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Bandwidth Enhancement using Two Dumble Shaped Defected Ground Structures and a strip of Gold on feed in a Rectangular Microstrip Patch Antenna for WLAN Application

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Abstract: This article presents Quarter-Wave Transmission fed Rectangular Microstrip Patch Antenna (QWT-RMPA) with Two Dumble shaped Defected Ground Structure (DGS) and a strip of gold on quarter wave feed, which generate wide bandwidth to cover IEEE 802.11 Wireless LAN. The RMPA designed on a durable low – cost FR4 epoxy dielectric substrate with ε_r = 4.4 and having thickness h = 1.6 mm. The overall size of RMPA is (35.9 X 57.94 X 1.66) mm^3. The proposed RMPA gives S_{11} < -10 dB from 4.52 GHz to 5.52 GHz with a total impedance bandwidth of 1 GHz is almost 5 times the conventional configuration. Also, the radiation characteristics are observed in the entire resonating band is a stable and Omni-directional. The dimensions of Quarter-wave feed and the transmission line are chosen to match characteristic impedance 50 Ω. The design, validation and optimization were carried out using Ansys. HFSS v15.0 is based on method of moment.

***Keywords* —Quarter-wave transformer, rectangular microstrip patch antenna, Wireless LAN, HFSS, Defected Ground Structure.**

I. INTRODUCTION

A Microstrip Patch Antenna consists of a radiating conducting material as Patch placed above the dielectric strong base as substrate and the bottom of the substrate called ground plane, usually the same material used for patch. Due to its attractive features like light weight low cost easy fabrication compatibility to MMIC and gives broadside radiation. Hence for the most of the wireless applications, the Microstrip patch antennas (MPA) are preferred. Most of the Probe-fed microstrip patches to enrich the impedance bandwidth either using thicker substrate with low-permittivity or by multi-dielectric materials are being used. There are many ways to enrich the impedance bandwidth one such technique is by etching the ground plane as DGS element of any shape because it behaves like a resonance

The microstrip Patch antenna surrounded by PBG for Ku band has reported 3 times greater than regular conventional MPA [1]. Dielectric resonator loaded on a microstrip feed with two substrates of h = 1.6 mm for bandwidth enhancement of a rectangular MPA and achieved maximum bandwidth of 10.57% [2]. Single layered circular MPA two narrow arc shaped near the boundary of radiating patch at a distance of 1 mm gives 2.3 times the conventional configuration, the bandwidth enhanced from (1951-1988) MHz to (1963-2063) MHz [3]. The presence of DGS helps the guided wave characteristics showing band gap properties, slow wave effects and band width enhancements [4].

The bandwidth enhanced by a multilayered dielectric substrates by a cavity resonate antenna from 9.1% to 18.3% compare to single layered substrate [5]. Microstrip fed rotatable square slot MPA gives two resonances, by embedding a patch in to the square slot the lower resonance is decreased and higher resonance increased and creates the broadband characteristics. The bandwidth enhances from 2.23 GHz to 5.35 GHz [6]. A substrate removed rectangular cavity backed slot MPA using FR4 substrate reports 6.2% improvement in efficiency and 24 % in the bandwidth [7]. AT&T has tried millimetre waves at 28 GHz and well known band, 15 GHz, at its preliminary site in Austin, Texas. In the lab, AT&T has accomplished pinnacle data speeds of 14 Gbps at 15 GHz. Investigation and plan of space cut H-formed microstrip antenna gives another way for improving the bandwidth [8]. The resonant cavity antenna with two dielectric superstrate enhances the bandwidth from 9% to 17.9% when compared to single

