TRIANGLE PATCH ANTENNA WITH SQUARE AND CIRCLE SHAPE SLOTS FOR MULTI-BAND APPLICATIONS

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***Abstract*—** This paper presents a multi-band triangle patch antenna with square and circle slots. By incorporating S-Shaped slot in the feed it converts linear polarization to circular polarization. The proposed antenna over all dimensions are 43x42x2.1mm^3. The operating frequencies and the bandwidth offered by the proposed antenna are 590MHz (9.46-10.05GHz), 330MHz (11.66-11.99GHz), 3.07GHz (12.32-15.39GHz) and 1.74GHz (16.26-18GHz). The peak gain of antenna is 7.53dBi at 9.53GHz. The antenna offers an axial ratio bandwidth of 540MHz (12.10-12.64GHz). The antenna suitable for multiband applications. Simulations were carried out using Ansys HFSS software.

Index Term*— Wideband, Low-profile, Multi-band, Circularly Polarized, Triangle patch.*

I. INTRODUCTION

Antennas are essential elements in wireless communications. An antenna transforms an electromagnetic wave into an electrical signal and an electrical signal into an electromagnetic wave. When the surface's flexibility and thickness are the main considerations of antenna design microstrip patch antennas are widely opted. Patch antenna becoming more and more popular in the mobile phone industry. Microstrip antennas are cheap and easy to construct. The antenna characteristics of circular polarization and multiband are in great demand for wireless applications. Circular polarization takes place when the two orthogonal electric field component vectors are precisely 90^0, or one-quarter wavelength, out of phase and have equal magnitudes. A multiband antenna has a design that allows one piece of the antenna to be active for one band while another portion is active for a different frequency. There are numerous techniques reported in the literature to improve the performance characteristics of microstrip antenna.

A Combined Triangle Quarter-Wavelength Patches dimensions are the substrate h_1 is 130x130x2mm^3 and substrate h_2 is 130x140x2mm^3 is suitable for LTE and GNSS applications. The maximum gain of an antenna is upto 8.14dBi at 1.935GHz is obtained. Circular polarization is achieved by coupling between two triangle quarter wave-length patches [1]. A multiband decoupled dual-antenna system with an overall size of the antenna is 95x60mm^2 and suitable for Wireless wide area networks and Long term evolution smartphone applications. To reduce decoupling between elements the slits and the extended ground is used. The operating bands are 740-965MHz and 1380-2703MHz [2].

A U-shaped microstrip patch antenna with dimensions 42x24x1.6mm^3 is suitable for multiband applications. The antenna operates over a frequency range is 3.1-10.6GHz with bandwidth 7.5GHz and gain varying from 2 to 5dB is presented [3]. Dielectric resonators are loaded on two rectangular antennas forming hybrid structures each of dimensions 50x50x7.2mm^3 suitable for tri-band and quad-band applications. The tri-band DR-loaded antenna operates at 2.93GHz, 3.26GHz and 5.5GHz and quad-band DR-loaded antenna operates at 2.48GHz, 2.84GHz, 3.26GHz and 5.5GHz [4].

A quad-band circularly polarized antenna is suitable for WLAN and WiMAX applications is presented. By loading an inverted U-shaped slot, I-shaped slot, L-shaped slot, and an frequency selective surface structure circular polarization was achieved. The operating frequency ranges of antenna are 2.37–2.75GHz and 3.4–8GHz and axial-ratio bandwidth of 2.35–2.48GHz, 3.45–3.75GHz, 5.25–5.45GHz and 5.7–5.87GHz [5]. A multiband monopole antenna's overall size is 22X50mm^2 with a larger ground of 88X50mm^2 is presented. The antenna operates over a frequency range of 880-960MHz, 1710-1880MHz,

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1850-1990MHz, 1920-2170MHz, 2300-2390MHz, 2400-2483MHz, 1559.052-1591.788MHz, 1575-425MHz, and 1602-1615.5MHz used for mobile phone applications. By loading tuning stub, and feeding strip at different corners circular polarization is achieved [6].

An equilateral triangle patch antenna dimensions are 150x150x34.4mm^3 containing an L-shaped probe feed for an ultra-high frequency reader and operate over a frequency range of 854 -1102MHz. By loading a semicircular notch in the patch circular polarization is obtained [7]. Circularly polarized equilateral triangle with single feed containing horizontal slot and cross slot with unequal lengths is presented. The equilateral triangle is of side length 48 mm and operates at center frequency of 1768 MHz and switch between LHCP and RHCP is attained by varying the feed position across the slot [8].

An Equilateral triangle with slotted ground plane for circular polarization and gain enhacement with overall size of antenna is 75X75mm^2 is presented. Three triangle shaped slots are loaded in the ground plane and by adjusting one of the triangle slot circular polarization is achieved. The maximum gain of an antenna is 3.3dB [9]. An equilateral triangle microstrip patch antenna with slots for broad-band applications are presented. In the triangular patch two pairs of narrow slits, one is close to the edges of the patch, and the other at the bottom of the patch is loaded to achieve dual frequency. The operating frequencies ranging from 1.16-2.06GHz [10].

