TRIPLE BAND HEXAGONAL PATCH ANTENNA WITH SLOTS

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Abstract— In this work, a hexagonal microstrip patch antenna with slots is presented. The overall dimension of the proposed antenna is 52x46x1.6mm^3. The proposed antenna operates over triple frequency ranges resulting in bandwidths of 930MHz (9.04-9.97GHz), 970MHz (10.31-11.28GHz), and 2.51GHz (11.49–14GHz). The peak gain of the antenna is observed to be 6.40dBi at 13.04GHz. The proposed antenna is suitable for X, and Ku band applications. The simulations are carried out using HFSS software.

Index Term— *Hexagonal, Microstrip patch, slot, and Triple band.*

I. INTRODUCTION

In wireless communications, the microstrip patch antenna form is widely opted for because of its low cost and ease of fabrication. An Antenna with triple frequency bands of operation is referred to as a triple band antenna in which each segment of the antenna structure radiates at a different frequency. For dual-band operation, the design of a rhombus slot antennafed by a co-planar waveguide (CPW) is reported with a rhombic ring-like feeding structure. The antenna impedance bandwidths of 607MHz and 1451MHz separately and gain vary from 1.9 to 2.9 dBi range in the lower band andfrom 4.1 to 5.5dBi in the upper band [1]. The slotted cylindrical DRA (SDRA) antennas (SDRA1) and (SDRA2) suitable for Wi-FI, IEEE 802.11ac, WiMax, and X-band are presented. By introducing rectangular curved slots to create asymmetry in the structure for circular polarization and impedance bandwidth. SDRA1 offers 10dB return loss bandwidth over a frequency range of 4.14-7.31GHz. SDRA2 a scaled-down version of SDRA1 has a 10dB return loss band over the frequency range of 7.34-12.94GHz. It is reported that peak gains of 6dBi and 5.52dBi are observed for SDRA1 and SDRA2 respectively [2]. To improve the bandwidth irregularly shaped slots are introduced onto the patch [3]. A novel compact tri-band printed antenna for WLAN and WiMAX applications is presented. The antenna provides over bandwidth and frequency ranges are 430MHz (2.33–2.76GHz), 730MHz (3.05–3.88GHz), and 310MHz (5.57–5.88GHz) [4]. A compact waveguide-fed coplanar antenna is suitable for applications of UWB and WLAN is reported. The antenna operates over a frequency range of 3-10.6GHz and the peak of the antenna is observed to be 5.8dBi [5].

The design represents a fractal antenna with a crinkle structure. The antenna operates over frequency ranges of 1.69-1.88GHz, 3.41-3.62GHz, and 5.13-5.44GHz, and the peak gain of the antenna is reported to be 2.7dBi [6]. Chip-based monopole antenna containing folded meander lines to attain miniaturization is communicated. The antenna operates over a frequency range of 2.69–2.84GHz and the peak gain of the antenna is observed to be 0.5dBi [7]. An asymmetric rhombic slotted circularly polarized probe-fed antenna with five asymmetric rhombic slots is designed for global-positioning system applications and the overall bandwidth of the proposedpentagonal patch antenna is 60MHz (1.53 to 1.59GHz) with a gain of more than 3.8dB [8]. Merging of planar rectangular monopole to achieve triple frequency operation. The overall dimension is 44x20x0.76mm^3. The antenna operates over a frequency range of 0.33GHz (2.37–2.7GHz), 0.47GHz (3.23–3.70GHz), and 2.29GHz (4.29 – 6.58GHz) [9].

Dual-band operating koch snowflake antenna is suggested with a slotted antenna structure on one side of the substrate and a microstrip feed line on another side. The antenna operates over frequency ranges

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of 2.24–2.93GHz, and 4.48–5.54GHz, and the peak gain of the antenna is observed to be 5.85dBi [10]. A printed triple band operating monopole antenna comprising of a rectangular ring with fork strip and rectangular DGS is described. The antenna operates over frequency ranges of 2.41 – 2.63GHz, 3.39 – 3.70GHz, 4.96 – 6.32GHz, and the gains are observed to be in the range of -0.10– 0.28dBi, 0.24–1.42dBi and 2.67–4.76dBi in each band respectively [11]. By using defected ground structure on the ground plane to achieve a triple band. The bandwidths are 4.94GHz (4.96–9.9GHz), 3.6GHz (11.0–14.6GHz), and 3.8GHz (16.20–20GHz) [12]. Paper-Based Inkjet-Printed Tri-Band U-Slot Monopole Antenna for Wireless Applications is presented. To enhance the bandwidth U shape slot is introduced [13].

