DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNA FOR DIFFERENT CONFIGURATION ON DIFFERENT SUBSTRATES

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Abstract: In this paper we have analyzed and designed a rectangular microstrip antenna in X band frequency range. The desired frequency is chosen to be 10 GHz at which the patch antenna is designed for two different configurations namely, inset fed patch antenna and quarter wave rectangular microstrip patch antenna. After calculating the various parameters such as width, effective dielectric constant, effective length and actual length, the antenna impedance is matched to 50 ohm of transmission feed line. It is also investigated how the performance properties of a microstrip patch antenna are affected by varying the dielectric constant of substrate and width to length ratio of the patch. The return loss is observed followed by the radiation pattern. The total simulation is done using the software Ansoft-HFSS.

Introduction: A Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure (1). The patch is generally made of conducting material such as copper and can take any possible shape [1]. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane [2]. Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and noncontacting. Here, the contacting method was implemented, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line and the radiating patch [3].

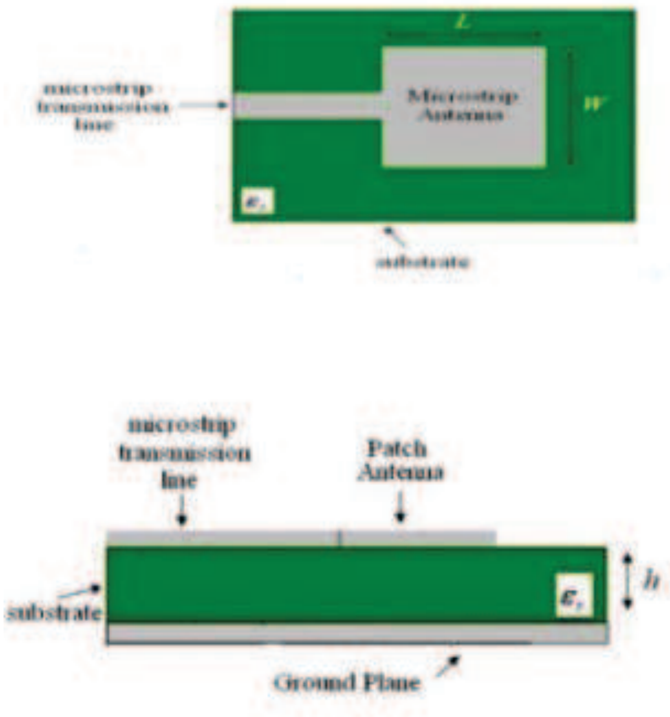

Figure 1: Microstrip patch antenna

Yahya S. H. Khraisat et al 2012 [4] explained the design, and fabrication of an inset fed rectangular microstrip patch antenna, the length of the antenna is nearly half wavelength in the dielectric, which governs the resonant frequency of the antenna. C. V´azquez et al. 2009 [5] reported a probe fed microstrip antenna design. The performance of the antenna element analysed using HFSS simulation software and Prototypes of the antenna element manufactured and measured for the experimental validation of the design.

In our paper, we have analyzed the simulation result of resonance frequencies as a function of notch width for an inset microstrip feed and inserting quarter wave transmission line to the feed of the rectangular microstrip patch antenna. An approximate formula is introduced to describe the resonance frequency that is then implemented in the design of notch width for inset-fed and quarter wave to the rectangular antennas to achieve better impedance matching and enhancing the bandwidth at X-band frequency range.

Design specifications and procedure:

Freuency : 9.5-10.5 GHz

Substrate: RT Duroid 5880 and FR4

Height: 0.787mm and 1.6mm

Dielectric constant: 2.2 and 4.4

Design of rectangular patch :

The width and length of the patch antenna are calculated by using transmission line design equations.