A monopole antenna for circular polarization and dual band applications is presented . The C-shaped slot and an L-shaped slot used for the higher band and lower band. The overall dimensions are 40x47x1.5mm^3 and the antenna operates over frequency ranges 2.32-2.70GHz and 4.76-6GHz and 3dB axial-ratio is 2.39-2.57GHz and 5.13-6GHz used for Wireless local area network and Wi-Fi applications [11].

Carbon nanotube based fractal antenna of dimensions 96mm x 72mm operating over multiple frequencies of 5.5GHz, 2.4GHz and 900MHz suitable for WLAN, Bluetooth and RFID applications is presented. The composite material substrate G10/FR4 is utilized for fabrication and the peak reported is 4.44dB [12].

Multiband operating printed antenna of dimensions 112 x 15 x 1.6mm^3 containing slotted patch and U-shaped ground plane is presented. The peak gains of the antenna are observed to be 6.3dBi and 4.2dBi in 1700-2700MHz and 5100-5900MHz respectively [13].

Square ring patch antenna of dimensions 7 x 65 x 1.52mm^3 comprising rhombus and inverse V slots to attain circular polarization is presented. The antenna operates over frequency ranges of 2.38-2.56GHz, 2.75-3.03GHz, 3.42-3.53GHz, and 5.16-5.54GHz and used for WLAN, WiMAX and Marine Service wireless applications [14].

The overall size of the antenna is 42x42x2.3mm^3 constructed on the single-layer substrate with an etched bowtie-shaped slot on the ground plane and a four-element periodic patch metasurface with truncated corners for circular polarization loaded on a substrate. The antenna operates over 3.75-6.67GHz covering the C-band satellite communication. The peak gain of antenna is 7dBi [15].

In this work, a triangle patch antenna with square and circle slots is designed. The S-Shaped slot is loaded in the feed to achieve multi-band, peak gain and axial ratio bandwidth.

The geometry, design steps and parameters and dimensions are presented in section II. The parametric analysis and simulated results are discussed in section III. The results and discussion are presented in section IV. Finally, a brief conclusion is explained in section V.

II. ANTENNA DESIGN

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A triangle patch antenna with square and circle slots is designed. The triangle patch antenna is designed with a length of 26mm. The square patch is incorporated in the centre of the patch to improve bandwidth and gain. To improve gain the four square slots are truncated in the edges of the square patch. The circle slot is placed in the center of the square patch. The rectangle slots are truncated in the corner of the circle to improve gain and bandwidth. The S-Shaped slot is incorporated in the feed to convert linear polarization to circular polarization as shown in figure 1. The proposed antenna is designed on an FR4 substrate with a dielectric constant 4.4, and loss tangent of 0.02, with an overall size of antenna 43x42x2.1mm^3. The dimensions and parameters of the proposed antenna are triangle patch length, feed width, feed length, substrate thickness, length and width of the antenna and length and width of the slots are presented in Table 1.

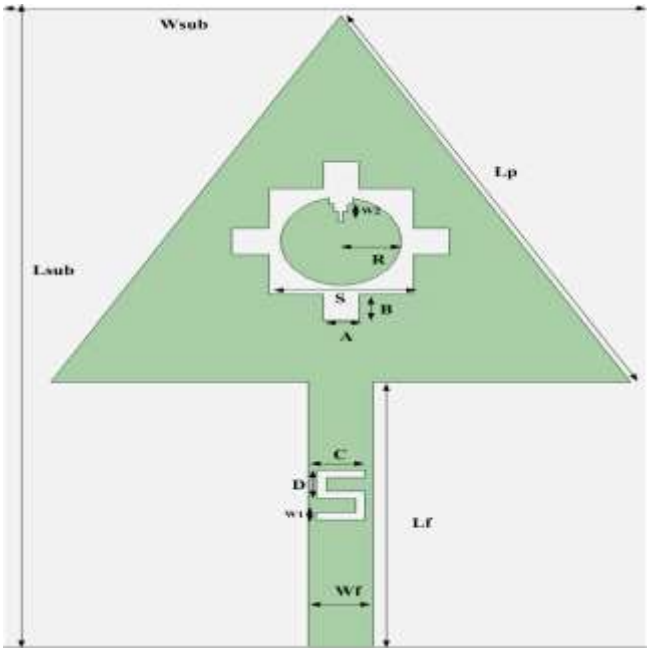

Figure 1. Triangle patch antenna with square and circle slots

Table 1. Dimensions of the proposed antenna

Parameters	Dimensions(mm)	Parameters	Dimensions(mm)
L_{sub}	42	R	2.5
W_{sub}	43	A	1.5
h_1	2.1	B	1.5
W_f	2.7	C	2
L_f	15	D	1
S	6	W_1	0.4
W_2	0.4		

III. PARAMETRIC ANALYSIS OF THE PROPOSED ANTENNA

A. Triangle patch antenna (TPA)

In this design, an triangle patch antenna with a microstrip feed line as shown in Figure 2. The dimensions of triangle patch antenna are 24mm on each side. The length and width of the feed are 15x2.7mm^2 and the substrate thickness is 2.1mm. Parametric analysis was done for the triangle patch length as shown in Figure 3.

