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# Grid-slot Hybrid Structure Wideband Aperture Coupled Microstrip Antenna Design for C-band Applications

***Abstract: -*** An aperture coupled ψ-shaped feeding grid-slot hybrid structure microstrip antenna is proposed in this paper to enhance the gain and bandwidth. Three metallic layers are used here. The three layers consist of a radiating patch at the top, an aperture placed in ground at the middle and a feeding line at the bottom. Two dielectric layers are combined among the three metallic layers. Firstly, a line-feeding aperture coupled microstrip antenna is designed and its performances are observed. Secondly, line feeding is replaced by ψ-shaped feeding and gradually 1×1, 2×2, 3×3 and 4×4 slots are cut periodically that create 2×2, 3×3, 4×4 and 5×5 grid patches and all times the performances are observed. Among them, ψ-shaped feeding with 4×4 grid patches gets the better performances. Then, by numerically changing the dimensions of the radiating slot, coupling slot and ψ-shaped feeding size, the performances of the aperture coupled microstrip antenna are optimized. The optimized antenna shows ($S_{11}$ < -10dB) a bandwidth of 2760MHz (4.47-7.23GHz) and its maximum gain is 11.13dBi. C-band (4-8GHz) applications are compatible with the antenna.

***Keywords:*** Aperture Coupled, Grid Slot, ψ-Shaped Feeding, Wideband, C-Band Applications

## I. INTRODUCTION

Microstrip antennas' attractive qualities—such as their low cost, light weight, small profile, conformability—have led to their widespread use in the fields of wireless communication systems, imaging, radar etc. However, traditional microstrip antennas have limitations in terms of gain, directivity, bandwidth, narrow impedance [1-4]. There are numerous methods for expanding the impedance bandwidth. Researchers developed the aperture-coupled antenna in the 1980s to address the narrow band and modest gain issue [4]. By connecting the patch to the aperture at its resonance, a single-element aperture-coupled patch antenna may expand its bandwidth. Because the resonances in the aperture are so near to each other, this feed approach generates significant backward radiation [5]. Pozar in 1992 addressed this issue by selecting the aperture,s resonance that is far from the operational band. By using additional radiating patches stacked vertically and decreasing the radiation power, the bandwidth might be expanded [6]. The aperture antenna's non-contact feed are exactly the magnetic counterpart of the edge-fed method. The capacitive characteristic of the non-contact feed counteracts the intrinsic high inductance of the excitation [7]. A stacked prob feed and aperture fed patch array with a relatively low dielectric laminate and a high dielectric substrate was used as the top layer to obtain a 25% impedance bandwidth [8]. By appropriately placing two thin arc-shaped slots along the patch's side borders, a broadband single-layer circular microstrip antenna may attain a bandwidth that is 2.3 times greater than that of a traditional antenna [9]. In [10], the aperture coupling technique is used with L-probe feeding to produce wideband circularly polarized operation. In [11], various shaped patches with line feeding are recommended for aperture-coupled antennas. In [12], a V-slot proximity coupled Y-shaped feeding antenna with an impedance bandwidth of 4.48–5.2GHz and a gain of 9dBi was proposed. A

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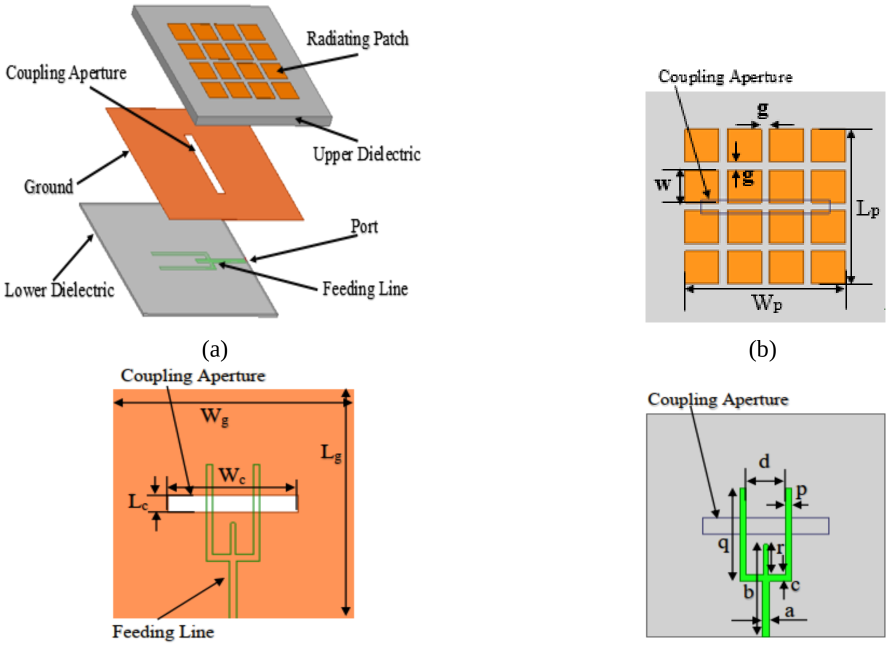
broadband mushroom antenna made of low-profile metamaterial was created. It is supplied by a microstrip line and enters via a slit in the ground plane. With a bandwidth of 4.77-6.16GHz, the antenna offers a gain of 9.9 dBi [13]. In [14], a proposal for a grid slot low profile metamaterial broadband antenna emerged. Here, 3×3 slots are created periodically, which produce 4×4 grid patches. Aperture-coupled line feeding technology was used whose impedance bandwidth is 4.54-6.00GHz and height gain is 9.8 dBi. For C-band satellite communication applications, a new wideband circularly polarised antenna with metasurface was created. Here, a slanted slot on the ground plane is cut to produce an aperture linked, and 2×3 slots on the patch are cut to create 3×4 rectangle patch arrays. 5.8dBi is the gain of that antenna and a -10 dB impedance bandwidth of 4.2 to 5.9GHz [15]. Four-by-four corner-truncated square patches were employed in a aperture coupled metasurface-based circularly polarised antenna. The antenna's gain is 7.5 dBi and its impedance bandwidth is 4.4–6.6 GHz [16]. A strip slot low-profile hybrid structure microstrip antenna is proposed in [17]. Here, the creation of three slots results in the production of four strips. Aperture-coupled Y-shaped feeding technology is used. The suggested antenna's maximum gain is 10.89 dBi, and its bandwidth ranges from 4.42 to 6.76 GHz. A microstrip low-profile wideband antenna with a quasi-periodic aperture was employed. The suggested antenna has a -10dB bandwidth of 3.96–5.73GHz and a height gain of 10.45dBi [18]. A wideband dual-polarized microstrip antenna with 4x4 square radiating patch components was linked to two Y-shaped feeding lines. With a -10dB impedance, the bandwidths for ports 1 and 2 are 4.23-6.62GHz and 4.26-6.61GHz, respectively. Port 1's measured gain spans from 6.4-10.1dBi, while port 2's ranges from 6.5-10.3dBi. [19]. A wideband dual-layer 4 × 4 patch cells low profile metasurface-loaded antenna is illustrated in [20]. The proposed antenna has a -10dB bandwidth of 4.08–6.38GHz and a maximum gain of 11.6dBi. In [21], grid-slot patches are used to boost bandwidth. The antenna's bandwidth runs from 1.95 to 4.15GHz, and its maximum strength is 9.6dBi. Using hash-shaped rafiating elements (four x four unit elements on the substrate), a high gain, low profile, wideband, single layer metasurface antenna is suggested in [22]. The antenna's maximum gain is 7.43dBi, and its bandwidth is 3.60-6.89GHz. In [23], a multistage 4 × 4 copper patch array high gain metasurface antenna is suggested. 10.5dBi is the maximum gain and a maximum bandwidth of 5.76-8.42GHz. Line feeding aperture linked strip slot antennas are utilised in C-band satellite applications [24]. The antenna's bandwidth ranges from 4.57 to 7.15GHz, and its maximum gain is 10.89dBi. Partially Reflective Surface aperture coupled antenna is used in [25] for gain enhancement. The gain that is maximum of the antenna is 12 dBi and its bandwidth is 4.0-5.7 GHz. It is used in C-band applications. In [26], microstrip-fed slot high-gain and wideband anisotropic metasurface (4 × 4 unit-cells) and aperture coupled structure is proposed. The gain that is maximum of the antenna is 10.7 dBi and its bandwidth is 3.32 to 5.91 GHz. A U-shaped wide slot coupled antenna with T-shaped microstrip feed structure is proposed in [27] to overcome the narrowband. A broadband high gain triangular ring metasurface is proposed in [28]. A narrow slot etched on the ground structure and an aperture connecting with a microstrip line on the back are used to feed the 64 mm x 64 mm square substrate. The antenna's total height is 7 mm. The antenna has a bandwidth of 4.8 to 6.1GHz and a height gain of 11.2 dBi.

