Enhancement of Radiation characteristics in a planar Microstrip patch Antenna using Defected Ground Structure

Pallavi H.V[a], Murti Mahadeva Naik G[b], A.P. Jagadeesh Chandra[c], Paramesha[d]

[a]Department of ECE, Government Engineering College, Hassan, Karnataka, India-573201, bpallavi178@gmail.com
[b]Department of ECE, Malnad College of Engineering, Hassan, Karnataka, India-573202, gmmn@mcehassan.ac.in
[c]Department of ECE, Adichunchanagiri Institute of technology, Chikamagalur, Karnataka, India-577102, apjchandra@gmail.com
[d]Department of ECE, Central University of Karnataka, Kalaburagi India-585367 parameshap91@gmail.com

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Abstract: A circular Defected Ground Structure is proposed to improve the radiation properties of a Rectangular Microstrip Patch Antenna with Quarter Wave Transformer feed (QWTRMPA). By crack down cross-polarization (XP) levels, higher isolation between co-polarization to cross-polarization radiation is achieved without disturbing the co-polarized radiation. In this design a circular slot etched on the ground plane as a Defected Ground Structure (DGS) results in a suppression of XP in H-plane. The conventional configuration resonates at 5.24 GHz, having a co-polarization peak gain of 4.5 dB and total isolation of 27 db. The proposed MPA shows compactness of 420 MHz by resonating at 4.82 GHz with total isolation of 44 db. The XP levels fall below 17 dB in H-plane when compared to the conventional configuration. The fabrications of proposed and conventional prototypes are done using the substrate FR4 epoxy whose dielectric constant is 4.4 and thickness of 1.6 mm. The simulation results go hand in hand with the experimental data.

Keywords: Antenna radiation patterns, Cross-polarization, HFSS, Defected Ground Structure, Isolation and Microwave Integrated Circuits

1. Introduction

Microstrip patch antenna (MPA) has been widely used for most of the wireless applications due to their attractive features like low cost, lightweight, compatibility to MMIC, easy fabrication and broadside radiations. The MPA concept is presented for the first time in 1953 [1], but the first work was patented in 1970 [2] and became dominant in all wireless communication applications from 1970 onwards. The MPAs have some drawbacks such as less gain, narrow bandwidth and more XP radiation. In Probe-fed microstrip patches usually, high cross-polarized radiation pattern gets distorted due to unwanted probe radiation [3]. Its significance is more in H-plane than that of E-plane. It is not desirable in wireless applications [4-5].

Several research groups have taken an interest to suppress cross-polarized radiation from the last two decades. Recently, the DGS technique is proposed to reduce the XP radiation by Guha *et al.* achieved 5-8 dB suppression [6]. A Circular Microstrip Patch Antenna (CMPA) with single and double arc DGS investigated using different dielectric substrates. The single and double arc DGS with RT/Duriod 5870 substrate achieved 10.08 dB and 11.13 dB XP suppression is achieved. But for FR4 epoxy 11.93 dB and 14.34 dB XP suppression is achieved. In both attempts observed a small reduction in peak gain [7]. Guha and the team further carried out the work using DGS technique [8-13]. The arc-shaped DGS provides 30 dB isolation in H-plane [8]. A CMPA with two new geometrics of DGS push down XP to 5 - 7 dB compared to the normal ground plane [9]. The dot-shaped DGS was used for suppression of orthogonal fields [10]. The CMPA with annular and circular shaped DGS provides10 dB to 12 dB XP suppression [11]. The rectangular and folded rectangular DGS reduces the XP levels to -32 dB, but smaller angular coverage [12]. The control of the third harmonic of the fundamental resonance and XP suppression of 12 dB is achieved by using compact DGS-integrated feed [13]. The XP suppression of about 15 dB is achieved by circular-shaped DGS [14]. A shorted non-radiating edge rectangular microstrip antenna with modified cavity model (MCM) using different substrates achieved XP suppression of 16 dB with a total isolation of 34 dB [15]. A patch antenna with two rectangular grooves in a ground plane gives H-plane XP less than 25 dB with $+90^0$ to -90^0 directions and improves XP radiation around 28 dB near 50^0 broadside directions [16]. Linear full wavelength R-DGS gives H-plane XP fields less than −30 dB [17]. Symmetric DGS integrated RMPA has improved the XP and gives almost 17 dB principal radiation planes and achieved XP suppression [18].

