Enhancement of Bandwidth in a Probe-Fed Rectangular Microstrip Patch Antenna using I – shaped Defected Ground Structure for Wireless Application

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Abstract:* This paper presents bandwidth enhancement in a Rectangular Microstrip Patch Antenna (RMPA) using Defected Ground Structure (DGS) for WLAN (Wireless Local Area Networks, 5.2/5.8 GHz) application. The RMPA is designed using FR4 epoxy substrate with a dielectric constant ε_r = 4.4 and having thickness h = 1.6 mm. The conventional RMPA is resonating at 4.65 GHz with an impedance matching of -16 dB and having impedance bandwidth of 200 MHz. The conventional RMPA gives co-pol peak gain of 5.64 dBi and the H – plane cross-pol levels are symmetrical at -20 dB. The conventional RMPA is modified by defecting I – shaped slot in the ground plane as DGS element, its dimension is optimized and approximately equals to (2 X λ/2.2) mm^2. The DGS slot enhances the impedance bandwidth by maintaining S_{11} below -10 dB from 4.6 GHz to 5.54 GHz. The modified RMPA enhances the bandwidth from 200 MHz to 0.94 GHz and is almost 5 times the conventional configuration.

***IndexTerms* – Rectangular Microstrip patch Antenna, cross polarization, Defected ground Structure, Wireless Local Area Networks.**

I. INTRODUCTION

A Microstrip Patch Antenna is basically a very thin metallic patch placed above the dielectric substrate and the bottom of the substrate is a metallic ground plane. Microstrip patch antennas (MPA) are widely used for wireless applications due to its attractive features like low cost, light weight, compatibility to MMIC, easy fabrication and broadside radiations. Out of different available patch shapes, rectangular and circular patch are simpler and also common. The MPA concept is presented for the first time in the year 1953 [1] but the first work patented in 1970 [2]. The DGS slot behaves like a resonance and they are of different shape and size producing different frequency responses, which alters the circuit elements. The shape and size of the defect in ground plane or on radiating patch will disturb the shielding current distribution. The defect influence change in circuit elements like resistance, capacitance and inductance, there by producing shift in resonance and impedance matching. The presence of DGS helps the guided wave characteristics showing band gap properties, slow wave effects and band width enhancements [3]. In Probe-fed microstrip patches to enhance the bandwidth usually thick, low-permittivity substrates are used. The single probe feed causes a high cross-polarised radiation and pattern gets distorted due to unwanted probe radiation, by introducing a second probe, located on the opposite resonant end of the patch are out of phase each other, there by probe radiation can be effectively suppressed and low cross-polarisation can be maintained [4]. The MPAs have some limitations which are, low gain, narrow bandwidth, high cross-polarized radiation (XP) etc. The XP radiation is more significant in the H-plane rather than the E-plane and is not desirable in wireless applications [5-6].

The microstrip antenna with photonic band gap structure with a square lattice of small metal pads makes substantial improvement in gain, bandwidth and reduction in mutual coupling. The antenna is designed using RT/Duriod with dielectric constant ε_r = 10.2 and achieved 500 MHz [7]. The bandwidth and directivity by a resonant cavity antenna (RCA) using two dielectric superstrates has been improved. The two cavities corresponding to two operating frequency bands that combines to form a single wide band of operation. The proposed technique is capable of enhancing the bandwidth from 9% of the single superstrate RCA to 17.9% of the two superstrate RCA, with only 0.1-dB reduction of the maximum directivity (17.5 dBi) [8]. A multilayered CRA with multiple dielectric superstrate layers was developed to enhance the bandwidth of the broadside directivity. When compared to the single-layered CRA, more than 100% bandwidth enhancement was achieved but in compromise, the maximum directivity was dropped by 0.4 dB and the volume was approximately doubled. A close match between the theoretical results and the full wave simulations was observed [9].

