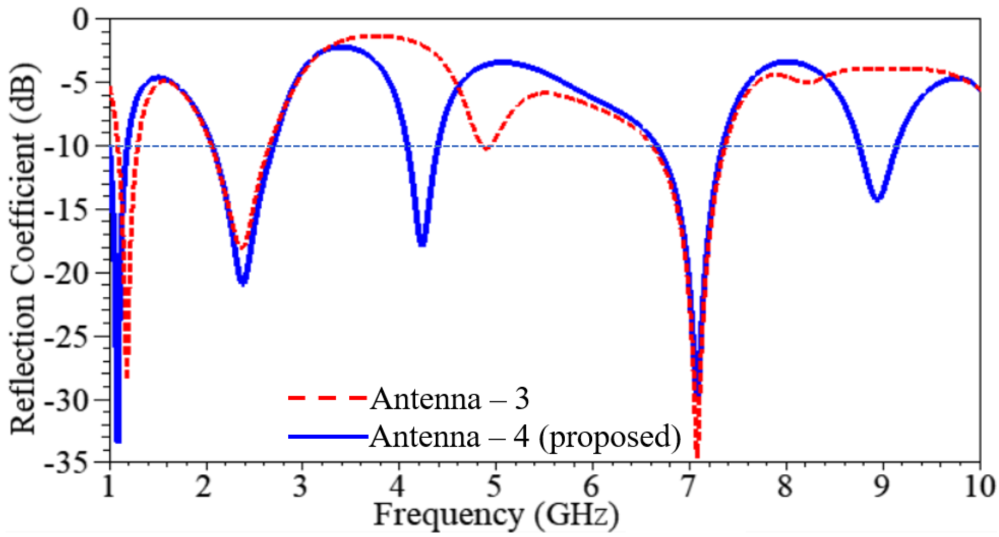


**Fig. 5**: Comparison of S11 curves of different structures of antennas with modified ground plane

Antenna – 3 radiates at three frequency bands, 1.18, 2.23, and 7.07GHz, with corresponding S11 of -28.49, -18.14, and -34.63dB, as shown in Fig. 5. The S11 curve of Antenna – 3 clearly shows that the frequency range has been changed to the lower side from 2.60 to 1.18GHz without affecting the dimensions of the antenna's radiating patch, which leads to miniaturization i.e.; the size of antenna almost reduced by 80% in comparison to initial geometry of antenna. Based on the foregoing, it can be concluded that Antenna – 3 performs better than the previously developed antenna known as Antenna – 2. Furthermore, the Antenna – 4 is developed to expand the number of frequency bands, and its S11 is shown in Fig. 5. Antenna – 4's S11 curve indicates five resonances with two extra frequency bands at 4.23 and 8.93GHz, without interfering with Antenna – 3's 2nd and 3rd frequency bands. But as we observe the 1$^{st}$ frequency band it shifts from 1.18GHz to 1.09GHz in comparison to Antenna 3. As, we compare the Antenna – 4 with the initial geometry of antenna i.e., Antenna – 1, the antenna size is reduced by almost by 83% because the 1$^{st}$ frequency band of Antenna – 1 radiates at 2.60GHz, whereas 1$^{st}$ frequency band of Antenna – 4 radiates at 1.09GHz. As a result of the discussion, it is evident that Antenna – 4 is the final geometry of the suggested antenna due to its superior performance in terms of size reduction, frequency bands, and S11. Table 2 compares the obtained results of the developed antennas with those of the proposed antenna (Antenna – 4) for a better understanding.

Table 2: Comparison of results for various proposed antenna structures

| Antenna design | Resonant frequency bands (GHz) | S11 (dB) | Bandwidth (MHz) | Gain (dB) | Reduction in size of antenna in comparison to Antenna - 1 |
|---|---|---|---|---|---|
| Antenna – 2 | 2.60 | -17.36 | 960 | 4.03 | NA |
| | 7.72 | -23.35 | 970 | 5.26 | |
| Antenna – 3 | 1.18 | -28.49 | 210 | 5.72 | 80% |
| | 2.37 | -18.14 | 590 | 4.16 | |
| | 7.07 | -34.63 | 760 | 4.99 | |
| Antenna – 4 (proposed) | 1.09 | -33.49 | 190 | 2.89 | 83% |
| | 2.38 | -20.96 | 630 | 3.44 | |
| | 4.23 | -17.98 | 310 | 3.20 | |
| | 7.07 | -30.21 | 670 | 4.82 | |
| | 8.93 | -14.35 | 390 | 5.42 | |