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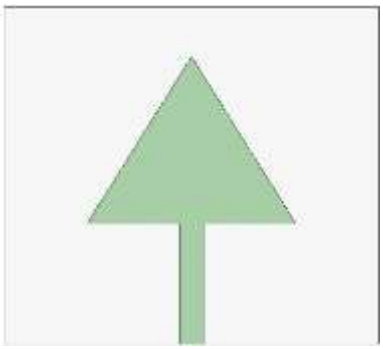

Figure 2. Triangle patch antenna (TPA)

i. Effect of the triangle patch length

Figure 3 shows the return loss of different length of the triangle patch. Dimensions of length of the patch are L_P = 22mm, L_P = 24mm and L_P = 26mm. For L_P = 22mm the antenna offers four bands at 11.62-12.11GHz, 13.28-14.73GHz, 15.66-16.53GHz, and 17.70-18GHz with a bandwidth of 490MHz, 1.45GHz, 870MHz, and 800MHz respectively. For L_P = 2 mm the antenna offers four bands at 9.65-9.76GHz, 10.73-11.19GHz, 12.43-15.60GHz, and 16.92-18GHz with a bandwidth of 110MHz, 460MHz, 3.17GHz, and 1.08GHz respectively. For L_P = 26mm the antenna offers seven bands at 9.08-9.34GHz, 10.23-10.58GHz, 11.90-12.31GHz, 12.73-13.46GHz, 14.07-15.01GHz, and 16.25-17.05GHz, 17.57-18GHz with a bandwidth of 260MHz, 350MHz, 410MHz, 730MHz, 940MHz, 800MHz, and 430MHz respectively. From all these variations the patch length of 24mm is an ideal parameter.

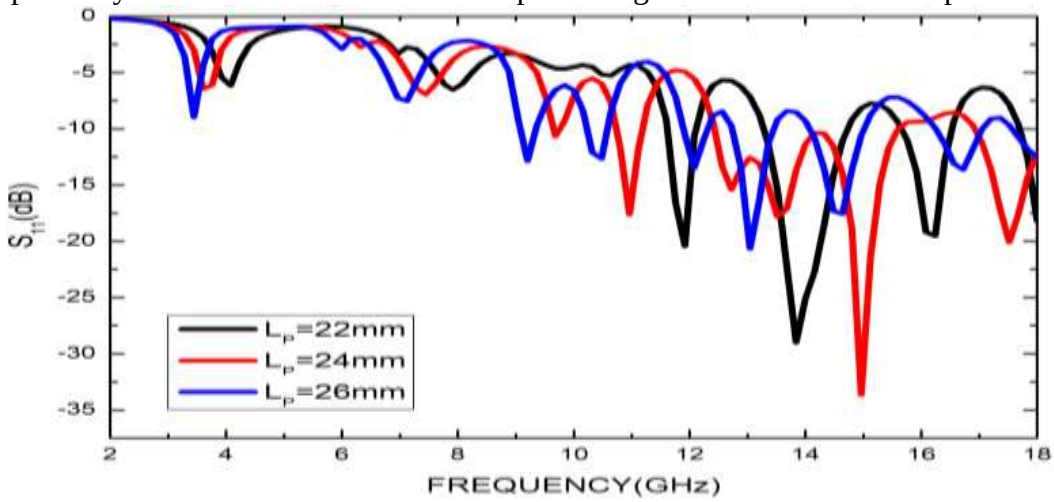

Figure 3. Return loss for different length of the triangle patch.

B. TPA with square slot

To improve the bandwidth of an antenna the square-shaped slot is loaded on the centre of the triangle patch antenna as shown in Figure 4. Parametric analysis has been done to finalize the length of the square-shaped slot. Parametric analysis is done for S = 4mm, S = 5mm, and S = 6mm. For S = 4mm the antenna offers four bands at 9.71-10.07GHz, 10.97-11.44GHz, 12.53-15.40GHz and 16.98-18GHz with a bandwidth of 360MHz, 470MHz, 2.87GHz, and 1.02GHz respectively. For S = 5mm the antenna offers five bands at 9.57-10.05GHz, 11.16-11.65GHz, 12.48-14.11GHz, 14.38-15.52GHz, and 16.90-18GHz with a bandwidth of 480MHz, 490MHz, 1.63GHz, 1.14GHz, and 1.1GHz respectively. For S = 6mm the antenna offers four bands at 9.48-9.99GHz, 11.64-11.95GHz, 12.51-13.97GHz, and 14.51-17.29GHz with a bandwidth of 510MHz, 310MHz, 1.46GHz, and 2.78GHz respectively. The length of the square slot S = 6mm is obtained best result. Variations of the different square slots plot are shown in Figure 5.