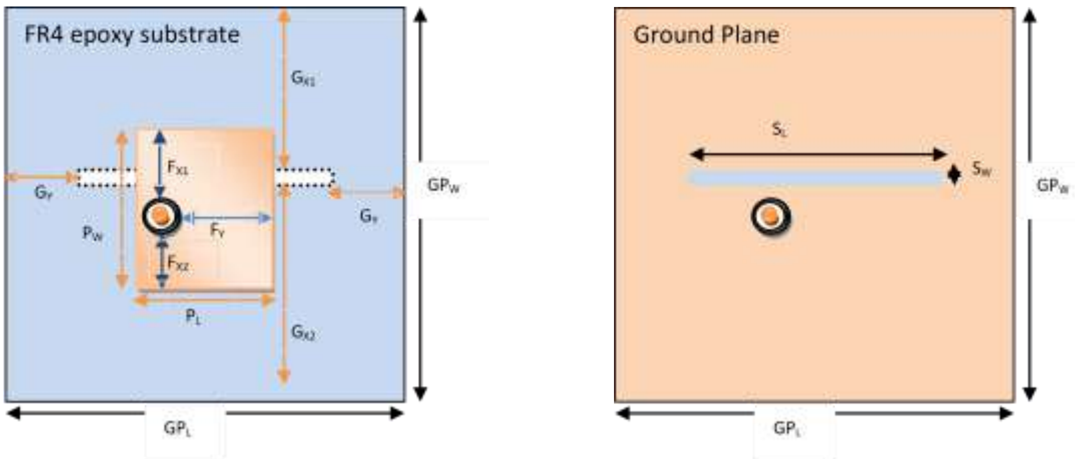
A single-layer single-patch wideband microstrip antenna could be developed and impedance bandwidth greater than 30% can easily be achieved for a microstrip antenna with a probe feed. The design is with an air substrate of thickness about 8% of the wavelength, the proposed antenna have an impedance bandwidth about 31.32%, with respect to center frequency [10]. E – shaped Microstrip patch Antenna designed to resonate at 5.8 GHz, which covers wide Band frequency from 3 GHz to 7 GHz having bandwidth of 4GHz with a peak gain and directivity of the propose antenna is 2.66db and 3db respectively [11]. A new compact coupled-fed patch antenna in a single-layer substrate using a pair of λ/4 resonators, the bandwidth of the patch antenna is significantly enlarged and the harmonic radiations are effectively suppressed. The measured and simulated results show that the bandwidth has been enlarged by 2.7 times and the higher mode radiations have been successfully suppressed. In addition, more symmetric radiation patterns and gains have been obtained [12]. For the three different shape microstrip patch using substrate Alumina with the dielectric constant of 9.4 and loss tangent of 4.0e-4 is verified. The conventional rectangular microstrip antenna bandwidth has been enhanced from 4.81% (100MHz) to 28.71% (610 MHz), 28.89% (630MHz) and 9.13% (110MHz) respectively using U, E and H-patch over the substrate. The E-shaped patch antenna has the highest bandwidth followed by U-shaped patch antenna and H-shaped patch antenna [13].

A hexagonal wide slot antenna fed by a 50Ω microstrip line with fork-like tuning stub has been designed using FR4 substrate with a dielectric constant ε_r = 4.4. The proposed antenna with optimal design parameters is found to be 900MHz for 1.5:1 VSWR bandwidth. The VSWR bandwidth is about three times larger than the hexagonal wide slot reference antenna [14]. The rectangular microstrip patch antenna is magnetically coupled to the Magnetoinductive (MI) waveguide. The unloaded rectangular microstrip patch antenna resonates at 37.10 GHz. When loaded with planar MI waveguide, its resonant frequency is reduced to 9.38 GHz with the bandwidth and gain of 44% and 4.16 dBi respectively. In loaded condition, the dimension of antenna is 12.50 mm X 3.70 mm (0.390 λ X 0.115 λ). The appreciable bandwidth is achieved in such a small size antenna [15]. A U-shape patch antenna with suitable geometry is taken to provide good response of bandwidth about 30 % at centre frequency 2.025 GHz using FR-4 glass epoxy material, on insertion of EBG structure, creating deformities at ground plane side, the band width of the antenna is improved tremendously about 49.36 % at centre frequency 2.35 GHz [16].

In this communication, the conventional and proposed RMPA configuration is designed to resonate at 4.8 GHz using dielectric substrate FR4 epoxy with a dielectric constant ε_r = 4.4 having thickness h = 1.6 mm. The RMPA is designed and simulated using HFSS 15.0v electromagnetic simulator [17]. The conventional RMPA is resonating at 4.65 GHz with S_{11} of -16 dB and having bandwidth 200 MHz. The conventional RMPA gives co-pol peak gain 5.64 dBi and the H – plane cross-pol levels are symmetrical at -20 dB. The proposed configuration from 200 MHz to 0.94 GHz gives almost five times the conventional configuration.