Asymmetric geometry of DGS of a rectangular MPA gives more than 28 dB isolation [19]. Dumbbell-shaped defect in Rectangular patch improve polarization purity more than 30 dB [20]. Dumbbell-shaped defected patch surface investigated for different W/L suppress the cross-polarization of 27 dB [21]. A small circularly polarized (CP) patch suppresses cross-polarization in the sideways from –14.2 to –26.1 dB [22]. Defected ground structure (DGS) with 2 × 2 DGS integrated microstrip array, etched 50% of the ground plane designed in X-band show 12 dB improvements [23].

Table-1: Previously reported works and proposed MPA

Ref	f_0 (GHz)	Co-pol Gain (dB)	H-XP Levels (dB)	Total Isolation (dB)	H-XP sup (dB)
[3]	1.6	8	-20	28	-
[4]	1.8	7.3	-23	30	-
[5]	1.75	7.9	-20	28	-
[6]	3.6	7	-20	27	5-8
[7]	6.97 to 7.00	5+ for FR4 & 7+ for RT/D	-	-	11.93 (SA), 14.54(DA) for FR4 10.08 (SA), 11.13 (DA) for RT/D
[9]	6	7	-30	37	12
[11]	5.9, 10	-	-24	30	11
[15]	4.8, 7.2 & 10	7.5	-27	34	16
[19]	10	5	-30	35	20
[22]	9.77	5	-30	35	10-12
Proposed MPA	**5.2**	**4.5**	**-39**	**44**	**17**

SA-Single Arch DGS. DA-Double Arch DGS

In most of the above works, the MPA's are excited with a coaxial probe feed configuration and this will add some unwanted probe radiations, which causes high XP in H-plane. Another drawback of vertical orientation probe is not suitable or compatible with the microwave integrated circuit (MIC) applications. The MPAs fed by planar feeds comparatively gives low XP of about -23 to -24 db. But still, there is a need for improving the isolation to satisfy the needs of wireless applications.

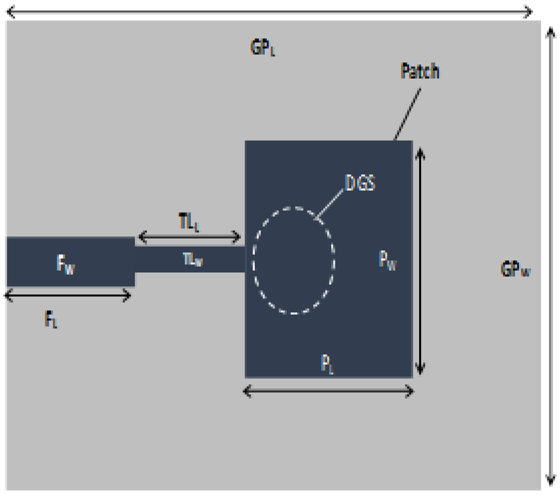
When DGS of any shape is integrated into the ground plane the current distribution is perturbated and the equivalent transmission line parameters are altered at the defected region. By optimizing the shape and its position will suppresses the unwanted orthogonal resonances, which weakens the fringing field there by XP levels are pull down to improve the isolation. Or equivalently the defect in the ground plane changes the line parameters like capacitance, inductance as well as resistances of MPA. Due to changes in RLC, a resonating frequency can shift either lower side or higher side.

In this paper, a QWT-RMPA having simple circular defect within ground plane has been proposed to reduce cross-polarized radiation. The conventional configuration resonates at 5.24 GHz with a maximum gain of 4.5 dB as well as co-polarization to XP isolation is 27 db. The proposed MPA with circular DGS shifts the resonating frequency to the lower side of 420 MHz by resonating at 4.82 GHz and gives co-polarization to XP isolation of 44 db. There by the proposed configuration reduces the XP levels to 17 dB in H-plane.

