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Design of Dual-Band Microstrip Antenna with U-Shaped Slot

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Abstract: *In some applications, it is required to have dual band characteristics instead of single band. This characteristic can be obtained by embedding a U-slot in the patch and hence the radiating patch includes a pair of step – slots. In this paper, we propose a dual band microstrip patch antenna with a U- shaped slot fed by coaxial feeding technique. The proposal antennas designed, simulated and optimized using Ansoft HFSS Vs 15. The simulation results are presented in terms of return loss, VSWR, input impedance, gain and radiation pattern. The dimensions are optimized to achieve the exact operating frequencies using resonating frequency control mechanisms. The results showed that the U-Shaped slot microstrip antennas efficiently operated at 2.4Ghz and 4.6Ghz.*

Keywords: VSWR, Input impedance, HFSS, Radiation pattern

I. INTRODUCTION

1.1 Objectives and Goals

- To study the need of U-shaped slot antenna characteristics, like VSWR, Input Impedance, Return loss and radiation pattern.
- To analyze the graphs of the surface plots of the antenna device along with the design of the structure in HFSS.

1.2 Software Required

- Ansoft HFSS Vs 15

1.3 Project Description

With the increased necessities for personal and mobile communications, the demand for smaller and low-profile antennas has brought the Microstrip Antennas (MSA) to the forefront. MSA also known as patch antenna with radiating patch on one side of the dielectric substrate and ground onother side. The basic and most common is rectangular MSA. MSA has properties like low size, weight, cost, good performance and ease of installing. The physical characteristics of MSA are compatible for use in mobile phones, Bluetooth personal networks and wireless local networks. These antennas suffer from few shortcomings like small efficiency, low power, very narrow frequency and bandwidth. A number of methods have been worked out by the researchers to overcome the limitations by increasing the permittivity of the substrate or by increasing the heightof the patch.

However, the results of both of these methods are inadequate since increasing patch height results in modifying the low-profile feature of the patch whereas the implementation of second is subject to material availability and suitability. Many applications require operating in a dual band of frequencies instead of single band; therefore, there is a need to modify the microstripantenna to operate in dual band. In this paper, a U-shaped slot microstrip patch antenna with coaxial feeding is designed to operate in dual band for Wireless Local Area Network (WLAN) applications. The addition of a slot on the radiating patch results in an increase in the current lengththat results in decrease of the fundamental resonance frequency which corresponds to reduced antenna size when compared to conventional patch antenna for a given resonant frequency.

II. DESIGN

For designing of a rectangular microstrip patch antenna with U-shaped slot as shown in Figure1 (a), we have to select the resonant frequencies and a dielectric medium for which the antenna is to be designed. The side view of the microstrip patch antenna with coaxial feeding method is explained in Figure1 (b). All the design parameters were calculated by equations that are explained in the following sections and the calculation results of all dimensions are shown

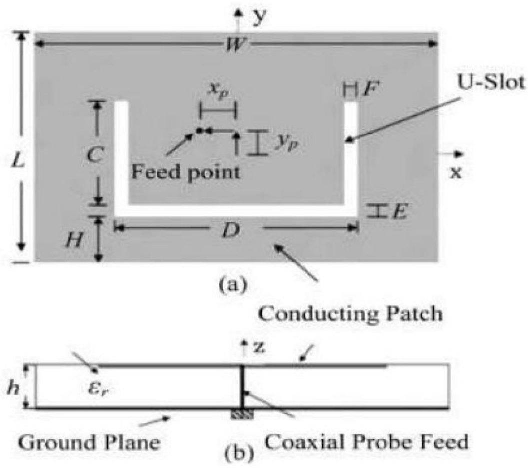

Figure 1: (a) Geometry Of A Rectangular U-Slot Microstrip Patch Antenna (b) Coaxial Probe Feeding Method

2.1 Operating Frequency

Operating frequency of the antenna can be calculated by Equation (1).

$$f_0 = \frac{f_L + f_h}{2}$$

Where fL is the lower frequency and fh is the higher frequency of the operating band.

The guided wavelength in the substrate of the antenna is given by the Equation (2).

