



Design of a Compact High Gain Wide Band Ψ Shaped Patch Antenna on Slotted Circular Ground Plane

Anitha Peram¹(✉), Agarala Subba Rami Reddy²,
and Mahendra N. Giri Prasad¹

¹ Department of ECE, JNTUA, Anantapuramu, Andhra Pradesh, India
anitha.peram@gmail.com

² G.K. College of Engineering, Sullurpet, Andhra Pradesh, India

Abstract. A compact wideband high gain Ψ shaped patch antenna on circular ground plane is proposed. The patch is designed and fabricated on FR4 substrate with a thickness of 1.6 mm and is compact in size as 122.7 mm² including ground plane. The SMA connector with a center radius of 0.36 mm is connected at a coordinate ($x = 5$ mm, $y = 3.3125$ mm) as a feeding line to give RF signal as input. A wide impedance bandwidth is obtained due to the slots on the radiating element and by placing shorting post near zero potential fields makes the structure compact. An impedance bandwidth is further enhanced by placing an inverted U-slot on ground plane. The proposed structure is resonating at five different frequencies 1.924 GHz, 2.88 GHz, 5.29 GHz, 8.58 GHz and 12.27 GHz yields an impedance bandwidth of 345 MHz, 92 MHz, 200 MHz and 4.77 GHz respectively. Reflection coefficient (S_{11}) at 8.58 GHz & 12.27 GHz is -36.37 dB and -44.61 dB respectively. The proposed antenna is giving a maximum gain of 6.1 dB and has a stable radiation pattern with in the resonating band. The designed antenna is fabricated and is experimentally validated for the results. It reveals that the proposed antenna is suitable for WLAN and X band applications.

Keywords: Circular ground plane · Shorting post · Inverted U slot
X band · WLAN band

1 Introduction

In the Recent years, broadband micro-strip antennas are attracting more attention in the areas such as wireless local area network (WLAN), Bluetooth, Global Positioning System (GPS), radar, satellite and biomedical telemetry systems. X band (8–12 GHz) technology is widely used in various applications due to high data transmission rates, short range and large bandwidth. Numerous applications of MPA which operates in the X-band region includes in satellite communications, military communications, RADAR, Amateur radio, Precision approach RADAR (PAR) (9–9.2 GHz), traffic light crossing detectors (10.4 GHz), motion detectors (10.57 GHz) etc.

Broadband antennas are of immense demand for these systems. Hence, it is required to develop a miniaturized broadband antenna with high gain, better efficiency and stable

radiation pattern. MPA is one which will fulfill the demands of Wireless communication due to its attractive advantages like less profile, low weight, low cost, easy to fabricate and conformal design. Apart from advantages it has limitations such as lower power handling, lower bandwidth and low efficiency [1]. A high gain, wide band, compact MPA at low cost with simple design is the challenging issues in designing MPA for commercial use. Since improvement in one will degrade the other parameter.

To enhance the bandwidth and gain of patch antenna, scientists and researchers have developed various methods over two decades. The bandwidth of an antenna can be increased by different techniques like, Multilayered configurations [2, 3], however if height is increased beyond $0.1\lambda_0$, surface wave excitation results in degradation of the antenna performance. Second, Stacked Multi-resonator and Planar Multi-resonator configurations [4, 5] increases a bandwidth up to 40%, the resulting configuration is larger in size compared to single resonator. Another method of increasing bandwidth is by using foam substrate and thick air [6] the resulting structure is larger in volume. Another miniaturized wide band approach is by reshaping the structure (placing slots) and defected ground plane structure, using shorting pins and shorting walls [8–10]. However, the obtained bandwidths of these antennas are below 30–80%. In [11–15] an X band MPA's were proposed using reshaping and defected ground plane approach, however not met enough bandwidth and gain criteria. Another method for improving the performance is the use of fractal antennas [16]. For further enhancement hybrid fractal slot is proposed [17] with a patch size of 40×40 mm i.e. complex in structure, large in size and gain is not stable throughout the band.