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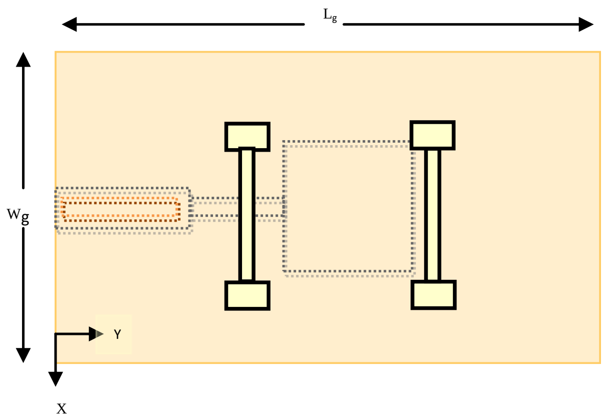
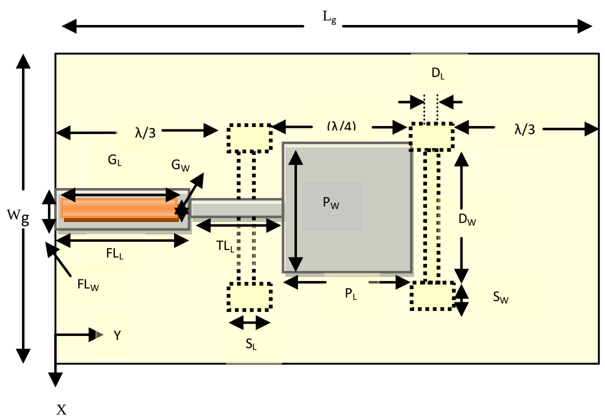
superstrate [9]. The microstrip-fed patch antennas with λ/4 microstrip line coupled as a proximity to a rectangular patch gives the bandwidth 2.7 times the traditional MPA and also suppress the harmful higher order harmonics [10]. I-shaped defect in ground plane perpendicular to radiating edge improves the bandwidth from 200 MHz to 940 MHz [11]

II. ANTENNA DESIGN

The Rectangular Microstrip Patch Antenna (RMPA) is designed to resonate at 5.2 GHz using FR4 epoxy as dielectric material having dielectric constant ε_r = 4.4, thickness h= 1.6mm and loss tangent tan δ = 0.02. The conventional along the Y-axis and are separated by (λ/3 – 3)



(a)



(b)

Figure-1: Proposed MPA Configuration, (a) Bottom view, (b) Top view

mm and a strip of Gold (1.5 X 12) mm^2 is placed on quarter-wave feed line by etching the same area in feed line. The RMPA is designed using transmission Line Model (TLM) and its dimensions are calculating using design equations given [12]. The RMPA is simulated using Finite Element Method (FEM) based electromagnetic simulator HFSS v 15.0 [13]. The Figure-1 (a) and (b) shows proposed RMPA configuration bottom view and top view. The dimension of all antenna elements is in millimeter and is shown in Table-1.

MPA segments	Dimensions (mm)
Length of ground plane (Lg)	35.9
Width of ground plane (Wg)	57.94
Length of Patch (P_L)	12.56
Width of Patch (P_W)	17.56
Length of feed (F_L)	14.896
Width of feed (F_W)	3.095
Length of Transmission line (TL_L)	8.294
Width of Transmission line (TL_W)	0.723
Length of 4 slots (S_L)	4
Width of 4 Slots (S_W)	3
Length of 2 Slots (D_L)	2
Width of 2 slots (D_W)	17

Table-1: Dimensions of conventional and proposed RMPA

III. OPTIMIZATION

A. *Four small DGS Slots*

The conventional configuration is defected with four rectangular slots etched at a distance of λ/3 mm from either edges of the ground plane are separated by a distance (λ/4 –

Dimen (mm^2)	f_0 (GHz)	S_{11} (dB)	BW (MHz)	Gain (dB)	XP
1X1	5.24	-35	190	4.8	-22, -21
1X2	5.24	-35.5	190	4.77	-22, -22
1X3	5.25	-37	200	4.8	-22, -23
1X4	5.25	-38	200	4.75	-24, -22
2X1	5.25	-42	190	4.49	-22, -23
2X2	5.25	-46	190	4.47	-23, -22
2X3	5.25	-42	190	4.53	-22, -22
2X4	5.25	-42	190	4.78	-22, -22
3X1	5.24	-48	190	4.7	-23, -22
3X2	5.25	-37	190	4.5	-23, -22
3X3	5.25	-35	200	4.8	-23, -21
3X4	**5.26**	**-40**	**220**	**4.83**	**-23, -23**
4X1	5.25	-35	190	4.61	-23, -22
4X2	5.25	-45	190	4.79	-24, -20
4X3	5.26	-39	200	4.81	-23, -21
4X4	5.27	-43	200	4.82	-23, -21