Where 0 is the guided wavelength in the substrate of the antenna, vo is the light speed in space(=3x10^8 m/sec).

$$\lambda_0 = \frac{v_0}{f_0}$$

The thickness of Dielectric substrate h is given by the Equation (3).

$$h \geq 0.06(\lambda_0 / \sqrt{\varepsilon_r})$$

2.2 Microstrip Patch Antenna Dimensions

Width of the rectangular microstrip patch W is determined by Equation (4).

$$W = \frac{v0}{2fo\sqrt{\frac{\varepsilon_r+1}{2}}}$$

Effective Dielectric constant εreff is given by Equation (5)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r -}{2}$$

Where h is the substrate thickness, W is the width of the microstrip patch.

Length of rectangular microstrip patch L is given by using Equation (6).

$$L = L_{eff} - 2\Delta L$$

Where L eff is the Effective Length of the rectangular microstrip antenna, it is given by Equation(7).

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$$L_{eff} = \frac{vo}{2fo\sqrt{\varepsilon_{reff}}}$$

ΔL is Length Extension, which can be determined by Equation,

$$\Delta L = 0.412h\frac{[(\varepsilon_{reff} +}{[(\varepsilon_{reff} -}$$

2.3 Bandwidth of the Antenna

The percentage value of Bandwidth of the antenna BW is given by Equation,

Where A is constant has multiple values at different states

$$A = 180 \quad \text{FOR } \frac{h}{\lambda_o\sqrt{\varepsilon_r}} \leq 0.045$$

$$A = 200 \quad \text{FOR } 0.075 \geq \frac{h}{\lambda_o\sqrt{\varepsilon_r}} \geq 0.045$$

$$A = 220 \quad \text{FOR } \frac{h}{\lambda_o\sqrt{\varepsilon_r}} \geq 0.075$$

$$BW\% = \frac{f_h - f_l}{f_o}$$

$$BW\% = \frac{Ah}{\lambda_o}\sqrt{\frac{W}{L}}$$

2.4 Slot Dimensions

Thickness of the slot E , F is given by Equation,

$$E = F = \frac{\lambda_0}{60}$$

U –slot length C can be determined by Equation (14)

$$\frac{C}{W} \geq 0.3$$

Width of the U-slot D is determined by Equation (15)

$$D = \left[\frac{c_0}{f_l * \sqrt{\varepsilon_{reff}}}\right] - 2(l + 2\Delta l - E)$$

To calculate the height of slot H with respect to x axis, the effective permittivity εreff(pp) and effective length extension ΔL−E−H of the pseudo-patch of the second resonance with effective patch width as D-2F were estimated by using Equation (17) &(18).Therefore, the height of slot iscalculated by using Equation(

$$H = L - E + 2\Delta_{L-E-H} - \frac{1}{\sqrt{\varepsilon_{reff\,(pp)}}}\left[\frac{c_0}{f_{r2}} - (2C + D)\right]$$

$$\varepsilon_{reff\,(pp)} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\frac{h}{D - 2F}\right]^{-0.5}$$

$$2\Delta_{L-E-H} = 0.824h\frac{(\varepsilon_{reff\,(pp)} + 0.3)\left(\frac{D-2F}{h} + 0.262\right)}{(\varepsilon_{reff\,(pp)} - 0.258)\left(\frac{D-2F}{h} + 0.813\right)}$$

2.5 Feed Location

Equations above are used to calculate the feed point with respect to x-axis (xp), and the feedpoint with respect to y-axis (yp).