For commercial applications of MPA, However enhancing the bandwidth and gain, compactness in structure are the major design considerations as improving of one will degrade the other. This made us to work on broadband Ψ -shaped patch antenna on circular ground plane with an inverted U slot achieves the desired goal.

In this article a design that provides simultaneously a compact, high gain and wide bandwidth MPA for commercial applications. The techniques such as modifying the shape of the patch, placing slots on ground plane and using a shorting pin are merged. Hence, the design employs a modified Ψ -shape patch on an inverted U-slot loaded circular ground plane with a shorting post near to probe feed to meet our goals. Parametric analysis is performed to attain good antenna performance. By optimizing the arm length of Ψ -shape patch, slot and the position of shorting post wider impedance bandwidths of 4.77 GHz in X band and 330 MHz in L band and a peak gain of 6.1 dBi is achieved. The designed antenna is fabricated and the results are validated experimentally which supports majorly X band applications.

2 Antenna Design and Configuration

The geometry of the proposed antenna is illustrated in Fig. 1. An MPA with a modified Ψ -shape patch as radiating element and a circular ground plane with an inverted U-slot is designed. The ground plane and patch are printed on opposite sides of Flame Resistant (FR4) substrate with a thickness of 1.6 mm, relative permittivity of 4.4 and a dielectric loss tangent ($\tan \delta$) of 0.02. An inverted U slot is placed below the Ψ patch on a circular ground plane with a diameter of 12.5 mm to get wide bandwidth. Slot and

Patch dimensions are chosen after numerous iterations. Optimized dimensions of the designed antenna are given in Table 1. A 50Ω co-axial probe feed is used to excite radiation. By placing shorting post a coordinate $(x = 5 \text{ mm}, y = 4.125 \text{ mm})$ with a diameter of 1 mm enhances the bandwidth further. The prototype of the designed patch is illustrated in Fig. 2.

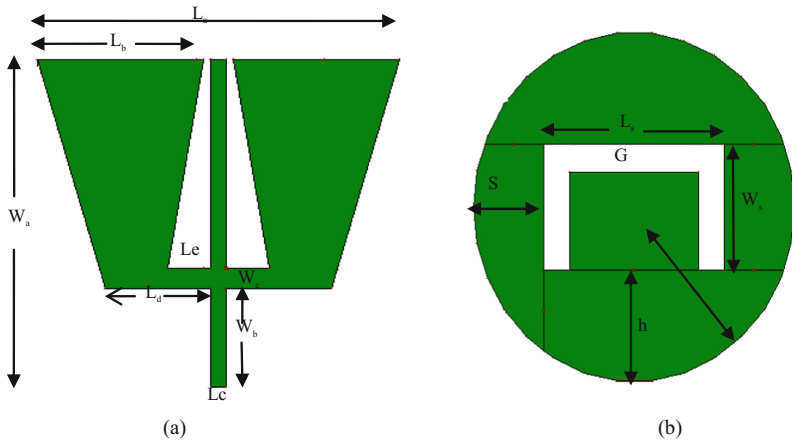


Fig. 1. Geometry of the proposed antenna (a) Radiating patch (b) Ground plane

Table 1. Designed antenna specifications

Parameter	L_a	L_b	L_c	L_d	L_e	W_a	G
Designed antenna	10	4.6	0.4	2.9	1.2	10	1
Parameter	W_b	W_c	W_s	L_s	R	h	S
Designed antenna	3	0.625	4.5	7	6.25	4	2.75