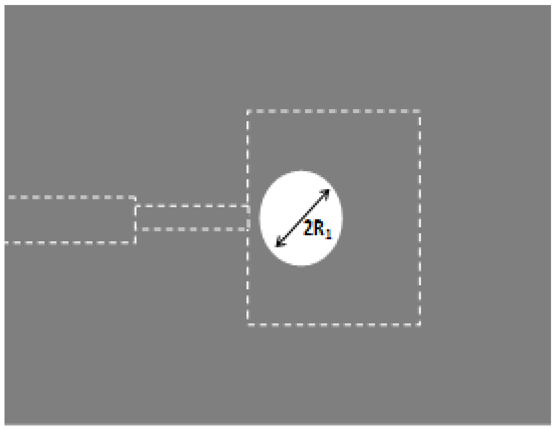
The XP levels, co-polarization peak gain and total isolation MPAs for different resonating frequency reported in the literature is shown in table-1.

2. Design Consideration

The rectangular patch antenna is designed here using Transmission Line Model (TLM) analysis and dimensions of patch are done using standard design equations [24]. The microstrip patch antenna designed should resonate at 5.2 GHz for wireless LAN (IEEE 802.11a) application. The microstrip patch antenna is configured using the substrate FR4 epoxy of ε_r = 4.4 having thickness say h =1.6 mm. The MPA being fed from a quarter-wave transformer at the centre of the radiating edge. The design and simulation are done using ANSYS HFSS Electromagnetic Simulator [25].



(a)



(b)

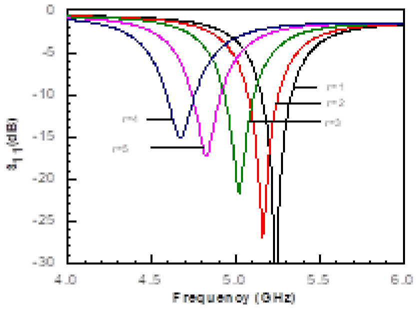
Figure-1: Schematic diagram of a proposed RMPA $GP_L = 58.94mm$, $GP_W = 35.9mm$, $P_W = 17.56mm$, $P_L = 12.56mm$, $F_L = 14.9mm$, $F_W = 3.06mm$, $TL_L = 8.3mm$, $TL_W = 0.72mm$, $R_1 = 4mm$, $\varepsilon_r = 4.4$ (a) Top appearance, (b) Bottom appearance.

A conventional rectangular microstrip patch antenna designed to resonate at 5.2 GHz through quarter-wave transformer feed. The feed and transmission line dimensions are chosen to match 50Ω. The proposed MPA consist of a circular groove of radius 'R_1' etched within ground plane as a DGS element. The schematic diagram of the top and bottom appearances of proposed MPA looks as depicted in Figure 1(a) and (b).

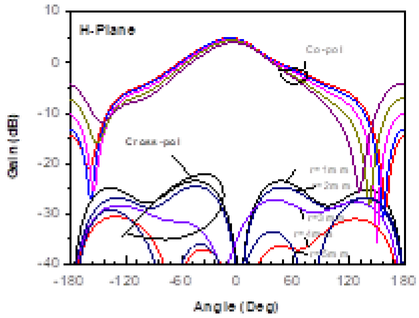
3. Antenna Simulation

3.1 Varying radius of circular DGS

The various slots of different shapes embedded in the ground plane and observed their effects through simulation. Finally, a circular slot reduced XP radiation remarkably and rigorous simulation is carried to optimize dimensions of slot. The radius of a circular one is optimized by set of simulation study and observed the effect on S_{11} and radiation characteristics. When the radius of slot R_1 = 1mm the MPA resonate at 5.23GHz with S_{11} of -33 dB and co-pol peak gain of 4.6 db. For 2 mm, 3 mm and 4 mm, resonance shift towards lower frequency, S_{11} shifting towards minima and XP levels reduced. At R_1 = 4 mm, the MPA pull-down XP levels to -39 db. Further, the radius is greater than 4 mm the MPA destroys XP suppression. The effect of S_{11} and radiation characteristics is shown in Figure-2 (a) and (b).



