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Heptagonal Shaped Slotted Broad Band Patch Antenna for Wireless Applications

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Abstract: A compact regular heptagonal shaped slotted broad band microstrip patch antenna is proposed in this paper. Keyhole shape is created in the center for multi band applications. The proposed antenna employs the concept of fractal geometry for multiband characteristics and split ground or partial ground to increase impedance matching, has been printed on FR4 epoxy (ε_r = 4.4) substrate of thickness h=1.6 mm and tangent loss δ=0.01. The presented antenna satisfies broad band characteristics and hence useful in wireless and other applications. The designed polygon shaped slotted antenna has been simulated using HFSS v15 Software, fabricated and the parameters are measured using microwave antenna testing unit. The measured and simulated results show similar response and resonate at 840 MHz, 3.9 GHz, 6.3 GHz and 9.5 GHz hence finds suitable for multiband applications. The three bands can be observed from 500 MHz-1.78 GHz (Band 1), 2.5-4.5 GHz (Band 2) and 5.3-15 GHz(Band 3) which founds useful for many wireless devices such as 5.2/5.8 GHz WLAN, 3.5/5.5 GHZ WiMAX, 2.4/3.6/4.9/5/5.9 GHz WiFi, TD-LTE 2300/2500 (2.305–2.4 GHz), GSM and Digital Multimedia Broadcasting (DMB). Thus the proposed antenna covers most of the bandwidth from 400 MHz to 15 GHz and is about 90.19%. The Radiation patterns and Return loss are omnidirectional having moderate gain. The size reduction of the antenna is by using etching of slots in the patch and reduced ground concept which is almost 60%. The simulation and measured results are found to be very much narrowly deviated.

Keywords: Heptagonal shaped, Fractal Antenna, Broad band, Partial Ground, Multi Band, Return loss, FR4 epoxy

I. INTRODUCTION

Microstrip patch antennas with fractal shapes are more researching interest in these days because of their adaptability for slim wireless communication devices. This leads to the design of multiband and broad band antennas for compact wireless devices and other related applications [1-12]. Space filling and self similarity characteristics of fractal geometry helps in reducing the size of the antenna and obtain multiband characteristics [1,5]. In spite of several advantages of microstrip patch antenna like low profile, low cost, light weight and ease of fabrication, it also suffers from narrow band width and low gain. The optimal aim of the researchers in the field of microstrip patch antenna is to improve the bandwidth [3] by various methods like using a good substrate with low dielectric constant, increasing the thickness of the substrate and etching suitable slots on the patch as well as ground plane [12]. A simple keyhole centered slotted heptagonal shaped patch antenna design for multi band applications are proposed in this paper. Polygonal shaped patch is selected because they provide multiband and broad band characteristics [2]. The feeding to the antenna is by a 50 ohm micro-strip line. The designed antenna is simulated and different parameters like return loss, bandwidth, gain, directivity and VSWR are studied with high frequency structure simulator (HFSS) Software. HFSS (High frequency Structure simulator) [13] is based on the principle of Finite Integration Technique (FIT).

Mukh Ram et al presented a rhombic fractal patch antenna for multiband applications [1] shows four resonant frequencies at 1.07 GHz, 4.5 GHz, 7.51 GHz and 13.18 GHz having return losses of -21 dB, -20.24 dB, -17.52 dB and -34.82 dB. The related frequency bands are 1.0 to 1.14 GHz, 4.43 to 4.57 GHz, 7.44 to 7.58 GHz and 12.83 to 13.81 GHz having bandwidth of 13.08%, 3.11%, 1.86% and 7.44%. F. Billoti et al proposed a design of polygonal patch antenna for portable devices [2] covers a wide band of 1.75 GHz to 2.55 GHz, resonating at 1.82 GHZ, 2.05 GHZ and 2.35 GHz. Bashar B et al explains design of broadband circular patch microstrip antenna for KU-band satellite communication applications [3] achieved an impedance bandwidth of 40.95% from 11.36 GHz to 17.21 GHZ at -29.18 dB with VSWR less than 2. R. Muthu Krishnan and G.K. Kannan presented a polygon shaped 3G mobile band antennas for high tech military uniforms [4] simulated three different antennas resonates at 2.1 GHz for different dielectric constants 0f 1.6 to 1.7 obtains the bandwidth of 90 MHz, 75 MHz and 80 MHz.

A broad band regular heptagonal shaped patch antenna with three frequency bands is designed on FR4 substrate with several slots on the patch of same size. Initially a truncated cone shaped slot is taken at the centre of the polygon followed by a keyhole shaped slot is created at the center of the patch. Three more slots are made on the outer surface of the polygon. The above structure is simulated, fabricated, measured and validated using HFSS v15 and antenna testing unit. The simulated and measured results are suitably matching each other.

II. PROPOSED ANTENNA DESIGN

Heptagon is a seven sided polygon with fourteen diagonals and five triangles, Sum of the interior angles is 900 deg and each interior angle is 128.3 deg. The side length of a regular polygon can be found, given the number of sides and radius.

$$Side\ length = 2r\sin\left(\frac{180}{n}\right) - - - - - - - - - - (1)$$

Where r is in radius and n is the number of sides.

