Performance Enhancement of Microstrip Line Quarter Wave Transformer Circular Patch Antenna with Narrow Slit at L Band

U.Srinivasa Rao, P Siddaiah

***Abstract*— In this paper, design of a Microstrip Line Quarter Wave Transformer-fed Circular Patch Antenna with Rectangular Slit is presented. The maximum size of proposed antenna is 60mm X 140mm. The substrate material used for this antenna has thickness of 1.588mm and relative permittivity (εr) is 2.2. The design frequency of the antenna is 2GHz. By selecting optimum parameters of proposed antenna, the simulated return loss of proposed antenna at design frequency (2 GHz) is -16 dB. The simulated radiation patterns shows that the antenna functions as expected, with a gain of 6dB at 2 GHz. The proposed antenna is useful for wireless communication systems.**

***Index Terms*— Quarter wave Transformer, Circular Patch Antenna, Slit, Gain, Return loss.**

I. INTRODUCTION

Highlight a section that you want to designate with a certain style, and then select the appropriate name on the style menu. The style will adjust your fonts and line spacing. **Do not change the font sizes or line spacing to squeeze more text into a limited number of pages.** Use italics for emphasis; do not underline.

II. DESIGN AND ANALYSIS OF CIRCULAR PATCH ANTENNA

The structure of the circular microstrip patch antenna fed by the microstrip line quarter wave transformer is shown in Fig.1. The circular microstrip patch antenna analysis and design can be divided into three tasks, namely design of the circular patch, the quarter wave transformer and microstrip feed line. Each of these tasks is presented in detail below.

A. Design of Circular Patch

Radius of the patch:

The radius 'R' of the patch is given by [3]:

$$R = \frac{F}{\left[1+\frac{2h}{\pi\varepsilon_r F\left[\ln\left(\frac{F\pi}{2h}\right)+1.7726\right]}\right]^{1/2}} \qquad (1)$$

Where $F = \frac{8.791 X 10^{9}}{f_r\sqrt{\varepsilon_r}}$

R= radius of the patch in mm; h= height of the patch substrate in mm; f_r= resonant frequency in Hz; ε_r = effective dielectric constant of the substrate.

Input impedance at the feed point:

The input impedance can be calculated using the equations in [4] which are quite tedious, and are not repeated here.

This calculation is anyway not very accurate, and the matching network had to be optimized through simulation.

B. Design of a Microstrip feed line

In this design we used 50Ω microstrip to excite the microstrip patch. For given characteristic impedance Z_o and dielectric constant ε_r width W_f of microstrip line is calculated from standard equations given below [7].

$$\frac{W_f}{h} = \begin{cases} \frac{8e^{A}}{e^{2A}-2} & for\ \frac{W_f}{h} < 2 \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right\}\right] & for\ for\ \frac{W_f}{h} > 2 \end{cases}$$
(2)

Where $A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)$ (3)

And B = $\frac{377\ \pi}{2Z_o\sqrt{\varepsilon_r}}$ (4)