Circularly polarized single feed microstrip patch antenna excited via an aperture of cross shape is presented. The antenna operates over a frequency range of 1.88-1.97GHz with a reported peak gain of 4.9dBi and a lower than 3dB AR threshold is observed over the region of 1.89-1.92GHz [14]. Dual-band operating DRA-loaded hybrid antenna containing radiating slot is presented. The antenna operates over a frequency range of 3300-3612MHz, and 4681-4912MHz and the peak gain obtained by the antenna is reported to be 4.7dBi, and 5.6dBi respectively [15].

In this paper, triple band hexagonal patch antenna with slots is designed. Inverted C-Shaped Slot results shift in the operating frequency with **a** peak gain of 6.40dBi at 13.04GHz.

II. ANTENNA CONFIGURATION

The proposed antenna consists of a hexagonal with inserted slots and a center feed. The proposed antenna is fabricated on FR 4 substrate with a height of 1.6mm. A four rectangular slot hexagonal patch with center feed antenna geometry is shown below in Figure 1.

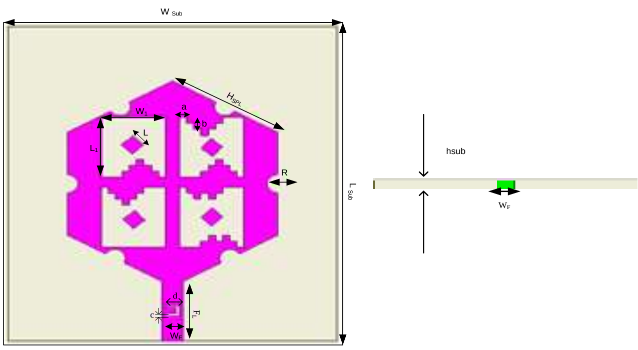

Figure 1. Proposed Hexagonal shaped antenna geometry
(a) Top view, (b) side view

Table.1 Dimension of the proposed antenna

Parameters	**Dimension(mm)**	**Parameter**	**Dimension(mm)**
L_{sub}	46	**L**	1.5
W_{sub}	52	**L_1**	10
h_{sub}	1.6	**W_1**	9
W_F	2.9	**a**	1
F_L	9.837	**b**	1
H_{PSL}	17	**c**	0.4
R	1.5	**d**	1.8

III. EVOLUTION OF PROPOSED ANTENNA

The periodic procedure steps to fabricate the proposed antenna are presented below in step by step manner.

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STEP 1: Hexagonal Patch Antenna (HPA)

This step is to design a hexagonal patch antenna with a center feed. The side length of a hexagonal patch is 17mm, as shown in Figure 2. The parametric analysis is done on the dimension of the hexagonal patch. The return loss plot of the patch antenna is shown in Figure 15. The obtained operating bandwidths are 40MHz (5.22-5.26GHz), 1.38GHz (10.60-11.98GHz) and 870MHz (13.13-14GHz). To improve the gain of the antenna, Cut a C-Shaped slots at six sides of HPA is introduced in the second step of the proposed design.

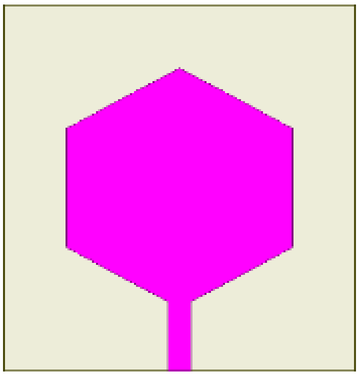

Figure 2. Hexagonal Patch Antenna

STEP 2: Cut a C-Shaped slots at six sides of the HPA

Cut a C-Shaped slots at six sides of HPA is cut on the hexagonal patch antenna with a radius is 1.5 mm as shown in Figure 3. The parametric analysis is done on the radius of circular slots. After introducing circular slots the antenna achieved a pentaband. The return loss of the HPA with circular slots is shown in Figure 15. The antenna obtained operating bandwidth of 150MHz (7.30-7.45GHz), 160MHz (9.62-9.78GHz), 260MHz (10.59-10.85GHz), 510MHz (11.41-11.92GHz) and 850MHz (13.11-13.96GHz). The peak gain is 6.43dBi is obtained at 13.4GHz. To obtain a better bandwidth and gain an HPA four Rectangle Slots are inserted in a patch.

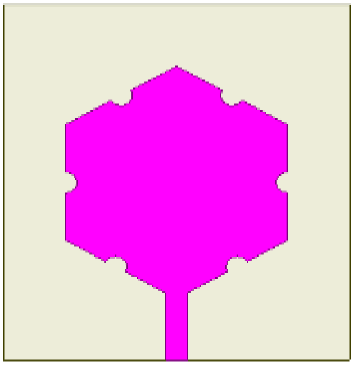

Figure 3. Cut a C-Shaped slots at six sides of the HPA

STEP 3: HPA with four Rectangle Slots

The HPA with four Rectangle slots is inserted in the middle of the patch as shown in Figure 4. The parametric analysis is done on the size of the rectangle slot. After inserting the four Rectangle slots the obtained operating bandwidths are 120MHz (4.22-4.34GHz), 190MHz (9.24-9.43GHz), 1.96GHz (9.96-11.92GHz), and 540MHz (12.90-13.44GHz). The peak gain of 6.64dBi is obtained at 11.48GHz. The return loss plot of the HPA with four Rectangle Slots is shown in Figure 15. To increase the bandwidth, an HPA with irregular shapes is inserted into the HPA with four Rectangle Slots.