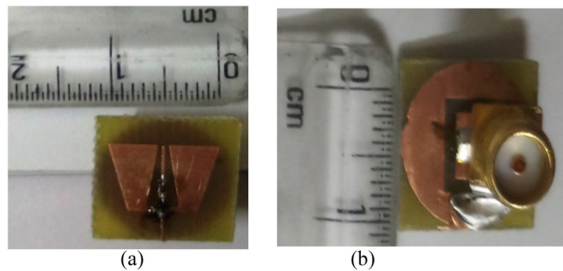


Fig. 2. Proto type of the fabricated structure (a) Top layer (b) Bottom layer

2.1 Parametric Study

To investigate the effect of parameters on antenna performance, some sensitive parameters are identified and studied based on design. Depending on the geometry of

ground plane and patch the frequency response is decided. Hence, to optimize the performance, parametric study have been performed with respect to (a) Effect of shorting post and inverted U slot on ground plane (b) Effect of slot width W_s i.e. width of vertical slots (c) Effect of G i.e. horizontal slot width. All simulation has been carried out by using IE3D simulator.

2.1.1 Effects of Shorting Post and U Slot

To study the effect of shorting post on antenna performance a simulation is carried out without shorting post by keeping all other parameters fixed and is presented in Fig. 3. From the figure it is seen that there is a significant effect on bandwidth. The Ψ patch with inverted U slot on ground plane resonates at 5.2 GHz and 12.71 GHz, which yields negligible bandwidth and reflection co-efficient.

The same antenna without U slot on ground plane and with shorting post at $(x = 5 \text{ mm}, y = 4.125 \text{ mm})$ coordinates, the patch is resonating at four different frequencies as 2.2 GHz, 3.16 GHz, 5.61 GHz and 11.268 GHz yields an impedance bandwidth of 2.56 GHz ($S_{11} < -10 \text{ dB}$ from 10.10 GHz to 12.66 GHz) in X band.

The same antenna with shorting post and an inverted U slot on ground plane resonates at five different frequencies 1.924 GHz, 2.88 GHz, 5.29 GHz, 8.58 GHz and 12.27 GHz. An impedance bandwidth of 345 MHz, 92 MHz, 200 MHz and 4.77 GHz is achieved at their corresponding resonating frequencies. Table 2 shows the effect of shorting post and U slot on reflection coefficient and hence on impedance bandwidth

On comparing, the patch without shorting post and with slot it is resonating at single frequency yields a very narrow bandwidth. With the insertion of shorting post excluding slot resonates at lower frequency and hence results in size reduction. By placing shorting post and slot makes the patch to resonate at two nearby frequencies which enhances the bandwidth. This can be attributed due to strong coupling between the patch and ground plane.