### *3.2 Surface current distribution*

The current distribution (CD) of final geometry of antenna at distinct frequency bands such as 1.09, 2.38, 4.23, 7.07 and 8.93GHz is illustrated in Fig. 6(a-e). It is clearly observed from Fig. 6(a), that strong current is concentrated at vertical extension as well as staircase geometry on ground plane which helps in shifting the frequency band towards the lower side. Likewise in Fig. 6(c) and (e), the strong current is saturated on staircase geometry of modified ground plane due to which the antenna exhibits the additional frequency bands such as 4.23 and 8.93GHz. Whereas, at 2.38GHz the S11 improved due to the more current on staircase geometry of radiating patch as well as transmission line. The number of frequency bands and the shift in the first frequency band of the antenna improve as a result of this significant CD on the antenna construction. In addition, Fig. 6 shows that the CD is constant across all frequencies, implying that the partial ground plane's staircase geometry and vertical extension had a significant influence in the suggested antenna's performance.

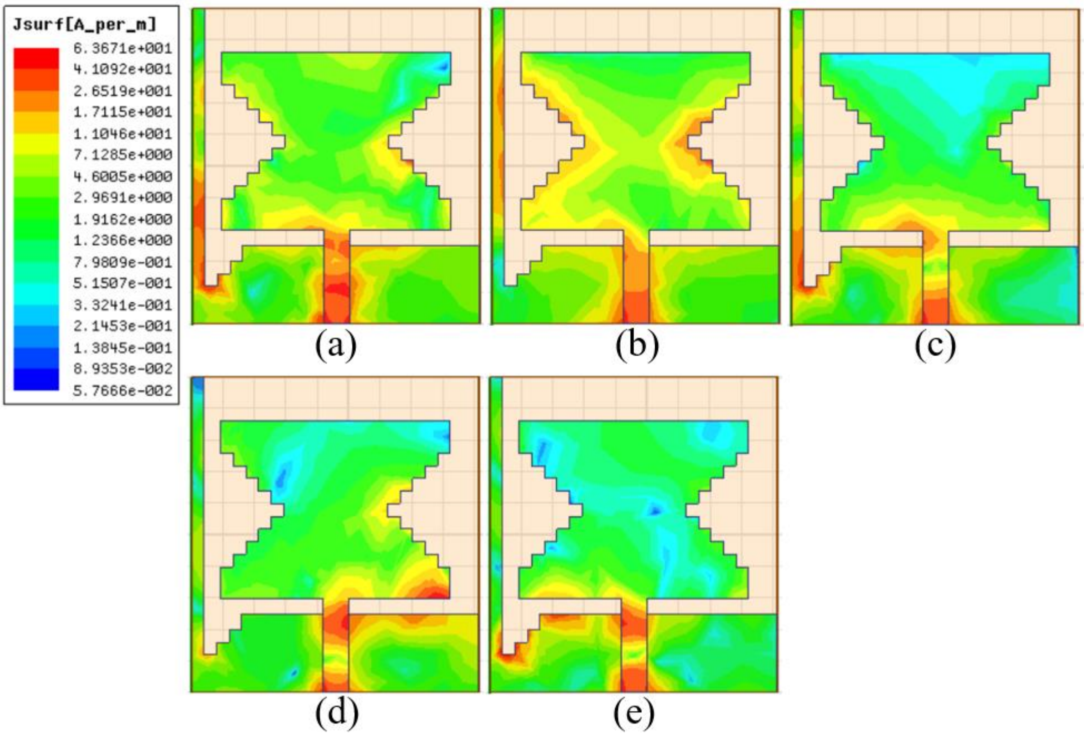


**Fig. 6**: CD of the proposed antenna at (a) 1.09, (b) 2.38, (c) 4.23, (d) 7.07 and (e) 8.93GHz frequency band

### *3.3 Gain and Radiation pattern*

The 3D gain plots of antenna at different resonant frequency bands are shown in Fig. 7, the gain of antenna must be positive so that antenna it can work efficiently at the desired frequency band for essential wireless communication applications. The suggested antenna's 3D gain plot is simulated at each resonant point, as illustrated in Fig 7. It can be projected from that proposed antenna exposes the gain 2.89, 3.44, 3.20, 4.82 and 5.42dB at the resonant frequencies 1.09, 2.38, 4.23, 7.07 and 