A MULTIBAND RHOMBUS PATCH ANTENNA WITH SLOTS FOR C, X, AND KU-BAND APPLICATIONS

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***Abstract*—** A multiband rhombus-shaped patch antenna with slots is presented in this paper. The dimensions of the proposed antenna are 50mm x 48mm x 1 mm. The rhombus patch antenna with rhombus slots results in a multiband operating at a bandwidth of 210MHz (6.70GHz to 6.91GHz), 230MHz (8.80GHz to 9.03GHz), 440MHz (10.36GHz to 10.80GHz), 860MHz (12.92GHz to 13.78GHz), 550MHz (15.15GHz to 15.70GHZ) and 400MHz (16.75GHz to 17.15GHz) with a peak gain of 6.87dBi at 6.8GHz and exhibits circular polarization at the frequency range of 8.39GHz to 8.41GHz. The proposed antenna is suitable for C, X, and Ku- band applications. Simulations are carried out using Ansys HFSS software.
***Key words*—** *Rhombus patch, slots, Microstrip feed line, Circular Polarization, Multiband.*

I. INTRODUCTION

A Microstrip Patch Antenna (MPA) is composed of a metallic patch radiator on a dielectric substrate with a thin electrical layer as well as a ground made of a metal like copper (or) gold. Microstrip patch antennas provide multiple-band operation with high stable gain and good directional radiation characteristics. The increasing need for frequency spectrum in the area of wireless communications is the main factor influencing the study of the multiband and wideband monopole. A quad-band dual-sense CP antenna is presented for wireless applications with multifunction. By utilizing a rhombus-shaped slit, and an inverted parasitic element (V-shaped), the surface currents of the antenna are balanced in the horizontal and vertical directions. The impedance bandwidth of 83.9 % (2.33-5.70GHz) is achieved. The 3-dB axial ratio bandwidths of 7.3%, 9.0%, 3.7%, and 7.1% are obtained with the frequency ranges of 2.38-2.56GHz, 2.75-3.03 GHz, 3.42-3.53GHz and 5.16-5.54GHz respectively. The maximum gains which are obtained within the axial ratio bandwidths are 2.5, 2.9, 3.4, and 2.7dBi [1].

A G-shape antenna is reported with peak gains of 4 dBi at 3.7 GHz, 1dBi at 5.2 GHz, and 5.2dBi at 5.8GHz for modern communication systems. The gain of the antenna is enhanced by suggesting a multiband antenna with an identical two-element patch. The impedance bandwidth of the antenna is increased by feeding the feed network [2]. An MPA is designed with plus-shaped slots for the applications of Bluetooth and Wi-MAX. A gain of 7.62 dBi at 2.4511GHz with a bandwidth of 90MHz (3.26%), and 70 MHz (2.17%). The return loss of -22dB at 2.4511GHz and 20dB at 3.2141GHz is obtained [3]. A planar antenna is reported with a gain of 2dBi for android devices. To enhance the gain of the antenna, three types of structures i.e., L-type, inverted F-type, and C-type are inserted in the patch antenna. The multiband is obtained with a bandwidth over 100MHz. The planar antenna obtained ten frequency bands of radiation between 800MHz to 9 GHz [4].

A rectangular microstrip antenna using a circular ring slot technique is presented for C-band, X-band, Ku-band, and K-band applications simply called four-band applications. The gains of 4.88 dBi, 3.83dBi, 4.19dBi, and 4.84dBi are obtained with the return loss of -23.92dB at 6.7GHz, -10.71dB at 10.85GHz, -15.12dB at 14.15GHz and 13.38dB at 19.50GHz respectively [5]. A square patch microstrip antenna is designed with circular polarization. To obtain the spacing between the resonant modes, vertical slots are inserted in the defective ground structure. The antenna exhibits axial ratio bandwidth of 114MHz (10.6%) that lies inside the impedance bandwidth of 669MHz (52%) with a peak gain of 5dBi [6].

