The Modal Conversion in coaxial probe fed Rectangular Microstrip Patch Antenna using DGS and DMS Techniques for Hex band Applications

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Abstract : In this paper, we have proposed a rectangular microstrip patch antenna (RMPA) for multi-band wireless applications. The RMPA is designed using RT/Duriod 5880, the thickness of 1.575 mm with a dielectric constant of ε_r=2.2. The proposed RMPA is designed with defected ground structure (DGS) and defected microstrip structure (DMS) for modal conversion and covering multiple frequency bands. The conventional RMPA is designed for a resonating frequency of 2.4 GHz using coaxial probe feed. The RMPA produces return loss (S_{11}) characteristics at 2.35GHz, 4.01 GHz and 4.72 GHz; the 2.35 GHz is a dominating resonance and the other two are higher order resonances. The conventional RMPA is modified with two rectangular slots, one triangular slot as DGS elements and two opposite triangles etched on the patch as DMS elements. The modified RMPA's S_{11} resonates at 1.65GHz, 1.8 GHz, 3GHz, 3.17 GHz, 3.88GHz, 4.44GHz and 4.91 GHz. Except the 4.91 GHz all six resonances are of dominating type, but each resonance has different peak gain and cross-polarization levels.

***IndexTerms* - Microstrip antenna, Antenna radiation patterns, Patch antennas, Slot antennas, receiving antennas, Transmitting antennas.**

I. Introduction

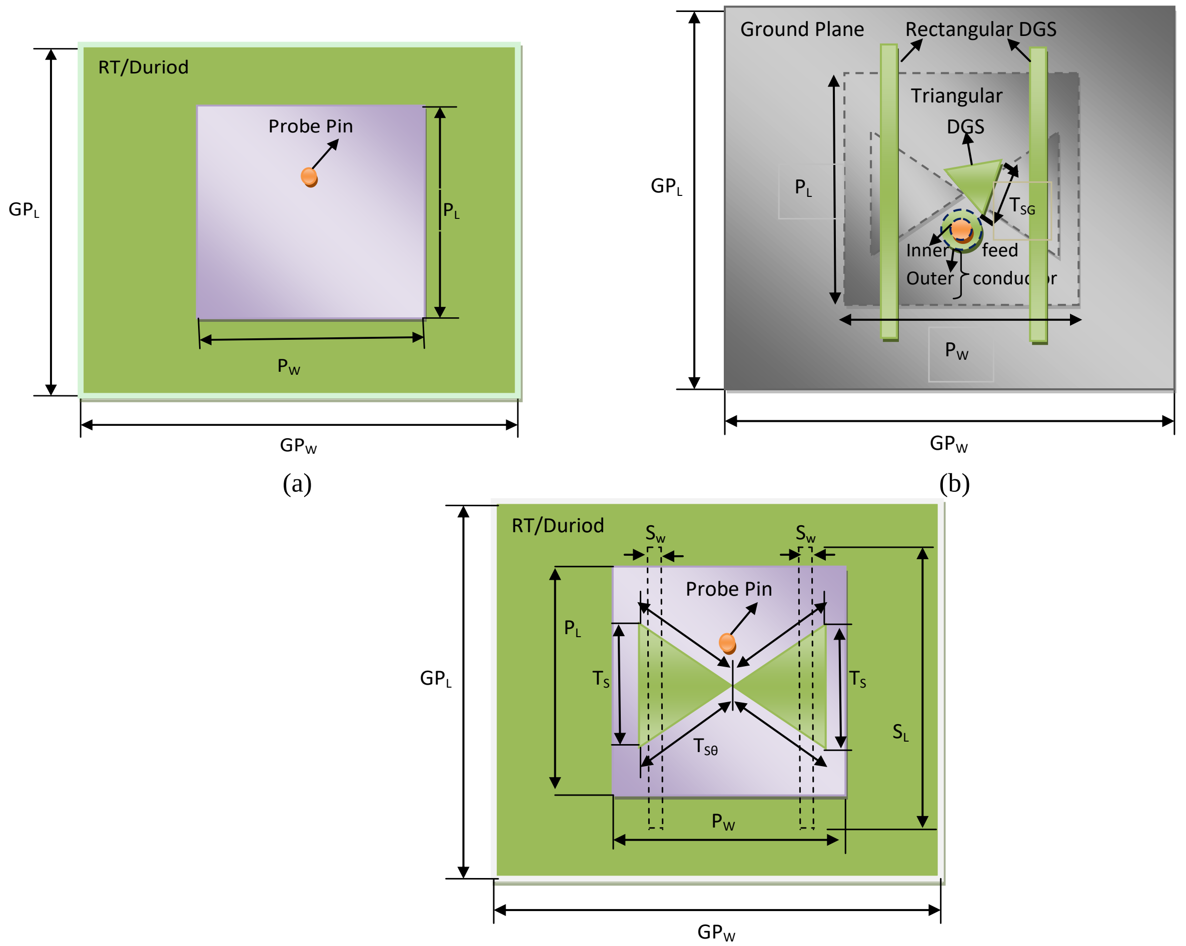
Microstrip patch antenna (MPA) has been widely used for wireless communication applications due to their attractive features, low cost, lightweight, compatibility to MMIC, easy fabrication and broadside radiations. The MPA concept is presented for the first time in 1953 [1]. To reduce the size of the antenna without much more adverse effect on bandwidth and the gain of an antenna, various methods have been proposed like using dielectric substrates with high permittivity [2]. The microstrip antenna of any patch shape is capable to resonate at many frequencies, which is a principal feature of resonant cavities. Therefore, microstrip antennas can be considered as cavities with moderate *Q* values [3]. The dual and triple-band microstrip antennas (MSAs) are realized by cutting a slot at an appropriate position inside the patch and cutting a rectangular slot on the radiating edge with half U-slot on the non-radiating edge of a rectangular MSA is reported [4]. The microstrip patch antenna designed with O-shaped patch element and ground plane has been modified with an inverted L-slot and two unequal slits are resonating at three different bands, viz. 2.35-2.86, 3.0-4.3, and 5.64-6.85 GHz with respective bandwidths of 510 MHz, 1.3 GHz, and 1.21 GHz is reported[5].