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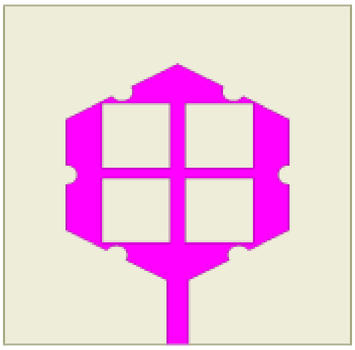

Figure 4. HPA with four Rectangle Slots

STEP 4: HPA with Irregular Shapes

An HPA with irregular shapes is created in the four Rectangle Slots, as shown in Figure 5. The parametric analysis is done on the size of the irregular shapes. The antenna is a quad-band antenna. The return loss plot of the antenna is shown in Figure 15. The antenna obtained an operating bandwidth of 50MHz (7.85-7.90GHz), 860MHz (9.09-9.95GHz), 850MHz (10.49-11.34GHz), and 2.47GHz (11.53-14GHz). The peak gain of 6.56dBi is obtained at 13.28GHz. The HPA with Rhombus slots is placed in the middle of rectangle slots, to achieve high bandwidth.

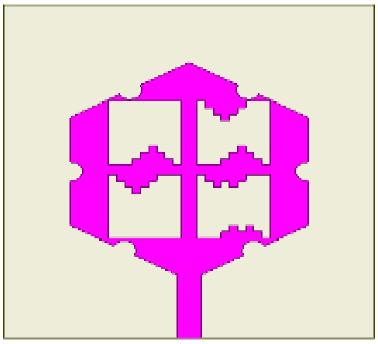

Figure 5. HPA with Irregular shapes

STEP 5: HPA with four Rhombus Slots

In this step HPA with four Rhombus Slots is placed in the middle of irregular shapes with a side length of 1.5. As shown in Figure 6. The parametric analysis is done on the side length of the rhombus slot. The return loss plot of the antenna is shown in Figure 15. The obtained operating bandwidths are 20MHz (7.27-7.29GHz), 40MHz (7.85-7.89GHz), 900MHz (9.06-9.96GHz), 850MHz (10.38-11.23GHz) and 2.48GHz (11.52-14GHz). The peak gain of 6.34dBi is obtained at 13.16GHz. To enhance the bandwidth, the inverted C-Shaped slot is inserted in the middle of the feed.

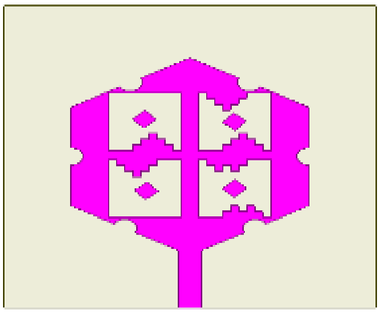

Figure 6. HPA with Rhombus Slots

STEP 6: Different types of shaped slots incorporated in the feed (Proposed Antenna)

An inverted C-Shaped slot is inserted in the feed a=0.4mm, b=1.8mm. As shown in figure 7. The parametric analysis is done on the size of the inverted C-shape. The return loss plot of the antenna is shown in figure 15. After inserting an inverted C-Shaped slot the antenna achieved a triple band. The obtained operating bandwidths are 930 MHz (9.04-9.97GHz), 970MHz (10.31-11.28GHz), and 2.51GHz (11.49-14GHz). The peak gain of 6.40dBi is obtained at 13.04GHz. The gain plot is presented in the result and discussion section.

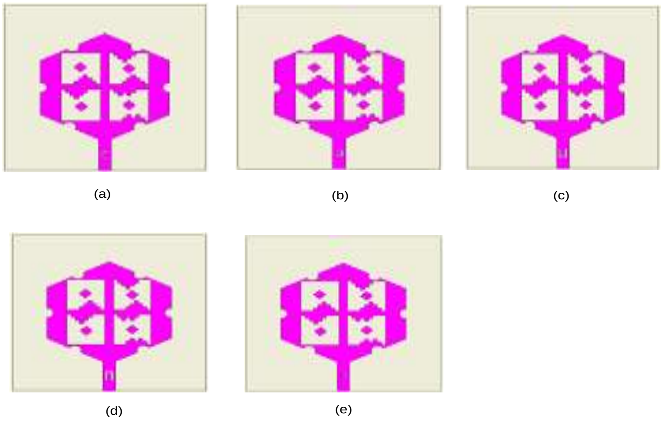

Figure 7. Different types of shaped slots incorporated in the feed (a) C-Shaped slot (b) Inverted C-Shaped slot (Proposed Antenna) (c) U-Shaped slot (d) Inverted U-Shaped slot (e) D-Shaped slot

IV. PARAMETRIC STUDY

The parametric analysis of the proposed hexagonal patch with center feed is done by varying the dimensions of the hexagonal shape, feed width, circular slot radius, different values of rectangle slots, dimensions of the irregular shapes, the side length of rhombus slot, different types of shaped slots incorporated in the feed.