A UWB microstrip slot antenna is designed using a very sharp frequency notched function. A square ring resonator is integrated into the tuning stub to reduce gain by about 24dBi at the boresight direction [7]. A low-profile planar antenna is reported with a minimum gain of 2 dBi for multiband, 4G, and

WLAN applications. To achieve multiband, a coupled-fed mechanism is utilized and an L-type, C-type, and F-type slots are inserted in the antenna design. The reported antenna is mostly utilized in the frequency range of 800MHz to 9GHz [8]. A patch antenna is designed with U-slot and multiple layers for wireless applications. A triple band of 1.6GHz, 1.9GHz, and 3.8 GHz is obtained with a bandwidth of 600MHz. Due to the three layers, the bandwidth of the antenna is enhanced [9]. A monopole antenna is designed with a multiband-wideband for ICMS, DECT, Bluetooth, and WLAN applications. The gain of above 4.6dBi is obtained with a directivity of 8.5dBi. The bandwidth of 200MHz, 1100MHz, and 2030MHz is obtained with the frequency bands around 1.96GHz, 3GHz, and 5GHz respectively. [10].

Based on the concepts of the fractal Sierpinski gasket and circular disc monopole, a unique technique for building a wideband quasi-log periodic monopole antenna has been described. It may be capable of working in currently existing systems, including TETRA, GSM, DCS1800, UMTS, WLAN, Bluetooth, and HIPERLAN containing an impedance bandwidth of 40% and gain of 4.7dBi [11]. A model circularly polarized microstrip-line-fed ring slot antenna design that used a meandered-slot section to introduce asymmetry of printed square and annular ring slot antennas which is designed with the dimensions of 80mm x 80mm x 1.6mm. The CP design applied to both square and circular ring slot antennas when compared to the center frequency of 1720MHz, the bandwidth with a 3-dB axial ratio is 65MHz within the CP bandwidth,and the antenna gain ranges from 3.5 to 4.3dBi [12]. Dielectric resonators are loaded on two rectangular antennas forming hybrid structures each of dimensions 50x50x7.2 mm^3 suitable for tri-band and quad-band applications. The tri-band DR-loaded antenna resonates at 2.93GHz, 3.26GHz, and 5.5 GHz, and the quad-band DR-loaded antenna resonated at 2.48 GHz, 2.84GHz, 3.26GHz, and 5.5GHz [13].

Fractal geometry is a recursive generating methodology that produces contours with infinitely intricate fine structures. This fractal geometry can be used to miniaturize wire and patch antennas. It has been shown that increasing the fractal dimension of the antenna leads to a higher degree of miniaturization and that a high degree of complexity in the structure of the antenna is not required for miniaturization. Two applications of fractal antennas can be used in tightly packed linear arrays and phased arrays [14]. A microstrip patch antenna is designed for the applications of android phones, L, S and C-band. To reduce the antenna size, a E-Shaped slit is etched on a fractal patch. Further to miniaturize the antenna, two slits (H and L-shape) are inserted on the ground plane. In the frequency range of 1GHz to 8GHz, the design gets a multiband response with directivity in the range of 3.11dBi-5.84dBi. The antenna is suitable for mobile phone applications, L-Band, S-Band, and C-Band applications [15]. The fractal Sierpinski antenna with multiband behavior is described which is mainly the triangular shape of a single-band bow-tie antenna. The obtained bandwidth of 21% [16].

In this paper, a rhombus patch antenna with slots is proposed which offers multi-band with high gain. The recommended antenna obtained a bandwidth of 210MHz (6.70GHz to 6.9GHz), 230 MHz (8.80GHz to 9.03GHz), 44MHz (10.36GHz to 10.80GHz), 860 MHz (12.92GHz to 13.78GHz), 550MHz (15.15GHz to 15.70 GHz) and 400MHz (16.75GHz to 17.15GHz) with a high gain of 6.87dBi at 6.8GHz. The proposed antenna can be used in the applications of C, X, and Ku-band.