The antenna is designed with a low-profile cylindrical monopole with a top-loaded meander line patch for K-PCS Operation, and a comer-truncated square-ring microstrip patch antenna with four-slits for GPS operation using FR-4 substrate reported impedance bandwidths are about l20MHz (1744MHz-1864MHz) for K-PCS band and 60MHz (I546MHz-1606MHz) for GPS-band having peak gain of about 7.3dBi[6]. A multi-band, wideband and EBG antenna is designed for voice and data communication, novel multiband antenna designs for multiple frequency applications. The first design is based on fractal concepts, is a Sierpinski gasket type, the second design combines a microstrip patch with a cylindrical dielectric resonator and operates at multiple frequencies. A dual-band antenna designed and resonates at 2.4GHz and 5GHz band [7]. Two multi-frequency patch antennas have been designed; the first one shows two dipolar modes at 1.06 GHz and 2.16 GHz and a monopole mode at 1.45 GHz. The second antenna is designed to work at closer frequencies. In this case, the frequency ratio is dramatically reduced to produce a dual dipolar antenna working at 1.81 GHz and 2.20 GHz. microstrip patch antennas partially filled within LH structures have been proposed [8].Compact circularly polarized dual band MPA for global applications with the uplink frequency (1.61GHz-1.625GHz) and downlink frequency (2.4835GHz-2.5GHz). Here 3dB of axial ratio bandwidth of various techniques is calculated and their comparisons are simulated [9]. Pair of modified U-shaped slots in the ground plane and a complex slots etched on the patch, two frequency wide bands of 1.38–3.98 GHz (97%) and 5.15–6.2 GHz (18%) is achieved [10]. The microstrip patch antenna was designed using FR4 substrate, consists of double square loops ring and one square loops elements, which is used to improve the bandwidths and gain onsets of operating frequencies for a U-slot patch antenna resonating at 2.45 GHz and 3.5 GHz are 9.3 dB and 7.3 dB achieved [11]. The proposed antenna is switchable between two resonance frequencies by PIN diode. The return loss was -22 dB at frequency 2.4GHz and -27 dB at 3.5GHz.The bandwidths were 65MHz at 2.4 and 50 MHz at 3.5GHz. Reconfigurable dual-band antenna for two heterogeneous transceivers i.e. WLAN 2.4 GHz and fixed WiMAX 3.5 GHz is designed analyzed and evaluated [12].

A convex pentagon shaped microstrip antenna that works at 1.8GHz and 2.45 GHz for cellular communication and Bluetooth / RFID applications. [13]. Loops on the patch are arranged in a symmetrical multi-antenna structure for a dual-polarized loop patch antenna system for 2.4 GHz WLAN applications has been proposed and tested[14]. Quad-frequency linearly-polarized and dual-frequency circularly-polarized microstrip-patch antennas with CRLH loading are called as dual- or multi-frequency Micro-strip patch antennas are proposed [15]. The antenna consists of a radiating rectangular patch with the defected ground plane. The patch of the antenna is separated from the ground plane by the FR-4 Epoxy substrate, reconfigurability is achieved by using ON/OFF states of the PIN diode. When PIN diode is OFF is operating in (3.6 GHz to 4.2 GHz) can be used for satellite communication in C-band for downlinks. When it is ON mode operates at (3.3GHzto 3.5 GHz and 4.4 GHz to 4.8 GHz). [16]. A multi-band microstrip patch antenna based on complementary split ring Resonator (CSRR) is designed to resonate at 5.7GHz for cellular communication in dual and triple and WiMAX applications [17]. Monopole ultra wideband antenna with E- and inverted L shaped which exhibit multi-resonant frequencies resonate at 2.20GHZ, 3.40GHZ and 5.84GHz and their return loss is given by -20.48dB, -18.56dB and -35.93dB respectively. [18].