A. Effect of Hexagonal Patch Dimensions

Figure 8 illustrates the return loss for varying side lengths of the hexagonal patch (H_{PSL}).

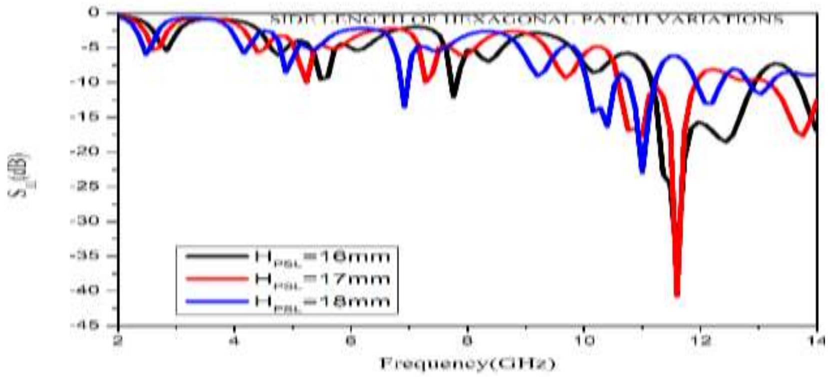

Figure 8. Return loss plot of the varying side lengths of the hexagonal patch

When a side length of hexagonal patch H_{SPL}= 16mm offering triple band with an operating bandwidth of 100MHz (7.72-7.82GHz), 1.77GHz (11.16-12.93GHz) and 330MHz (13.67-14GHz). The peak gain of 5.37dBi is obtained at 11.6GHz. H_{PSL}= 17mm offers dual bands with an operating bandwidth of 1.34GHz (10.59-11.93GHz), and 840MHz (13.16-14GHz). The peak gain of 5.96dBi is obtained at 11.6GHz. For H_{PSL} = 18mm offers a pentaband with an operating bandwidth of 120MHz (6.86-6.98GHz), 490MHz (10.05-10.54GHz), 450MHz (10.77-11.22GHz), 440MHz (11.92-12.36GHz) and 390MHz (12.83-13.22GHz). The peak gain of 5.66dBi is obtained at 11GHz. The side length of the hexagonal patch H_{PSL}=17mm is selected as the proposed antenna patch dimension because the gain is high. when compared with remaining patch variations.

B. Effect of feed width

For feed width = 2.7mm offers a quad-band with an operating bandwidth of 30MHz (5.22-5.25GHz), 1.31GHz (10.62-11.93GHz), 220MHz (12.59-12.81GHz), and 790MHz (13.21-14GHz). The peak gain of 5.71dBi is obtained at 11.6GHz. Width = 2.8mm offers a dual-band with an operating

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bandwidth of 1.34GHz (10.59-11.93GHz), and 840MHz (13.16-14GHz). The peak gain of 5.96dBi is obtained at 11.6GHz. Width = 2.9mm offers a triple band 40MHz (5.22-5.26GHz), 1.38GHz (10.60-11.98GHz) and 870MHz (13.13-14GHz). The peak gain of 6.01dBi is obtained at 11.6GHz. The feed width of 2.9mm was chosen for step 1 because both bandwidth and gain are balanced compared to the remaining variations.