II. ANTENNA MODELING

Initially, a rhombus-shaped patch antenna is designed, and then the rhombus patch antenna is etched with circle slots at the edges. Then a circle slot is etched at the center of the rhombus patch antenna and this circle slot is cut using a square. To improve the antenna performance, a circle is inserted inside the first circle slot. Finally, to further improve, a plus-shaped slot is placed inside the second circle slot. The recommended rhombus patch antenna with slots is shown in Fig. 1.

Fig. 1 shows the suggested patch design starts with a square shape the patch is rotated by 45 degrees, and the outcome after rotating the square form can be described as a rhombus. The geometry of a rhombus-shaped patch antenna with slots is shown in the following figure. Table. 1 shows the dimensions of the proposed antenna that has been designed.

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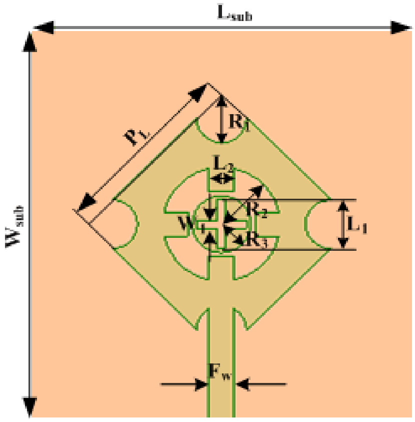

Fig. 1 Geometry of the proposed Rhombus Patch

Table.1 Dimension of the proposed Slotted Octagonal Patch Antenna.

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L_{sub}	48	R_3	3.5
W_{sub}	50	L_1	6
P_L	16	W_1	1
R_1	3	L_2	3
R_2	7	F_W	3

III. DESIGNING STEPS OF THE PROPOSED ANTENNA

STAGE-1: DESIGNING OF RHOMBUS PATCH ANTENNA

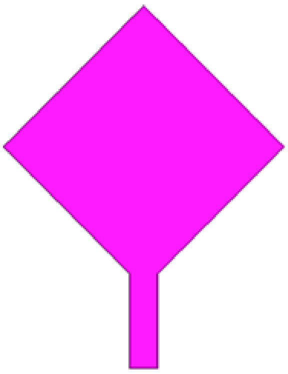

Fig. 2 Rhombus Patch Antenna (RPA)

The Rhombic shape antenna is designed with a Fr4_epoxy substrate with a thickness of 1mm has been considered. The basic patch antenna of rhombus shape is considered to develop the design which is shown in Fig.2. The dimensions considered for the RPA are a length of 16mm, a feed width of 3mm, and a feed length of 6.5Mmm.

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A. OPTIMIZATION OF PATCH LENGTH

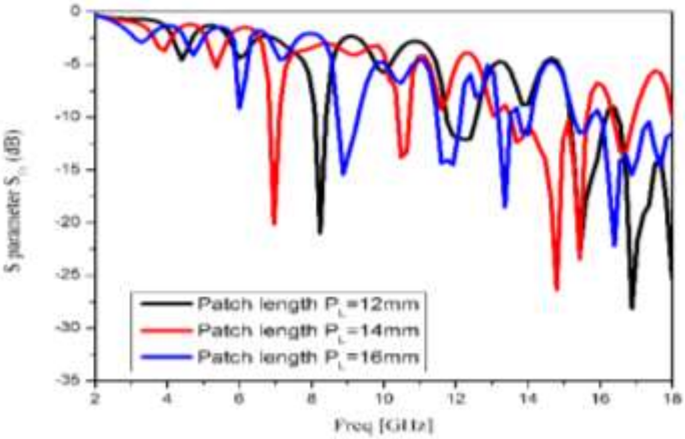

Fig. 3 Return loss for the variations of patch lengths.

