Design and Analysis of Microstrip Patch Antenna on Different Substrates For Wireless Communication

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Abstract

In this paper we have analyzed and designed a rectangular microstrip antenna in S band frequency range. The desired frequency is chosen to be 2.4GHz at which the patch antenna is designed on two different substrates such as RT-duroid and FR4. After calculating the various parameters such as width, effective dielectric constant, effective length and actual length, the antenna impedance is matched to 50Ω 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 the 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.

1. 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 fig.(1). The patch is generally made of conducting material such as copper and can take any possible shape [1-3]. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane [4]. With the ever-increasing need for wireless communication, it is important to design broadband antennas to cover a wide frequency range. The design of an efficient wide band small size antenna, for recent wireless applications, is a major challenge. Microstrip patch antennas have found extensive application in wireless communication system owing to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed networks [5].

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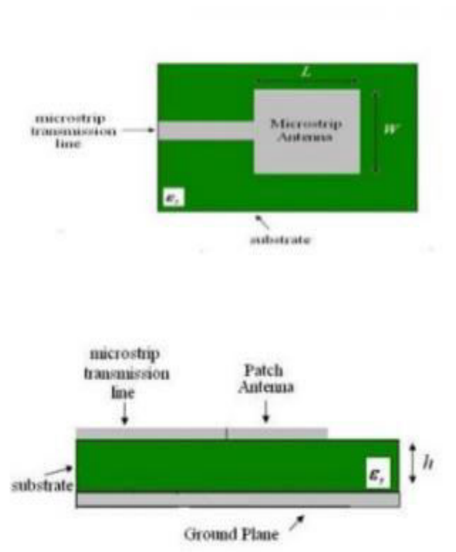

Figure 1: Microstrip patch antenna

2. 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

(a) 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

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

Actual length of the patch is determined as

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

(a) ***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,

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

(b) 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

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

(c) 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_0 and ϵ_r, the design equations are

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

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,

$$L_f = \lambda_g/4 \qquad (8)$$

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.

(a) 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.

3. RESULTS AND DISCUSSIONS

3.1 *Design and simulation of the Standard quarter wave rectangular patch Antenna*

Initially, the microstrip standard quarter wave rectangular patch antenna was designed to meet the basic requirements such as, 2.4GHz operation frequency, 50Ω feed line, minimum return loss of -10dB and minimum gain 5dB. Considering the design method and choosing the quarter wave rectangular microstrip patch antenna configuration and substrate RT-duroid with thickness 1.57mm the antenna was defined with the values tabulated in table 1. The designed standard antenna fig.2 was modeled and simulated using Ansoft's HFSS three-dimensional full-wave electromagnetic field software.

Table 1: The geometry of quarter wave rectangular patch antenna

Parameter	Optimized value (mm)
Width(W)of Patch	9.4
Length(L) of Patch	11.3
Feed line width(W_f)	5
Transformer width(W_t)	0.7
Transformer length(L_t)	10.1