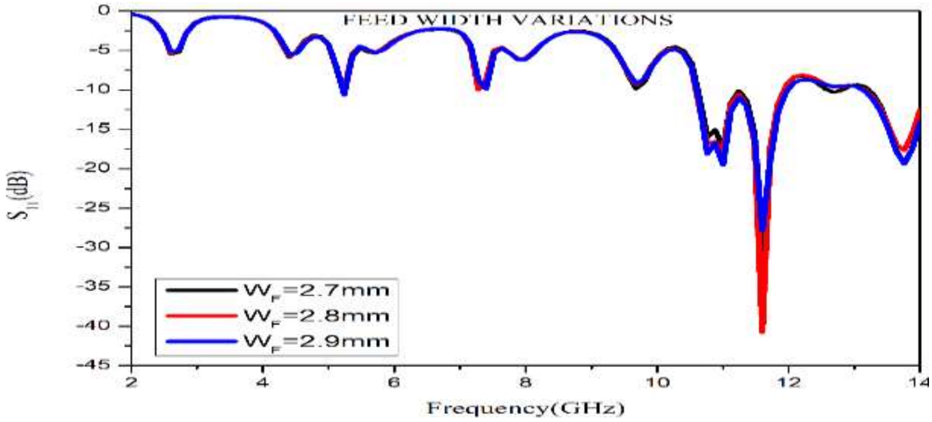

Figure 9. Return loss for varying different dimensions of feed width

__C.__ Effect of different Cut a C-Shaped slots at six sides of HPA

The C-shaped slots radius R = 0.5mm offers a triple band with an operating bandwidth of 40MHz (5.22-5.26GHz), 1.37GHz (10.59-11.96GHz), and 900MHz (13.10-14GHz). The peak gain of 5.81dBi is obtained at 11.6GHz. R = 1mm offers a quad-band with an operating bandwidth of 80MHz (7.34-7.42GHz), 320MHz (10.59-10.91GHz), 950MHz (11.02-11.97GHz), and 880MHz (13.12-14GHz). The peak gain of 5.88dBi is obtained at 11.6GHz. R = 1.5mm offers a quad band 150MHz (7.30-7.45GHz), 160MHz (9.62-9.78GHz) and 260MHz (10.59-10.85GHz), 510MHz (11.41-11.92GHz) and 850MHz (13.11-13.96GHz). The peak gain of 6.43dBi is obtained at 13.4GHz. The circle slot radius R = 1.5mm was chosen for step 2 because the gain is high compared to the remaining circle radius variations.

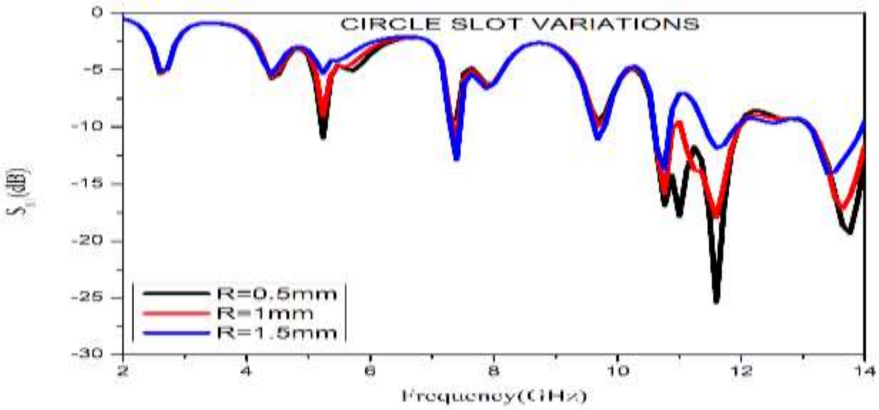

Figure 10. Return loss for varying different radius of the C-Shaped slot

__D.__ Effect of different values of Rectangle Slots

For the rectangle slot, W_1 = 7mm, L_1 = 8mm offers a dual-band with an operating bandwidth of 160MHz (9.43-9.59GHz) and 580MHz (11.18-11.76GHz). The peak gain of 5.10dBi is obtained at 11.48GHz. W_2 = 8mm, L_2 = 9mm offers a triple band with an operating bandwidth of 150MHz (4.45-4.60GHz), 1.12GHz (9.27-10.39GHz), and 980MHz (10.59-11.57GHz). The peak gain of -1.65dB is obtained at 4.52GHz. For W_3 = 9mm, L_3 = 10mm offers a quad band 120MHz (4.22-4.34GHz), 190MHz (9.24-9.43GHz) and 1.96GHz (9.96-11.92GHz) and 540MHz (12.90-13.44GHz). The peak gain of 6.64dBi is obtained at 11.48GHz. The Rectangle slot W_3 = 9mm, L_3 = 10mm is selected for step 3 because both bandwidth and gain are high compared to the remaining rectangle slot variations.

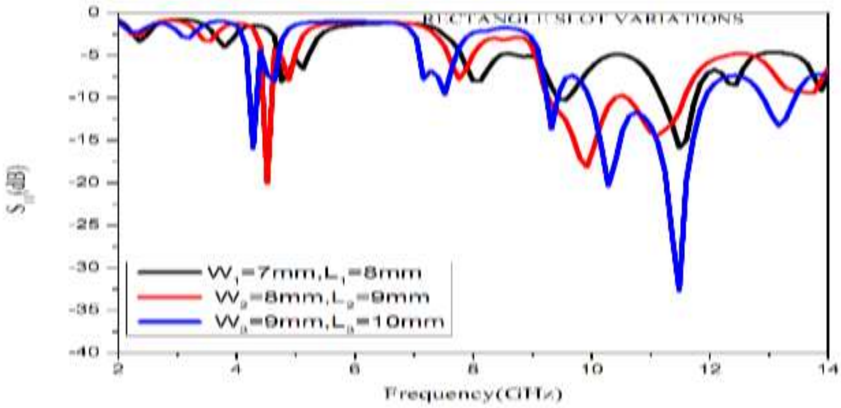

Figure 1 1. Return loss for varying different values of Width (W) and Length (L) of the four Rectangle Slot