C. Design of the Quarter wave Transformer

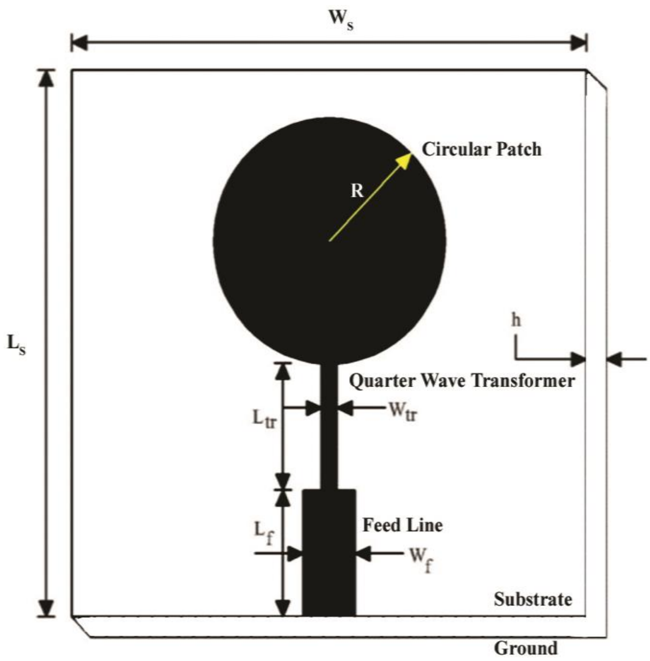

Fig.1 Geometry of the Circular Patch Antenna

The quarter-wave transformer is a simple and useful method for matching real load impedance to different source impedance, and is frequently used in antennas [6].

The single section quarter-wave transformer has a length equal to quarter wave in micro-strip and its characteristic impedance Z, should be given by [7]:

$$Z_c = \sqrt{(Z_0 Z} \tag{5}$$

Where Z_0 the characteristic impedance of the 50Ω is line and Z_{in} is the input impedance of the circular patch. The width Wtr of the quarter-wave transformer can be finding out by equation (2) for calculated value of Z_c, from equation (5). The geometry of the proposed circular patch antenna is shown in Fig.1

I. DESIGN SPECIFICATION OF CIRCULAR PATCH ANTENNA

The proposed circular patch antenna operating frequency is 2 GHz was designed with the following specifications.

TABLE I
DESIGN SPECIFICATIONS OF CIRCULAR PATCH ANTENNA

Parameters	Values/Dimensions
Frequency band used	L band
Operating frequency (f_r)	2GHz
Substrate material used	RT Duroid 5880
Dielectric constant (ε_r)	2.2
Substrate thickness (h)	1.588 mm
Radius of the circular patch (R)	28.52 mm
Length of the substrate (L_s)	138.52 mm
Width of the substrate (W_s)	60 mm
Length of the transformer (L_{tr})	28.62 mm
Width of the transformer (W_{tr})	0.74 mm
Length of the feed line (L_f)	10 mm
Width of the feed line (W_f)	3 mm

III. DESIGN PROCEDURE OF CIRCULAR PATCH ANTENNA

A. Conventional Microstrip Line Quarter Wave Transformer Circular Patch Antenna without slit

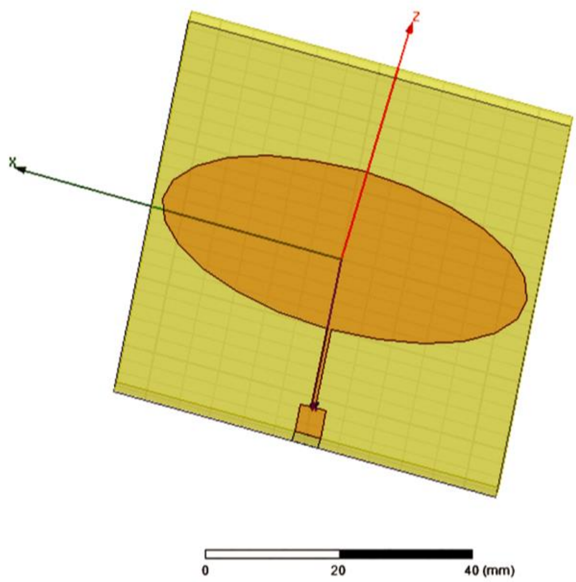

Fig.2 Geometry of the Conventional Circular Patch Antenna without slit

In present case of study comparison analysis of circular patch without any slit and circular patch with narrow rectangular slit is investigated under similar conditions. A planer geometry of conventional patch of radius R=28.52mm is placed on the substrate of dielectric material RT Duroid 5880 having W_s X L_s= 60mm X 140mm and thickness h=1.588mm, dielectric constant for substrate is ε_r=2.2 and the loss tangent is 0.0018, the antenna excited with microstrip line having dimensions L_f = 10mm and W_f= 3mm through a quarter wave transformer having dimension L_{tr}=28.62mm and W_{tr}=0.74mm. The circular patch antenna is designed based on cavity model to obtain the best output in terms of return loss and VSWR. The structure of conventional circular patch antenna in shown in Fig.2

The return loss, 3D gain, 2D E-plane pattern, 2D H-plane pattern, 3D Electric field pattern, VSWR, E-plane Half Power Beam Width and H-plane Half Power Beam Width plots of conventional circular patch antenna without any slit is simulated on HFSS are shown in Fig.3, 4, 5, 6, 7, 8, 9 and 10 respectively. The snapshot of the Antenna parameters for circular patch antenna without any slit shown in Table II.