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Figure 4. TPA with square slot

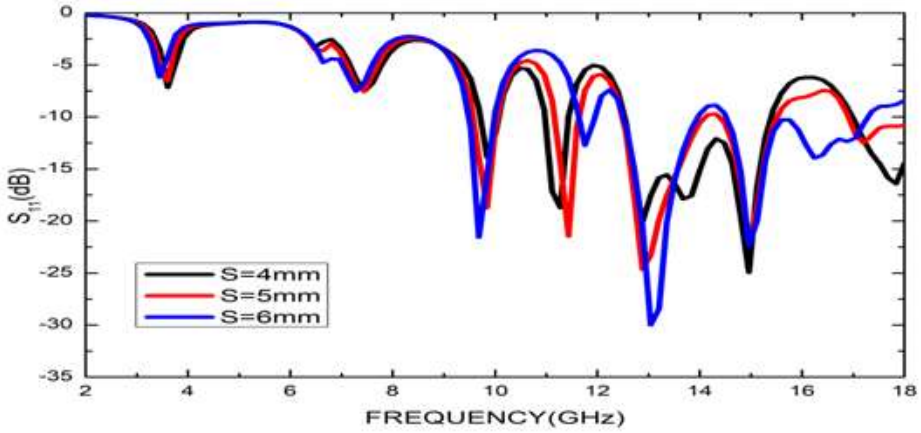

Figure 5. Return loss for different length of the square slots

C. TPA with four Square slot

The square shape slot TPA is designed with four square slots that is inserted middle of the edge of the square as shown in Figure 6. Parametric analysis was done for dimensions as follows B = 0.5mm, B = 1mm, and B = 1.5mm as shown in Figure 7. For B = 0.5mm, the antenna offers five bands at 9.47-9.99GHz, 11.66-11.96GHz, 12.51-13.96GHz, 14.55-15.71GHz, and 15.80-17.31GHz with a bandwidth of 520MHz, 300MHz, 1.45GHz, 1.16GHz, and 1.51GHz respectively. For B = 1mm, the antenna offers five bands at 9.47-10.03GHz, 11.71-12.03GHz, 12.47-13.98GHz, 14.46-15.56GHz, and 16.03-17.44GHz with a bandwidth of 560MHz, 320MHz, 1.51GHz, 1.1GHz, and 1.41GHz respectively. For B = 1.5mm, the antenna offers five bands at 9.44-10.07GHz, 11.75-12.16GHz, 12.35-13.91GHz, 14.24-15.41GHz, and 17.07-18GHz with a bandwidth of 630MHz, 410MHz, 1.56GHz, 1.17GHz, and 930MHz respectively. From all these variations the length of the square slot B =1.5mm is obtained as an ideal parameter.

Figure 6. TPA with four Square slot

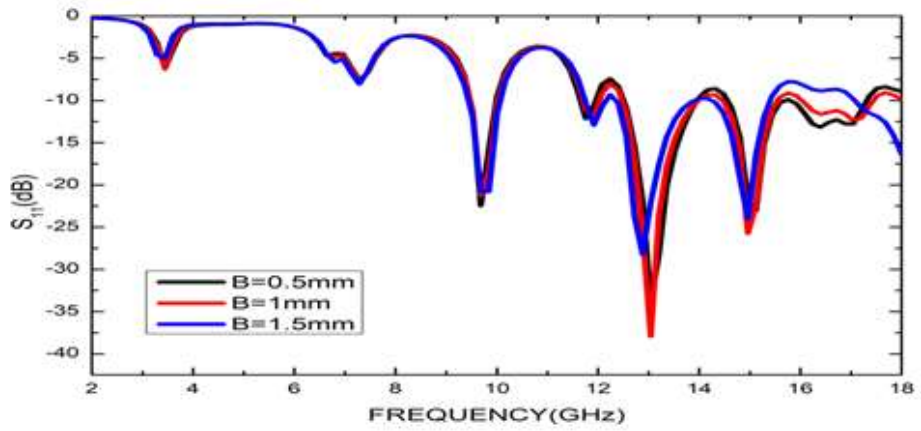

Figure 7. Return loss for different length of the four square shape slots

D. TPA with square and circle slots

A circle shape slot is placed on the centre of the square slot. The upper substrate thickness is 2.1mm. The radius of the circle is 2.5mm as shown in Figure 8. The return loss of different radius of the circle and its dimensions are R = 2mm, R = 2.5mm, and R = 3mm as shown in figure 9. For R = 3mm, the antenna offers five bands at 9.13-10.10GHz, 11.70-11.82GHz, 12.42-15.37GHz, 16.11-17.13GHz, and 17.86-18GHz with a bandwidth of 970MHz, 120MHz, 2.95GHz, 1.02GHz and 140MHz respectively. For R = 2. mm, the antenna offers four bands at 9.41-10.07GHz, 11.62-12.06GHz, 12.37-15.46GHz, and 16.20-18GHz with a bandwidth of 660MHz, 440MHz, 3.09GHz, and 1.8GHz respectively. For R =