E. *Effect of dimensions of the Irregular Shapes*

For irregular shapes, a = 0.7mm, b = 0.7mm offers a triple band with an operating bandwidth of 880MHz (9.13-10.01GHz), 680MHz (10.56-11.24GHz), and 1.28GHz (12.72-14GHz). The peak gain of 5.82dBi is obtained at 13.4GHz. a = 1mm, b = 1mm offers a quad-band with an operating bandwidth of 50 MHz (7.85-7.90GHz), 860MHz (9.09-9.95GHz), and 850MHz (10.49-11.34GHz) and 2.47GHz (11.53-14GHz). The peak gain of 6.56dBi is obtained at 13.28GHz. For a = 1. mm, b = 1.3mm offers a hexa band 20MHz (4.75-4.77GHz), 70MHz (7.24-7.31GHz) and 90MHz (7.72-7.81GHz), 960MHz (8.88-9.84GHz), 320MHz (10.17-10.49GHz) and 2.21GHz (11.79-14GHz). The peak gain of 5.89dBi is obtained at 13.52GHz. The slots with irregular shapes a = 1mm, and b = 1mm are selected for step 4 because both bandwidths are high compared to the remaining irregular shapes variations.

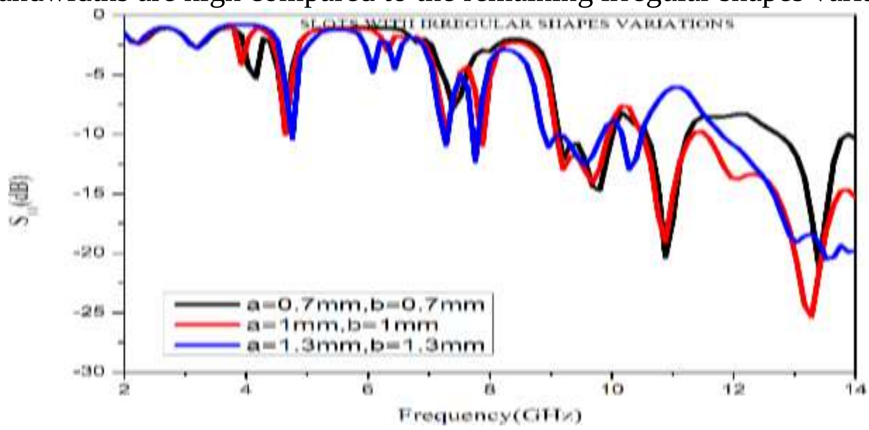

Figure 1 2. Return loss for varying different values of a and b of the irregular shapes

F. *Effect of the side length of Rhombus slot*

For side length of Rhombus slot L = 1mm offers a triple band with an operating bandwidth of 880MHz (9.04-9.92GHz), 780MHz (10.40-11.18GHz), and 2.48GHz (11.52-14GHz). The peak gain of 6.42dBi is obtained at 13.16GHz. L = 1.5mm offers a pentaband with an operating bandwidth of 20MHz (7.27-7.29GHz), 40MHz (7.85-7.89GHz), 900MHz (9.06-9.96GHz), 850MHz (10.38-11.23GHz), and 2.48GHz (11.52-14GHz). The peak gain of 6.34dBi is obtained at 13.16GHz. L = 2mm offers a penta band 30MHz (7.26-7.29GHz), 60MHz (7.84-7.90GHz), 940MHz (9.08-10.02GHz), 810MHz (10.42-11.23GHz) and 2.43GHz (11.57-14GHz). The peak gain of 5.93dBi is obtained at 13.28GHz. The side length of Rhombus slot L = 1.5mm is chosen for step 5 because bandwidth is high compared to the remaining rhombus slot variations.

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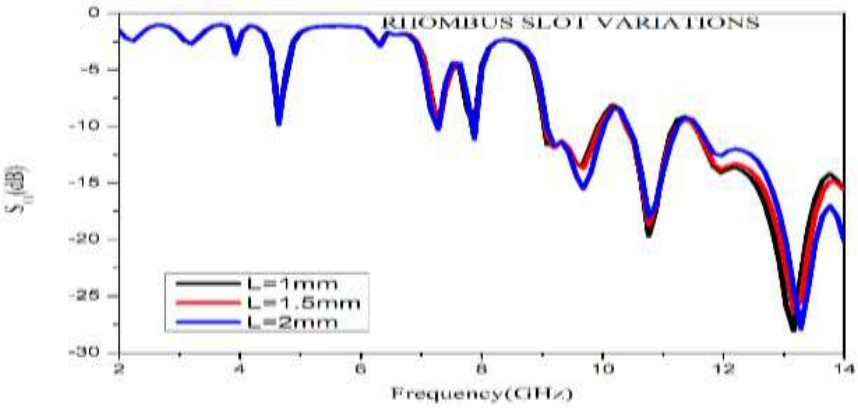


Figure 1 3. Return loss for varying side lengths of Rhombus Slot

G. *Effect of different types of shaped slots incorporated in the feed*

For the C-Shaped slot, a =0.4 mm, b =1.8 mm offers a quad-band with an operating bandwidth of 20MHz (7.86-7.88GHz), 890MHz (9.02-9.91GHz), 930MHz (10.33-11.26GHz) and 2.54GHz (11.46-14GHz). The peak gain of 6.06dBi is obtained at 13.04GHz.