Table-2: Four rectangular DGS slot dimensions are altered

3) mm along the Y- axis and are approximately separated by λ/3.5 mm along the X-axis. The four square slots of dimension (1 X 1) mm^2 etched in the ground plane at a distance λ/7 from one edge and λ/12 from other edge along X-axis. The dimension of these four slots is varied in steps of 1 mm along X and Y-axis and its f_0, S_{11}, bandwidth, gain and cross-polarization (XP) levels are tabulated in Table-2. The Table-2 clearly shows there is a small variation in the resonant frequency, bandwidth, gain and cross-polarization levels, but remarkable variations in return loss characteristics i.e varying from -35 dB to -48 dB. When slots are at (3X4) mm^2 the RMPA is resonating at 5.26 GHz

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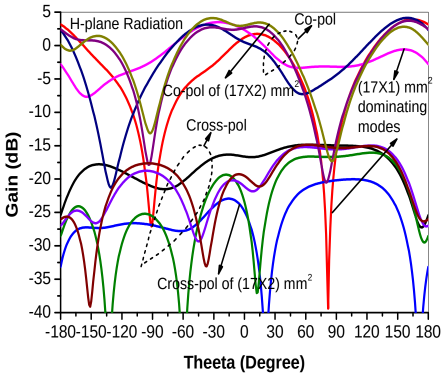
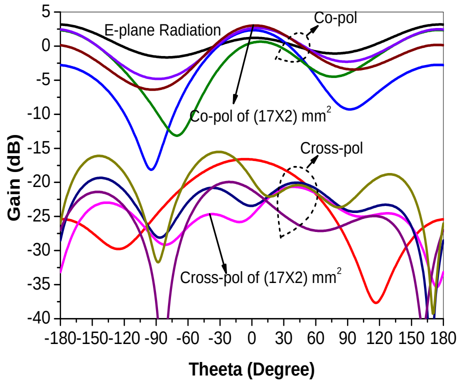
with S_{11} -40 dB, bandwidth of 220 MHz and symmetric cross-polarization level -23 dB reported compare to all other dimensions.



(a)



(b)

Figure-3: Radiation characteristics due to varying width of rectangular slots, (a) H-plane, (b) E-plane

B. Two large DGS Slots

For further optimization, two rectangular slots of dimension (17X4) mm^2 etched in the ground plane in order to join two (3X4) mm^2 slots parallel to radiating edges as

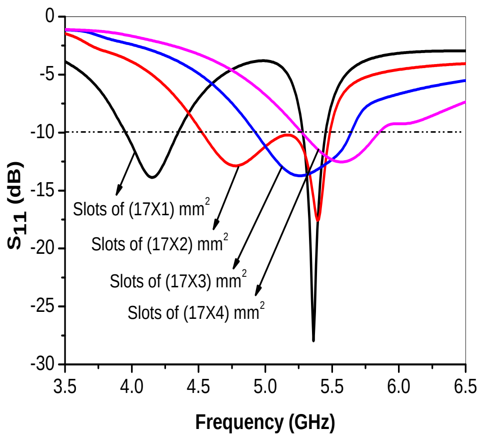


Figure-2: S_{11} characteristics due to variation of two

shown in Figure-1(a). The dimensions of these slots were also optimized and its S_{11} and radiation characteristics are shown in Figure-2 and Figure-3. From Figure-2, when slot dimensions are (17X4) mm^2 and (17X4) mm^2depicts almost same bandwidth, but upper shift in resonating frequency band. Two slots are at (17X1) mm^2 the RMPA gives two resonances 4.15 GHz and 5.36 GHz with S_{11} of -14.2 dB and -28.45 dB respectively. These two resonances are dominating type and RMPA can be used as dual band application. With the intension for bandwidth enhancement, when slots are (17X2) mm^2 the RMPA gives resonating band from 4.6 GHz to 5.46 GHz having 860 MHz bandwidth.