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2 mm, the antenna offers four bands at 9.44-10.08GHz, 11.71-12.17GHz, 12.32-15.40GHz, and 16.29-18GHz with a bandwidth of 640MHz, 460MHz, 3.08GHz, and 1.71GHz respectively. From all these variations the radius of the circle of 2.5mm obtained the best results.

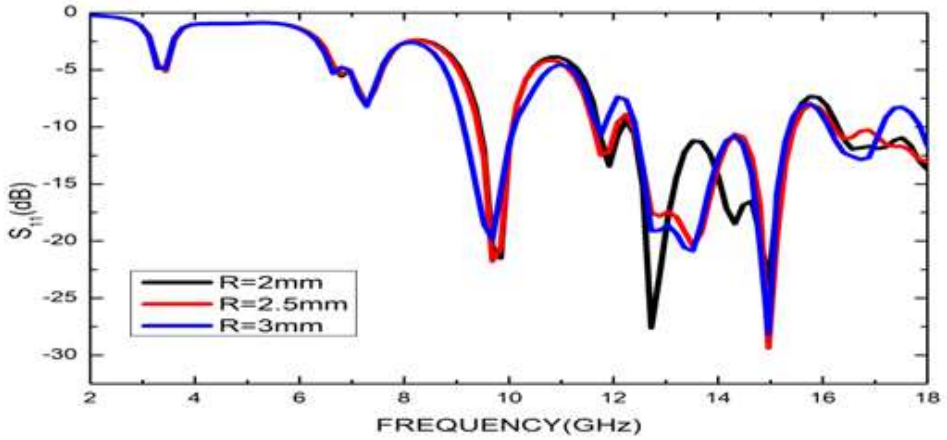

Figure 8. TPA with square and circle slots **Figure 9.** Return loss for different radius of circle

F. TPA with truncated rectangle slots in the circle

To enhance the bandwidth and gain of the antenna the rectangle slots are truncated in the circle shape slot as shown in Figure 10. Figure 11 shows the variations of the rectangle shape slots and their dimensions are as follows W_1 = 0.2mm, W_1 = 0.4mm, and W_1 = 0.6mm. For W_1 = 0.2mm, the antenna offers four bands at 9.39-10.06GHz, 11.59-12.02GHz, 12.35-15.42GHz, and 16.19-18GHz with a bandwidth of 670MHz, 430MHz, 3.07GHz, and 1.81GHz respectively. For W_1 = 0.4mm, the antenna offers four bands at 9.39-10.05GHz, 11.57-12.01GHz, 12.33-15.42GHz, and 16.14-18GHz with a bandwidth of 660MHz, 440MHz, 3.09GHz, and 1.86GHz respectively. For W_1 = 0.6mm, the antenna offers four bands at 9.41-10.07GHz, 11.62-12.05GHz, 12.33-15.43GHz, and 16.19-18GHz with a bandwidth of 660MHz, 430MHz, 3.1GHz, and 1.81GHz respectively. From all these variations the length of the rectangle slot width of 0.4mm obtained the best results.

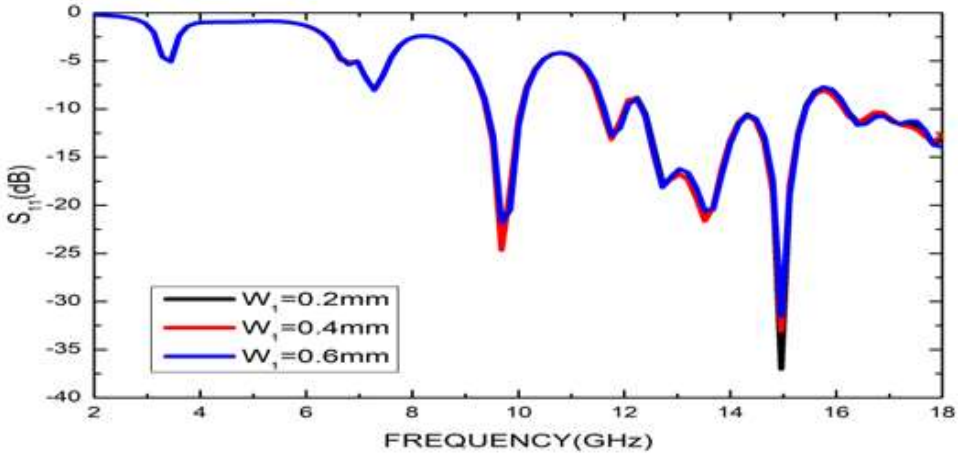

Figure 10. TPA with truncated rectangle slots in the circle **Figure 11.** Return loss for different rectangle slots width