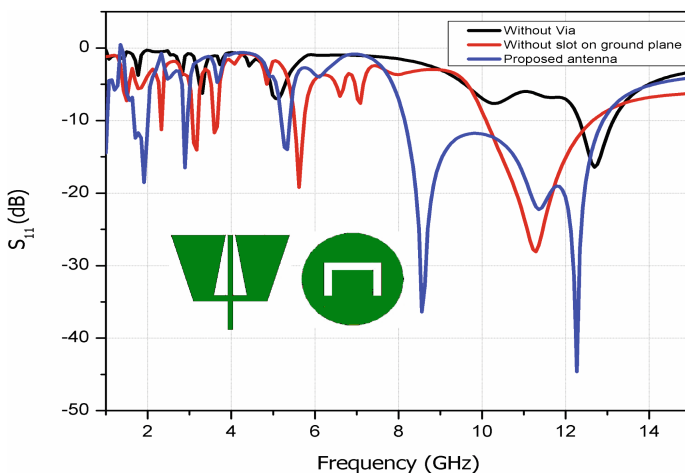


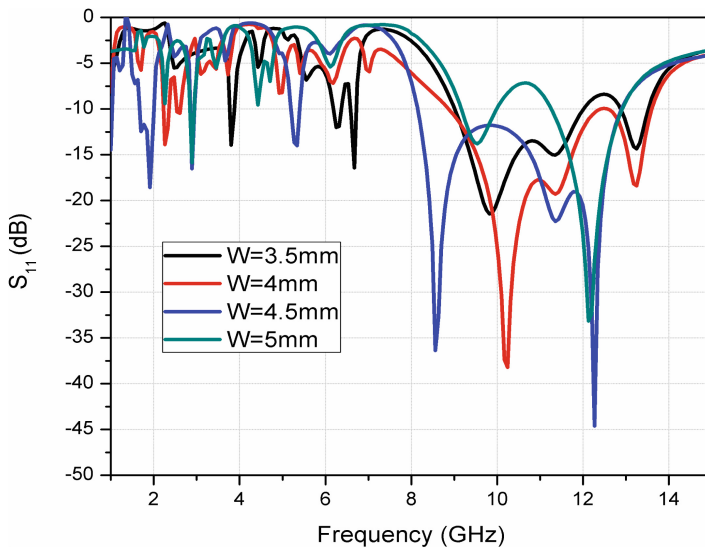
Fig. 3. Simulated S_{11} characteristics by considering the effect of slot and shorting post

Table 2. Comparison results by considering the effects of shorting posts and U slot

Antennas	Return loss ($S_{11} < -10$ dB)	Bandwidth	Resonating frequency f_0 in GHz
Proposed antenna	8.14 GHz–12.91 GHz	4.77 GHz	8.58 & 12.27
Antenna without slot on ground plane and with via	10.10 GHz–12.66 GHz	2.56 GHz	11.268
Antenna without via and with slot	12.31 GHz–13.14 GHz	0.83 GHz	12.71

2.1.2 Effect of Slot Width W_s ; Width of Vertical Slots

With other parameters optimized, for different values of slot width the designed antenna is simulated for reflection coefficient which is shown in Fig. 4. Slot width is varied from 3.5 mm to 5 mm and it can be seen that there is a significant variation in bandwidth and impedance matching. Good impedance matching and bandwidth can be found for a slot width of 4.5 mm further increase in width decreases both bandwidth and matching. A slot width of 4.5 mm produces multiple resonances and thus achieves wide bandwidth with a compact size.

**Fig. 4.** Simulated S_{11} for different slot widths of the proposed antenna

2.1.3 Effects Gap Between the Slots

From Fig. 5, it can be seen that the variation in slot gap majorly affects impedance matching. Good impedance matching is found for a gap of 1 mm. A coupling between the patch and ground plane increases due to decrease in overlapping area. A slight increase in bandwidth can be seen for a gap of 0.8 mm than the proposed antenna, however reduces impedance matching. Further increase in gap reduces the bandwidth and impedance matching due to increase in overlapping area.

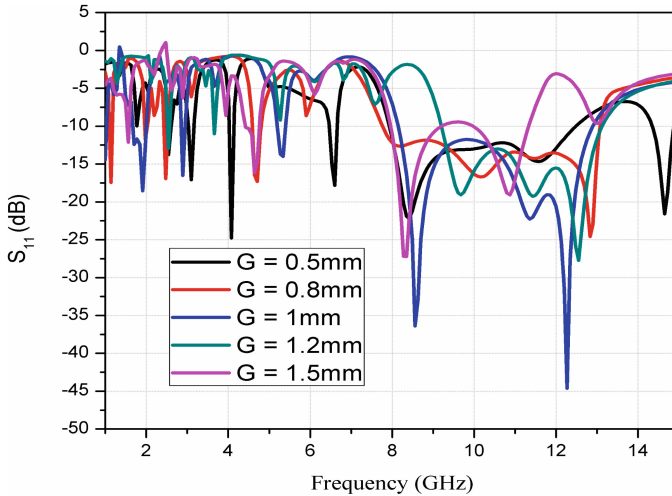
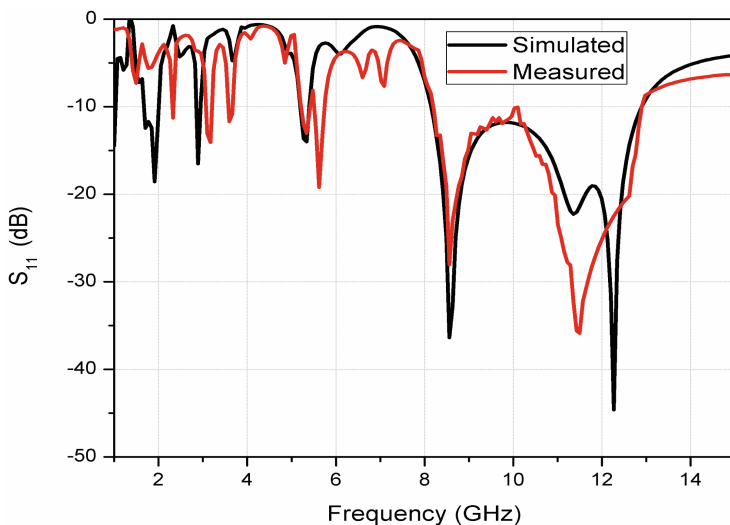