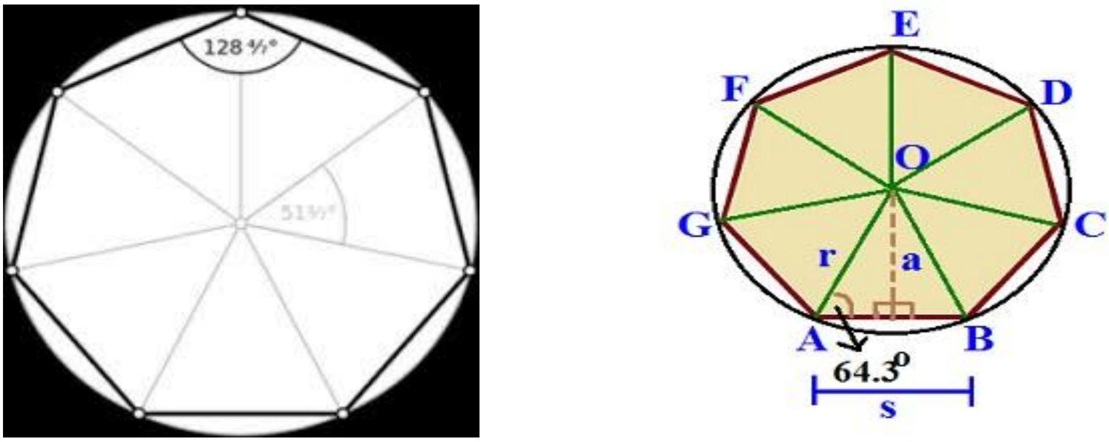


Figure 1: Construction of regular polygon (heptagon)

The area of a regular polygon is calculated using the equation

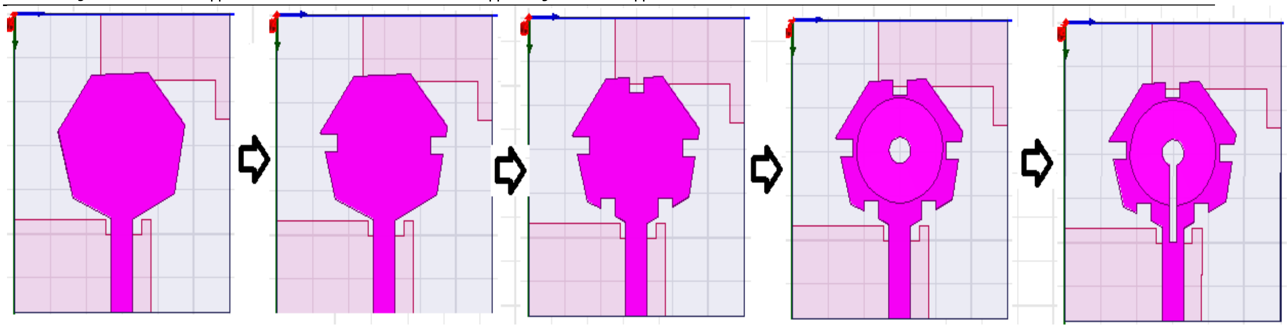
$$A = \frac{7}{4}a^2\cot\left(\frac{180}{7}\right) - - - - - - - - - - - -(2)$$

Regular heptagon of side length 7.8 mm is constructed for this work and the area calculated as 224.5 mm^2. The construction of regular heptagon is represented in figure 1. Another geometry used is a truncated cone of lower radius r1= 6 mm, the upper radius r2=1.5 mm and height h=0.05 mm. Slot of truncated cone is taken at the centre of the regular heptagon with the above specifications. The area removed by the truncated cone can be calculated using the formula

$$F = \pi(r1 + r2)\sqrt{(\mathrm{r1} - \mathrm{r2})^2 + h^2} - - - - - (3)$$

The reduced area around 106 mm using truncated cone. Five slots of area 4 mm are taken at the outer side of the heptagon which again reduces the area of around 20 mm^2. Finally another slot is removed as keyhole shape in the inner circle of the cone of area 10 mm^2. Thus the overall reduction in size of the patch is 136 mm^2. The ground used here is a partial or split ground type.

Initially a regular heptagon is used as patch and then successive iterations have performed on this to obtain the proposed antenna as shown in the figure 2. The corresponding result of return loss v/s frequency is plotted and analyzed. Similarly successive iterations 2, 3 and 4 are carried out and the results are compared. Finally the proposed antenna is arrived at iteration 5. Figure 2 shows all the successive schematics of all the iterations. Also the responses of all the iterations are summarized in figure 3. The proposed response shows a good multiband characteristic resonate at 840 MHz, 3.9 GHz, 6.3 GHz and 9.5 GHz hence finds suitable for multi band applications. The three bands are ranging from 500 MHz-1.78 GHz (Band 1), 2.5-4.5 GHz (Band 2) and 5.3-15 GHz which founds useful for many wireless devices such as WLAN, WiMAX, WiFi, GSM and Digital Multimedia Broadcasting (DMB). The reduction in size of the antenna is achieved by taking slots at different iterations like two slots at the side of the heptagon in iteration 2, three slots at the top and bottom in iteration 3, truncated cone at the centre of the patch in iteration 4 and a keyhole like slot at the proposed structure. Similar to patch the ground plane is also slotted to make the antenna more compact.