In this paper, a ψ-shaped feeding aperture coupled grid-slot hybrid structure microstrip antenna is suggested to improve the gain and bandwidth. The HFSS software is used to carefully simulate the suggested strip-slot hybrid structure.

## II. ANTENNA DESIGN PROCEDURE AND DIMENSIONS

Figure 1 (a-d) depicts the suggested aperture coupled ψ-shaped feeding grid-slot hybrid structure microstrip antenna. Figure 1(a) illustrates the three metallic layers that are used here. The three layers are a feeding line at the bottom, an aperture placed in the ground at the middle, and a radiating patch at the top. The three metallic layers are joined by two dielectric layers. Arlon AD255C (tm) material is used for both dielectric layers whose relative permittivity is 2.55. The dimensions of $W_g \times L_g \times h$ and $W_g \times L_g \times h_0$ are used for upper and lower substrate material. $W_p$ and $L_p$ represent the patche's width and length, respectively [16]. By cutting periodically 3×3 narrow slots in the patch, 4×4 grids are created that is shown in Figure 1(b). Here, w is the size of every grid and g is the size of every slot. Figure 1(c) shows that the ground is cut in the middle, which creates a narrow slot of width and length of $W_c$ and $L_c$, respectively. Figure 1(d) shows the ψ-shaped feeding that develops on the lower dielectric's bottom layer. The ψ-shaped feeding's dimensions are shown in Figure 1(d). Here, copper has been used as a radiating patch, ground plane and feeding line whose thickness is referred to as t. The suggested antenna's optimal dimensions are shown in Table 1.



(a) (b)

(c) (d)

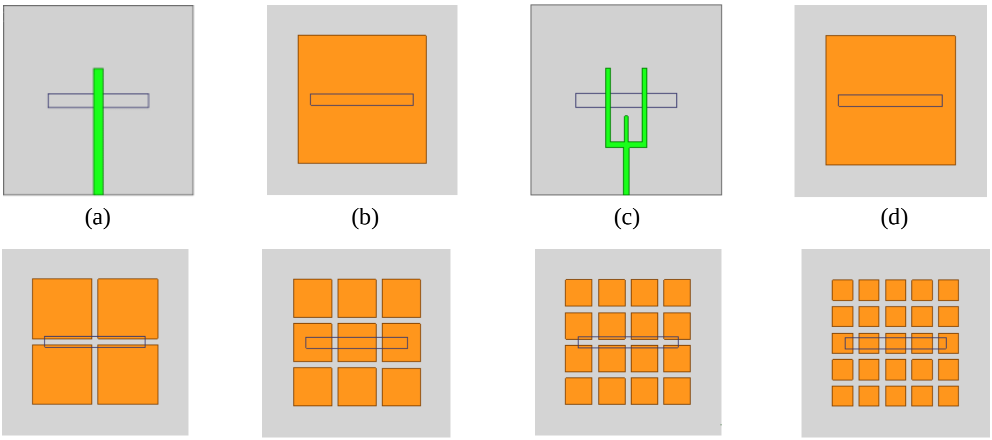
**Figure 1. Optimal dimensions and geometry of the suggested antenna: (a) layered structure's perspective view,(b) top layer of grid-slot patch,(c) coupling aperture in the middle layer of the ground,(d) ψ-shaped feeding microstrip line on the lower layer.**

**Table 1. The optimal dimensions of the suggested antenna (Unit: mm)**

| Wp | Lp | g | w | Wg | Lg | h | $h_0$ | Wc |
|---|---|---|---|---|---|---|---|---|
| 40 | 40 | 1 | 9.25 | 60 | 60 | 3.25 | 0.813 | 32 |
| Lc | a | b | c | d | p | q | r | t |
| 2.85 | 1.85 | 18 | 1.75 | 6.25 | 1.5 | 25 | 3 | 0.035 |

## III. STRUCTURE EVALUATION

Several methods are employed to improve the antenna's performances. Firstly, a basic line feeding aperture coupled microstrip antenna is created that is shown in Figure 2(a-b). Secondly, the line feeding is replaced by ψ-shaped feeding; those are shown in Figures 2 (b-c). Thirdly, the radiating patch develops 1×1 narrow slots, which are followed by the creation of 2×2, 3×3, and 4×4 narrow slots, as illustrated in Figures 2 (d-h) sequentially.