The antenna is designed to meet five frequency bands which are 0.9GHz, 1.8GHz, 2.1GHz, 2.45GHz and 2.8GHz. The microstrip patch antenna was designed to operate as a dual band and capital L-slot was introduced to design as triple band antenna. [19]. The antenna is designed for frequency 1GHz by using FR4 as a substrate with a dielectric constant of 4.4, and a loss factor of 1.02. [20]. Two separate U-shaped patches operating at different frequencies and a multi-stub microstrip feed line operating at 1.9GHz and 2.6GHz dual-band bandpass responses, band gains are 6.7 and 7.3dBi. [21].

A novel multiband patch antenna with unidirectional radiation is proposed by integrating resonators in the design to work for four bands at 4.6, 5.05, 5.8, and 6.3GHz. The proposed antenna is designed by using Rogers 4003 as substrate [22]. The antenna designed to operate in the frequency bands of 1.78-2.74GHz and 3.33-6.06GHz that covers LTE, BLUETOOTH, Wi-MAX and WLAN application. The antenna consists of two concentric square ring slots etched on the corner truncated square patch monopole radiator to improve the bandwidth and isolation up to 15dB isolation and less than 10dB[23]. Multiband microstrip antenna with multiple ring patches are arranged concentrically and two varactor diodes are mounted on each ring patch. L-shaped feeding probe is used to excite the ring patches [24]. A low profile asymmetric coplanar strip (ACS) fed tri-band antenna is designed with one L-shape radiating element and two more rectangular radiating planes are added to the radiating patch, in order to generate three resonant frequencies (2.3GHz–2.5GHz), (3.35GHz–3.7GHz) and (6.2GHz–8.6GHz). [25].



(a) (b) (c)

Figure 1: Schematic diagram (a) Conventional RMPA, (b) Bottom view of modified RMPA, (c) Top view of modified RMPA

II. ANTENNA CONFIGURATION

The conventional rectangular microstrip patch antenna (RMPA) of substrate RT/Duriod 5880 has thickness h=1.575mm with a dielectric constant of ε_r=2.2 is fed by coaxial probe feed. The RMPA designed to resonate at 2.4 GHz. The dimension of a conventional antenna patch is (41 X 49) mm^2 with a thickness of 0.03mm. For proper radiation, the length and width of the ground plane is ($P_L + \lambda/4$=103.5 mm) and ($P_W + \lambda/4$=111.5 mm), but the length and width are taken equal (G_L=G_W=80 mm) and thickness t=0.03mm. The conventional antenna is simulated using HFSS [26], which results the S_{11} is below -10dB at 2.35 GHz, 4.01GHz and 4.72 GHz. Only the 2.35 GHz is dominating type and the other two are higher order resonances of non-dominating type.

The conventional MPA is modified with two symmetric rectangular slots of length $\lambda/2$ and they are optimized to (60 X 1) mm^2 and one triangle shape of its two sides approximately equals to $\lambda/8$ is optimized as (14.9 X 13.6 X 14.9) mm^3 are etched in ground plane as DGS elements. Also, the conventional antenna patch has defected with two opposite symmetric triangles with sides are $\lambda/6$ and then sides are optimized to a dimension (22.7 X 20 X 20) mm^3. The schematic diagram of conventional RMPA is shown in figure-1(a). The bottom and top view of modified RMPA is shown in figure-1(a) and (b). The proposed RMPA is resonating at 1.65GHz, 1.8 GHz, 3GHz, 3.17 GHz, 3.88GHz, 4.44GHz and 4.91 GHz, all the resonance are of dominating type except 4.91 GHz resonance, all dominating resonances are having different peak gains and XP levels. The rectangular and triangular slots dimension and position are finalized through optimization. All the dimensions of conventional and modified RMPA's are given in millimetre and are given in Table-1.