Iteration1 Iteration2 Iteration3 Iteration4 Iteration5

Figure 2 Successive iterations to arrive the proposed antenna

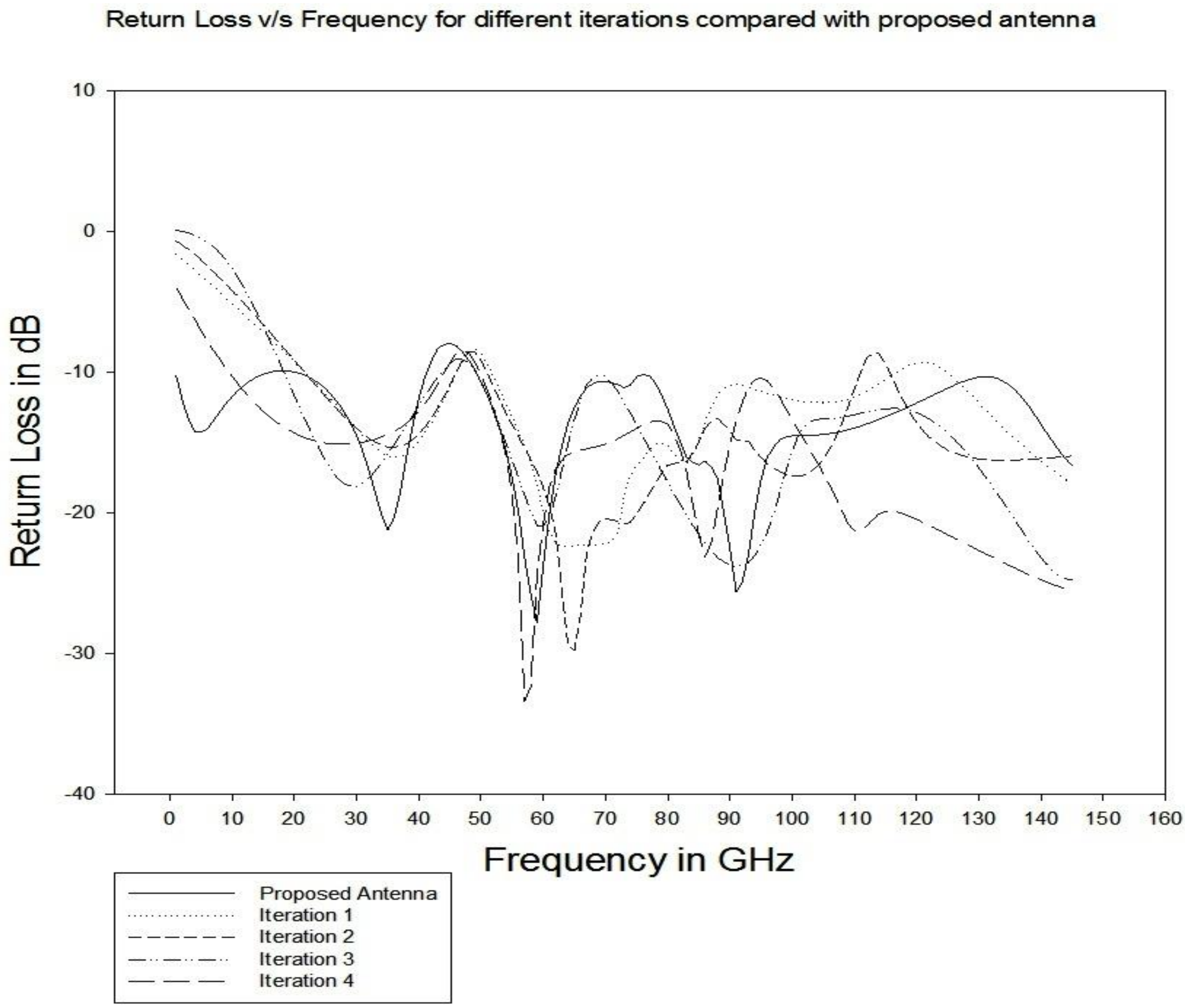


Figure 3: Comparision of Simulated Return Loss(dB) vs Frequency(GHz) of all the iterations

The top and bottom view of the proposed heptagonal shaped microstrip patch antenna with a keyhole at the centre is shown in the figure 4 and 5. This structure is printed on a FR4 substrate of dimensions 34x30x1.6 mm. The other side of the patch is a partial ground plane. The complete dimension of all the slots and other geometry of the antenna is shown in the table 1. The overall structure of the proposed antenna consists of a radiating patch, dielectric substrate and a ground plane. The patch is selected as a regular heptagon of length 7.86 mm in which four outer slots were created of size 2x2 mm and an inner slot of size 10x1 mm. The substrate used here is FR4 having dielectric constant of 4.4 of size 34x30x1.6. The ground plane is modified as a partial ground with three splits of size 10.6x19 mm, 7.5x18 mm and 12x2 mm. A 50 Ω microstrip line feeding is given to the antenna of size 10.55x3 mm. To improve the impedance matching of the antenna Partial ground [14] concept is used here.