G. S-Shaped slot in the feed

To enhance the gain and convert the linear polarization to the circular polarization antenna the S-Shaped slot is truncated in the feed of the triangle patch as shown in Figure 12. Figure 13 shows the variations of the S-Shaped slot. Dimensions are as follows rectangle width W_2 = 0.2mm, rectangle width W_2 = 0.4mm, and rectangle width W_2 = 0.6mm. For rectangle width W_2 = 0.2mm, the antenna offers five

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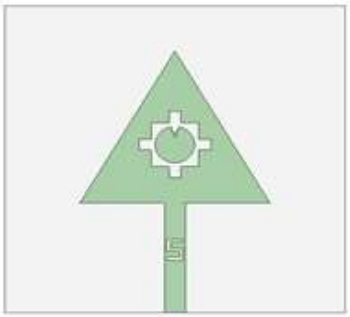
bands at 9.44-10.06GHz, 11.65-12.04GHz, 12.18-14.18GHz, 14.42-15.39GHz, and 16.23-18GHz with a bandwidth of 620MHz, 390MHz, 2GHz, 970MHz and 1.77 GHz respectively. For rectangle width W_2 = 0.4mm, the antenna offers four bands at 9.46-10.05GHz, 11.66-11.99GHz, 12.32-15.39GHz, and 16.26-18GHz with a bandwidth of 590MHz, 330MHz, 3.07GHz, and 1.74GHz respectively. For rectangle width W_2 = 0.6mm, the antenna offers four bands at 9.50-10.06GHz, 11.678-11.99GHz, 12.37-15.35GHz, and 16.28-18GHz with a bandwidth of 560MHz, 320MHz, 2.98GHz, and 1.72GHz respectively. From all these variations the rectangle slot width of 0.4mm obtained the best results.



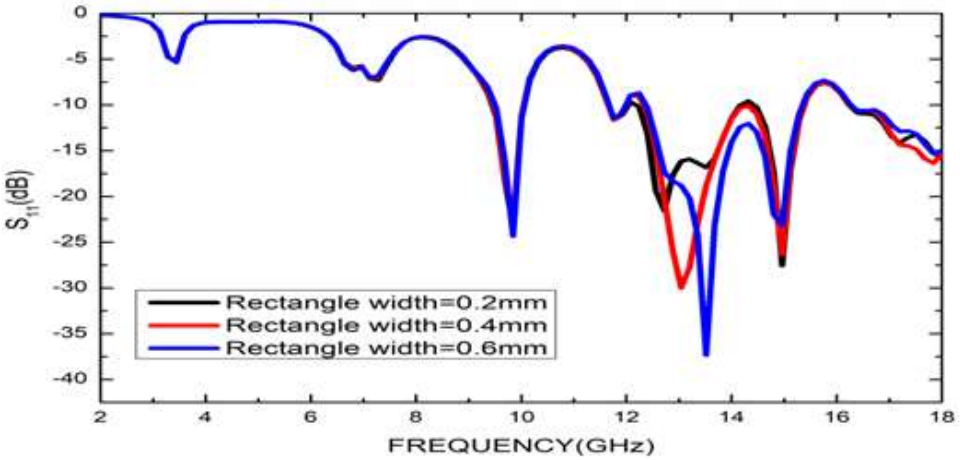


Figure 12. S-Shaped slot in the feed **Figure 13.** Return loss for different widths of S-Shaped slot in the feed

IV. RESULTS AND DISCUSSION

The antenna's return loss, gain, axial ratio and radiation pattern are computed. The operating frequency ranges of the triangle patch antenna with square and circle slots for multi-band applications are 9.46-10.05GHz, 11.66-11.99GHz, 12.32-15.39GHz, and 16.26-18GHz with a bandwidth of 590MHz, 330MHz, 3.07GHz, and 1.74GHz as shown in Figure 14. The least return loss is -29.96dB at 13.04GHz as shown in Figure 14. The peak gain of an antenna is 7.53 dBi at 9.53GHz as shown in Figure 15. E-plane and H-plane radiation patterns at 13.04GHz as shown in figure 17. The axial ratio bandwidth of 540MHz (12.10-12.64GHz) as shown in figure 16. Comparison table of the proposed antenna is presented in Table 2.

