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Research paper

CPW-fed Dual band circular patch antenna with tapered and ridge ground for WiMAX/WLAN and UWB applications.

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Abstract

A coplanar wave guide (CPW)-fed dual band circular patch antenna with tapered and ridge ground is designed and its performance is verified experimentally for ultra-wideband (UWB) applications. The proposed antenna is compact in size has the overall dimensions (25x35x1.6) mm3 and fabricated on FR4 substrate. Ground of the antenna is tapered and ridged on either side to get the desired performances .The dual frequency circular patch antenna which exhibits wide frequency bands over the UWB range. Antenna has wide dual band ranging from 2.6--6.67GHz (87.8%) and 7.5--10.5GHz (33.3%).Antenna can provide omnidiretional radiation patterns, appropriate for (Worldwide interoperability for microwave access (WiMAX), Wireless local area network (WLAN) and UWB applications.

Keywords: *Dual Band; CPW-Fed; Tapered and Ridge Ground; Circular Patch; Wi-MAX; WLAN; UWB.*

1. Introduction

Microstrip patch antennas are quickly growing in wireless communication, due to their attractive qualities such as low profile, light weight and ease of fabrication. Due to this reason they are preferred for wireless communication system, however they pertaining to narrow impedance bandwidth. There are several techniques to overcome this serious disadvantage in order to achieve UWB performance. Planar microstrip antennas with different geometries have been experimentally characterized in[1-21].Compact wide-slot hexagonal with large bandwidth for UWB applications is presented in [1].Circular disc monopole antenna whose operation is heavily depends on feed gap [2] is designed. Bandwidth enhancement achieved through tapered step on the ground plane is presented in [3].Circular patch antenna which operates in S-band for circular polarization is presented in [4].To reduce the antenna size with defective ground structure is designed in [5].Dual band antenna designs with split-ring resonator is presented in [6].WLAN applications with dual band is reported by Sun et al in [7].Samsuzzaman et al presented swastika shape patch antenna for WLAN/WiMAX(Worldwide interoperability for microwave access) in [8].CPW- fed fish tail antenna for dual band applications is presented in [9].Antennas with defective ground structures are designed in [10-12].Antenna with trapezoidal shape with U-slot for S- band rejection is presented in [13].A simple printed circular monopole antenna for UWB applications with partial back ground is represented in [14].A triple band antenna for WiMAX and WLAN applications is proposed in [15] with somewhat larger ground. Wide band is achieved with compact design [16] of T-shape with asymmetrical ground. Circular and elliptical shape stubs with wide band [17] is designed for UWB applications. The antenna presented in [18] has large width as 47mm which covers the UWB region. Single and multiple half-wave length U-shaped to generate the frequency band notched function is presented in [19].V-shaped slots inserted to achieve frequency band notch function is presented in [20]. A distinct triple band for planar monopole antenna with triple bands is presented in [21] which suits for WiMAX/WiFi applications. Internet of things applications dual ultra wideband antenna is designed in [22] by Qasim et al. Miniature multiband patch antenna using meta material loading is presented in [23].Dual band antenna for RFID applications is presented in [24].

2. Antenna design

Fig 1) a. shows the geometry of the basic circular patch antenna. The overall dimensions of the antenna are (35(L) x25(W)) mm^2.The antenna consists of circle radius R=7.3mm. The antenna is fabricated on FR4 substrate which has dielectric constant ϵ_r=4.4 and thickness of 1.6mm.The radiating patch is fed by 50-Ω coplanar wave guide (CPW) transmission line with a width FW of 3mm and a length $FL_1$of 13.2 mm in the Antenna 1. The space between the feed transmission line and ground is S=0.3mm. Feed line is terminated with standard SMA connector. The radiating patch has circular in shape, its effective radius is calculated by the formula [25] given in equation (1). Radiating patch effective radius (R_e) is calculated as 7.72 mm from the formula given in equation (1).

