# 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 u-shaped slot fed by coaxial feeding technique. The proposed antenna is designed, simulated and optimized using Ansoft HFSS Vs 13. 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 mechanism. The results showed that the U-shaped slot microstrip antenna is efficiently operated at 2.4 GHZ and 4.6 GHZ resonant frequencies for WLAN applications.*

**Keywords—***Microstrip, patch antenna, WLAN, Ansoft HFSS*

## I. Introduction

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 on other side. The basic and most commonly is rectangular MSA. MSA has properties like low size, weight, cost, good performance and ease of installing [1]. The physical characteristics of MSA are compatible for use in mobile phones, Bluetooth personal networks and wireless local networks [2]. These antennas suffer from few shortcomings like small efficiency, low power, very narrow frequency and bandwidth[3]. 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 height of 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 [5]. Many applications require operating in a dual band of frequencies instead of single band; therefore there is a need to modify the microstrip antenna 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 slot on the radiating patch results increase in the current length that 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.

**Design process**

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 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 [9] and the calculations results of all dimensions are shown in Table 1.

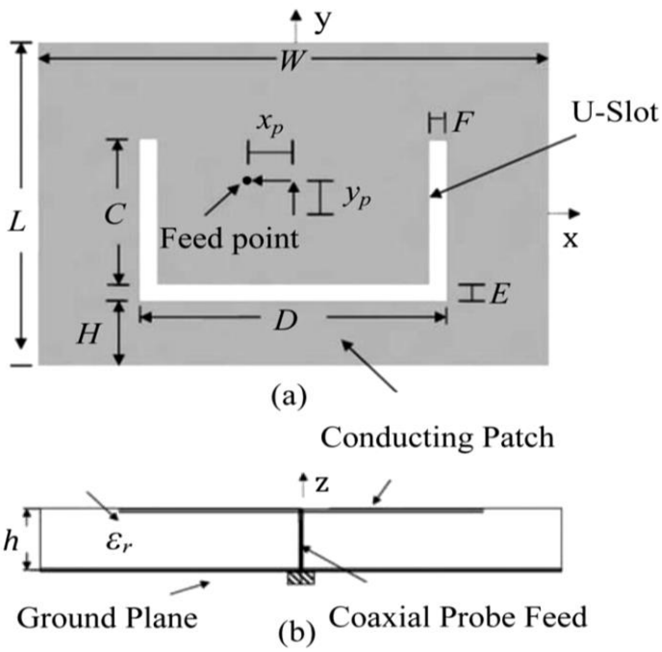



**Figure 1: (a) Geometry Of A Rectangular U-Slot Microstrip Patch Antenna (b) Coaxial Probe Feeding Method**

**Operating frequency**

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

$$f_0 = \frac{f_L + f_h}{2} \quad (1)$$

Where $f_L$ is the lower frequency and $f_h$ is the higher frequency of operating band.

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

$$\lambda_0 = \frac{v_0}{f_0} \quad (2)$$

Where $\lambda_0$ is the guided wavelength in the substrate of the antenna, $v_o$ is the light speed in space (=3x10^8 m/sec).

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

$$h \geq 0.06(\lambda_0 / \sqrt{\varepsilon_r}) \quad (3)$$

Where $\varepsilon_r$ is the dielectric constant of the dielectric material.

**Microstrip Patch Antenna Dimensions**

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

$$W = \frac{v0}{2fo\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (4)$$

Effective Dielectric constant $\varepsilon_{reff}$ is given by Equation (5) [4]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-0.5} \quad (5)$$

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).

$$L = L_{eff} - 2\Delta L \quad (6)$$

Where $L_{eff}$ is the Effective Length of the rectangular microstrip antenna, it is given by Equation (7).

$$L_{eff} = \frac{vo}{2fo\sqrt{\varepsilon_{reff}}} \quad (7)$$

$\Delta L$ is Length Extension, which can be determined by Equation (8)

$$\Delta L = 0.412h \frac{\left[(\varepsilon_{reff} + 0.3)\left(\left(\frac{W}{h}\right) + 0.264\right)\right]}{\left[(\varepsilon_{reff} - 0.258)\left(\left(\frac{W}{h}\right) + 0.8\right)\right]} \quad (8)$$

**Ground Plane Dimensions**

Length of the ground plane $l_g$ is given by Equation (9)

$$l_g = 6h + L \quad (9)$$

Width of the ground plane $w_g$ is calculated by Equation (10)

$$w_g = 6 * h + W \quad (10)$$

**Bandwidth of the Antenna**

The percentage value of Bandwidth of the antenna BW is given by Equation (11) [10].