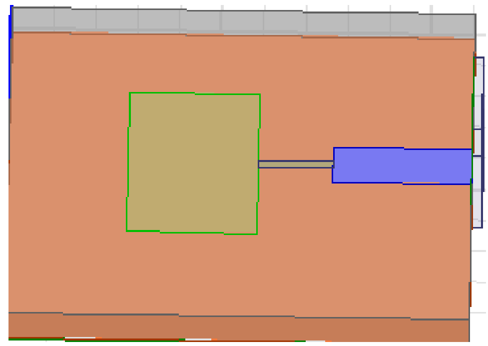

Figure 2: Single element quarter wave rectangular patch antenna modeled in HFSS

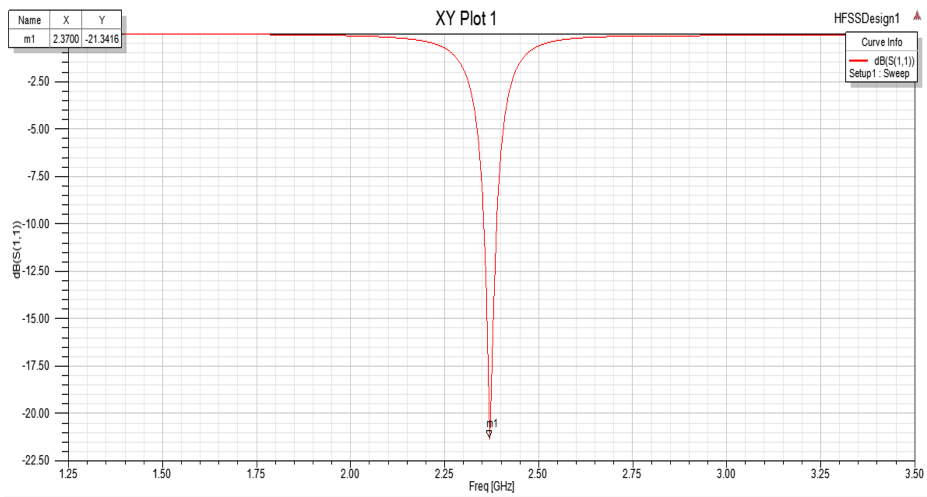

Figure 3: Quarter wave rectangular patch Antenna S11 [dB] simulated in HFSS

The simulation results of variation of return loss verses frequency of standard patch Antenna is as shown in fig.3. The microstrip patch antenna was designed for the S - band frequencies (2-6 GHz). From the figure it's clear that the antenna resonates at 2.37 GHz with a return loss equal to –21.34 dB. The bandwidth over return loss less than -10dB was found to be 0.225GHz with a lower cut off frequency (f_L) at 2.35 GHz and upper cut-off frequency (f_H) at 2.42GHz for the conventional RMSA.

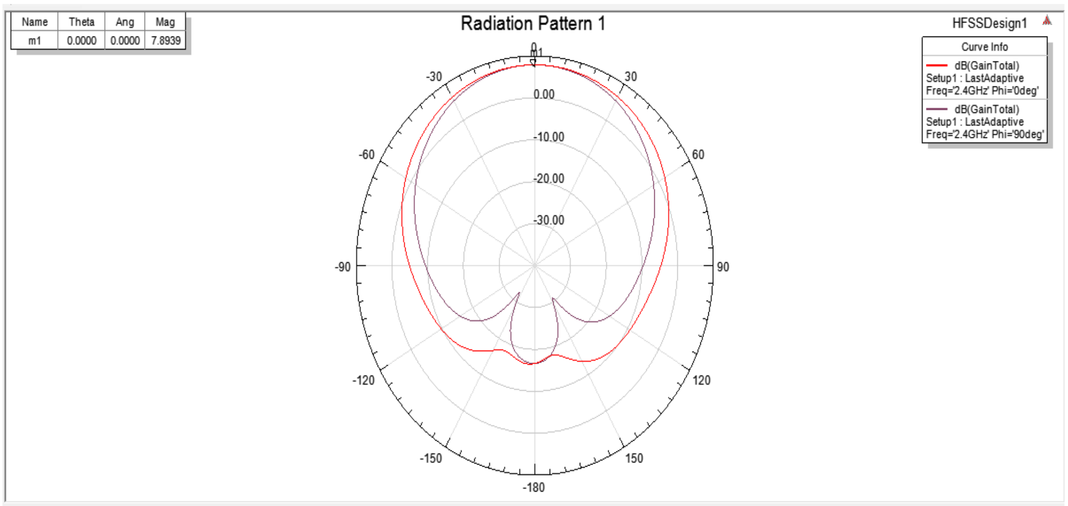

Figure 4: Radiation pattern of quarter wave rectangular patch Antenna

Since a microstrip patch antenna radiates normal to its patch surface, the elevation pattern for φ = 0 and φ = 90 degrees would be important. Figure 4 shows the gain of the antenna resonate at 2.37 GHz for φ = 0 and φ = 90 degrees. The maximum gain is obtained in the broadside direction and this is measured to be 7.89 dB. This is desired for good antenna.