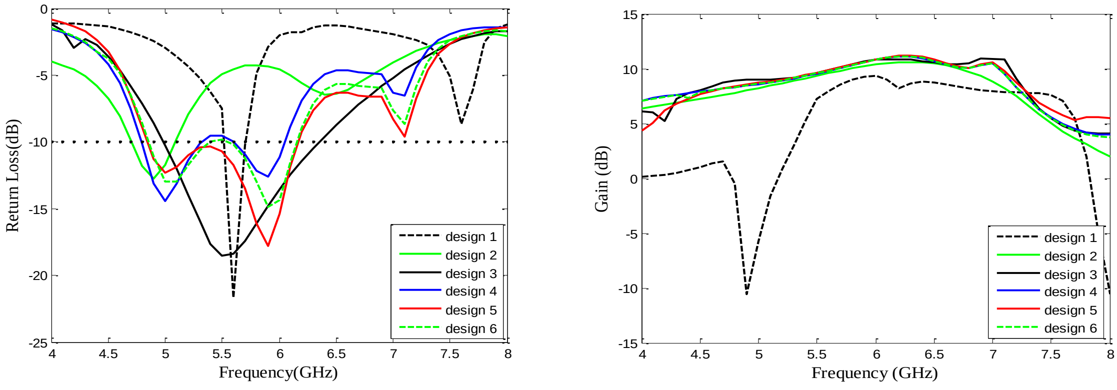


(a) (b) (c) (d)

(e) (f) (g) (h)

**Figure 2. Structure evaluation: (a-b) line feeding analysis (design 1), (c-h) ψ-shaped feeding analysis (design 2-6)**

Figures 3 (a-b) illustrate that among the designed antennas, ψ-shaped feeding with 3×3 slots gets the better ($s_{11}$ < -10 dB) bandwidth of 1320 MHz (4.85-6.17 GHz) and maximum gain of 11.17 dBi. The performance can be enhanced by optimising the patch slot, aperture-coupled slot, and ψ-shaped feeding structure dimensions those are discussed the bellow sections.

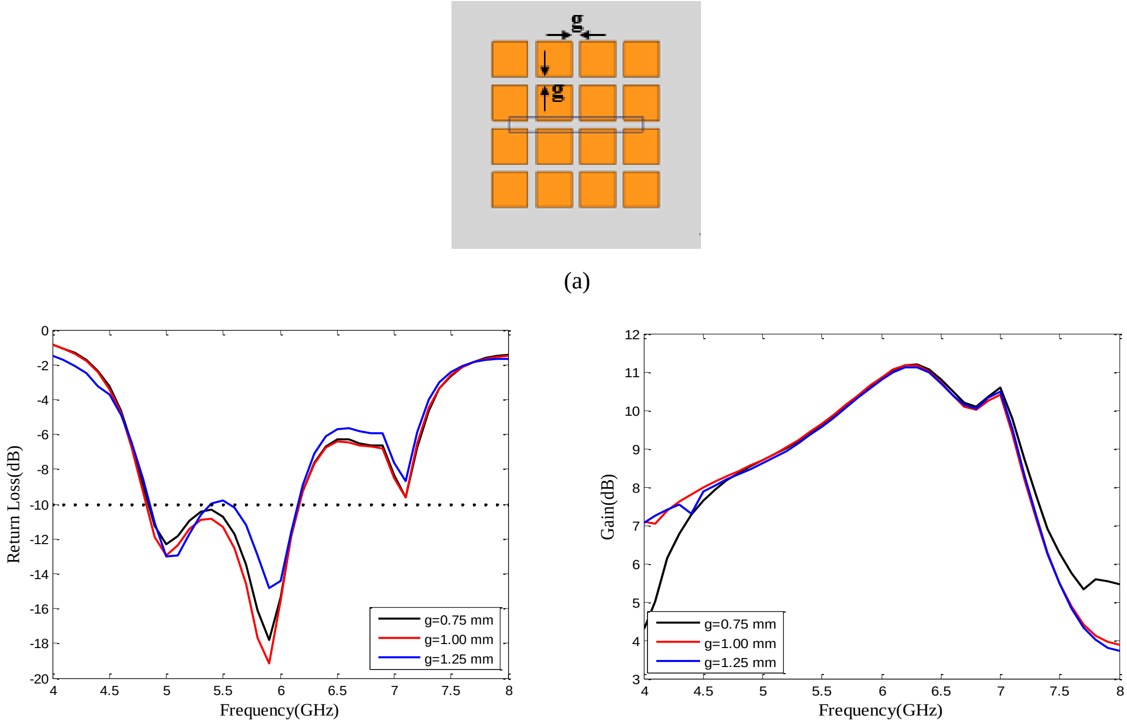


(a) (b)

**Figure 3. (a) Return loss plot (b) gain plot**

## A. *Parametric analysis of grid-slot*

Here to optimize the dimensions of 3×3 narrow slots, ‘g’ is changed gradually from 0.75 to 1.25 mm with a distance of 0.25mm and the performances of the bandwidth and gain are shown in Figures 4(a-c) respectively. All times, the slots are placed periodically. From the Figures 4(b-c), it is seen that when ‘g’ is 1 mm, its bandwidth gets better value and there is no huge effects to the gain. So the length of 1mm is the optimized value for three slots.



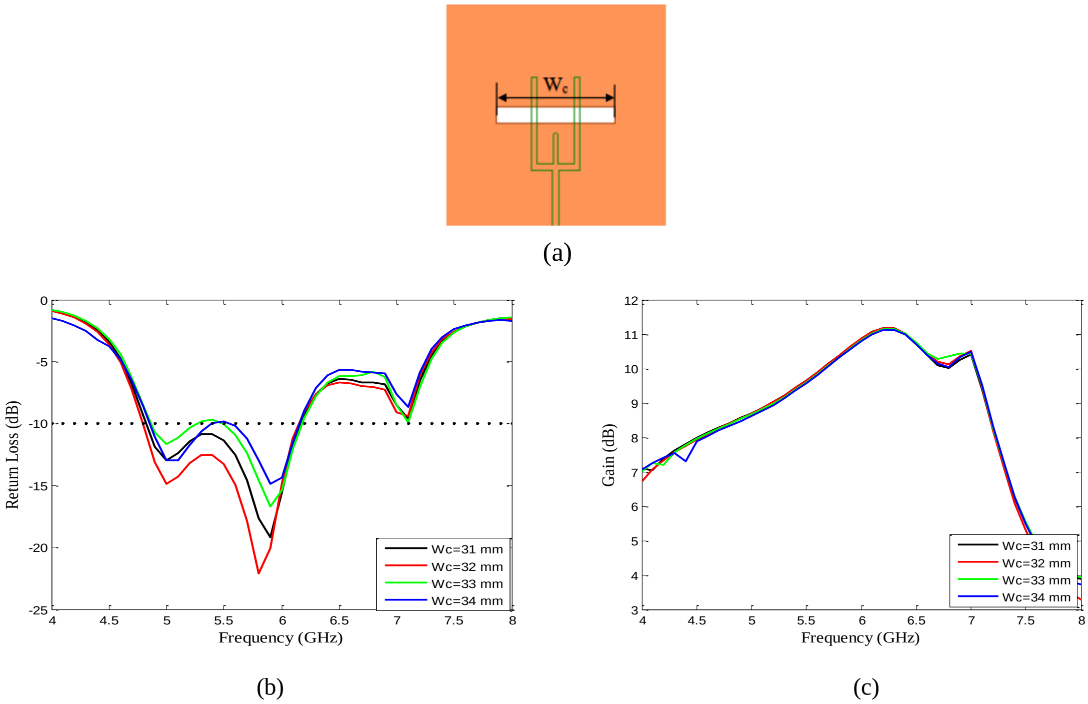
(a)

(b) (c)

**Figure 4. (a) Grid-slot patch structure (b) return loss plot, (c) gain plot for different value of ‘g’.**

## B. *Parametric analysis of aperture coupled slot*

The aperture coupled slot is optimized by changing its width and length $W_c$ and $L_c$. The width $W_c$ is changed from 31 to 34mm with a distance of 1mm and the performances of ($s_{11} < -10$ dB) bandwidth and gain are shown in Figures 5(a-c). From Figures 5(b-c), it is seen that the bandwidth is better when the width $W_c$ is 32mm and there is no huge change in gain.