Fig. 5. Simulated S_{11} by considering the effect of slot gap

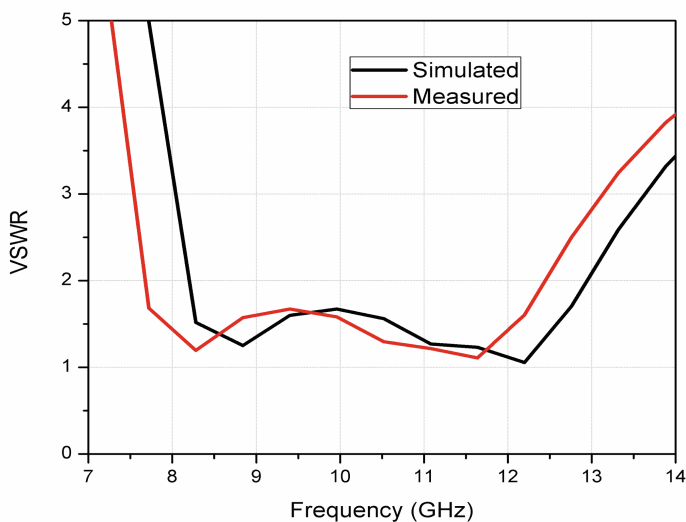
3 Measured Results

The designed antenna is fabricated on FR4 substrate with a thickness of 1.6 mm and is tested for experimental verification through The Agilent N5230A (10 MHz–50 GHz) series network analyzer. The return loss parameters of simulated and measured results comparison is shown in Fig. 6(a). The measured impedance bandwidth is about 4.77 GHz ($S_{11} < -10$ dB from 8.14 GHz to 12.91 GHz). Comparison of simulated and measured results reveals that there is a good correlation throughout the band. Slight variation may be due to fabrication errors. $VSWR < 2$ for the designed antenna is from 8.14 GHz to 12.91 GHz and are verified through VNA. The designed antenna has a minimum VSWR of 1.055 at 8.58 GHz which is illustrated in Fig. 6(b).

The proposed antenna gain is measured by two antenna method after attaining S_{21} parameters of Horn antenna and AUT using anechoic chamber of 5 m \times 3 m \times 3 m and is shown in Fig. 7. The simulated and measured gain of the proposed patch antenna



(a)



(b)

Fig. 6. Simulated and measured results of the designed antenna (a) S_{11} characteristics (b) VSWR characteristics

ranges from 5.2 dBi to 6.13 dBi in the resonating band (8–13 GHz). For practical applications gain variation should be within 2 dBi in the resonating band which satisfies the requirement. From 2–15 GHz gain variation is between 4–6 dBi. The simulated radiation pattern in E and H planes at resonating frequencies are shown in Fig. 8. The radiation pattern is omnidirectional both in E and H planes.