The Figure-3(a) shows H-plane radiation characteristics due to rectangular slot dimensions variation from (1x1) mm^2 to (4x4) mm^2 and not much variation in co-polarized peak gain compared to four rectangular slots, but there is a change in angular coverage and cross-polarization levels. The Figure-3(b) shows E-plane radiation characteristics, the cross-polarization levels are lowered for (17X2) mm^2 for both E and H-plane without changing co-polarized peak gain. Finally combination of all DGS elements looks like two dumble shaped defect in the ground plane.

C. Position variation of Dumble defects.

The four small rectangular slots are etched at (±10, ±5,0) and two larger slots are etched at (-7 ,-9 ,0) and (-7 ,6 ,0) in the ground plane forms dumble shape. Further investigation the position of dumble DGS are move close and moving away from each other, and observed the return loss characteristics.

The Figure-4 (a) is return loss characteristics (S_{11}) due to moving dumble DGS close to each other by 1 mm. When slots are disturbed from its reference position suddenly S_{11} shifts up from standard -10 dB and its resonance is shifting towards lower side. When dumble DGS slots are moving from each other by 1 mm almost same effect is reveled except the resonating frequency is shifting to upper side is shown in Figure-4 (b). The RMPA generates dual resonance first resonance is between 4.5 GHz to 5 GHz and the second is between 5.25 GHz to 5.75 GHz. As slots are moving away from the reference position the lower resonance impedance matching decreases while upper resonance increases.

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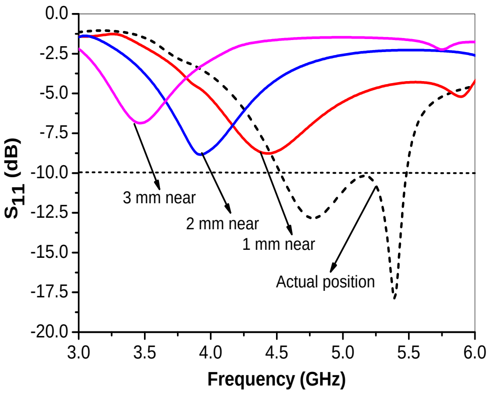
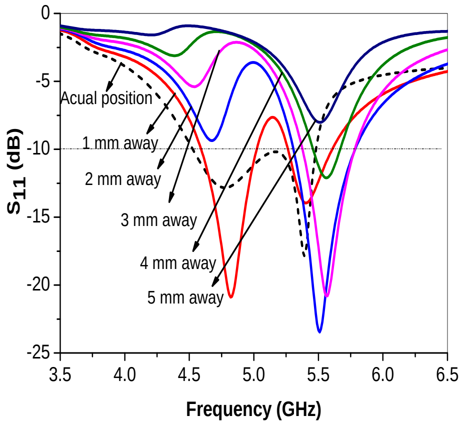


(a)



(b)

Figure-4: S_{11} characteristics of dumble shaped DGS due position variation, (a) Moving close to each other, (b) Moving away from each other.

D. *Feed defect and placing Gold strip*

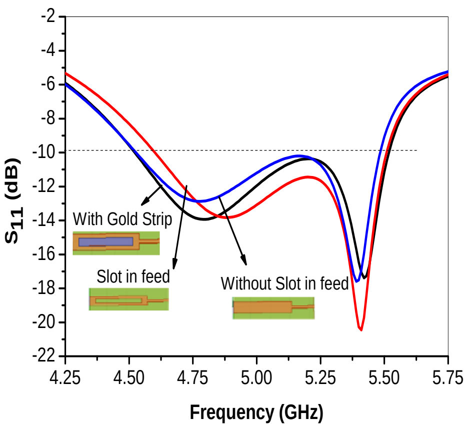
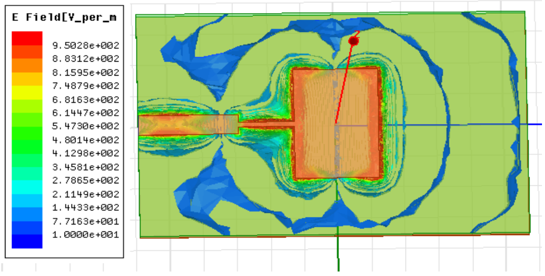


