Design of A Pentagon Microstrip Antenna for Radar Altimeter Application

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Abstract

In the navigational applications, radar and satellite requires a device that is a radar altimeter. The working frequency of this system is 4.2 to 4.3GHz and also requires less weight, low profile, and high gain antennas. The above mentioned application is possible with microstrip antenna as also known as planar antenna. In this paper, the microstrip antennas are designed at 4.3GHz (C-band) in rectangular and circular shape patch antennas in single element and arrays with parasitic elements placed in H-plane coupling. The performance of all these shapes is analyzed in terms of radiation pattern, half power points, and gain and impedance bandwidth in MATLAB. This work extended here with designed in different shapes like Rhombic, Pentagon, Octagon and Edges-12 etc. Further these parameters are simulated in ***ANSOFT-HFSS^{TM} V9.0*** *simulator.*

Keywords

Rectangular patch, Circular Patch, Pentagon shape, impedance bandwidth, radio altimeter etc.

1. Introduction

A radio altimeter is a device, which is used to measure a low altitude or distance from an aircraft or spacecraft to ground surface or to a sea level. This distance is calculated under the craft in vertical direction. Radio altimeter is a part of radar. The working principle of radar is, it transmits radio waves towards ground level or sea level and receives an echo signal after time duration. This value of time is depending on speed of the vehicle and height between craft (air or space) and ground. Here an antenna places a pivotal role to transmit the radio waves and receiving of waves either at the same frequency or at a band of frequencies. The working principle of a radio altimeter is shown in Fig1. Here two antennas are used, one for transmitting radio waves and other for receiving an echo signal reflected by ground or surface of terrains. The receiving time is a ratio of two times of altitude between craft and reflected region to light velocity in space. Generally, frequency modulated continuous wave is preferred than simple continuous wave technique [1]. Radio altimeter [1-9] is working in the band of 4.2GHz to 4.4GHz [2] and receiving frequency is differed from transmitted signal at a rate of 40Hz per foot. The altimeters are also used in both civil and military aircrafts. In civil applications these are used at low visibility conditions and automatic landing systems. Civil applications altimeters give the readings up to 2,500 feet and weather altimeters give up to 60,000feet above the ground level (AGL). Military applicator altimeter is used to fly quite low over the land and the sea to avoid

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radar detection and targeting by anti-aircraft guns or surface to air missiles.

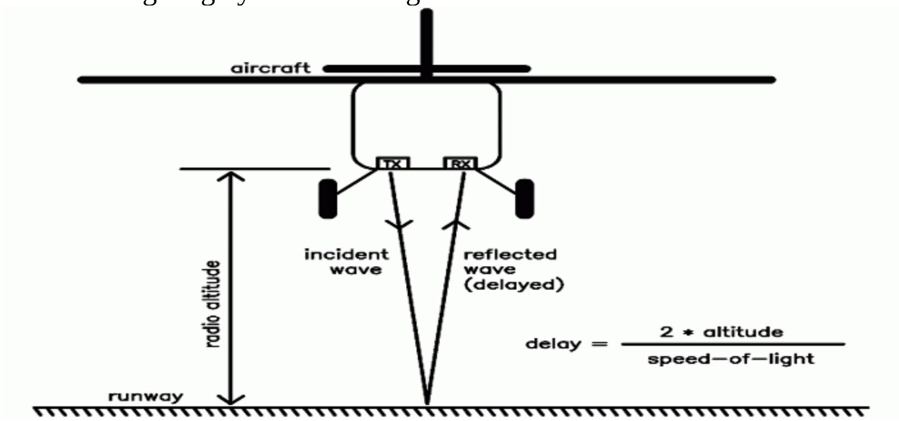


Fig: 1 Basic Conceft of Radio Altimeter

The apt antenna for radio altimeter is a microstrip antenna and also called as patch antenna [10-11]. They are also used in the millimeter-wave frequency range. Microstrip patch antenna consists of a patch of metal that is on top of the grounded dielectric substrate of thickness *h*, with relative permittivity and permeability ε_r and μ_r (=1) as shown in Fig.2a &2b. The metallic patch may be of various shapes with rectangular, circular, and triangular etc.

