

Design and Optimization of Planar Antenna With horizontal slit for ISM Band(2.4 GHz) Applications

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Abstract--- The ever increasing demand of communication equipment and the emergence of new technologies require an efficient design of antenna that is of smaller size for wider range of frequency for ISM Band application such as W-LAN. The (ISM) band ranges from 2 GHz to 2.8 GHz which also include WLAN according to IEEE 802.11g standard that extended throughput to up to 54 Mbit/s using the same 2.4 GHz band. Because of the various advantages like low profile, ease of integration, low cost etc. Microstrip antenna found vast application in communication system. Here we report the investigation on Planar antenna using probe feed technique. Analysis is done on the two different substrate i.e. FR-4 and RT Duroid 5880 with dielectric constant 4.3 and 2.2 respectively with introduction of a horizontal slit along the width of the patch. The antenna is simulated using CST (Computer Simulation Technology) microwave studio v.2011 and the antenna parameters like return loss, VSWR, Gain, Bandwidth have been analyzed. The design procedure for patch antenna for ISM Band application is illustrated.

Keywords---ISM Band, Planar antenna, VSWR, Return loss

I. INTRODUCTION

An antenna is a device which converts electrical power into electromagnetic wave and vice versa.[2] There are many types of antenna available in the market but because of the various advantages of microstrip antenna we have selected the microstrip patch antenna.[6] Microstrip antenna consists of very small conducting patch, ground plane and substrate, in which substrate is sandwiched between the ground plane and the radiating patch.[4] The concept of microstrip patch antenna was developed during the revolution in electronics circuit miniaturization and large-scale integration in 1970s.[2] Because of the various disadvantages of the other conventional antenna like bulkiness, cost etc. microstrip patch antenna comes into the picture and it has advantages like low cost, light weight and also these antennas are integrated with microwave integrated circuits.[7] The telemetry and communication antenna used onboard missiles need to be thin and conformal.[10] They are often in the form of microstrip patch antenna. Another very important and essential application of microstrip patch antenna is in satellite communication.[5] Typically the microstrip patch antennas are characterized by their length, width, gain and radiation patterns etc.[8] Various parameters of the microstrip patch antenna and their design considerations are discussed in the subsequent sections. Section II describes the introduction to microstrip patch antenna. Section III describes the design consideration and the design specification. Next section IV describes the simulation results and comparison of the simulation results for two different substrate i.e. FR-4 and RT Duroid and the last section V gives the conclusion.

II. MICROSTRIP PATCH ANTENNA

The radiating metallic patch can be designed of any shape theoretically, but mostly conventional shape like circular and Rectangular is used [1]. Some of the other configurations used are complex for analysis and it requires very large numerical calculations. In its most common form, 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.[4] It is illustrated below in figure 1.

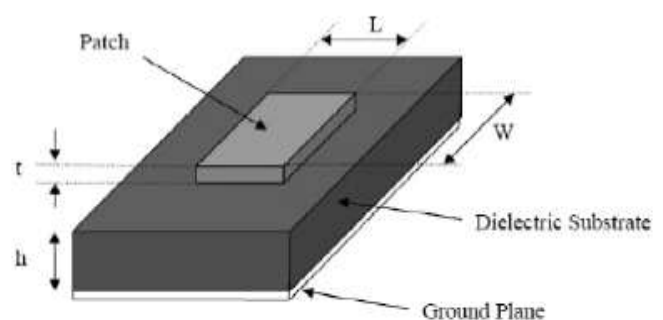


Figure 1: Structure of microstrip patch antenna

The patch is usually made of conducting radiating materials such as gold, copper etc.[3] and it can be of any possible shape. The Radiating metallic patch and the probe feed lines are usually photo etched on the dielectric substrate. Microstrip patch antenna radiate mainly because of the fringing fields effect between the patch edge and the ground plane.[10] For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$, where λ_0 is the free space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the thickness of patch). The height h of the dielectric substrate is usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$. The dielectric

constant of the substrate (ϵ_r) is typically in the range $2.2 \leq \epsilon_r \leq 12$. [1]