$$x_p = \frac{l}{2\sqrt{\varepsilon reff}}$$

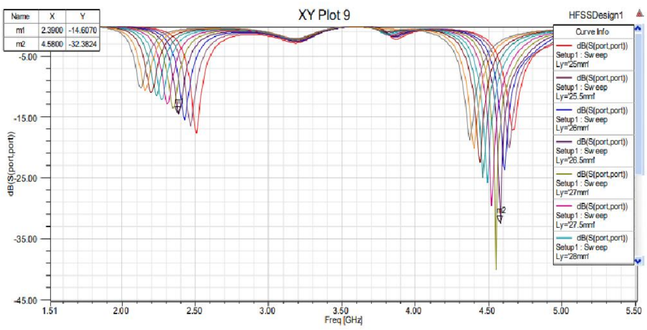
$$y_p = \frac{w}{2}$$

Parameters	Value
Operating frequency	2.4 GHz and 4.6 GHz
Dielectric constant of the substrate ε_r	4.6
Height of dielectric substrate	3.5 mm
Loss tangent (δ)	0.0025
ε_{reff}	4.035
Location of feed point (x_p, y_p)	(0.0,6.9)
Length of the patch(L)	27.97 mm
Width of the patch(W)	37.35 mm
Length of the ground	48.97 mm
Width of the ground	58.35 mm
slot lengths (C)	11.21 mm
slot width (D)	6.036 mm
Thickness of the slot (E=F)	2.08 mm
$\varepsilon_{eff(pp)}$	3.127
Estimate of the position U-slot (H)	7.28 mm
Coax inner radius	0.104 mm
Coax outer radius	0.354 mm
Coax feed length	20.83 mm

III. RESULT AND ANALYSIS

3.1 Variation of Length

When the value of 'L' is increased, the lower resonant frequency moves downwards and slight changes occur in the higher resonating frequency and vice versa. The value L=26.5mm gives the optimized result.



3.2 Variation of Width

As 'W' varies, higher resonating frequencies move upward with decrease in the return loss and there is no significant change in lower frequency band. The value W=37 mm gives theoptimized result.

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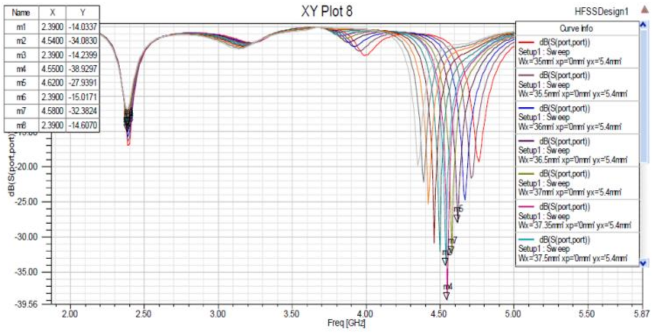
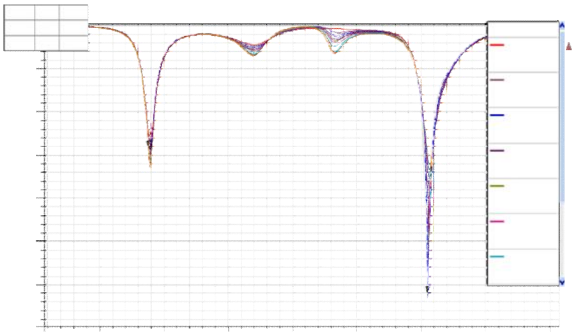


3.3 Variation of Position of Feed

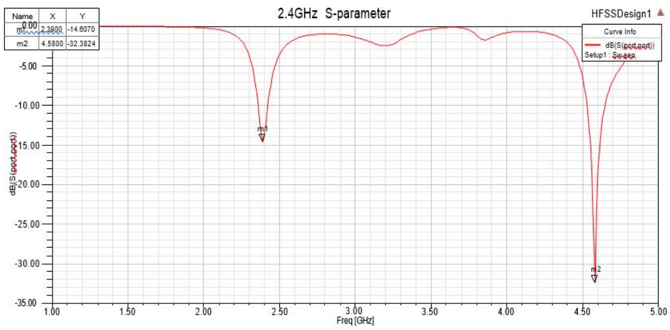
As 'Yx' varies, higher resonating frequencies move upward with decrease in the return loss;slight changes are observed. The value Yx=5.4 mm gives the optimized result.



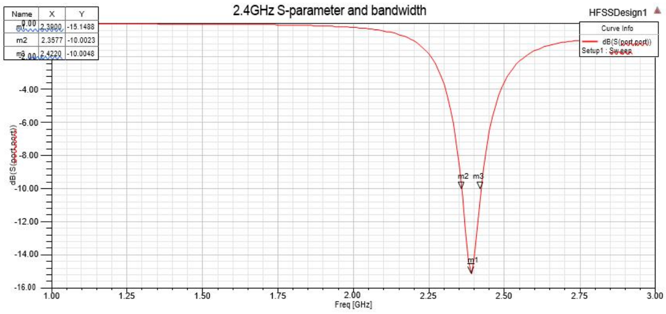
IV. RETURN LOSS

The simulation result of the return loss is shown below, as seen all values are negative and the minimum value is taken because it has low reflection power (pref) which is marked as resonant frequency. The designed antenna resonates at 2.4 GHz and 4.6 GHz, respectively. The return lossfor 2.4 GHz is -14.86 dB and bandwidth is 0.06 GHz as shown and the return loss for 4.6 GHz is -32.38 dB with bandwidth of 0.16 GHz as shown. below figures show Return Loss for both 2.4GHz and 4.6GHz frequencies.