$$R_e = R\sqrt{1+\frac{2h}{\pi R\varepsilon_r}(\ln\frac{\pi R}{2h}+1.7726)} \quad (1)$$

$$f_{nm}=\frac{\chi_{nm}}{\sqrt{\varepsilon_r}}\frac{c}{2\pi R_e} \quad (2)$$

Where $f_{nm}$is resonant frequency of the TM_{nm}mode. The antenna is excited with dominant mode TM_{11} and its value is 1.841,c is velocity of light in free space. Resonant frequency for the dominant mode when circle is radiating patch is calculated by the formula given in equation (2) as 5.43 GHz for the Antenna 1. When circular radiating patch is excited, the value of the lower cut off frequency is given by formula [26] in equation (3)

$$f_L = \frac{7.2}{(L+M+P)} \qquad (3)$$

where f_L is in GHz and L=2R, M=R/4 and P is the distance from the ground to radiating patch where R is the circular radiating patch radius as shown in Fig 1,and the dimensions given in centi meters. Calculated value of f_L=3.7GHz for the P value 0.32cm.

Antenna 1 is modified to get Antenna 2 with ground ridged and arcs with 1mm dimension on either side are attached to the circular radiating patch. There are small slits of 1mm dimension are placed over the top of the antenna which makes the outer circle as arcs. The distance between the circular radiating patch and the arc patch is 0.7mm.

(A)

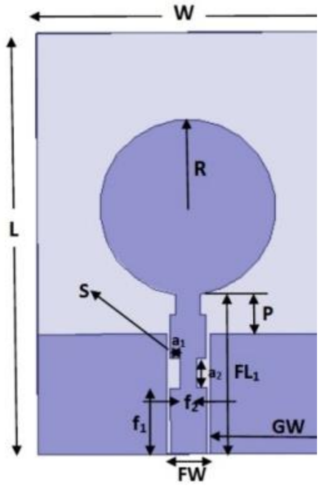

Fig. 1: Antenna 1.

(B)

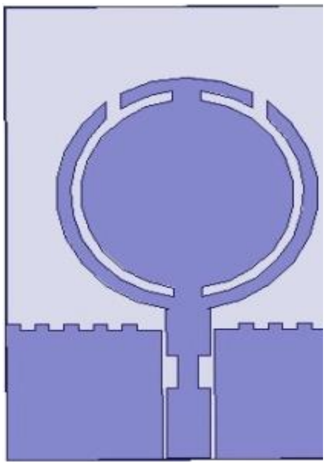

Fig. 1: Antenna 2.

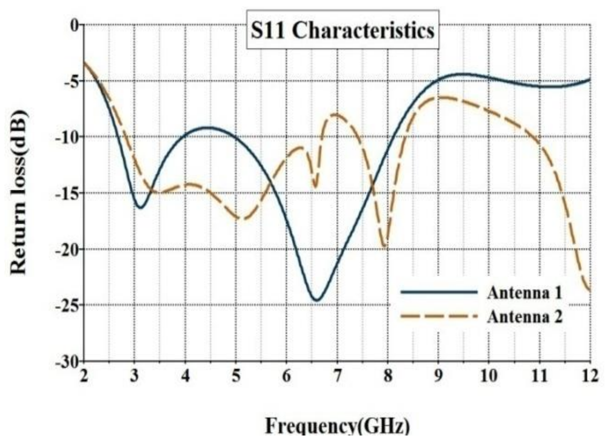

Fig. 2: S_{11} Characteristics of Antenna 1 and Antenna 2.

With this modifications Antenna 2 bandwidth (BW) increased to 80.7% from 59.6%of the band 1 as shown in Table 1.But it reduces the bandwidth percentage of band 2.In order to get two wide bands, antenna is proposed with tapered and ridged ground in this paper.