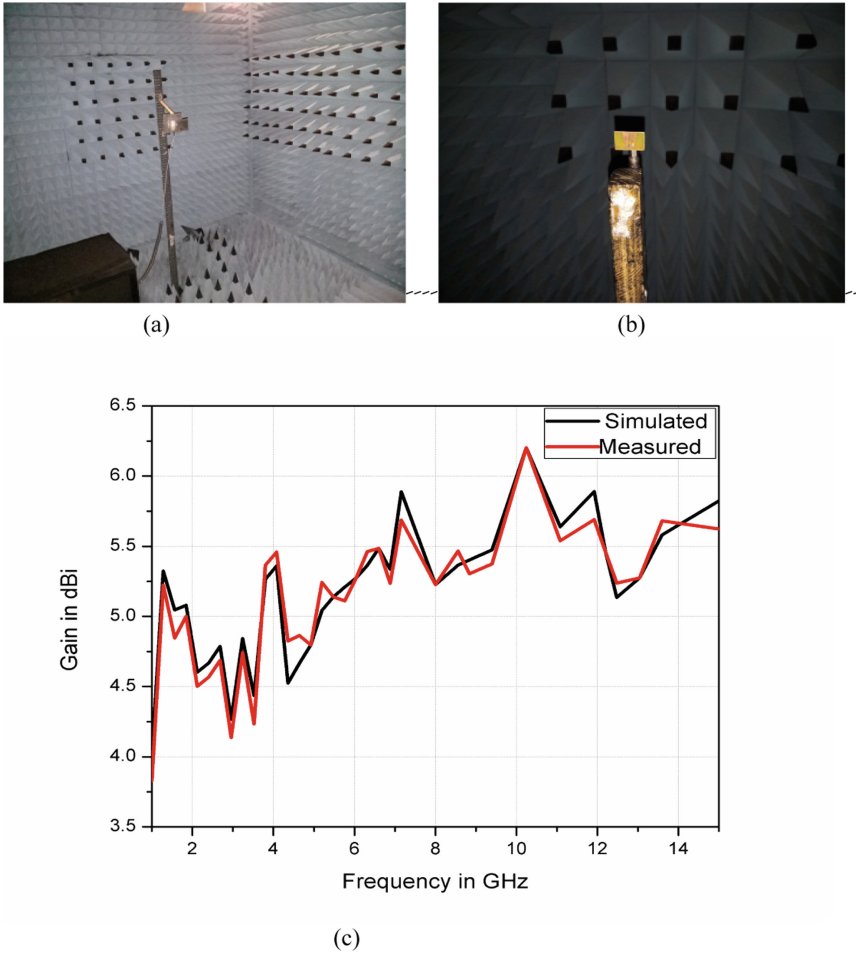
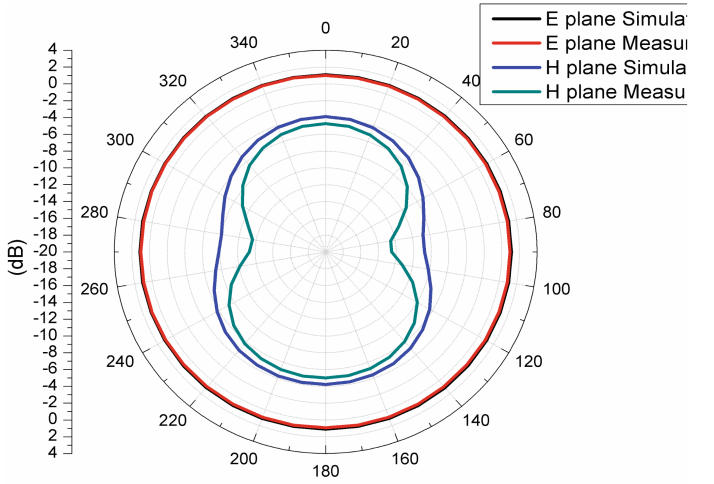
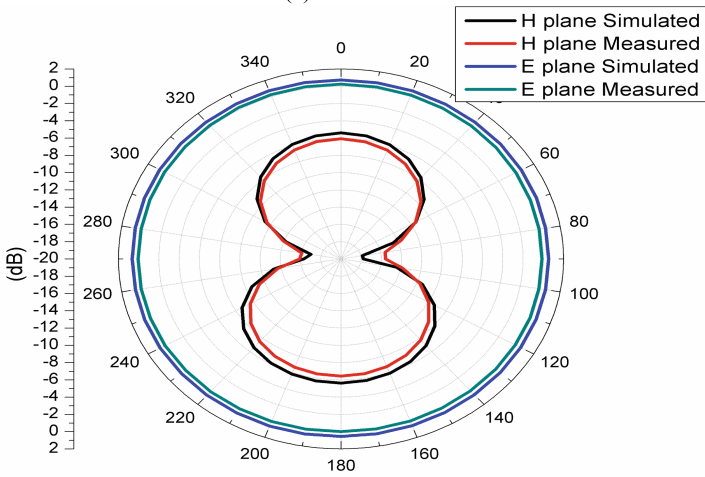