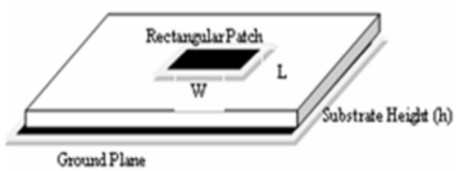


Fig. 2a Rectangular Patch MicroStrip Antenna

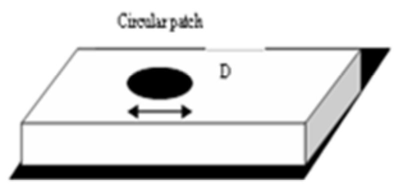


Fig. 2b Circular Patch Microstrip Antenna

The general single antennas offer low gain and low directivity. These values are not suitable for various areas like cellular, mobile, satellite communication, navigation, biomedical etc. and these parameters are to be improved. The most popular method is an array i.e., arrangement of similar patches in different structures like linear, ring, cross etc. The scientists YAGI and UDA observed and suggested the designing parameters like distance between different patches [10]. These patches are named as reflector, driven and directors. Along with these parameters the patch size can be changed for effective results. This well known method is named after these scientists as Yagi-Uda array.

Antenna array has large number of elements and has several problems if microstrip antenna elements are used. First, if each element is connected to a feed line, the resulting feeding network will introduce unwanted radiations as a result the copper losses [10-11]. Second, for phase array, each individual element will require a phase shifter in order for the beam to be steered, with result that a great number of phase shifters are needed in large arrays; the cost of the phase shifters is likely to be increased. K.F.Lee et.al[12] suggested that problem will be reduced if the array is divided in to sub arrays and feeding is given to only one patch in each of the sub array [12] , with

several closely spaced parasitic patches (called Reflector, and Directors) around it. The element that is directly fed is called driven element.
J.Huang [13] presented the work on rectangular patch yagi-array antenna. Parasitic patches are arranged linearly as shown in Fig.2 .He designed an antenna at 6.9GHz (C-band) and 1.58 GHz (L band), for linear polarization. In his observations the beam tilted towards end-fire direction. He continued his work for circular polarization too. D.P.Gray, et al [17] studied on linearly polarized yagi-array at L-band (1-2GHz) with 4-elements and also in S-band (2 - 4GHz) with six elements. He extended his work with different substrate materials and heights. In the later years, researchers continued the similar topic. Yang-Chang et al [14] continued their work on rectangular patch linearly polarized yagi-array antenna at 38GHz and observed response with different sizes and distance between elements. Chow Yen Desmond Sim et al [18] presented the work on Annular–ring microstrip patch for circular polarization at S-band frequency range. Garima et al [16] simulated the work on circular patch in C-band at 6GHz and observed low directivity with single patch.

Krishna Kumar et.al[5], has done work on Octagonal microstrip antenna for Radar and Space-Craft Applications. He had designed antenna in HFSS and observed results.

Before designing, the practical antenna can simulate using softwares like **ANASOFT-HFSS™ V9.0** [23] and MATLAB. By simulation antenna characteristics can be analyzed and synthesized. These characteristics can be visualized in all dimensions Mr. M.Ben Ahmed et al., [19-24] designed a patch antenna for multi applications like GSM/PCS/UMTS/HIPERLAN for Mobile Cellular Phones in softwares. Later he tested practically and observed that both results are similar.

2. Design Procedure

In this paper Yagi antenna at 4.3GHz (C band) in linear structure with both rectangular and circular patches (Fig. 3) having linear polarization [13] is designed. Further, work was extended to different shapes [5] of patches like Square, Rhombic, Pentagon, Octagon and Edge-12 which is nearer to circular structure. All these structures are designed in ansoft HFSS simulator [23] which is working in finite discrete time domain(FDTD) and analyzed in terms of percentage impedance bandwidth and gain in dB on both E-Plane and H-plane.