Table 2: Summary of the simulation results quarter wave rectangular patch antenna

Sl. No.	**Parameter Specification**	***Inset fed patch Antenna***
1	Return loss	-21.34 dB
2	Resonant Frequency	2.4 GHz
4	Impedance bandwidth	0.225GHz
5	Half power beam width	71°
6	Input impedance	50Ω
7	Gain	7.89 dB

3.2 *Designing of RMSA for 2.4 GHz on FR4 Epoxy Substrate*

In this simulation study the design of RMSA on FR4 Epoxy substrate (dielectric constant Ɛr = 4.4) of thickness 1.6mm for the center frequency of 2.4 GHz. The dimensions of the patch and structure of the rectangular microstrip patch antenna calculated manually using standard equations implemented using HFSS simulation software are given in table 3.

Table 3: The geometry of quarter wave rectangular microstrip patch antenna

Substrate	FR4 EPOXY (Ɛr = 4.4)
Resonant frequency (fr)	2.4 GHz
Height of dielectric substrate (h)	1.6 mm
Length of ground plane (Lg)	30 mm
Width of ground plane (Wg)	30 mm
Length of patch (Lp)	13 mm
Width of patch (Wp)	15 mm
Length of feed (Lf)	6 mm
Width of feed (Wf)	4.92 mm
Length of transmission line (Lt)	8 mm
Width of transmission line (Wt)	1.5 mm

With the design parameters values of microstrip patch antenna as given in table 3.The design of rectangular microstrip patch antenna is implemented in HFSS software version 15.0 is as shown in fig.5.

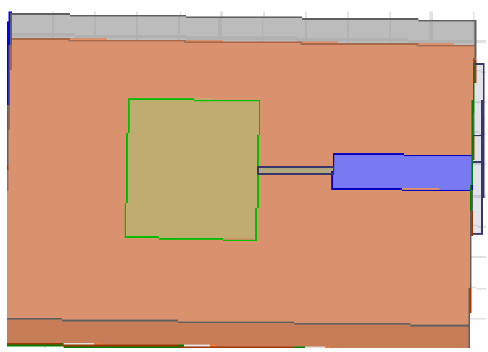

Figure 5: quarter wave rectangular microstrip patch antenna on FR4 substrate

3.3 *Return loss of RMSA on FR4 Epoxy substrate*

Fig. 6 shows plot for Return Loss versus frequency. From the fig. 6 it is clear that the RMSA resonant at 2.31 GHz of frequency with the return loss equal to –25.65 dB. This is clearly under the minimum desired value of return loss. The bandwidth over return loss less than -10dB was found to be 0.18GHz with a lower cut off frequency (f_L) at 2.3GHz and upper cut-off frequency (f_H) at 2.4GHz for the conventional RMSA on FR4 substrates.