The width of the patch is given by

$$w = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_{r+1}}} \qquad (1)$$

Actual length of the patch is determined as

$$L= \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2(\Delta l) \qquad (2)$$

Design of extension length (Δl): The extension length Δl is usually deducted from the calculated length L of rectangular microstrip patch antenna (RMSA) in order to retain the actual length of the patch constant.

$$\Delta L= 0.412\frac{(\varepsilon_{eff}+0.3)}{(\varepsilon_{eff}-0.258)}\frac{\left(\frac{W}{h}+0.264\right)h}{\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

Here, ϵ_{eff} is the effective dielectric constant and is calculated using the formula,

$$\varepsilon_{eff}= \frac{\epsilon r+1}{2}+\frac{\epsilon r-1}{2}[1+12\frac{h}{W}]^{-1/2} \qquad (4)$$

Design of elemental length (L):

Once the extension length and effective dielectric constant are determined using above equations, then elemental length of RMSA is found by using equation

$$L= \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2(\Delta l) \qquad (5)$$

Parameter	Optimized value (mm)
Width(W)	11.8
Length(L)	9.75
Y_o (feed offset)	3.0
W_o(notch)	0.9

Design of microstrip line feed: The 50Ω microstrip line feed is designed by calculating the values of W/h ratio for the known values of characteristic impedance Z_o and ϵ_r, the design equations are

$$\frac{W_f}{h} = \left(\frac{8e^A}{e^{2A}-2}\right)\text{for}\frac{W_f}{h} < 2 \qquad (6)$$

$$\text{Where, } A= \frac{Z_0}{60}\sqrt{\frac{\epsilon_{r+1}}{2}}+\frac{\epsilon_{r+1}}{\epsilon_{r-1}}\left(0.23+\frac{0.11}{\epsilon_r}\right) \qquad (7)$$

By using above equations the width of the microstrip line feed W_f can be determined by multiplying the value of h to the value obtained as per their $\frac{wf}{h}$ condition. The length of the microstrip feed line L_f is obtained from effective guide wavelength λ_g. The length L_f is commonly taken as $\lambda_g/4$ for single element RMSA in order to keep minimum loss in microstrip feed. However, L_f can be extended to any value as it acts as connecting link between patch and source which is given by,

$L_f = \lambda_g/4$

The input resistance for the inset- feed is given by

$$R(y=y_o) =R (=y_o) \text{Cos}2[\frac{\pi y0}{L}] \qquad (8)$$

Using the above formulas, the calculated values of width and length of rectangular microstrip patch for RT duroid and FR4 substrate of dielectric constant 2.2 and 4.4 respectively modeled and optimized in 3D EM HFSS software.

Design of Ground Plane*:* The transmission line model is considered for the infinite ground planes. However, for practical considerations, it is essential to have a finite ground plane. Similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery for better efficiency. Hence, for this design, the ground plane dimensions would be given as L_g = 6h+L, W_g = 6h+W.

In this work, the ground plane of single element antenna is taken as L_g*W_g = 2cm *2cm, which are quite larger than the required ground plane size.

Results And Discussions: Design and simulation of the Standard inset fed patch Antenna: Initially, the microstrip standard inset fed patch antenna was designed to meet the basic requirements such as, 10 GHz operation frequency, 50 Ohms feed line, minimum return loss of 14 dB and minimum gain 5 dB. Considering the design method and choosing the inset fed microstrip-line feed configuration and substrate RT-duroid with thickness 0.787 mm the antenna was defined with the values tabulated in Table 1. The designed standard antenna (Figure. 2) was modeled and simulated using Ansoft's HFSS three-dimensional full-wave electromagnetic field software.