For Rectangular Patch Antenna:

Width of the patch $W= [C/2*f_r]*sqrt\{2/(\varepsilon_r+1)\}$ --- (1)
Where C is velocity of light in free space
f_r is a resonant frequency or operating frequency
Length of the patch 'L' is generally **$\lambda o/3 < L < \lambda o/2$**

Circular Patch Antenna:

$$Radius(a) = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\left[\ln \frac{\pi F}{2h}\right] + 1.7726\right]\right\}^{\frac{1}{2}}} \quad \text{--- (2)}$$

where

$$F = \frac{8.791}{f_{r\sqrt{\epsilon_r}}} \times 10^9$$

$$directivity = \frac{41253}{\Theta_{1d}\Theta_{2d}} \qquad \text{--- (3)}$$

The percentage bandwidth [11] is calculated from return loss (S_{11}) graph of antenna below 10dB.

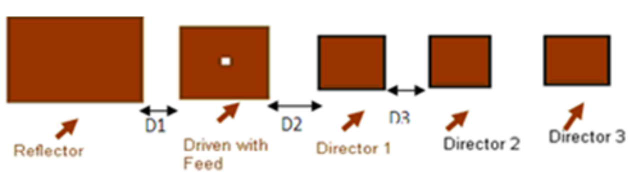
$$\%\text{Impedance bandwidth} = 200 \times \frac{(f_h - f_l)}{(f_h + f_l)} \qquad \text{----- (4)}$$

Where f_h and f_l are upper and lower frequency values from return loss.

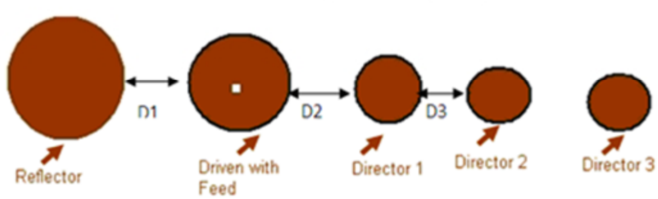
The array structure shown in Fig.3 is designed with RT-Duroid material as substrate and assumed and calculated values are given in Table-1.

Table: 1

Relative Permittivity	$\varepsilon_r = 2.2$
Height	h=0.1588cm
Rectangular patch as driven element	Width(w)=2.7578cm, Length(L)= 2.4296cm
Circular patch as driven element	Radius ‘ a’= 1.2874cm
Reflector size	Driven Element size increased by 0.3cm
Director size	Driven Element size decreased by 0.1cm
Distance between reflector and driven element	D1 0.2 λ
Distance between director1 and driven element	D2 = 0.4λ
Distance between director2 and director1	D3 = 0.8λ
Distance between director3 and director2	D4 = 0.05λ
Distance between director3 and director4	D5 = 0.05λ



Rectangular Patch Linearly Polarized Yagi-Array Antenna



Circular Patch Linearly Polarized Yagi-Array Antenna

Fig.3 Microstrip Array With Parasitic Elements

3. Results

With the values obtained in section2, arrays with different combinations 2-directors (red line in Fig.6), 3-directors (green line in Fig.6), and 4-directors (blue line in Fig.6) are designed and simulated in MATLAB. The simulated values of single element are tabulated in Table-2 and pattern on E-Plane and H-Plane is shown in Fig.4.