(a)

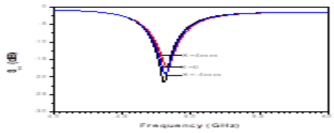


(b)

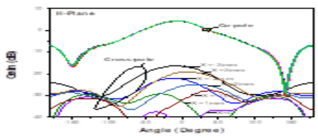
Figure-2: Simulated results due to varying radius of Circular DGS slot; (a) S_{11} characteristics, (b) H-Plane radiation characteristics.

3.2 Varying position of circular DGS

The position optimization of circular DGS slot is shifted in steps of 0.5 mm along X-axis and observed S_{11} and H-plane radiation characteristics for slot radius 4 mm. The simulated S_{11} with H-plane radiations are depicted in Figure-3(a) and (b). From the comparative plot observed that, the suppression of XP destroys along the X-axis except at X = 0 mm and there is slight alteration in return loss (S_{11}). At X= 0 mm better XP suppression is reveled.

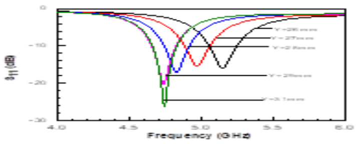


(a)

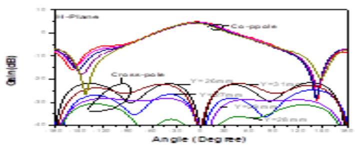


(b)

Figure-3: Simulated results due to position of DGS slot along X-axis: (a) Return loss characteristics (b) H-Plane radiations



(a)



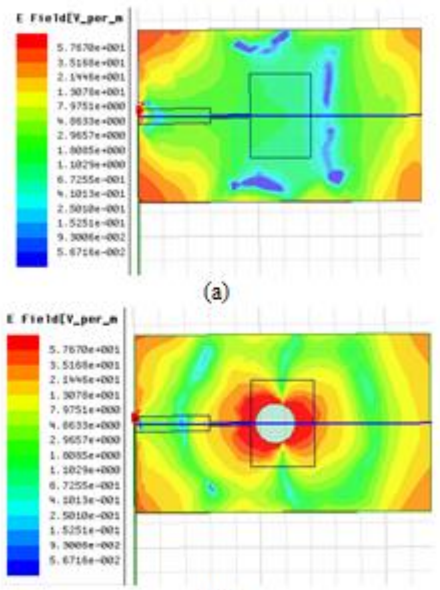
(b)

Figure-4: Simulated results due to shifting circular DGS along Y-axis (a) S_{11} characteristics. (b) H-Plane radiation.

Further, the position of circular DGS slot is shifted along Y-axis in steps of 1 mm and observed S_{11} and H-plane radiation characteristics are highlighted in Figure 4(a) -4(b). From simulation study it is found that, when the slot is at X = 0 mm and Y = 28 mm a good amount of XP suppression is achieved. After through simulation in radius and position variation of DGS slot, at slot radius 4 mm and its position (0, 28) mm the XP levels shift down to -39 dB in H-plane, which suppress the XP of about 17 dB compare to conventional configuration.

4. Working Mechanism

The working principles of RMPA are analyzed through simulation. The magnitude comparison of E-fields in the ground plane of conventional and proposed MPA are observed at 90^0 as depicted in Figure-5. It was evident that the fields concentrate more around the periphery of the circular DGS for the proposed structure and is one of the reasons for reduction in cross-polarized radiation. The magnitude of electric-field after simulation is observed for both types of structures on the radiating patch surface as illustrated in the Figure-6. It clearly indicates that due to circular DGS slot the E-field magnitude is disturbed and varies sinusoidally over the entire patch. This structure which is proposed one exhibits maximum-intensity electric fields at the edges which does not radiate when compared to conventional configuration, which lowers the cross-polarized radiation for proposed one.



(a)

(b)

Figure-5: E-field's magnitude on the ground plane (a) conventional MPA at 90^0, (b) proposed MPA at 90^0

For further corroboration, the Figure-7 depicts vector current distribution in the ground surface. The observation shows that the current on the surface in proposed MPA significantly perturbed as a result of the circular DGS.

The behavior of rectangular MPA having circular slot within ground structure is studied through optimization. The circular DGS slots behave like XP suppressor by weakening the orthogonal components of E-fields. The shape and size of the imperfection in ground plane will disturb the shielding current distribution and reduce fringing effect, there by XP levels are shifted down compared to the basic structure.