Table 1: The calculated and optimized values of inset fed patch antenna

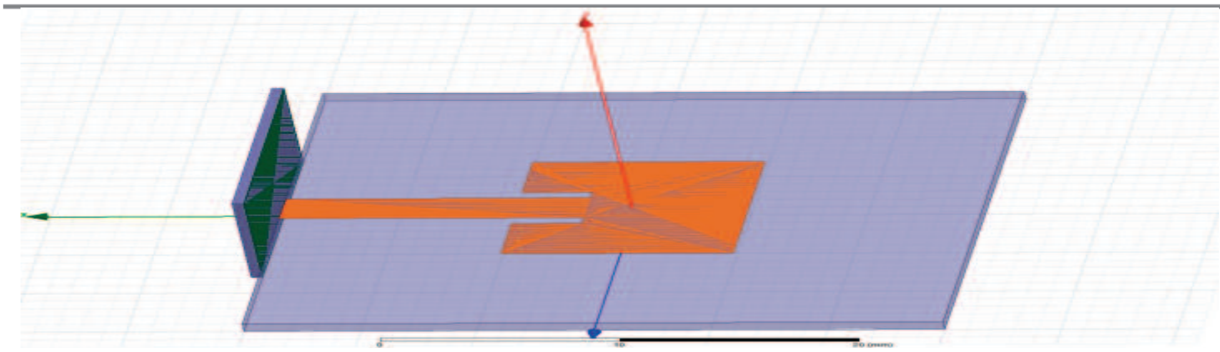

Figure 2: Single element inset fed patch antenna modeled in HFSS

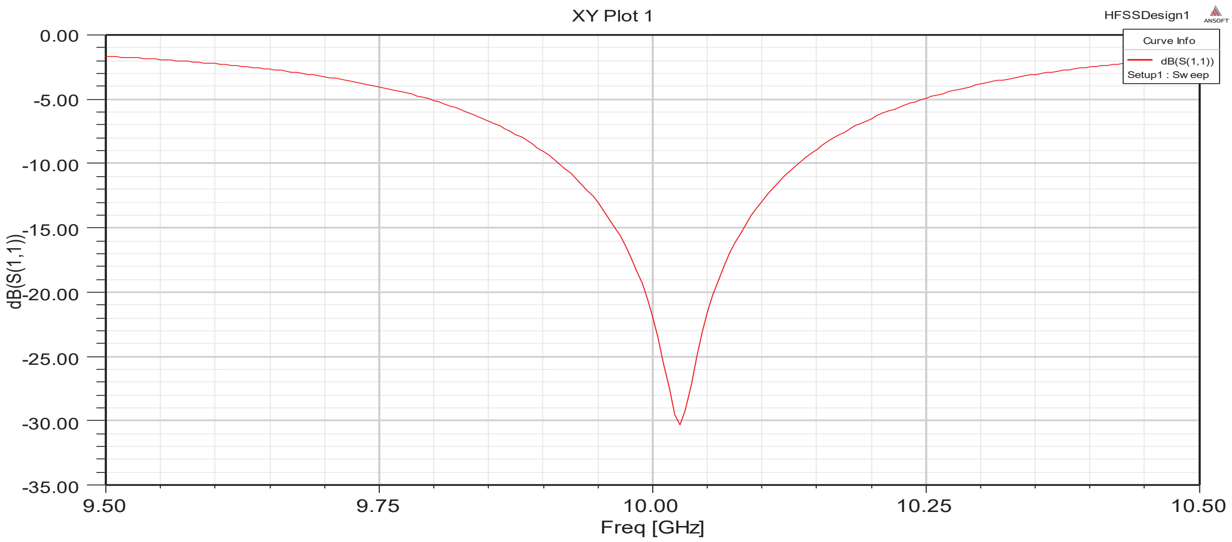

Figure 3: Standard inset fed patch Antenna S11 [dB] simulated in HFSS

The simulation results of variation of return loss verses frequency of standard inset fed patch Antenna is as shown in figure 3. The antenna resonates at 10.02 GHz of frequency with minimum return loss of -30 dB. The bandwidth over return loss less than -10dB was found to be 0.217 GHz with a lower cut off frequency (f_L) at 9.7 GHz and upper cut-off frequency (f_H) at 10.21GHz for the conventional RMSA.