By keeping the distance between the elements constant and varying the frequency form 1GHz to 20GHz (includes L-band, S-band, C-band, X-band, Ku-band and K-band) responses are calculated and tabulated in Table-3 . From the response with 2-directors, it is observed that

- Up to 8GHz no side lobes are presented.
- At 4.3GHz the response on E-Plane of a rectangular patch array is shown in Fig.5, H-Plane is shown in Fig.7 and E-plane of circular patch array is shown in Fig.6.
- Here directivity is around 14.38dB and it is higher than single patch element and beam steered is 32.65^0 in end-fire direction.
- As frequency increased, directivity also increased and from 8GHz onwards side lobes are generated in circular patch array. Response at 15GHz is shown in Figs (8-9).
- By Keep frequency constant and vary the distances between elements and response tabulated in Table-4.
- The directivity is decreased as permittivity (ε_r) is increased and tabulated in Table-5.
- The height (h) and permittivity (ε_r) both are simultaneously changed and response is tabulated in Table-6.
- The rectangular patch array antenna at 4.3GHz is designed and simulated in ANSOFT-HFSS is shown in Fig.10.
- The return loss (S_{11}) is shown in Fig.11 represents, it resonates at two frequencies, one is at 3.93GHz with -10dB and second is at 7.17GHz with -33dB.
- The directivity of an array in dB (shown in Fig. 12) in $\varphi = 0^o$deg plane shows 12.27dB with 49.9^0 tilt towards end fire direction.
- Feed tuning in rectangular patch and array is difficult than other structures like circular, 5 edges (pentagon) and more.
- Referring to the Fig.13 the radius of a pentagon is 1.377cm which is designed in ansoft HFSS .
- From Fig.14 the return loss that replicates is indicated with $S_{11.}$ It is tuned at the resonating frequencies FR1=4.36GHz and FR2= 9.09GHz respectively and also called dual tuned antenna. It is suitable for both radio altimeter application and space craft applications.
- Fig.15 implies that FR1 offers 100MHz bandwidth from 4.21GHz to 4.31GHz below -10dB as represented in the S_{11} graph.
- It produces a gain of 7.44dB with main beam along 0 deg direction as shown in Fig.16.
- Fig.17 resembles FR2 that offers maximum gain of 6.57dB and main beam is tilted with 52deg towards end- fire .
- FR2 offers a bandwidth of 730MHz .The % impedance bandwidth corresponding to FR2 is 7.8 as tabulated in Table 7.
- Fig.18 resembles the current distribution of the pentagon patch which is referred in Fig.13.
- Fig. 19 shows the 3D representation at FR1.Similarily the 3D representation is in Fig.20.
- The above criterion are repeated for different shapes like Rhombic, Square, Octagon, Edge-12 etc and is shown in Table-7.

Table:2 Comparison between Rectangular and Circular Single Patch Antenna

Shape of a patch	**E-plane (HPBW) (deg)**	**H-Plane (HPBW) (deg)**	**E-Plane Directivity (dB)**	**H-Plane Directivity (dB)**
Rectangular Shape	85	80	7.566177	8.092756
Circular Shape	155	110	2.347921	5.326702

Table 3: Response of an Antenna w.r.to Frequency

Rectangular -Yagi Antenna with 2-Directors					
Frequency (GHz)	**Shift angle(Tilt) (deg)**	**E-field (dB)**	**HPBW (deg)**	**Directivity (dB)**	
1	33.29	6.604	41.26	13.84397	
2	33.94	6.674	40	14.11336	
3	33.32	6.745	40	14.11336	
3.5	32.06	6.767	40	14.11336	
4	33.29	6.809	38.76	14.38688	
4.3	32.65	6.824	38.76	14.38688	
6	33.1	6.922	38.76	14.38688	
10	31.78	7.094	37.5	14.67393	
15	23.99	7.208	35	15.27319	
25	17.98	7.104	30	16.61213	
Circular patch-Yagi Antenna with 2-Directors					
Frequency (GHz)	**Shift Angle (deg)**	**E-field (dB)**	**HPBW (deg)**	**Directivity (dB)**	
3.5	34.49	3.295	38.34	14.48151	
4.3	35.37	3.903	38.34	14.48151	
5	34.42	4.366	38.34	14.48151	
6	37.71	5.001	36.66	14.87071	
8	27.09	5.994	31.66	16.144	SLL=1.277
10	25.91	6.774	31.66	16.144	
15	24.49	7.717	25	18.195	SLL=3.057
20	36.57	7.524	21.66	19.441	SLL=0.863