III. ANTENNA DESIGN PROCEDURE

The microstrip patch antenna is designed for a resonating frequency f_0 = 2.4 GHz. The dimensions of the patch are calculated as follows and calculated dimensions are given in Table-1

Step-1: calculating the width of the patch (w)

$$W = \frac{C}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Step-2: calculating the effective dielectric constant

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

Step-3: calculating the incremental length due to the fringing field (ΔL)

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} + 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{3}$$

Step-4: calculating the length of the patch (L)

Representation	Description	Size (mm)
GP_W	The width of the Ground Plane	80
GP_L	Length of Ground Plane	80
P_W	Width of Patch	49
P_L	Length of Patch	41
h	Height of substrate	1.575
t	Thickness of copper	0.03
T_{SG}	The side length of DGS triangle	14.5
T_S	The side length of DMS Triangle(along X-axis)	22.7
$T_{S\theta}$	Inclined length of DMS triangle	20
S_W	Slot Width	1
S_L	Slot length	60

Table-1: Dimensions of conventional and modified RMPA

$$L = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

Step-5: calculating the effective length of the patch (L_{eff})

$$L_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} \qquad (5)$$

IV. DGS elements and its optimization

1. EFFECT OF ONE RECTANGULAR DGS SLOT

The conventional RMPA is modified with a rectangular slot etched in the ground plane and its length is varied in steps of λ/2 and is shown in table-2. From table-2 it is clear that, compare to alliteration, when the length of the slot is less than λ/2(60 mm) the peak gain is maximum, therefore the length is fixed at 60mm. For all the values of length of the slot, there exist three to four resonances, but among them only a dominating mode at 2.34 GHz.

'L' of slot	f_0(GHz)	BW_{-10dB} (MHz)	S_{11}(dB)	Peak Gain(dB)
λ/8	2.34	25	-18	8.15
λ/6	2.34	30	-16	8.11
λ/4	2.34	30	-14.5	8.17
λ/2	2.34	30	-17	7.85
<λ/2(60mm)	2.34	30	-14.3	8.34

L=length, f_0=resonating frequency, BW=Bandwidth, S_{11}= reflection coefficient

Table 2: Results due to varying the length of one rectangular DGS slot

2. EFFECT OF BOTH RECTANGULAR DGS SLOTS

Since the length of the first rectangular slot is fixed at 60 mm, a second rectangular slot of the same length is etched in the ground and the RMPA resonating at five different resonating frequencies are well below -10 dB (S_{11}). The resonances are 1.66 GHz, 1.79 GHz, 2.17 GHz, 3.26 GHz and 4.32 GHz. The first four resonances are of dominating type and the last resonance is not a dominating mode. The length of both slots is again varied in steps of λ/2 by observing S_{11} and radiation characteristics. When both slots are of length exactly equal to λ/2 the antenna becomes a dual band, but the length is decreased to 60 mm the antenna behaves like a quad-band antenna. The result obtained due to the simultaneous variation of both rectangular DGS slots is shown in table-3.

'L' of slot	f_0(GHz) dominating modes only	BW_{-10dB} (MHz)	S_{11}(dB)	Peak Gain(dB)
λ/10	2.34	30	-18	8.15
λ/8	2.34	25	-19	8.4
λ/6	2.34	30	-16	8.33
λ/4	2.34	30	-16	8.5
λ/2(Dual band)	1.88, 2.17	20, 25	-12, -14	3.5, 8.3
<λ/2(60mm) (Triple band)	1.66, 1.8, 2.17	0, 30	-10,-16, -17.34	5.74, 5.11, 8.30

L=length, f_0=resonating frequency, BW=Bandwidth, S11= reflection co-efficient

Table 3: Results due to varying the length of both rectangular DGS slot simultaneously.

3. EFFECT OF TRIANGULAR DGS

After fixing the length of two rectangular DGS slots, a polyhedron of triangular shape etched in the ground plane, which results there are a 10 MHz in bandwidth obtained at 1.66 GHz resonance due to the shift of S_{11} below -10 dB. Due to triangular DGS, there is slight up-shift in S_{11} for other resonances are observed but they are below -10dB and remains quad-band antenna. The side length of DGS triangular is chosen 14.5mm (< λ / 8).

V. DMS ELEMENTS AND ITS OPTIMIZATION

The ground plane has defected with two rectangular slots and one triangular slot one by one, found improvements in the