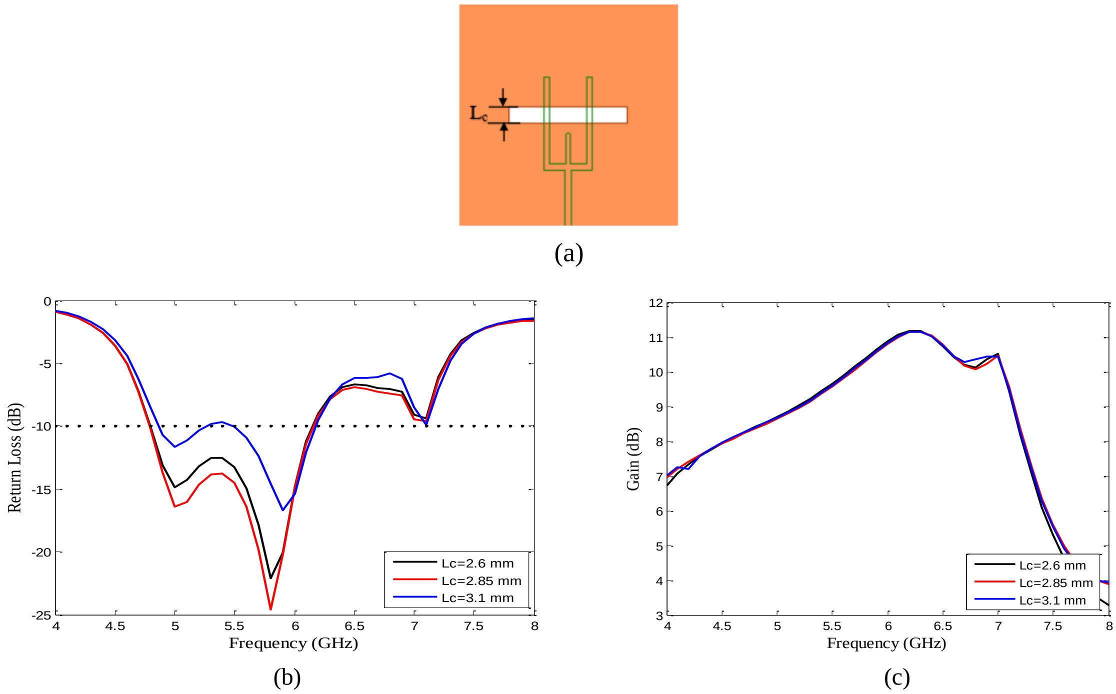
(a)

(b)

(c)

**Figure 5. (a) Coupling aperture structure (b) return loss plot, (c) gain plot for different value of ‘Wc’.**

Again, with a distance of 0.25mm, the length $L_c$ is changed from 2.6 to 3.1 mm and the performances of ($s_{11} < -10$ dB) bandwidth and gain are shown in Figures 6 (a-c). From Figures 6(b-c), it is seen that the bandwidth is better when the length $L_c$ is 2.85 mm and there is no huge change in gain. So it can be considered that the optimized width is 32 mm and length is 1.85 mm.



(a)

(b)

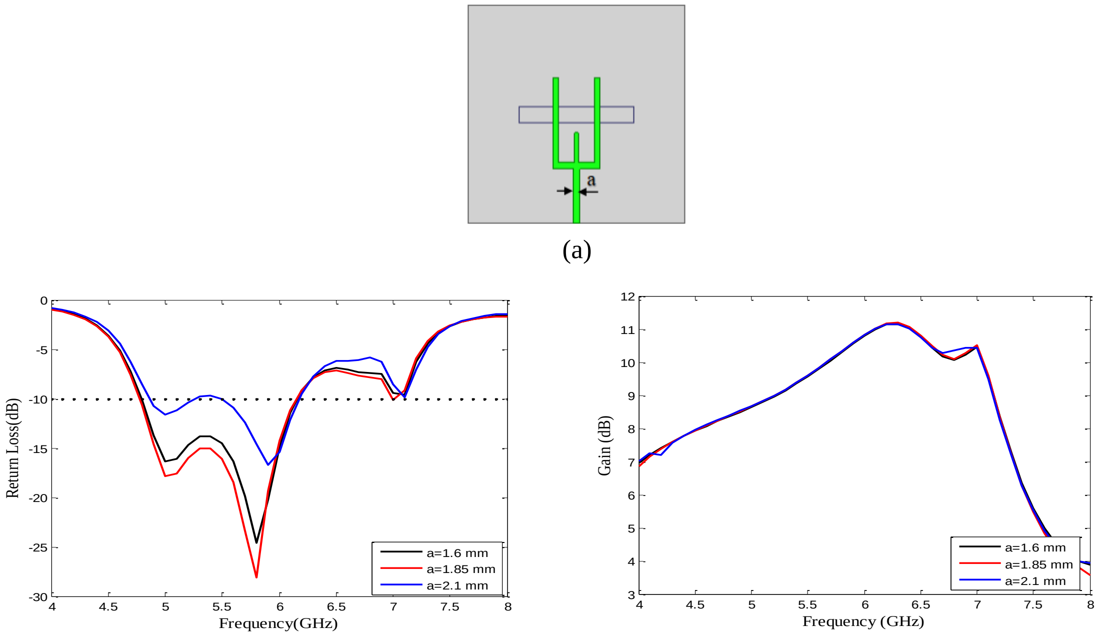
(c)

**Figure 6. (a) Coupling aperture structure (b) return loss plot, (c) gain plot for different value of ‘Lc’.**

### C. *Parametric analysis of ψ-shaped feeding*

The ψ-shaped feeding is optimized by changing its dimensions. With a distance of 0.25mm, the width of ‘a’ is altered from 1.6 to 2.1 mm, and Figure 7(a-c) displays the -10dB bandwidth and gain performances. From Figures

7(b-c), it is seen that there is no huge change in bandwidth and gain but the return loss is lower when the width ‘a’=1.85 mm. So it can be choosen the optimized width ‘a’=1.85 mm.