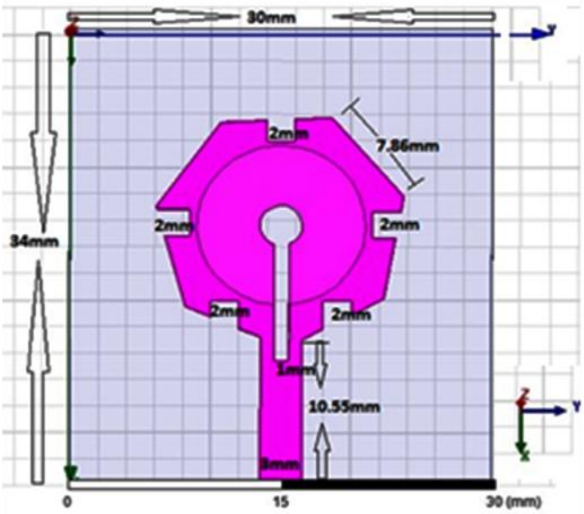


Figure 4: Proposed antenna (Patch View)

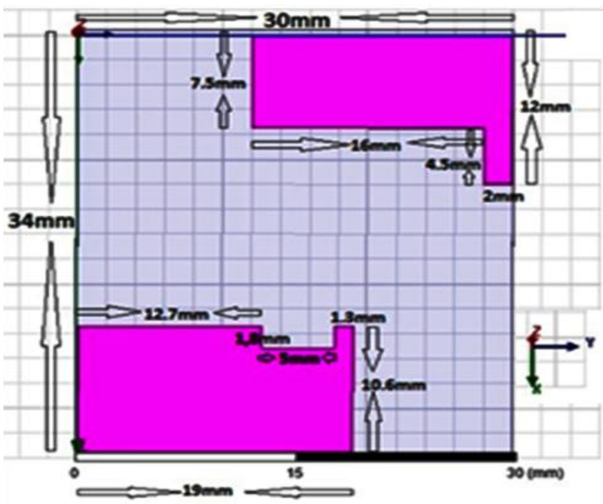


Figure 5: Proposed antenna (Ground View)

Table 1: Dimensions of the proposed antenna

Parameter	Specifications	Dimensions(mm)
Patch	Polygon (Seven sided)	7.86
	Cone	Outer radius =6 Inner radius=1.5
	Slots(outer)	2x2
	Slot(inner)	10x1
Feed	Line feeding	10.55x3
Substrate	FR4(ε_r = 4.4)	34x30x1.6
Ground(Partial)	G1	10.6x19
	G2	7.5x18
	G3	12x2
	Slot	1.8x5

III. RESULTS AND DISCUSSIONS

The simulation results of return loss V/s frequency is shown in figure 6 indicate three useful bands. Band 1 resonates at 840 MHz having return loss of -14.4 dB ranging from 500 MHz to 1.78 GHz with a bandwidth of 1.28 GHz. This band covers UHF and part of L band applied for TD-LTE 2300/2500 (2.305–2.4 GHz) and GSM applications. Band 2 resonates at 3.9 GHz having return loss of -21.2 dB ranging from 2.5 GHz to 4.5 GHz with a bandwidth of 2 GHz. This band covers S band and part of C band useful in 2.4/3.6 GHz WiFi, 4.2 GHz-4.4 GHz Radio Altimeters and Digital multimedia broadcasting (DMB). Band 3 is a broad band resonates at 6.3 GHz and 9.5 GHz having return loss of -27.83 dB and -26.34 dB ranging from 5.3 GHz to 15 GHz with a bandwidth of 9.7 GHz. This band is covers C band, X band and part of Ku band used for 5.8 GHz WLAN, 5.5 GHZ WiMAX, 7.05 GHz Satellite Radio Uplink and 5.9 GHz WiFi. The details of the three bands are summarized in the table 2.

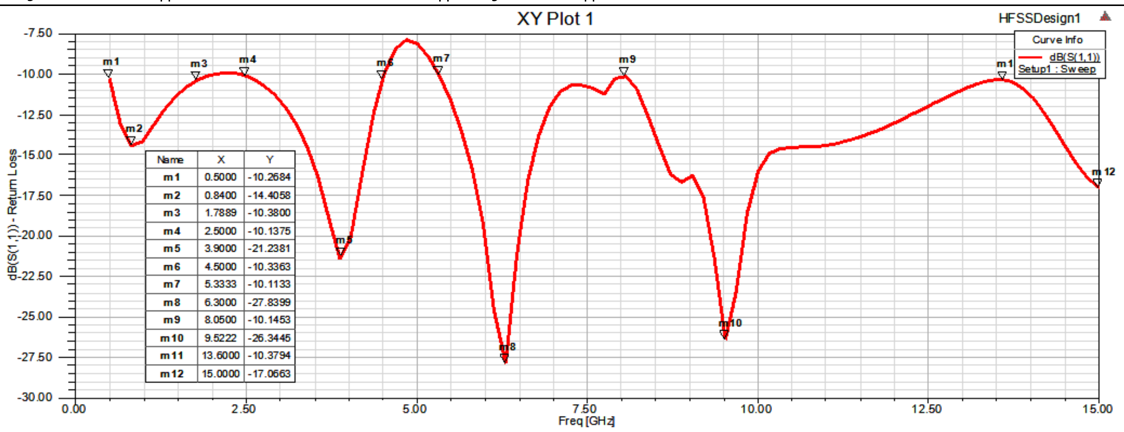


Fig. 6 Plot of Simulated Return Loss(dB) vs Frequency(GHz).