Table 1: BW Comparison of Antenna 1 and Antenna 2

	BW(%),band 1(GHz)	BW (%), band 2(GHz)
Antenna 1	59.6(2.67—3.94)	47.2(5.00-8.09)
Antenna 2	80.7(2.83—6.69)	11.7(7.41—8.33)

2.1. Proposed antenna design

Proposed antenna design is the modification of Antenna 2 design with the tapered ground with angle k which is calculated between horizontal axis and ground of the antenna. By selecting the different dimensions of the ground length and the changing the angle (k) between the horizontal line and ground the impedance bandwidth of the proposed antenna is changed accordingly. Feed length FL for this is 11.5mm.For the proposed antenna, angle k=56.2° and ground length (GL) =10mm.All the simulations has been carried out with high frequency structure simulator (HFSS).

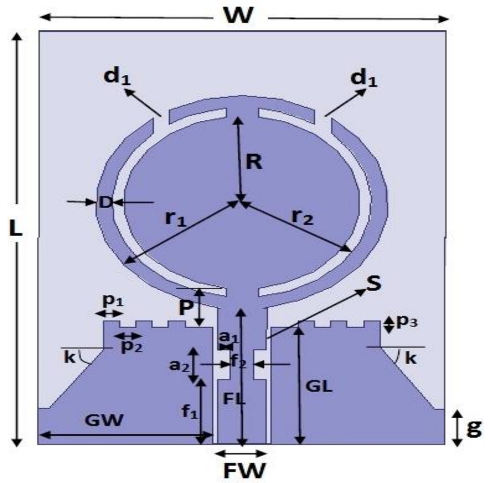

Fig. 3: Fabricated Antenna Design.

Table 2: Antenna Dimensions

Parameter	Dimension	Parameter	Dimension
W	25 mm	a_1	0.8 mm
L	35 mm	a_2	2.5 mm
FW	3 mm	f_1	6.5 mm
FL	11.5 mm	f_2	1.4 mm
S	0.3 mm	P	3.2 mm
GW	10.7 mm	p_1	1 mm
GL	10 mm	p_2	1 mm
g	3 mm	p_3	0.5 mm
R	7.3 mm	d_1	1 mm
r_1	9 mm	D	1 mm
r_2	8 mm	k	56.2 degrees

3. Simulation and measured return loss characteristics

Fabricated antenna structure is shown in Fig.4.S_{11} measurement is carried out using ANRITSU VNA masterMS-2037C which is shown in Fig.5. Measured results are well agreed with the simulation results. Dual band is achieved where $S_{11}\leq$ -10dB over the frequency ranges for measured return loss curves are 2.6GHz--6.67GHz and 7.5GHz—10.5GHz as shown in Fig.6 and Table 3.In simulation, frequency ranges for return loss curves are 2.82GHz—6.65GHz and 7.56GHz—10.48GHz. Return loss is measured at its minimum value -27.2 dB at the frequency 5.6GHz of the band 1 and -15dB at 8.2GHz of the band 2 regions.

Fig. 4: Fabricated Antenna.

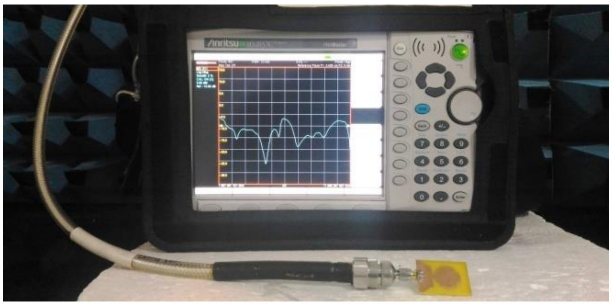

Fig. 5: Measurement Set-Up of VNA Master.

