Improved Isolation in a Rectangular Microstrip Patch Antenna with defected Ground Plane and Patch using coaxial probe fed for wireless LAN Application

[1]Murthi Mahadeva Naik G, [2,3]Naveen Kumar S K, [4]Meghavarshini S K, [4]Soujanya N S
[1]Associate Professor, [2,3]Professor, [4]PG Students
[1]Department of ECE, Malnad College of Engineering, Hassan, Karnataka, India-573202
[2]Department of Electronics, Mangalore University, Mangalore, Karnataka, India-573202
[3]Department of Electronics, University of Mysore, Hemagangothri PG center, Hassan, Karnataka, India-573201
[4]PG Students, Department of Electronics and Communication, Malnad College of Engineering, Hassan, Karnataka, India-573202

Abstract: A Microstrip Patch Antenna (MPA) with defected ground plane and patch to improve isolation between co-polarization to cross-polarization (XP) radiation is proposed. The proposed MPA consists of two rectangular slots as DGS elements in the ground plane and one circular slot/dot etched near the probe on the patch. Due to these elements, the proposed MPA reduce the cross-polarized (XP) radiation up to 20 dB to provide higher isolation without affecting the dominant mode input impedance and co-polarized radiation pattern of a conventional MPA. The conventional MPA is designed with a centre frequency of 5.2 GHz with a coaxial probe feed using dielectric substrate FR4 epoxy having dielectric constant $\varepsilon_r = 4.4$ and thickness h = 1.6mm. The proposed MPA resonates at 5.04 GHz with a bandwidth of 240 MHz and having S_{11} of -14 dB. The XP level of proposed MPA is shifting form -20 dB to -40 dB over -65^0 to 65^0 by suppressing XP of 20 dB compare to conventional configuration. The proposed MPA achieves an total isolation of almost 45 dB from co-pol peak gain to cross-pol cross-pol radiation.

IndexTerms - Microstrip Patch Antenna, Cross Polarization, Defected Ground Structure, Defected Microstrip Surface, Circular microstrip patch antenna, Isolarion.

I. INTRODUCTION

Microstrip patch antennas are widely used in the field of wireless communication for their compact size, low cost, flexibility, efficiency, easy to fabricate etc. Microstrip patch antenna (MPA) is resonating in its fundamental $TM_{n,m}$ mode and radiates in linearly polarized fields aligned in a plane of reference as E-plane. But some degree of orthogonally polarized fields is always associated with the radiating energy, resulting in cross-polarized (XP) radiation. The antenna parameter like, gain, bandwidth, XP levels, return loss etc. are improved by structural modification of conventional MPA. The modification may be by etching slots in ground plane or radiating patch or shorting pins and etc. There are various research groups working in the field of microstrip antenna by using different techniques such as thicker substrate, reducing the dielectric constant, gap coupled multiple resonators, loading the patch and ground plane etc. The use of thicker substrate causes low power and low efficiency, high Q*;* poor scan performance, lower polarization purity [1].The rectangular microstrip patch antenna with RT duroid-5880 reported an Isolation of about 20dB between Co-polarization and Cross polarization level. The XP levels are below -35dB and -20dB in H-Plane and E-Plane respectively [2]. Introduction of circularly symmetrical slot near the co-axial feed location of corner truncated square Microstrip patch antenna is designed, here both the circular polarization and harmonic suppression performance can realize. The MPA suppressed more than 10-20dBi at second and third harmonic frequencies [3].

The multilayer is built by laminates and prepress of the RO4350B substrate system from Rogers Corporation, possessing a measured relative permittivity ε_r of 3.8 to 3.9 at 77GHz. A symmetric and homogeneous radiation patterns in amplitude and phase with low cross polarization is proposed [4]. A rectangular microstrip patch using a thin copper strip of thickness 0.1 mm was designed with Taconic's TLY-3-0620 PTFE substrate with $\varepsilon_r = 2.3$ at 9.07GHz, The investigation was repeated on the same patch with glass substrates with dielectric constants $\varepsilon_r = 5.5$ and $\varepsilon_r = 1.0$ operating at 5.90GHz and 12.80GHz respectively and reports a good amount of XP suppression with the present MPA [5]. A simple and compact rectangular microstrip antenna with circular arc defected patch surface is proposed for significant suppression of cross polarized (XP) radiation and improved polarization purity and 25dB of XP radiation isolation from Co-polarized radiation is revealed [6]. A linearly shaped full wavelength (R-DGS) resonant type defected ground structure has been reported suppression of the H-plane XP fields well below -30dB for different patch geometries [7].