$$BW\% = \frac{Ah}{\lambda_o}\sqrt{\frac{W}{L}} \quad (11)$$

Where A is constant has multiple values at different states

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

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

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

$$BW\% = \frac{f_h - f_l}{f_o} \quad (12)$$

**Slot Dimensions**

Thickness of the slot E , F is given by Equation (13) [11]

$$E = F = \frac{\lambda_0}{60} \quad (13)$$

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

$$\frac{C}{W} \geq 0.3 \quad (14)$$

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

$$D = \left[\frac{c_0}{f_l * \sqrt{\varepsilon_{reff}}}\right] - 2(l + 2\Delta l - E) \quad (15)$$

To calculate the height of slot H with respect to x axis , the effective permittivity $\varepsilon_{reff(pp)}$ and effective length extension $\Delta_{L-E-H}$ 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 is calculated by using Equation(16)[9].

$$H = L - E + 2\Delta_{L-E-H} - \frac{1}{\sqrt{\varepsilon_{reff(pp)}}}\left[\frac{c_0}{f_{r2}} - (2C + D)\right] \quad (16)$$

$$\varepsilon_{reff(pp)} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\frac{h}{D - 2F}\right]^{-0.5} \quad (17)$$

$$2\Delta_{L-E-H} = 0.824h \frac{\left(\varepsilon_{reff(pp)} + 0.3\right)\left(\frac{D-2F}{h} + 0.262\right)}{\left(\varepsilon_{reff(pp)} - 0.258\right)\left(\frac{D-2F}{h} + 0.813\right)} \quad (18)$$

**Feed Location**

Equations 19 and 20 are used to calculate the feed point with respect to x-axis ($x_p$), and the feed point with respect to y-axis ($y_p$).

$$x_p = \frac{l}{2\sqrt{\varepsilon reff}} \quad (19)$$

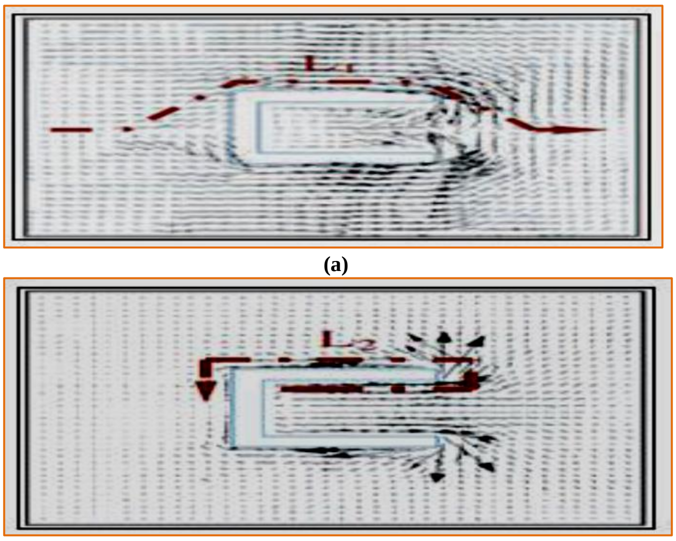
$$y_p = \frac{w}{2} \quad (20)$$

**Table 1: Geometry parameters of the antenna**

| Parameters | Value |
|---|---|
| Operating frequency | 2.4 GHz and 4.6 GHz |
| Dielectric constant of the substrate $\varepsilon_r$ | 4.6 |
| Height of dielectric substrate | 3.5 mm |
| Loss tangent ( δ) | 0.0025 |
| $\varepsilon_{reff}$ | 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. Frequency Control

In this section, a method of resonant frequency control is used. As the proposed MSA is a dual-band antenna so it has two frequencies of operation. The radiating patch has a U-shaped slot; therefore it provides two current paths (L1 and L2) which lead to the two resonant frequencies ($f_1$ and $f_2$). The average current lengths are shown in Figure 3(a, b).




(a)

(b)

**Figure 3: Currents Paths (L1 and L2) (a) For f1 (b) For f2**

Now in accordance with the L1 and L2 the approximated values of resonant frequencies can be calculated from equations below [8].

$$f_1 = \frac{c}{2\sqrt{2\varepsilon_{eff} l_1}} \quad (21)$$

$$f_2 = \frac{c}{2\sqrt{2\varepsilon_{eff} l_2}} \quad (22)$$

Where $L_1$ and $L_2$ are the average lengths of the current paths of first and second resonant frequencies, c is the velocity of light in free space and $\varepsilon_{eff}$ is the effective permittivity.