II. ANTENNA CONFIGURATION

The conventional rectangular microstrip patch antenna with a coaxial probe feed is designed to resonate at 4.8 GHz using transmission line model. The RMPA is designed using FR4 epoxy substrate with a dielectric constant ε_r = 4.4 and having thickness h = 1.6 mm. The designed RMPA gives the patch length P_L=14.4 mm, width P_W=19 mm and thickness t=0.03mm. For better radiation characteristics the length and width of ground plane is chosen ($\lambda/2 + P_L$) mm X ($\lambda/2 + P_W$) mm. The coaxial probe is feed at a distance of λ/6.5 from the edge of the radiating patch on Y – axis (F_Y), F_{X1} and F_{X2} from either side of the patch on X – axis. The conventional RMPA is modified with rectangular slot of optimized dimension (S_L X S_W) mm^2 etched in ground plane. The rectangular slot is etched at a distance G_Y from the edge of ground plane along Y – axis, G_{X1} and G_{X2} from either side of ground plane along X – axis. The schematic diagram of modified MPA configuration is shown in figure-1(b). The side view of a proposed MPA is shown in figure-2. The schematic diagram of top and bottom view for the proposed configuration is shown in figure-1. All the dimensions of conventional and modified RMPA are given in Table-1.



(a) (b)

Figure-1: Schematic diagram of proposed rectangular microstrip patch antenna with coaxial feed, (a) Top view, (b) Bottom view.

(GP_W)			
Length of Ground Plane (GP_L)	45.65	Feed position on X-axis (F_{X1})	4.4
Slot length (S_L)	28.8	Feed position on X-axis (F_{X2})	12.6
Slot width (S_W)	2	Feed position on Y-axis (F_Y)	9.35
Substrate thickness (h)	1.6	Thickness of copper (t)	0.03

Table-1: Dimension of conventional and proposed MPA

III. ANTENNA DESIGN

The microstrip patch antenna is designed for a resonating frequency f_0 = 4.8 GHz. The dimensions of the patch and ground plane are calculated using transmission line model [18]. The main intension of the design involves enhancing the bandwidth of the RMPA. The bandwidth of RMPA is inversely proportional to the quality factor 'Q' is given by,

$$BW = \frac{VSWR-1}{Q\sqrt{VSWR}} \quad (1)$$

Where VSWR is defined in terms of reflection coefficient 'Γ'

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (2)$$

The 'Γ' is a measure of reflected signal at the feed-point of the antenna. It is defined in terms of input impedance Z_{in} of the antenna and the characteristic impedance Z_0 of the feed line as given below:

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \qquad (3)$$

The BW is the frequency range over which VSWR is less than 2 or sometimes for stringent applications, the VSWR requirement is specified to be less than 1.5. Conversion of BW from one VSWR level to another can be accomplished by,

$$\frac{BW_1}{BW_2} = \frac{(VSWR_1 - 1)}{\sqrt{VSWR_1}} \frac{\sqrt{VSWR_2}}{(VSWR_2 - 1)} \qquad (4)$$

The expression for calculating the approximate percentage of bandwidth for the RMPA in terms of patch dimensions and substrate parameters is given by

$$\%BW = \frac{Ah}{\lambda_0 \sqrt{\varepsilon_r}} \sqrt{\frac{W}{L}} \qquad (5)$$

$$A = 180 \text{ for } \frac{h}{\lambda_0 \sqrt{\varepsilon_0}} \le 0.045 \qquad (6)$$

Where *W* and *L* are width and length of the RMPA. With an increase in *W*, BW increases. However, *W* should be taken less than λ to avoid excitation of higher order modes. For other regularly shaped patches, values of equivalent *W* can be obtained by equating the area with that of the RMPA. Another simplified relation for quick calculation of BW (in megahertz) for VSWR = 2 of the MSA operating at frequency *f* in gigahertz, with *h* expressed in centimeters is given by BW = $50hf^2$ [19].