III. DESIGN SPECIFICATION AND PROCEDURE

A. Design Specification

There are three important parameters which are to be considered carefully for the designing of a rectangular microstrip patch antenna for various communication application. [1]

- Resonant Frequency (f_r): The ISM Band uses the frequency range from 2000-2800 MHz [6]. Hence the antenna designed must be able to operate for this frequency range. The default resonant frequency chosen for this research design simulation is 2.4 GHz.
- Dielectric constant of the substrate material (ϵ_r): The dielectric material chosen for this design is RT Duroid and FR-4 which has dielectric constants of 2.2 and 4.3 respectively.
- Height of dielectric substrate (h): For the Microstrip patch antenna to be used in communication system, it is very essential that the antenna is kept light and compact in size [7]. Hence, the height of the dielectric substrate is chosen as 1.6 mm.

Hence, the design specification for the mentioned design are chosen as $f_r = 2.4$ GHz, $\epsilon_{r(\text{RT Duroid})} = 2.2$, $\epsilon_{r(\text{FR-4})} = 4.3$ and $h = 1.6$ mm

B. Design Procedure

Step 1: Calculation of Width (W)

The width of the Microstrip patch antenna is given by

$$W = \frac{c}{2 * f_r} \sqrt{\frac{2}{\epsilon_r + 1}}$$

By substituting $C = 3 \times 10^8$ m/s, $\epsilon_r = 2.2$ and $f_r = 2.4$ GHz, it can be easily determined that $W = 0.0494$ m = 49.4 mm and if $\epsilon_r = 4.3$ than $W = 0.0303$ m = 30.3 mm.

Step 2: Calculation of effective dielectric constant (ϵ_{reff})

The effective dielectric constant is given by

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{1 + 12 \frac{h}{w}}$$

By substituting $\epsilon_r = 2.2$, $W = 49.4$ mm and $h = 1.6$ mm, it can be determined that $\epsilon_{\text{reff}} = 2.307$ and for $\epsilon_r = 4.3$, $W = 49.4$ mm we get $\epsilon_{\text{reff}} = 4.594$.

Step 3: Determination of the effective length (L_{eff})

The effective length is given by

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

By substituting $\epsilon_{\text{reff}} = 2.307$, $c = 3 \times 10^8$ m/s and $f_r = 2.4$ GHz, it can be determined that $L_{\text{eff}} = 41.14$ mm and for FR-4 we get $L_{\text{eff}} = 28.6$ mm.

Step 4: Determination of the length extension (ΔL)

The length extension may be given by

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{w}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{w}{h} + 0.8 \right)}$$

By substituting $\epsilon_{\text{reff}} = 2.307$ we get $\Delta L = 0.8245$ and other corresponding value it can be determined that $\Delta L = 0.7208$ mm.

Step 5: Determination of actual length of patch (L):

The actual length is obtained by using expression

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

By substituting $L_{\text{eff}} = 41.14$ mm and $\Delta L = 0.8245$ mm, the actual length can be determined as $L = 39.491$ mm and for $L_{\text{eff}} = 28.6$ mm and $\Delta L = 0.7208$ mm, the actual length can be determined as $L = 27.159$ mm

From the above mathematical calculation, the patch Parameters has been calculated for the substrate RT Duroid with dielectric constant 2.2. In similar manner the patch parameters are calculated for the substrate FR-4 with dielectric constant 4.3 by using the above equations. Here we have used $h = 1.6$ mm. The results are summarized in table 1 given below.

Table 1: Comparison of patch parameter for different Substrate material

Patch Parameter	FR-4($\epsilon_r=4.3$)	RT Duroid($\epsilon_r=2.2$)
Length(L)	27.15	39.49
Width(W)	30.3	49.4

From the above comparison, one can say that the substrate with low dielectric constant leads to a larger size of antenna. So that design for the microstrip antenna mostly substrate with higher dielectric constant is chosen.