Now let us consider coaxial fed MSA with U-shaped slot as shown in Figure 1. By performing various simulations it is investigated that the first resonant frequency "$f_1$" can be controlled by adjusting the length "L" of the initial radiating patch as shown in Figure 4 as parametric analysis for length L. This is due to the fact that as the patch length increases the first current path "$L_1$" increases the first radiating frequency $f_1$ decreases and vice-versa. But now the method of controlling the second radiating frequency "$f_2$" is to be investigated, so variation in all the parameters are to be recorded that leads to the change in the second current path length "$L_2$". It is quite clear from the Figure 1 that all the appropriate parameters related to the U-shaped slot are C, E and the patch width (W).

**Effect of length (L) variation**: when the value of 'L' is increased, the lower resonant frequency moves downwards and slight change occur in higher resonating frequency and vice versa. The value L=26.28 mm gives the optimized result as shown in Figure 4.

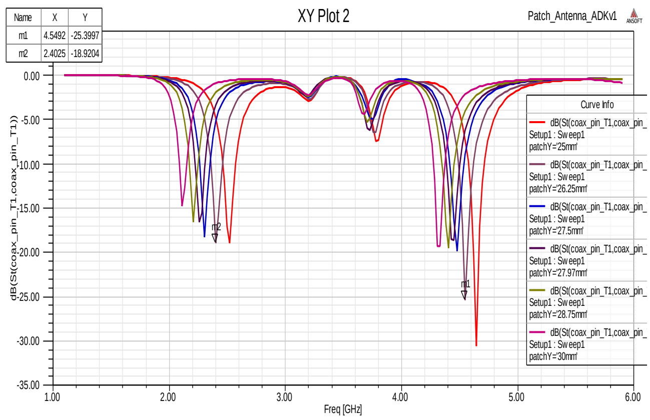



**Figure 4: Effect of length (L) variation on return loss**

**Effect of width (w) variation**: As 'W' varies, higher resonating frequency move upward with decrease in the return loss and there is no significant change in lower frequency band. The value W=36.6 mm gives the optimized result as shown in Figure 5.

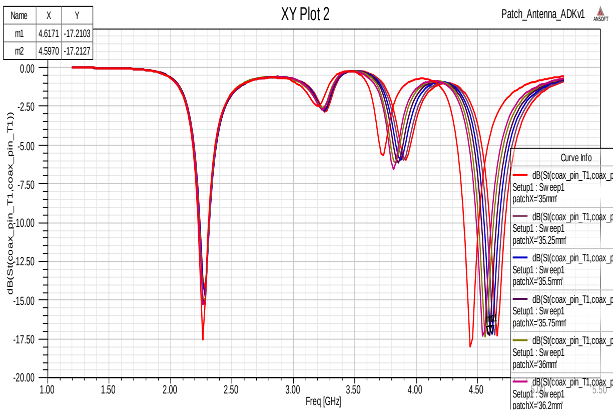
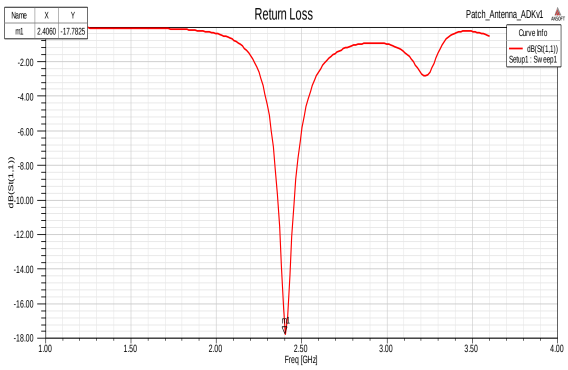



**Figure 5: Effect of width (W) variation on return loss**

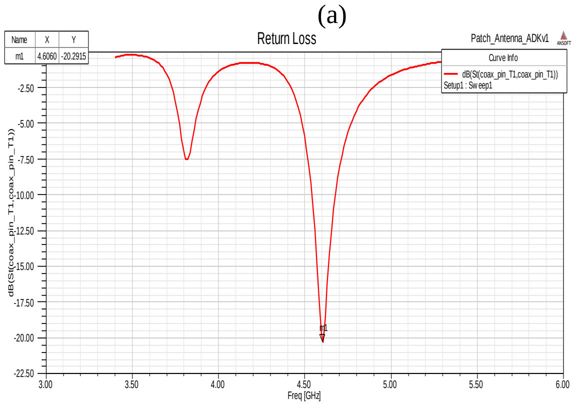
## IV.Results and Discussion for Coax-fed U-shaped slot Dual band MPA