Figure 3 illustrates the return loss for the patch length variations. The parametric analysis of the RPA is done with lengths (PL) of 12mm, 14mm, and 16mm respectively. When PL is 16mm the RPA obtained a bandwidth of 3.88GHz in the range of (15.56-19.44GHz) frequency band and achieved a gain of 4.21dBi at 17.48GHz. When RPA lengths of 12 and 14mm, a bandwidth of 1.51GHz (16.49-18.00GHz) are obtained with a gain of 4.96dBi at 16.88GHz and 2.11GHz (13.53-15.64GHz) is achieved with a gain of 3.93dBi at 14.80GHz respectively. Hence, a length of 16mm is chosen as an ideal parameter for the RPA.

B. OPTIMIZATION OF FEED WIDTH

The parametric analysis is done for the RPA with the feed widths (FW) of 2.8mm, 3mm, and 3.2mm. Fig. 4 represents the return loss plot for the different variations of the feed width. When the feed width FW is 2.8 mm, the RPA offers a bandwidth of 2.48GHz (1.52GHz to 8.00GHz) with a gain of 4.33dBi at16.40GHz. When FW is 3mm, the RPA delivers a bandwidth of 1.99GHz (16.01GHz to 18.00GHz) with a gain of 4.21dBi at 16.40GHz. Finally, when FW is 3.2 mm, the RPA obtained a bandwidth of 2.6GHz (15.36GHz to 18.00GHz) with a gain of 3.92 dBi at 16.40GHz. Here feed width of 3mm is chosen as the ideal parameter for the rhombus patch antenna.

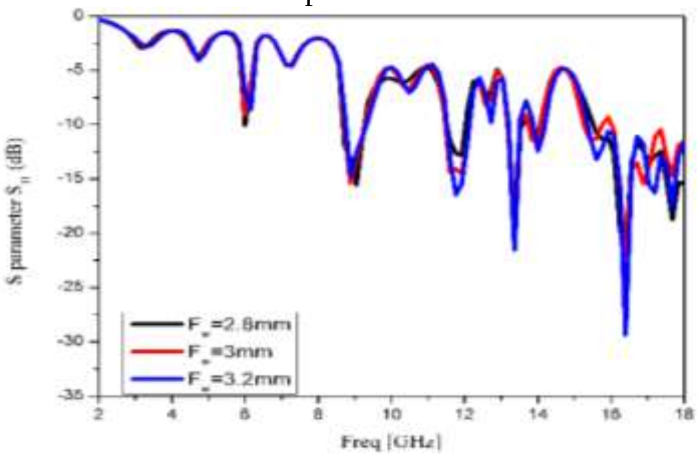

Fig. 4 Return loss for feed width variations of RPA.

STAGE 2: CIRCULAR SLOTS AT THE EDGES OF RPA

In this stage, for performance incrementation of the antenna, the RPA edges are cut with circles. RPA with the circles is shown in Fig. 5.

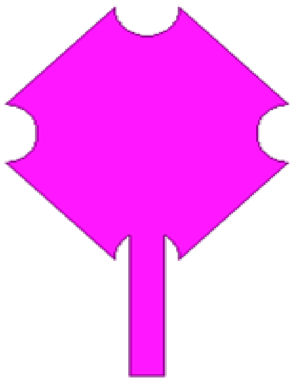

Fig. 5 Circle slots at the edges of RPA.

The parametric analysis has been done for the radius of the circles with R1=2, 3, and 4mm. From the obtained results, a radius of 3mm is selected as the ideal parameter. When the circle radius is 3mm, the RPA offers a peak gain of 5.34dBi at 16.72GHz and delivers a bandwidth of 1.37GHz (15.56GHz to 16.93GHz). The return loss plots for the different variations of the circle radius are presented in Fig. 6.