Table 4: Response of an Antenna w.r.to distance between elements

Distance (λ)	Tilt (deg)	E (dB)	HPBW (deg)	Directivity (dB)
Distance between Reflector and Driven Element (D1)				
0.1	31.31	4.664	20	14.11336
0.2	32.65	6.824	19.38	14.38688
0.3	33.88	7.891	19.38	14.38688
Distance between Director and Driven Element				
D2(λ), D3(λ)				
0.3, 0.8	35.8	7.701	57.5	10.9612
0.4, 0.8	37.13	1.875	38.76	14.38688

Table 5: Response of an Antenna w.r.to SUBSTRATE (ε_r)

Rectangular patch -Yagi Antenna with 2-Directors, h=0.1588 cm					
Frequency (GHz)	ε_r	Tilt (deg)	E (dB)	HPBW (deg)	Directivity (dB)
4.3	2.2	32.65	6.824	38.76	14.38688
4.3	2.34	33.1	6.62	38.76	14.38688
4.3	3.5	32.79	5.282	42.5	13.58678
4.3	4.4	31.1	4.629	47.5	12.62068
4.3	6.15	31.09	3.997	86.26	7.438366
4.3	10.2	30.83	3.93	103.76	5.833956
Circular patch -Yagi Antenna with 2-Directors					
Frequency (GHz)	ε_r	Tilt (deg)	E (dB)	HPBW (deg)	Directivity (dB)
4.3	2.2	32.65	6.824	38.76	14.38688
4.3	2.34	35.71	3.702	38.34	14.48151
4.3	3.5	33.07	2.592	51.66	11.89147
4.3	4.4	33.27	2.103	51.66	11.89147
4.3	10.2	32.73	1.25	110	5.326702

Table 6: Response of an Antenna w.r.to Substrate and Height

Rectangular-Patch Yagi with different Heights and ε_r at Frequency 4.3GHz					
ε_r	Height (cm)	Tilt (deg)	E (dB)	HPBW (deg)	Directivity(dB)
2.2	0.0794	32.88	6.829	40	14.113
2.2	0.1588	32.65	6.824	38.7	14.386
2.2	0.3176	32.7	6.898	37.5	14.673
2.2	0.6352	35.06	6.713	35	15.273
3.5	0.6352	36.9	5.189	37.5	14.673
6.15	0.6352	31.9	3.912	53.7	11.545
Circular-patch Yagi					
2.2	0.0794	34.5	3.885	38.3	14.481
2.2	0.3176	35.45	3.933	38.3	14.481
2.2	0.6352	35.6	3.987	38.3	14.481
3.5	0.6352	32.29	2.623	51.6	11.891
10.2	0.6352	31.9	1.255	88.3	7.2314

Table: 7 Response of different Shapes of patch antenna

Name of an antenna Structure	**Impedance Band Width(%)**	**FR1 (GHz)**	**Gain (DB)**	**FR2 (GHz)**	**Gain (DB)**
Rectangle	1.72	3.82	6.94	----	---
Square	5.1	3.91	6.823	7.73	5.89
Circle	8.84	4.39	7.355	9.27	5.58
Rhombic	5.81	4.62	7.63	9.19	4.87
Pentogon	7.8	4.36	7.44	9.09	6.57
Octagon	6.89	4.03	7.05	8.64	5.07
Edges12	5.45	4.09	7.10	8.36	4.31