### Return Loss (RL)

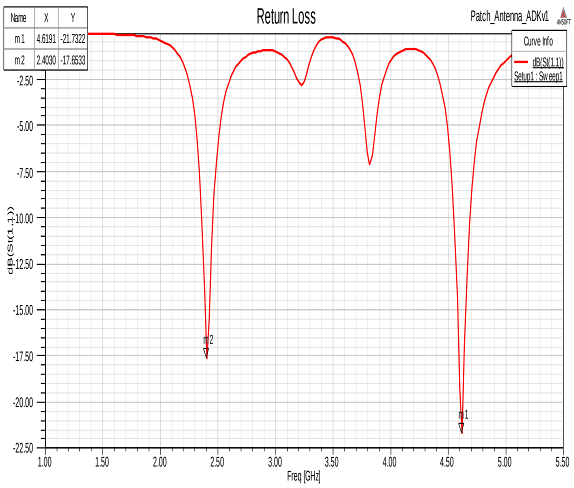
The simulation result of the return loss is shown in Figure 6, as seen all values are negative and the minimum value is taken because it has low reflection power ($p_{ref}$) which marked as resonant frequency. In Figure 6, the designed antenna resonates at 2.4 GHz and 4.6 GHz, respectively. The return loss for 2.4 GHz is -17.7825 dB and bandwidth is 0.11 GHz as shown in Figure 6(a) and the return loss for 4.6 GHz is 20.2915 dB with bandwidth of 0.14 GHz as shown in Figure 6(b). Figure 6(c) shows Return Loss for both 2.4 GHz and 4.6GHz frequencies.




(a)




(b)

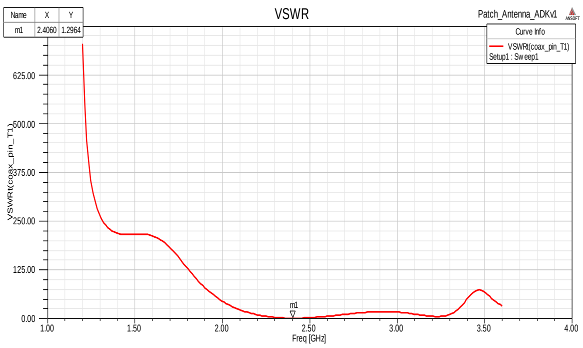



**(c)**

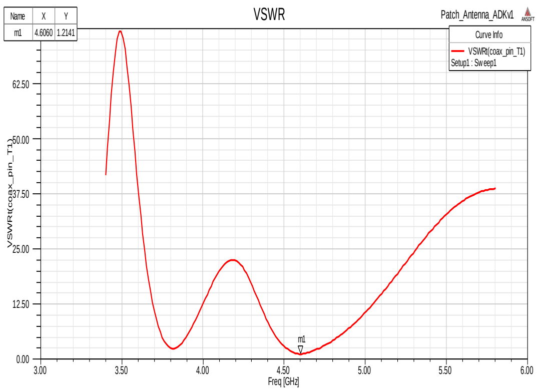
**Figure 6: Return Loss Vs Frequency (a) Return Loss For 2.4 GHz (b)Return Loss For 4.6 GHz (c) Return Loss For Both 2.4 GHz and 4.6GHz**

### Voltage Standing Wave Ratio (VSWR)

Ideally, VSWR must lie in the range of 1-2, that which has been achieved for 2.4 GHz and 4.6 GHz operating frequencies as shown in Figure 7. The VSWR ratio at 2.4 GHz is 1.2964 and at 4.6 GHz are 1.2141 as in Figures 7(a) and (b), respectively.




(a)



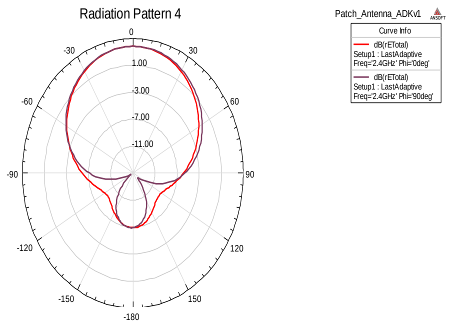

(b)

**Figure 7: VSWR vs Frequency curve at (a) 2.4GHz (b) 4.6 GHz**

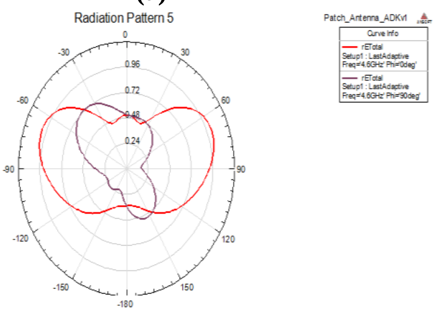
## Radiation Pattern

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial coordinates which are specified by the elevation angle (θ) and the azimuth angle (φ) [6]. A Microstrip patch antenna radiates normal to its patch surface.

