Slotted Rectangular Microstrip Antenna for Dual Band Operation

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ABSTRACT
This paper covers two aspects of Microstrip antenna designs. The first is the analysis and design of single element rectangular Microstrip antenna which operates at the centre frequency of 2.4 GHz. The second aspect is the design of dual band rectangular microstrip antenna which operates at 2.4 GHz and 3.6 GHz used in 802.11b/g/n and 802.11y WLAN channels respectively. Both antennas are modeled, designed and simulated. Here for the rectangular patch, Inset Line Feed technique is used to design both the antennas. First, the design parameters for single element of rectangular patch antenna is calculated from the transmission line model equation and then the antenna design is extended to operate in dual band using the slots at radiating edges and near the inset feed line and obtained good radiation characteristics. The simulation process has been carried out in Advanced Design System(ADS) with the specifications ε_r=4.6 and h=1.6mm and f_r =2.4GHz.

General Terms
Advanced Design System (ADS) ,Microstrip Antenna (MSA).

Keywords
Microstrip Antenna, Rectangular Patch Antenna, Dual Frequency Antenna, Inset Fed , slot Antenna, S-Parameters.

1. INTRODUCTION
Nowadays, wireless communication systems are becoming increasingly popular. There have been ever growing demands for Microstrip antenna designs that possess the following highly desirable attributes: small size, low cost and ease of fabrication. In the recent decades, slot antennas have again become the subject of great interest to the engineering designer due to their miniaturization potential and relatively wide bandwidth. A microstrip slot antenna is a kind of the antenna, having slots on the geometry plane of microstrip patch [1]. This antennas are printed on the epoxy printed circuited boards. Printed slot antennas have attracted much attention due to their low profile, light weight and ease of integration with monolithic microwave integrated circuit (MMIC). However, their narrow bandwidth is a drawback. Several techniques on bandwidth enhancement of the antennas have been reported, such as slots, surface meandering, aperture coupled patches, or near frequency resonators [2]. These techniques increase the bandwidth up to several tens percent. One may think about increasing the substrate height, but this implies the appearance of surface waves, which reduce considerably the antenna efficiency. Dual-band operations of antenna have presented to satisfy WLAN standards in an antenna element [3]. A simple method to achieve the dual band characteristic in a microstrip antenna is embedding a slot in the patch as the structure proposed in [9] in which the radiating patch includes a pair of step-slots. Double rectangular microstrip patches operate at 2.4 GHz and 3.6 GHz for the solution of wireless local area network (WLAN) frequency bands. In this paper, we propose a design of slot antenna having rectangular shaped slot along inset fed line.

2. DESIGN PROCEDURE
For design, we start with conventional microstrip patch antenna and calculate the length and width of the patch using standard antenna design equations [4]-[6] at 2.4 GHz. The first design step is to choose a suitable dielectric substrate of appropriate thickness (h). Three most common substrate materials used are rexolite (ε_r=2.6), RT Duroid (ε_r=2.2) and Alumina (ε_r=9.8). Here substrate with ε_r=4.6 having thickness (h) =1.6mm is chosen as the substrate material for the patch antenna. First the dimensions of the patch and feed line are to be determined and the feed line is to be placed properly to resonate at 2.4 GHz and 3.6 GHz. Then the modifications of antenna structure is studied and simulated to create multiple resonances. For efficient radiation, patch width is given by [2]:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

v_0 = velocity of light=3×10^{11}mm/sec.

The Effective dielectric constant is given by [3,4,8]:

$$\varepsilon_r = \left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right)\left(\varepsilon_r - \frac{1}{2}\right) + \left(\varepsilon_r + \frac{1}{2}\right)$$

Where,
ε_{reff} .=Effective dielectric constant
ε_r =Dielectric constant of substrate
h =Height of dielectric substrate
W =Width of the patch
For a given resonance frequency fr, the effective length is given by [3]:

$$L_{eff} = \frac{c}{f_r\sqrt{\varepsilon_{eff}}}$$

The actual length of patch is given by [7]:

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

Where,

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_r + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_r - 0.258)(\frac{W}{h} + 0.8)}$$