Segments	Frequency 4.8 GHz Dimensions (mm)	Segments	Frequency 4.8 GHz Dimensions (mm)
Width of the Patch(P_w)	19	Slot position on Y-axis (G_Y)	8.6
Length of the Patch (P_L)	14.4	Slot position on X-axis (G_{X1})	20
Width of Ground Plane (GP_W)	50.25	Slot position on X-axis (G_{X2})	28.25
Length of Ground Plane (GP_L)	45.65	Feed position on X-axis (F_{X1})	4.4
Slot length (S_L)	28.8	Feed position on X-axis (F_{X2})	12.6
Slot width (S_W)	2	Feed position on Y-axis (F_Y)	9.35

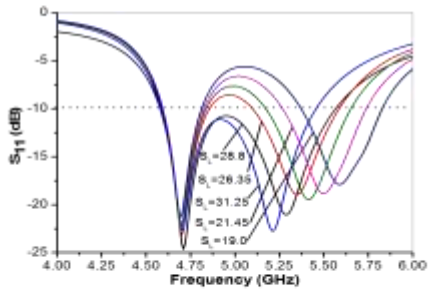
Table – 1: Dimensions of conventional and proposed configuration

IV. OPTIMIZATION OF DGS SLOT

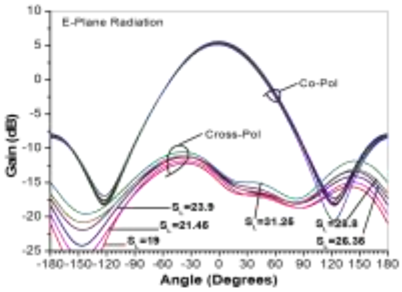
The conventional configuration ground plane is defected with rectangular slot as DGS element. The position of slot in the ground plane is chosen at distance of λ/2 from the edge of positive X – axis and λ/7 from the edge of Y – axis, which locates near the coaxial feed. The dimension of rectangular slot is (λ/2 X 2) mm^2 and optimized its length, width and position of the slot. The effect of S_{11}, bandwidth and radiation characteristics due to optimization of slot is given in subsequent subsection.

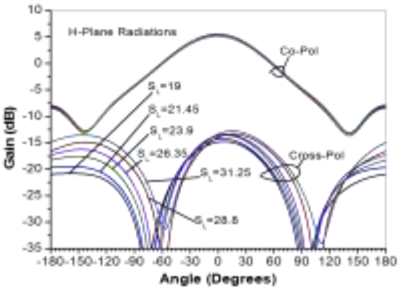
Slot Length Optimization:

The length of rectangular DGS slot in the ground plane of the proposed RMPA has been optimized by set of simulation study and the effect on S_{11} and radiation characteristics are observed. Initially the dimension of slot is chosen (λ/2 X 2) mm^2. Due to the slot, the RMPA resonates below -10 dB (S_{11}) over the frequency range 4.58 GHz to 5.46 GHz with a bandwidth of 880 MHz. The impedance matching throughout the band varies from -11.2 dB to -22.3 dB with a co-pol peak gain of 5.11 dB and shows poorer cross-pol (XP) levels are at -10 dB and -15 dB. The length of the slot decreased by λ/25 (2.45 mm), the effects of S_{11} and radiation pattern are observed. The S_{11}, E-plane and H-plane radiation characteristics are shown in figure-2. When the slot length is 28.8 mm [($\frac{\lambda}{2}$ - $\frac{\lambda}{25}$) mm] achieves maximum bandwidth by maintaining S_{11} below -10 dB shown in figure-2 (a). Figure-2(b) and (c) shows E – plane and H – plane radiation characteristics. The radiation characteristic gives a broadside co-pol peak gain of 5.1 dBi in E and H – plane at 4.66 GHz. The peak gain decreases as resonating frequency increases within the resonating band. The RMPA gives H – plane cross polarization level at -11 dB and -16 dB.



(a)



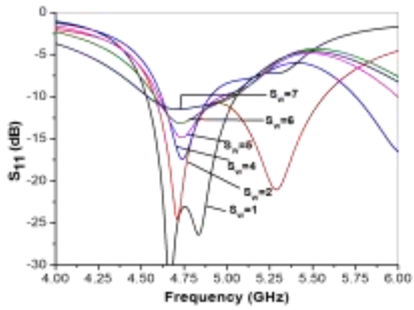


(b) (c)