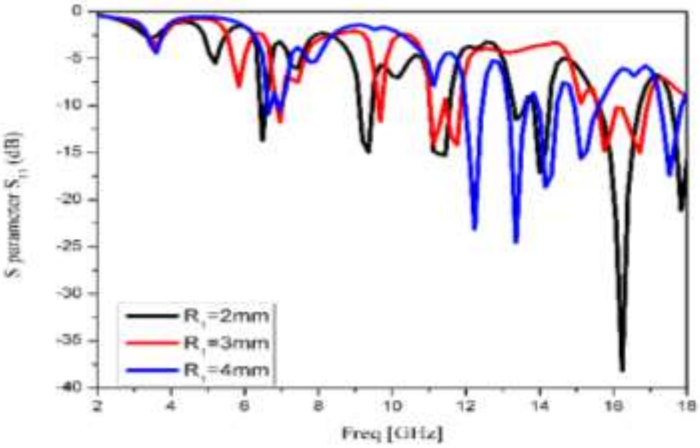

Fig. 6 Return loss for the variations of the radius of the circle slots at the edges of RPA

STAGE 3: A CIRCLE SLOT IN THE CENTER OF RPA

To increment the performance of the antenna, a circle slot is etched in the middle of the RPA. Fig. 7 illustrates a circle slit in the middle of the rhombus patch antenna. The parametric analysis of the radius of the circle slot has been done with 5mm, 6mm, and 7mm. From the obtained results, the radius of the first circle slot R1=7 mm is chosen as the ideal parameter. When R1=7mm, the rhombus patch antenna obtained a dual band with a peak gain of 3.87 dBi at 10.96GHz and 6.69dBi at 16.24GHz and achieved a bandwidth of 840MHz (10.81GHz to 11.65GHz) and 750MHz (15.91GHz to 16.66GHz). Return loss plots for the different variations of the radius of the first circle slot are presented below in Fig. 8.

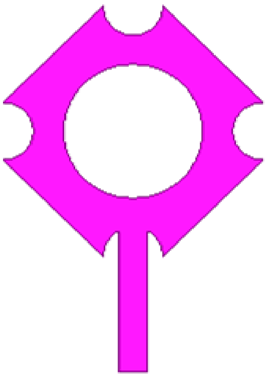

Fig. 7 A circle slot etched in the middle of RPA

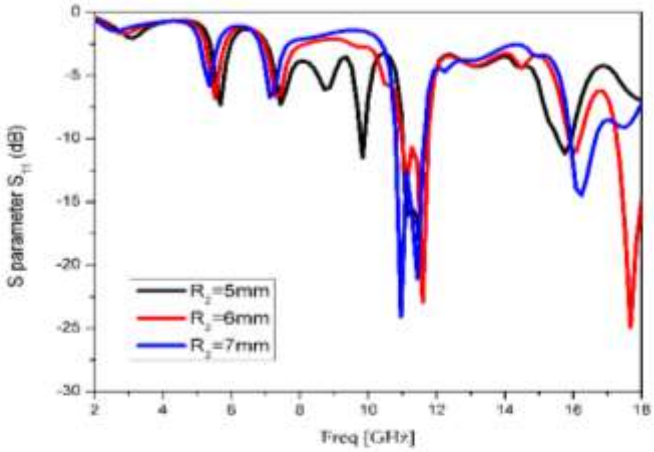

Fig. 8 Return loss for the radius variations of the first circle slot

STAGE 4: EFFECT OF CIRCLE SLOT IN THE MIDDLE OF RPA

Furthermore, to increase the antenna performance, the first circle slot is cut by utilizing squares. The length dimensions used for the square slots are 1mm, 2mm, and 3mm. The parametric analysis for the square slot length has been done and presented below in Fig. 10. From the obtained results, RPA offers a peak gain of 5.82 dBi at 15.28GHz and obtained a triple band with a bandwidth of 160MHz (6.57GHz to 6.73GHz), 260MHz (8.42GHz to 8.68 GHz) and 9MHz (10.30 GHz to 10.39GHz) respectively. Therefore, a square slot length (L2) of 3 mm is chosen as the ideal parameter.