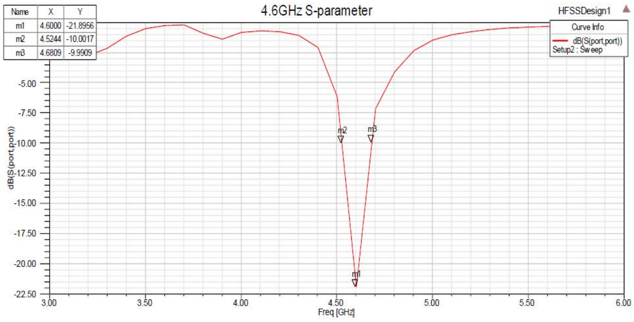
S-parameter for 2.4GHz and 4.6GHz with frequency sweep from 1GHz to 5GHz @Wx=37mm, Ly=26.5mm and yx=5.4mm (OPTIMIZED



2.4Ghz S-Parameter



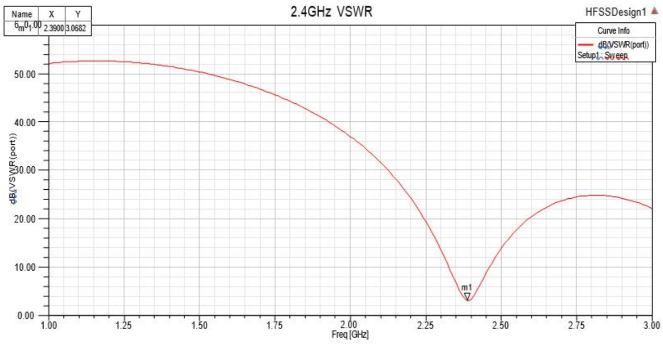
2.4 Ghz S-Parameter and Bandwidth



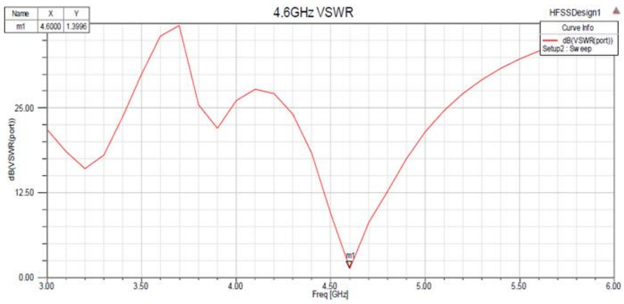
4.6Ghz S-Parameter

4.1 VSWR

Ideally, VSWR must lie in the range of 1-2, which has been achieved for 2.4 GHz and 4.6 GHz operating frequencies as shown below. The VSWR ratio at 2.4 GHz is 3.0862 and at 4.6 GHz are 1.3996 as in Figures 7(a) and (b), respectively.



2.4 Ghz VSWR



4.6Ghz VSWR

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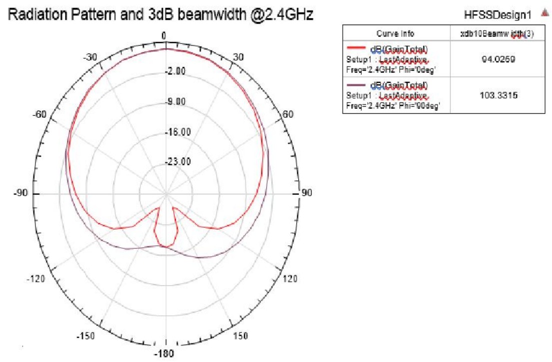
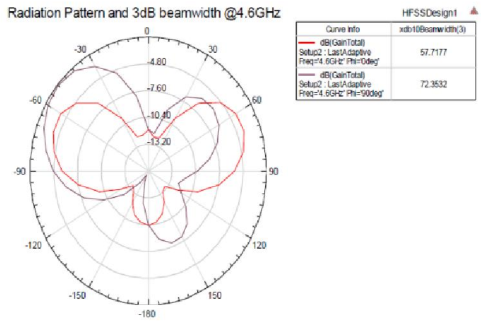
4.2 Radiation Pattern

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as afunction of the spatial coordinates which are specified by the elevation angle (θ) and the azimuth angle (φ) . A Microstrip patch antenna radiates normally to its patch surface.