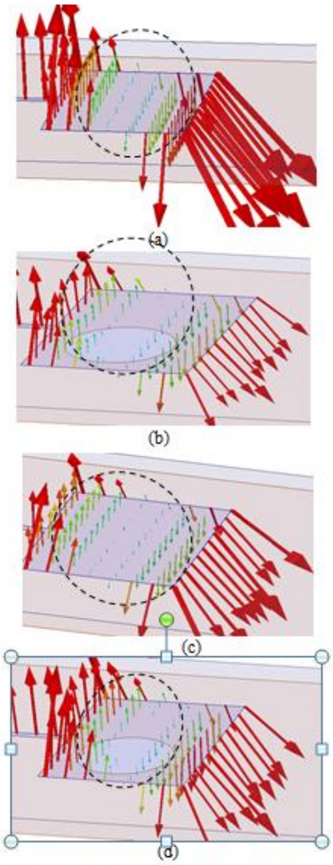


Figure-8: Field portrays of E-field patterns of conventional and proposed MPA (a) conventional at 90⁰ b) proposed at 90⁰ (c) conventional at130⁰. (d) Proposed at 130⁰.

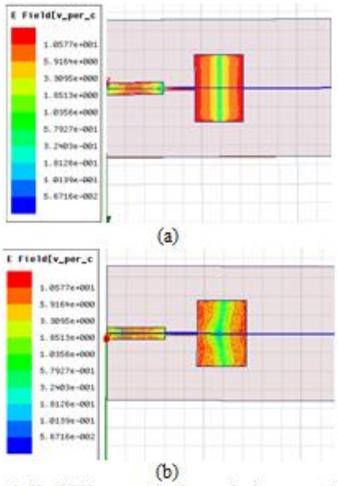


Figure-6: E-field's magnitude variation on radiating patch (a) conventional MPA at 90⁰, (b) proposed MPA at 90⁰

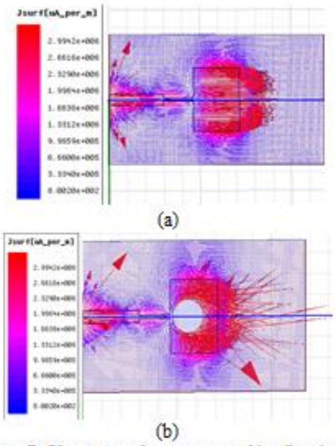


Figure-7: Vector surface current distribution on ground plane (a) conventional MPA at 40⁰, (b) proposed MPA at 40⁰

The fact can be observed in the simulated E -field portrays of model electric fields of conventional and proposed MPA configurations at different phase angles. Figure-8 (a) and (c) shows the field distribution of conventional configuration. From Figure-8 (a) and (c), we observe fields that are not strong enough over YZ-plane particularly, i.e., orthogonal to the principal plane of resonance. These fields are the main source of XP radiations in the MPA. These weak fields are vertically polarized in nature, results no radiation along the broadside and produce oblique radiation in H-plane causing high XP radiation. In the proposed configuration the circular groove within ground plane helps to confine current distribution within the patch area and reduces fringing fields by reducing the fringing current across the edges that are radiating. This enhances the radiation in H-plane as depicted in Figure-8 (b) and (d). This defect in turn influences change in resistance, capacitance, and inductance of an MPA, due to which producing shift, in resonance and impedance matching.

5. Simulated Results

The Figure-9 depicts simulated reflection coefficient and radiation characteristics of conventional and proposed MPA configurations. The reflection coefficient plot of the conventional MPA is resonating at the intended resonating frequency, 5.24 GHz with a good return loss of about -30 dB. Due to circular DGS the S_{11} of proposed MPA shifting the resonance towards the lower side 4.82 GHz with return loss -18 dB and is a good symptom of miniaturization. The Figure-9 (b) shows the H-plane radiation having XP suppression of about 17 dB in the proposed configuration when compared to the conventional configuration. The H-plane XP levels are at -39 dB for proposed configuration instead of -22 dB for conventional MPA. The Figure-9 (c) shows E-plane radiation characteristics of conventional and proposed MPA. The XP levels of E-plane are also suppressed considerably without changing co-polarized peak gain.