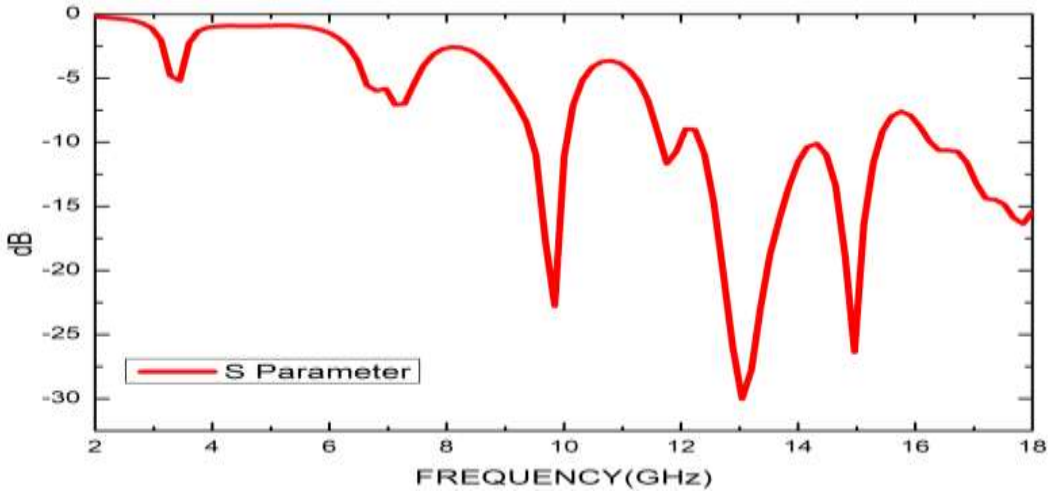


Figure 14. Return loss of the proposed antenna

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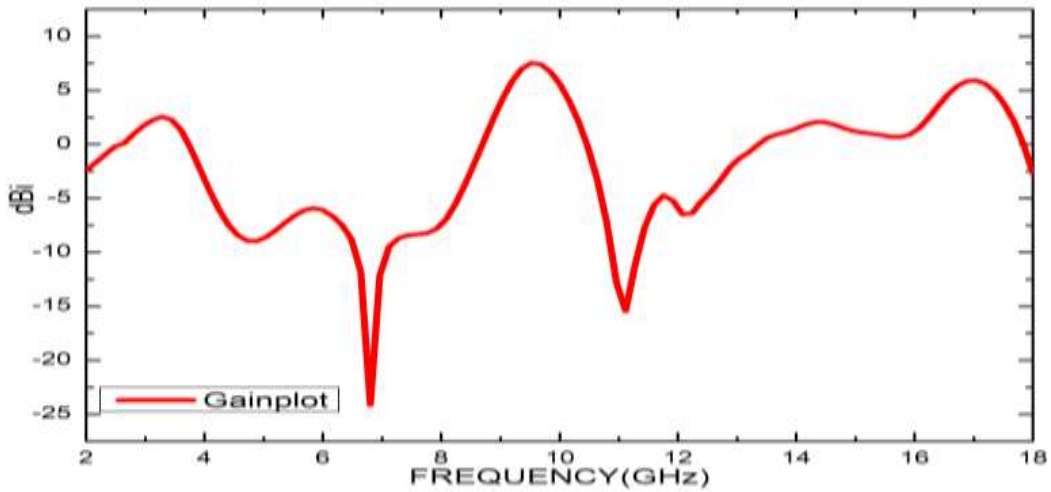