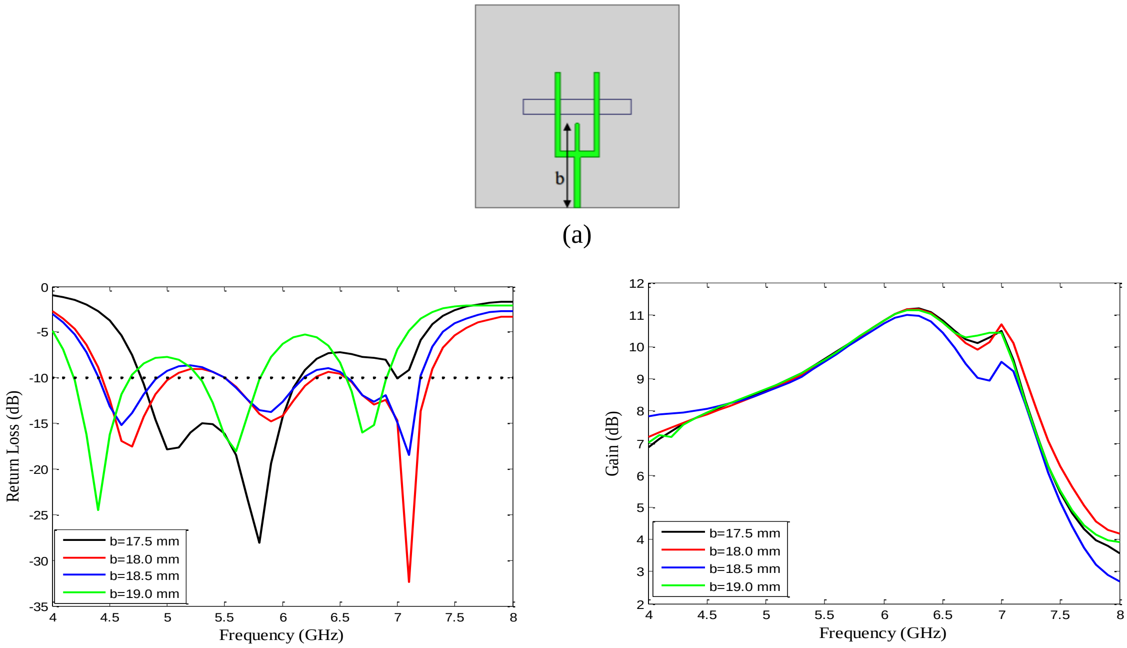


(a)

(b) (c)

**Figure 7. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of ‘a’.**

With a distance of 0.5mm, the length of ‘**b**’ is altered from 17.5 to 19 mm and the performances of ($s_{11}$ < -10 dB) bandwidth and gain are shown in Figures 8(a-c). The antenna is shown to be resonated at three frequencies in Figure 8(b) and when ‘b’=18 mm, its bandwidth is better compared to others. Figure 8(c) shows that there is no huge effect to the gain when ‘b’ is changed.

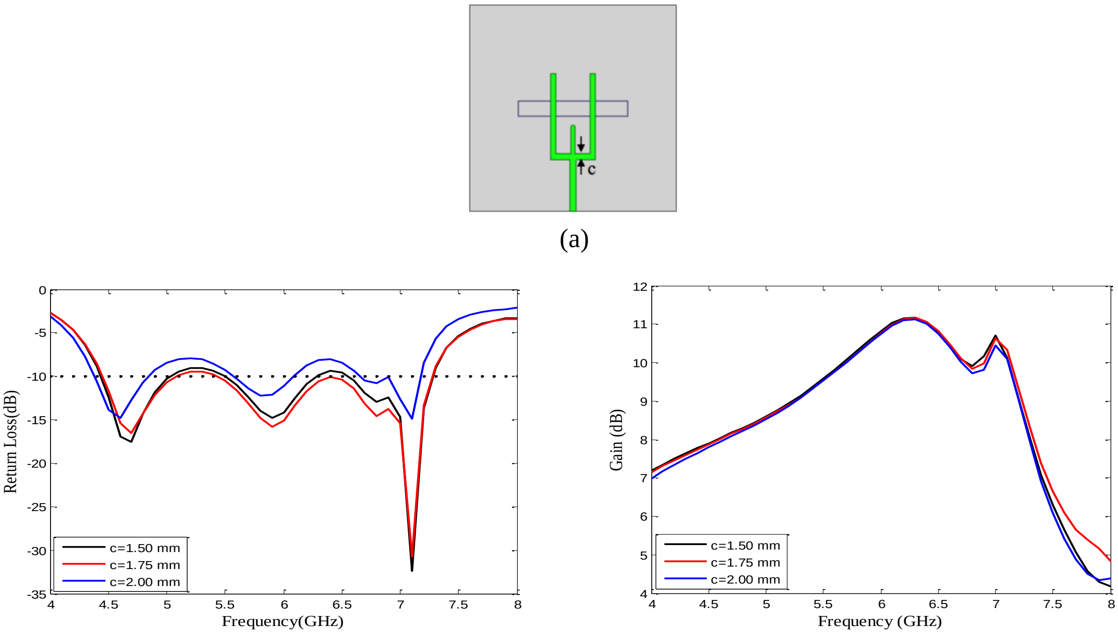


(a)

(b) (c)

**Figure 8. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of ‘b’.**

With a distance of 0.25mm, the length of ‘c’ is altered from 1.50 to 2.00mm and the performances of ($s_{11}$ < -10 dB) bandwidth and gain are shown in Figures 9(a-c). From Figure 9(b), it is seen that when ‘c’= 1.75 mm, its bandwidth and return loss is good but there is no huge change. Figure 9(c) shows that the gain is approximately same.



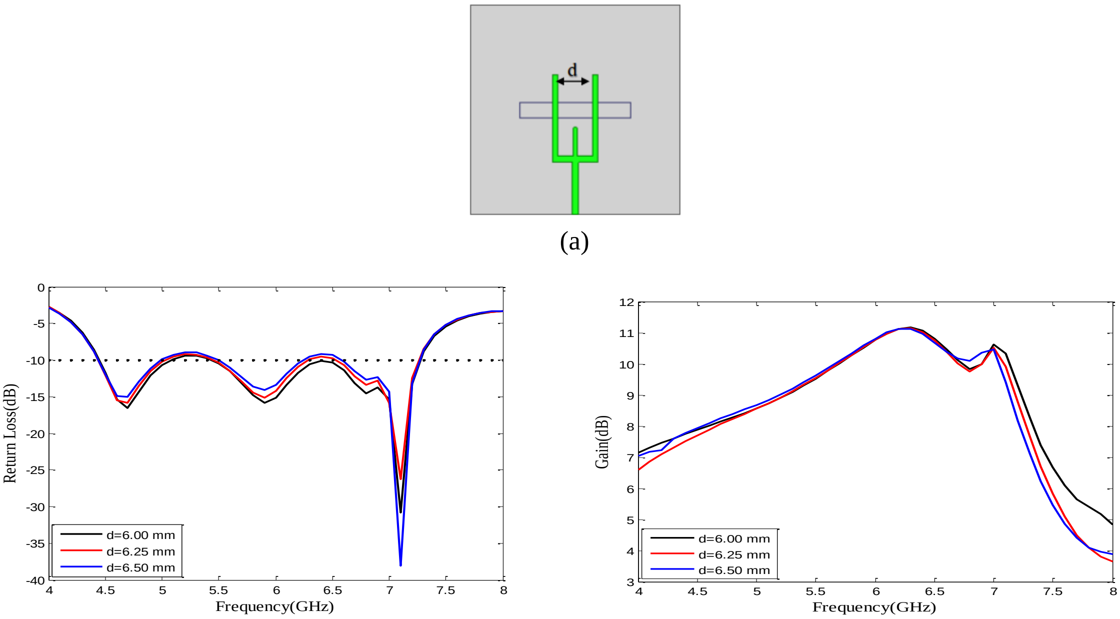
(a)