For Inverted C-Shaped slot a = 0.4mm, b = 1.8mm offers a triple band with an operating bandwidth of 930MHz (9.04-9.97GHz), 970MHz (10.31-11.28GHz), and 2.51GHz (11.49-14GHz). The peak gain of 6.40dBi is obtained at 13.04GHz.

For U-Shaped slot a = 3mm, b = 2mm, W= 0.5mm offers a triple band with an operating bandwidth of 60MHz (4.61-4.67GHz), 180MHz (7.78-7.96GHz), and 1.53GHz (9.70-11.23GHz). The peak gain of 6.19dBi is obtained at 10.04GHz.

For Inverted U-Shaped slot a = 3mm, b = 2mm, W= 0.5mm offers a quad-band with an operating bandwidth of 90MHz (7.59-7.68GHz), 820MHz (8.68-9.50GHz), 1.52GHz (10.05-11.57GHz), and 880MHz (13.12-14GHz). The peak gain of 9.01dBi is obtained at 10.4GHz.

For D-Shaped slotR_1 = 1.3mm, R_2= 1.1mm offers a triple band with an operating bandwidth of 40MHz (7.85-7.89GHz), 910MHz (9.03-9.94GHz), and 3.69GHz (10.31-14GHz). The peak gain of 6.29dBi is obtained at 13.16GHz.

Inverted C-Shaped slot a = 0.4mm, b = 1.8mm is chosen for step 6 because both bandwidth and gain are balanced compared to the remaining variations.

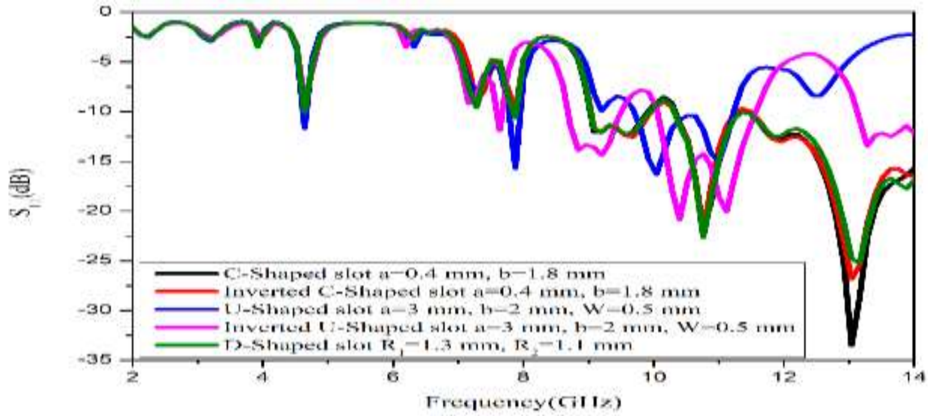


Figure 1 4. Return loss for varying side lengths of Rhombus Slot

V. SIMULATED RESULTS AND DISCUSSION

The return loss plot of the proposed antenna design step (1- 6) is shown in Fig.15 below.

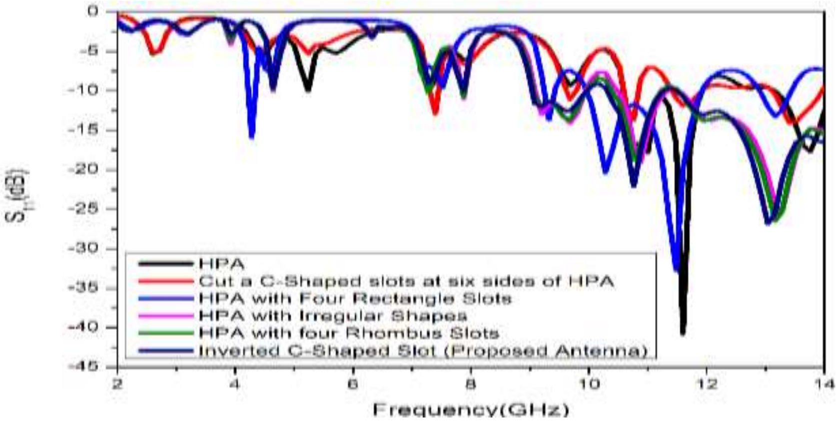


Figure 15. The return loss of the design steps (1 -6) proposed antenna

GAIN:

The peak gain of the Proposed Antenna is 6.40dBi at 13.04GHz.