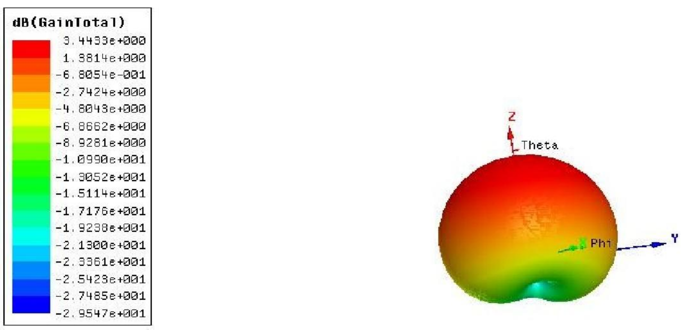
The radiation pattern is well represented in the form of a three-dimensional graph of power versus elevation and azimuth angles but more commonly represented by E-plane or H-plane where one angle is held fixed while the other is varied as shown in Figure below. The elevation pattern for Φ=0 and Φ=90 degrees would be important. Figures below show the 2D radiation pattern of the antenna atthe designed frequency for Φ=0 and Φ=90 degrees.





4.3 Antenna Gain

Antenna gain is defined as antenna directivity times a factor representing the radiation efficiency,which is defined as the ratio of the radiated power (Pr) to the input power (Pi). In Microstrip patch antennas the gain is between 5-8 dB . The simulated results show the gains of the designed dual band antenna are given in Figure below. Since the graph represents that it is a high directional antenna, the gain of the antenna is high at a specific direction. The gains of the designed antenna are 3.44 dB and 1.61 dB at 2.4 GHz and 4.6 GHz frequencies, respectively as in Figure below.



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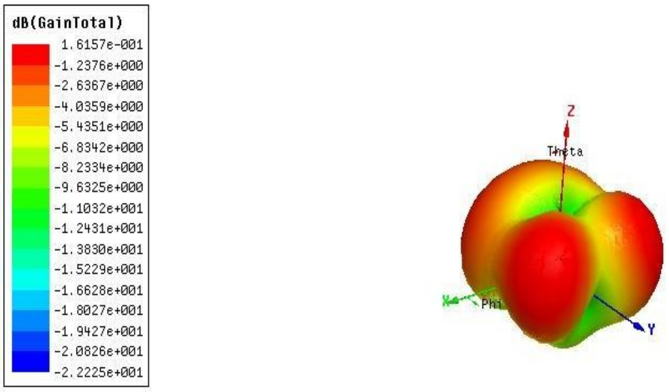
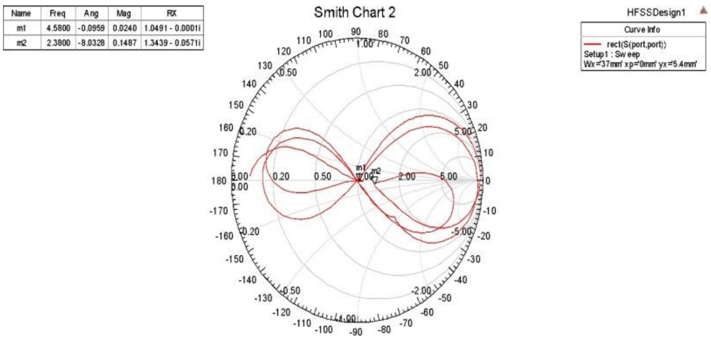


V. INPUT IMPEDANCE

S-Parameter Smith Chart of Rectangular Microstrip patch antenna with proposed material structure is represented in Figure below. It shows the impedance variation within the simulated frequency range and the basis of smith chart information about impedance matching can be easily obtained. The center of the chart corresponds to impedance matched conditions. The impedance values read from the chart are normalized values. Moreover moving away from the load (towards the generator) corresponds to moving in a clockwise direction. One complete revolution around the chart is made by moving a distance l = 0.5 along the transmission line. The input impedance as shown in Figure below at 2.4GHz and 4.6 GHz are ***1.3439- 0.0571i*** and ***1.0491-0.0001i*** respectively, which are near to the center of the chart where input impedance match is obtained.