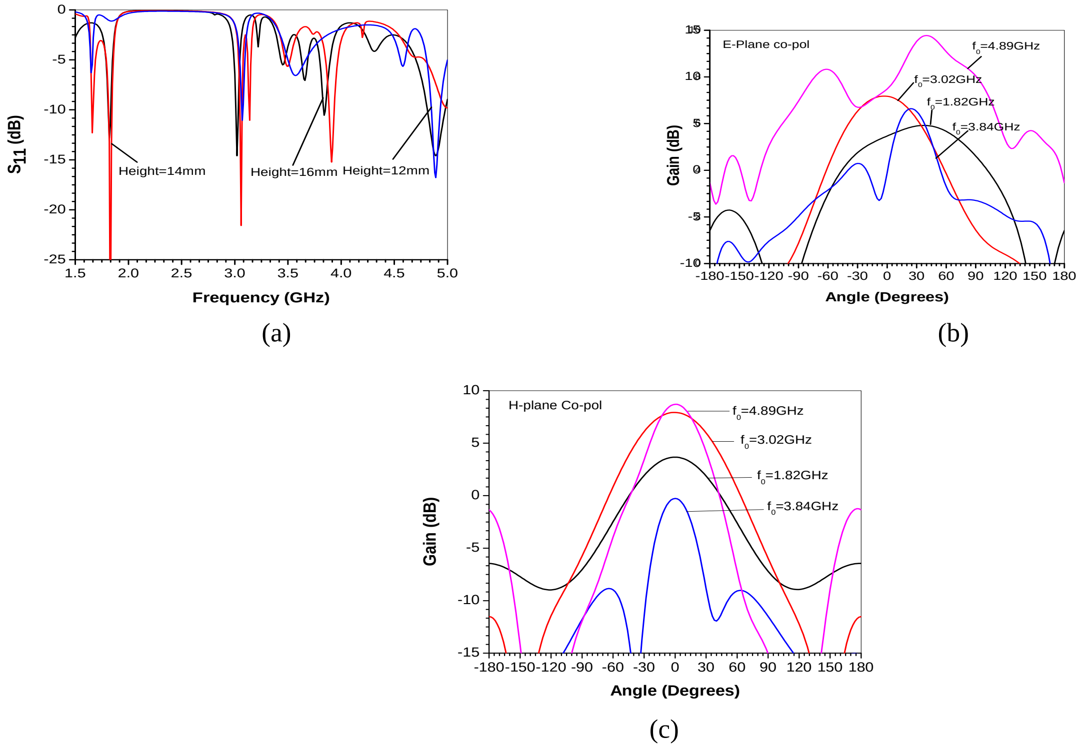


Figure 2:Return loss and radiation pattern at width =16mm (a) Combined return loss due to width varies of both Triangular DMS (b) E-plane radiation at width =16mm (c) H-plane radiation at width =16mm,

number of dominating modes for the frequency range between1.5 GHz to 5.5 GHz. For further investigation the conducting patch is defected with polyhedron of the triangular shape is etched at one edge of the patch and observed the S_{11} and radiation characteristics. The triangular DMS element demolishes all the resonances and resonating at new resonances at 1.83 GHz and 4.53 GHz. The 1.83GHz is a dominating type with a gain of 4.5 dB and 4.53 GHz is not a dominating type. If the same triangle is