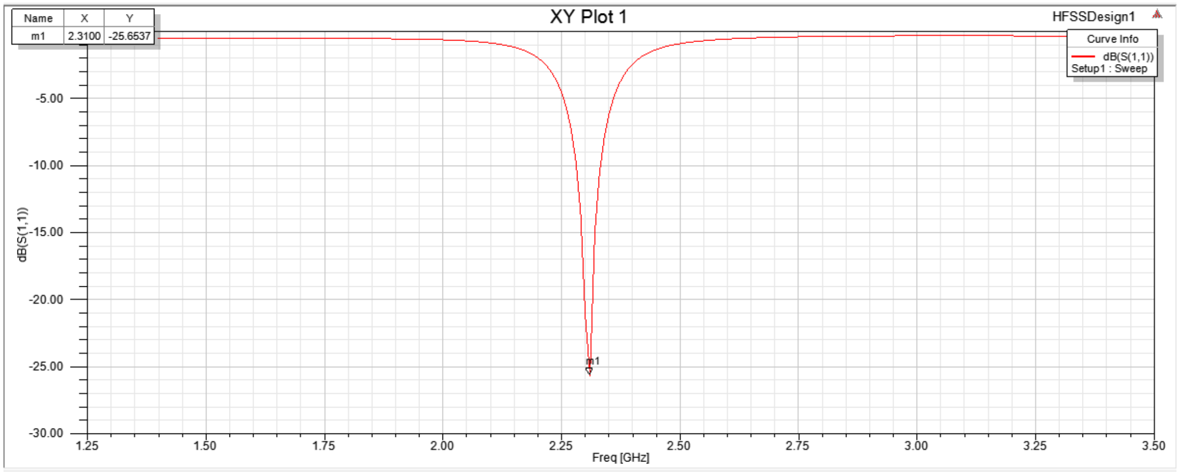

Figure 6: Simulation of S11 of quarter wave rectangular microstrip patch antenna on FR4 substrate

3.4 *Radiation pattern of RMSA on FR4 Epoxy substrate*

Since a microstrip patch antenna radiates normal to its patch surface, the elevation pattern for φ = 0 and φ = 90 degrees would be important. Figure 7 shows the gain of the antenna resonate at 2.31 GHz for φ = 0 and φ = 90 degrees. The maximum gain is obtained in the broadside direction and this is measured to be 2.91 dB for both φ = 0 and φ = 90 degrees is linearly polarized.

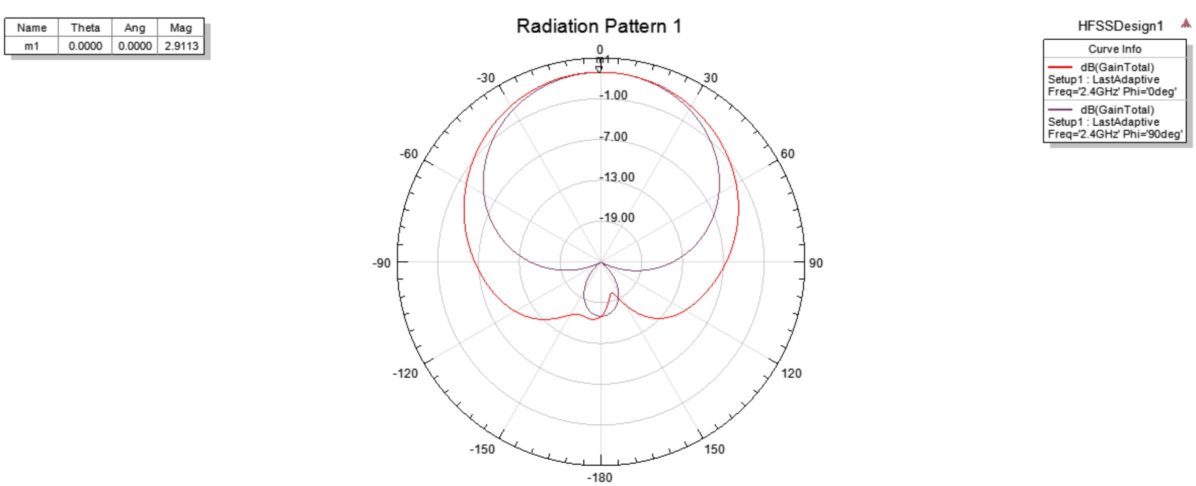

Figure 7: Radiation pattern of quarter wave rectangular microstrip patch antenna simulation in HFSS

4. Conclusion

Quarter wave rectangular patch antenna was designed on different substrates such as RT- Duroid and FR4 substrates respectively and simulated in HFSS simulation software for performance comparison. All the two patch antennas had nearly same resonating frequency of 2.31 and 2.37GHz respectively. The microstrip patch antenna designed on RT-Duroid substrate gain is 7.91dB higher than the microstrip patch antenna designed on FR4 substrates i.e., 2.37dB. The above results shows that a RMSA on RT-Duroid substrates radiation pattern and gain is enhancement in the performance of the antenna compared to RMSA on FR4 substrates. This study indicates that, selection of substrate material, thickness of the substrate is important while designing the patch antenna for improving the performance of the antenna parameter in the field of desired application. This microstrip patch antenna suits in the application of wireless communication systems.

Reference

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