VI. SURFACE CURRENT PLOT

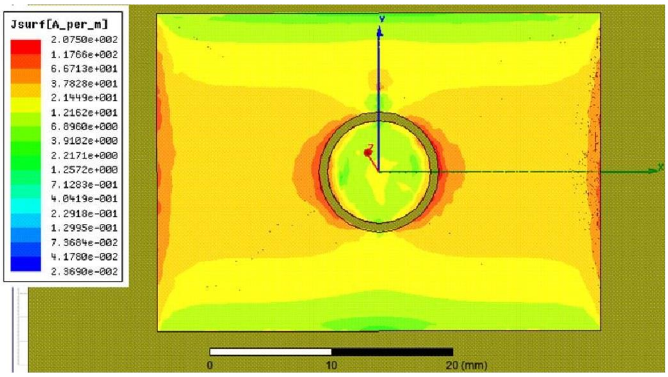
Surface currents can be strongly divergent, because of its relation with surface charge: ∂(rho)/∂t + div(**J**) = 0, in case the surface charge is very dynamical.Surface currents are weaker currents than volume currents, and require much less electrons/holes than volume 'drift' currents.

Relatively few extra electrons are required to charge a conductor with a negative high voltage. The conductivity of surface current electrons/holes must be much higher than that of volume 'drift' currents. The electrons/holes at the conductor surface can have a velocity that approachesthe speed of light, and this is proved by the fact that a change of 'line potential' at one end of theline spreads with almost the velocity of light to the other end of the line. The surface current plots are pasted below for 2.4GHz and 4.6GHz frequencies.

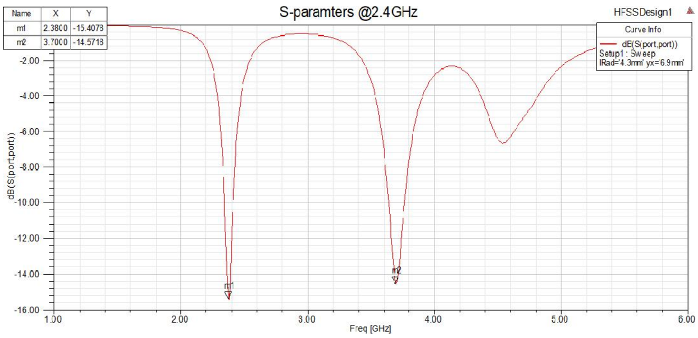
VII. CONCLUSION

In this project, a dual-band U-slot patch antenna with a coaxial feed technique has been presented to work at WLAN applications. The simulation results of the designed antenna are analyzed considering return loss, gain, VSWR, input impedance and radiation patternsusing Ansoft HFSS simulation software. The proposed antenna can be used to achieve dualband through etching U-slot on the patch, so it can be much easier to fabricate. The proposed antenna has achieved good impedance matching, stable radiation pattern and satisfied return loss. The measured results show that the obtained impedance bandwidths are 0.11 GHz (2.35- 2.46GHz), 0.14 GHz (4.55-4.4.69GHz) respectively, good enough for wireless applications. In addition, the proposed antenna has good radiation characteristics and gains in the dual operating bands, so it can emerge as an excellent candidate for dual band generation of wireless communication.