IV. SIMULATION RESULTS

Here the antenna is simulated with two different substrate i.e. Duroid and FR-4 and the result is simulated using CST (Computer Simulation Technology) microwave studio version 2011 and using CST antenna parameter like Return loss (S_{11}), Bandwidth (MHz), gain and VSWR (Voltage Standing Wave Ratio) are analyzed. Figure below shows the coaxial feed microstrip patch antenna using CST microwave studio.

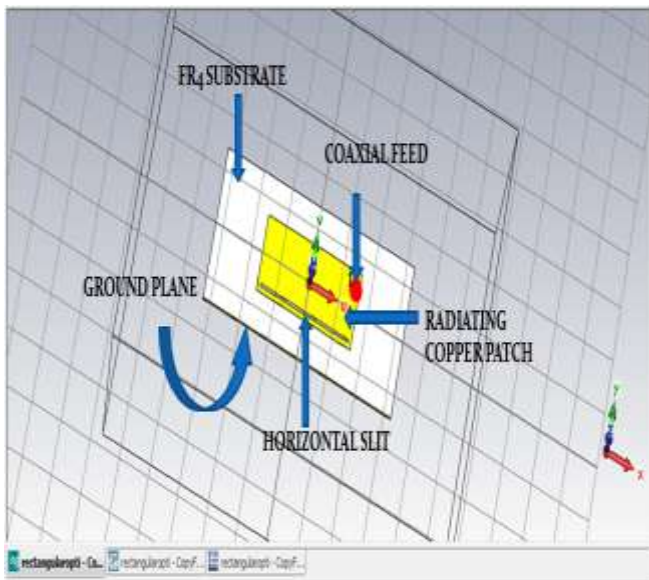


Figure 2: Microstrip patch antenna designed using CST

A. Return Loss

A frequency range of 2.0 GHz to 3.0 GHz is chosen to obtain the above results. The resonate frequency is selected as the one at which the return loss has minimum value also the bandwidth can be determined from the return loss plot or the VSWR plot. The bandwidth of the antenna is said to be that range of frequencies over which the return loss (S_{11}) is greater than -10.0 dB (-10.0 dB corresponds to a VSWR of 1.24 which is an acceptable figure) as shown in figure 5. For the substrate RT Duroid ($\epsilon_r = 2.2$) return loss of -17.94 dB is obtained at the resonant frequency. It can be seen that for the substrate FR-4 the return loss is of -19.15 dB obtained at the frequency 2.4 GHz. For both the substrate the return loss Vs frequency graph is given below.