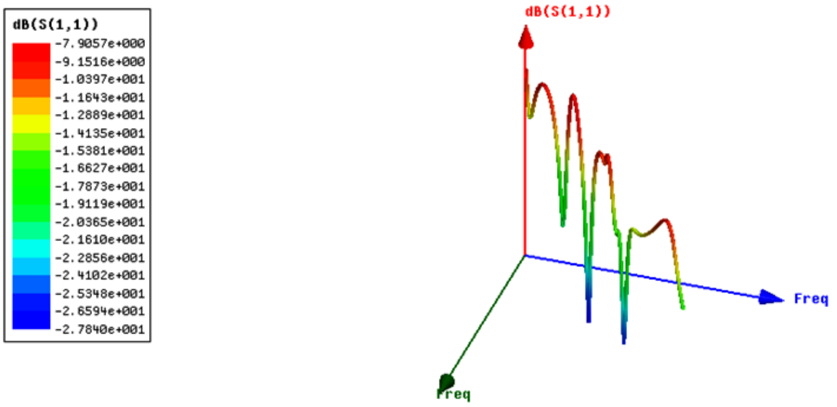


Fig. 7 3-D Plot of Simulated Return Loss vs Frequency.

The figure 7 shows 3-D simulated return loss plots for proposed antenna. The antenna resonates at particularly four different frequencies of three useful bands. We select the response from the point where it shows the return loss of -10db. Figure 8 explains VSWR characteristics which are kept less than 2:1. The gain of the proposed antenna at 3 GHz is shown in Figure 9.

Table 2: Details of Band-1 and Band-2

Bands	**Resonant Frequency**	**Maximum Return Loss**	**Range**	**Bandwidth**	**Applications**
Band-1	840 MHz	-14.4 dB	500 MHz-1.78 GHz	1.28 GHz	GSM
Band-2	3.9 GHz	-21.2 dB	2.5-4.5 GHz	2 GHz	WiFi, DMB
Band-3	6.3, 9.5 GHz	-27.83 dB, -26.34 dB	5.3-15 GHz	9.7 GHz	WLAN, WiFi, WiMAX

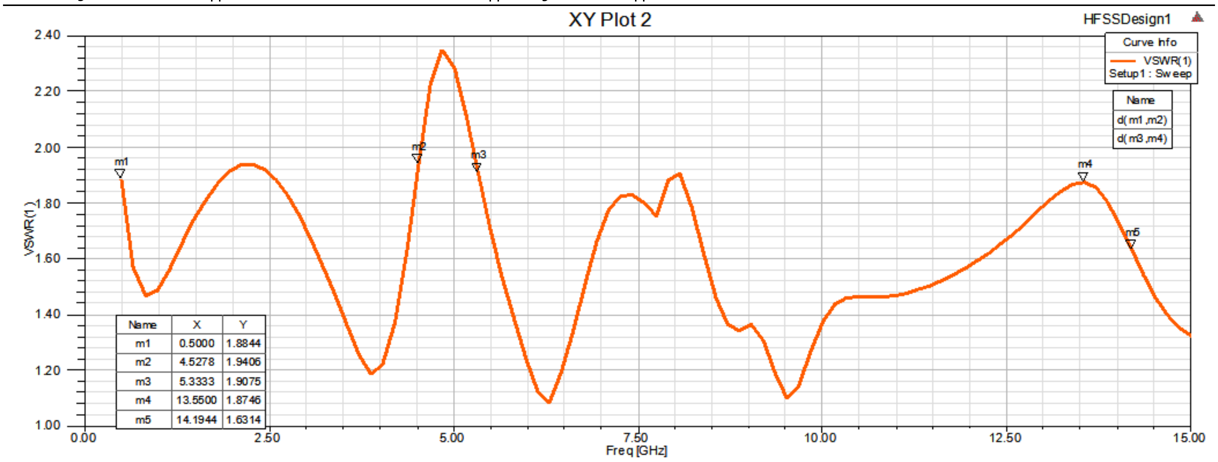


Figure 8 Plot of VSWR v/s Frequency.