Figure-5: S_{11} due to with and without defect and gold strip

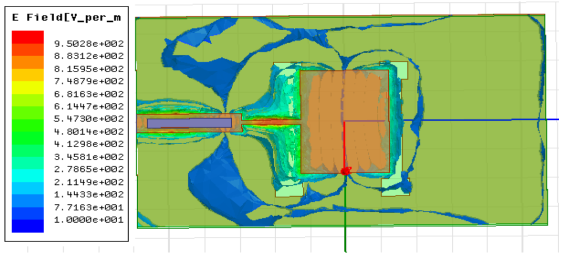
The RMPA with two dumble shaped DGS resonates from 4.6 GHz to 5.46 GHz having 860 MHz. As a trial the quarter-wave feed line is defected with rectangular shape of size (1.5X12) mm^2, the RMPA resonates from 4.66 GHz to 5.48 GHz having bandwidth 820 MHz, a small decrement is observed. A Gold strip of same size is filled in the slot, enhances the bandwidth from 850 MHz to 1000 MHz. The reason for enhancement is due to change in conductivity of gold and copper. The proposed RMPA resonates from 4.52 GHz to 5.52 GHz having 1 GHz bandwidth. The Figure-5 shows return loss characteristics of the three cases.

IV. WORKING PRINCIPLES.

A. *E-field Distribution*



(a)



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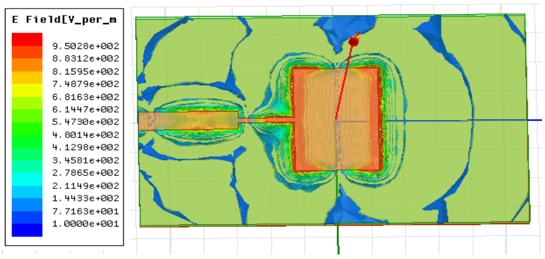
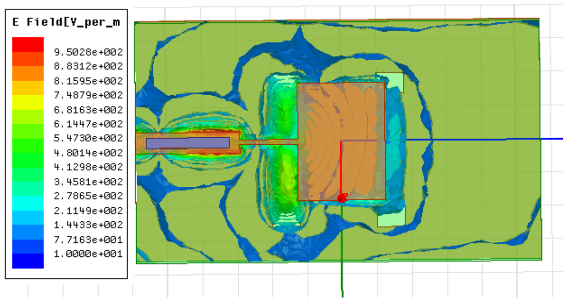


(c)



(d)

Figure-6: E-field distribution, (a) Conventional MPA at 60^0, (b) Proposed MPA at 60^0, (c) Conventional MPA at 120^0, (b) Proposed MPA at 120^0.

The conventional and proposed MPA configurations E-field, studied through simulation to find the reason for the bandwidth enhancement The E-field distribution in a substrate of conventional and proposed MPA configurations is shown in Figure-6

The Figure-6 (a) and (c) shows E-field magnitude variation conventional configuration at 60^0 and 120^0 looks almost uniform variation throughout the substrate and field

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is weaker at the periphery of the radiating patch. The Figure-6 (b) and (d) shows E-field magnitude variation proposed patch at 60^0 and 120^0, due to two dumble shaped DGS the E-field is highly denser at the around the radiating patch compare to basic patch.