Defected ground structure (DGS) approach for designing almost all kinds of printed and dielectric resonator antennas. DGS describing dumbbell shaped defect and since then it was primarily known for circuit applications. DGS was first integrated with a planar antenna in 2005 especially to control its radiation properties and a series of subsequent investigations explored its strength and possibilities [8].Cross headed dumbbell defected rectangular microstrip patch antenna with probe feed operating at frequency band range 10.15GHz and 9.66GHz respectively, eliminates higher order orthogonal resonance without altering its dominant mode field configuration and achieved more than 28dB of XP radiation isolation from peak Co-polarized radiation in H-plane and E-plane [9]. Differential fed patch antenna array was developed using Low Temperature Co-feed Ceramic (LTCC) multilayer technology with high gain and low cross polarization level. Antenna elements constructed by radiation patches and L-shaped feeds. Coaxial feed suppress the surface wave, enhanced the gain and radiation performance. This antenna array achieves cross polarization level lower than -35dB in both E-plane and H-plane respectively [10]. Symmetric-DGS integrated rectangular microstrip patch antenna was designed using RT5870 substrate achieved 17dB suppression in H-plane XP level [11]. Rectangular microstrip Patch antenna (RMPA) with L-shaped DGS suppresses the XP radiation more than 15dB [12].

Rectangular patch with dumbbell-shaped defected patch surface was designed using RT5870 substrate achieves more than 30dB Co-to Cross polarization ratio over entire angular range around the broadside direction with wide impedance bandwidth is is reported [13]. The XP fields are more significant in H-plane than in E-plane asymmetrically shaped DGS for the first time and have demonstrated several improved features in terms of performance and size compared to its earlier versions: 1) maximum suppression spanning over the widest angle around the bore-sight; 2) smallest in size among all DGSs that are capable of suppressing over 10 dB; and 3) works over entire ϕ-plane. Specific investigation has been carried out to excite the TM02 mode in the patch resulting in a strong radiation with 2.4-dBi peak gain and pattern resembling the H-plane XP radiation. For RMPA with W/L=1.6 and around 17-24dB of Co-XP isolation is observed [14]. Asymmetrical DGS and different orientations of the defects with reference to the patches of different aspect ratio achieved more than 28-dB isolation between Co-polarization and Cross polarization has been achieved over 190^0 angle range [15].

Complementary opening defect microstrip structure (CODMS) microstrip patch antenna with Arlon AD255A(tm) substrate having two rectangular ring slots with opposite direction of short side opening suppress the higher order harmonics of about 15dB in both E-plane and H-plane [16]. Circularly polarized microstrip antenna using FR4 substrate with relative permittivity ϵ_r= 4.4, a compact mean du-line ring cavity (MLRC) structure is introduced, which can reduce the cross polarization from -14.2dB to 26.1dB in horizontal direction and increase 3dB axial ratio is reported [18]. A 2x2 defected ground structure integrated array has been designed using RT5870 substrate for X-band shows 12dB improvement in isolation between the co-polarization and cross polarization radiations [19]. To suppress the mutual coupling between two patch antennas a parasitic isolator is printed between the two patches to control the polarization of the coupling field to reduce the cross polarization level. It is designed using FR4 epoxy substrate and achieved isolation and XP level are 19.6dB and -13.2dB respectively [20]. A polygon shaped microstrip patch antenna array with FR4 epoxy substrate reduces the mutual coupling of about 2.2dBwith a gain 6dBi [21].

In this paper we propose a rectangular microstrip patch antenna defected with two rectangular slots etched in the ground plane and a circular small dot near the probe on the patch is etched to provide higher isolation between co - pol to cross – pol by suppressing XP radiation without affecting the co-polarized radiation pattern. The proposed configuration gives an isolation of 45 dB by suppressing 20 dB XP radiation.

II. ANTENNA CONFIGURATION

The geometry of conventional and proposed rectangular microstrip patch antenna is shown in figure-1. The MPA designed to resonate at 5.2 GHz with a coaxial probe feed using FR4 epoxy substrate having dielectric constant ε_r = 4.4 with thickness h=1.6mm. The conventional MPA is defected with two rectangular slots of dimension (S_L X S_W) etched at a equal distance from either side of X – axis in the ground plane and a circular slot/dot etched on the patch near the probe of radius 'R'. The figure-1(a)

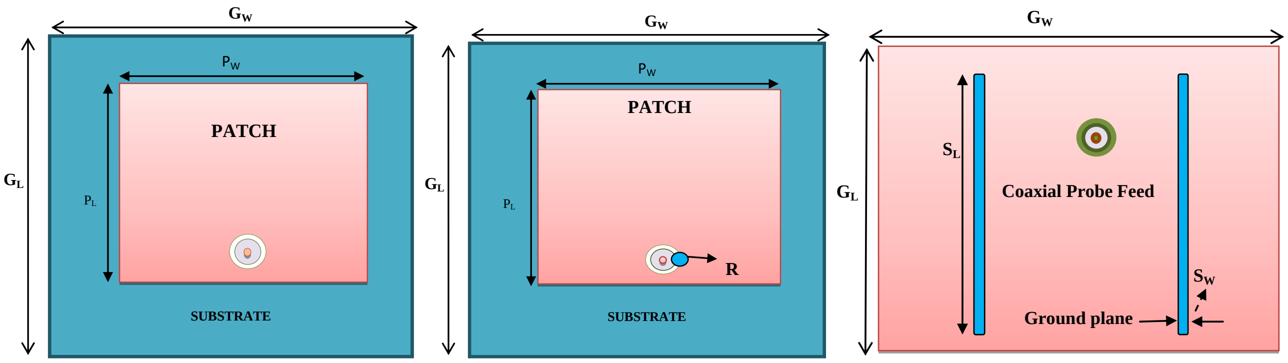


Figure-1: Schematic diagram rectangular microstrip patch antenna with coaxial feed (a) Conventional MPA, (b) top view of Proposed MPA, (c) Bottom view of Proposed MPA.

shows conventional configuration, figure-1 (b) and (c) shows the top and bottom view of proposed configuration. The dimension of patch and ground plane is shown in table-1.