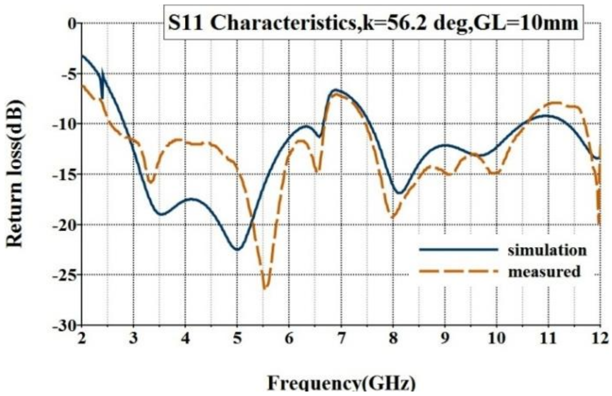

Fig. 6:S_{11} Characteristics of Proposed Antenna.

Proposed antenna exhibits wide dual bands with impedance bandwidth of87.8% and 33.3%.It can be used for WiMAX application which is occupies the frequency range of3.3GHz—3.7GHz ,and covering the WLAN frequency range 5.15GHz –5.85GHz as per the standard of IEEE 802.11 a. The antenna exhibits the entire UWB range except small notch between the 6.7GHz to 7.5GHz frequency range. It can be used for ITU-R applications in the lower, upper 4GHz band and6 GHz band and 8 GHz applications.

Table 3: BW Characteristics of Proposed Antenna

k=56.2º	BW(%),band 1(GHz)	BW(%), band 2(GHz)
GL=10mm (Simulation)	80.9(2.82-- 6.65)	32.4(7.56—10.48)
GL=10mm (Measured)	87.8(2.6--6.67)	33.3 (7.5—10.5)

4. Parametric analysis

By changing the angle k between the horizontal axis and ground of the antenna we can get the different dual bandcharacteristics as shown in Fig. 7 and Table 4, ground length (GL) is varied so that the distance P between the radiating patch and ground is also changing in proportion to ground length GL.

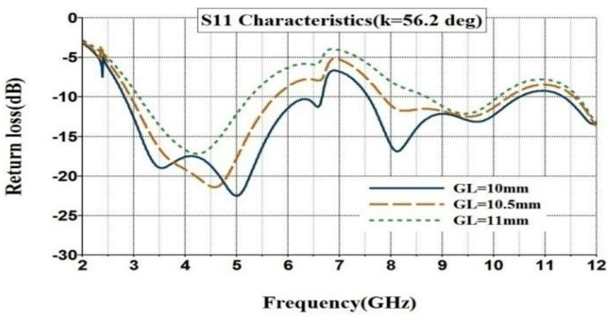

Fig. 7:S_{11} Characteristics of Proposed Antenna Varying GL (K=56.2º).

By keeping the angle k is equal to 56.2 degrees and varying the ground length GL frequency bands are changed accordingly as shown in Fig. 7 and Table 4. The distance between the radiating patch and feed is also varied in proportion.

Table 4: BW Characteristics for Varying GL (K=56.2º)

k=56.2º	BW(%),band1(GHz)	BW(%), band 2(GHz)
GL=10mm	80.9(2.82-- 6.65)	32.4 (7.56—10.48)
GL=10.5mm	64.2(2.94—5.73)	26.7(7.85—10.27)
GL=11mm	51.02(3.1—5.24)	15.12(8.68—10.1

By changing the angle 'k' to 52.6º and keeping it constant and vary the ground length (GL) insteps of 1mm the observed simulation characteristics are shown in Fig. 8 and Table 5.

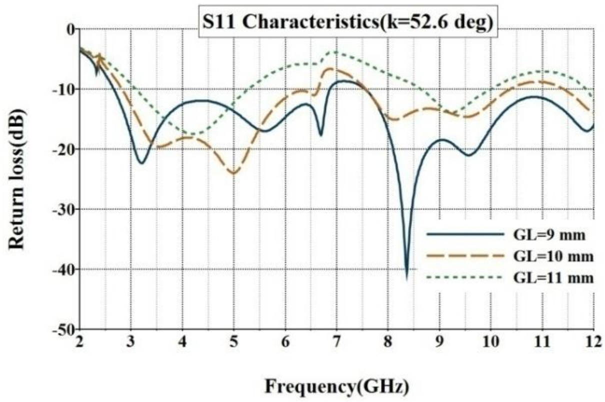

Fig. 8: S_{11} Characteristics Antenna Varying GL (K=52.6º).