8.93GHz correspondingly. Figure 8 shows the proposed antenna's 2D radiation pattern in the H (XY plane) and E (YZ plane) at different resonant frequencies. The solid (red) and (black) curve signifies the radiation patterns resembles to an angle of phi = 0° and 90°. At both the planes, the proposed antenna exhibits almost the omni-directional pattern at 1.09GHz. Whereas, at other frequency bands such as 2.83 and 4.23GHz the antenna displays the bi-directional pattern at phi = 0° and omni-directional pattern at phi = 90°. But, at higher frequency bands such as 7.07 and 8.93GHz, the pattern is somewhat distorted due to adjacent resonant frequencies or modes at higher order. The radiation curves also indicate that the planned antenna emits maximum radiation in all directions, making it a viable contender for many wireless communication standards.

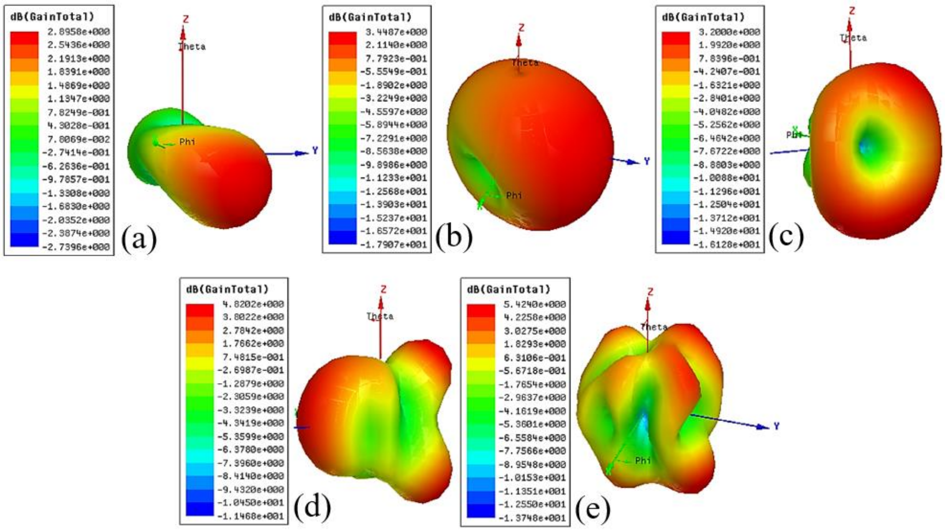


**Fig. 7**: 3D gain plot of proposed antenna at (a) 1.09, (b) 2.38, (c) 4.23, (d) 7.07 and (e) 8.93GHz frequency band

Table 3 shows a comparison of the proposed antenna with existing antennas of the same type. When compared to the other reference antennas, the suggested antenna demonstrates a greater number of frequency bands. In addition, when compared to other antennas having positive gain values throughout all frequency bands, the suggested antenna shows a greater percentage reduction in size. Due to the antenna's small size and multiband frequency characteristics, it can be used for a variety of wireless applications, including GPS (1.22GHz), GSM band (1.71–1.88GHz), WLAN (2.4–2.485), Wi-Fi (2.4–2.485), Bluetooth of the ISM band (2.41–2.49GHz), RFID/Bluetooth (2.4GHz), LTE 2300/LTE 2500 (2.3–2.4GHz/2.5–2.69GHz), mobile/fixed satellite navigation (6.61–7.04GHz) and television broadcasting (7.91 – 8.62GHz).