III. ANTENNA DESIGN PROCEDURE

The rectangular misrostrip patch antenna is designed to resonate at 5.2 GHz for wireless LAN application with an intention of providing good isolation between co-pol and cross-pol radiation. The conventional microstrip antenna with h<< P_L and h<< P_W, the patch dimensions are decided using the following design equations. For dominant mode TM_{10}, the resonant frequency is a function of patch length and is given by,

$$f_r = \frac{C}{2L\sqrt{\varepsilon_r}} \qquad (1)$$

Where 'c' is velocity of light, 'f_r' is resonant frequency, 'ε_r' is the effective dielectric constant of the substrate. The width of the patch is,

$$W = \frac{C}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (2)$$

Due to fringing fields, the effective dielectric constant of microstrip line ε_{reff} is,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (3)$$

Where 'h' is height of substrate.

The fringing length of the patch is approximated as ΔL is given by,

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} + 0.258)\left(\frac{w}{h} + 0.8\right)} \quad (4)$$

The effective length of the patch (L_{eff}) is,

$$L_{eff} = L + \Delta L \quad (5)$$

Finally the resonating frequency with fringing effect is given by.

$$f_0 = \frac{C}{2\,L_{eff}\sqrt{\varepsilon_{reff}}} \quad (6)$$

The fringing factor $q = \frac{f_0}{f_r}$ (7)

As the substrate height increases the fringing also increases and leads larger separation between radiating edges and lower

Discription	Dimension (mm)
Width of the Patch(P_w)	17.6
Length of the Patch (P_L)	13.2
Width of Ground Plane (G_W)	27.2
Length of Ground Plane (G_L)	22.8
Optimized slot dimension	
Slot Width S_W	0.21
Slot Length S_L	22
Circle radius	0.5
Thickness of copper	0.03

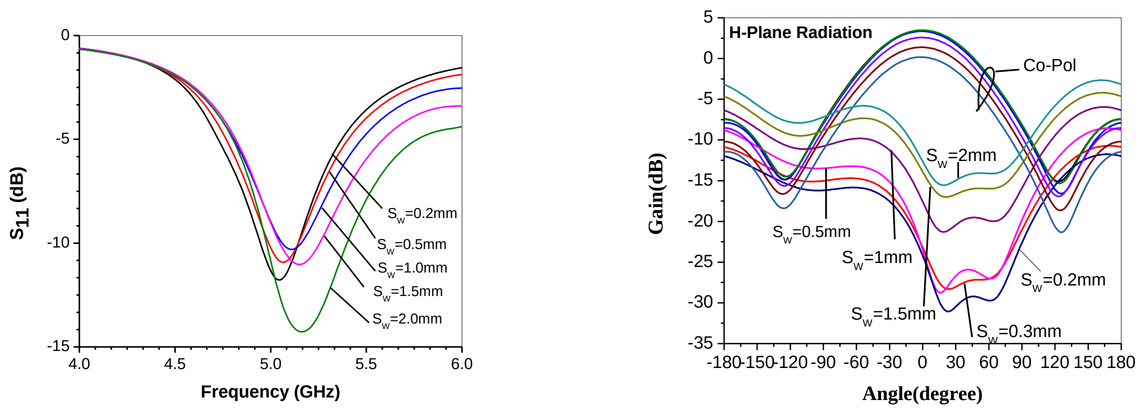
Table-1: Dimension of conventional and proposed MPA

resonating frequencies. So as to reduce the fringing effect a smaller thickness substrate is preferred.

IV. OPTIMIZATION.

(1). Slot width variation:

The conventional configuration is designed for a resonating frequency of 5.2 GHz using FR4 epoxy substrate having dielectric constant $\varepsilon_r = 4.4$ and thickness h = 1.6mm. The designed MPAs are simulated using HFSS v15.0 [22]. The simulated conventional