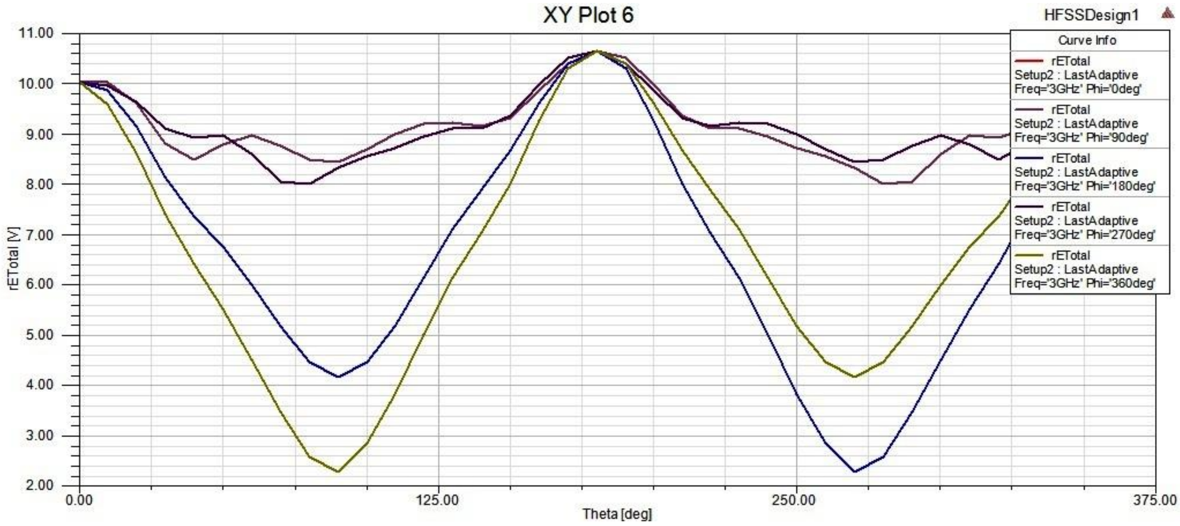


Figure 9 Plot of Gain at 3 GHz.

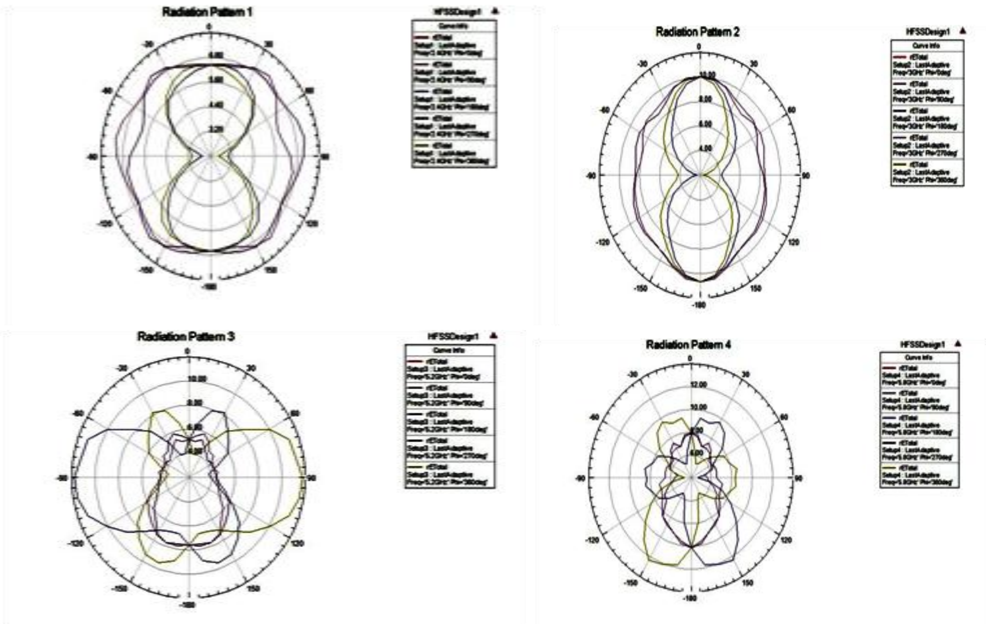


Figure 10: Plot of Radiation Pattern at 2.4 GHz, 3 GHz, 5.2 GHz and 5.8 GHz

Figure 10 shows the simulated radiation patterns at 2.4 GHz, 3 GHz, 5.2 GHz and 5.8 GHz. Moderately omnidirectional radiation patterns are observed in the above graph. Hence the proposed regular heptagonal shaped slotted broad band microstrip patch antenna represents good omnidirectional radiation patterns in the entire frequency bands. The Surface Current density distribution, Electric field density and Magnetic field density are noticed in the figures 12,13 and 14.