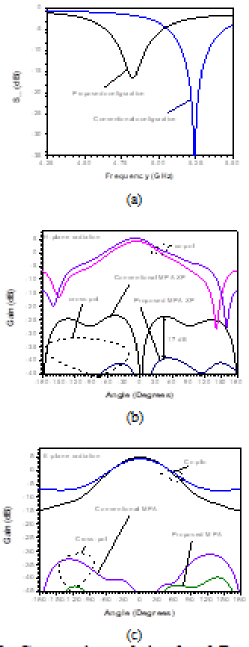


Figure-9: Comparison of simulated Results (a) S_{11} characteristics. (b) H-plane radiation characteristics, (c) E-plane radiation characteristics.

The reactance of MPA's is analyzed through smith chart shown in Figure-10. Due to loading of DGS slot, the inductive loading has been revealed for the proposed configuration. As a proof, when radius of DGS element changes from 1 mm to 4 mm the MPA resonating frequency moves from bottom half of smith chart to upper half. The resistance of the MPA is nearly equal to characteristics impedance $Z_0 = 50\Omega$.

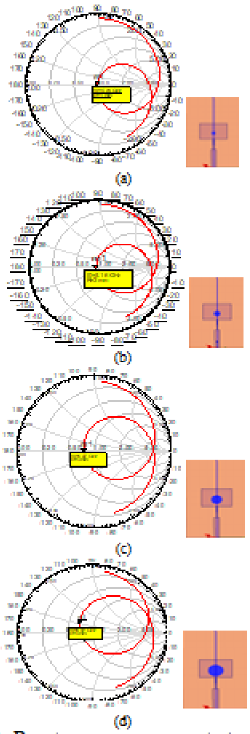


Figure-10: Reactance measurement at resonating frequency through Smith chart due to radius of circular DGS variation (a) R=1 mm (b) R=2 mm (c) R=3 mm (d) R=4 mm.

6. Prototypes And Experimental Verification

The prototypes of conventional and proposed rectangular patch antennas are fabricated using commercially available FR4 substrate, the top and bottom view of proposed configurations are shown in Figure-11. The experimental setup for the measurement of S_{11} using Agilent Technologies, N5230A vector network analyzer is shown in Figure-11 (c) and the radiation measurement in automatic anechoic chamber setup shown in Figure-11 (d).

The measured S_{11} of the conventional and proposed MPA configurations is as shown in Figure-12 (a). The comparative plot reveals the same as simulation study. The circular DGS slot resonating frequency shift towards lower side. Similarly, the radiation characteristics comparison over the principal planes has been accomplished and the results are presented in Figure-12 (b) and (c). For the comparison and better understanding, the E-plane radiations shown in Figure-12 (c), observed no change in peak co-pol, but suppression in XP radiation. The aim is to

suppress H-plane XP and because of a circular slot, XP is pull-down from -22 dB to -39 db. As a result, XP suppression of 17 dB with total isolation of 44 dB is achieved.

7. Conclusion

A rectangular patch antenna with a circular defected ground plane using a quarter-wave transformer feed is proposed for reducing cross-polarized radiation to achieve a good separation between co-polarization to cross-polarization radiation. A circular DGS slot in the proposed MPA gives 17 dB XP suppression compared to conventional MPA with total isolation of 44 dB achieved in H-plane. This high isolation planner feed MPAs are useful for high-quality sensors and wireless communication applications.