By using transmission line model analysis the input resistance due to the two identical slots at the edges of patch which are separated by distance λ/2 is given by [3]:

$$R_{in} = \frac{1}{2(G1 \pm G2)}$$

Where,
G1=Conductance
G12=Mutual conductance

$$G1 = \frac{1}{120\pi^2}\int_0^n [\sin(\frac{k_0 W}{2}\cos\theta)]\, sin^3\theta d\theta$$

And,

$$\frac{1}{120\pi^2}\int_0^n [\sin\left(\frac{k_0 W}{2}\cos\theta\right)]J_0(k_0 L\sin\theta)\, sin^3\theta d\theta$$

Where, k_0 = wave number = $2\pi f_r / \lambda$

The characteristic impedance of any line is a function of the geometry of the line and the dielectric constant. As the input impedance varies rapidly as a function of cos2((∏/L) y0) and becomes zero at the centre of the patch an inset cut is required to match the load and input impedances. Here a 50Ω feed line is used so the feeding point also should be also 50Ω to get perfect matching. The length of inset cut (y_0) is calculated by the formula [4]:

$$R_{in}(y = y_0) = \frac{1}{2(G1 \pm G12)}cos^2(\frac{\pi}{L}y_0)$$

$$y_0 = \frac{L}{\pi}\cos^{-1}\sqrt[2]{\frac{R_{in}}{R_{in_0}}}$$

According to the above formulas using ε_r =4.6 with standard thickness h=1.6 mm the antenna dimensions are shown in table 1:

Table 1: Single Band Patch Dimensions

W	**L**	**W_f**	**y_0**
37.35 mm	28.80 mm	4 mm	6 mm

Here Fig 1 depicts the layout of a Single Band patch Antenna designed with ε_r =4.6, h=1.6mm. W,is the width of the antenna,L is the length , y_0 ,inset feed length and W_f is the inset feed width. An impedance of 50Ω is given at the input port shown in the figure 2. The below Fig. 2 shows the Return Loss plot of single Band Antenna with maximum return loss of -20.35 dB at 2.4 GHz frequency. The return is very high, it means that most of the power is radiated, only a little amount of power is reflected back i.e., only 9% of the power is getting reflected to port 1. Antenna efficiency is observed to be above 91%. Both simulations are performing at single frequency of 2.4 GHz.