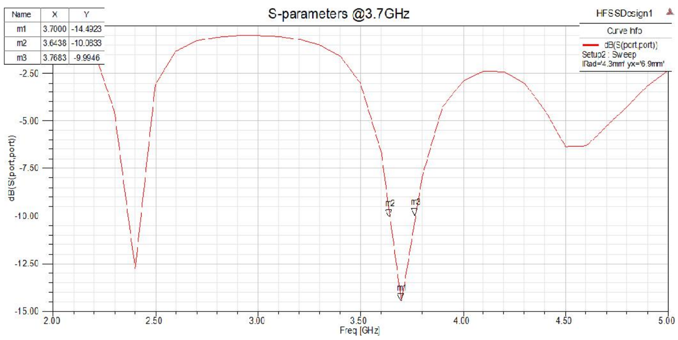
VIII. FUTURE ENHANCEMENTS



Ring Slot shaped micro antenna

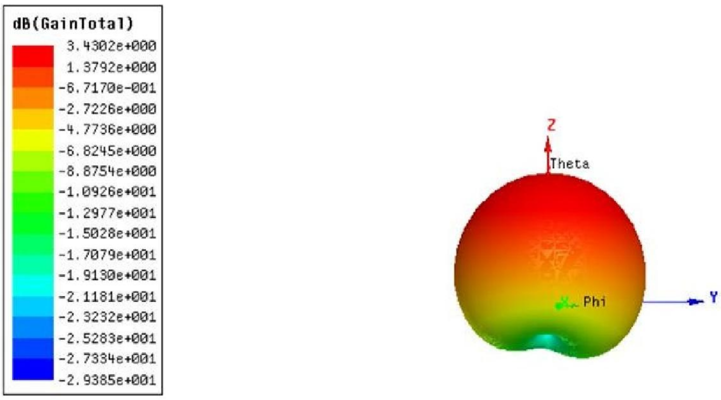


S- parameters 2.4 GHz and 3.7GHz

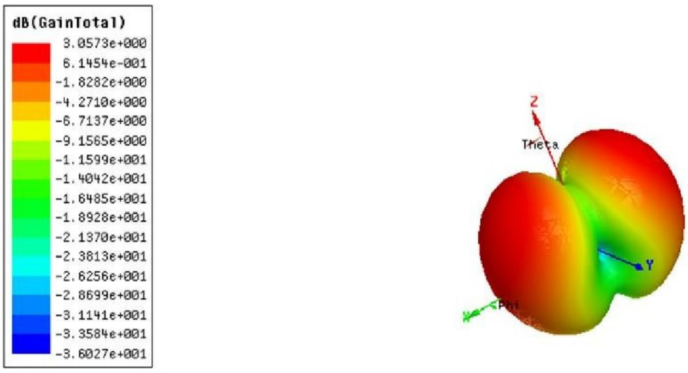


3D Gain Polar plots:

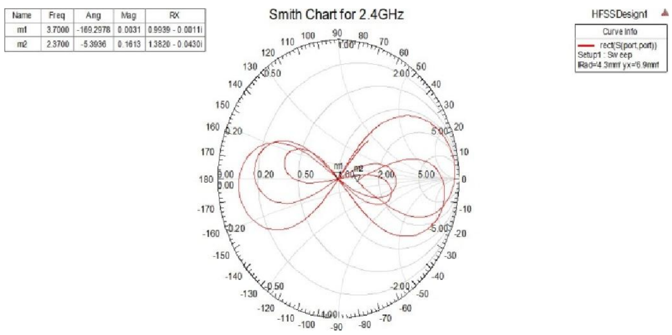
2.4GHz



3.7Ghz



Input Impedance



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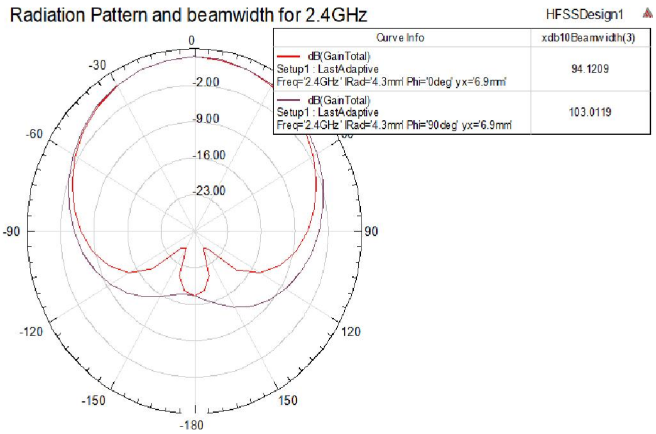
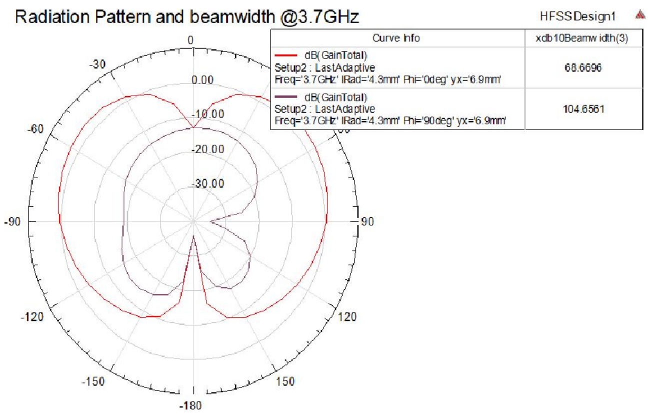
Radiation pattern and Beam Width