(b)

(c)

**Figure 9. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of 'c'.**

With a distance of 0.25mm, the width of '**d**' is altered from 6 to 6.5mm and the performances of ($s_{11} < -10$ dB) bandwidth and gain are shown in Figures 10(a-c). From Figures 10(b-c), it is seen that there is no huge change in return loss, bandwidth and gain.



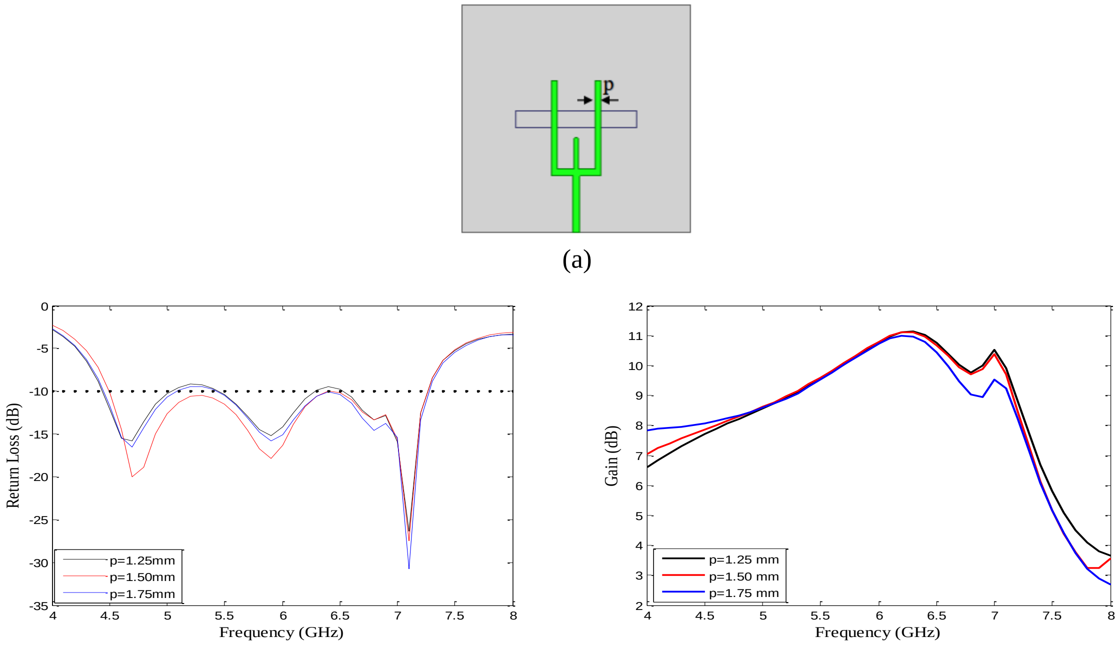
(a)

(b)

(c)

**Figure 10. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of 'd'.**

With a distance of 0.25mm, the width of 'p' is altered from 1.25 to 1.75 mm and the performances of ($s_{11} < -10$ dB) bandwidth and gain are shown in Figures 11(a-c). From Figure 11(a), it is seen that the bandwidth is approximately same but return loss is good when 'p'= 1.50 mm and Figure 11(b) shows that the gain is approximately same.

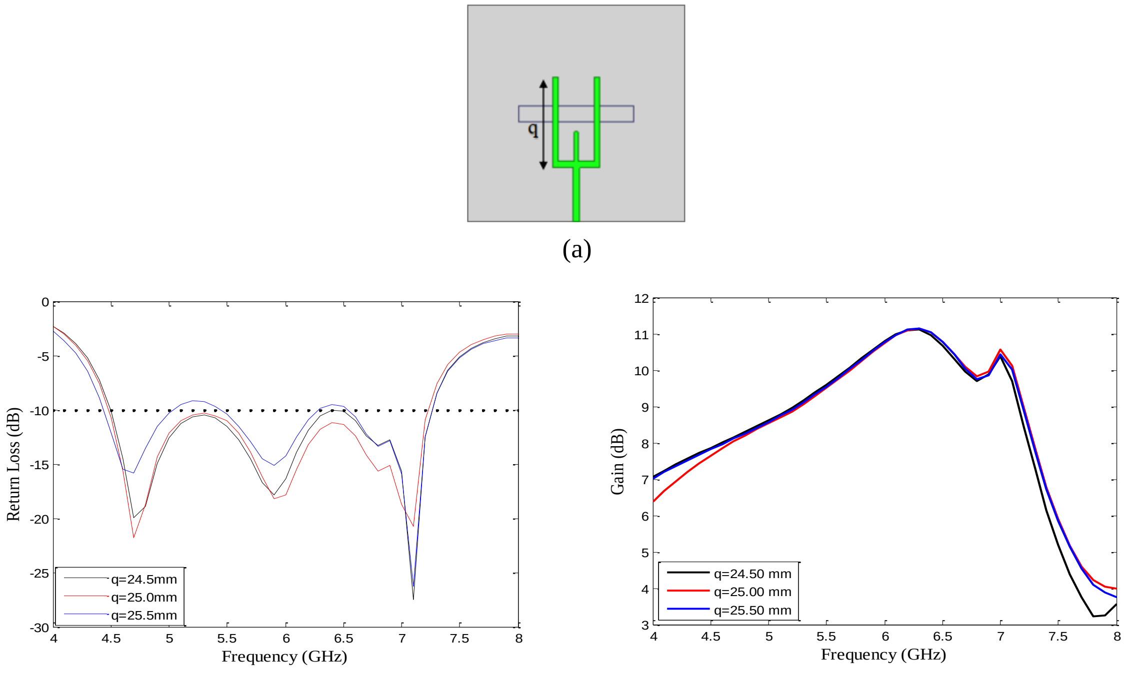


(a)

(b) (c)

**Figure 11. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of ‘p’.**

With a distance of 0.5mm, the length of ‘q’ is altered from 24.5 to 25.5 mm and the performances of ($s_{11}$ < -10 dB) bandwidth and gain are shown in Figures 12(a-c). Figure 12(b) shows that the antenna is cut at three varient frequencies. The return loss is significantly lower than -10dB and better than the others when ‘q’ is 25mm. Figure 12(c) shows that there is no huge effect on the gain. So the optimized value is ‘q’= 25mm.