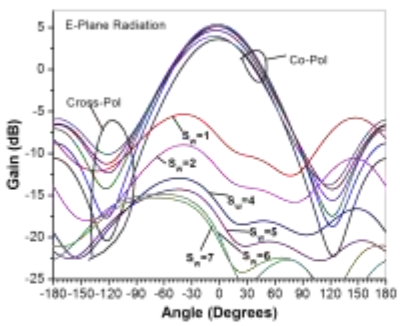
Figure-2: Simulated return loss and radiation characteristics due variation of DGS slot length, (a) Return loss, (b) E-Plane radiation characteristics, (c) H-Plane radiation characteristics,

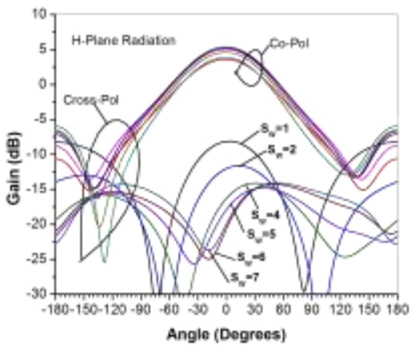
Slot Width Optimization:

The RMPA gives higher bandwidth at the slot length S_L = 28.8 mm [($\frac{\lambda}{2}$ - $\frac{\lambda}{25}$) mm], then for further investigation the width of the slot is varied in steps of 1 mm and observed the S_{11} and radiation characteristics. The figure-3(a) shows return loss characteristics and it is observed that, when slot width S_W = 2 mm, S_{11} is below -11 dB over the frequency range 4.62 GHz to 5.50 GHz having a total bandwidth of 0.88 GHz. The figure-3(a) and (b) shows E-plane and H-plane radiation characteristics. From figure-3(b) observed that, as slot width increases the E - plane cross-pol level decreases with slight increment in co-pol peak gain and is a good symptom for having higher isolation between co-pol to cross-pol but the bandwidth and impedance matching decreases. There is similar effect found in H – plane radiation and is shown in figure-3(c).



(a)



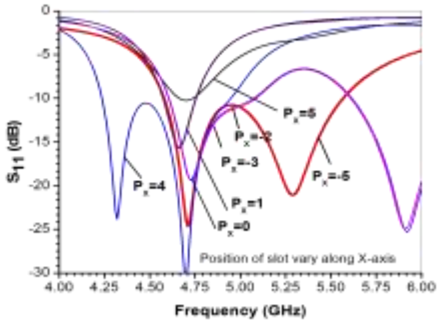


(b) (c)

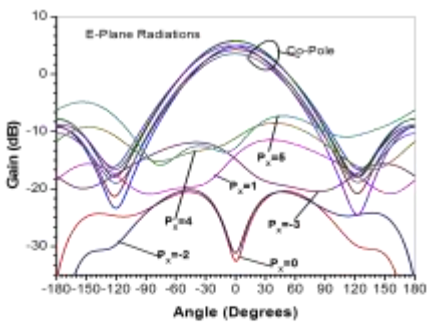
Figure-3: Simulated return loss and radiation characteristics due variation of DGS slot width, (a) Return loss, (b) E-Plane radiation characteristics, (c) H-Plane radiation characteristics.

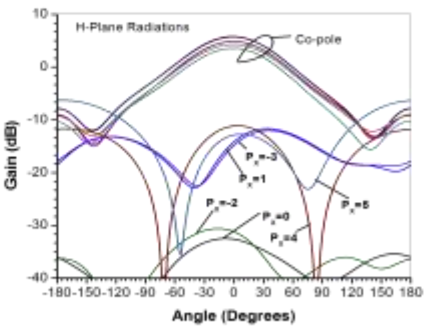
Slot Position Optimization:

For furthermore investigation in improvement of the bandwidth of proposed RMPA, the position of the slot is also varied in steps of 1mm along X – axis and observed the effect of return loss and radiation characteristics is shown in figure-4. As the position of slot shifts by 1 mm along the X – axis obtains single, dual and wideband resonances. At P_X = +5 and +1 gives single resonance of dominating type, at P_X = -2 and -3 gives dual resonance, in which the fundamental is of dominating type and the other one is of higher order resonance. At P_X = 4 and -5 the RMPA gives wideband resonances, resonating from 4.15 GHz to 4.8 GHz with a bandwidth of 650 MHz and 4.6 GHz to 5.54 GHz with a bandwidth of 940 MHz respectively and is shown in figure-4(a). The XP levels in E – plane and H – plane are below -22 dB and below -29 dB, when slot is at P_X = 0 and P_X = 2 respectively. But these two merges to single resonances with small bandwidth. The proposed RMPA gives wideband and having compromise in XP level, which reports -9 dB in E – plane and -12 dB in H – plane. Usually H – plane radiations are more important than E – plane radiation. The E – plane and H – plane radiations are shown in figure-4(b) and (c).