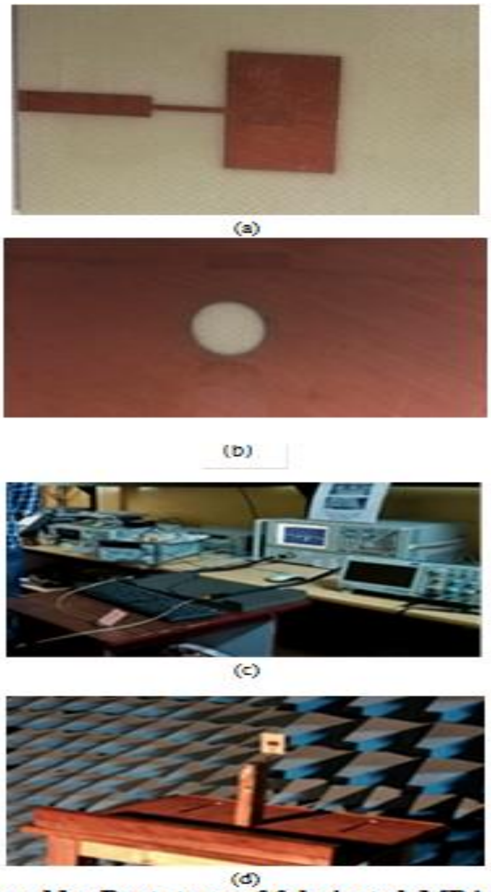


Figure-11: Prototype of fabricated MPA and Measurement setup (a) Top view (b) bottom view (MPA's are depicted without SMA connector), (c) Measurement of S_{11}, (d) Radiation's measurement in anechoic chamber.

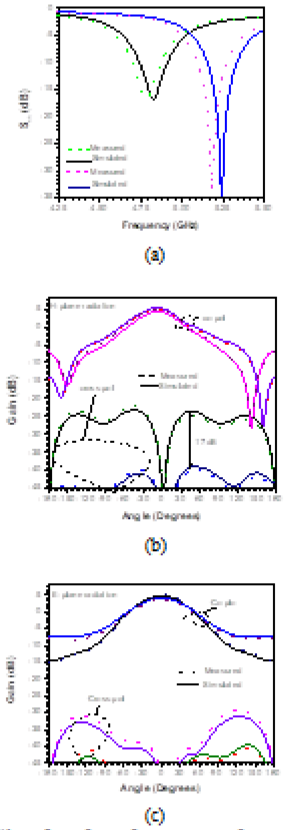


Figure-12: Simulated and measured results (a) Return loss characteristics. (b) H-plane radiation characteristics, (c) E-plane radiation characteristics.

8. Acknowledgement

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References

1. G. A. Deschamps, "Microstrip Microwave Antennas," Presented at the third USAF Symposium on Antennas, 1953.
2. R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, "Microstrip Antenna Design Handbook", Norwood, MA: Artech House, 2001.
    A. Petosa, A. Ittipiboon and N. Gagnon, "Broad Suppression of unwanted probe radiation in wideband probe-fed microstrip patches," Electronic letters 4th March 1999, Vol. 35, No. 5, pp355-357
3. T. Chiou and K. L. Wong, 'Broad-Band Dual-Polarized Single Microstrip Patch Antenna with High Isolation and Low Cross Polarization', IEEE Transactions on Antennas and Propagation, VOL. 50, NO. 3, pp 399-402, MARCH 2002
4. P. Li, H. W. Lai, K. M. Luk and K. L. Lau, "A Wide band Patch Antenna with Cross-Polarization Suppression," IEEE Antennas and Wireless Propagation Letters, 3, 2004, pp. 211- 214.
5. D. Guha, M. Biswas, and Y. M. M. Antar, "Microstrip patch antenna with defected ground structure for cross polarization suppression," IEEE Antennas Wireless Propag. Lett., vol. 4, pp. 455–458, 2005.
6. Arnab Nandi and Ashim Kumar Biswas, "Suppression of Cross-Polarized Radiation for Circular Patch Antenna using Different Substrates and Defected Ground Structures". Proceedings of 2017 Asia Pacific Microwave Conference, 978-1-5386-0640-7/17$31.00 © 2017 IEEE, pp 576-579.
7. D. Guha, C. Kumar and S. Pal, 'Improved Cross-Polarization Characteristics of Circular Microstrip Antenna Employing Arc-Shaped Defected Ground Structure (DGS)' IEEE antennas and wireless propagation letters, vol. 8, pp 1367-1370, 2009.
8. C. Kumar and D. Guha, "New Defected Ground Structures (DGSs) to Reduce Cross-Polarized Radiation of Circular Microstrip Antennas," Applied Electromagnetic Conference AEMC2009, Kolkata, India, 2009, pp. 1-4.