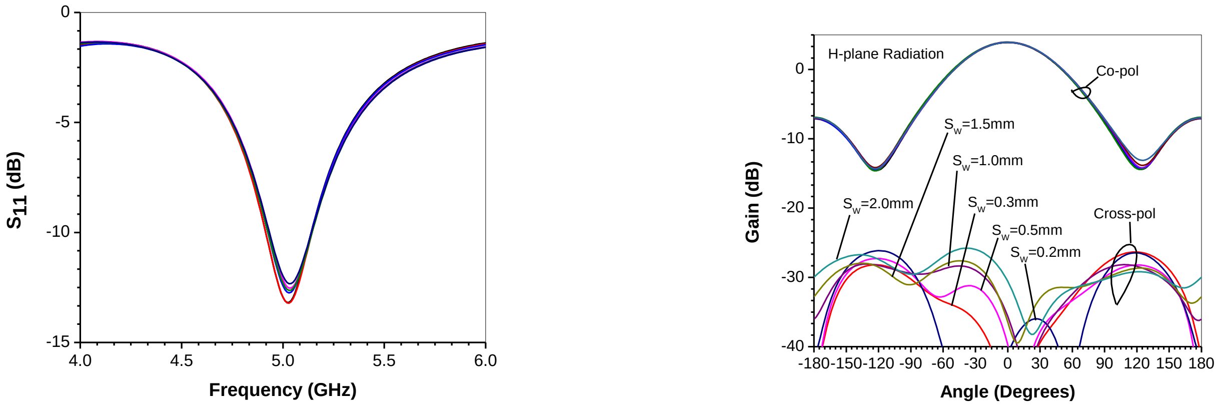


(a) (b)

Figure-2: Simulated return loss and H-plane radiation characteristics due to one rectangular slot width variation (a) Return loss, (b) H-plane radiation.

configuration resonates at 5.05 GHz with a bandwidth of 250 MHz and having impedance matching of -17 dB. The conventional MPA shows broadside radiation with co-pol peak gain of 4.4 dB and XP levels are symmetric at -20 dB.

The conventional configuration is defected with one rectangular slots etched in ground plane at a distance of λ/8 from edge of the X – axis of length λ/2.5 and its width is varied. The return loss and H-plane radiation is shown in figure-2. From figure-2(b), as slot width increases the XP level shifts up but at S_W = 0.2mm reports -32 dB XP with a narrow angular coverage of 0^0 to 50^0. As XP level is at -32 dB over 0^0 to 50^0 to widen the angular coverage another rectangular slot etched in the ground plane at a distance of -λ/8 from edge of the X – axis of length λ/2.5 and its width is varied with the presence of first slot. The S_{11} and H-plane radiation characteristic is shown in figure-3. The figure 3(a) shows return loss characteristics due to variation of width of only the second slot and observed that there is no change in resonance, bandwidth but small changes in matching. The figure-3(b) shows H-plane radiation characteristics and observed that the XP level -30 dB over wider angular coverage from -100^0 to 100^0. At S_W = 0.2 mm the XP level is -33 dB over the coverage angle -60^0 to 60^0.



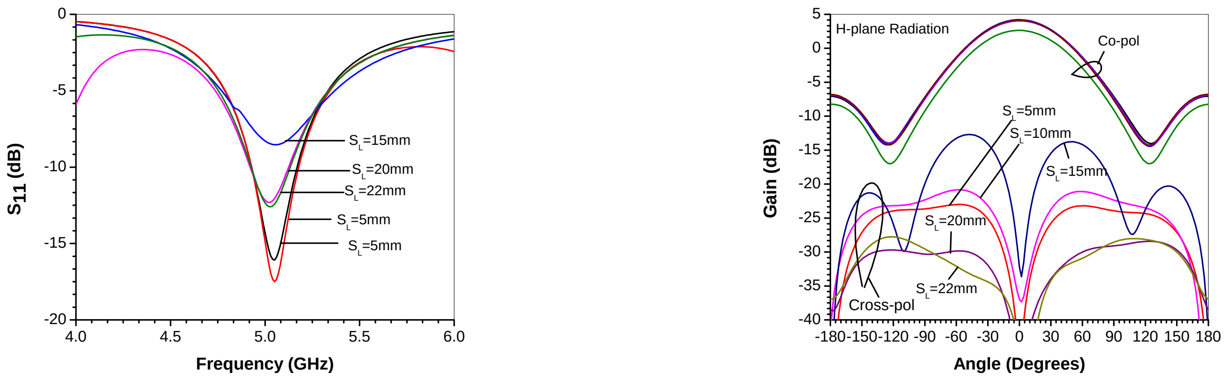
(a) (b)

Figure-3: Simulated return loss and H-plane radiation characteristics due to variation of width of the second slot by fixing the first slot (a) Return loss, (b) H-plane radiation.

(2). Slot length variation:

The width of the slots varied individually and observed the effect on S_{11} and radiation characteristics. The width of the slot is fixed at 0.2mm and observed that the XP level is at -33 dB over -60^0 to 60^0. For further optimization the length of both slots are varied and observed the effect on S_{11} and H-plane radiation characteristics is shown in figure-4.