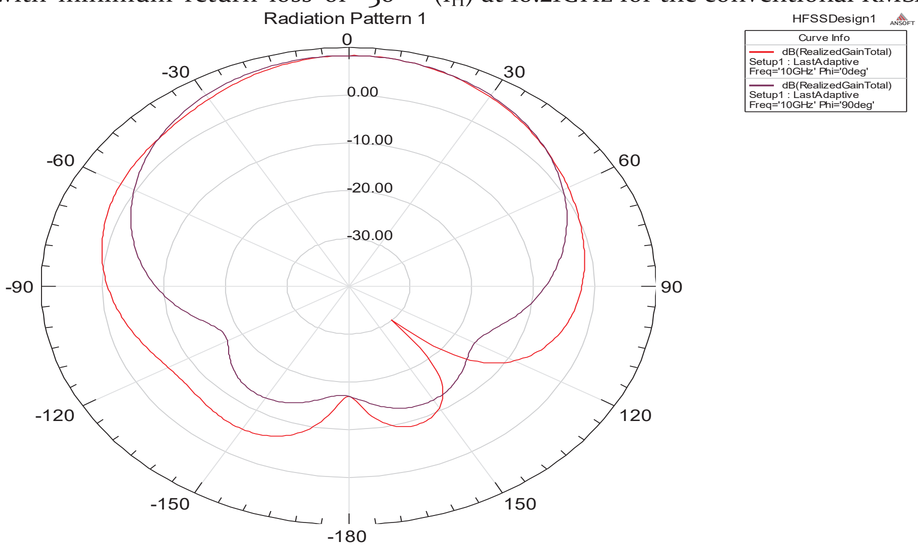

Figure 4: Radiation pattern of Standard ant inset fed patch Antenna

The radiation patterns observed at 10.02 GHz of the conventional RMSA are as shown in figure 4. The co-polar pattern is broad sided and linearly polarized. The half power beam width (HPBW) observed was found to be

71° and the gain was found to be 8dB. The simulations results of the inset fed patch Antenna RMSA are summarized in Table 2.

Table 2: Summary of the Simulation results of inset fed patch Antenna

Sl. No.	Parameter Specification	*Inset fed patch Antenna*
1	Return loss	-30dB
2	Resonant Frequency	10.02 GHz
4	Impedance bandwidth	0.217GHz
5	Half power beam width	71°
6	Input impedance	50Ω
7	Gain	8dB

Design and simulation of the quarter wave microstrip patch Antenna: Initially, the microstrip standard antenna was designed to meet the basic requirements such as, 10 GHz operation frequency, 50 Ohms feed line, minimum return loss of 14 dB and minimum gain 5 dB. Considering the design method and choosing quarter wave microstrip-line feed configuration and substrate Fr4 with thickness 1.6mm the antenna was defined with the values tabulated in Table 2. The designed quarter wave microstrip antenna (Figure. 5) was modeled and simulated using Ansoft's HFSS three-dimensional full-wave electromagnetic field software.

Table 3: The calculated and optimized values of quarter wave microstrip patch antenna

Parameter	Optimized value (mm)
Width(W)of Patch	6.2
Length(L) of Patch	9.0
Feedline width(wf)	2.2
Transformer width(wt)	0.44
Transformer length(lt)	3.6