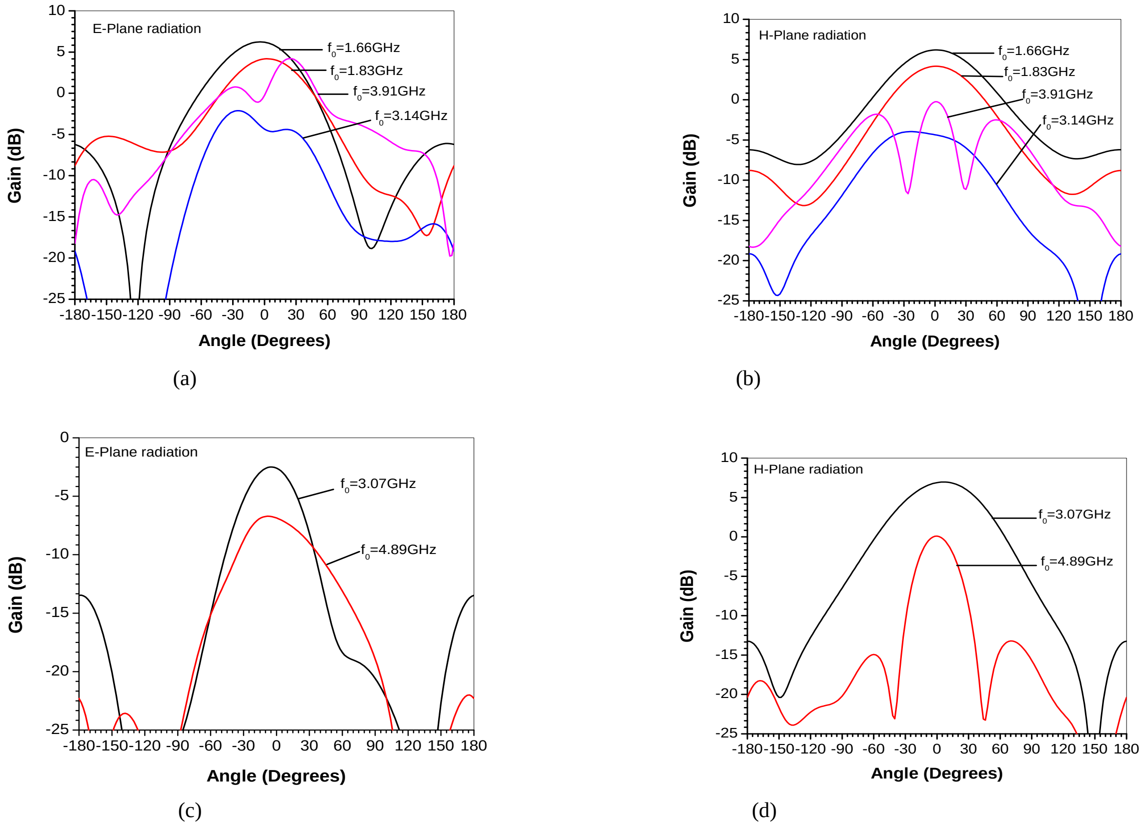


Figure 3: Radiation pattern due to variation in width of both Triangular DMS slots, (a) E-plane radiation at width t=14mm (b) H-plane radiation at width =14mm, (c) E-plane radiation at width =12mm (d) H-plane radiation at width =12mm

shifted to exactly opposite end of the patch is resonating at 1.81 GHz, 3.06 GHz and 4.46 GHz. The 1.81 GHz and 3.06 GHz are of dominating type with a Gain 3.6 dB and 2.0 dB respectively, but 4.46 GHz is not a dominating type. Retaining both triangular DMS elements in the patch and all DGS elements creates six resonances with S_{11} below -10 dB. The resonances at 1.65GHz with matching -18dB, 1.8 GHz with matching -22dB, 3GHz with matching -15dB, 3.17 GHz with matching -12dB, 3.88GHz with matching -14dB, 4.44GHz with matching -12dB and 4.91 GHz with matching -17dB. The DMS triangle width is varied in steps of 2 mm and observed S_{11} and its radiation characteristics are shown in figure-2 and figure-3.

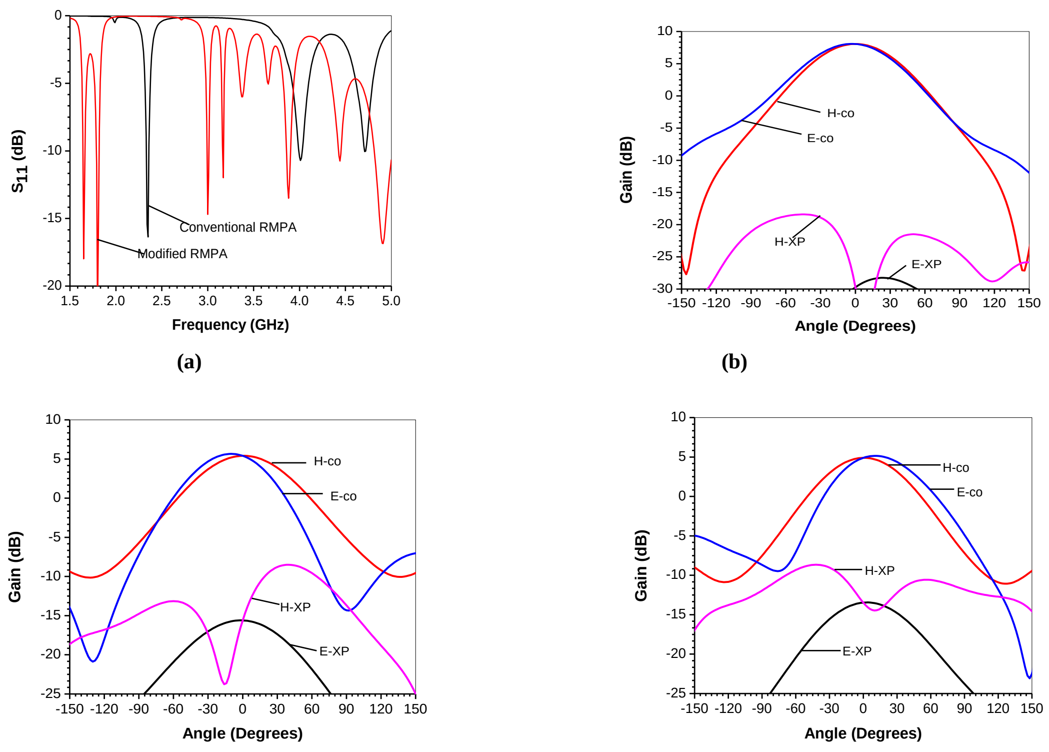
The figure-2 (a) shows that, the return loss characteristics due to varying width of both DMS triangular slots for 16 mm, 14mm and 12mm. When widths of both triangles are at 16 mm the RMPA resonates at 1.82 GHz, 3.02 GHz, 3.84 GHz and 4.89 GHz. The E-plane and H-plane radiation characteristics are shown in figure-2(b) and (c).