The figure-4(a) shows, as length of the slots decreases, higher impedance matching is achieved due to resistance of the MPA is closer to the characteristic impedance of 50 Ω, but there is no change in LC component is observed. When length increases the resistance increases above 50 Ω and matching decreases. The resonance is neither shifting to lower nor higher frequency side, due



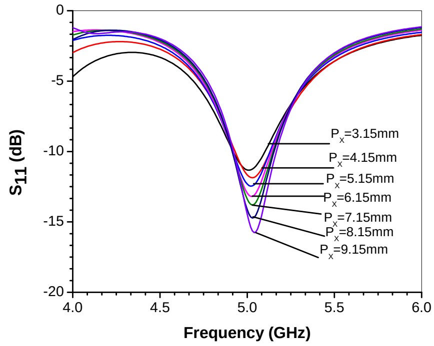
(a) (b)

Figure-4: Simulated return loss and H-plane radiation characteristics due to varying the length of both rectangular slots (a) Return loss, (b) H-plane radiation.

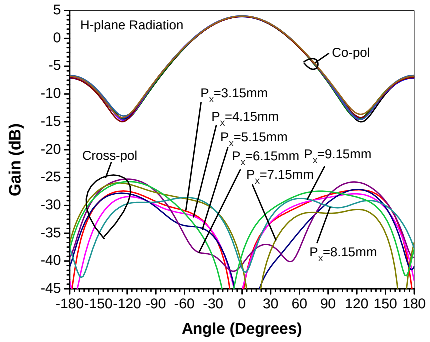
to no changes in reactance of the MPA. The figure-4(b) shows the H-plane radiation characteristics, as length of the slots varies the XP levels moves up and down. The length of the slots is at S_L=22mm the XP level is at-35 dB over -30^0 to 30^0 is observed.

(3). Slot position variation:

The dimension of both slots are finalized through optimization is (22 X 0.2) mm^2. These two slots in ground plane reduce the XP level to -35 dB, but angular coverage is from -30^0 to 30^0. In order to extend the angular coverage, the position of slots moved inward and outward from their fixed position (-6.15, -11, 0) and (6.15, -11, 0). The S_{11} plot and H-plane radiation characteristics is shown in figure-5. As the slots move away from its fixed position the S_{11} matching increases without shifting resonance, but XP level increases and slots move closure to each other the matching decreases and XP level increases again. At P_X = 6.15 mm the XP level shifts to -37 dB over angular range -70^0 to 70^0.



(a)

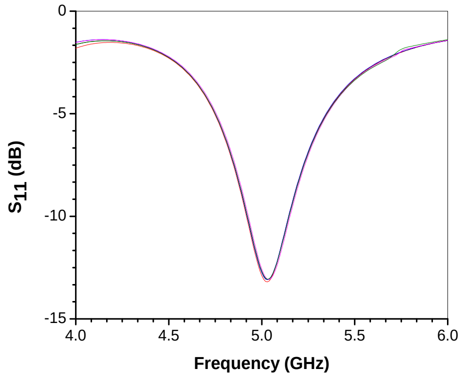


(b)

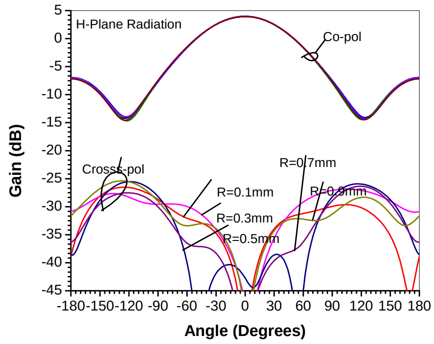
Figure-5: Simulated return loss and H-plane radiation characteristics due to varying the position of rectangular slots (a) Return loss, (b) H-plane radiation.

(4). Circular DMS slot radius variation:

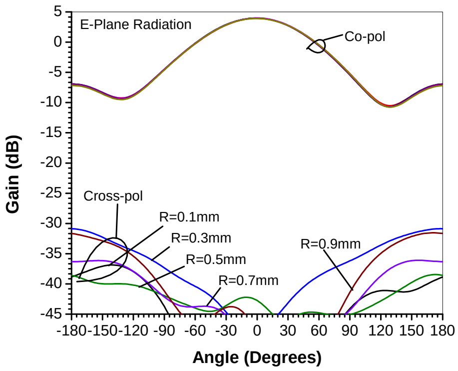
The two rectangular DGS slots etched in the ground plane and optimized their dimension, varied the position of slots and achieved XP level at -37 dB over the angular range -70^0 to 70^0. For further investigation to reduce the XP level the radiating patch is defected with circular slot, in order to make directional radiation and to disturb the shielding current the slot is etched near the probe at position (2, -3.5, 1.63).



(a)



(b)



(c)

Figure-6: Simulated return loss and radiation characteristics (a) Return loss, (b) H-plane radiation characteristics (c) E-plane radiation characteristics

The figure-6(a) shows S_{11} plot, when varying radius of circular slot etched on the radiating patch. There is no effect on S_{11}due to varying the radius of the slot. The RLC components are remains same for all the values of R. But the decrement in H-plane XP level is observed. The XP levels are at -40dB over the angular range -60^0 to 60^0 without changing co-pole peak gain is shown in figure-6(b). The figure-6(c) shows E-plane radiation characteristics and it is observed that the XP levels are below -40 dB over angular range -150^0 to 150^0 has been reported.