9. C. Kumar and D. Guha, "A New Look Into the Cross Polarized Radiation Form of a Circular Microstrip Antenna and Suppression Using Dot-Shaped DGS," IEEE AP-S Symposium, Toronto, 2010.
10. C. Kumar and D. Guha, "Nature of Cross-Polarized Radiation from Probe-Fed Circular Microstrip Antennas and Their Suppression using Different Geometries of Defected Ground Structure (DGS)," IEEE Trans. Antennas Propag. AP-60, 1, January 2012, pp. 92-101.
11. C. Kumar and D. Guha, " Modulation of Substrate Fields: Key to Realize Universal DGS Configuration for Suppressing Cross-Polarized Radiations from a Microstrip Patch Having any Geometry," 978-1-4673-0462-7/12/$31.00 ©2012 IEEE.
12. S. Biswas, D. Guha, and C. Kumar, “Control of higher harmonics and their radiations in microstrip antennas using compact defected ground structures,” IEEE Trans. Antennas Propag., vol. 61, no. 6, pp. 3349–3353, June 2013.
13. M. K. Khandelwal, B. K. Kanaujia, S. Dwari, S. Kumar and A.K. Gautam, “Analysis and design of wide band Microstrip-line-fed antenna withdefected ground structure for Ku band applications” Int. J. Electron. Commun. (AEÜ) 68 (2014) 951–957.
14. D Ghosh, S K. Ghosh, S Chattopadhyay, S Nandr, D Chakrabortyt, R Anand, R Rajt, and A Ghosh, “Physical and Quantitative Analysis of Compact Rectangular Microstrip Antenna with Shorted Non-Radiating Edges for Reduced Cross-Polarized Radiation Using Modified Cavity Model” IEEE Antennas and Propagation Magazine, Vol. 56, No.4, August 2014.
15. A Ghosh, Dia Ghosh, S Chattopadhyay, and L. L K Singh, “Rectangular Microstrip Antenna on Slot-Type Defected Ground for Reduced Cross-Polarized Radiation”, IEEE Trans. Antennas Propag., vol. 14, 2015.
16. C Kumar and D Guha, “Reduction in Cross-Polarized Radiation of Microstrip Patches Using Geometry-Independent Resonant-Type Defected Ground Structure (DGS)”, IEEE Trans. Antennas Propag., vol. 6, JUNE 2015
17. M I Pasha, C Kumar, and D Guha, “Rectangular Microstrip Patch with Symmetrically Shaped Defected Ground Structure for Improved Cross-Polarization Characteristics”, 978-1-4673-9536-6/15/$31.00 ©2015 IEEE.
18. C. Kumar and D. Guha, ‘Asymmetric Geometry of Defected Ground Structure for Rectangular Microstrip: A New Approach to Reduce its Cross-Polarized Fields’, IEEE Trans. Antennas Propag, vol. 64, no. 6, june 2016
19. S Chakraborty, A Ghosh, S Chattopadhyay, and L. L Kumar Singh, “Improved Cross-Polarized Radiation and Wide Impedance Bandwidth from Rectangular Microstrip Antenna with Dumbbell-Shaped Defected Patch Surface”, IEEE Trans. Antennas Propag, vol. 15, 2016.
20. A Ghosh, S Chakraborty, S Chattopadhyay, A Nandi and B Basu, “Rectangular microstrip antenna with dumbbell shaped defected ground structure for improved cross polarised radiation in wide elevation angle and its theoretical analysis” IET Microw. Antennas Propag., 2016, Vol. 10, Iss. 1, pp. 68–78 & the Institution of Engineering and Technology 2016.
21. Xi Chen, Dan Wu, Long Yang, and Guang Fu, “Compact Circularly Polarized Microstrip Antenna with Cross-Polarization Suppression at Low-Elevation Angle”, IEEE Trans. Antennas Propag, vol. 16, 2017.
22. C Kumar, M I Pasha, and D Guha, “Defected Ground Structure Integrated Microstrip Array Antenna for Improved Radiation Properties” IEEE Trans. Antennas Propag, vol. 16, 2017.
23. C.A. Balanis, “Antenna theory analysis & design”, 2nd Ed., John Wiley & sons, inc., 2005, New York.
24. High frequency structure simulator (HFSS), Ansoft, v 15.0