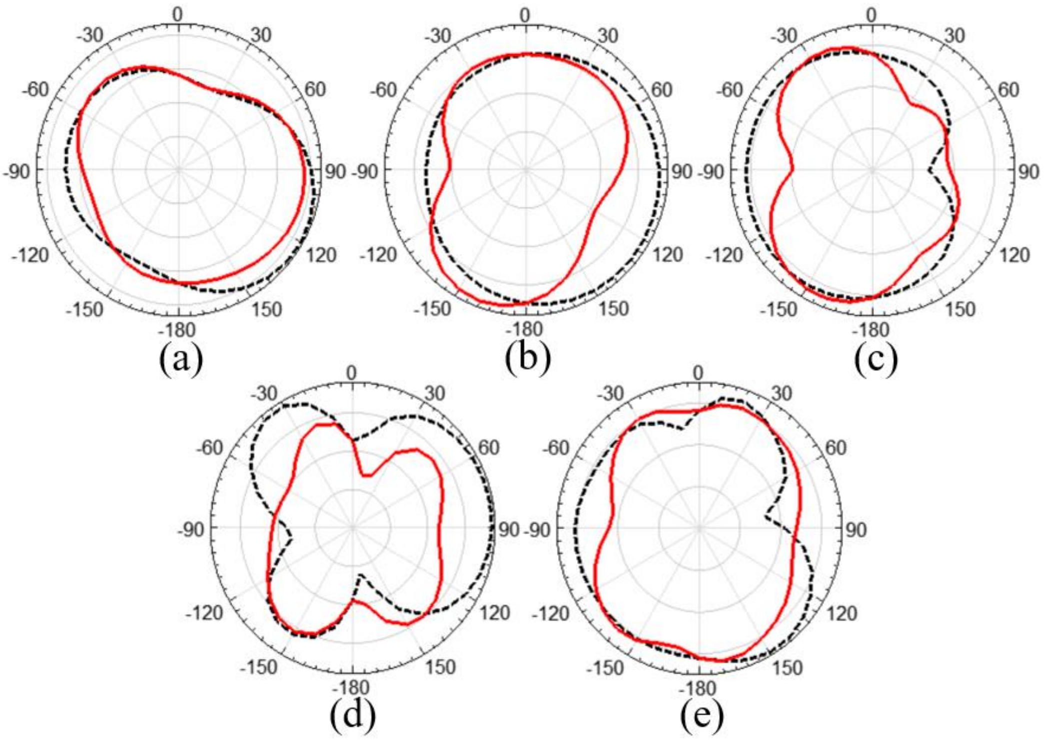


**Fig. 8**: 2D radiation pattern of the proposed antenna at (a) 1.09, (b) 2.38, (c) 4.23, (d) 7.07 and (e) 8.93GHz frequency band

Table 3: The proposed antenna comparison with existing antennas

| References | Antenna size ($mm^2$) | Frequency bands (GHz) | Gain (dB) | Size Reduction (%) |
|---|---|---|---|---|
| [18] | 864 | 3.5 | 2.15 | 81.6 |
| [19] | 1600 | 3.5/5.8/10.0 | -0.89/3.1/4.95 | 75.5 |
| [20] | 527 | 3.5/7.0/10.0 | -- | 50.0 |
| [21] | 1200 | 2.4/3.4/5.2/5.8 | 4.45/5.22/5.4/4.9 | 37.5 |
| [22] | 1600 | 3.5/5.8 | 2.2/0.88 | 6.0 |
| [23] | 1710 | 2.1/2.6/4.8 | 7.9 (maximum) | 55.44 |
| [24] | 2675 | 3.1/3.5/7.2/8.1 | 4.6/5.2/4.0/4.4 | 72.17 |
| Proposed | 2280 | 1.09/2.38/4.23/7.07/8.93 | 2.89/3.44/3.20/4.82/5.42 | 83.0 |

## Conclusion

The design of reduced size antenna loaded with etched staircase fractal structure for multiband applications has been presented in this article. The proposed antenna was designed and investigated for performance characteristics after a thorough examination of literature based on the miniaturization technique. Different structures of antenna such as Antenna – 1 to Antenna – 4 (proposed) are designed and analyzed. It is observed that Antenna – 4 which is designated as final geometry of proposed antenna reveals five frequency points 1.09, 2.38, 4.23, 7.07 and 8.93GHz with corresponding S11 of -33.49, -20.96, -17.98, -30.21, -14.35dB. Also, proposed antenna exhibits the size reduction of 83% as the frequency band shifts from 2.49 to 1.09GHz in comparison to Antenna – 1 to Antenna – 4. The suggested antenna can be employed for a variety of wireless applications since it has multi-frequency features and a positive gain value across all of the operational frequency bands.

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