V. WORKING PRINCIPLES.

Figure-7 shows the electric field vector compared between conventional and proposed configuration. From figure-7, it clearly demonstrated that the field intensities at the non-radiating edges for the proposed antenna were much lower than those of the conventional patch. The conventional and proposed configuration is compared at 21^0, 51^0, 72^0 and 238^0. From the comparison, it could be noted that all other higher-order orthogonal modes that are mainly responsible for cross-polarized radiation would ideally be minimized at the non-radiating edges for the proposed antenna therefore be attributed with the reduction of the cross-polarized radiation for the proposed antenna.

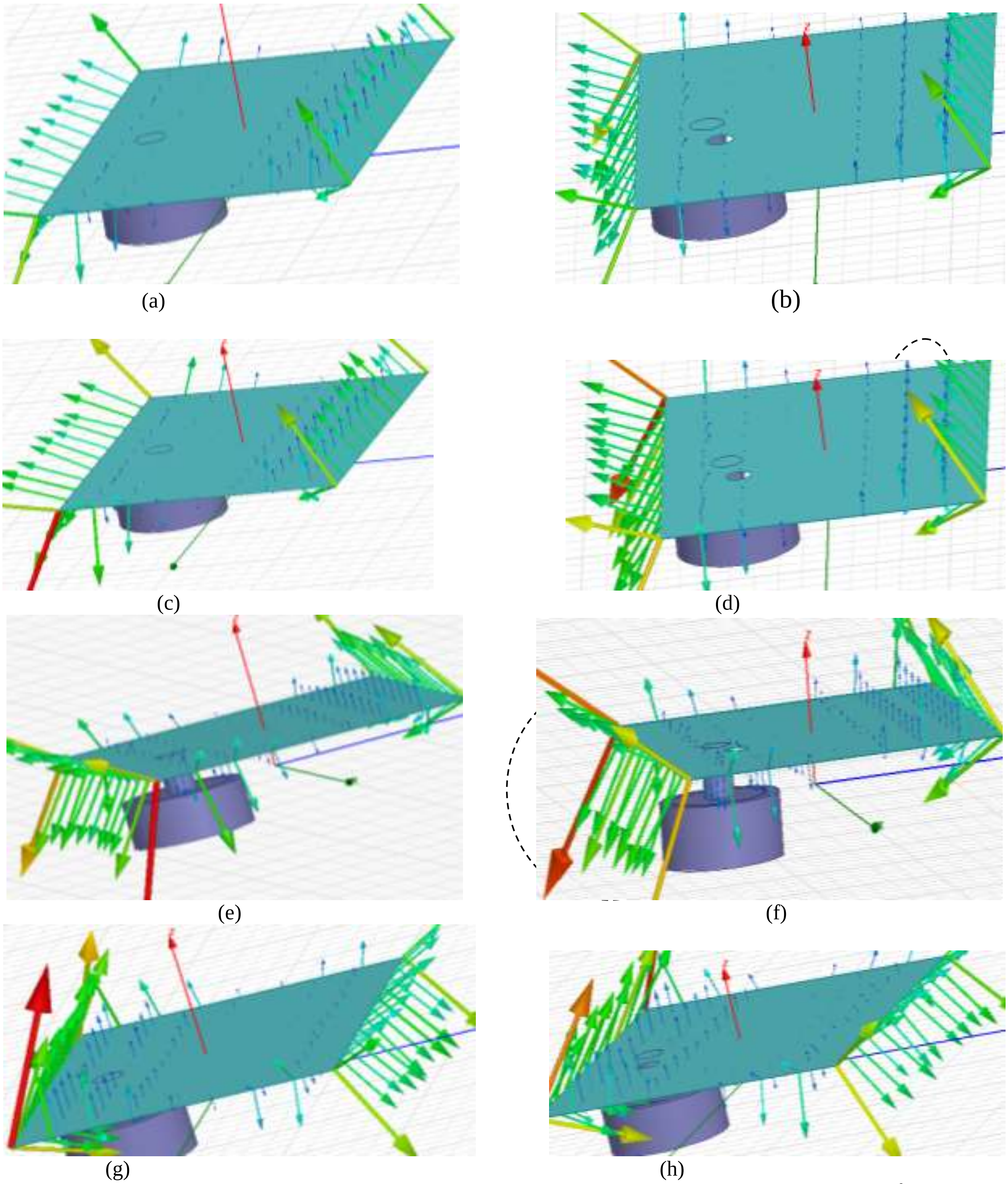
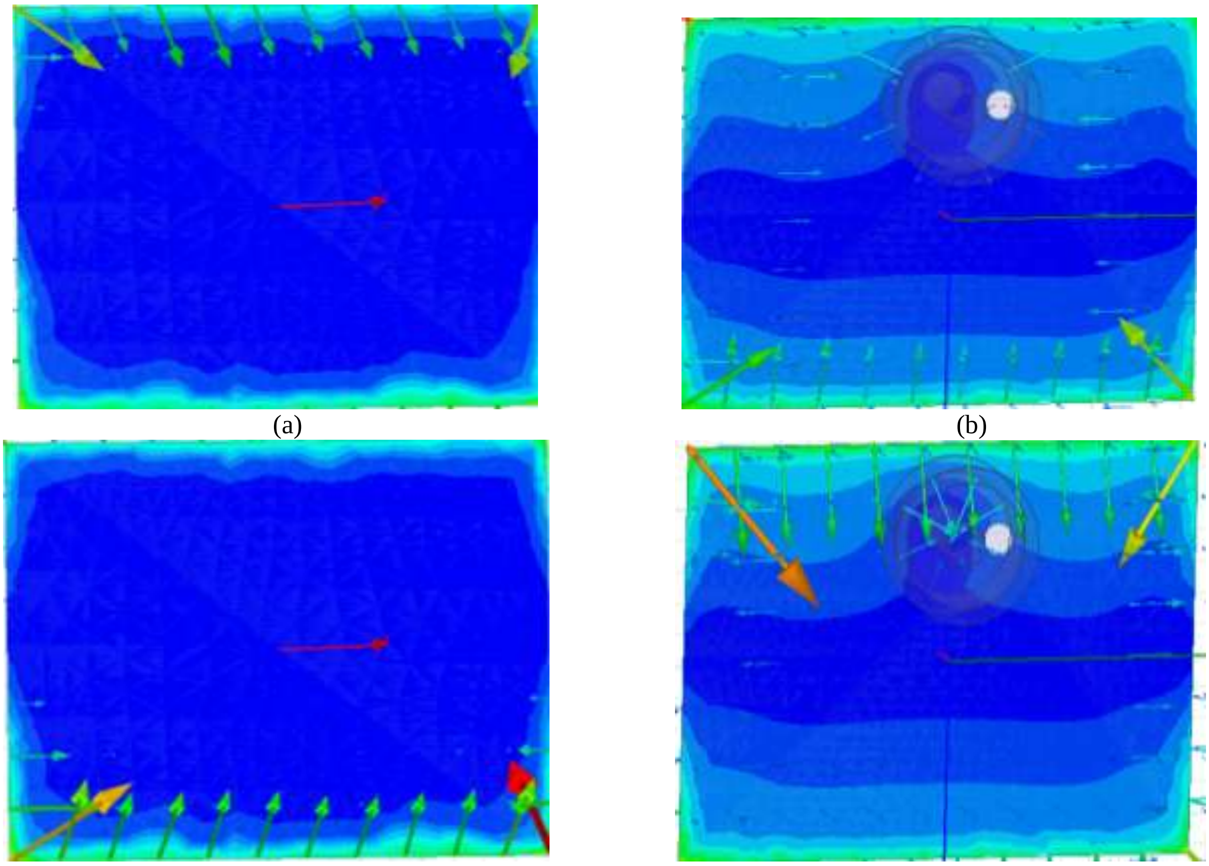