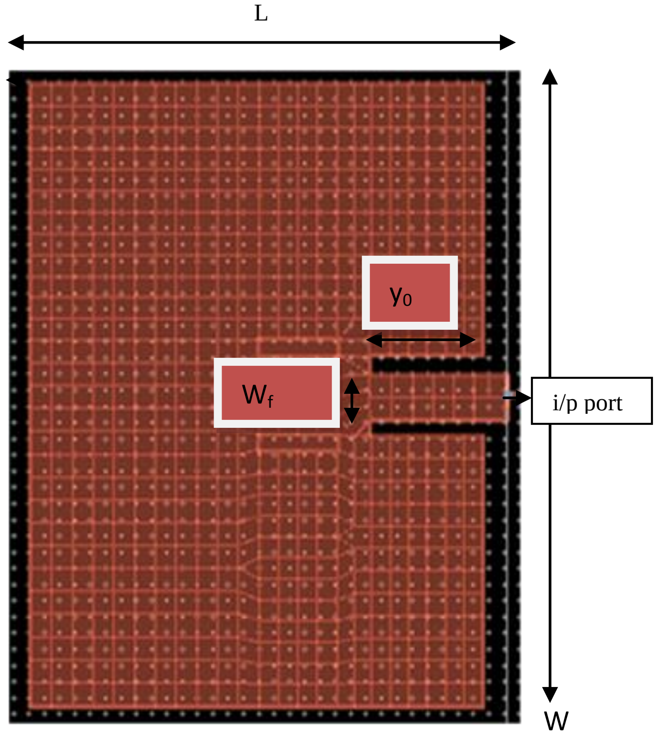

Fig 1: Single Band Patch Antenna

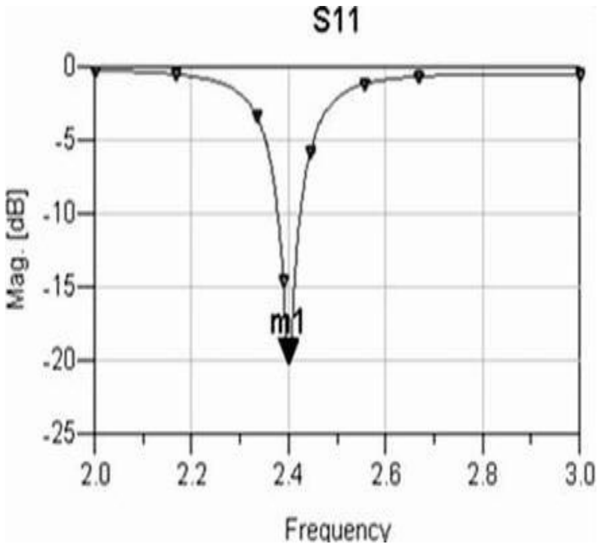

Fig 2: Return Loss Plot of Single Band Antenna (S-parameters)

3. MODIFICATIONS OF ANTENNA STRUCTURE FOR DUAL BAND

The dual band microstrip antenna (MSA) is realized by cutting the slots of different shapes like, U-slot, V-slot, pair of rectangular slots and step slots, etc [9–13]. The geometry of dual band rectangular microstrip antenna is shown in fig 3. It is constructed on the substrate having dielectric constant (ε_r) 4.6 and thickness (h) at 1.6 mm. The proposed structure is simulated using ADS. The design is for a resonant frequency of around 2.4 GHz AND 3.6 GHz. The first stage involves the creation of additional TMoδ resonant modes at a resonant frequency above that of the fundamental TM01 mode, with the same polarization sense. The next stage is to simultaneously bring the input impedance of all modes to 50Ω at resonances through the use of an inset feed position control.

3.1 Creation of Additional Resonant Modes

The first point to note in the design process is the effect of slot separation on the patch design. With reference to the value of slot separation, simulation results have shown that placing the slots close to the radiating & non-radiating edges of patch increase the effect of slot length on resonant frequency. This gives greater freedom to tune the resonant frequency of the TMoδ mode. Increasing the slot width produces an increase in input impedance of the TM01 mode.

In Fig 3, A Dual Band Patch Geometry is designed in ADS Layout Design where rectangular slots are inserted of particular dimension described in table 2. An impedance of 50Ω is given at the input port to analyse the S-parametric values in Graphical form as Shown in Fig.4.The simulations gives output at two Resonant frequencies of 2.4 GHz and 3.6 GHz with return loss of – 18.803 dB and -21.31 dB respectively. The power reflected back for -18.80 dB is 11% and for -21.31 db is 8% at i/p port. Antenna efficiency is observed to be above 89% and 92% respectively for dual band operation respectively.

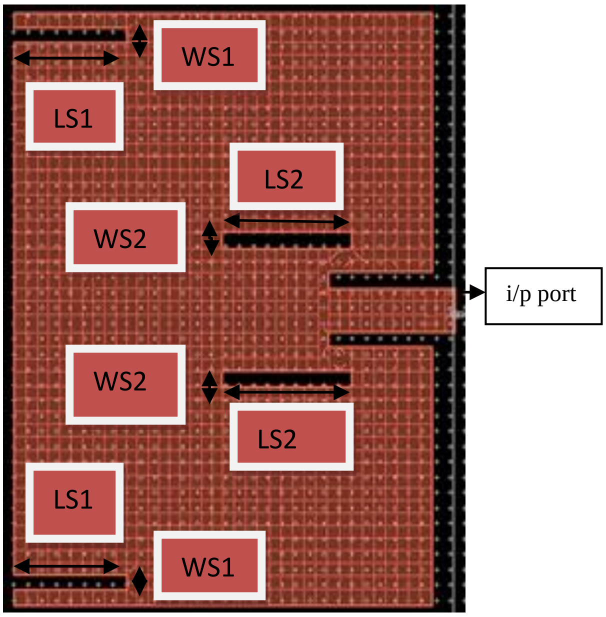

Fig 3: Dual Band Patch Geometry

Table 2: Slot Dimensions

WS1	WS2	LS1	LS2
1.65 mm	1.95 mm	9.6 mm	9.2 mm

As the slot width increases further, a stage is reached where the input impedance is too high for impedance matching. Regarding the effect of the slot lengths LS1 & LS2 on creating an additional TMoδ mode, the simulation results indicate that the slot length LS1 and LS2 must take on a value of 30% L and 31% L.