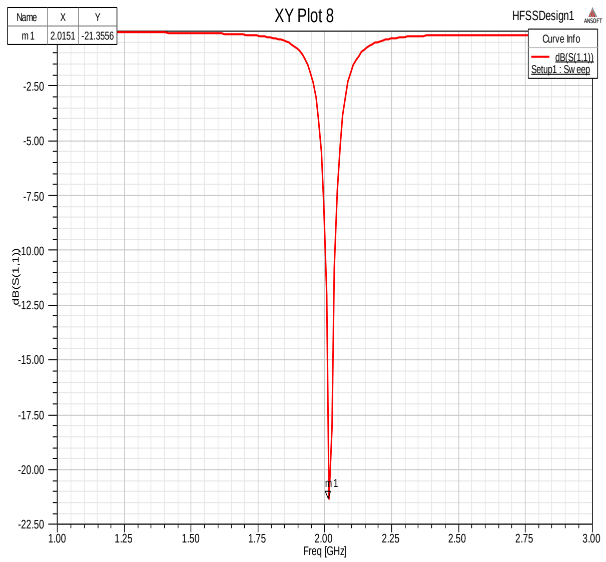

Fig.3 Simulated Return losses for Conventional Circular Patch Antenna without Slit

The Fig.3 shows the return loss of the antenna and the antenna resonates essentially at 2.0151 GHz with a return loss of -21.3555dB.

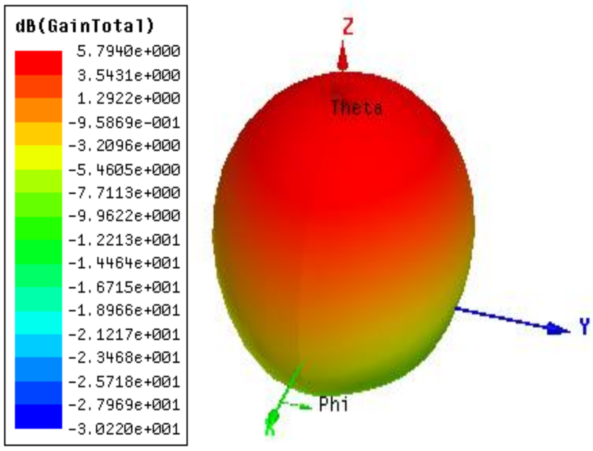

Fig.4 3D Gain pattern at 2GHz

The Fig.4 shows the 3dB gain and the gain of the antenna at 2GHz is 5.79dB.