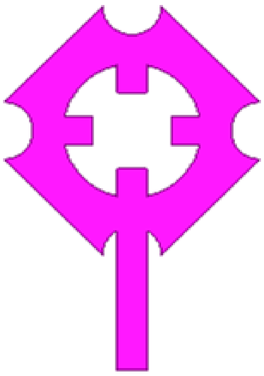

Fig. 9 Effect of circle slot in the middle of RPA

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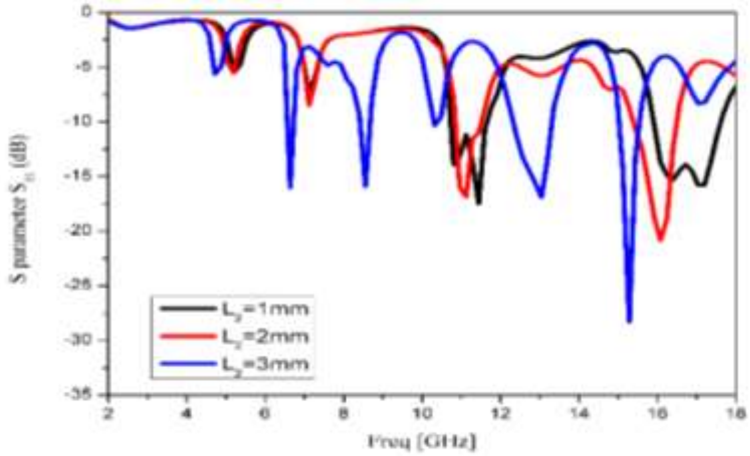

Fig. 10 Effect of circle slot in the middle of RPA

STAGE 5: INSERTING A CIRCLE SLIT INSIDE THE FIRST CIRCLE SLOT

Fig. 11 illustrates a circle slit inserted inside the first circle slot. Furthermore, to improve the gain of the antenna a circle slit is inserted inside the first circle slot. For the radius (R3) of the second circle slot, different variations have been done with 2mm, 3mm, and 3.5mm. From the obtained results, when the radius is 3.5mm, a peak gain of 6.28dBi at 8.88GHz and offers a multiband with a bandwidth of 310MHz (8.72GHz to 9.03GHz), 520MHz (10.55GHz to 11.07GHz), 860MHz (13.20GHz to 14.06GHz), 590MHz (15.41GHz to 16GHz) and 380MHz (17.27GHz to 17.65GHz) respectively.

Fig. 11 Inserting a circle slit inside the first circle slot

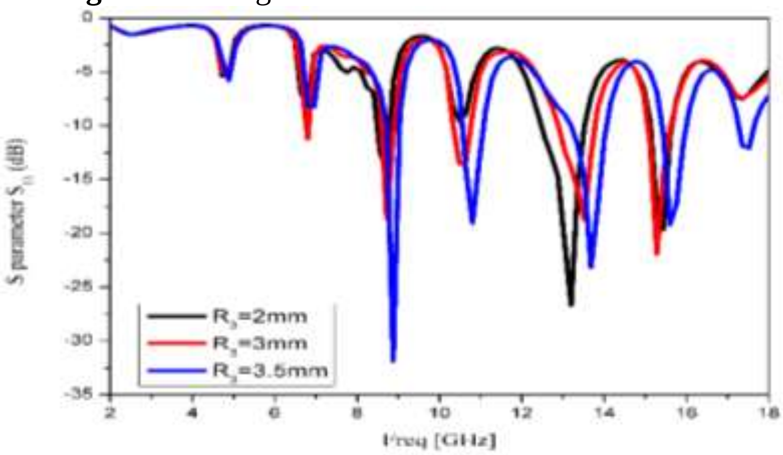

Fig.12 Return loss for different variations of the radius of second circle slit.