(a)





(b) (c)

Figure-4: Simulated return loss and radiation characteristics due variation of DGS slot position, (a) Return loss, (b) E-Plane radiation characteristics, (c) H-Plane radiation characteristics,

V. SIMULATED RESULTS.

The reflection coefficient of conventional and proposed RMPA is shown in Figure-5. The reflection coefficient plot of the conventional RMPA is resonating at 4.65 GHz with an impedance matching of -16 dB and having impedance bandwidth of 200 MHz. The S_{11} of proposed RMPA configuration resonates at wider band from 4.6 GHz to 5.54 GHz with a bandwidth of 940 MHz, which is almost FIVE times greater than conventional configuration without changing co-pol peak gain. But the gain decreases within the resonating band as resonating frequency moves higher side and is shown in figure-6.

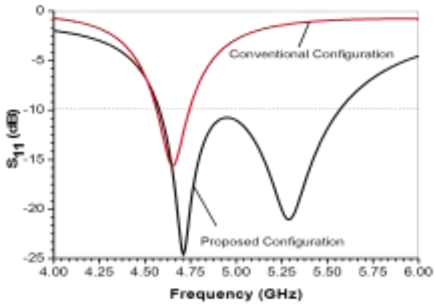
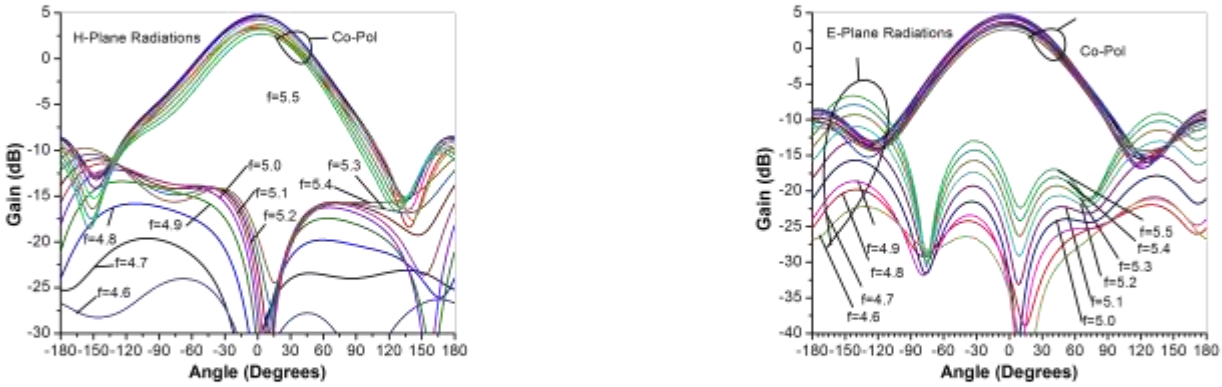


Figure-5: Comparison of simulated return loss characteristics of conventional and proposed configuration.



(a) (b)

Figure-6: Simulated radiation characteristics within the resonating band, (a) H – plane, (b) E – plane.

The figure-6(a) shows the H – plane radiation characteristics simulated for every 0.1 GHz within the resonating band 4.6 GHz to 5.54 GHz. It is interesting to see that the XP levels are in the range from -20 dB and -28 dB for the desired resonating frequency 4.6 GHz to 4.8 GHz with a small change co-pol peak gain. Similar effect is observed in E – plane radiation characteristics shown in figure-6(c). The resonating frequency varied in steps of 0.1 GHz within the resonating band and tabulated its co-pol peak gain, H – plane XP and E – plane XP is shown in table-2.

From the table-2 it is clear that, the peak gain increase from the beginning of resonating band at 4.6 GHz has 3.3150 dBi to a maximum of 5.01 at 4.9 GHz and again decreases to 1.582 at 5.5 GHz. Interesting to note that for the entire band the proposed RMPA gives a positive gain. The reason for changes in gain and cross-pol level in a resonating band is because, the RMPA behaves like capacitive or inductively at resonant frequencies. The resonating frequency, coverage angle, the normalized magnitude and reactance in rectangular form is tabulated and is shown in table-3.