Fig. 7. Radiation pattern and gain measurement through anechoic chamber (a) Transmitter (b) AUT (c) Simulated and Measured Gain

Current distribution at 8.58 GHz and 12.2 GHz is shown in Fig. 9. It reveals that strong coupling exists between the slot edges and patch shows that performance depends on slot length and width. Current is concentrated at the edges of U-shaped inverted slot and Ψ -shaped patch. Table 3 shows the comparison study of the proposed antenna with respect to literature.



(a)



(b)

Fig. 8. Radiation patterns in E and H planes at (a) 8.58 GHz & (b) 12.27 GHz

Table 3. Comparison study with respect to literature

Parameters	[9]	[6]	[10]	[11]	[12]	[13]	[16]	[17]	Our work
Resonating frequency in GHz	9.56	9.6	9	11.4	9.75	10.53	2.46 & 9.4	5.7, 6.4 & 8.4	5.3, 8.58 & 12.27
Bandwidth in GHz	3.04	1.2	0.11	0.0114	1.801	4.06	0.45, 2.44	0.158, 0.1593, 0.2677	0.2 & 4.77
Patch size in mm	100 × 9 × 3.2	50 × 50 × 2.4	11.01 × 13.9 × 1.6	4 × 9 × 1.57	17.56 × 18.04 × 1.6	8.5 × 7.5 × 4.662	40 × 39 × 1.6	60 × 55 × 1.6	11.1 × 11.1 × 1.6
Gain in dBi	6	14	N/A	4.82	3.56	5.23	5.73	3.74	6.1

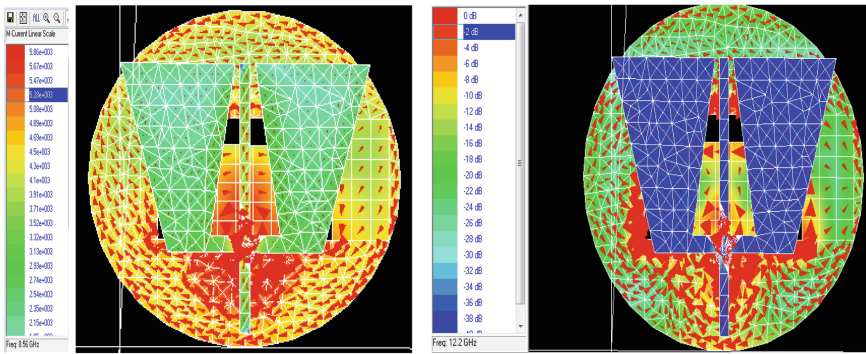


Fig. 9. Current distribution of the proposed patch antenna at 8.56 GHz and 12.2 GHz

4 Conclusion

High gain wide band Ψ shaped patch antenna with an inverted U slot on circular ground plane is presented. The designed antenna is fabricated on FR4 substrate with a thickness of 1.6 mm and is tested for result yields a good impedance bandwidth of 4.77 GHz (8.14 GHz–12.91 GHz) with a maximum gain of 6.1 dB. Compactness is achieved by placing shunting post along the zero potential field makes it easy to integrate. The experimental result shows that there is a good correlation between the simulated and measured ones. The proposed design best suits for WLAN and X band applications.