3.2 Insertion of Slots for Dual Band Operation

With reference to the value of slot separation [9],[10], experimental results have shown that placing the slots close to the nonradiating edges of the patch increases the effect of slot length on resonant frequency.Considering the value of slot width WS1, the requirement to achieve impedance matching of both and modes effectively place a constraint on this value. Increasing the slot width produces an increase in input impedance of the mode. As the slot width increases further, a stage is reached where the input impedance is too high for traditional impedance matching. A further reason for placing a limit on the value of slot width is the fact that the resonant frequency of the mode remains largely unaffected. For this design, experimental results indicate that the slot-width value should not exceed 3 mm. Placing this constraint on the slot-width value is beneficial from a designer"s point of view, as only the effect of slots on the additional mode need be considered. This reduces the complexity of the design process. Regarding the effect of slot length on creating an additional mode, experimental results indicate that the slot length l1 must take on a value of between 30% L and 31% L. Increasing within these constraints can produce a frequency ratio of 1.4.

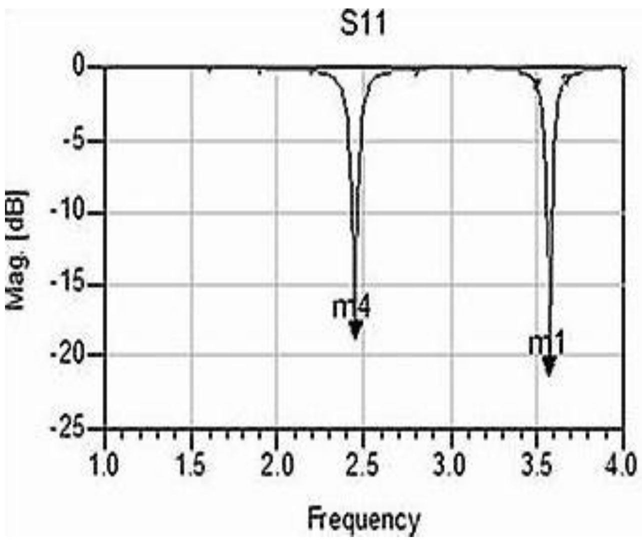

Fig 4: Return Loss Plot of Dual Band(S- Parameters)

4. RESULTS AND DISCUSSIONS

The simulated result of single band patch antenna is obtained at the resonant frequency of 2.4 GHz. The return loss is found to be -20.35dB from the curve shown in fig. 2. It is observed that most of the power is radiated, only a little amount of power is reflected back i.e., only 9% of the power is getting reflected to input port. The Antenna efficiency is observed to be above 91%. It is shown in fig. 4 useful return loss peaks of the dual band patch antenna at 2.4 GHz and 3.6 GHz are -18.803 dB and -21.31 dB respectively. The power reflected back for -18.80 dB is 11% and for -21.31 db is 8% to input port. Antenna efficiency is observed to be above 89% and 92% respectively for dual band operation. The Inset feed and the two slots are used to design the dual band rectangular Microstrip patch antenna. The centre frequency is selected as the one at which the return loss is minimum and is obtained at the desired frequencies.

Table 3 : Comparison of single patch and Dual Band patch Antenna

Antenna type	Operating frequency	Return Loss	Application
Single Band Patch Antenna	2.4GHz	-20.35dB	802.11b/g/n WLAN
Dual Band rectangular Patch Antenna	2.4GHz and 3.6GHz	-18.80dB and -21.31dB	802.11y WLAN

5. CONCLUSION

A multi-slot patch antenna is proposed for dual frequency band applications. The simulation results show the operation of antenna at 2.4 GHz and 3.6 GHz with consistency of S-Parameters. The antenna designed is best suitable for operating in wireless channels i.e., 802.11b/g/n and 802/11y WLAN applications. Microstrip slot antenna design is presented here with slots in the centre of the patch near feed line and near the edges. The location of the slots is chosen to obtain the good radiation characteristics at the required frequencies. The inset feed point which is placed close to the center has served the purpose of reducing input impedance. Both the results are compared and reported that inset fed microstrip slot antenna gives good radiation properties. In future, the antenna is to be designed with shorting wall to get wider bandwidth and fabricated in high frequency substrate.The dual band antenna shows that with correct selection of slot dimensions and positions, a dual frequency response can be achieved, while still allowing the use of a planar feed substrate.

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