When widths of both triangles are at 14mm the RMPA generates four resonances at 1.66 GHz, 1.83 GHz, 3.14 GHz and 3.91 GHz. The E-plane and H-plane radiation characteristics are shown in figure-3(a) and (b). Similarly, the width is reduced to 12 mm the RMPA resonates at 3.07 GHz and 4.89 GHz. The E-plane and H-plane radiation characteristics are shown in figure-3(c) and (d). From the above optimization, if we reduce the width of the triangle the RMPA decreases the number of resonances. Finally, the width of both triangles is incremented by 2mm i.e. from 16mm to 18mm and is the final modified RMPA.

VI. RESULTS OF CONVENTIONAL AND PROPOSED RMPA.

The conventional RMPA is designed to resonate at 2.4 GHz frequency using coaxial probe feed and a dielectric substrate RT/Duriod 5880 with a dielectric constant ε_r=2.2 and thickness h=1.575mm. The conventional RMPA produces return loss (S_{11}) characteristics at 2.35GHz, 4.01 GHz and 4.72 GHz. The 2.35 GHz is a dominating resonance with a peak gain of 8 dB and XP levels are at (-18 dB, -21 dB) is shown in figure-4(a) and (b). The other two are the higher order resonances and are not depicted here. The conventional RMPA is modified with two rectangular slots of size (60 X 1) mm^2, one symmetric triangular slot as DGS elements of side 14.5 and two opposite triangles etched on the patch as DMS elements of sides (22.7, 20, 20) mm. The modified RMPA's S_{11} resonates at 1.65GHz, 1.8 GHz, 3GHz, 3.17 GHz, 3.88GHz, 4.44GHz and 4.91 GHz is shown in figure-4(a). Except the 4.91 GHz all six resonances are of dominating type, but each resonance has different peak gain, coverage angles and cross-polarization levels. The conventional antenna resonates at 2.35 GHz with two higher order modes; due to the defect in the ground and patch the proposed RMPA converts the higher order modes into dominating modes.

The figure-4(c) is a radiation characteristic of a proposed RMPA at 1.65 GHz having a peak gain of 5.6 dB with XP levels (-14



(b) (d)

Figure 4: Return loss and Radiation characteristics, (a) S_{11} of conventional and Modified RMPA, (b) conventional RMPA, (c) Modified at 1.65 GHz, (d) Modified at 1.8 GHz

dB, -9 dB). The radiation characteristic at 1.8 GHz has a peak gain of 5.2 dB with XP levels (-9 dB, -13 dB).

The figure-5(a) shows the radiation characteristic of a proposed RMPA at 3 GHz has a peak gain of 7.2 dB with XP levels are at (-11 dB, -13 dB). The figure-5(b) is the radiation characteristic at 3.17 GHz with a peak gain of 6 dB, but it has a narrow