It is observed that when the ground length is maintained proper feed distance (P), bandwidth is significantly improves, when the ground length approaches nearer to radiating patch bandwidth reduces due to interference

Table 5: BW Characteristics for Varying GL (K=52.6º)

k=52.6º	BW(%),band 1(GHz)	BW(%), band 2(GHz)
GL=9mm	88.6 (2.64 —6.86)	46.9(7.57--12.22)
GL=10mm	80.6(2.81--6.62)	31.8(7.54—10.34)
GL=11mm	52.27(3.08—5.26)	14.1(8.66—9.97)

For the next case angle 'k' is changed to 48.3 degrees and keeping the angleconstant ,then vary the ground length(GL) in steps of 1 mm.S_{11} characteristics and bandwidths of the two bands are shown in Fig. 9 and Table 6 respectively

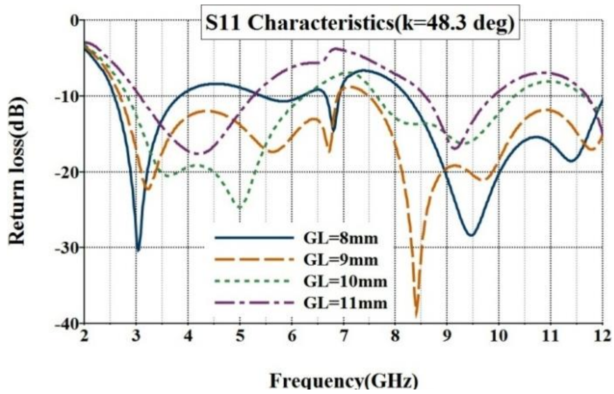

Fig. 9:S_{11} Characteristics Antenna Varying GL (K=48.3º) and R=7.3MM.

Table 6: BW Characteristics for Varying GL(K=48.3º,R=7.3)

k= 48.3º	BW(%),band 1(GHz)	BW(%), band 2(GHz)
GL=8mm	17.7(2.58—3.80)	37.3(8.24—12.02)
GL=9mm	86.6(2.69—6.80)	48.2(7.52—12.3)
GL=10mm	74.9 (2.83—6.22)	29.6(7.64—10.2)
GL=11mm	54.1(3.08—5.24)	13.9(8.58—9.87)

Maintaining the angle 'k'=48.3 degrees the radius of the circular radiating patch is changed to 9.3mm so that it centre position in y –direction has been shifted to positive y direction to 23.5mm.

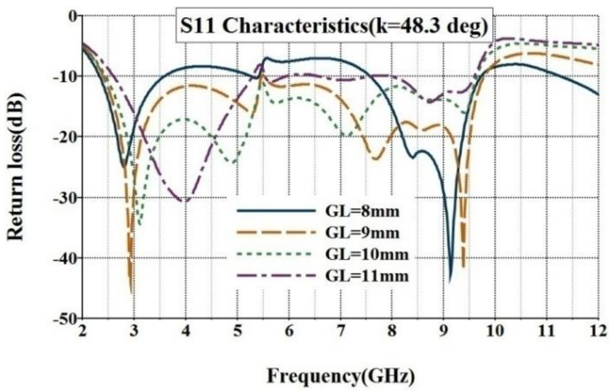

Fig. 10: S_{11} Characteristics Antenna Varying GL (K=48.3º) and R=9.3MM.

Varying the ground length (GL) in steps of 1mm, then S_{11} characteristics and BW characteristics are shown in Fig. 10 and Table 7 respectively. In this case it is observed that for the GL value is equal to 10 mm wide band is achieved with bandwidth of 118.5%.