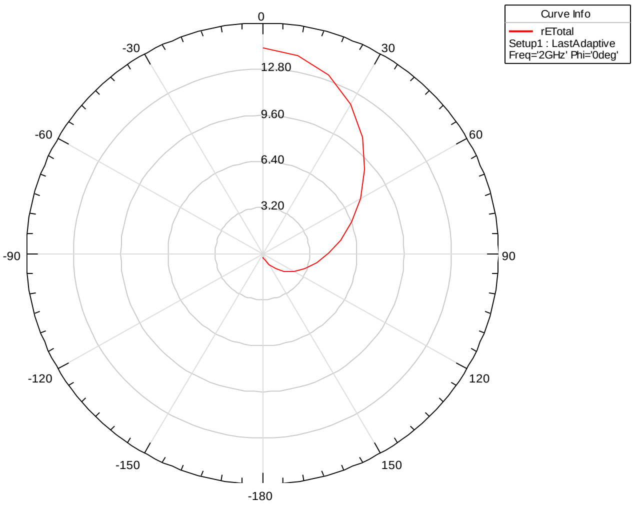

Fig.5 2D E-Plane Radiation Pattern

The Fig.5 shows the 2D E-Plane Radiation pattern

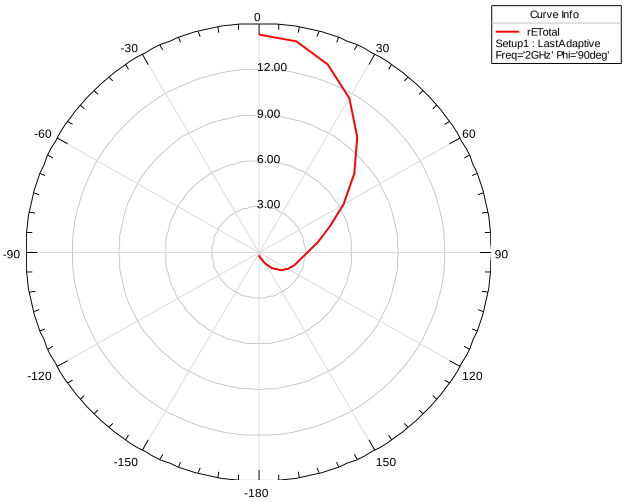

Fig.6 2D H-Plane Radiation Pattern

The Fig.6 shows the 2D H-Plane Radiation pattern.

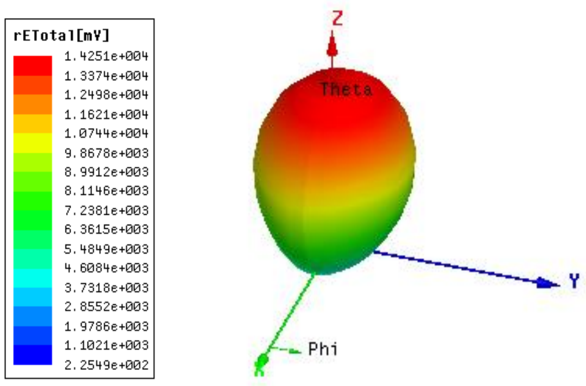

Fig.7 3D Electric Field Radiation Pattern

The Fig.7 shows the 3D Electric field pattern.

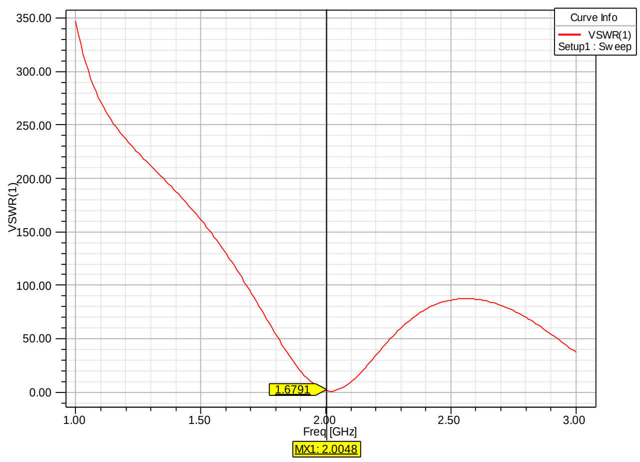

Fig.8 VSWR for Circular Patch Antenna without Slit

The Fig.8 shows the VSWR plot and VSWR 2.00487GHz is 1.6791.