(a)

(b) (c)

**Figure 12. (a) ψ-shaped feeding structure (b) return loss plot, (c) gain plot for different value of ‘q’.**

## IV. RESULTS AND DISCUSSIONS

The grid slot hybrid structure aperture coupled ψ-shaped feeding microstrip antenna is optimized in the preceding part. The performances of the antenna are discussed in the following section using the optimized value.

### *A. Return loss and Bandwidth*

Return loss measures the amount of power reflected back and the efficiency of the impedance match between the antenna and the transmission line. In most situations, an RL of less than -10 dB is often acceptable. In other words, less than 10% of the power is reflected and over 90% of the power is transferred. The range of frequencies across which a microstrip patch antenna may function efficiently is known as its bandwidth; this range is often defined as the range where the return loss is less than -10 dB [3]. Figure 13 displays the proposed antenna's return loss plot. The antenna has return losses of -21.8209 dB, -18.22 dB, and -20.7789 dB at the three resonance frequencies of 4.7, 5.9, and 7.1 GHz. Figure 13 illustrates the proposed antenna's bandwidth (s11 < -10 dB), which is 2760 MHz (4.47-7.23 GHz).

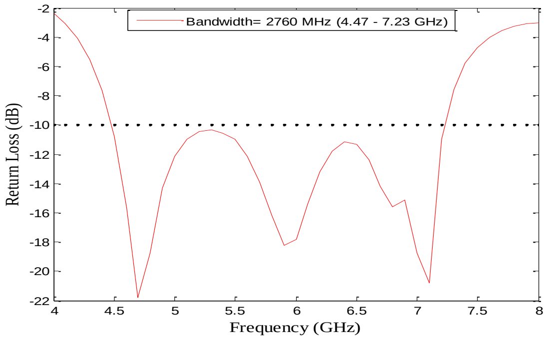
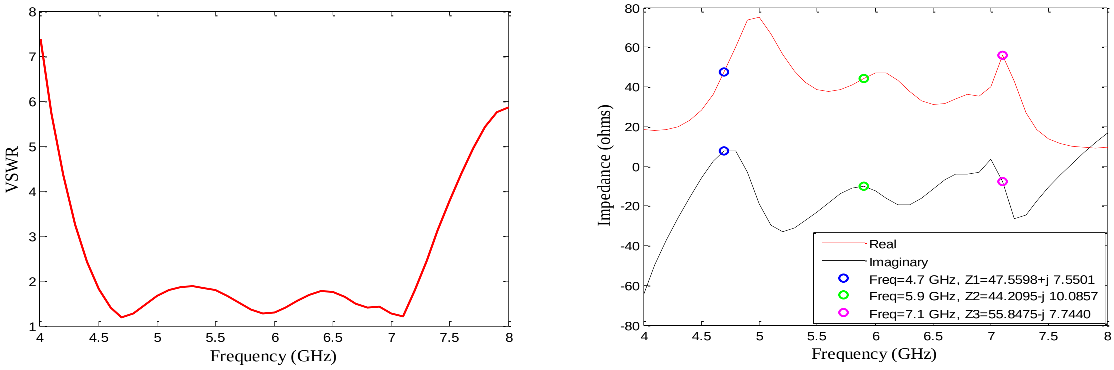


**Figure 13. Frequency vs return loss plot**

### *B. VSWR and Characteristic Impedance*

Power transmission efficiency from a transmission line to the antenna is measured by “Voltage Standing Wave Ratio (VSWR)”. In general, most systems can tolerate VSWR ≤ 2. A microstrip line's characteristic impedance is the transmission line's impedance between the patch and the ground plane, considering the size and characteristics of the substrate. The feed line's input impedance, usually 50 Ω, is what it is designed to match [3]. Figures 14(a-b) show the proposed antenna's VSWR and input impedance. The VSWR at three cut of frequencies are 1.17, 1.27 and 1.20 those are lower than 2.0 respectively. The characteristic impedance are 47.5598 + j7.5501 ohm, 44.2095 – j10.0857 ohm and 55.8475 – j7.7440 ohm at frequency of 4.7, 5.9 and 7.1 GHz respectively.

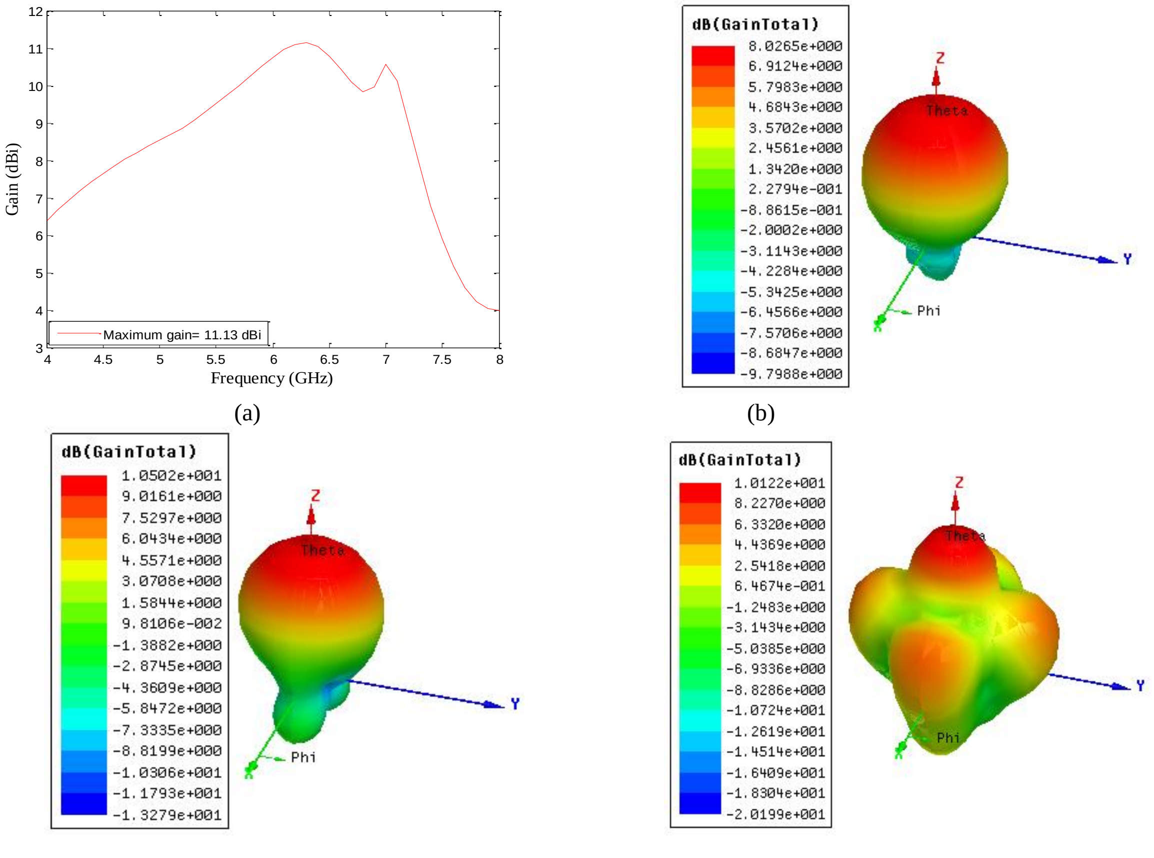


(a) (b)