Table 7: BW Characteristics of Antenna Varying GL(K=48.3º,R=9.3)

k= 48.3º	BW (%),band 1(GHz)	BW (%), band 2(GHz)
GL=8mm	41.3(2.33—3.55)	24.8(7.58—9.73)
GL=9mm	76.5(2.41—5.41)	56.1(5.5—9.78)
GL=10mm	118.5(2.46—9.62)(Wide band achieved)	
GL=11mm	54.1(2.61—5.27)	13.9(8.09—9.58)

Based on parametric studies conducted here, it is concluded that when length of the ground altered it modifies feed gap distance P which in turn affects the impedance bandwidth of the antenna.

5. Results and discussion

The proposed antenna exhibits the dual wide band over the regions 2.6GHz to 6.67GHz and 7.5GHz to 10.5 GHz. The measured S_{11} is less than -10 dB for these frequencies. In the band1 region antenna can be used for WiMAX application for the region of 3.3GHz-3.7GHz and WLAN application within the frequency region 5.15GHz –5.825 GHz simultaneously without any interference. According to International telecommunication union, radio communication sector(ITU-R) fixed service ITU-R-F.635 which denotes the radio frequency channel based on homogeneous pattern for fixed wireless system operating in lower 4 GHz band as 3.4GHzto 4.2GHz.By ITU-R-F.1099 channel arrangements for high and medium capacity fixed wireless systems in upper 4GHz band as 4.4GHz-5GHz. For high capacity wireless systems, ITU-R.F.383 denotes in the lower 6GHz region as 5.925 GHz to 6.425GHz and for F.386 it denotes the 8GHz applications over the region 7.725GHz-8.5GHz. This corresponds to the bandwidth of 87.8% and 33.3% respectively. Radiation characteristics are shown Fig.12, Fig.13 and Fig.14 for the for the frequencies 3.3 GHz, 5.8GHz and9.1 GHz respectively. E-Plane (yz-plane) is monopole and H-plane (xz plane) is omni directional.

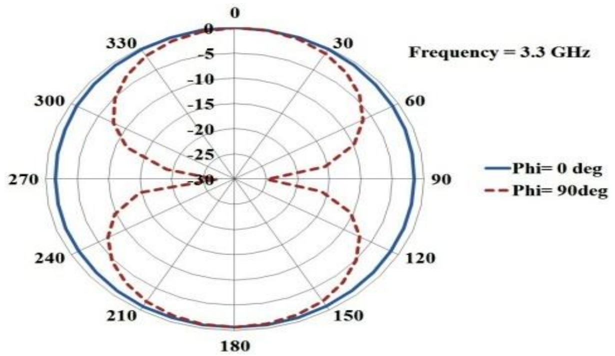

Fig. 11: Radiation Pattern of the Proposed Antenna at 3.3 GHz.

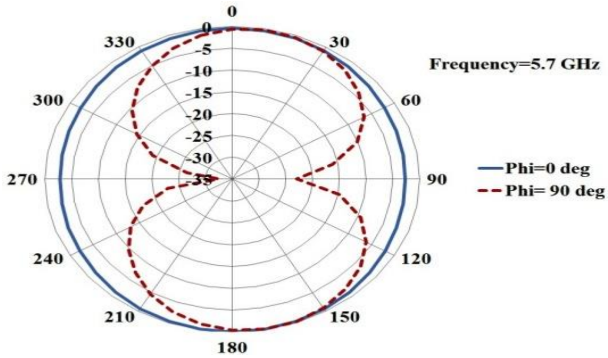

Fig. 12: Radiation Pattern of the Proposed Antenna at 5.7 GHZ.