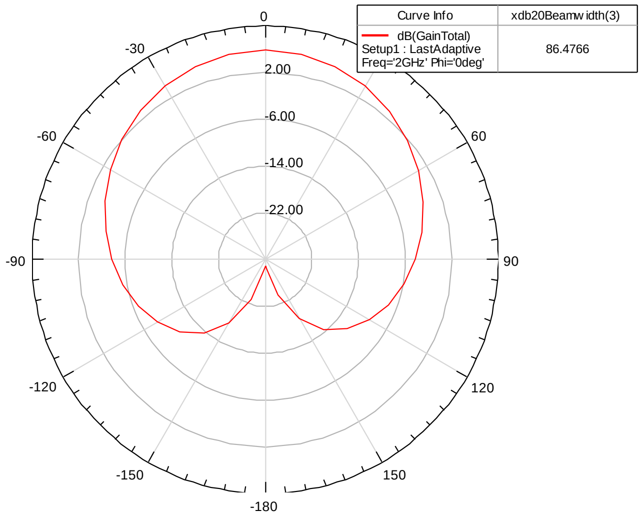

Fig.9 E-Plane Half Power Beam Width

The Fig.9 shows the E-Plane Half Power Beam Width & Half Power Beam Width in E-Plane at 2GHz is 86.4766.

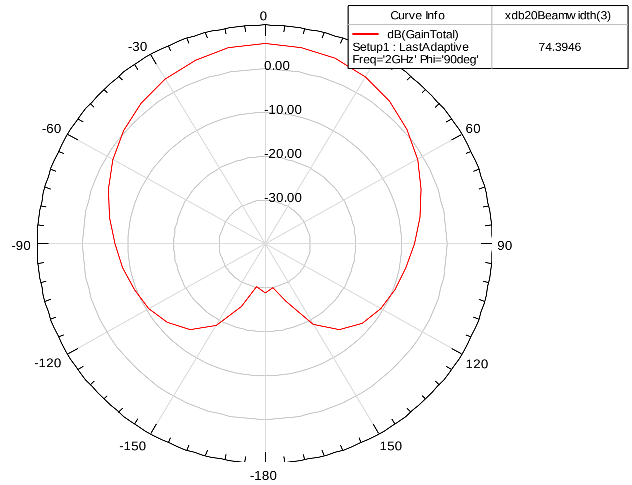

Fig.10 H-Plane Half Power Beam Width

The Fig.10 shows the H-Plane Half Power Beam Width & Half Power Beam Width in H-Plane at 2GHz is 74.3946.

TABLE II
SNAPSHOT OF ANTENNA PARAMETERS OF CIRCULAR PATCH ANTENNA WITHOUT SLIT

Antenna Parameters:

Quantity	Value	Units
Max U	0.26934	W/sr
Peak Directivity	3.9265	
Peak Gain	3.7966	
Peak Realized Gain	3.3847	
Radiated Power	0.86202	W
Accepted Power	0.8915	W
Incident Power	1	W
Radiation Efficiency	0.96692	
Front to Back Ratio	2969.3	
Decay Factor	0	

Maximum Field Data:

rE Field	Value	Units	At Phi	At Theta
Total	14.251	V	200deg	0deg
X	2.722	V	140deg	60deg
Y	14.217	V	200deg	0deg
Z	6.3335	V	90deg	40deg
Phi	14.217	V	360deg	0deg
Theta	14.217	V	270deg	0deg
LHCP	10.429	V	190deg	0deg
RHCP	9.7118	V	330deg	0deg
Ludwig3/X dominant	1.9274	V	310deg	60deg
Ludwig3/Y dominant	14.217	V	200deg	0deg

The above Table II is the snapshot of antenna parameters of conventional circular patch antenna and the antenna radiation efficiency at 2GHz is 96.6%.

B. Microstrip Line Quarter Wave Transformer Circular Patch Antenna with slit

To achieve the improved performance of planner circular patch, a narrow a rectangular slit of dimension L_{slit}=20mm and W_{slit}=5mm is etched in X-Y plane on circular patch having the same dimension as that of conventional circular patch as shown in Fig.11.

The antenna is then simulated under the conditions similar to circular patch without any slit. The simulated results shows that the antenna resonates exactly at 2GHz .

The return loss, 3D gain, 2D E-plane pattern, 2D H-plane pattern, 3D Electric field pattern, VSWR, E-plane Half Power Beam Width and H-plane Half Power Beam Width plots of circular patch antenna with a narrow rectangular slit is simulated results on HFSS are shown in Fig.12, 13, 14, 15, 16, 17, 18 & 19 respectively. The snapshot of the Antenna parameters for circular patch antenna with narrow rectangular slit shown in Table III.