Figure-7: Simulated electric field vector of conventional and proposed configuration, (a) conventional at 21^0, (b) proposed at 21^0 (c) conventional at 51^0, (d) proposed at 51^0 (e) conventional at 72^0, (f) proposed at 72^0 (g) conventional at 238^0, (h) proposed at 238^0.

Figure-8 shows the simulated electric-field magnitude distribution along beneath of the patch surface for both types of structures. It clearly shows for conventional MPA, the electric field distribution along the length and width of the patch. But for the proposed MPA, the electric field varies along the length of the patch with different intensity. For the proposed antenna, there was only one variation along the length of the patch and no variation along the width of the patch as was evident for the conventional structure. The high-intensity electric fields that thus existed at the non-radiating edges contributed to cross-polarized radiation for the conventional patch, which was not the case for the proposed structure. The conventional and proposed configuration is compared at 55^0 shown in figure-8(a) and (b). Similarly both are compared at 234^0.



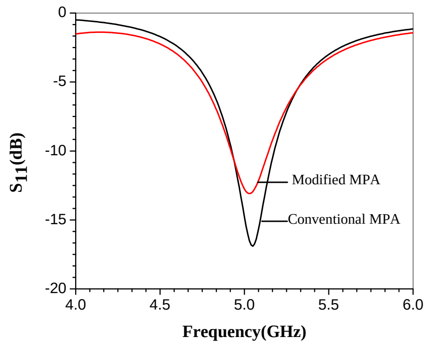
(a) (b) (c) (d)

Figure-8: Simulated Electric field distribution of conventional and proposed configuration (a) conventional at 55^0 (b) proposed at 55^0, (c) conventional at 234^0, (d) proposed at 234^0.

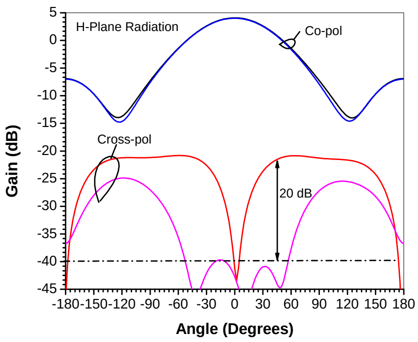
VI. RESULTS AND DISCUSSIONS.