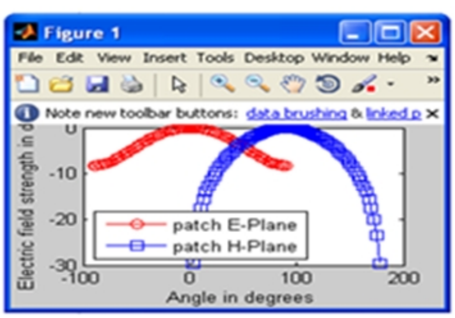


Fig 4 Radiation Pattern of Rectangular patch at 4.3GHz on E-Plane and H-Plane

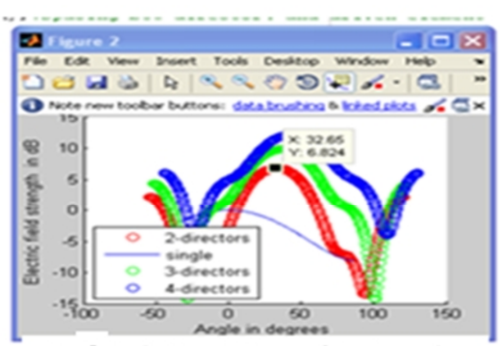


Fig 5 Radiation Pattern of Rectangular patch Array at 4.3GHz E-Plane

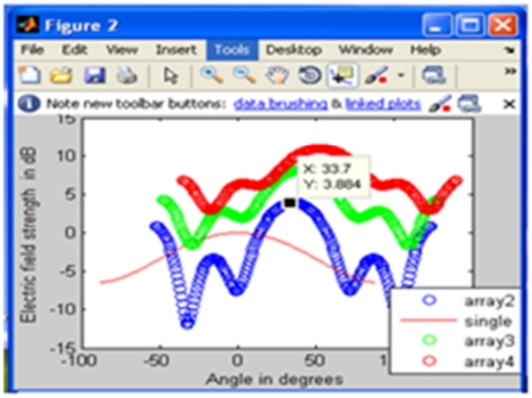


Fig.6 Radiation Pattern of Circular patch Array at 4.3GHz E-Plane

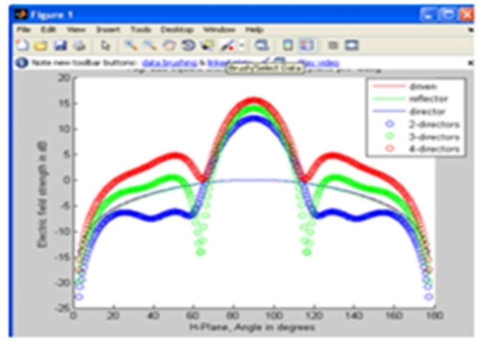


Fig 7 Radiation Pattern of Rectangular patch Array at 4.3GHz on H-Plane

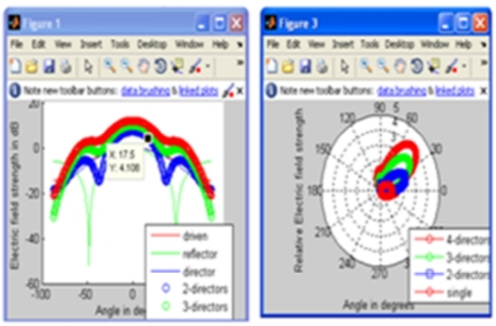


Fig.8 Radiation Pattern of Rectangular patch Array at 15GHz on E-Plane

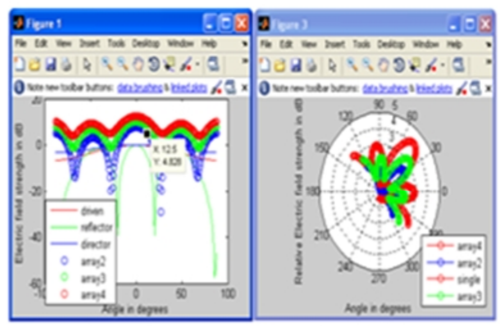


Fig 9 Radiation Pattern of Circular patch Array at 15GHz on E-Plane