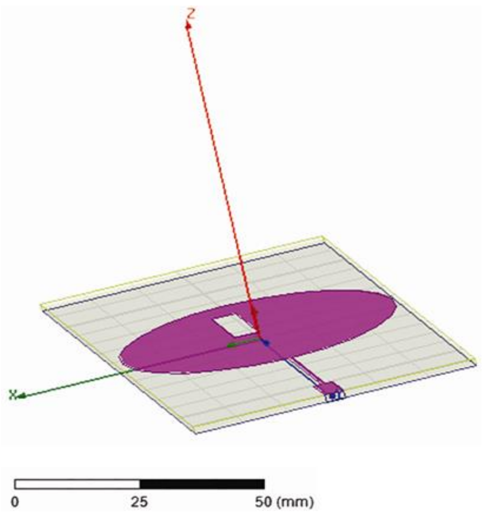

Fig.11 Geometry of the Circular Patch Antenna with Rectangular Slit

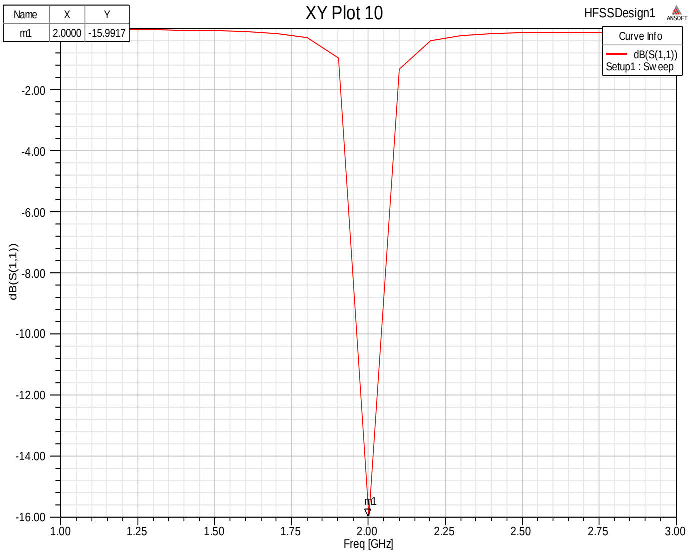

Fig.12 Simulated Return losses for Circular Patch Antenna with Rectangular Slit

The Fig.12 shows the return loss plot and return loss at 2GHz is -15.9917dB.

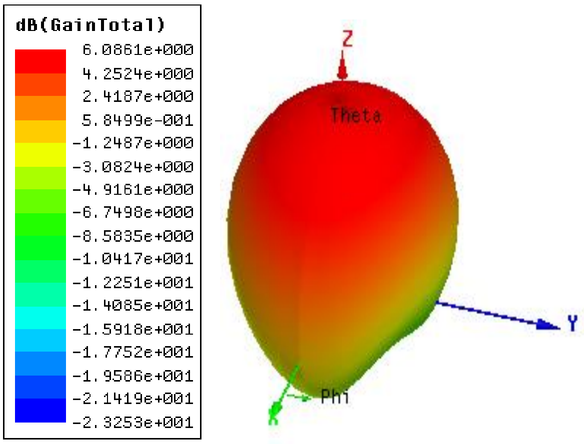

Fig.13 3D Gain pattern at 2GHz

The Fig.13 shows the 3dB gain and the gain of the antenna with rectangular slit at 2GHz is 6.086dB.