B. Vector current Distribution

For further investigation, the vector current distribution is also observed. The Figure-7 (a) and (c) shows the vector

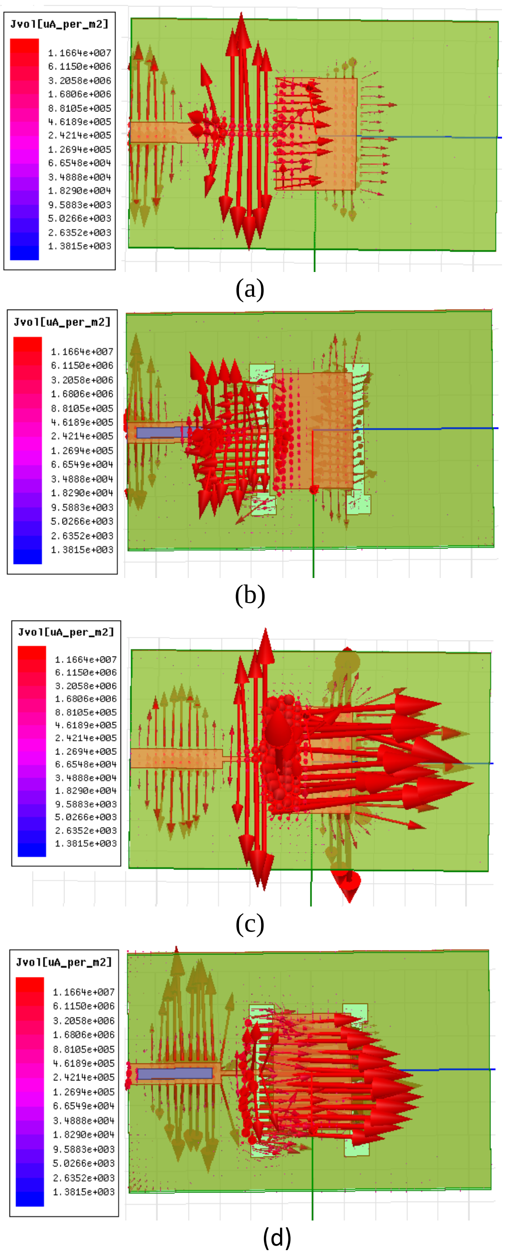

Figure-7: Vector current distribution, (a) conventional MPA 16^0, (b) modified MPA at 16^0, (c) conventional MPA 101^0, (d) modified MPA at 101^0

current distribution at 16^0 and 101^0 of a conventional configuration. In conventional MPA the field vectors are oscillating 90^0 apart and have weaker fields at the radiating edges. For the modified configuration field vectors orientation is more than 90^0 and is clearly depicted in Figure-7 (b) and (d), the vertical fields are inclined at the resonating edges at 16^0 and 101^0. Due to above reasons the bandwidth of conventional MPA is enhanced more than 5 times the conventional configuration.

V. SIMULATED RESULTS

The simulated results of conventional and proposed RMPA configuration are compared,

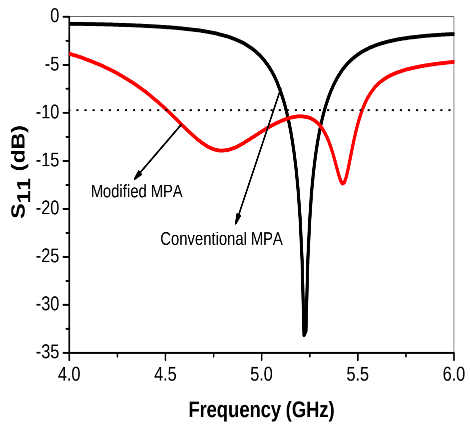

Figure-8: S_{11} plot of conventional and proposed MPA

A. Return loss (S_{11}) charecteristics.

The conventional MPA engraved with two dumble shaped defect in the ground plane and a strip of Gold placed on the feed line, which enhances the MPA bandwidth from 190 MHz to 1 GHz (resonating from 4.52 GHz to 5.52 GHz). The return loss characteristics of conventional and proposed configuration are shown in Figure-8.