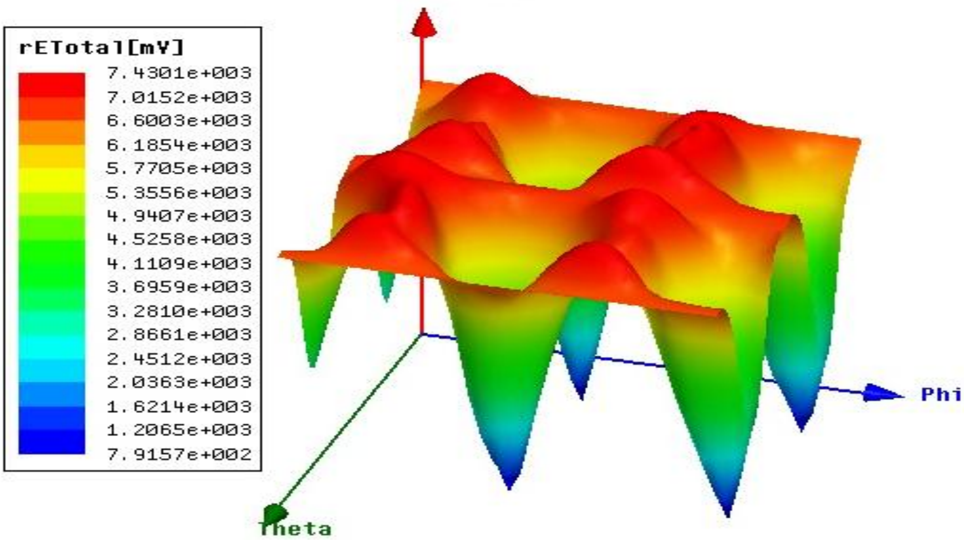
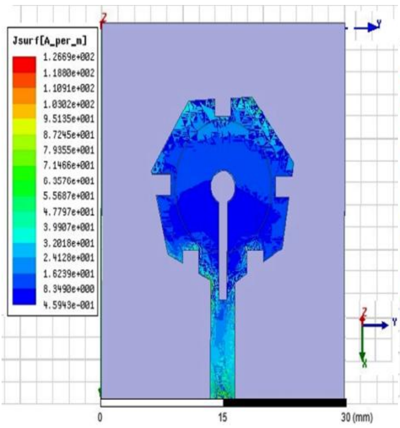
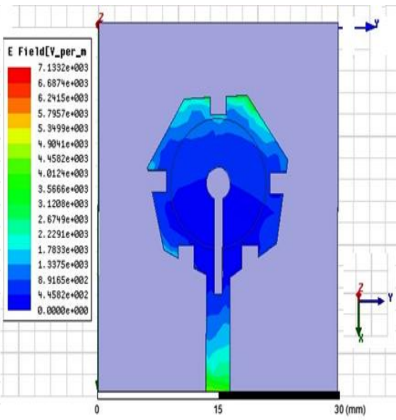


Figure 11 3-D Plot of Simulated Radiation Pattern

Figure 10 shows the simulated radiation patterns at 2.4 GHz, 3 GHz, 5.2 GHz and 5.8 GHz. Moderately omnidirectional radiation patterns are observed in the above graph. Hence the proposed regular heptagonal shaped slotted broad band microstrip patch antenna represents good omnidirectional radiation patterns in the entire frequency bands. The Surface Current density distribution, Electric field density and Magnetic field density are noticed in the figures 12,13 and 14.





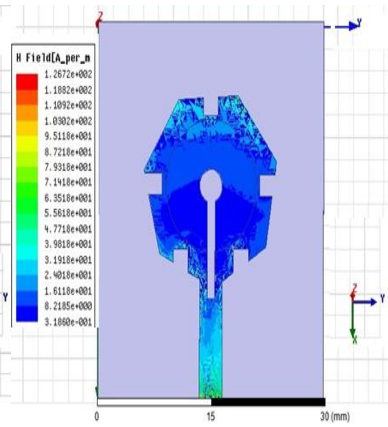


Figure 12: Surface current density Figure 13: Electric field density Figure 14: Magnetic field density

Once the simulation of the proposed antenna gives the expected results in all the parameters the same antenna is fabricated for the practical final model. Fabrication of the proposed antenna is carried out in mechanical machine based milling method. The fabricated model needs to be tested by measuring all the parameters in a antenna measuring unit. The deviation between simulated and measured results are shown in the figure 15. We can notice that the measured results and simulated results are in good validation. The final fabrication model of the proposed antenna is shown in two figures. Figure 16 shows the top patch view and figure 17 is the bottom ground plane view of the proposed antenna. The fabricated antenna testing unit schematics are highlighted in the figure 18.