References

1. Kumar, G., Ray, K.P.: Broadband Microstrip Antennas. Artech House, Boston (2003)
2. Wnuk, M., Przesmycki, R., Nowo-sielski, L., Bugaj, M.: Multilayer microstrip antenna on flat base in the X band (8.5 GHz–12 GHz). In: Progress in Electromagnetics Research Symposium (PIERS), vol. 7, pp. 216–220 (2011)

3. Sarkar, D., Saurav, K., Srivastava, K.V.: Multi-band microstrip-fed slot antenna loaded with split-ring resonator. *Electron. Lett.* **50**(21), 1498–1500 (2014)
4. Anguera, J., Boada, L., Puente, C., Borja, C., Soler, J.: Stacked H-shaped microstrip patch antenna. *IEEE Trans. Antennas Propag.* **52**(04), 983–993 (2004)
5. Wong, K.-L., Tung, H.-C., Chiou, T.-W.: Broadband dual-polarized aperture-coupled patch antennas with modified H-shaped coupling slots. *IEEE Trans. Antennas Propag.* **50**(02), 188–191 (2002)
6. Sharma, A.K., Mittal, A.: Diagonal slotted diamond shaped dual circularly polarized microstrip patch antenna with dumbbell aperture coupling. In: *The European Conference on Wireless Technology, IEEE Conference*, pp. 463–465 (2005)
7. Mandal, K., Sarkar, P.P.: A compact low profile wideband U-shape antenna with slotted circular ground plane. *Int. J. Electron. Commun. (AEÜ)* **70**, 36–340 (2016)
8. Verma, S., Ansari, J.A.: Analysis of U-slot loaded truncated corner rectangular microstrip patch antenna for broadband operation. *Int. J. Electron. Commun. (AEÜ)* **69**, 1483–1488 (2015)
9. Claudius, L., Thomas, F.E.: Unidirectional radiation efficient stacked aperture antenna for X-band application. *J. Antennas Wirel. Propag. Lett.* **7**, 264–266 (2008)
10. Verma, A., Srivastava, N.: Analysis and design of rectangular microstrip antenna in X band. *MIT Int. J. Electron. Commun. Eng.* **1**(1), 31–35 (2011)
11. Mazumdar, B.: A compact microstrip antenna for X band application. *Int. J. Recent Technol. Eng.* **1**, 104–106 (2012)
12. Harrabi, A., Razban, T., Mahe, Y., Osman, L., Gharsallah, A.: Wideband patch antenna for x-band applications. In: *Proceedings of the Progress in Electromagnetics Research Symposium, Stockholm, Sweden* (2013)
13. Lakrit, S., Ammor, H.: Design on X-band wideband and high-gain multi-layer microstrip antenna. *J. Eng. Sci. Technol. Rev.* **7**(3), 176–179 (2014)
14. Anitha, P., Reddy, A.S.R., Giri Prasad, M.N.: Design of a compact micro-strip patch antenna with enhanced bandwidth on modified ground plane for x-band applications. *J. Eng. Technol.* **6**, 112–120 (2018). Special Issue (Emerging Trends in Engineering Technology)
15. Anitha, P., Reddy, A.S.R., Giri Prasad, M.N.: Design of a compact dual band patch antenna with enhanced bandwidth on modified ground plane. *Int. J. Appl. Eng. Res.* **13**(1), 118–122 (2018). ISSN 0973-4562
16. Sharma, N., Sharma, V.: A design of Microstrip Patch Antenna using hybrid fractal slot for wideband applications. *Ain Shams Eng. J.* 1–7 (2017). <https://doi.org/10.1016/j.asej.2017.05.008>
17. Gupta, M., Mathur, V.: Koch boundary on the square patch microstrip antenna for Ultra Wideband applications. *Alexandria Eng. J. AEJ* **57**(3), 2113–2122 (2017)