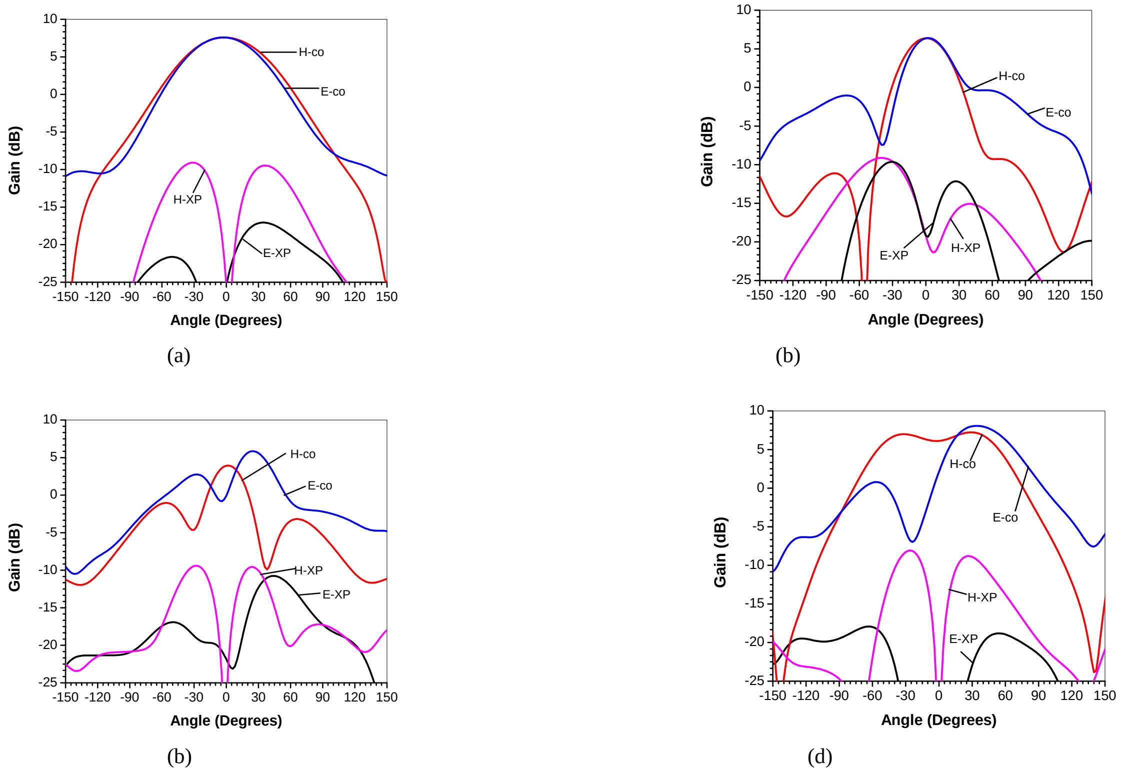


Figure 5: Radiation characteristics, (a) Modified at 3 GHz (b) Modified at 3.17 GHz (c) Modified at 3.88 GHz, (d) Modified at 4.44 GHz

angular coverage -30^0 to $+30^0$ and having XP levels are below -10dB. The radiation characteristic for 3.88 GHz resonance is shown in figure-5(c), the H-plane co-pol radiation has a peak gain 5 dB at the 0^0 with coverage angle from -30^0 to $+30^0$, but the E-plane has a peak gain at $+30^0$ instead of 0^0. Normally H-plane radiations are important than E-plane radiations. The figure-5(d) shows a flat H-plane co-pol for the coverage angle of $\pm 60^0$ with variable gain from (6.15 - 7.2) dB a peak gain of slight, but E-plane peak gain again appears at $+30^0$ and having 1.1 dB at 0^0.

When a rectangular slot etched in the ground and even its length is varied there is a small shift in S_{11}, another slot etched at opposite end of ground starts disturbing the current distribution and exactly both slots are at $\lambda/2$ generates the dual resonance. Further optimizing the length of both slots generates nearby additional resonance. When the patch is defected, the shielding current gets disturbed and generating multiple resonances.

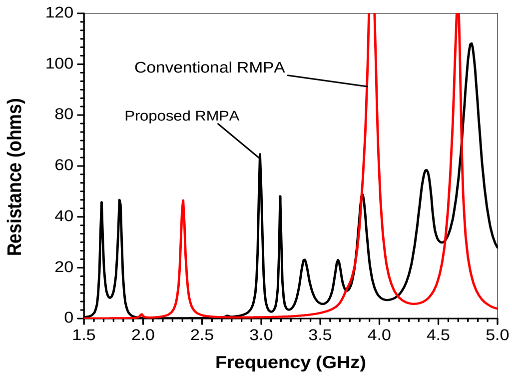


Figure-6: Comparison of the resistance value of conventional and proposed RMPA along the frequency of operation

The impedance matching along the frequency range from 1.5 GHz to 5.5 GHz is also observed and is shown in figure-6. The conventional RMPA is exactly matched to 50Ω at 2.35GHz and offers higher resistance for the higher order modes generating at 4.01 GHz and 4.72 GHz. The proposed RMPA resonates at seven different frequencies of 1.65 GHz, 1.8 GHz, 3 GHz, 3.17 GHz, 3.88 GHz, 4.44 GHz and 4.91 GHz. The impedance matching of 50Ω is obtained at1.65 GHz, 1.8 GHz, 3.17 GHz, 3.88 GHz, but a very small mismatch for 3 GHz of 60 Ω and 4.44 GHz of 57Ω. It is almost 110Ω for higher order mode at 4.91 GHz.

VII. CONCLUSION

The conventional rectangular microstrip patch antenna is designed to resonate at 2.4 GHz and is modified with two rectangular slots, triangular slot in ground plane as DGS elements and two opposite triangular slots in the patch as DMS elements are proposed. The multiple frequencies can be obtained by changing the slot dimensions and Hex-band RMPA is proposed. The proposed RMPA is resonating at 1.65GHz, 1.8 GHz, 3GHz, 3.17 GHz, 3.88GHz and 4.44GHz, the bandwidth of all resonances are between 20MHz to 30 MHz with a peak gain of about 6 dB for all the resonances. At each resonance, there is good impedance matching is observed. The RMPA is simulated using FEM-based HFSS v15.0 simulator.

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