The radiation pattern is good 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 8. The elevation pattern for Φ=0 and Φ=90 degrees would be important. Figures 8 (a) and (b) below show the 2D radiation pattern of the antenna at the designed frequency for Φ=0 and Φ=90 degrees.




**(a)**

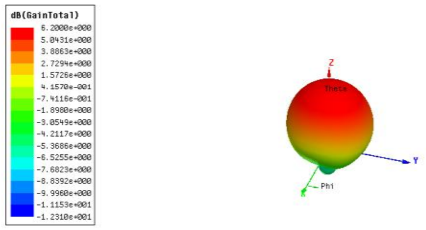



**(b)**

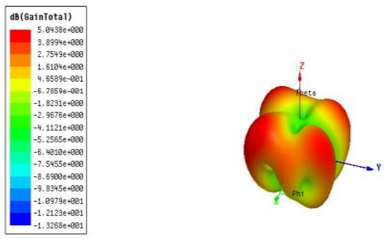
**Figure 8: Radiation Pattern For (a) 2.4 GHz (b) 4.6 GHz**

## 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 ($P_r$) to the input power ($P_i$). In Microstrip patch antenna the gain is between 5-8 dB [7]. The simulated results show the gains of the designed dual band antenna are given in Figure 9. Since the graph represents that it is a high directional antenna so the gain of the antenna is high at a specific direction. The gains of the designed antenna are 6.2 dB and 5.0438 dB at 2.4 GHz and 4.6 GHz frequencies, respectively as in Figure 9.




**(a)**



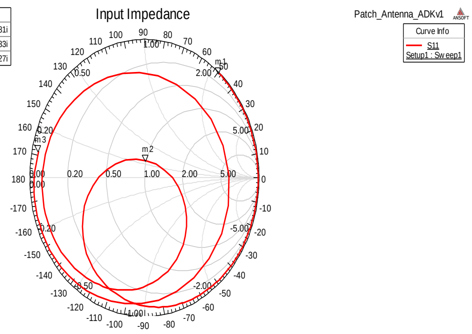

**(b)**

**Figure 9: Gain 3D for (a)2.4 GHz (b)4.6GHz**

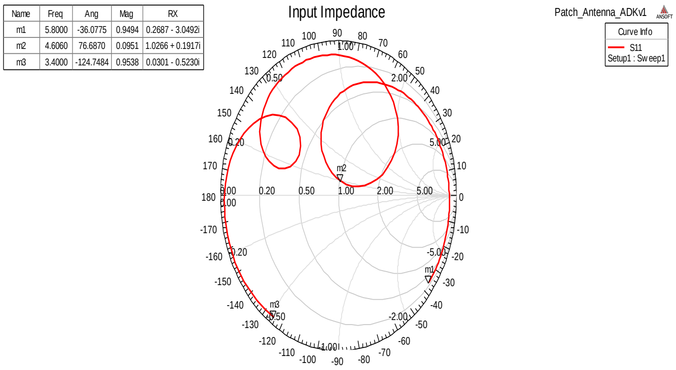
## Input Impedance

S-Parameter Smith Chart of Rectangular Microstrip patch antenna with proposed material structure is represented in Figure 10. 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 condition. 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 $l = 0.5\lambda$ along the transmission line [6]. The input impedance as shown in Figure 10 at 2.4GHz and 4.6 GHz are 1.0003+0.2583i and 1.0266+ 0.1917i respectively, which are near to the center of the chart where input impedance match, is obtained.

| Name | Freq | Ang | Mag | RX |
|---|---|---|---|---|
| m1 | 1.2000 | 49.3209 | 0.9968 | 0.0093 + 2.1781i |
| m2 | 2.4060 | 82.5815 | 0.1280 | 1.0003 + 0.2583i |
| m3 | 3.6000 | 168.2636 | 0.9420 | 0.0302 + 0.1027i |




**(a)**




**(b)**

**Figure 10: Input Impedance For (a) 2.4 GHz(b)4.6 GHz**

## V.Conclusion

In this paper, a dual-band U-slot patch antenna with a coaxial feed technique has been presented to work at WLAN applications. The simulation results of designed antenna are analyzed considering return loss, gain, VSWR, input impedance and radiation patterns using Ansoft HFSS simulation software. The proposed antenna can be used to achieve dual band through etching U-slot on the patch, so it can be much easier to be fabricated. The proposed antenna have 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.

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