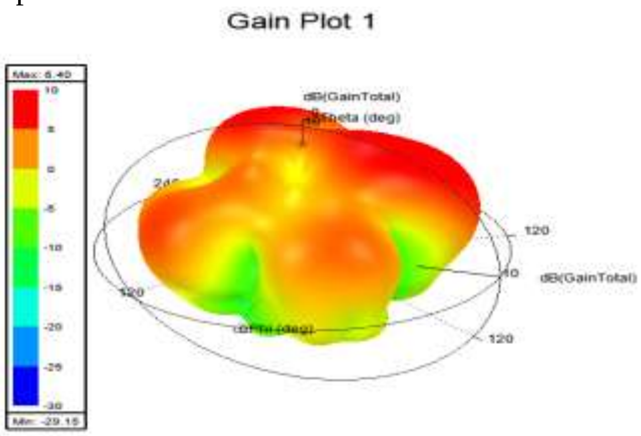
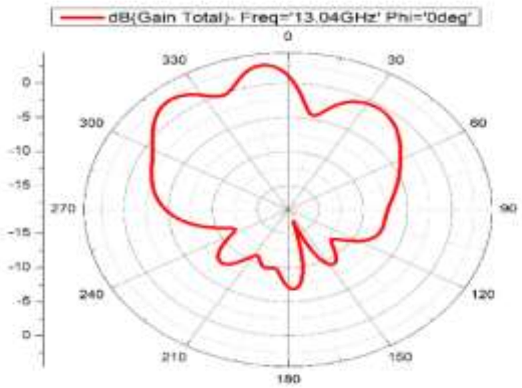


Figure 16. Gain at 13.04GHz

RADIATION PATTERN:

The simulated far-field patterns of the proposed antenna at obtain bands in both E- and H-planes are shown in Figure 17.



(a) E-Plane

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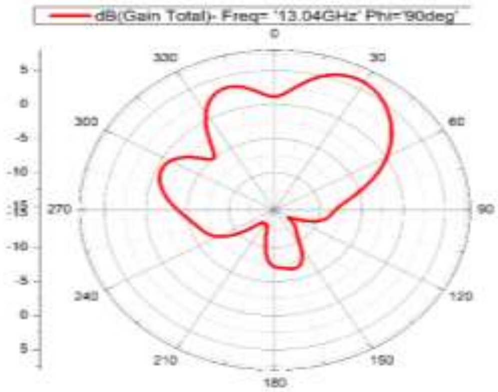

(b) H-Plane

Figure 17. Radiation patterns of the proposed antenna at 13.04GHz

Table.2 Comparing the performance of the proposed antenna

Type of proposed antenna	**Operating bands with bandwidth (GHz)**	**Peak Gain (dBi)**
HPA	40 MHz (5.22-5.26 GHz) 1.38 GHz (10.60-11.98 GHz) 870 MHz (13.13-14 GHz)	6.01dB at 11.6GHz
Cut a C-Shaped slot at six sides of the HPA	150 MHz (7.30-7.45 GHz) 160 MHz (9.62-9.78 GHz) 260 MHz (10.59-10.85 GHz) 510 MHz (11.41-11.92 GHz) 850 MHz (13.11-13.96 GHz)	6.43dB at 13.4GHz
HPA with four rectangle slots	120 MHz (4.22-4.34 GHz) 190 MHz (9.24-9.43 GHz) 1.96 GHz (9.96-11.92 GHz) 540 MHz (12.90-13.44 GHz)	6.64dB at 11.4GHz
HPA with irregular shapes	50 MHz (7.85-7.90 GHz) 860 MHz (9.09-9.95 GHz) 850 MHz (10.49-11.34 GHz) 2.47 GHz (11.53-14 GHz)	6.56dB at 13.28GHz
HPA with four rhombus slots	20 MHz (7.27-7.29 GHz) 40 MHz (7.85-7.89 GHz) 900 MHz (9.06-9.96 GHz) 850 MHz (10.38-11.23 GHz) 2.48 GHz (11.52-14 GHz)	6.34dB at 13.16GHz
Inverted C-Shaped slot (Proposed Antenna)	930 MHz (9.04-9.97 GHz) 970 MHz (10.31-11.28 GHz) 2.51 GHz (11.49-14 GHz)	6.40dB at 13.04GHz

VI. Conclusion

In this paper, a Triple band Hexagonal Patch antenna with slots is presented. The proposed antenna obtained a triple band operating with a bandwidth of 930MHz (9.04-9.97GHz), 970MHz (10.31-11.28GHz), and 2.51GHz (11.49-14GHz). The peak gain of the Proposed antenna is 6.40 dBi. The proposed antenna covers the X and K_u bands.

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