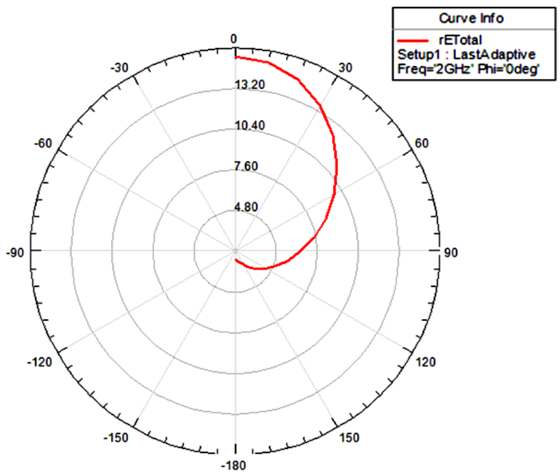

Fig.14 2D E-Plane Radiation Pattern

The Fig.14 shows the 2D E-Plane radiation pattern.

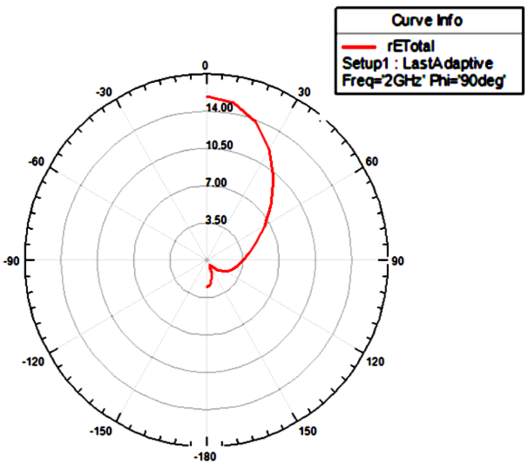

Fig.15 2D H-Plane Radiation Pattern

The Fig.15 shows the 2D H-Plane radiation pattern.

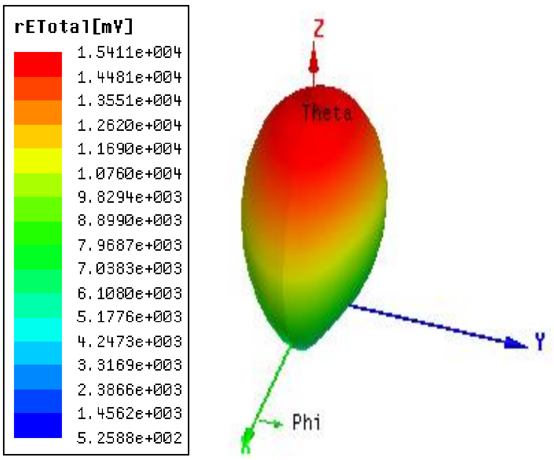

Fig.16 3D Electric Field Radiation Pattern

The Fig.16 shows the 3D electric field pattern.

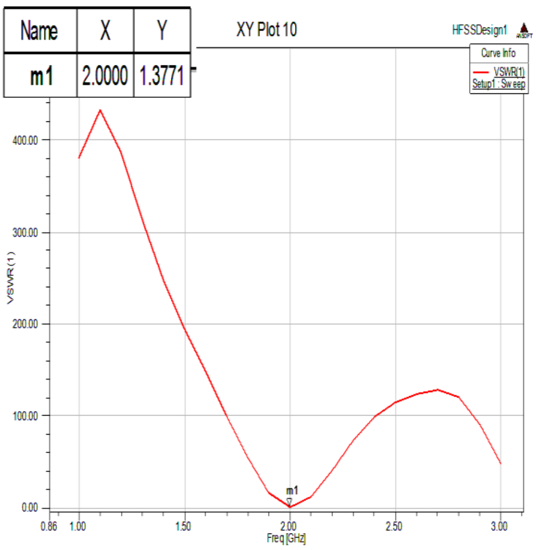

Fig. 17 VSWR for Circular Patch Antenna with Rectangular Slit

The Fig.17 shows the VSWR plot and VSWR at 2GHz is 1.3771.