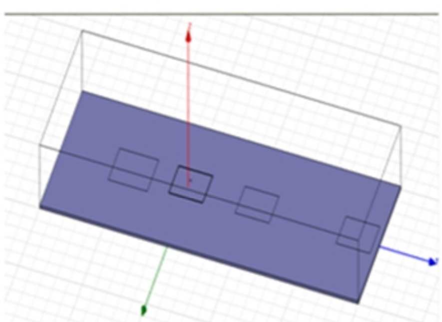


Fig 10 Rectangular patch 4-Element Yagi-Array design in Anasoft-HFSS

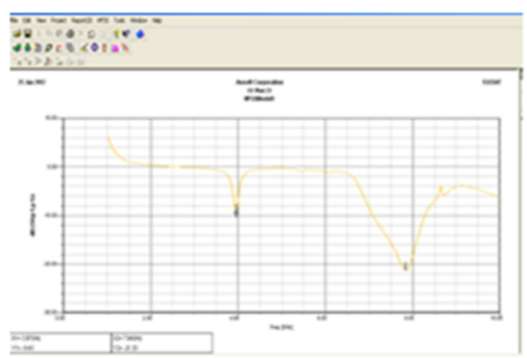


Fig. 11 Return loss S_{11}(dB)of Rectangular patch Array

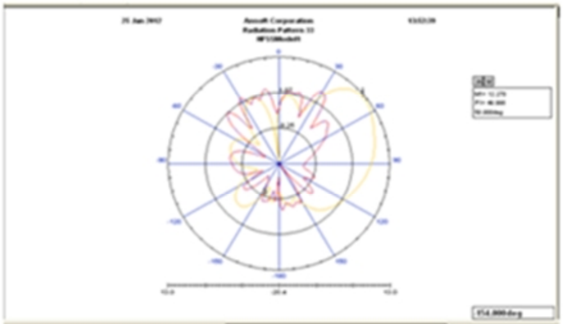


Fig.12 Directivity of rectangular patch Array at 3.93GHz in φ=0° plane

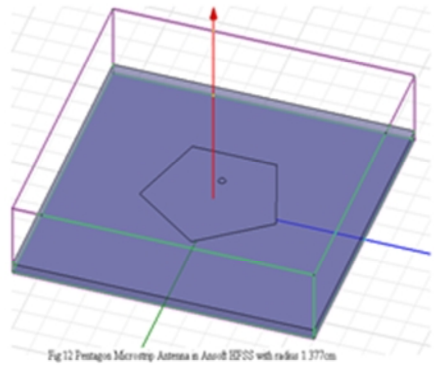


Fig:13 Pentagon Microstrip Antenna in Ansoft HFSS with radius 1.377cm

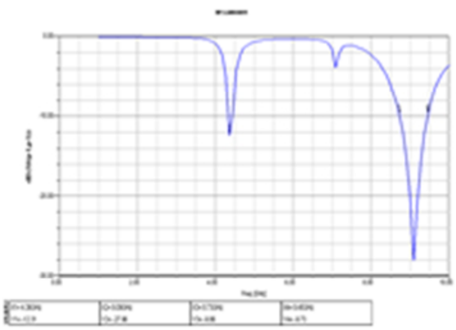


Fig:14 return loss S_{11} (dB) of Pentagon Microstrip Antenna in Ansoft HFSS (1GHz- 10GHz)

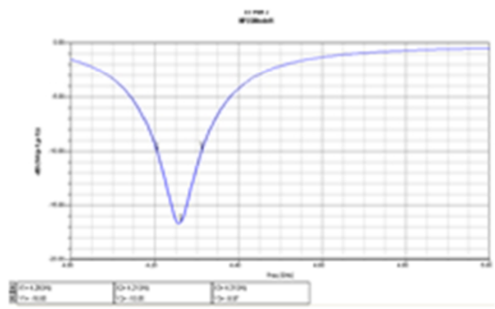


Fig:15 Return Loss S_{11} (dB) of Pentagon Microstrip Antenna (4GHz-5GHz)