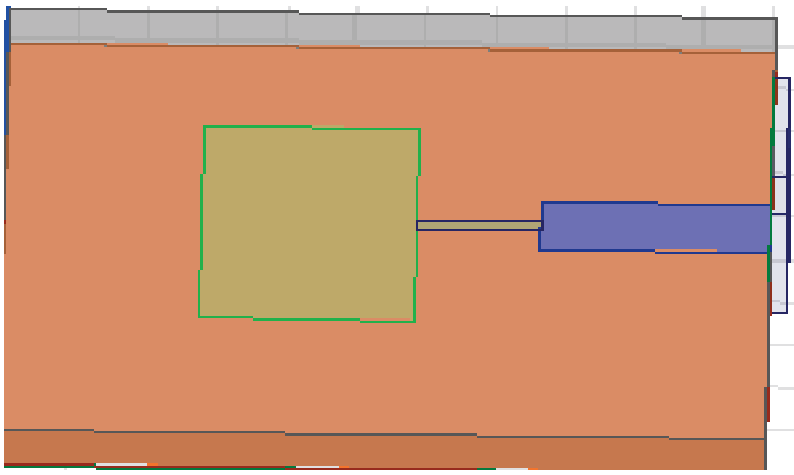

Figure 5: Fabricated quarter wave microstrip patch antenna

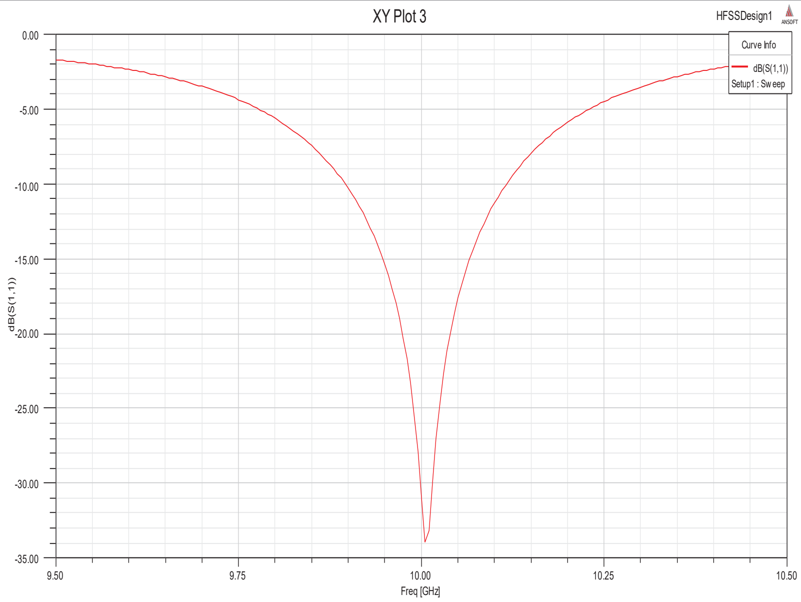

Figure 6: Quarter wave microstrip patch antenna S11 [dB] simulated in HFSS

The simulation results of variation of return loss verses frequency of *quarter wave microstrip patch antenna* is as shown in figure 6. The antenna resonates at 10 GHz of frequency with minimum return loss of -34 dB, indicating that 99% of the power is received by the copper patch antenna without losses. The bandwidth over return loss less than -10dB was found to be 0.316 GHz with a lower cut off frequency (f_L) at 9.85 GHz and upper cut-off frequency (f_H) at 10.13GHz for the quarter wave microstrip patch antenna.

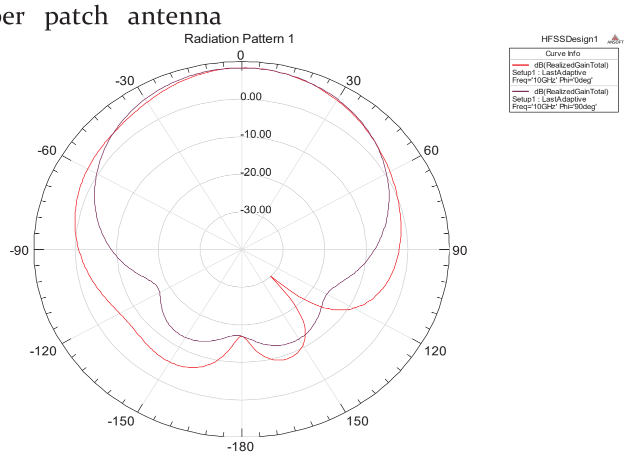

Figure 7: Radiation pattern of quarter wave microstrip patch antenna, Gain (dB)

The radiation patterns observed at 10 GHz of the conventional RMSA are as shown in figure 7. The co-polar pattern is broad sided and linearly polarized. The half power beam width (HPBW) observed was found to be 74° and the gain was found to be 8.3dB. The simulations results of the quarter wave microstrip patch antenna are summarized in Table 2.

Table 4: Summary of the Simulation results quarter wave RMSA

Sl. No.	**Parameter Specification**	***Quarter wave microstrip patch antenna***
1	Return loss	-35dB
2	Resonant Frequency	10 GHz
4	Impedance bandwidth	0.316GHz
5	Half power beam width	71°
6	Input impedance	50Ω
7	Gain	8.3dB

Conclusions: This work presents X-band Microstrip patch antennas designed and modeled in HFSS in two different configurations such as inset fed patch antenna and quarter wave rectangular microstrip patch antenna. The results showed that the antenna designed with quarter wave rectangular microstrip patch antenna presents enhanced bandwidth is 0.316GHz comparing to the inset fed patch antenna 0.217GHz. This X-band Microstrip patch antennas find applications in radar communication systems.

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