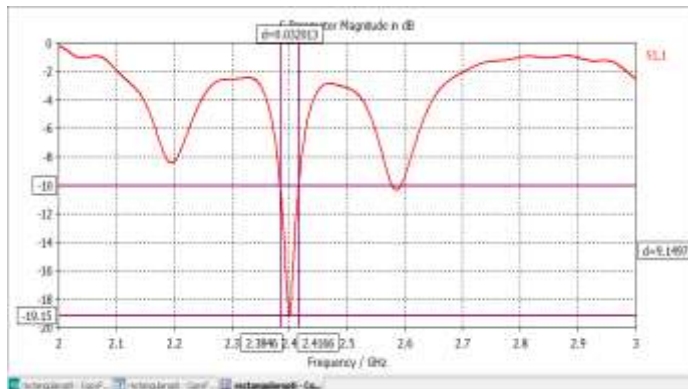


Figure 3: Return loss Vs Frequency graph for FR-4

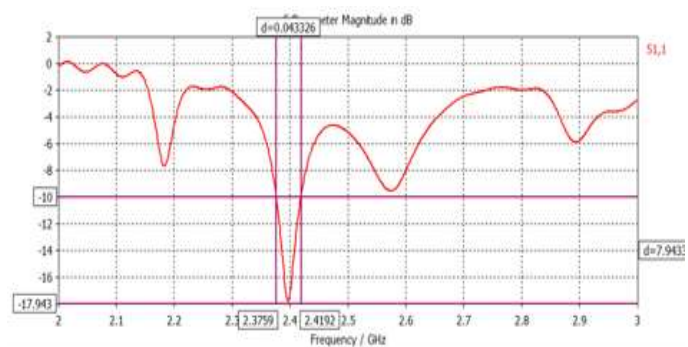


Figure 4: Return loss Vs Frequency graph for RT Duroid

Above figure 4 shows the return loss Vs frequency graph for the rectangular patch antenna with substrate RT Duroid. From the above figure one can say that the antenna will resonate at frequency i.e. 2.4 GHz with return loss -17.94 dB.

B. VSWR

VSWR plot for both the RT Duroid and FR-4 substrate is given below.

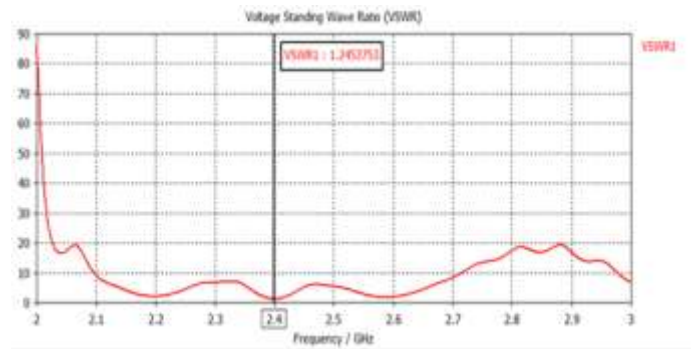


Figure 5: VSWR plot for the substrate FR-4

Here in both the figure 5 and figure 6 measure line is shows for the resonate frequency and which is used for the W-LAN and other ISM Band application .

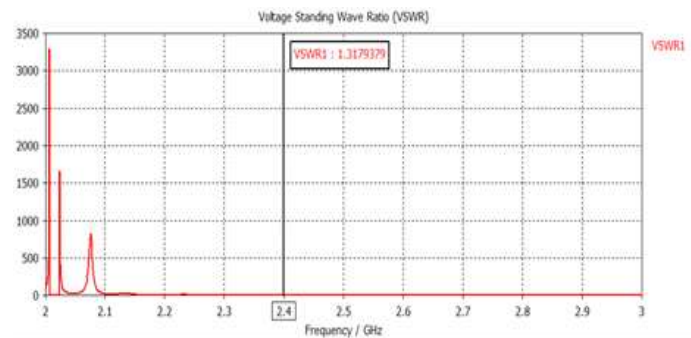


Figure 6: VSWR plot for the substrate RT Duroid

Figure 5 shows that antenna has a good impedance match at 2.4 GHz because the VSWR for that is 1.24 and which is very good. Also from the figure 6 we can say that antenna has a good impedance match at 2.4 GHz because the VSWR for that is 1.31.

Table II: Comparison of Simulation result for different dielectric substrate material

Patch Parameter	Return Loss S_{11} (dB)	VSWR	Band width (MHz)	Gain (dB)	Direct ivity (dBi)
Slit in FR-4 ($\epsilon_r = 4.3$)	-19.15	1.24	32	0.836	7.249
Slit in RT Duroid ($\epsilon_r = 2.2$)	-17.7	1.31	42	10.30	10.6

V. CONCLUSION

The microstrip patch antenna is designed and simulated using CST Microwave studio. The analysis is carried on two different substrate (namely FR-4 epoxy and RT Duroid whose permittivity varies) with introduction of a horizontal slit along the width of the patch. Coaxial feeding is used as the antenna provides acceptable return loss, Gain, VSWR, Bandwidth etc. In the proposed model multiband is obtained for the antenna in which the substrate is chosen as RT Duroid gives better efficiency in term of bandwidth(42 MHz), Gain(10.30 dB) and Directivity (10.6) when compared to antenna designed using FR-4 epoxy. The antenna will resonate at the frequency which includes our research work frequency 2.4 GHz for ISM Band applications.

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