STAGE-6: ETCHING A PLUS SLOT INSIDE THE SECOND CIRCLE SLOT

In this stage, to increase the antenna performance a plus-shaped slot is etched inside the second circle slit. The parametric analysis has been done for the lengths and widths of the plus-shaped slot. The lengths and widths are L_1=4mm and W_1= 0.5mm, L_1=6mm, W_1= 0.5mm, L_1=6mm and W_1= 1mm, L_1=6mm, and W_1= 1.5mm respectively. From the obtained results, when slot length L_1=6mm and

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width W_1=1mm the RPA offers a peak gain of 6.87dBi at 6.80GHz with a bandwidth of 210MHz (6.70GHz to 6.91GHz), 230 MHz (8.80GHz to 9.03GHz), 440MHz (10.36GHz to 10.80 GHz), 860MHz (12.92GHz to 13.78GHz), 520MHz (15.18GHz to 15.70GHz) and 400MHz (16.75GHz to 17.15GHz) respectively. Therefore, a length of 6mm and a width of 1 mm are chosen as the ideal parameters. RPA with a plus-shaped slot inside the second circle slit is shown in Fig. 13. Return loss plot is presented below in Fig. 14.

Fig. 13 RPA with a plus-shaped slot inside the second circle slot

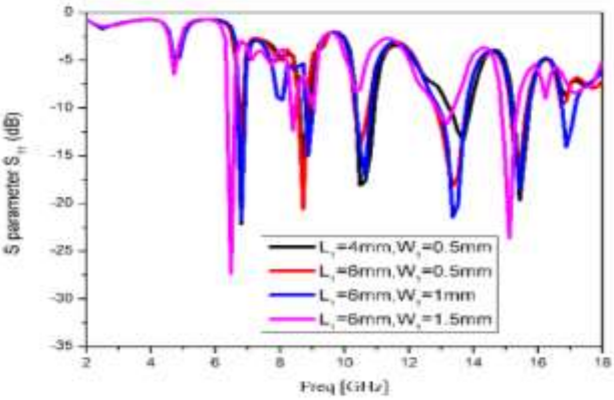

Fig. 14 Return loss for plus slot RPA

IV. RESULTS AND DISCUSSIONS

In this section, the simulated results of the proposed antennas are discussed. Return loss, gain, axial ratio, and radiation pattern of the proposed antennas are presented.

RETURN LOSS:

A comparison of the return loss obtained for all six stages of the proposed antennas in this paper is shown in Fig.15.

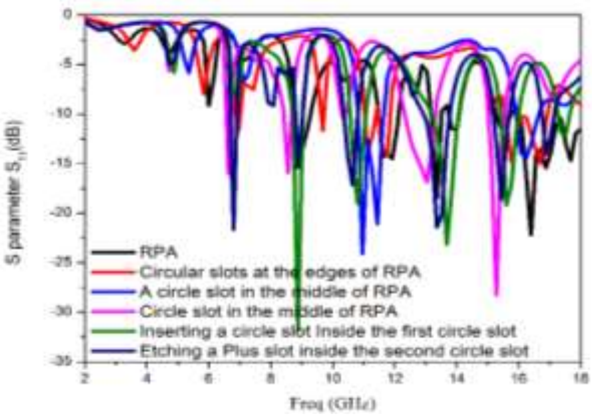

Fig. 15 Comparison of the return loss for the proposed antennas.

From the comparison, it is evident the final proposed antenna is operating in the multi band with a peak gain of 6.87dBi at 6.8GHz.

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AXIAL RATIO

The axial ratio obtained for the proposed antenna is shown in Fig. 16. The recommended antenna obtained axial ratio is less than 3dB with a frequency range of 8.39GHz to 8.41GHz at 8.4GHz.

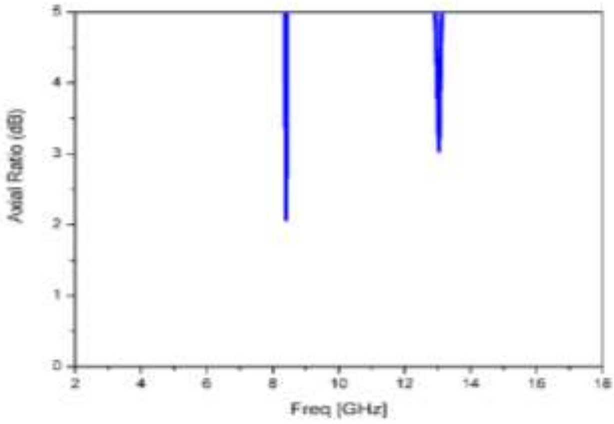


Fig. 16 The axial ratio for the proposed antenna.