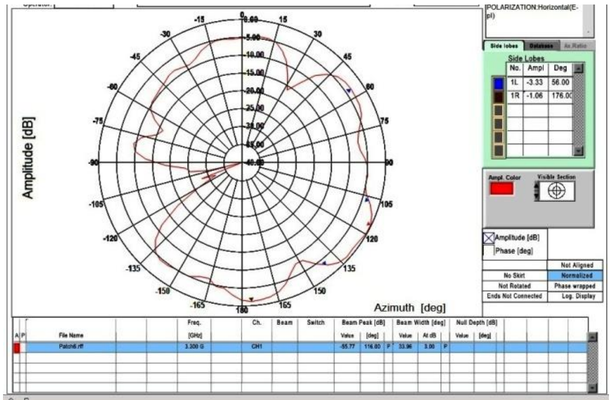

Fig. 13: Tested Radiation Pattern of the Proposed Antenna at 3.3 GHZ and Phi=90 Deg.

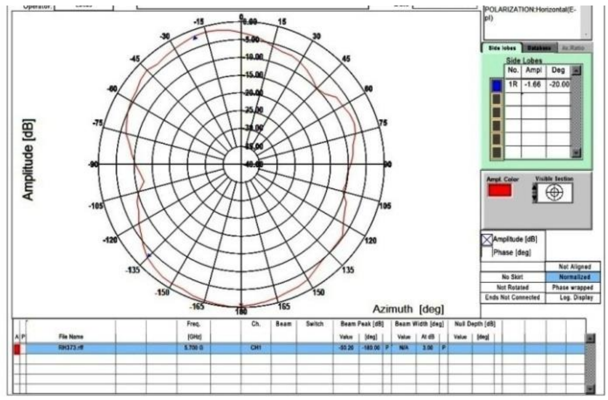

Fig. 14: Tested Radiation Pattern of the Proposed Antenna at 5.7 GHZ and Phi=90 Deg.

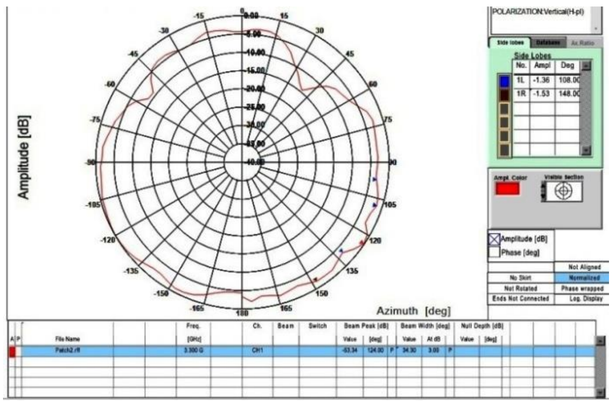

Fig. 15: Tested Radiation Pattern of the Proposed Antenna at 3.3 GHZ and Phi=0 Deg.

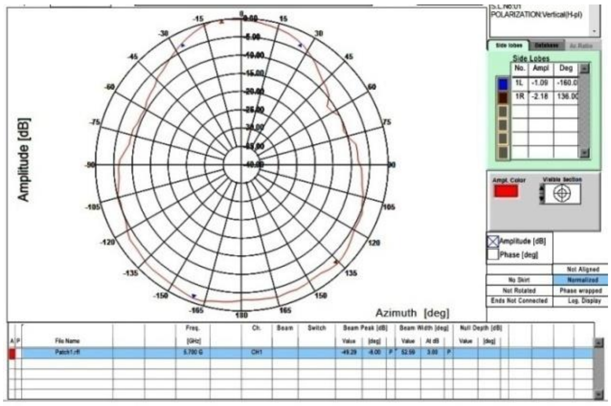

Fig. 16: Tested Radiation Pattern of the Proposed Antenna at 5.7 GHZ and Phi=0 Deg.

Radiation patterns shown in Fig 12 and Fig 13 are simulated and from Fig 14 to 17 are measured values; all the radiation patterns are normalized. Gain variation plots are shown in Fig. 18,Fig 19 and Fig 20 at the frequencies 3.3GHz ,5.7GHzand9.1 GHz respectively. It is observed that gain is maintained almost 3 dB throughout the frequency region.