Frequency (GHz)	Gain (dB)	E-Plane XP		H-Plane XP	
		-ve Angle	+ve Angle	-ve Angle	+ve Angle
4.6	3.3150	-24	-28	-23	-23
4.7	4.5514	-23	-25	-20	-19
4.8	4.8575	-21	-23	-17	-17
4.9	5.01	-19	-22	-15	-16
5.0	4.6171	-17	-20	-14	-15
5.1	4.23	-15	-19	-13	-15
5.2	3.714	-14	-18	-14	-15
5.3	2.6197	-12	-16	-14	-16
5.4	2.145	-11	-15	-14	-16
5.5	1.582	-10	-15	-13	-16

Table-2: Simulated radiation characteristics data within the resonating band.

Frequency (GHz)	Coverage Angle (Degrees)	Magnitude (Normalized)	Rectangular Reactance (Normalized)
4.6	-49.6675	0.0991	1.1233-J1.715
4.7	-117.9878	0.2212	0.7569-J0.3109
4.8	-148.6920	0.3881	0.4683-J0.2224
4.9	-169.3823	0.5167	0.3211-J0.0834
5.0	175.6090	0.6015	0.2492+J0.036
5.1	164.2024	0.6565	0.2112+J0.1327
5.2	155.064	0.6928	0.19+J0.2135
5.3	147.4002	0.7165	0.1746+J0.2838
5.4	140.1246	0.7319	0.1746+j0.3529
5.5	134.8346	0.7380	0.1761+J0.4049

Table-3: Simulated RMPA component values at resonant frequency

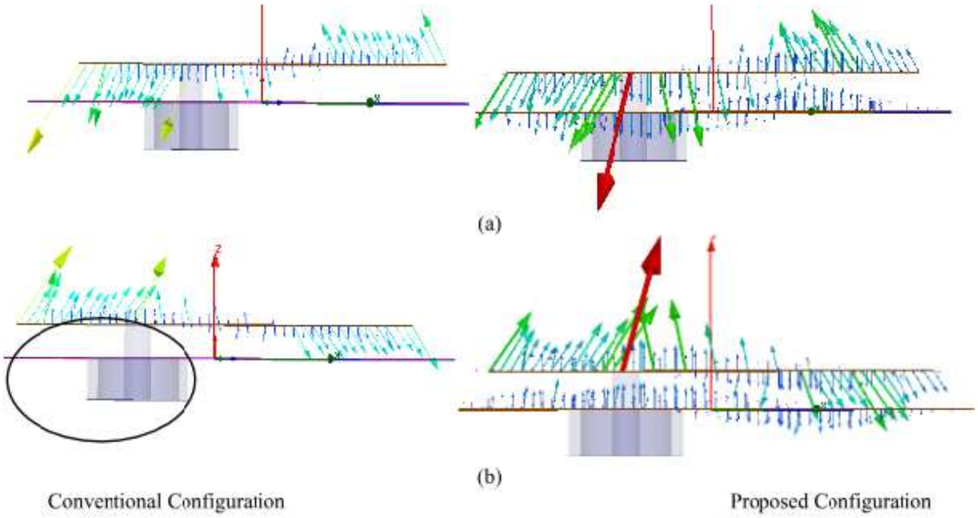


Figure-7: Simulated current density of conventional and proposed configuration, (a) $\phi = 91°$, (b) $\phi = 273°$.

The figure-7 shows the current density on a radiating patch. The current distribution is weak in conventional configuration when compared to proposed configuration.

VI. CONCLUSION

A rectangular microstrip patch antenna with defected ground plane using coaxial probe feed is proposed for bandwidth enhancement. The proposed RMPA is designed using FR4 epoxy substrate with a dielectric constant $\varepsilon_r = 4.4$ and having thickness h = 1.6 mm. The proposed RMPA consists of I – shaped slot in the ground plane of dimension (28.8 X 2) mm^2 is resonating from 4.6 GHz to 5.54 GHz having total impedance bandwidth of 940 MHz compare to 200 MHz conventional configuration. The proposed RMPA enhances the bandwidth almost five times the conventional configuration and produces a positive peak gain throughout its resonating band.

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