GAIN:

The gain plot of the proposed antenna is presented in Fig. 17. The proposed antenna obtained a peak gain of 6.87dBi at 6.8GHz.

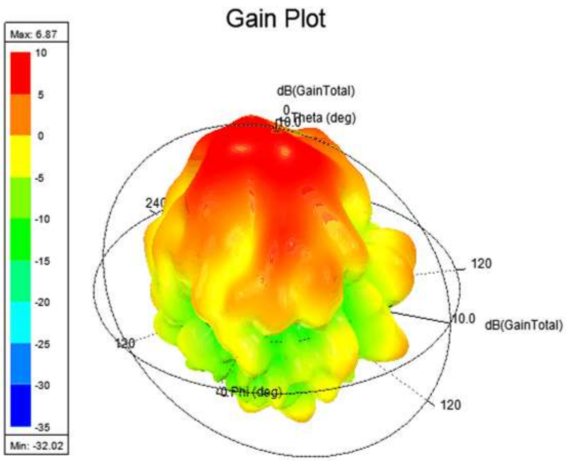
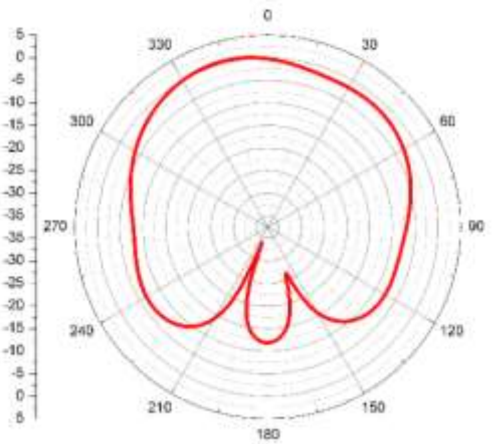


Fig. 17 3D gain plot of the proposed antenna at 6.8GHz.

RADIATION PATTERN:

The radiation patterns of the proposed rhombus patch antenna are shown in Fig. 18. Radiation patterns are taken at the least return loss.



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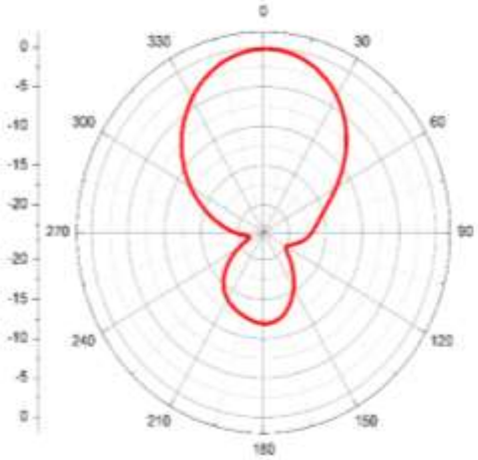
(a)



(b)

Fig. 18 The radiation pattern of the Proposed antenna at 6.80 GHz for (a) E-Plane, and (b) H-Plane

V. CONCLUSION

A Rhombic patch antenna with slots for multi-band operation is described in this paper. The proposed design operates with a bandwidth of 210MHz (6.70GHz to 6.91GHz), 230MHz (8.80GHz to 9.03GHz), 440MHz (10.36GHz to 10.80GHz), 860 MHz (12.92GHz to 13.78GHz), 550MHz (15.15GHz to 15.70GHZ) and 400MHz (16.75GHz to 17.15GHz) and achieved a peak gain of 6.87dBi at 6.8GHz. The proposed antenna is suitable for C, X, and Ku-band applications.

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