B. Radiation characteristics..

The radiation characteristic of conventional and proposed configuration is shown in Figure-9. The H-plane radiation characteristic of a conventional MPA is shown in Figure-9 (a). It is observed that peak gains of 4.67dB with cross-polarization levels are symmetric at -22dB. The conventional configuration ground plane is defected with dumble DGS elements and a Gold strip, which enhances the bandwidth and H-plane cross-polarization levels are lowered by almost 8 dB without affecting co-polarization peak gain is shown in Figure-9 (a). Usually H-plane radiation characteristics are more important than E-plane in planar MPAs. The E-plane radiation characteristics of conventional and proposed MPAs are depicted in Figure-9 (b). In E-plane reports same gain but there is a drastic decrement in cross-polarization levels.

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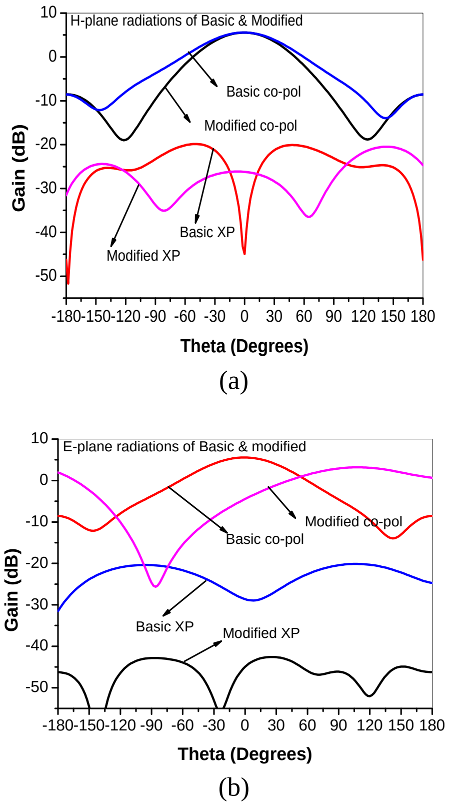

Figure-9: Radiation characteristics conventional and proposed configuration, (a) H-plane, E-plane

B. *Resistance of MPAs.*

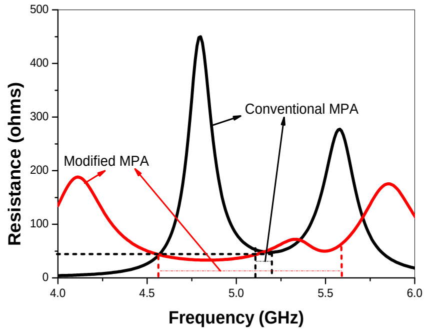

Figure-10: Input resistance of conventional and modified configuration

The impedance offered by any microwave device or transmission line is equals to characteristic impedance 50 Ω, hence device or transmission line achieves maximum power transfer. The input resistance offered by conventional and modified configuration is shown in Figure-10.

The Figure-10 clearly depicts, the conventional MPA maintains nearly 50 Ω from 5.15 GHz to 5.21 GHz for small band. But the modified MPA maintains 50 Ω for the exact resonating band from 4.52 GHz to 5.52 GHz, there by the bandwidth of modified MPA is increased for the same band.

C. *Reactance or imaginary value of MPAs.*

Since MPA is designed for a microwave frequency range, any device operated under microwave frequency, inter lead inductances and capacitances are to be considered. Sometimes the MPA behaves like inductive, capacitive or purely resistive at its resonating frequency.

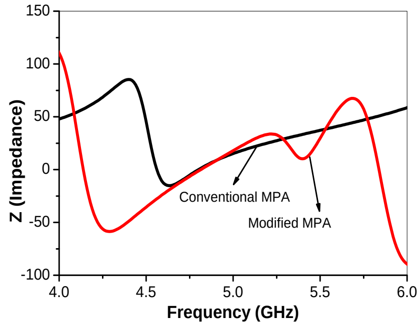

Figure-11: Comparison of imaginary value of conventional and modified MPA

From the Figure-11, the imaginary values of inductance and capacitance are almost shows the same value over the resonating band. Hence positive and negative reactance are cancel each other and their by MPA behaves like resistive and is the reason for enhancing bandwidth.