The reflection coefficient of conventional and proposed MPA is shown in Figure-9(a). The reflection coefficient plot of the conventional MPA is resonating at 5.05 GHz with a good impedance matching of about -17 dB and having bandwidth of 250 MHz. The S_{11} of proposed MPA configuration resonates at 5.04 GHz with impedance matching of -14 dB and having bandwidth of 240 MHz. The s11 of conventional and proposed configuration parameters are almost same except due to loading of DGS and DMS slots, the inductive loading is revealed a shift in S_{11} minima. The Figure-9(b) shows the H-plane radiation, it is observed that there is XP suppression of about 20 dB in proposed configuration when compared to conventional configuration. The H-plane XP level is at -40dB over the angular range -65^0 to 65^0. Since the width of the coverage is smaller the MPA is placed at suitable height. The proposed MPA gives almost 45 dB isolation between co-pol to cross-pol. The figure-10(c) shows E-plane radiation characteristics of conventional and proposed MPA. The XP levels of E-plane are less than -40 dB over angular coverage -150^0 to 150^0 without changing co-polarized peak gain.

The impedance matching of conventional and proposed MPA are exactly same even conventional MPA defected with two rectangular slots in the ground plane and a circular slot etched in the radiating patch. The figure-10 (a) shows the resistance comparison of both MPAs. The figure 10(b) shows the admittance chart of conventional MPA and figure-10(c) shows the admittance chart of proposed MPA. The component values of conventional and proposed configuration are well matched.



(a)



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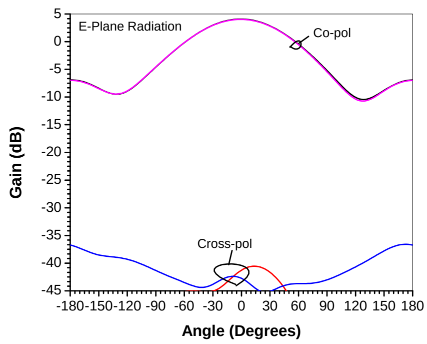
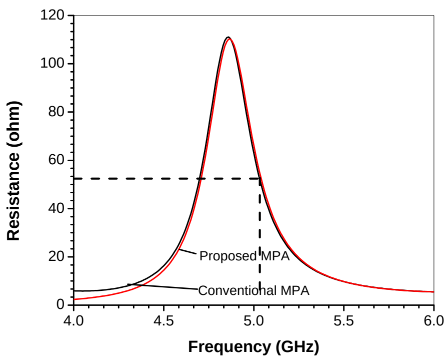
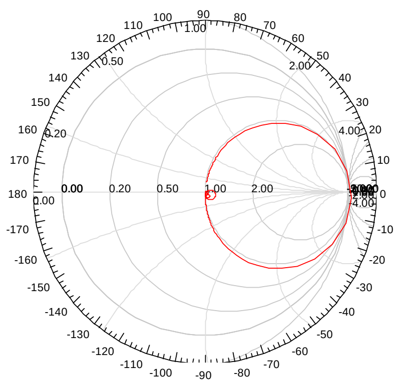


(c)

Figure-9: Simulated return loss and radiation characteristics of conventional and proposed configurations (a) Return loss, (b) H-plane radiation characteristics (c) E-plane radiation characteristics



(a)



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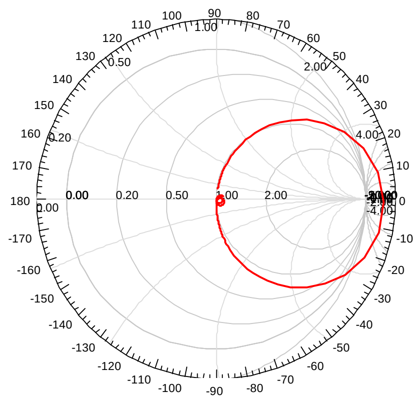

(c)

Figure-10: Simulated resistance and admittance of conventional and proposed configuration (a) Resistance comparison, (b) Admittance of conventional MPA and (c) Admittance of proposed MPA.

VII. CONCLUSION

A rectangular microstrip patch antenna with defected ground plane and defected radiating patch using coaxial probe feed is proposed for improving the isolation between co-pol to cross-pol radiation is proposed. The MPAs are designed using FR4 epoxy substrate with dielectric constant ε_r = 4.4 having thickness h = 1.6 mm. The proposed MPA is resonating at 5.04 GHz almost same as that of conventional configuration resonance (5.05 GHz) with a bandwidth of 240 MHz (250 GHz) and having S_{11} of -14dB (-17 dB). The proposed MPA gives the total isolation of 45 dB from co-pol peak gain to cross-pol by reducing cross polarized radiation up to 20 dB when compared to conventional configuration.

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