**Figure 14. (a) VSWR plot and (b) characteristic impedance plot of proposed antenna**

### *C. Gain*

In comparison to an isotropic radiator, a microstrip patch antenna's gain is a crucial metric that shows how well it can direct radiated power in a particular direction [3]. The frequency versus gain curve is shown in Figure 15(a) where the gain is varied from 7.59 dBi to 11.13 dBi at frequencies from 4.47 to 7.23GHz respectively. Figure 15(b-d) shows the recommended antenna's 3D gain plot. The gains at the three cutoff frequencies of 4.7, 5.9, and 7.1 GHz are 8.0265, 10.502, and 10.12 dBi, respectively.



(a) (b)

(c) (d)

**Figure 15. (a) Frequency vs gain plot (b) 3D gain at 4.7 (c) 3D gain at 5.9 (d) 3D gain at 7.1GHz**

### *D. Directivity*

In contrast to an isotropic radiator, a microstrip patch antenna's directivity is a measurement of how concentrated its emitted power is in a particular direction. It is dependent upon the operating frequency and the patch's physical size [3]. The frequency versus directivity curve is shown in Figure 16 where the minimum and maximum directivity varies from 7.65 to 11.21 dBi at frequencies from 4.47 to 7.23GHz respectively.

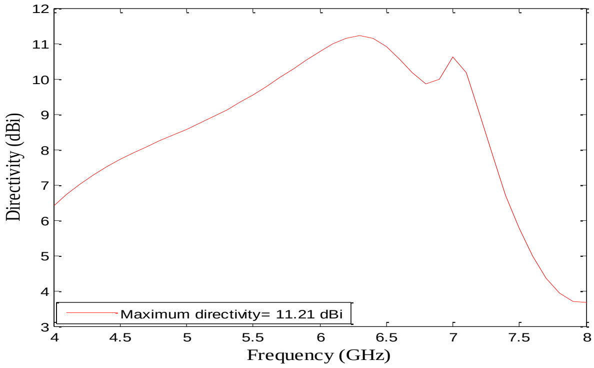
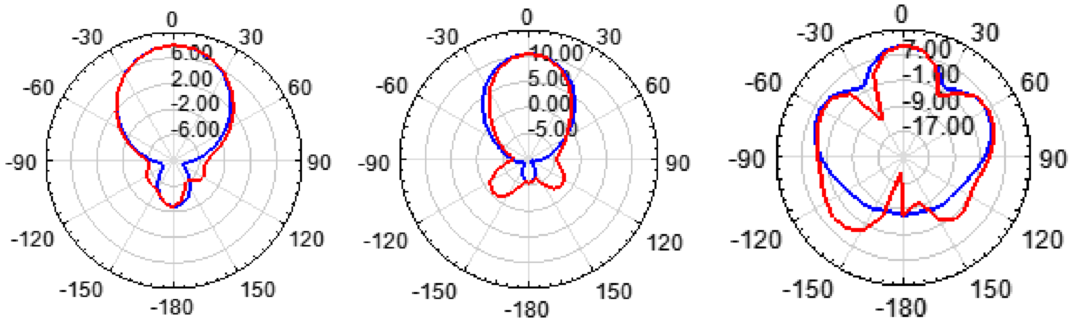


**Figure 16. Frequency vs directivity plot**

### *E. 2D Radiation Pattern*

A microstrip antenna's 2D radiation pattern is a visual depiction of the energy in a particular plane, often the H-plane or the E-plane. The relative intensity of the received or radiated power in various directions is usually shown by this pattern [3]. Figures 17 (a-c) display the proposed antenna's 2D radiation pattern at three cut off frequencies of 4.7, 5.9 and 7.1GHz respectively when phi=$0^0$ (red color) and phi=$90^0$ (blue color).



(a) (b) (c)

**Figure 17. 2D gain Plot for (a) 4.7, (b) 5.9, (c) 7.1 GHz**

## V. COMPARATIVE RESULTS WITH RELEVANT PAPERS

To show the advantages of the proposed antenna, a comparative report has been made with the recent relevant papers that is displaced in Table 2. It is clear from Table 2 that the suggested antenna shows the better advantages in terms of size, bandwidth, gain and efficiency.

**Table 2: Comparative results with relevant papers**

| Ref. | Overall Size ( mm×mm×mm) | Bandwidth (GHz) | Peak gain (dBi) | Efficiency |
|---|---|---|---|---|
| [12] | 75 × 75× 4.575 | 1.04 (4.48-5.52) | 9 | -- |
| [13] | 60 × 60× 4.1 | 1.39 (4.77-6.16) | 9.9 | 95% |
| [14] | 60 × 60× 4.1 | 1.46 (4.54-6.00) | 9.8 | 97% |
| [15] | 34× 28× 4 | 1.70 (4.20-5.90) | 5.8 | -- |
| [16] | 38.8× 38.8× 3.5 | 2.40 (4.55-6.95) | 7.5 | -- |
| [17] | 60 × 60× 4.063 | 2.34 (4.42-6.76) | 10.89 | 85% |
| [18] | 68 × 68× 3.25 | 1.77 (3.96-5.73) | 10.45 | 90% |
| [20] | 68 × 68× 5.302 | 2.30 (4.08-6.38) | 11.6 | -- |
| [26] | 70 × 70 × 4 | 2.59 (3.32-5.91) | 10.7 | -- |
| [28] | 65 × 65 × 7 | 1.30 (4.80-6.10) | 11.2 | -- |
| Proposed | 60 × 60× 4.063 | 2.72 (4.42-7.14) | 11.13 | 99% |

## VI. CONCLUSION

The proposed aperture coupled ψ-shaped feeding grid-slot hybrid structure microstrip antenna is designed and optimized its performances properly. The line feeding aperture coupled is replaced by ψ-shaped feeding. The square patch is swapped out with grid slot patches, which have 4x4 grids and 3x3 narrow slots. The grid-slot, coupling slot, and feeding parameters are numerically varied to verify the antenna's performance. The proposed antenna shows a bandwidth of 2760 MHz, gain of 11.13 dBi and efficiency of 99% which are better compared with others. The suggested antenna has return losses of -21.8209 dB, -18.22 dB, and -20.7789 dB at three different frequencies of 4.7, 5.9 and 7.1 GHz. C-band applications are compatible with the antenna.

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