Figure 15. Gain plot of the proposed antenna

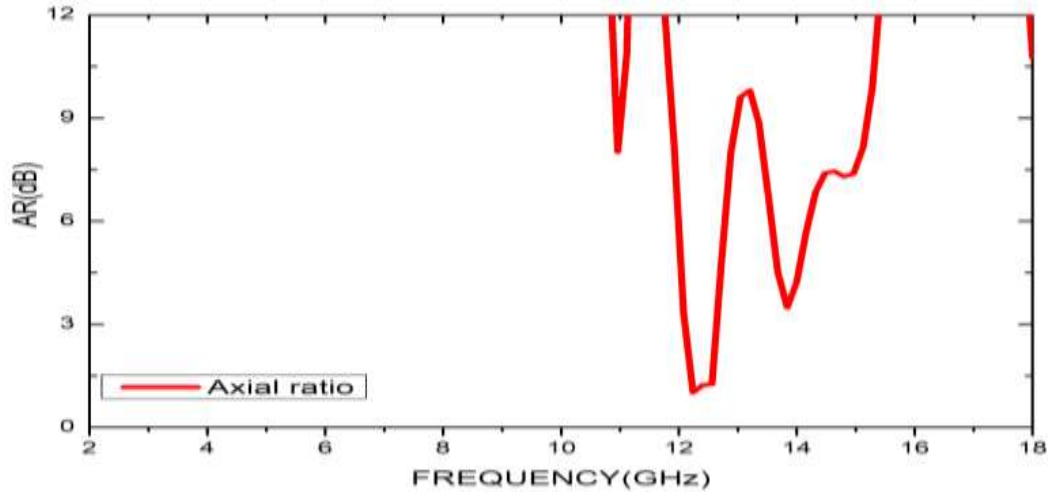
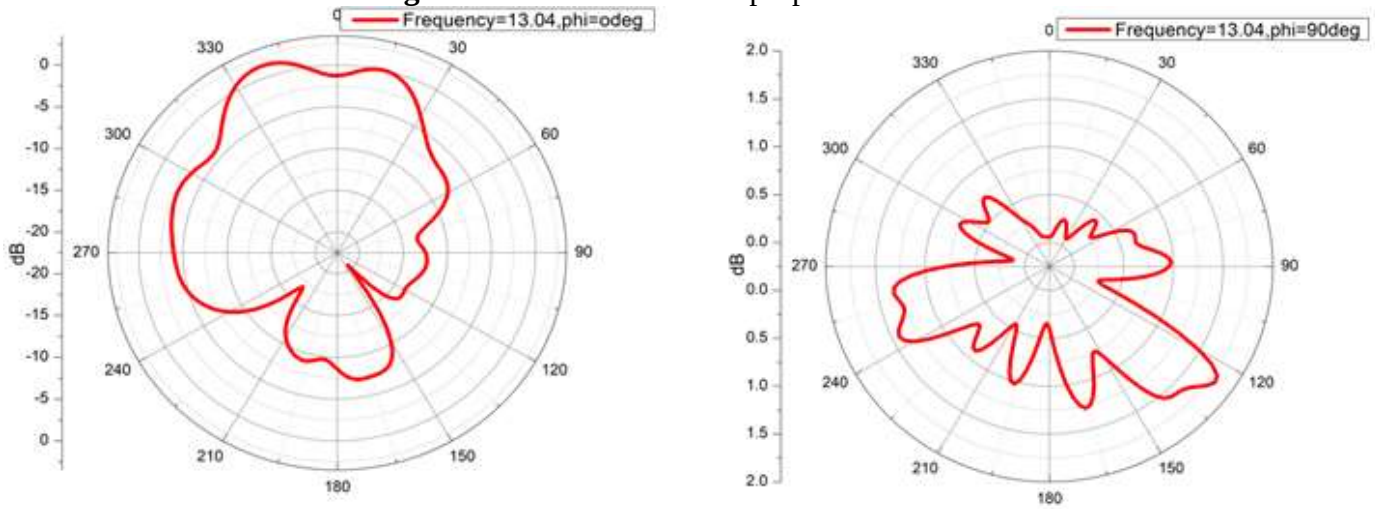


Figure 16. Axial ratio of the proposed antenna



(a) **(b)**

Figure 17. Radiation pattern of E-plane and H-plane of the proposed antenna at 13.04GHz

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Table 2. Comparison table of the proposed antenna

Proposed antenna	Bandwidth and operating frequencies (GHz)	Peak gain(dBi)	Axial ratio
TPA	(9.65-9.76 GHz)110MHz (10.73-11.19 GHz)460MHz (12.43-15.60 GHz)3.17GHz (16.92-18 GHz)1.08GHz	5.21dBi at 9.68GHz	NIL
TPA with square slots	(9.48-9.99 GHz)510MHz (11.64-11.95 GHz)310GHz (12.51-13.97 GHz)1.46GHz (14.51-17.29 GHz)2.78GHz	7.12dBi at 9.68GHz	NIL
TPA with four square slots	(9.44-10.07 GHz) 630MHz (11.75-12.16 GHz)410MHz (12.35-13.91 GHz)1.56GHz (14.24-15.41 GHz)1.17GHz (17.07-18 GHz)930MHz	8.49dBi at 17.04GHz	NIL
TPA with square and circle slots	(9.41-10.07 GHz) 660MHz (11.62-12.06 GHz)440MHz (12.37-15.46 GHz)3.09GHz (16.20-18 GHz)1.8GHz	7.38dBi at 9.68GHz	NIL
TPA with truncated circle slot	(9.39-10.05 GHz) 660MHz (11.57-12.01 GHz)440MHz (12.33-15.42 GHz)3.09GHz (16.14-18 GHz)1.86GHz	7.40dBi at 9.67GHz	NIL
S-shaped slot in the feed	(9.46-10.05 GHz) 590GHz (11.66-11.99 GHz)330MHz (12.32-15.39 GHz)3.07GHz (16.26-18 GHz)1.74GHz	7.53dBi at 9.53GHz	(12.10-12.64 GHz) 540MHz

V. CONCLUSION

This paper presents a multi-band triangle patch antenna with square and circle slots. By loading an S-Shaped slot in the feed it converted linear polarization to circular polarization. The operating frequencies and the bandwidth offered by the proposed antenna are 590MHz (9.46-10.05GHz), 330MHz (11.66-11.99GHz), 3.07GHz (12.32-15.39GHz) and 1.74GHz (16.26-18GHz) with a peak gain 7.53dBi at 9.53GHz and Axial ratio bandwidth is 540MHz (12.10-12.64GHz). The proposed antenna is suitable for X-band and K_u band satellite communications.

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