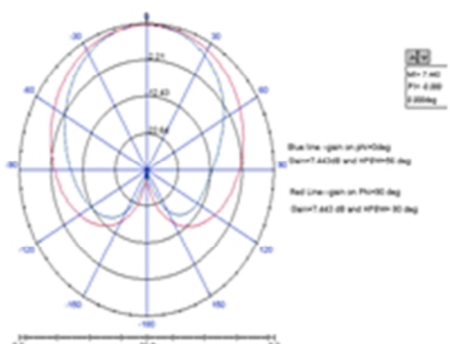


Fig:16 Radiation pattern of Pentagon Microstrip Antenna at 4.36GHz

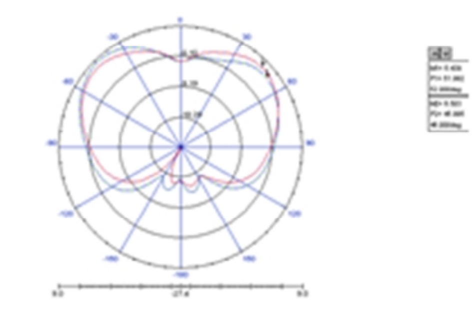


Fig:17 Radiation pattern of Pentagon Microstrip Antenna at 9.09GHz

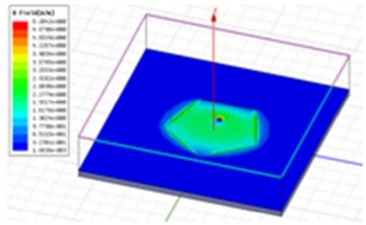


Fig.18 Current distribution on Pentagon Microstrip Antenna at 4.36GHz

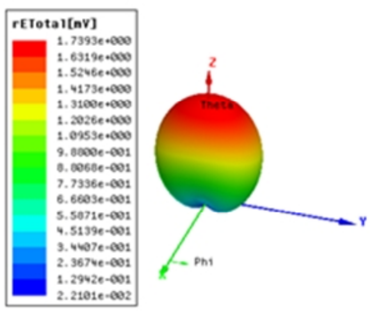


Fig.19 3D Radiation pattern of Pentagon Microstrip Antenna at 4.36GHz

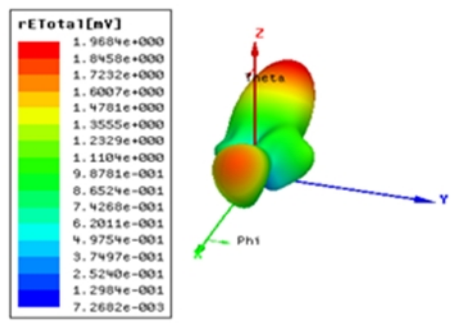


Fig.20 3D Radiation pattern of Pentagon Microstrip Antenna at 9.09GHz

4. Conclusion

The design of rectangular patch Yagi antenna and circular patch Yagi antenna that operates at linear polarization has been done using MATLAB, ANSOFT-HFSS software. Calculations show that area of a circular patch is less than area of a rectangular patch. The antennas were simulated in MATLAB and results are tabulated. Results (Table 2) shows the comparison that circular patch Yagi antenna radiates electric field towards broadside than rectangular patch and it offers high directivity for frequency above 15GHz, around 3dB even though it has side lobes. The effect of different distances between reflector and driven element is almost negligible (from Table 3). In both the arrays, the performance is degraded due to high values of relative permittivity ε_r (from Table 4) and the effect of substrate on the result is very less at low relative permittivity ε_r (from Table 5). Finally rectangular patch yagi-array designed in Anasoft HFSS and compared with MATLAB results and observed 2dB difference. Referring to the Table 7 it is proved that both the pentagon & circle shapes acts as a perfect choice in the design of radio altimeter . This design offers dual resonant frequency band with is exactly not available with the rectangular structure. With this innovative step there is an increase in the probability of utilization of the other structures of radio altimeter. This work can be extended for different Yagi designs for circular polarization at different frequencies for different applications.

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