D. *VSWR of MPAs*

The VSWR of any antenna and transmission line is usually less than 2 at the resonating band or resonating frequency. The Figure-12 shows the VSWR of conventional

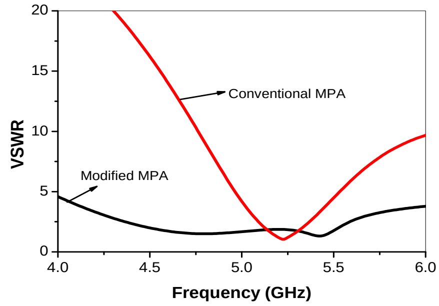

Figure-12: VSWR plot of conventional and modified configuration

and proposed configuration. For the conventional MPA shows less than 2 at the resonating frequency. But for the proposed configuration reveled same for entire resonating band.

E. *Radiation Patterns of MPAs.*

The Figure-13 (a) shows the radiation pattern of a convenstional configuration and achieved a good broad side radiation with co-polarization peak gain of 4.67 dB. The Figure-13 (b) shows radiation pattern of proposed MPA, due to Dumble DGS slots and a Gold strip placed above the

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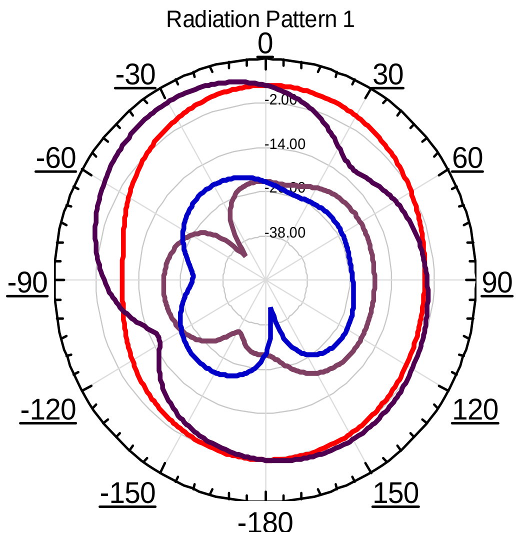
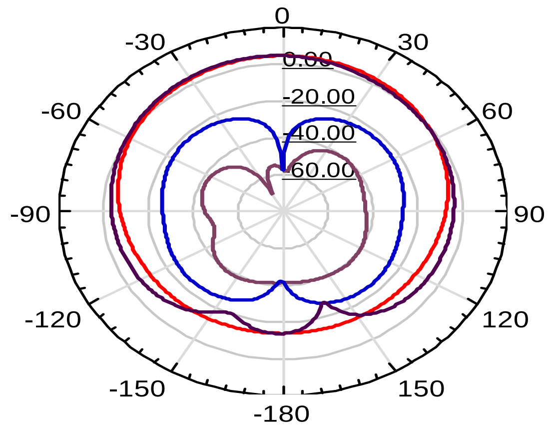
feed line the modified MPA enhances the bandwidth without changing co-polarized peak gain.

VI. Conclusion

The Rectangular Microstrip Patch Antenna using quarter-wave transformer feed is designed to resonate at 5.2 GHz. The RMPA designed using FR4 Epoxy substrate having dielectric constant ε_r = 4.4 and thickness h = 1.6 mm. The conventional configuration resonates at 5.22 GHz with S_{11} of -29.83 dB and having 190 MHz bandwidth. The conventional RMPA gives co-polarization gain of 4.67 dB in E-plane and H-plane and having -22 dB symmetric cross-polarization levels.



(a)



(b)

Figure-13: Radiation pattern (a) conventional and (b) proposed configuration

The conventional configuration is defected with two dumble shaped DGS elements below the radiating edges of the patch and a rectangular defect in feed line, on a defect piece of Gold metal placed of same dimension on quarter wave feed line. The proposed RMPA resonating from 4.52 GHz to 5.52 GHz and maintains return loss well below standard -10 dB. The proposed RMPA gives bandwidth more than 5 times the conventional configuration. The proposed configuration gives cross-polarization levels at -22 dB, -20 dB positive and negative angular coverage without changing co-polarization peak gain.

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