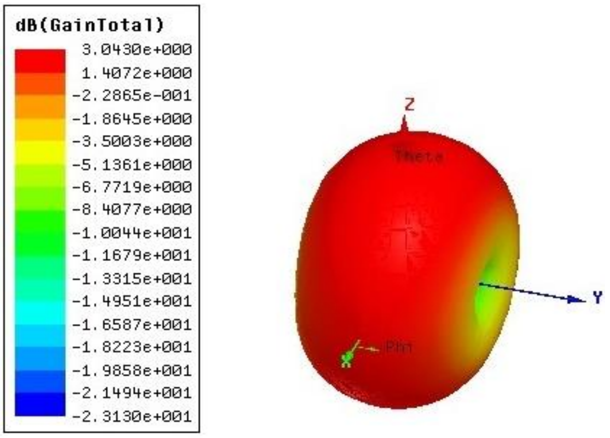

Fig. 17: Gain of the Antenna at 3.3 GHz.

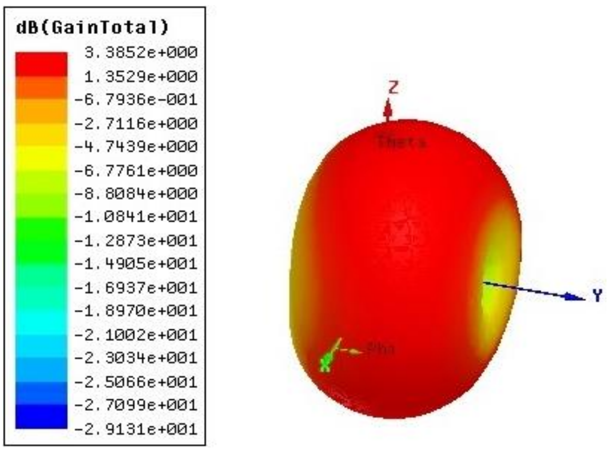

Fig. 18: Gain of the Antenna at 5.7 GHZ.

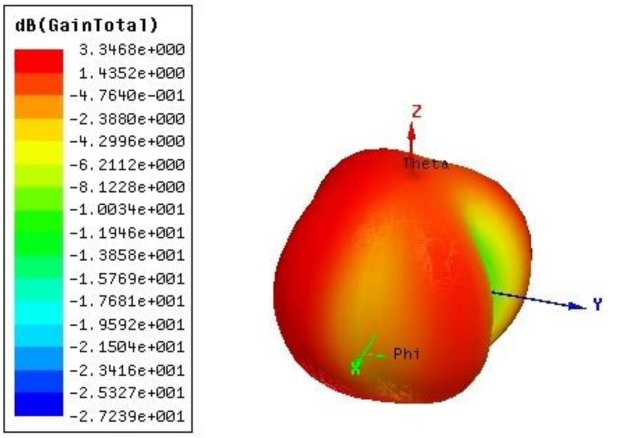

Fig. 19: Gain of the Antenna at 9.1 GHZ.

Table 8: Comparison of Existing with Proposed Antenna

Ref	Type	Size	Total area(mm^2)	Bandwidth (GHz)
[1]	UWB	30×30	900	2.9-18
[7]	Dual- Band	40×30	1200	2.39-2.59/5-6.1
[8]	Tri–Band	40×40	1600	2.28-3.23/3.28-3.94/5.05-6.17
[9]	Dual-Band	25×50	1250	3.4-3.6/7.4-14.4
[24]	Dual-Band	29.5×29.5	870.25	2.10-2.36/5.11-6
Proposed	Dual-Band	25×35	875	2.6-6.67/7.5-10.5

It is shown in Table 8, comparison of existing with the proposed antenna with their size and bandwidth characteristics.

6. Conclusion

Compact circular patch antenna proposed here is a good candidate for WiMAX, WLAN and UWB applications. After presenting the basic configuration, proposed antenna is designed and parametric analysis is carried out by varying the key parameters. Return loss bandwidth (below-10 dB) of nearly 60% has been obtained for wide range, which exhibits good gain over the frequency range.

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