2.4GHz



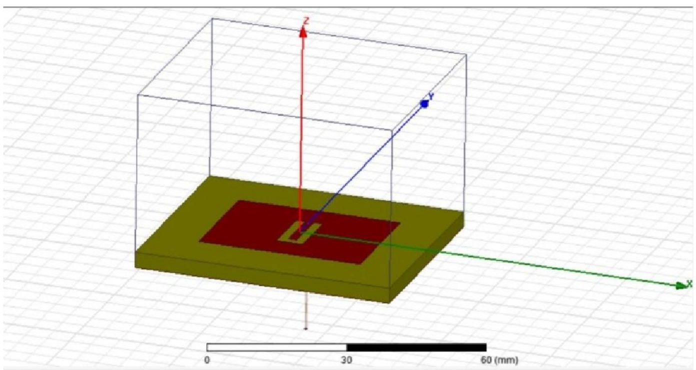
3.7Gz

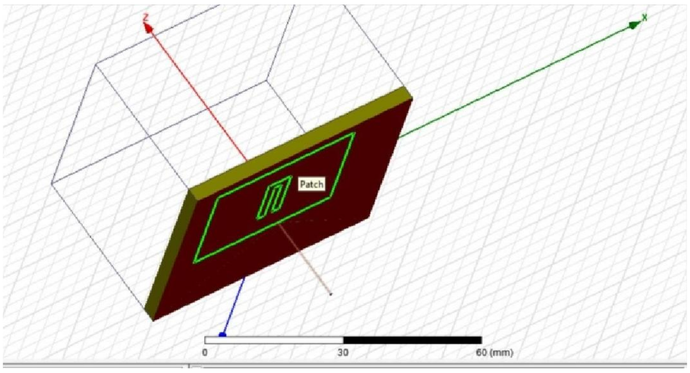


APPENDIX

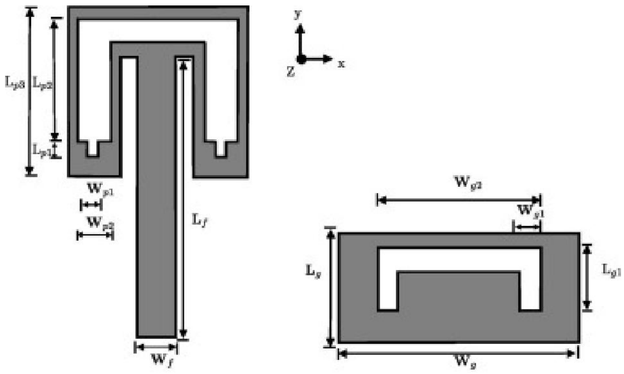
Antenna Design

We have to select the resonant frequencies and a dielectric medium for which the antenna is to be designed. The side view of the microstrip patch antenna with coaxial feeding method





	Name	Value	Unit	Evaluated Value	Type
	Wg	58.35	mm	58.35mm	Design
	Lg	48.97	mm	48.97mm	Design
	Wx	37	mm	37mm	Design
	Ly	26.5	mm	26.5mm	Design
	C	11.21	mm	11.21mm	Design
	D	6.036	mm	6.036mm	Design
	E	2.08	mm	2.08mm	Design
	slotF	2.08	mm	2.08mm	Design
	H	7.28	mm	7.28mm	Design
	t	3.5	mm	3.5mm	Design
	yx	5.4	mm	5.4mm	Design
	rad	0.354	mm	0.354mm	Design
	fLength	20.83	mm	20.83mm	Design
	innerRad	0.104	mm	0.104mm	Design
	xp	0	mm	0mm	Design



(a) Patch (b) Ground

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