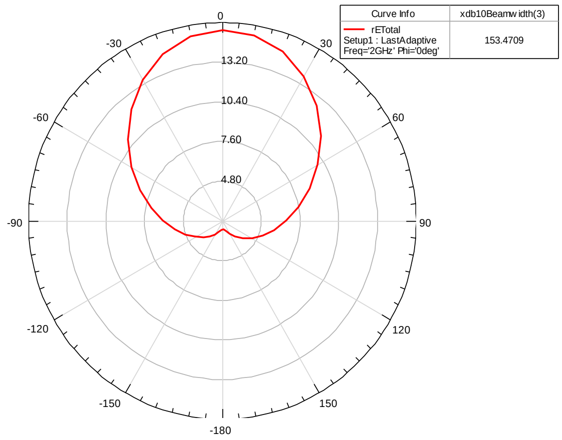

Fig.18 E-Plane Half Power Beam Width

The Fig.18 shows the E-Plane half power beam width and half power beam width in E-Plane at 2GHz is 153.4709.

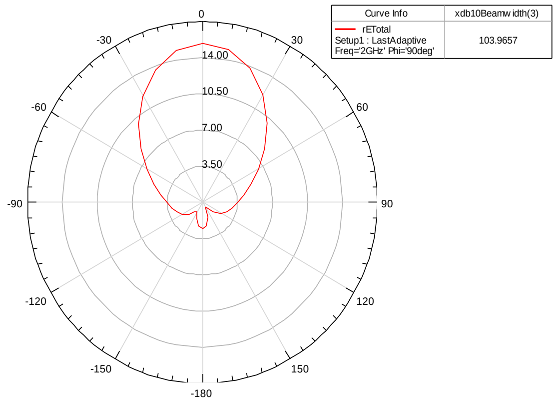

Fig. 19 H-Plane Half Power Beam Width

The Fig.19 shows the H-Plane half power beam width and half power beam width in H-Plane at 2GHz is 103.9667.

TABLE III
SNAPSHOT OF ANTENNA PARAMETERS OF CIRCULAR PATCH ANTENNA WITH RECTANGULAR SLIT

Antenna Parameters:

Quantity	Value	Units
Max U	0.31501	W/sr
Peak Directivity	4.2102	
Peak Gain	4.0608	
Peak Realized Gain	3.9586	
Radiated Power	0.94024	W
Accepted Power	0.97483	W
Incident Power	1	W
Radiation Efficiency	0.96451	
Front to Back Ratio	36.148	
Decay Factor	0	

Maximum Field Data:

rE Field	Value	Units	At Phi	At Theta
Total	15.411	V	240deg	0deg
X	2.9952	V	220deg	70deg
Y	15.397	V	240deg	0deg
Z	6.4395	V	90deg	40deg
Phi	15.397	V	180deg	0deg
Theta	15.397	V	90deg	0deg
LHCP	11.079	V	240deg	0deg
RHCP	10.713	V	60deg	0deg
Ludwig3/X dominant	2.5567	V	220deg	180deg
Ludwig3/Y dominant	15.397	V	240deg	0deg

The above Table III is the snapshot of antenna parameters of circular patch antenna with a narrow rectangular slit and the antenna radiation efficiency at 2GHz is 96.4%.

IV. Discussion

Comparison of HFSS simulated results for circular patch antenna with and without slit:

PARAMETER	Without slit	with slit
Operating frequency (GHz)	2.12	2.0
Gain (dB)	5.78	6.08
Bandwidth(MHz)	55	110
E Plane Beam-width (degrees)	86.47	153.47
H Plane Beam-width (degrees)	74.3	103.965
VSWR	1.679	1.3771
Efficiency (%)	96	96.45

V. Conclusion

A circular microstrip patch antenna fed by microstrip line through quarter-wave transformer has been designed and simulated. The parametric analysis has been carried out to determine the effect of circular patch radius, and quarter wave transformer width, on return loss and resonant frequency. The bandwidth of this circular patch antenna enhanced by simply placing a narrow rectangular slit technique is also discussed. The simulated antenna satisfies the < -l0dB return loss at 2GHz and provides good radiation pattern. So, finally the performance of the microstrip line quarter wave transformer circular patch antenna with narrow slit was enhanced and Simulation results shows that the antenna should be useful for L band communication systems.

Acknowledgments

Extending our grateful thanks to the authorities of Acharya Nagarjuna University for their support and encouragement to write this paper.

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