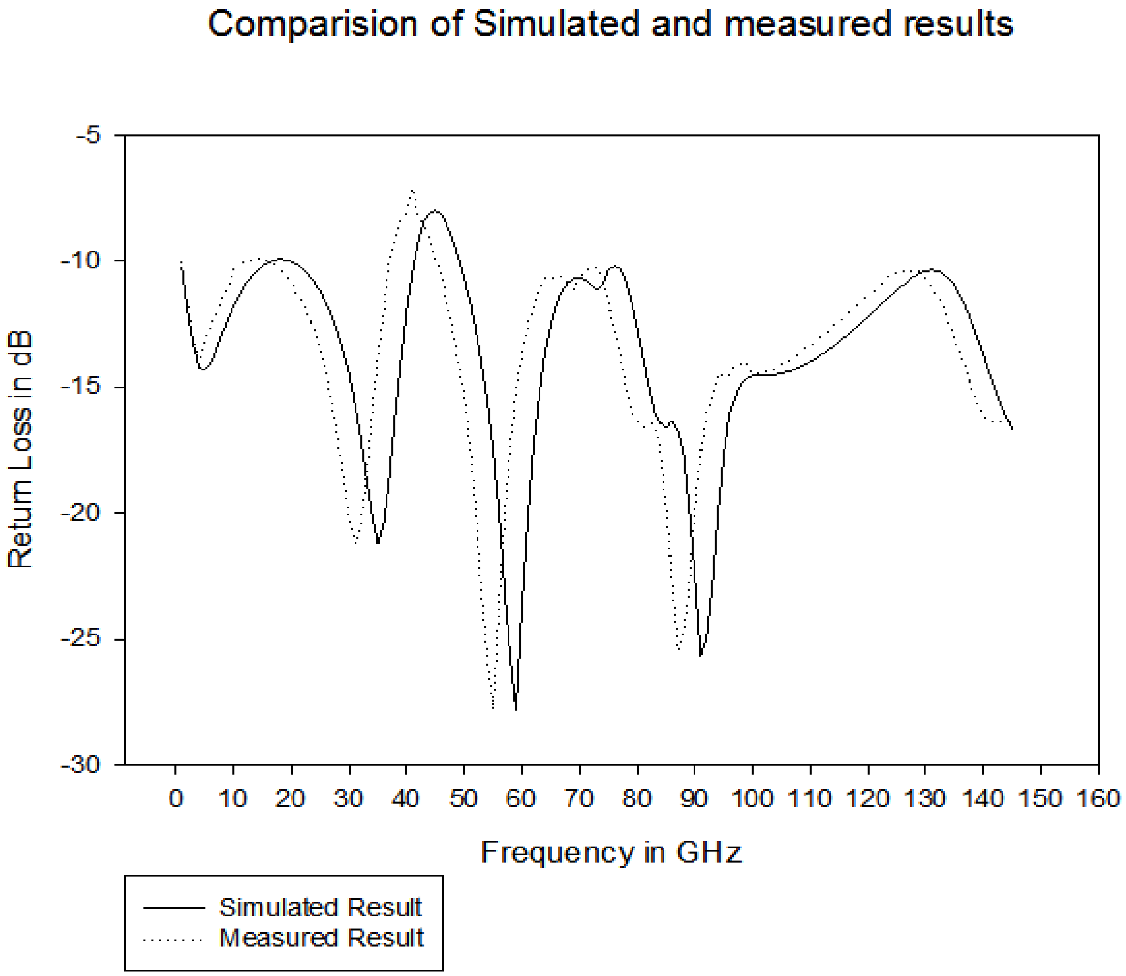


Figure 15. Plot of Return Loss[dB] V/s Frequency[GHz](Measure and Simulated)

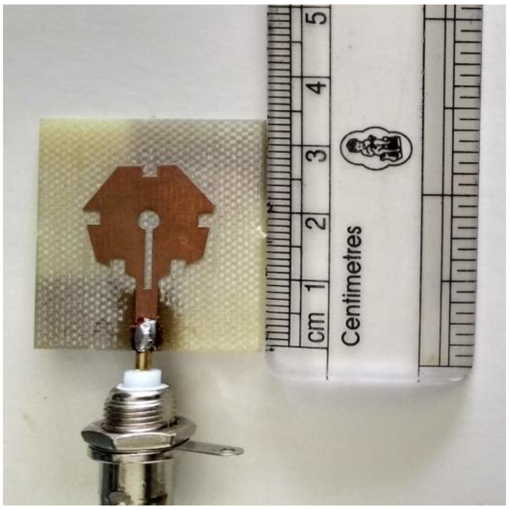


Fig. 16 Fabricated proposed patch Antenna.(Top View)

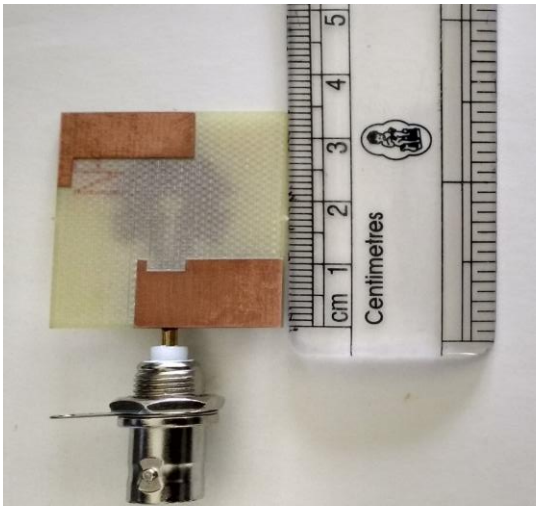


Fig. 17 Fabricated Proposed Antenna Ground view.

Fig. 18 Antenna measuring setup.

IV. CONCLUSION

A Compact regular heptagonal shaped broad band antenna for wireless applications like WLAN, WiFi, WiMAX, GSM and DMB has been proposed in this article. The characteristics of the presented antenna were simulated and practically measured. The slots on the patch and the ground plane not only reduce the size of the antenna but also create multiband behavior for several applications. The proposed antenna has good return loss, radiation patterns, higher gain and VSWR<2 suggest that the antenna is suitable for WLAN, WiFi, WiMAX, GSM, DMB and other applications. The broadband operation has overall bandwidth of about 90.19% is achieved over 400 MHz to 15 GHz. The measured and simulated results show similar response and resonate at 840 MHz, 3.9 GHz, 6.3 GHz and 9.5 GHz having return loss of -14.4 dB, -21.2 dB, -27.83 dB and -26.34 dB. The three bands can be observed from 500 MHz-1.78 GHz (Band 1), 2.5-4.5 GHz (Band 2) and 5.3-15 GHz(Band 3) which founds useful for many wireless devices such as 5.2/5.8 GHz WLAN, 3.5/5.5 GHZ WiMAX, 2.4/3.6/4.9/5/5.9 GHz WiFi, TD-LTE 2300/2500 (2.305–2.4 GHz), GSM and Digital Multimedia Broadcasting (DMB).

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